


Hooper Foundation Accossion


# SMITHSONIAN MISCELLANEOUS COLLECTIONS VOLUME 71, NUMBER 1 <br> SMITHSONIAN <br> PHYSICAL TABLES 

REPRINT OF SEVENTH REVISED EDITION

PREPARED BY
FREDERICK E. FOWLE
AID, SMITHSONIAN ASTROPHYSICAL OBSERVATORY

(Publication 2539)

CITY OF WASHINGTON
PUBLISHED BY THE SMITHSONIAN INSTITUTION



## ADVERTISEMENT.

In connection with the system of meteorological observations established by the Smithsonian Institution about 1850, a series of meteorological tables was compiled by Dr. Arnold Guyot, at the request of Secretary Henry, and the first edition was published in 1852. Though primarily designed for meteorological observers reporting to the Smithsonian Institution, the tables were so widely used by physicists that it seemed desirable to recast the work entirely. It was decided to publish three sets of tables, each representative of the latest knowledge in its field, and independent of one another, but forming a homogeneous series. The first of the new series. Meteorological Tables, was published in 1893, the second, Geographical Tables, in 1894, and the third. Physical Tables, in 1896. In 1909 yet another volume was added, so that the series now comprises: Smithsonian Meteorological Tables, Smithsonian Geographical Tables, Smithsonian Physical Tables, and Smithsonian Mathematical Tables.

The fourteen years which had elapsed in igio since the publication of the first edition of the Physical Tables, prepared by Professor Thomas Gray, had brought such changes in the material upon which the tables must be based that it became necessary to make a radical revision for the fifth and sixth revised editions published in igIo and 1914. The latter edition was reprinted thrice. For the present seventh revision extended changes have been made with the inclusion of new data on old and new topics.

Charles D. Walcott, Secretary of the Smithsonian Institution.

[^0]
## PREFACE TO 7тн REVISED EDITION.

The present edition of the Smithsonian Physical Tables entails a considerable enlargement. Besides the insertion of new data in the older tables, about 170 new tables have been added. The scope of the tables has been broadened to include tables on astrophysics, meteorology, geochemistry, atomic and molecular data, colloids, photography, etc. In the earlier revisions the insertion of new matter in a way to avoid renumbering the pages resulted in a somewhat illogical sequence of tables. This we have tried to remedy in the present edition by radically rearranging the tables; the sequence is now, - mathematical, mechanical, acoustical, thermal, optical, electrical, etc.

Many suggestions and data have been received: from the Bureau of Standards, - including the revision of the magnetic, mechanical, and X-ray tables, - from the Coast and Geodetic Survey (magnetic data), the Naval Observatory, the Geophysical Laboratory, Department of Terrestrial Magnetism, etc.; from Messrs. Adams of the Mount Wilson Observatory, Adams of the Geophysical Laboratory (compressibility tables), Anderson (mechanical tables), Dellinger, Hackh, Humphreys, Mees and Lovejoy of the Eastman Kodak Co. (photographic data), Miller (acoustical data), Van Orstrand, Russell of Princeton (astronomical tables), Saunders, Wherry and Lassen (crystal indices of refraction), White, Worthing and Forsythe and others of the Nela Research Laboratory, Zahm (aeronautical tables). To all these and others we are indebted for valuable criticisms and data. We will ever be grateful for further criticisms, the notification of errors, and new data.

Frederick E. Fowle.
Astrophysical Observatory, Smithsonian Institution, May, 1919.

## NOTE TO REPRINT OF 7 7 тн REVISED EDITION.

Opportunity comes with this reprint to insert in the plates a number of corrections as well as some newer data. Gratitude is especially due to Messrs. Wherry and Smith of the Bureau of Chemistry, Department of Agriculture, for suggestions.

Frederick E. Fowle.

## TABLE OF CONTENTS.

Introduction: units of measurement, dimensional and conversion formulae, standards: . . . . . . . . . . . . . . . . . . . . . . . xxiii
General discussion, xxiii; Fundamental units, xxiii; Derived units, xxiv; Conversion factors and dimensional formulae, xxv; Dimensional reasoning, xxv .
Dimensional formulae: ..... xxvi
Geometrical and mechanical units, xxvi; Heat units, xxviii; Electric and mag- netic units, xxix; Electrostatic system, xxx; Electromagnetic system, xxxi.
Fundamental standards: ..... xxxiii
Standards of length, xxxiv; Standards of mass, xxxiv; Standards of time, xxxiv; Standards of temperature, xxxiv.
Numerically different systems of units: ..... xxxv
Proposed systems of units (table I), xxxv; Gaussian systems, xxxv; Practical electromagnetic system, xxxvi; International electric units, xxxvi.
The standards of the International Electric Units: ..... xxxviiiResistance, xxxviii: Mercury standards, xxxviii; Secondary standards, xxxix;Resistance standards in practice, xxxix; Absolute ohm, xxxix.
Current, xl: Silver voltameter, xl; Resistance standards used in currentmeasurements, xli; Absolute ampere, xli.
Electromotive force, xli: International volt, xli; Weston normal cell, xli; Portable Weston cell, xliii; Absolute and semi-absolute volts, xliii.
Quantity of electricity, xliv: Standards, xliv.
Capacity, xliv.
Inductance, xliv: Inductance standards, xliv.
Power and energy, xlv: Watt, xlv; Standards and measurement, xlv.
Magnetic units, xlv: Table II. - The ordinary and ampere-turn units xlvi.
TABLE PAGE

1. Spelling and abbreviations of common units of weight and measure ..... 2
2. Fundamental and derived units, conversion factors ..... 3
(a) Fundamental units ..... 3
(b) Derived units ..... 3
3. Tables for converting U. S. weights and measures:
(I) Customary to metric ..... 5
(2) Metric to customary ..... 6
4. Miscellaneous equivalents U.S. and metric weights and measures ..... 75. Equivalents of metric and British imperial weights and measures:
(I) Metric to imperial ..... 8
(2) Multiples, metric to imperial ..... 9
(3) Imperial to metric ..... 10
(4) Multiples, imperial to metric ..... II
Mathematical Tables
5. Derivatives and integrals ..... 12
6. Series ..... 13
7. Mathematical constants ..... 14
8. Reciprocals, squares, cubes and square roots of natural numbers ..... 15
9. Logarithms, 4-place, 1000-2000 ..... 24
ir. Logarithms, 4-place ..... 26
10. Antilogarithms, 4 -place ..... 28
11. Antilogarithms, 4-place, $0.9000-1.0000$ ..... 30
12. Circular (trigonometric) functions, arguments ( ${ }^{\circ}$, , $)$. ..... 32
13. " " " (radians) ..... 37
14. Logarithmic factorials, n !, $\mathrm{n}=\mathrm{I}$ to 100 ..... 40
15. Hyperbolic functions ..... 41
16. Factorials, 1 to 20 ..... 47
17. Exponential functions ..... 48
18. Values of $e^{x^{2}}$ and $e^{-x^{2}}$ and their logarithms ..... 54
19. " " $e^{\frac{\pi}{4} x}$ " $e^{-\frac{\pi}{4} x}$ " ..... 55
20. " " $e^{\sqrt{\frac{\pi}{4}} x^{2}} e^{-\sqrt{\frac{\pi}{4}} x}$ " " ..... 55
21. " " $e^{x}$ " $e^{-x}$ " " " , $x$ fractional ..... 56
22. Least squares: probability integral, argument $h x$ ..... 56
23. $x / r$ ..... 57
24. values of $0.6745 \sqrt{1 /(n-\mathrm{I})}$ ..... 57
" " $0.6745 \sqrt{\mathrm{I} / n(n-\mathrm{I})}$ ..... 58
25. 

" " $0.8453 \sqrt{\mathrm{I} / n(n-\mathrm{I})}$ ..... 58
28.
58
29. " " $0.8453\{\mathrm{I} / n \sqrt{n-1}\}$
59
30. formulae
60
31. Inverse probability integral, diffusion integral
62
32. Logarithms of gamma function, $n$ between I and 2
64
33. Values for the first seven zonal harmonics, $\theta=0^{\circ}$ to $\theta=90^{\circ}$
66
34. Cylindrical harmonics, oth and ist orders, $x=0$ to $3.5,6$-place.
68
35. $x=4$ to ${ }^{5} 5,4$-place
68
36. (a) ist ten roots cylindrical harmonic of zeroth order $=0$
68
(b) " fifteen"68
37. Values for $\int_{0}^{\frac{\pi}{2}}\left(1-\sin ^{2} \theta \sin ^{2} \Phi\right)^{ \pm \frac{1}{2}} d \Phi$; argument $\theta$; also logs ..... 69
38. Moments of inertia, radii of gyration, corresponding weights ..... 70
39. International atomic weights, valencies ..... 71
40. Volume of glass vessel from weight of its volume of $\mathrm{H}_{2} \mathrm{O}$ or Hg . . . . 72
41. Reductions of weighings in air to vacuo . . . . . . . . . . . . . . 73
42. Reductions of densities in air to vacuo . . . . . . . . . . . . . . 73

Mechanical Properties
43. Introduction and definitions . . . . . . . . . . . . . . . . . . . 74
44. Ferrous metals and alloys: Iron and iron alloys . . . . . . . . . . 75
45. " " " " carbon steels . . . . . . . . . . . . 76
46. " " " " heat treatments . . . . . . . . . . 76
47. " " " " alloy steels . . . . . . . . . . . . 77
48. " " " " steel wire, specification values . . . . . 78
49. " " " " " " experimental values . . . 78
50. " " " " semi-steel . . . . . . . . . . . . . 78

5I. " " " " steel wire rope, specification values ... 79
52. " " " " plow-steel rope, " " . . . 79
53. " " " " steel wire rope, experimental values . . 79
54. Aluminum, miscellaneous . . . . . . . . . . . . . . . . . . . . 80
55. Aluminum: (a) sheet, experimental values . . . . . . . . . . . . 80
(b) " specification values . . . . . . . . . . . 8I
56. Aluminum alloys . . . . . . . . . . . . . . . . . . . . . . . 8I
57. Copper: miscellaneous experimental values . . . . . . . . . . . . 82
58. " rolled, experimental values . . . . . . . . . . . . . . . 82
59. " wire, specification values, hard-drawn . . . . . . . . . . 82
60. " " medium hard-drawn . . . . . . . . . . . . . . . 83

6I. " " soft or annealed . . . . . . . . . . . . . . . . . 83
62. " plates . . . . . . . . . . . . . . . . . . . . . . . . 83
63. Copper alloys: nomenclature . . . . . . . . . . . . . . . . . . 83
64. " " copper-zinc alloys or brasses . . . . . . . . . . . . 84
copper-tin " " bronzes. . . . . . . . . . . 84
65. " " three or more metals . . . . . . . . . . . . . . . 85
66. Miscellaneous alloys . . . . . . . . . . . . . . . . . . . . . . 88
67. " metals: tungsten; zinc; white metal . . . . . . . 89
68. Cement and concrete: (a) cement . . . . . . . . . . . . . . . . 90
" " " (b) cement and cement mortars . . . . . . . 90
(c) concrete . . . . . . . . . . . . . . . 9I
69. Stone and clay products: (a) American building stones . . . . . . . 92
" " " " (b) Bavarian building stones . . . . . . 92
" " " " (c) American building bricks . . . . . . 93
" " " " (d) brick piers, terra-cotta piers . . . . 93
(e) various bricks . . . . . . . . . . . . 93
70. (a) Sheet rubber . . . . . . . . . . . . . . . . . . . . . . . . 94
(b) Leather belting . . . . . . . . . . . . . . . . . . . . . . 94

7I. Manilla rope . . . . . . . . . . . . . . . . . . . . . . . . . 95
72. Woods: hardwoods, metric units . . . . . . . . . . . . . . . . . 96
73. " conifers, metric units . . . . . . . ... . . . . . . . . . 97
74. Woods: hardwoods, English units ..... 98
75. " conifers, English units ..... 99
76. Rigidity Modulus ..... 100
77. Variation of moduli of rigidity with the temperature ..... 100
78. Interior friction, variation with the temperature ..... IOI
79. Hardness ..... IOI
8o. Relative hardness of the elements ..... IOI
8r. Poisson's ratio ..... IOI
82. Elastic moduli of crystals, formulae ..... 102
83. ". " " " numerical results ..... 103
Compressibility of Gases
84. Compressibility of O , air, $\mathrm{N}, \mathrm{H}$, different pressures and temperatures ..... 104
85. " " ethylene at ..... 104
86. Relative gas volumes at various pressures, $\mathrm{H}, \mathrm{N}$, air, $\mathrm{O}, \mathrm{CO}_{2}$ ..... 104
87. Compressibility of carbon dioxide, pressure-temperature variation ..... 105
88. " " gases, values of ..... 105
89. " " air and oxygen between $18^{\circ}$ and $22^{\circ} \mathrm{C}$ ..... 105
90. Relation between pressure, temperature and volume of sulphur dioxide ..... 106
91. " " ammonia ..... 106
92. Compressibility of liquids ..... 107
93. " " solids ..... 108
Densities
94. Specific gravities corresponding to the Baumé scale ..... 109
95. Densities of the solid and liquid elements ..... IIO
96. " " various woods ..... II2
97. " " " solids ..... 113
98. " " " alloys ..... 114
99. " " " natural and artificial minerals ..... 115
100. " " molten tin and tin-lead eutectic ..... 115
1or. Weight in grams per square meter of sheet metal ..... 116
102. " " various common units of sheet metal ..... in6
103. Densities of various liquids ..... 117
104. Density of air-free water between $0^{\circ}$ and $41^{\circ} \mathrm{C}$ ..... 118
105. Relative volume of water between $0^{\circ}$ and $40^{\circ} \mathrm{C}$ ..... 119
106. Density and volume of water, $-10^{\circ}$ to $250^{\circ} \mathrm{C}$ ..... 120
107. " " " " mercury, $-10^{\circ}$ to $360^{\circ} \mathrm{C}$ ..... 121
108. Density of aqueous solutions of salts, bases and acids ..... 122
io9. " " " ethyl alcohol, temperature variation ..... 124
iro. " " " methyl alcohol, cane-sugar, sulphuric acid. ..... 126
iII. " " various gases ..... 127
112. Volume of gases, - values of $\mathbf{x}+0.00367 t$ :(a) for values of $t$ between $0^{\circ}$ and $10^{\circ} \mathrm{C}$ byo. $1^{\circ}$ steps128
(b) " " "" " $-90^{\circ}$ and $+1990^{\circ} \mathrm{C}$ by $10^{\circ}$ steps ..... 129
(c) logarithms for $t$ between $-49^{\circ}$ and $399^{\circ} \mathrm{C}$ by $\mathrm{r}^{\circ}$ steps ..... I30
(d) " " " " $+400^{\circ}$ and $1990^{\circ} \mathrm{C}$ by $10^{\circ}$ steps ..... 132
113. Density of moist air: $h / 760, h$ from 1 to 9 ..... I33
114. " " " " $\log h / 760, h$ from 80 to 800 ..... 133
115. $0.378 e$ in equation $h=B-0.378 e$ ..... I35
116. Maintenance of air at definite humidities ..... I35
117. Pressure of mercury and water columns ..... I36
Barometric Tables
118. Reduction of barometer to standard temperature ..... I37
rig. " " " " gravity, in. and mm, altitude term ..... 138
120. " " " " latitude $45^{\circ}, 0^{\circ}$ to $45^{\circ}$, mm ..... 139
121. " " " " " " $45^{\circ}$ to $90^{\circ}$, mm ..... 140
122. $0^{\circ}$ to $45^{\circ}$, inches ..... 141
123. " " " " " " $45^{\circ}$ to $90^{\circ}$, inches ..... 142
124. Correction to barometer for capillarity, mm and inches ..... 143
125. Volume of mercury meniscus in $\mathrm{mm}^{3}$ ..... 143
126. Barometric pressure corresponding to the boiling point of water: (a) metric scale ..... 144
(b) inch scale ..... 144
127. Determination of heights by the barometer ..... 145
Acoustics
128. Velocity of sound in solids ..... 146
129. " " " " liquids and gases ..... 147
130. Musical scales ..... 148
131. " " ..... 148
132. Fundamental tone, its harmonics and equal tempered scale ..... 149
133. Relative strength of the partials of musical instruments ..... 149
134. Characteristics of the vowels ..... 149
135. Miscellaneous sound data ..... 149
Aerodynamics
136. Kinetics of bodies in resisting medium, Stokes law ..... 150
137. Flow of gas through tubes ..... 150
138. Air pressure, large square normal planes, various speeds ..... 151
139. Correction factor for small square normal planes ..... 151
140. Effect of aspect ratio ..... 152
14I. Ratios of pressures on inclined and normal planes ..... 152
142. Skin friction ..... 152
143. Variation of air resistance with aspect and angle ..... I53
144. " " " " " shape and size ..... 153
145. " " " ". " " " " and speed ..... 153
146. Friction ..... I 54
147. Lubricants ..... 154
148. Lubricants for cutting tools ..... 154
Viscosity
149. Viscosity of fluids and solids, general considerations ..... 155
150. " " water in centipoises, temperature variation ..... 155
151. " " ethyl-alcohol-water mixtures, temperature variation ..... 155
152. " and density of sucrose aqueous solutions, temp. variation ..... 156
153. " " " " glycerol ..... 156
154. " " " " castor oil, temperature variation ..... 156
155. " of miscellaneous liquids ..... 157
156. " " organic liquids ..... 158
157. Specific viscosity of solutions, density and temperature variation ..... 159
158. " " " " atomic concentrations, $25^{\circ} \mathrm{C}$ ..... 163
159. Viscosity of gases and vapors ..... 164
160. " " " " " : temperature and pressure variation ..... 165
161. Diffusion of an aqueous solution into pure water ..... 166
162. " " vapors ..... 167
163. " " gases and vapors ..... 168
164. " metals into metals ..... 168
165. Solubility of inorganic salts in water, temperature variation ..... 169
166. " " a few organic salts in water, temperature variation ..... 170
167. " " gases in water ..... 170
168. " " change of, produced by uniform pressure ..... 171
169. Absorption of gases by liquids ..... 172
170. Capillarity and surface tension, water and alcohol in air ..... 173
171. " " " " miscellaneous liquids in air ..... 173
172. " " " " aqueous solutions of salts ..... 173
173. " " " " liquids-air, -water, -mercury ..... 174
174. " " " " " liquids at solidifying point ..... 174
175. thickness of soap films ..... 174
Vapor Pressures
176. Vapor pressures of elements ..... 175
177. and rates of evaporation, $\mathrm{Mo}, \mathrm{W}, \mathrm{Pt}$ ..... 175
178. " " organic liquids ..... 176
179. of ethyl alcohol ..... 178
180. " " " methyl alcohol ..... 178
181. (a) carbon disulphide ..... 179
(b) chlorobenzene ..... 179
(c) bromobenzene ..... 179
(d) aniline ..... 179
(e) methyl salicylate ..... 180
( $f$ ) bromonaphthalene ..... 180
(g) mercury ..... 180
182. Vapor pressure of solutions of salts in water ..... 181
183. Pressure of saturated water vapor over ice, low temperatures ..... 183
184. " " " " " " water, low temperatures ..... 183
185. " " " " " " " $0^{\circ}$ to $374^{\circ} \mathrm{C}$ ..... 183
186. Weight in g per $\mathrm{m}^{3}$ of saturated water vapor ..... 185
187. Weight in grains per $\mathrm{ft}^{3}$ of saturated water vapor ..... 185
188. Pressure of aqueous vapor in atmosphere, various altitudes ..... 185

189. 

sea-level ..... 186
190. Relative humidity, arguments, vapor pressure and dry temperature ..... 187

191. 

wet and dry thermometers ..... 189
Thermometry
192. Stem correction for thermometers, centigrade ..... 190
193. Jena glass, $0^{\circ}$ to $360^{\circ} \mathrm{C}$ ..... 190
194. " " " " " " $0^{\circ}$ " " " ..... 19I
195. normal, $0^{\circ}$ to $100^{\circ} \mathrm{C}$ ..... I9I
196. Gas and mercury thermometers, formulae ..... 192
197. Comparison of hydrogen and $16^{\text {III }}$ thermometers, $0^{\circ}$ to $100^{\circ} \mathrm{C}$ ..... 192
198. $59^{\text {III }} \quad$ " $\quad 0^{\circ}$ " $100^{\circ} \mathrm{C}$. ..... 192
199.$-35^{\circ} \mathrm{C}$.192
200. Comparison of air and $16^{\text {III }}$ thermometers, $0^{\circ}$ to $300^{\circ} \mathrm{C}$ ..... 193
201. $59^{\text {III }} \quad$ " $100^{\circ}$ to $200^{\circ} \mathrm{C}$ ..... 193
202. " " hydrogen and various mercury thermometers ..... 194
203. " " air and high temperature ( $59{ }^{\text {III }}$ ) mercury thermometer ..... 194
204. " H, toluol, alcohol, petrol ether, pentane thermometers ..... 194
205. Platinum resistance thermometry ..... 195
206. Thermodynamic scale; temperature of ice point, Kelvin scale ..... 195
207. Standard points for the calibration of thermometers ..... 195
208. Calibration of thermo-element, $\mathrm{Pt}-\mathrm{Pt} \cdot \mathrm{Rh}$ ..... 196
209. Cu-constantan. ..... 196
210. Mechanical equivalent of heat, summary to 1900 (Ames) ..... 197
21I. " " " " best value ..... 197
212. Conversion factors, work units ..... 197
213. English and American horse power, altitude and latitude variation ..... 197
Melting and Boiling Points
214. Melting points of the chemical elements ..... 198
215. Boiling points of the chemical elements ..... 199
216. Melting points, effect of pressure ..... 200
217. Freezing point of water, effect of pressure ..... 200
218. Boiling point, effect of pressure ..... 200
219. Inorganic compounds, melting and boiling points, densities ..... 201
220. Organic compounds, melting and boiling points, densities: ..... 203
(a) Paraffin series ..... 203
(b) Olefine series ..... 203
(c) Acetylene series ..... 204
(d) Monatomic alcohols ..... 204
(e) Alcoholic ethers ..... 204
(f) Ethyl ethers ..... 204
(g) Miscellaneous ..... 205
221. Melting points of various mixtures of metals ..... 206
222. ..... 206
223. Low-melting-point alloys ..... 206
224. Transformation and melting points, minerals and eutectics ..... 207
225. Lowering of freezing points by salts in solution ..... 208
226. Raising of boiling points by salts in solution ..... 210
227. Freezing mixtures ..... 211
228. Critical temperatures, pressures, volumes, densities of gases ..... 212
Thermal Conductivity
229. Thermal conductivity of metals and alloys ..... 213
230. " " insulators, high temperatures ..... 214
231. " " various substances ..... 214
232. " " building materials ..... 215
233. " " various insulators ..... 216
234. . " water and salt solutions ..... 216
235. " " organic liquids ..... 217
236. " " gases ..... 217
237. Diffusivities ..... 217
Expansion Coefficients
238. Linear expansion of the elements ..... 218
239. " " " miscellaneous substances ..... 219
240. Cubical expansion of solids ..... 220
241. " " " liquids ..... 221
242. " " " gases ..... 222
Specific Heats
243. Specific heats of elements. ..... 223
244. Heat capacities, true and mean specific heats, and latent heats of fusion of the metallic elements, $0^{\circ}$ to $1600^{\circ} \mathrm{C}$ ..... 225
245. Atomic heats, atomic volumes, specific heats at $50^{\circ} \mathrm{K}$, elements ..... 226
246. Specific heats of various solids. ..... 227
247. " " " water and mercury ..... 227
248. " " " various liquids ..... 228
249. " heat of saturated liquid ammonia, $-50^{\circ}$ to $+50^{\circ} \mathrm{C}$ ..... 228
250. Heat contents of saturated liquid ammonia, $-50^{\circ}$ to $+50^{\circ} \mathrm{C}$ ..... 228
251. Specific heats of minerals and rocks ..... 229
252. " " (true and mean) of silicates, $0^{\circ}$ to $1400^{\circ} \mathrm{C}$ ..... 229
253. .". " of gases and vapors, also $c_{p} / c_{v}$ ..... 230
Latent Heats
254. Latent heats of vaporization ..... 231
255. " " " " formulae ..... 232
256. " " " " ammonia ..... 232
257. "Latent heat of pressure variation" of liquid ammonia ..... 232
258. Latent and total heats of vaporization of elements, - theoretical ..... 233
259. Properties of saturated steam ..... 234
260. Latent heats of fusion ..... 240
Heats of Combustion, Formation, etc.
261. Heats of combustion of some carbon compounds ..... 241
262. " " " " miscellaneous compounds ..... 241
263. Heat values and analyses of various fuels: (a) coals and coke ..... 242
(b) peats and woods ..... 242
(c) liquid fuels ..... 242
(d) gases ..... 242
264. Chemical and physical properties of explosives ..... 243
265. Additional data on explosives ..... 244
266. Ignition temperatures of gaseous mixtures ..... 244
267. Explosive decomposition, ignition temperatures ..... 244
268. Flame temperatures ..... 244
269. Thermochemical data: heats of formation from elements ..... 245
270 . " " " " " of ions ..... 246
271. " " " " neutralization. ..... 246
272. " " " ." dilution of sulphuric acid ..... 246
Radiation
273. Radiation formulae and constants for perfect (black-body) radiator ..... 247
${ }^{274}$. " in calories for perfect radiator, various temperatures ..... 247
275. " distribution in spectrum for various temperatures ..... 247
276. Black-body spectrum intensities, $50^{\circ}$ to $20000^{\circ} \mathrm{K}$ ..... 248
277. Relative emissive powers of various bodies for total radiation ..... 249
278. Emissivities of metals and oxides ..... 249
279. ..... 249
280. Temperature scale for tungsten, - color, black-body and true tem- peratures ..... 250
28I. Color minus brightness temperature for carbon ..... 250
Cooling by Radiation, Conduction, and Convection
282. Cooling by radiation and convection: ordinary pressures ..... 251
283. " " " " " different pressures ..... 251
284. Cooling by radiation and convection: very small pressures ..... 252
285. " " " " temperature and pressure effect ..... 252
286. Conduction of heat across air spaces, ordinary temperatures ..... 253
287. Convection of heat in air at ordinary temperatures ..... 253
288. " and conduction of heat by gases at high temperatures: ..... 254
(a) $s$ as function of $a / B$ ..... 254
(b) $\phi$ in watts per cm . as $f\left(T^{\circ} \mathrm{K}\right)$ ..... 254
289. Heat losses from incandescent filaments: ..... 255
(a) Wires of platinum sponge ..... 255
(b) " " bright platinum ..... 255
The Eye and Radiation
290. Spectral variation of sensitiveness as function of intensity (Lumina- tion intensities under various circumstances) ..... 256
291. Threshold sensibility as related to field brightness ..... 256
292. Heterochromatic threshold sensibility ..... 257
293. Contrast or photometric sensibility ..... 257
294. Glare sensibility ..... 257
295. Rate of adaptation of sensibility ..... 257
296. Apparent diameter of pupil and flux density at retina ..... 258
297. Relative visibility of radiation of different wave-lengths ..... 258
298. Miscellaneous eye data: physiological; persistence of vision; sensi- bility to small differences of color; flicker ..... 258
Photometric Tables
299. Photometric definitions and units ..... 259
300. " standards ..... 260
301. Intrinsic brightness of various light sources ..... 260
302. Visibility of white lights ..... 260
303. Brightness, Crova wave-length, mechanical equivalent of light ..... 261
304. Luminous and total intensity and radiant luminous efficiency of a black-body; minimum energy necessary for light sensation ..... 261
305. Color of light emitted by various sources ..... 261
306. Efficiency of various electric lights ..... 262
Photographic Data
307. Numerical constants characteristic of a photographic plate ..... 263
308. Relative speeds of various photographic materials ..... 263
309. Variation of resolving power with plate and developer ..... 263
310. Photographic efficiencies of various lights ..... 264
3II. Relative intensification of various intensifiers ..... 264
Spectrum Wave-lengths
312. Wave-lengths of the Fraunhofer lines ..... 265
313. Standards: Red cadmium line, $76 \mathrm{~cm}, 15^{\circ} \mathrm{C}$, Angstroms ..... 266
314. Standards: International secondary Fe arc standards, Angstroms ..... 266
315. " International secondary Fe arc standards, Angstroms ..... 266
316. " Neon wave-lengths ..... 266
317. " International tertiary Fe arc standards, Angstroms ..... 267
318. Reduction of wave-lengths in air to standard conditions: ..... 268
(a) $\left(d-d_{0}\right) / d_{0} \times$ 1000; $B, 60$ to $78 \mathrm{~cm}, t, 9^{\circ}$ to $35^{\circ} \mathrm{C}$ ..... 268
(b) $\delta=\lambda_{0}\left(n_{0}-n_{0}{ }^{\prime}\right)\left(d-d_{0}\right) / d_{0}$ ..... 268
319. Spectra of the elements ..... 269
320. Spectrum lines of the elements (Kayser) ..... '270
321. Standard solar wave-lengths (Rowland) ..... 272
322. Spectrum series, general discussion ..... 275
323. " limits of some of the series ..... 276
324. " first terms and vibration differences ..... 276
Indices of Refraction
325. Indices of refraction of glass (American) ..... 277
326. Dispersion of glasses of Table 325 ..... 277
327. Indices of refraction of glasses made by Schott and Gen, Jena ..... 278
328. Dispersion of Jena glasses ..... 278
329. Changes of indices for $\mathrm{I}^{\circ} \mathrm{C}$ change for some Jena glasses ..... 278
330. Index of refraction of rock-salt in air ..... 279
331. Change of indices for $\mathrm{I}^{\circ} \mathrm{C}$ change for rock-salt ..... 279
332. Index of refraction of silvine (potassium chloride) in air ..... 279
333. " fluorite in air ..... 280
334. Change of indices for $\mathrm{I}^{\circ} \mathrm{C}$ change for fluorite ..... 280
335. Index of refraction of iceland spar $\left(\mathrm{CaCO}_{3}\right)$ in air ..... 280
336. " " " " nitroso-dimethyl-aniline ..... 280
337. " quartz $\left(\mathrm{SiO}_{2}\right)$ ..... 28I
338. Indices of refraction for various alums ..... 28I
339. " " refraction: Selected isotropic minerals ..... 282
340. " " " Miscellaneous isotropic solids ..... 283
34I. Selected uniaxial minerals (positive) ..... 284
" " " " " (negative) ..... 284
342. Miscellaneous uniaxial crystals ..... 285
343. Selected biaxial minerals (a) positive ..... 286
" ". " (b) negative ..... 287
344. Miscellaneous biaxial crystals ..... 289
345. Liquefied gases, oils, fats, waxes ..... 289
346. Liquids relative to air ..... 290
347 . Solutions of salts and acids relative to air ..... 291
348. Gases and vapors ..... 292349. " " " Air, $15^{\circ} \mathrm{C}, 76 \mathrm{~cm}$; also corrections for reduc-ing wave-lengths and frequencies in air to vacuo (see Table 318) . 293350. Media for microscopic determinations of refractive indices: liquidswith $n_{D}(0.589 \mu)=1.74$ to 1.87294
351. Media for microscopic determinations of refractive indices: resin-like substances, $n_{D}(0.589 \mu)=1.88$ to 2.10 ..... 294
352. Media for microscopic determinations of refractive indices: perma- nent standard resinous media, $n_{D}=1.546$ to 1.682 ..... 294
353. Optical constants of metals ..... 295
354. ..... 296
Reflecting Power
355. Reflecting power of metals (see Table 359) ..... 296
356. Light reflected when incident light is normal to transparent medium ..... 297
357. " " " $n$ is near unity or equals $\mathrm{I}+d n, i=0^{\circ}$ to $90^{\circ}$. ..... 297
358. " " " $n=1.55, i=0^{\circ}$ to $90^{\circ}$, polarization percentages. ..... 297
359. Reflecting power of metals (see Table 355) ..... 298
360. Percentage diffuse reflection from various substances ..... 298
361. Reflecting power of pigments, $\lambda=0.44 \mu$ to $0.70 \mu$ ..... 299
362. Infra-red diffuse reflecting power of dry pigments ..... 299
363. Reflecting power of powders (white light) ..... 300
364. Variation of reflecting power of matt and silvered surfaces with angle ..... 300
365. Infra-red reflectivity of tungsten, temperature variation ..... 300
Transmissive Powers
366. Transmissibility of radiation by dyes, $\lambda=0.44 \mu$ to $0.70 \mu$ ..... 301
367. ..... 302
368 . " " " " " " 0.280 to $0.644 \mu$ ..... 302
369. " by Jena ultra-violet glasses, 0.280 to $0.397 \mu$ ..... 302
370 . " of radiation by glasses (American) 0.5 to $5.0 \mu$ ..... 303
371. " by same glasses for various lights ..... 304
372. " of radiation by substances of Tables 330 to 338 . ..... 305
373. Color screens (Landolt) ..... 306
374. " " (Wood) ..... 306
375. " " (Jena glasses) ..... 307
376. Transmissibility of radiation by water, $\lambda=0.186 \mu$ to $0.945 \mu$ ..... 307
377. Transmission percentages of radiation by moist air, $0.75 \mu$ to $20 \mu$ ..... 308
378. Long-wave absorption by gases, $23 \mu$ to $314 \mu$ ..... 309
379. Properties with wave-lengths $108 \pm \mu$ :
(a) Percentage reflection ..... 309
(b) Percentage transparency ..... 309
(c) Transparency of black absorbers, $2 \mu$ to $\mathbf{1 0} 8 \mu$ ..... 309
380. Rotation of plane of polarized light by solutions ..... 310
381. " " " " " " sodium chlorate and quartz ..... 310
382. Electrical equivalents ..... 311

## Electromotive Powers

383. Data for voltaic cells: (a) double-fluid cells ..... 312
(b) single-fluid cells ..... 313
(c) standard cells ..... 313
(d) secondary cells ..... 313
384. Contact potential differences, solids with liquids and liquids with liquids in air ..... 314
385. Contact potential differences between metals in salt solutions ..... 316
386. Thermoelectric power of metals ..... 317
387. " " alloys ..... 318
388. against platinum. ..... 319
389. ". " " " of platinum-rhodium alloys ..... 319
390. pressure effect ..... 320
391. Peltier and Thomson heats, pressure effects ..... 320
392. Peltier effect ..... 321
393. " " Fe-constantan, $\mathrm{Ni}-\mathrm{Cu}, 0^{\circ}$ to $560^{\circ} \mathrm{C}$ ..... 32 I
394. " electromotive force in millivolts ..... 322
395. The tribo-electric series ..... 322
Electrical Resistance
396. Auxiliary table for computing wire resistances. ..... 322
397. Resistivity of metals and some alloys, temperature coefficients ..... 323
398. Resistance of metals under pressure, temperature coefficients ..... 326
399. Resistance of mercury and manganin under pressure ..... 326
400. Conductivity and resistivity of miscellaneous alloys ..... 327
401. Conducting power of alloys, temperature coefficients ..... 328
402. Allowable carrying capacity of rubber-covered copper wires ..... 329
403. Resistivities at high and low temperatures ..... 330
404. Volume and surface resistivity of solid dielectrics ..... 331
405. Variation of resistance of glass and porcelain with temperature ..... 332
(a) Temperature coefficients for glass, porcelain and quartz ..... $33^{2}$
Wire Tables
406. Tabular comparison of wire gages ..... 333
407. Introduction; mass and volume resistivity of copper and aluminum ..... 334
408. Temperature coefficients of copper ..... 335
409. Reduction to standard temperature, copper ..... 335
410. Annealed copper wire table, English units, B. \& S. gage ..... 336
411. Metric units, B. \& S. gage ..... 339
412. Hard-drawn aluminum wire table, English units, B. \& S. gage ..... 342
413. Metric units, B. \& S. gage ..... 343
414. Ratio of alternating to direct current resistances for copper wire ..... 344
415. Maximum diameter of wires for high-frequency-alternating-to-direct- current ratio of $\mathrm{I} . \mathrm{or}$ ..... 344
Electrolysis
416. Electrochemical equivalents ..... 345
417. Conductivity of a few dilute solutions ..... 346
418. Electrochemical equivalents and densities of nearly normal solutions ..... 346
419. Specific molecular conductivity of solutions ..... 347
420. " " " " limiting values ..... 348
42 I. " " . ". " temperature coefficient ..... 348
421. Equivalent conductivity of salts, acids, bases in solution ..... 349
422. " some additional salts in solution ..... 351
423. " conductance of separate ions ..... 352
424. Hydrolysis of ammonium acetate and ionization of water ..... 352
Dielectric Strength
425. Steady potential for spark in air, ball electrodes ..... 353
426. Alternating potential for spark in air, ball electrodes ..... 353
427. Steady and alternating potential for longer sparks in air ..... 354
428. Effect of pressure of the gas on the dielectric strength ..... 354
429. Dielectric strength of various materials ..... 355
430. Potential in volts for spark in kerosene ..... 355
Dielectric Constants
431. Specific inductive capacity of gases, atmospheric pressure ..... 356
432. Variation of dielectric constant with the temperature (gases) ..... 356
433. " " " " " " pressure (gases) ..... 357
434. Dielectric constant of liquids ..... 357
435. " " " liquids, temperature coefficients ..... 359
436. " " " liquefied gases ..... 359
437. " " " standard solutions for calibration ..... 360
438. " " " solids ..... 360
439. " " " crystals ..... 361
Wireless Telegraphy
44r. Wave-lengths, frequencies and oscillation constants ..... 362
440. Antennae resistances for various wave-lengths and heights ..... 364
441. Dielectric properties of non-conductors ..... 364
Magnetic Properties
442. Definitions and general discussion ..... 365
443. Composition and magnetic properties of iron and steel (old data) ..... 367
444. Magnetic properties of iron and steel ..... 368
445. Cast iron in intense fields ..... 368
446. Corrections for ring specimens ..... 368
447. Magnetic properties of various types of iron and steel ..... 369
448. " " " a specimen of very pure iron ( $0.017 \% \mathrm{C}$ ) ..... 369
449. " " " electrical sheets ..... 369
450. " American magnet steel ..... 370
451. " " " a ferro-cobalt alloy ..... 370
452. " " " a ring sample transformer steel, weak field ..... 370
453. " " " iron in very weak fields ..... 370
454. Permeability of some specimens of Table 445 ..... 37 I
455. Magnetic properties of soft iron at $0^{\circ}$ and $100^{\circ} \mathrm{C}$ ..... 37 I
456. " " " steel at $\circ^{\circ}$ and $100^{\circ} \mathrm{C}$ ..... 37 I
457. Magnetism and temperature, critical temperature ..... 372
458. Temperature variation for paramagnetic substances ..... 372
459. " effect on susceptibility of diamagnetic elements ..... 372
460. " " " " paramagnetic elements ..... 372
461. Magnetic properties of cobalt at $0^{\circ}$ and $100^{\circ} \mathrm{C}$ ..... 373
462. nickel " " " " " ..... 373
463. " " " magnetite ..... 373
464. " " " Lowmoor wrought iron ..... 373
465. " " " Vicker's tool steel ..... 373
466. " " " Hadfield's manganese steel ..... 373
467. " " " saturation values for steels ..... 373
468. Demagnetizing factors for rods ..... 374
469. ..... 374
470. Dissipation of energy in cyclic mangetization, Steinmetz constant ..... 375
471. Energy losses in transformer steels ..... 376
472. Magnetic susceptibility ..... 377
Magnetto-optic Rotation
473. Magneto-optic rotation, general discussion ..... 378
474. solids, Verdet's constant ..... 379
475. liquids, Verdet's constant ..... 380
476. salt and acid water solutions ..... 381
477. gases, Verdet's constant ..... 382
478. Verdet's and Kundt's constants ..... 382
48i. Values of Kerr's constant ..... 383
479. Dispersion of Kerr effect ..... 383
480. ..... 383
Various Magnetic Effects
481. Resistance of metals, variation in transverse magnetic field ( Bi ) ..... 384
482. Increase of resistance in transverse magnetic field (Ni) ..... 384
483. Change of resistance of various metals in magnetic field ..... 384
484. Transverse galvanomagnetic and thermomagnetic effects ..... 385
485. Variation of Hall constant with temperature ..... 385

## Cathode and Canal Rays

489. Cathode and canal rays ..... 386
490. Speed of cathode rays ..... 386
491. Cathodic sputtering ..... 386
Röntgen (X-Rays) Rays
492. X-rays, general properties ..... 387
493. Röntgen secondary rays ..... 387
494. Corpuscular rays ..... 388
495. Intensity of X-rays; ionization ..... 388
496. Mass absorption coefficients, $\lambda / d$ ..... 389
497. Absorption coefficients of characteristic radiations in gases ..... 389
498. X-ray spectra and atomic numbers ..... 390
(a) K-series ..... 390
(b) L-series ..... 391
(c) M-series ..... $39^{2}$
(d) Tungsten X-ray spectrum ..... 392
499. X-ray absorption spectra and atomic numbers ..... 393
Radioactivity
500. Relative phosphorescence excited by radium ..... 394
501. The production of $a$ particles (Helium) ..... 394
502. Heating effect of radium and its emanation ..... 394
503. Stopping powers of various substances for $\alpha$ rays ..... 395
504. Absorption of $\beta$ rays by various substances ..... 395
j05. " " $\gamma$ rays by various substances ..... 395
505. Table of miscellaneous properties ..... 396
506. Total number of ions produced by the $\alpha, \beta$, and $\gamma$ rays ..... 398
507. Amount of radium emanation ..... 398
508. Vapor pressure of the radium emanation in cm of Hg ..... 398
509. References to spectra of radioactive substances ..... 398
Molecular, Atomic and Ionic Data
5 II. Molecular velocities ..... 399
510. " free paths, collision frequencies and diameters ..... 399
511. Cross sections and lengths of some organic molecules ..... 400
512. Size of diffracting units in crystals ..... 400
513. Electrons; Rutherford atom; Bohr atom; Magnetic field of atom ..... 401
514. Electron emission from hot metals ..... 403
515. Photo-electric effect ..... 403
516. Ionizing potentials, resonance potentials, single line spectra ..... 403
517. Contact (Volta) potentials ..... 404
(a) Electron affinity of the elements ..... 404
(b) Voltage of electrolytic cells ..... 404
518. Ionic mobilities and diffusions, - ionic mobilities ..... 405
52I. Diffusion coefficients ..... 405

## Colloids

522. General properties of colloids ..... 406
523. Molecular weights of colloids ..... 406
524. Brownian movement ..... 406
525. Adsorption of gas by finely divided particles ..... 407
526. Heats of adsorption ..... 407
527. Molecular heats of adsorption and liquefaction ..... 407
528. Miscellaneous constants, atomic, molecular, etc. ..... 408
529. Radiation wave-length limits ..... 408
530. Periodic system of the elements (Mendelejeff) ..... 409
531. Atomic numbers ..... 409
532. Periodic system of the elements and radioactive isotopes (Hackh) ..... 410
Astronomical Data
533. Stellar spectra and related characteristics ..... 4II
534. The Harvard spectrum classification ..... 4II
535. Apex and velocity of solar motion ..... 4II
536. Motion of the stars ..... 412
537. Distances of the stars ..... 4I2
538. Brightness of the stars ..... 4I3
539. Masses and densities ..... 413
540. Miscellaneous astronomical data ..... 414
54r. The first-magnitude stars ..... 415
541. Wolf's observed sun-spot numbers, 1750 to 1917 ..... 415
542. Length of degrees on the earth's surface ..... 416
543. Equation of time ..... 416
544. Planetary data ..... 416
545. Numbers and equivalent light of the stars ..... 417
546. Albedos ..... 417
547. Duration of sunshine ..... 417
548. The solar constant. ..... 418
549. Solar spectrum energy and its transmission through the atmosphere ..... 418
550. Intensity of solar energy in various sections of spectrum ..... 418
551. Distribution of brightness (radiation) over the solar disk ..... 418
552. Transmission of radiation through moist and dry air (see Table 376) ..... 4I9
553. Brightness of sky at altitudes of 1730 m and sea-level ..... 4IS,
554. Relative distribution in normal spectrum of sun and sky light ..... 419
555. Air masses ..... 419
556. Relative intensity of solar radiation for various months ..... 420
Meteorological Data
557. Mean monthly and yearly temperatures for representative stations ..... 420
558. The earth's atmosphere, variation with latitude, miscellaneous ..... 42 I
possible of the complex relationships involving them. Further it seems desirable that the units should be extensive in nature. It has been found possible to express all measurable physical quantities in terms of five such units: ist, geometrical considerations - length, surface, etc., - lead to the need of a length; 2nd, kinematical considerations - velocity, acceleration, etc., -introduce time; 3rd, mechanics - treating of masses instead of immaterial points - introduces matter with the need of a fundamental unit of mass; 4th, electrical, and $5^{\text {th }}$, thermal considerations require two more such quantities. The discovery of new classes of phenomena may require further additions.

As to the first three fundamental quantities, simplicity and good use sanction the choice of a length, $L$, a time interval, $T$, and a mass, $M$. For the measurement of electrical quantities, good use has sanctioned two fundamental quantities, - the dielectric constant, $K$, the basis of the "electrostatic" system and the magnetic permeability, $\mu$, the basis of the "electromagnetic" system. Besides these two systems involving electrical considerations, there is in common use a third one called the "international" system which will be referred to later. For the fifth, or thermal fundamental unit, temperature is generally chosen. ${ }^{1}$

Derived Units. - Having selected the fundamental or basic units, - namely, a measure of length, of time, of mass, of permeability or of the dielectric constant, and of temperature, - it remains to express all other units for physical, quantities in terms of these. Units depending on powers greater than unity of the basic units are called "derived units." Thus, the unit volume is the volume of a cube having each edge a unit of length. Suppose that the capacity of some volume is expressed in terms of the foot as fundamental unit and the volume number is wished when the yard is taken as the unit. The yard is three times as long as the foot and therefore the volume of a cube whose edge is a yard is $3 \times 3 \times 3$ times as great as that whose edge is a foot. Thus the given volume will contain only $\mathrm{I} / 27$ as many units of volume when the yard is the unit of length as it will contain when the foot is the unit. To transform from the foot as old unit to the yard as new unit, the old volume number must be multiplied by $1 / 27$, or by the ratio of the magnitude of the old to that of the new unit of volume. This is the same rule as already given, but it is usually more convenient to express the transformations in terms of the fundamental units directly. In the present case, since, with the method of measurement here adopted, a volume number is the cube of a length-number, the ratio of two units of volume is the cube of the ratio of the intrinsic values of the two units of length. Hence, if $l$ is the ratio of the magnitude of the old to that of the new unit of length, the ratio of the corresponding units of volume is $l^{3}$. Similarly the ratio of two units of area would be $l^{2}$, and so on for other quantities.

[^1]Conversion Factors and Dimensional Formulae. - For the ratios of length, mass, time, temperature, dielectric constant and permeability units the small bracketed letters, $[l],[m],[t],[\theta],[k]$, and $[\mu]$ will be adopted. These symbols will always represent simple numbers, but the magnitude of the number will depend on the relative magnitudes of the units the ratios of which they represent. When the values of the numbers represented by these small bracketed letters as well as the powers of them involved in any particular unit are known, the factor for the transformation is at once obtained. Thus, in the above example, the value of $l$ was $I / 3$, and the power involved in the expression for volume was 3 ; hence the factor for transforming from cubic feet to cubic yards was $l^{3}$ or $1 / 3^{3}$ or $\mathrm{I} / 27$. These factors will be called conversion factors.

To find the symbolic expression for the conversion factor for any physical quantity, it is sufficient to determine the degree to which the quantities length, mass, time, etc., are involved. Thus a velocity is expressed by the ratio of the number representing a length to that representing an interval of time, or $[L / T]$, and acceleration by a velocity number divided by an interval-of-time number, or $\left[L / T^{2}\right]$, and so on, and the corresponding ratios of units must therefore enter in precisely the same degree. The factors would thus be for the just stated cases, $[l / t]$ and $\left[l / t^{2}\right]$. Equations of the form above given for velocity and acceleration which show the dimensions of the quantity in terms of the fundamental units are called dimensional equations. Thus $[E]=\left[M L^{2} T^{-2}\right]$ will be found to be the dimensional equation for energy, and $\left[M L^{2} T^{-2}\right]$ the dimensional formula for it. These expressions will be distinguished from the conversion factors by the use of bracketed capital letters.

In general, if we have an equation for a physical quantity,

$$
Q=C L^{a} M^{b} T^{c},
$$

where $C$ is a constant and $L, M, T$ represent length, mass, and time in terms of one set of units, and it is desired to transform to another set of units in terms of which the length, mass, and time are $L_{i}, M_{i}, T_{l}$, we have to find the value of $L_{l} / L, M_{l} / M, T_{l} / T$, which, in accordance with the convention adopted above, will be $l, m, t$, or the ratios of the magnitudes of the old to those of the new units.
Thus $L_{1}=L l, M_{1}=M m, T_{1}=T t$, and if $Q_{1}$ be the new quantity number,

$$
\begin{aligned}
Q_{1} & =C L_{,}{ }^{a} M_{,}^{b} T_{c}^{c}, \\
& =C L^{a} l^{c} M^{b} m^{b} T^{c} t^{c}=Q l^{a} m^{b} t^{c},
\end{aligned}
$$

or the conversion factor is $\left[l^{a} m^{b} c^{c}\right]$, a quantity precisely of the same form as the dimension formula [ $\left.L^{a} M^{b} T^{c}\right]$.

Dimensional equations are useful for checking the validity of physical equations. Since physical equations must be homogeneous, each term appearing in them must be dimensionally equivalent. For example, the distance moved by a uniformly accelerated body is $s=v_{0} t+\frac{1}{2} a t^{2}$. The corresponding dimensional equation is $[L]=[(L / T) T]+\left[\left(L / T^{2}\right) T^{2}\right]$, each term reducing to $[L]$.

Dimensional considerations may often. give insight into the laws regulating physical phenomena. ${ }^{1}$ For instance Lord Rayleigh, in discussing the intensity
${ }^{1}$ See "On Physically Similar Systems; Illustrations of the Use of Dimensional Equations." E. Buckingham, Physical Review, (2) 4, p. 345, 1914.

Absolute Force of a Center of Attraction, or "Strength of a Center," is the intensity of force at unit distance from the center, and is the force per unit mass at any point multiplied by the square of the distance from the center. The dimensional formula is $\left[F L^{2} M^{-1}\right]$ or $\left[L^{3} T^{-2}\right]$.

Modulus of Elasticity is the ratio of stress intensity to percentage strain. The dimensional of percentage strain, a length divided by a length, is unity. Hence the dimensional formula of a modulus of elasticity is that of stress intensity [ $M L^{-1} T^{-2}$ ].
Work is done by a force when the point of application of the force, acting on a body, moves in the direction of the force. It is measured by the product of the force and the displacement. The dimensional formula is $[F L]$ or $\left[M L^{2} T^{-2}\right]$.

Energy. - The work done by the force produces either a change in the velocity of the body or a change of its shape or configuration, or both. In the first case it produces a change of kinetic energy, in the second, of potential energy. The dimensional formulae of energy and work, representing quantities of the same kind, are identical [ $\left.M L^{2} T^{-2}\right]$.

Resilience is the work done per unit volume of a body in distorting it to the elastic limit or in producing rupture. The dimensional formula is $\left[M L^{2} T^{-2} L^{-3}\right]$ or $\left[M L^{-1} T^{-2}\right]$.
Power or Activity is the time rate of doing work, or if $W$ represents work and $P$ power, $P=d w / d t$. The dimensional formula is $\left[W T^{-1}\right]$ or $\left[M L^{2} T^{-3}\right]$, or for problems in gravitation units more conveniently $\left[F L T^{-1}\right]$, where $F$ stands for the force factor.

Exs. - Find the number of gram-cms in one ft.-pd. Here the units of force are the attraction of the earth on the pound and the gram of matter. (In problems like this the terms "grams" and "pd." refer to force and not to mass.) The conversion factor is [ $f l$ ], where $f$ is 453.59 and $l$ is 30.48 . The answer is $453.59 \times 30.48=13825$.

Find the number of ft .-poundals in 1000000 cm -dynes. Here $m=1 / 453.59, l=1 / 30.48$, $t=1 ; m l^{2} t^{-2}=1 / 453.59 \times 30.48^{2}$, and $10^{6} m l^{2} t^{-2}=10^{6} / 453.59 \times 30.48^{2}=2.373$.

If gravity produces an acceleration of $32.2 \mathrm{ft} . / \mathrm{sec}$. $/ \mathrm{sec}$., how many watts are required to make one horse-power? One horse-power is 550 ft .-pds. per sec., or $550 \times 32.2=177 \mathrm{IO} \mathrm{ft}$.-poundals per second. One watt is $10^{7}$ ergs per sec., that is, $10^{7}$ dyne-cms per sec. The conversion factor is [ $m l^{2} t^{-3}$ ], where $m$ is $453.59, l$ is 30.48 , and $t$ is r , and the result has to be divided by $10^{7}$, the number of dyne-cms per sec. in the watt. $17710 m^{2} t^{-3} / 10^{7}=17710 \times 453.59 \times 30.48^{2} / 10^{7}$ $=746.3$.

## HEAT UNITS.

Quantity of Heat, measured in dynamical units, has the same dimensions as energy $\left[M L^{2} T^{-2}\right]$. Ordinary measurements, however, are made in thermal units, that is, in terms of the amount of heat required to raise the temperature of a unit mass of water one degree of temperature at some stated temperature. This involves the unit of mass and some unit of temperature. If we denote temperature numbers by $\theta$, the dimensional formula for quantity of heat, $H$, will be $[M \theta]$. Unit volume is sometimes used instead of unit mass in the measurement of heat, the units being called thermometric units. The dimensional formula now changed by the substitution of volume for mass is [ $\left.L^{3} \theta\right]$.

Specific Heat is the relative amount of heat, compared with water as standard substance, required to raise unit mass of different substances one degree in temperature and is a simple number.

Coefficient of Thermal Expansion of a substance is the ratio of the change of length per unit length (linear), or change of volume per unit volume (voluminal), to the change of temperature. These ratios are simple numbers, and the change of temperature varies inversely as the magnitude of the unit of temperature. The dimensional formula is $\left[\theta^{-1}\right]$.

Thermal Conductivity, or Specific Conductance, is the quantity of heat, $H$, transmitted per unit of time per unit of surface per unit of temperature gradient. The equation for conductivity is therefore $K=H / L^{2} T \theta / L$, and the dimensional formula $[H / \theta L T]=\left[M L^{-1} T^{-1}\right]$ in thermal units. In thermometric units the formula becomes $\left[L^{2} T^{-1}\right]$, which properly represents diffusivity, and in dynamical unjts [ $M L T^{-3} \theta^{-1}$ ].

Thermal Capacity is mass times the specific heat. The dimensional formula is $[M]$.

Latent Heat is the quantity of heat required to change the state of a body divided by the quantity of matter. The dimensional formula is $[M \theta / M]$ or $[\Theta]$; in dynamical units it is $\left[L^{2} T^{-2}\right]$.

Note. - When $\theta$ is given the dimensional formula $\left[L^{2} T^{-2}\right]$, the formulae in thermal and dynamical units are identical.

Joule's Equivalent, $J$, is connected with the quantity of heat by the equation $M L^{2} T^{-2}=J H$ or $J M \Theta$. The dimensional formula of $J$ is $\left[L^{2} T^{-2} \theta^{-1}\right]$. In dynamical units $J$ is a simple number.

Entropy of a body is directly proportional to the quantity of heat it contains and inversely proportional to its temperature. The dimensional formula is $[M \theta / \theta]$ or $[M]$. In dynamical units the formula is $\left[M L^{2} T^{-2} \Theta^{-1}\right]$.

Exs. - Find the relation between the British thermal unit, the large or kilogram-calorie and the small or gram-calorie, sometimes called the "therm." Referring all the units to the same temperature of the standard substance, the British thermal unit is the amount of heat required to warm one pound of water $\mathrm{I}^{\circ} \mathrm{C}$, the large caloric, a kilogram of water, $\mathrm{I}^{\circ} \mathrm{C}$, the small calorie or therm, I gram, $\mathrm{I}^{\circ} \mathrm{C}$. ( I ) To find the number of kg-cals. in one British thermal unit. $m=.45359, \theta=5 / 9 ; m \theta=.45359 \times 5 / 9=.25199$. (2) To find the number therms in one kg-cal. $m=1000$, and $\theta=1 ; m \theta=1000$. (3) Hence the number of small calories or therms in one British thermal unit is $1000 \times .25199=251.99$.

## ELECTRIC AND MAGNETIC UNITS.

A system of units of electric and magnetic quantities requires four funaamental quantities. A system in which length, mass, and time constitute three of the fundamental quantities is known as an "absolute" system. There are two absolute systems of electric and magnetic units. One is called the electrostatic, in which the fourth fundamental quantity is the dielectric constant, and one is called the electromagnetic, in which the fourth fundamental quantity is magnetic permeability. Besides these two systems there will be described a third in common use called the "international" system.

In the electrostatic system, unit quantity of electricity, $Q$, is the quantity which exerts unit mechanical force upon an equal quantity a unit distance from it in a vacuum. From this definition the dimensions and the units of all the other electric and magnetic quantities follow through the equations of the mathematical theory of electromagnetism. The mechanical force between two quantities of electricity in any medium is

$$
F=\frac{Q Q^{\prime}}{K r^{2}},
$$

where $K$ is the dielectric constant, characteristic of the medium, and $r$ the distance between the two points at which the quantities $Q$ and $Q^{\prime}$ are located. $K$ is the fourth quantity entering into dimensional expressions in the electrostatic system. Since the dimensional formula for force is $\left[M L T^{-2}\right]$, that for $Q$ is


The electromagnetic system is based upon the unit of the magnetic pole strength. The dimensions and the units of the other quantities are built up from this in the same manner as for the electrostatic system. The mechanical force between two magnetic poles in any medium is

$$
F=\frac{m m^{\prime}}{\mu r^{2}}
$$

in which $\mu$ is the permeability of the medium and $r$ is the distance between two poles having the strengths $m$ and $m^{\prime} . \mu$ is the fourth quantity entering into dimensional expressions in the electromagnetic system. It follows that the dimensional expression for magnetic pole strength is $\left[M^{\frac{1}{2}} L^{\frac{3}{3}} T^{-1} \mu^{\frac{1}{2}}\right]$.
The symbols $K$ and $\mu$ are sometimes omitted in the dimensional formulae so that only three fundamental quantities appear. There are a number of objections to this. Such formulae give no information as to the relative magnitudes of the units in the two systems. The omission is equivalent to assuming some relation between mechanical and electrical quantities, or to a mechanical explanation of electricity. Such a relation or explanation is not known.

The properties $K$ and $\mu$ are connected by the equation $\mathrm{I} / \sqrt{K \mu}=v$, where $v$ is the velocity of an electromagnetic wave. For empty space or for air, $K$ and $\mu$ being measured in the same units, $I / \sqrt{K \mu}=c$, where $c$ is the velocity of light in vacuo, $3 \times 10^{10} \mathrm{~cm}$ per sec. It is sometimes forgotten that the omission of the dimensions of $K$ or $\mu$ is merely conventional. For instance, magnetic field intensity and magnetic induction apparently have the same dimensions when $\mu$ is omitted. This results in confusion and difficulty in understanding the theory of magnetism. The suppression of $\mu$ has also led to the use of the "centimeter" as a unit of capacity and of inductance; neither is physically the same as length.

## ELECTROSTATIC SYSTEM.

Quantity of Electricity has the dimensional formula [ $M^{\frac{1}{3}} L^{\frac{3}{2}} T^{-1} K^{\frac{1}{2}}$ ], as shown above.

Electric Surface Density of an electrical distribution at any point on a surface is measured by the quantity per unit area. The dimensional formula is the ratio of the formulae for quantity of electricity and for area or $\left[M^{\frac{1}{3}} L^{-\frac{1}{2}} T^{-1} K^{\frac{1}{2}}\right]$.

Electric Field Intensity is measured by the ratio of the force on a quantity of electricity at a point to the quantity of electricity. The dimensional formula is therefore the ratio of the formulae for force and electric quantity or $\left[M L T^{-2} / M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-1} K^{\frac{1}{2}}\right]$ or $\left[M^{\frac{1}{2}} L^{-\frac{1}{2}} T^{-1} K^{-\frac{1}{2}}\right]$.

Electric Potential and Electromotive Force. - Change of potential is proportional to the work done per unit of electricity in producing the change. The dimensional formula is the ratio of the formulae for work and electrical quantity or $\left[M L^{2} T^{-2} / M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-1} K^{\frac{1}{2}}\right]$ or $\left[M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1} K^{-\frac{1}{2}}\right]$.

Capacity of an Insulated Conductor is proportional to the ratio of the quantity of electricity in a charge to the potential of the charge. The dimensional formula is the ratio of the two formulae for electric quantity and potential or $\left[M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-1} K^{\frac{1}{2}} / M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1} K^{-\frac{1}{2}}\right]$ or $[L K]$.

Specific Inductive Capacity is the ratio of the inductive capacity of the substance to that of a standard substance and therefore is a number.

Electric Current is quantity of electricity flowing past a point per unit of time. The dimensional formula is the ratio of the formulae for electric quantity and for time or $\left[M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-1} K^{\frac{1}{2}} / T\right]$ or $\left[M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-2} K^{\frac{1}{2}}\right]$.

Electrical Conductivity, like the corresponding term for heat, is quantity per unit area per unit potential gradient per unit of time. The dimensional formula is $\left[M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1} K^{\frac{1}{2}} / L^{2}\left(M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1} K^{-\frac{1}{3}} / L\right) T\right]$ or $\left[T^{-1} K\right]$.

Resistivity is the reciprocal of conductivity. The dimensional formula is [T K ${ }^{-1}$ ].

Conductance of any part of an electric circuit, not containing a source of electromotive force, is the ratio of the current flowing through it to the difference of potential between its ends. The dimensional formula is the ratio of the formulae for current and potential or $\left[M^{\frac{1}{2}} L^{\frac{3}{2}} T^{-2} K^{\frac{1}{2}} / M^{\frac{1}{2}} L^{\frac{1}{2}} T^{-1} K^{-\frac{1}{2}}\right]$ or $\left[L T^{-1} K\right]$.

Resistance is the reciprocal of conductance. The dimensional formula is $\left[L^{-1} T K^{-1}\right]$.

Exs. - Find the factor for converting quantity of electricity expressed in ft.-grain-sec. units to the same expressed in c.g.s. units. The formula is [ $m^{\frac{1}{2}} l^{\frac{3}{2}} t^{-1} k^{\frac{1}{2}}$ ], in which $m=0.0648$, $l=30.48, t=\mathrm{I}, k=\mathrm{I}$; the factor is $0.0648 \frac{1}{3} \times 30.48^{3}$, or 42.8 .

Find the factor required to convert electric potential from mm-mg-sec. units to c.g.s. units. The formula is $\left[m^{\frac{1}{l} l} \frac{l}{2} t^{-1} k^{-\frac{1}{2}}\right]$, in which $m=0.00 \mathrm{I}, l=0.1, t=1, k=1$; the factor is $0.001^{\frac{1}{2}}$ $\times 0 . \mathrm{I}^{\frac{1}{2}}$, or o.or.

Find the factor required to convert electrostatic capacity from ft.-grain-sec. and specificinductive capacity 6 units to c.g.s. units. The formula is $[l k]$ in which $l=30.48, k=6$; the factor is $30.48 \times 6$, or 182.88 .

## ELECTROMAGNETIC SYSTEM.

Many of the magnetic quantities are analogues of certain electric quantities. The dimensions of such quantities in the electromagnetic system differ from those of the corresponding electrostatic quantities in the electrostatic system only in the substitution of permeability $\mu$ for $K$.
ence standards are accurately compared copies, not necessarıy duplicates, of the primaries for use in the work of standardizing laboratories and the production of working standards for everyday use.

Standard of Length. - The primary standard of length which now almost universally serves as the basis for physical measurements is the meter. It is defined as the distance between two lines at $0^{\circ} \mathrm{C}$ on a platinum-iridium bar deposited at the International Bureau of Weights and Measures. This bar is known as the International Prototype Meter, and its length was derived from the "métre des Archives," which was made by Borda. Borda, Delambre, Laplace, and others, acting as a committee of the French Academy, recommended that the standard unit of length should be the ten-millionth part of the length, from the equator to the pole, of the meridian passing through Paris. In 1795 the French Republic passed a decree making this the legal standard of length, and an arc of the meridian extending from Dunkirk to Barcelona was measured by Delambre and Mechain for the purpose of realizing the standard. From the results of that measurement the meter bar was made by Borda. The meter is now defined as above and not in terms of the meridian length; hence subsequent measures of the length of the meridian have not affected the length of the meter.

Standard of Mass. - The primary standard of mass now almost universally used as the basis for physical measurements is the kilogram. It is defined as the mass of a certain piece of platinum-iridium deposited at the International Bureau of Weights and Measures. This standard is known as the International Prototype Kilogram. Its mass is equal to that of the older standard, the "kilogram des Archives," made by Borda and intended to have the same mass as a cubic decimeter of distilled water at the temperature of $4{ }^{\circ} \mathrm{C}$.

Copies of the International Prototype Meter and Kilogram are possessed by the various governments and are called National Prototypes.

Standard of Time. - The unit of time universally used is the second. It is the mean solar second, or the 86400th part of the mean solar day. It is founded on the average time required for the earth to make one rotation on its axis relatively to the sun as a fixed point of reference.

Standard of Temperature. - The standard scale of temperature as adopted by the International Committee of Weights and Measures (I887) depends on the constant-volume hydrogen thermometer. The hydrogen is taken at an initial pressure at $0^{\circ} \mathrm{C}$ of one meter of mercury, $0^{\circ} \mathrm{C}$, sea-level at latitude $45^{\circ}$. The scale is defined by designating the temperature of melting ice as $\circ^{\circ}$ and of condensing steam as $100^{\circ}$ under standard atmospheric pressure. This is known as the Centigrade scale (abbreviated C).

A scale independent of the properties of any particular substance, and called the thermodynamic, or absolute scale, was proposed in 1848 by Lord Kelvin. In it the temperature is proportional to the average kinetic energy per molecule of a perfect gas. The temperature of melting ice is taken as $273.13^{\circ}$, that of the boiling point, $373.13^{\circ}$. The scale of the hydrogen thermometer varies from it only in the sense that the behavior of hydrogen departs from that of a perfect gas. It is customary to refer to this scale as the Kelvin scale (abbreviated K).

## NUMERICALLY DIFFERENT SYSTEMS OF UNITS.

The fundamental physical quantities which form the basis of a system for measurements have been chosen and the fundamental standards selected and made. Custom has not however generally used these standards for the measurement of the magnitudes of quantities but rather multiples or submultiples of them. For instance, for very small quantities the micron $(\mu)$ or one-millionth of a meter is often used. The following table ${ }^{1}$ gives some of the systems proposed, all built upon the fundamental standards already described. The centi-meter-gram-second (cm-g-sec. or c.g.s.) system proposed by Kelvin is the only one generally accepted.

Table 1.
PROPOSED SYSTEMS OF UNITS.

|  | Weber • and Gauss | Kelvin c.g.s. | $\begin{gathered} \text { Moon } \\ \text { r} 89 \mathrm{r} \end{gathered}$ | Giorgi <br> MKS <br> (Prim. <br> Stds.) | France r9I4 | B. A. Com., 1863 | Practical (B. A. Com., 1873) | Strout r89 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Length | mm | cm | dm | m | m | m | $10^{9} \mathrm{~cm}$ | $10^{9} \mathrm{~cm}$ |
| Mass | mg | g | Kg | Kg | $10^{6} \mathrm{~g}$ | g | $10^{-11} \mathrm{~g}$ | $10^{-9} \mathrm{~g}$ |
| Time | sec. | sec. | sec. | sec. | sec. | sec. | sec. | sec. |

Further the choice of a set of fundamental physical quantities to form the basis of a system does not necessarily determine how that system shall be used in measurements. In fact, upon any sufficient set of fundamental quantities, a great many different systems of units may be built. The electrostatic and electromagnetic systems are really systems of electric quantities rather than units. They were based upon the relationships $F=Q Q^{\prime} / K r^{2}$ and $m m^{\prime} / \mu r^{2}$, respectively. Systems of units built upon a chosen set of fundamental physical quantities may differ in two ways: (г) the units chosen for the fundamental quantities may be different; (2) the defining equations by which the system is built may be different.

The electrostatic system generally used is based on the centimeter, gram, second, and dielectric constant of a vacuum. Other systems have appeared, differing from this in the first way, - for instance using the foot, grain and second in place of the centimeter, gram and second. A system differing from it in the second way is that of Heaviside which introduces the factor $4 \pi$ at difierent places than is usual in the equations. There are similarly several systems of electromagnetic units in use.

Gaussian Systems. - "The complexity of the interrelations of the units is increased by the fact that not one of the systems is used as a whole, consistently for all electromagnetic quantities. The 'systems' at present used are therefore combinations of certain of the systems of units.

[^2] quent matter in this introduction is based upon this circular.
"Some writers ${ }^{1}$ on the theory of electricity prefer to use what is called a Gaussian system, a combination of elec trostatic units for purely electrical quantities and electromagnetic units for magnetic quantities. There are two such Gaussian systems in vogue, - one a combination of c.g.s. electrostatic ånd c.g.s electromagnetic systems, and the other a combination of the two corresponding Heaviside systems.
"When a Gaussian system is used, caution is necessary when an equation contains both electric and magnetic quantities. A factor expressing the ratio between the electrostatic and electromagnetic units of one of the quantities has to be introduced. This factor is the first or second power of $c$, the number of electrostatic units of electric charge in one electromagnetic unit of the same. There is sometimes a question as to whether electric current is to be expressed in electrostatic or electromagnetic units, since it has both electric and magnetic attributes. It is usually expressed in electrostatic units in the Gaussian system."

It may be observed from the dimensions of $K$ given in Table 1 that $[\mathrm{I} / K \mu]$ $=\left[L^{2} / T^{2}\right]$ which has the dimensions of a square of a velocity. This velocity was found experimentally to be equal to that of light, when $K$ and $\mu$ were expressed in the same system of units. Maxwell proved theoretically that $\mathrm{I} / \sqrt{K \mu}$ is the velocity of any electromagnetic wave. This was subsequently proved experimentally. When a Gaussian system is used, this equation becomes $c / \sqrt{K \mu}$ $=\%$ For the ether $K=\mathrm{I}$ in electrostatic units and $\mu=\mathrm{I}$ in electromagnetic units. Hence $c=v$ for the ether, or the velocity of an electromagnetic wave in the ether is equal to the ratio of the c.g.s. electromagnetic to the c.g.s. electrostatic unit of electric charge. This constant $c$ is of primary importance in electrical theory. Its most probable value is $2.9986 \times 10^{10}$ centimeters per second.

[^3]The International Electric Units. - The units used in practical measurements, however, are the "International Units." They were derived from the "practical" system just described, or as the latter is sometimes called, the "absolute" system. These international units are based upon certain concrete standards presently to be defined and described. With such standards electrical comparisons can be more accurately and readily made than could absolute measurements in terms of the fundamental units. Two electric units, the international ohm and the international ampere, were chosen and made as nearly equal as possible to the ohm and ampere of the "practical" or "absolute" system.

[^4]This system of units, sufficiently near to the "absolute" system for the purpose of electrical measurements and as a basis for legislation, was defined as follows:
" r . The International Ohm is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, r4-452I grams in mass, of a constant cross-sectional area and of a length of ro6.300 centimeters.
" 2 . The International Ampere is the unvarying electric current which, when passed through a solution of nitrate of silver in water, in accordance with specification II attached to these Resolutions, deposits silver at the rate of 0.00111800 of a gram per second.
" 3. The International Volt is the electrical pressure which, when steadily applied to a conductor the resistance of which is one international ohm will pro.duce a current of one international ampere.
"4. The International Watt is the energy expended per second by an unvarying electric current of one international ampere under the pressure of one international volt."

In accordance with these definitions, a value was established for the electromotive force of the recognized standard of electromotive force, the Weston normal cell, as the result of international coöperative experiments in 1910. The value was I .0183 international volts at $20^{\circ} \mathrm{C}$.

The definitions by the 1908 International Conference supersede certain definitions adopted by the International Electrical Congress at Chicago in 1893. Certain of the units retain their Chicago definitions, however. They are as follows:
"Coulomb. As a unit of quantity, the International Coulomb, which is the quantity of electricity transferred by a current of one international ampere in one second.
"Farad. As a unit of capacity, the International Farad, which is the capacity of a condenser, charged to be a potential of one international volt by one international coulomb of electricity.
"Joule. As a unit of work, the Joule, which is equal to $10^{7}$ units of work in the c.g.s. system, and which is represented sufficiently well for practical use by the energy expended in one second by an international ampere in an international ohm.
"Henry. As the unit of induction, the Henry, which is the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second."
"The choice of the ohm and ampere as fundamental was purely arbitrary. These are the two quantities directly measured in absolute electrical measurements. The ohm and volt have been urged as more suitable for definition in terms of arbitrary standards, because the primary standard of electromotive force (standard cell) has greater simplicity than the primary standard of current (silver voltameter). The standard cell is in fact used, together with resistance standards, for the actual maintenance of the units, rather than the silver voltameter and resistance standards. Again, the volt and ampere have some claim
for consideration for fundamental definition, both being units of quantities more fundamental in electrical theory than resistance."

For all practical purposes the "international" and the "practical" or "absolute" units are the same. Experimental determination of the ratios of the corresponding units in the two systems have been made and the mean results are given in Table 382. These ratios represent the accuracy with which it was possible to fix the values of the international ohm and ampere at the time they were defined (London Conference of 1908). It is unlikely that the definitions of the international units will be changed in the near future to make the agreement any closer. An act approved July 12, 1894, makes the International units as above defined the legal units in the United States of America.

## THE STANDARDS OF THE INTERNATIONAL ELECTRICAL UNITS.

RESISTANCE
Resistance. - The definition of the international ohm adopted by the London Conference in 1908 is accepted practically everywhere.

Mercury Standards. - Mercury standards conforming to the definition were constructed in England, France, Germany, Japan, Russia and the United States. Their mean resistances agree to about two parts in 100,000. To attain this accuracy, elaborate and painstaking experiments were necessary. Tubes are never quite uniform in cross-section; the accurate measurement of the mass of mercury filling the tube is difficult, partly because of a surface film on the walls of the tube; the greatest refinements are necessary in determining the length of the tube. In the electrical comparison of the resistance with wire standards, the largest source of error is in the filling of the tube. These and other sources of error necessitated a certain uniformity in the setting up of mercury standards and at the London Conference the following specifications were drawn up:

## SPECIFICATION RELATING TO MERCURY STANDARDS OF RESISTANCE.

The glass tubes used for mercury standards of resistance must be made of a glass such that the dimensions may remain as constant as possible. The tubes must be well annealed and straight. The bore must be as nearly as possible uniform and circular, and the area of cross-section of the bore must be approximately one square millimeter. The mercury must have a resistance of approximately one ohm.

Each of the tubes must be accurately calibrated. The correction to be applied to allow for the area of the cross-section of the bore not being exactly the same at all parts of the tube must not exceed 5 parts in ro,000.

The mercury filling the tube must be considered as bounded by plane surfaces placed in contact with the ends of the tube.

The length of the axis of the tube, the mass of mercury the tube contains, and the electrical resistance of the mercury are to be determined at a temperature as near to $0^{\circ} \mathrm{C}$ as possible. The measurements are to be corrected to $\circ^{\circ} \mathrm{C}$.

For the purpose of the electrical measurements, end vessels carrying connections for the current and potential terminals are to be fitted on to the tube. These end vessels are to be spherical in shape (of a diameter of approximately four centimeters) and should have cylindrical pieces attached to make connections with the tubes. The outside edge of each end of the tube
is to be coincident with the inner surface of the corresponding end vessel. The leads which make contact with the mercury are to be of thin platinum wire fused into glass. The point of entry of the current lead and the end of the tube are to be at opposite ends of a diameter of the bulb; the potential lead is to be midway between these two points. All the leads must be so thin that no error in the resistance is introduced through conduction of heat to the mercury. The filling of the tube with mercury for the purpose of the resistance measurements must be carried out under the same conditions as the filling for the determination of the mass.

The resistance which has to be added to the resistance of the tube to allow for the effect of the end vessels is to be calculated by the formula

$$
A=\frac{0.80}{1063 \pi}\left(\frac{\mathrm{I}}{r_{1}}+\frac{\mathrm{I}}{r_{2}}\right) \mathrm{ohm},
$$

where $r_{1}$ and $\gamma_{2}$ are the radii in millimeters of the end sections of the bore of the tube.
The mean of the calculated resistances of at least five tubes shall be taken to determine the value of the unit of resistance.

For the purpose of the comparison of resistances with a mercury tube the measurements shall be made with at least three separate fillings of the tube.

Secondary Standards. - Secondary standards, derived from the mercury standards and used to give values to working standards, are certain coils of manganin wire kept in the national laboratories. Their resistances are adjusted to correspond to the unit or its decimal multiples or submultiples. The values assigned to these coils are checked from time to time with the similar coils of the other countries. The value now in use is based on the comparison made at the U.S. Bureau of Standards in IgIo and may be called the "igio ohm." Later measurements on various mercury standards checked the value then used within 2 parts in 100,000 . Thus the basis of resistance measurement is maintained not by the mercury standards of a single laboratory, but by all the mercury standards of the various national laboratories; it is furthermore the same in all countries, except for very slight outstanding discrepancies due to the errors of measurement and variations of the standards with time.

Resistance Standards in Practice. - In ordinary measurements, working standards of resistance are usually coils of manganin wire (approximately 84 per cent $\mathrm{Cu}+\mathrm{I} 2$ per cent $\mathrm{Mn}+4$ per cent Ni ). They are generally used in oil which carries away the heat developed by the current and facilitates regulation and measurement of the temperature. The best type is inclosed in a sealed case for protection against atmospheric humidity. Varying humidity changes the resistance of open coils often to several parts in 10,000 higher in summer than in winter. While sealed I ohm and o.I ohm coils may remain constant to about I part in 100,000.

Absolute Ohm. - The absolute measurement of resistance involves the precise determination of a length and a time (usually an angular velocity) in a medium of unit permeability. Since the dimensional formula of resistance in the electromagnetic system is $[L \mu / T]$, such an absolute measurement gives $R$ not in $\mathrm{cm} / \mathrm{sec}$. but in $\mathrm{cm} \times \mu / \mathrm{sec}$. The definitions of the ohm, ampere and volt by the 1908 London conference tacitly assume a permeability equal to unity. The relation of the international ohm to the absolute ohm has been measured in different ways involving revolving coil, revolving disk, and alternate current methods. Probably the most accurate determination was made
in 1913 by F. E. Smith of the National Physical Laboratory of England, using a modification of the Lorentz revolving disk method. His result was
x international ohm $=\mathrm{I} .0005^{2} \pm 0.00004$ absolute ohms,
or, in other words, while one international ohm is represented by a mercury column 106.300 cm long as specified above, one absolute ohm requires a similar column 106.245 cm long. Table 305 of the 6th revised edition of these tables contains data relative to the various determinations of the ohm.

## CURRENT.

The Silver Voltameter. - The silver voltameter is a concrete means of measuring current in accordance with the definition of the international ampere. As used for the realization of the international ampere "it consists of a platinum cathode in the form of a cup holding the silver nitrate solution, a silver anode partly or wholly immersed in the solution, and some means to prevent anode slime and particles of silver mechanically detached from the anode from reaching the cathode. As a standard representing the international ampere, the silver voltameter includes also the chronometer used to measure time. The degree of purity and the mode of preparation of the various parts of the voltameter affect the mass of the deposit. There are numerous sources of error, and the suitability of the silver voltameter as a primary standard of current has been under investigation since 1893 . Differences of as much as o.r per cent or more may be obtained by different procedures, the larger differences being mainly due to impurities produced in the electrolyte (by filter paper, for instance). Hence, in order that the definition of current be precise, it must be accompanied by specifications for using the voltameter."

The original specifications were recognized to be inadequate and an international committee on electrical units and standards was appointed to complete the specifications. It was also recognized that in practice standard cells would replace secondary current standards so that a value must be fixed for the electromotive force of the Weston normal cell. This was attempted in ig10 at the Bureau of Standards by representatives of that institution together with one delegate each from the Physikalische-Technische Reichanstalt, The National Physical Laboratory and the Laboratoire Central d'Electricité. Voltameters from all four institutions were put in series under a variety of experimental conditions. Standard Weston cells and resistance standards of the four laboratories were also intercompared. From the joint comparison of standard cells and silver voltameters particular values were assigned to the standard cells from each laboratory. The different countries thus have a common basis of measurement maintained by the aid of standard cells and resistance standards derived from the international voltameter investigation of 1910.

It was not found possible to draw up satisfactory and final specifications for the silver voltameter. Provisional specifications were submitted by the U. S. Bureau of Standards and more complete specifications have been proposed in correspondence between the national laboratories and members of the inter-
national committee since 1910, but no agreement upon final specifications has yet been reached.

Resistance Standards Used in Current Measurements. - Precise measurements of currents require a potentiometer, a standard cell and a resistance standard. The resistance must be so designed as to carry the maximum current without undue heating and consequent change of resistance. Accordingly the resistance metal must have a small temperature resistance coefficient and a sufficient area in contact with the air, oil, or other cooling fluid. It must have a small thermal electromotive force against copper. Manganin satisfies these conditions and is usually used. The terminals of the standard must have sufficient contact area so that there shall be no undue heating at contacts. ${ }^{1}$ It must be so designed that the current distribution does not depend upon the mode of connection to the circuit.

Absolute Ampere. - The absolute ampere ( $\mathrm{Io}^{-1} \mathrm{c}$.g.s. electromagnetic units) differs by a negligible amount from the international ampere. Since the dimensional formula of the current in the electromagnetic system is $\left[L^{\frac{1}{2}} M^{\frac{1}{2}} / T \mu^{\frac{1}{2}}\right]$ which is equivalent to $\left[F^{\frac{1}{2}} / \mu^{\frac{1}{1}}\right]$, the absolute measurement of current involves fundamentally the measurement of a force in a medium of unit permeability. In most measurements of high precision an electrodynamometer has been used of the form known as a current balance. A summary of the various determinations will be found in Table 293 of the 6th Revised Edition of these tables.

The best value is probably the mean of the determinations made at the U. S. Bureau of Standards, the National Physical Laboratory and at the University of Gröningen, which gives

$$
\text { I international ampere }=0.9999 \mathrm{I} \text { absolute ampere } .
$$

The separate values were $0.9999^{2}, 0.99988$ and 0.99994 , respectively. "The result may also be expressed in terms of the electrochemical equivalent of silver, which, based on the 'r910 mean voltameter,' thus equals 0.00111810 g per absolute coulomb. By the definition of the international ampere, the value is $0.001 r 1800 \mathrm{~g}$ per international coulomb."

## ELECTROMOTIVE FORCE.

International Volt. - "The international volt is derived from the international ohm and ampere by Ohm's law. Its value is maintained by the aid of the Weston normal cell. The national standardizing laboratories have groups of such cells, to which values in terms of the international ohm and ampere have been assigned by international experiments, and thus form a basis of reference for the standardization of the standard cells used in practical measurements."

Weston Normal Cell. - The Weston normal cell is the standard used to maintain the international volt and, in conjunction with resistance standards, to maintain the international ampere. The cell is a simple voltaic combination
${ }^{1}$ See "Report to the International Committee on Electrical Units and Standards," 1912, p. 199. For the Bureau of Standards investigations see Bull. Bureau of Standards, 9, pp. 209, 493; 10, p. 475, 1912-14; 13, p. 147, 1915; 9, p. 151, 1912: 13, pp. 447. 479, 1916.
difference which exists between the terminals of a resistance of one international ohm when the latter carries a current of one absolute ampere. The emf of the Weston normal cell may be taken as i.or821 semi-absolute volts at $20^{\circ} \mathrm{C}$.

## QUANTITY OF ELECTRICITY.

The international unit of quantity of electricity is the coulomb. The faraday is the quantity of electricity necessary to liberate I gram equivalent in electrolysis. It is equivalent to 96,500 coulombs.

Standards. - There are no standards of electric quantity. The silver voltameter may be used for its measurement since under ideal conditions the mass of metal deposited is proportional to the amount of electricity which has flowed.

## CAPACITY.

The unit generally used for capacity is the international microfarad or the one-millionth of the international farad. Capacities are commonly measured by comparison with standard capacities. The values of the standards are determined by measurement in terms of resistance and time. The standard is some form of condenser consisting of two sets of metal plates separated by a dielectric. The condenser should be surrounded by a metal shield connected to one set of plates rendering the capacity independent of the surroundings. An ideal condenser would have a constant capacity under all circumstances, with zero resistance in its leads and plates, and no absorption in the dielectric. Actual condensers vary with the temperature, atmospheric pressure, and the voltage, frequency, and time of charge and discharge. A well-constructed air condenser with heavy metal plates and suitable insulating supports is practically free from these effects and is used as a standard of capacity.

Practically air condenser plates must be separated by m m or mort and so cannot be of great capacity. The more the capacity is increased by approaching the plates, the less the mechanical stability and the less constant the capacity. Condensers of great capacity use solid dielectrics, preferably mica sheets with conducting plates of tinfoil. At constant temperature the best mica condensers are excellent standards. The dielectric absorption is small but not quite zero, so that the capacity of these standards with different methods of measurement must be carefully determined.

## INDUCTANCE.

The henry, the unit of self-inductance, is also the unit of mutual inductance. The henry has been known as the "quadrant" and the "secohm." The length of a quadrant or quarter of the earth's circumference is approximately $10^{9} \mathrm{cms}$. and a henry is $10^{9} \mathrm{cms}$. of inductance. Secohm is a contraction of second and ohm; the dimensions of inductance are $[T R]$ and this unit is based on the second and ohm.

Inductance Standards. - Inductance standards are measured in international units in terms of resistance and time or resistance and capacity by alternate-
current bridge methods. Inductances calculated from dimensions are in absolute electromagnetic units. The ratio of the international to the absolute henry is the same as the ratio of the corresponding ohms.

Since inductance is measured in terms of capacity and resistance by the bridge method about as simply and as conveniently as by comparison with standard inductances, it is not necessary to maintain standard inductances. They are however of value in magnetic, alternating-current, and absolute electrical measurements. A standard inductance is a circuit so wound that when used in a circuit it adds a definite amount of inductance. It must have either such a form or so great an inductance that the mutual inductance of the rest of the circuit upon it may be negligible. It usually is a wire coil wound all in the same direction to make self-induction a maximum. A standard, the inductance of which may be calculated from its dimensions, should be a single layer coil of very simple geometrical form. Standards of very small inductance, calculable from their dimensions, are of some simple device, such as a pair of parallel wires or a single turn of wire. With such standards great care must be used that the mutual inductance upon them of the leads and other parts of the circuit is negligible. Any inductance standard should be separated by long leads from the measuring bridge or other apparatus. It must be wound so that the distributed capacity between its turns is negligible; otherwise the apparent inductance will vary with the frequency.

## POWER AND ENERGY.

Power and energy, although mechanical and not primarily electrical quantities, are measurable with greater precision by electrical methods than in any other way. The watt and the electric units were so chosen in terms of the c.g.s. units that the product of the current in amperes by the electromotive force in volts gives the power in watts (for continuous or instantaneous values). The international watt, defined as "the energy expended per second by an unvarying electric current of one international ampere under an electric pressure of one international volt," differs but little from the absolute watt.

Standards and Measurements. - No standard is maintained for power or energy. Measurements are always made in electrical practice in terms of some of the purely electrical quantities represented by standards.

## MAGNETIC UNITS.

C.G.S. units are generally used for magnetic quantities. American practice is fairly uniform in names for these units: the c.g.s. unit of magnetomotive force is called the "gilbert," of reluctance, the "oersted," following the provisional definitions of the American Institute of Electrical Engineers (i894). The c.g.s. unit of flux is called the "maxwell" as defined by the 1900 Paris conference. The name "gauss" is used unfortunately both for the unit of induction (A.I.E.E. 1894) and for the unit of magnetic field intensity or magnetizing force. "This double usage, recently sanctioned by engineering societies, is based upon the mathematical convenience of defining both induction and magnetizing force
as the force on a unit magnetic pole in a narrow cavity in the material, the cavity being in one case perpendicular, in the other parallel, to the direction of the magnetization: this definition however applies only in the ordinary electromagnetic units. There are a number of reasons for considering induction and magnetizing force as two physically distinct quantities, just as electromotive force and current are physically different."

In the United States "gauss" has been used much more for the c.g.s. unit of induction than for the unit of magnetizing force. The longer name of "maxwell per $\mathrm{cm}^{2}$ " is also sometimes used for this unit when it is desired to distinguish clearly between the two quantities. The c.g.s. unit of magnetizing force is usually called the "gilbert per cm."

A unit frequently used is the ampere-turn. It is a convenient unit since it eliminates $4 \pi$ in certain calculations. It is derived from the "ampere turn per cm." The following table shows the relations between a system built on the ampere-turn and the ordinary magnetic units. ${ }^{1}$

Table II.
THE ORDINARY AND THE AMPERE-TURN MAGNETIC UNITS.

| Quantity |  | Ordinary magnetic units. | Ampere-turn units. | Ordinary units in I ampereturn unit |
| :---: | :---: | :---: | :---: | :---: |
| Magnetomotive force | $\mathfrak{F}$ | Gilbert | Ampere-turn | $4 \pi / 10$ |
| Magnetizing force | H | Gilbert per cm. | Ampere-turn per cm. | $4 \pi / 10$ |
| Magnetic flux | $\Phi$ | Maxwell | Maxwell | I |
| Magnetic induction | B | $\left\{\begin{array}{l}\text { Maxwell per } \\ \mathrm{cm} .^{2} \text { Gauss }\end{array}\right.$ | $\left\{\begin{array}{l}\text { Maxwell per cm. }{ }^{2} \\ \text { Gauss }\end{array}\right.$ | I |
| Permeability | $\mu$ |  |  | 1 |
| Reluctance | $R$ | Oersted | $\left\{\begin{array}{l}\text { Ampere-turn per } \\ \text { Maxwell }\end{array}\right.$ | $4 \pi / 10$ |
| Magnetization intensity | J |  | Maxwell per cm. ${ }^{2}$ | I/ $4 \pi$ |
| Magnetic susceptibility | $\kappa$ |  | Maxwell | $\mathrm{I} / 4 \pi$ |
| Magnetic pole strength | m |  | Maxwell | I/ $4 \pi$ |

[^5]
## PHYSICAL TABLES

Table 1.

## SPELLING AND ABBREVIATIONS OF THE COMMON UNITS OF WEIGHT AND MEASURE.

The spelling of the metric units is that adopted by the International Committee on Weights and Measures and given in the law legalizing the metric system in the United States (1866). The period is omitted after the metric abbreviations but not after those of the customary system. The exponents " 2 " and " 3 " are used to signify area and volume respectively in the metric units. The use of the same abbreviation for singular and plural is recommended. It is also suggested that only small letters be used for abbreviations except in the case of A. for acre, where the use of the capital letter is general. The following list is taken from circular 87 of the U. S. Bureau of Standards.

| Unit. | Abbreviation. | Unit. | Abbreviation. |
| :---: | :---: | :---: | :---: |
| acre | A | kilogram | kg |
| are | a | kiloliter | kl |
| avoirdupois | av. | kilometer | km |
| barrel | bbl. | link | li. |
| board foot | bd. ft. | liquid | liq. |
| bushel | bu. | - liter | 1 |
| carat, metric | c | meter | m |
| centare | ca | metric ton | t |
| centigram |  | micron | $\mu$ |
| centiliter | cl | mile | mi. |
| centimeter | cm | milligram | mg |
| chain | ch. | milliliter | ml |
| cubic centimeter | $\mathrm{cm}^{3}$ | millimeter | mm |
| cubic decimeter | $\mathrm{dm}^{3}$ | millimicron | $\mathrm{m} \mu$ |
| cubic dekameter | $\mathrm{dkm}^{3}$ | minim | $\min \text {. or } m$ |
| cubic foot cubic hectometer | $\begin{aligned} & \text { cu. ft. } \\ & \mathrm{hm}^{3} \end{aligned}$ | ounce ounce, apothecaries' | oz. ${ }_{\text {oz. ap. or }}$ |
| cubic inch | cu. in. | ounce, avoirdupois | oz. av. |
| cubic kilometer | $\mathrm{km}^{3}$ | ounce, fluid | fl. oz. |
| cubic meter | $\mathrm{m}^{3}$ | ounce, troy | oz. t. |
| cubic mile | cu. mi. | peck | pk. |
| cubic millimeter |  | pennyweight pint | dwt. |
| decigram | dg | pound | lb. |
| deciliter |  | pound, apothecaries' | lb. ap. |
| decimeter | dm | pound, avoirdupois | lb. av. |
| decistere | ds | pound, troy | lb. t. |
| dekagram | dkgr | quart | qt. |
| dekaliter |  | rod | rd. |
| dekameter | dkm | scruple, apothecaries' | s. ap. or $Э$ |
| dekastere | dks | square centimeter | $\mathrm{cm}^{2}$ |
| dram dram, apothecaries' | dr. <br> dr. ap. or 3 | square chain | sq. ch. |
| dram, apothecaries dram, avoirdupois | dr. ap. or 5 dr. av. | square decimeter square dekameter | $\mathrm{dkm}^{2}$ |
| dram, fluid | fl. dr. | square foot | sq. ft. |
| fathom | fath. | square hectometer | $\mathrm{hm}^{2}$ |
| foot | ft . | square inch | sq. in. |
| firkin |  | square kilometer | $\mathrm{km}^{2}$ |
| furlong | fur. | square meter |  |
| gallon | gal. | square mile | sq. mi. |
| grain | gr. | square millimeter | $\mathrm{mm}^{2}$ |
| gram |  | square rod | sq. rd. |
| hectare | ha | square yard | sq. yd. |
| hectogram | hg | stere |  |
| hectoliter | hl | ton | tn. |
| hectometer | hm | ton, metric |  |
| hogshead | hhd. | troy | t. |
| hundredweight inch | cwt. <br> in. | yard | yd. |

## Conversion Factors.

To change a quantity from one system of units to another: substitute in the corresponding conversion factor from the following table the ratios of the magnitudes of the old units to the new and multiply the old quantity by the resulting number. For example: to reduce velocity in miles per hour to feet per second, the conversion factor is $l t^{-1} ; l=5280 / 1, t=3600 / \mathrm{I}$, and the factor is $5280 / 3600$ or $\mathbf{1} 467$. Or we may proceed as follows: e. $g$., to find the equivalent of I c.g.s. unit of angular momentum in the pd.ft.m. unit, from the Table $1 \mathrm{~g} \mathrm{~cm}^{2} / \mathrm{sec} .=x \mathrm{lb} . \mathrm{ft}^{2} / \mathrm{min}$, where $x$ is the factor sought. Solving, $x=1 \mathrm{~g} / \mathrm{lb} . \times \mathrm{cm}^{2} / \mathrm{ft.}^{2} \times \mathrm{min} . / \mathrm{sec} .=1 \times .002205 \times .0010-6$ $\times 60=.0001425$.

The dimensional formulæ lack one quality which is needed for completeness, an indication of their vector characteristics; such characteristics distinguish plane and solid angle, torque and energy, illumination and brightness.

## (a) Fundamental Units.

The fundamental units and conversion factors in the systems of units most commonly used are: Length $[l]$; Mass $[\mathrm{m}]$; Time $[t]$; Temperature $[\theta]$; and for the electrostatic system, Dielectric Constant [ $k$ ]; for the electromagnetic system, Permeability [ $\mu$ ]. The formulae will also be given for the International System of electric and magnetic units based on the units length, resistance [ $r$ ], current [ $i$ ], and time.
(b) Derived Units.

| Name of unit. <br> (Geometrical and dynamical.). |  |  |  | Name of units. <br> (Heat and light.) |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $x$ | y | $z$ |  | $x$ | ${ }^{\text {y }}$ | = | - |
| Area, surface | - | 2 | - | Quantity of heat: |  |  |  |  |
| Volume.. | - | 3 | - | thermal units...... | 1 | $\bigcirc$ | $\bigcirc$ | 1 |
| Angle... | - | 。 | - | thermometric units. dynamical units | ${ }^{\circ}$ | 3 | - | $\stackrel{1}{\circ}$ |
| Solid angle. | - | - | - |  |  |  |  |  |
| Curvature.. | - | -1 | - | Coefficient of thermal |  |  |  |  |
| Angular velocity | - | - | -1 | expansion........ | - | - | - | - |
| Linear velocity. | - | 1 | -1 | Thermal conductivity: |  |  |  |  |
| Angular acceleration.. | - | - | -2 | thermal units....... | 1 | -1 | -1 | - |
| Linear acceleration... | - | I | -2 | thermometric units or diffusivity.... | 。 | 2 | -1 |  |
| Density. | 1 | -3 | - | dynamical units.... | I | ${ }_{1}$ | -3 | -1 |
| Moment of inertia...... | $\stackrel{1}{\circ}$ | 2 | -2 | Thermal capa | I | - | - | - |
| Momentum. | 1 | 1 |  | Latent heat: |  |  |  |  |
| Moment of momentum. | I | 2 | -I | thermal units: | - | - | $\bigcirc$ | ${ }^{1}$ |
| Angular momentum. | 1 | 2 | -1 | dynamical units. | - | 2 | $-2$ | - |
| Force............ | 1 | 1 | -2 | Joule's equivalent.... | - | 2 | -2 | I |
| Moment of couple, torque............. |  | 2 | -2 | Entropy: |  |  |  |  |
| Work, energy........... | I | 2 | ${ }_{-2}$ | heat in thermal units | 1 | - | - | - |
|  |  |  |  | heat in dynamical units.......... |  |  |  |  |
| Power, activity.. | I | ${ }_{-1}^{2}$ | -3 -2 |  | 1 | 2 | -2 | 1 |
| Modulus of elasticity.... | 1 | -I | -2 | Luminous intensity.... | - | - | - | ${ }^{1}$ * |
| Compressibility | -I | I |  | Illumination........... | $\bigcirc$ | $-2$ | $\bigcirc$ | ${ }_{1}{ }^{*}$ |
| Resilience. |  | -1 | -2 | Visibility. | 1 | -2 | 3 | ${ }_{1}{ }^{*}$ |
| Viscosity. | I | - | - | Luminous efficiency. | - | -2 | 3 | ${ }^{1} *$ |

[^6]TABLE 2 (continued).
FUNDAMENTAL AND DERIVED UNITS.
Conversion Factors.
(b) Derived Units.


[^7]TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES.*
(1) CUSTOMARY TO METRIC.

| LINEAR. |  |  |  |  | CAPACITY. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Inches to millimeters. | Feet to meters. | Yards to meters. | $\begin{gathered} \text { Miles } \\ \text { to } \\ \text { kilometers. } \end{gathered}$ |  | Fluid drams to miltiliters or cubic centimeters. | $\begin{gathered} \text { Fluid } \\ \text { ounces } \\ \text { to } \\ \text { milliliters. } \end{gathered}$ | Liquid quarts to liters. | Gallons to liters. |
| 1 | 25.4001 | 0.304801 | 0.914402 | 1.60935 | I | 3.70 | 29.57 | 0.94633 | 3.78533 |
| 2 | 508001 | 0.609601 | 1.828804 | 3.21869 | 2 | 7.39 | 59.15 | 1. 89267 | 7.57066 |
| 3 | 76.2002 | 0.914402 | 2.743205 | 4.82804 | 3 | 11.09 | 88.72 | 2.83900 | I 1.35600 |
| 4 | 101.6002 | 1.219202 | 3.657607 | 6.43739 | 4 | 14.79 | 118.29 | 3.78533 | 15.14133 |
| 5 | 127.0003 | 1. 524003 | 4.572009 | 8.04674 | 5 | 18.48 | 147.87 | 4.73167 | 18.92666 |
| 6 | 152.4003 | 1.828804 | 5.486411 | 9.65608 | 6 | 22.18 | 177.44 | 5.67800 | 22.71199 |
| 7 | 177.8004 | 2.133604 | 6.400813 | 11.26543 | 7 | 25.88 | 207.01 | 6.62433 | 26.49733 |
| 8 | 203.2004 | 2.438405 | 7.315215 | 12.87478 | 8 | 29.57 | 236.58 | 7.57066 | 30.28266 |
| 9 | 228.6005 | 2.743205 | 8.229616 | 14.48412 | 9 | 33.27 | 266.16 | 8.51700 | 34.06799 |
| SQUARE. |  |  |  |  | WEIGHT. |  |  |  |  |
|  | Square inches to square centimeters. | Square feet to square decimeters. | Square yards to square meters. | Acres to hectares. |  | Grains to millygrams. | Avoirdupois ounces to grams. | Avoirdupois pounds to kilograms. | Troy ounces to grams. |
| 1 | 6.452 | 9.290 | 0.836 | 0.4047 | 1 | 64.7989 | 28.3495 | 0.45359 | 31.10348 |
| 2 | 12.903 | 18.581 | 1. 672 | 0.8094 | 2 | 129.5978 | 56.6991 | 0.90718 | 62.20696 |
| 3 | 19.355 | 27.871 | 2.508 | 1.2141 | 3 | 194.3968 | 85.0486 | 1.36078 | 93.31044 |
| 4 | 25.807 | 37.16I | $3 \cdot 345$ | 1.6187 | 4 | 259.1957 | 113.3981 | ェ.81437 | 124.41392 |
| 5 | 32.258 | 46.452 | 4.181 | 2.0234 | 5 | 323.9946 | 141.7476 | 2.26796 | 155.51740 |
| 6 | 38.710 | 55.742 | 5.017 | 2.428 I | 6 | 388.7935 | 170.0972 | 2.72155 | 186.62088 |
| 7 | 45.16I | 65.032 | 5.853 | 2.8328 | 7 | 453.5924 | 198.4467 | 3.17515 | 217.72437 |
| 8 | 51.613 | 74.323 | 6.689 | 3.2375 | 8 | 518.3913 | 226.7962 | 3.62874 | 248.82785 |
| 9 | 58.065 | 83.613 | $7 \cdot 525$ | 3.6422 | 9 | 583.1903 | 255.1457 | 4.08233 | 279.93133 |
| CUBIC. |  |  |  |  | 1 Gunter's chain $=20.1168$ meters. <br> I sq. statute mile $=259.000$ hectares. <br> 1 fathom $=1.829$ meters. <br> I nautical mile $=1853.25$ meters. <br> 1 foot $=0.304801$ meter. <br> 1 avoir. pound $=453.5924277$ grams. <br> 15432.35639 grains $=1.000$ kilogram. |  |  |  |  |
|  | Cubic inches to cubic centimeters. | Cubic feet to cubic meters. | Cubic yards to cubic meters | Bushels to hectoliters. |  |  |  |  |  |
| I | 16.387 | 0.02832 | 0.765 | 0.35239 |  |  |  |  |  |
| 2 | 32.774 | 0.05663 | 1.529 | 0.70479 |  |  |  |  |  |
| 3 | 49.161 | 0.08495 | 2.294 | 1.05718 |  |  |  |  |  |
| 4 | 65.549 | 0.11327 | 3.058 | 1.40957 |  |  |  |  |  |
| 5 | 81.936 | 0.14159 | 3.823 | 1.76196 |  |  |  |  |  |
| 6 | 98.323 | 0.16990 | $4 \cdot 587$ | 2.11436 |  |  |  |  |  |
| 7 | 114.710 | 0. 19822 | $5 \cdot 352$ | 2.46675 |  |  |  |  |  |
| 8 | 131.097 | 0.22654 | 6.116 | 2.81914 |  |  |  |  |  |
| 9 | 147.484 | 0.25485 | 6.88 I | 3.17154 |  |  |  |  |  |

According to an executive order dated April 15, 1893, the United States yard is defined as $3600 / 3937$ meter, and the avoirdupois pound as $1 / 2.20462$ kilogram.

I meter (international prototype) $=1553164.13$ times the wave-length of the red Cd. line. Benoit, Fabry and Perot. C. R. 144, t 7007 differs only in the decimal portion from the measure of Michelson and Benoit 14 years earlier.

The length of the nautical mile given above and adopted by the U. S. Coast and Geodetic Survey many years ago, is defined as that of a minute of arc of a great circle of a sphere whose surface equals that of the earth (Clarke's Spheroid of 1866 ).

* Quoted from sheets issued by the United States Burean of Standards.

Smithsonian tables.

TABLES FOR CONVERTING U. S. WEIGHTS AND MEASURES.
(2) METRIC TO CUSTOMARV.


By the concurrent action of the principal governments of the world an International Bureau of Weights and Measures has been established near Paris. Under the direction of the International Committee, two ingots were cast of pure platinum-iridium in the proportion of 9 parts of the former to I of the latter metal. From one of these a certain number of kilograms were prepared, from the other a definite number of meter bars. These standards of weight and length were intercompared, without preference, and certain ones were selected as International prototype standards. The others were distributed by lot, in September, 8889 , to the different governments, and are called National prototype standards. Those apportioned to the United States were received in 1890 , and are kept at the Bureall of Standards in Washington, D. C.

The metric system was legalized in the United States in 1866.
The International Standard Meter is derived from the Mètre des Archives, and its length is defined by the distance between two lines at $\circ^{\circ}$ Centigrade, on a platinum-iridium bar deposited at the International Bureau of Weights and Measures.

The International Standard Kilogram is a mass of platinum-iridium deposited at the same place, and its weight in vacuo is the same as that of the Kilngram des Archives.

The liter is equal to the quantity of pure water at $4^{\circ} \mathrm{C}(760 \mathrm{~mm} . \mathrm{Hg}$. pressure) which weighs y kilogram and $=$ t.006027 cu. dm. (Trav. et Mem. Bureau Intern. des P. et M. 14, 1910, Benoit.)
(For other equivalents than those below, see Table 3.)

## LINEAR MEASURES.

I mil (.001 in.) $=25.4001 \mu$
$x$ in. $=.000015783$ mile
r hand $(4 \mathrm{in})=.10.16002 \mathrm{~cm}$
m link $(.66 \mathrm{ft}$. $)=20.11684 \mathrm{~cm}$
I span. (9 in.) $=22.86005 \mathrm{~cm}$
1 fathom $(6 \mathrm{ft}$. $)=1.828804 \mathrm{~m}$
1 rod ( 25 links) $=5.029210 \mathrm{~m}$
I chain (4 rods) $=20.11684 \mathrm{~m}$
I light year $\left(9.5 \times 10^{12} \mathrm{~km}\right)=5.9 \times 10^{12}$ miles
I par sec $\left(31 \times 10^{12} \mathrm{~km}\right)=19 \times 10^{12}$ miles
${ }_{6}^{\frac{1}{4}} \mathrm{in} .=.397 \mathrm{~mm} \quad \frac{1}{32} \mathrm{in} .=.794 \mathrm{~mm}$
$\frac{1}{16} \mathrm{in} .=1.588 \mathrm{~mm} \quad \frac{1}{8} \mathrm{in} .=3.175 \mathrm{~mm}$
$\frac{1}{4} \mathrm{in} .=6.350 \mathrm{~mm} \quad \frac{1}{2} \mathrm{in} .=12.700 \mathrm{~mm}$
I Ångström unit $=.0000000001 \mathrm{~m}$
I micron $(\mu)=.00000$ I $\mathrm{m}=.00003937 \mathrm{in}$.
I millimicron $(\mathrm{m} \mu)=.000000001 \mathrm{~m}$
I $\mathrm{m}=4.970960$ links $=1.0936 \mathrm{II}$ yds.
$=.198838 \mathrm{rod}=.0497096$ chain

## SQUARE MEASURES.

r sq. link ( 62.7264 sq. in. $)=404.6873 \mathrm{~cm}^{2}$ I sq. rod $(625$ sq. links $)=25.29295 \mathrm{~m}^{2}$
I sq. chain ( r 6 sq. rods) $=404.6873 \mathrm{~m}^{2}$
I acre ( io sq. chains) $=4046.873 \mathrm{~m}^{2}$
I sq. mile $(640$ acres $)=2.589998 \mathrm{~km}^{2}$
. $\mathrm{km}^{2}=.3861006$ sq. mile
I $\mathrm{m}^{2}=24.7104$ sq. links $=10.76387$ sq. ft .
$=.039537$ sq. rod. $=.00247104$ sq. chain

## CUBIC MEASURES.

r board foot ( $\mathrm{I} 44 \mathrm{cu} . \mathrm{in}$ ) $=2359.8 \mathrm{~cm}^{3}$
r cord ( $\mathrm{r} 28 \mathrm{cu} . \mathrm{ft}$.) $=3.625 \mathrm{~m}^{3}$

## CAPACITY MEASURES.

$\mathrm{I} \operatorname{minim}(\mathrm{m})=.0616102 \mathrm{ml}$
iff. dram $(60 \mathrm{~m})=3.6966 \mathrm{r} \mathrm{ml}$
i fl. oz. (8 fl. dr.) $=1.80469 \mathrm{cu} . \mathrm{in}$. $=29.5729 \mathrm{ml}$
1 gill (4 fl.oz.) $=7.21875 \mathrm{cu} . \mathrm{in} .=118.292$ ml
r liq. pt. $(28.875 \mathrm{cu} . \mathrm{in})=..473167 \mathrm{l}$
r liq. qt. $(57.75 \mathrm{cu} . \mathrm{in})=$.
I gallon (4 qt., 23r cu. in.) $=3.785332 \mathrm{l}$
I dry pt. $(33.6003 \mathrm{I} 25 \mathrm{cu} . \mathrm{in})=..550599 \mathrm{l}$
I dry qt. $(67.200625 \mathrm{cu} . \mathrm{in}$. $)=$ r.IOI 198 l
r pk. ( 8 dry qt., 537.605 cu . in. $)=8.809581$
r bu. $(4$ pk., $2150.42 \mathrm{cu} . \mathrm{in})=.35.2383 \mathrm{l}$
r firkin ( 9 gallons) $=34.06799 \mathrm{l}$
r liter $=.264178$ gal. $=$ I.05671 liq. qt. $=33.8147 \mathrm{fl} . \mathrm{oz} .=270.518 \mathrm{fl} . \mathrm{dr}$. $1 \mathrm{ml}=16.23 \mathrm{II}$ minims .
$\mathrm{Idkl}=18.620 \mathrm{dry} \mathrm{pt} .=9.08 \mathrm{IO} 2 \mathrm{dry}$ qt.
$=\mathrm{I} .13513 \mathrm{pk} .=.28378 \mathrm{bu}$.

## MASS MEASURES.

Avoirdupois weights.
1 grain $=.064798918 \mathrm{~g}$
I dram av. $(27.34375 \mathrm{gr})=.1.771845 \mathrm{~g}$
1 oz av. ( 16 dr. av. $)=28.349527 \mathrm{~g}$
I pd. av. ( $16 \mathrm{oz} . \mathrm{av}$. or 7000 gr .)
$=14.583333 \mathrm{oz}$. ap. ( 5 ) or oz. t.
$=1.2152778$ or $7000 / 5760 \mathrm{pd}$. ap or t .

$$
=453.5924277 \mathrm{~g}
$$

I $\mathrm{kg}=2.20462234 \mathrm{I}$ pd. av.
$\mathrm{Ig}=15.432356 \mathrm{gr} .=.5643833 \mathrm{av} . \mathrm{dr}$.
$=.03527396$ av. oz.
I short hundred weight (ioo pds.)
$=45.359243 \mathrm{~kg}$
I long hundred weight ( 112 pds.)
$=50.802352 \mathrm{~kg}$
I short ton ( 2000 pds.)
$=907.18486 \mathrm{~kg}$
I long ton ( 2240 pd .)
$=1016.04704 \mathrm{~kg}$
I metric ton $=0.98420640$ long ton
$=1.1023112$ short tons

## Troy weights.

I pennyweight (dwt., 24 gr .) $=1.555174 \mathrm{~g}$; gr., oz., pd. are same as apothecary

## A pothecaries' wieights.

I gr. $=64.7989 \mathrm{I} 8 \mathrm{mg}$
I scruple (Э, 20 gr .) $=1.2959784 \mathrm{~g}$
1 dram (3. 3, Э) $=3.887935 \mathrm{I} \mathrm{g}$
Ioz ( $\overline{3}, 8$ 3) $=31.10348 \mathrm{I} \mathrm{g}$
I pd ( $\mathrm{I} 2 \mathrm{~J}, 5760 \mathrm{gr}$. $)=373.24177 \mathrm{~g}$
$1 \mathrm{~g}=15.432356 \mathrm{gr} .=0.771618$ Э
$=0.2572059 \overline{5}_{\overline{3}}=.03215074$ 年
$\mathrm{r} \mathrm{kg}=32.150742 \overline{\mathrm{~J}}=2.679228 \mathrm{jpd}$.
I metric carat $=200 \mathrm{mg}=3.0864712 \mathrm{gr}$.
U. S. $\frac{1}{2}$ dollar should weigh 12.5 g and the smaller silver coins in proportion.

* Taken from Circular 47 of the U.S. Bureau of Standards, 1915, which see for more complete tables.

Table 5.

## EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEIGHTS AND MEASURES.*

(1) METRIC TO IMPERIAL.
(For U.S. Weights and Measures, see Table 3.)

## LINEAR MEASURE.

$\underset{(.001 \mathrm{~m} .)}{\mathrm{millimeter}}(\mathrm{mm}) \quad.\}=0.03937 \mathrm{in}$. i centimeter (.or m.) $=0.39370$ "
I decimeter (. Im ) = 3.9370 I "
I Meter (m.) . . . $=\left\{\begin{array}{c}39.370113 \mathrm{ft} \\ 3.280843 \mathrm{ft} \\ 1.09361425\end{array}\right.$
I dekameter \} . = 10.936 I 4 "
( I om. )
$\left.\begin{array}{c}\text { ı hectometer } \\ \text { (100 m.) }\end{array}\right\} . \quad .=109.361425$
$\underset{(\mathrm{I}, 000 \mathrm{~m} .)}{\mathrm{I} \text { kilometer }}\} . .=0.62137$ mile.
$\underset{\substack{\text { (Io,000 m.) }}}{\text { myriameter }}\} . .=6.21372$ miles.
I micron . . . . . $=0.001 \mathrm{~mm}$.

## SQUARE MEASURE.

isq. centimeter . . $=0.1550 \mathrm{sq}$. in.
$\left.\begin{array}{l}\text { I sq. decimeter } \\ \text { (ioo sq. centm.) }\end{array}\right\}=15.500 \mathrm{sq}$. in.
I sq. meter or centi- $\}=\{10.7639$ sq. ft.
are (ioo sq. dcm.) $\}=\{$ i.1960 sq. yds.
I ARE ( I 00 sq . m.) $=119.60 \mathrm{sq}$. yds.
$\left.\begin{array}{c}\text { I hectare ( } 100 \mathrm{ares} \\ \text { or } 10,000 \mathrm{sq} . \mathrm{m} .)\end{array}\right\}=\quad 2.4711$ acres.

## CUBIC MEASURE.

I cub. centimeter
(c.c.) $(\mathrm{r}, \infty 00$ cubic $\}=0.06 \mathrm{I} \circ$ cub. in. millimeters)
I cub. decimeter
$\left.\begin{array}{l}\left.\begin{array}{l}\text { (c.d.) (i,000 cubic } \\ \text { centimeters) }\end{array}\right\}=6 r .024 \text { "" } \quad \text { " }{ }^{\text {cub. decimeter }}\end{array}\right\}$
$\left.\begin{array}{c}\text { I CUB. METER } \\ \text { or stere }\end{array}\right\} . \quad .=\{35 \cdot 3148 \mathrm{cub} . \mathrm{ft}$. $\underset{(\mathrm{r}, 000 \text { c.d. })}{\text { or stere }}\} .=\left\{\begin{array}{r}35.3 \mathrm{I} 48 \mathrm{cub} . \mathrm{ft} . \\ \mathrm{I} .307954 \mathrm{cub} . \mathrm{yds} .\end{array}\right.$

## MEASURE OF CAPACITY.

$\left.\begin{array}{l}\text { I mililiter (ml.) }(.001 \\ \text { liter) }\end{array}\right\}=0.0610$ cub. in.

1 deciliter (. 1 liter) $. \quad=0.176$ pint.
I Liter ( $\mathrm{I}, 000$ cub.
centimeters or I $\}=1.75980$ pints.
cub. decimeter)
I dekaliter (ıoliters) . = 2.200 gallons.
I hectoliter ( 100 " ) . = 2.75 bushels.
a kiloliter ( $\mathrm{I}, 000$ " ) . = 3.437 quarters.

## APOTHECARIES' MEASURE.

I cubic centi- $\quad 0.035^{20}$ fluid ounce. meter $\quad(\mathrm{I}\}=\{0.28 \mathrm{r} 57$ fluid drachm. gram w't) $\quad$ t 5.43236 grains weight.
I cub. millimeter $=0.01693 \mathrm{minim}$.

## AVOIRDUPOIS WEIGHT.

I milligram (mgr.) . . = o.01 543 grain.
I centigram (.01 gram.) $=0.15432$
I decigram (.I ") $=1.54324$ grains.
I GRAM . . . . . . $=15.43236$
I dekagram (io gram.) $=5.64383$ drams.
i hectogram ( 100 ") $=3.52739 \mathrm{oz}$.
I KILOGRAM ( $\mathrm{I}, 000$ " $)=\left\{\begin{array}{l}2.2046223 \mathrm{lt} \\ \mathrm{I} 5432.3564\end{array}\right.$
I KILOGRAM ( 1,000 ) $=\left\{\begin{array}{r}15432.3564 \\ \text { grains. }\end{array}\right.$
I myriagram ( I o kilog.) $=22.04622 \mathrm{lbs}$.
I quintal ( 100 ") $=1.96841 \mathrm{cwt}$.
I millier or tonne $\}$
( $\mathrm{I}, 000$ kilog.) $\} \cdot .=0.9842$ ton.

## TROY WEIGHT.

I gram $\cdot \quad=\left\{\begin{array}{l}0.03215 \text { oz. Troy. } \\ 0.64301 \text { pennyweight. } \\ 15.43236 \text { grains. }\end{array}\right.$

APOTHECARIES' WEIGHT.
I GRAM $\cdot \cdots=\left\{\begin{array}{c}0.25721 \text { drachm. } \\ 0.77162 \text { scruple. } \\ 15.43236 \text { grains. }\end{array}\right.$

Note.-The Meter is the length, at the temperature of $n^{\circ} \mathrm{C}$., of the platinum-iridium bar deposited at the International Bureau of Weights and Measures at Sèvres, near Paris, France.

The present legal equivalent of the meter is $39.370 \pm 13$ inches, as above stated.
The Kilogram is the mass of a platinum-iridium weight deposited at the same place.
The Liter contains one kilogram weight of distilled water at its maximum density ( $4^{\circ} \mathrm{C}$.), the barometer being at ; 60 millimeters.
*In accordance with the schedule adopted under the Weights and Measures (metric system) Act, 1897 .

EQUIVALENTS OF METRIC AND BRITISH IMPERIAL WEICHTS AND MEASURES.
(2) METRIC TO IMPERIAL.
(For U.S. Weights and Measures, see Table 3.)

| LINEAR MEASURE. |  |  |  |  | MEASURE OF CAPACITY. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & \text { Millimeters } \\ & \text { to } \\ & \text { inches. } \end{aligned}$ | $\begin{gathered} \text { Meters } \\ \text { to } \\ \text { feet. } \end{gathered}$ | Meters to yards. | Kilometers to miles. |  | Liters to pints | $\begin{aligned} & \text { Dekaliters } \\ & \text { to } \\ & \text { gallons } \end{aligned}$ | $\begin{aligned} & \text { Hectoliters } \\ & \text { to } \\ & \text { busuels. } \end{aligned}$ | Kiloliters to quarters. |
| I | 0.03937011 | 3.2808 .4 | 1.09361 | 0.62137 | I | 1.75980 | 2.19975 | 2.74969 | 3.43712 |
| 2 | 0.07874023 | 6.56169 | 2.18723 | 1.24274 | 2 | $3 \cdot 51961$ | 4.3995 I | $5.4993{ }^{\text {S }}$ | 6.87423 |
| 3 | 0.11811034 | 9.84253 | 3.28084 | 1.86412 | 3 | 5.27941 | 6.59926 | 8.24908 | 10.31135 |
| 4 | 0.15748045 | 13.12337 | 4.37446 | 2.48549 | 4 | 7.03921 | 8.79902 | 10.99877 | 13.74846 |
| 5 | 0.19685056 | 16.4042 I | $5 \cdot 46807$ | 3.10686 | 5 | 8.79902 | 10.99877 | 13.74846 | $17.1855^{8}$ |
| 6 | 0.23622068 | 19.68506 | 6.56169 | 3.72823 | 6 | 10.55882 | 13.19852 | 16.49815 | 20.62269 |
| 7 | 0.27559079 | 22.96590 | 7.65530 | 4.34960 | 7 | 12.31862 | 15.39828 | 19.24785 | 24.05981 |
| 8 | - 31496090 | 26.24674 | 8.74891 | 4.97097 | 8 | 14.07842 | 17.59803 | 21.99754 | 27.49692 |
| 9 | 0.35433102 | 29.52758 | 9.84253 | $5 \cdot 59235$ | 9 | 15.83823 | 19.79778 | 24.74723 | 30.93404 |
| SQUARE MEASURE. |  |  |  |  | WEIGHT (Avoirdupois). |  |  |  |  |
|  | Square centimeters to square mehes. | Square meters to square feet. | Square meters to square yards. | Hectares to acres. |  | Milligrams to grains. | Kilograms to grains. | Kilograms to pounds. | $\begin{aligned} & \text { Quintals } \\ & \text { to } \\ & \text { hundred- } \\ & \text { weights. } \end{aligned}$ |
| 1 | 0. 15500 | 10.76393 | I. 19599 | 2.4711 | 1 | 0.01543 | I 5432.356 | 2.20462 | 1.96841 |
| 2 | 0.31000 | 21.52786 | 2.39198 | 4942 I | 2 | 0.03086 | 30864.713 | 4.40924 | 3.9 .3633 |
| 3 | 0.46500 | 32.29179 | $3 \cdot 58798$ | 7.4132 | 3 | 0.04630 | 46297.069 | 6.61387 | 5.90524 |
| 4 | 0.62000 | 43.05572 | 4.78397 | 9.8842 | 4 | 0.06173 | 61729.426 | 8.81849 | 7.87365 |
| 5 | 0.77500 | 53.81965 | 5.97996 | 12.3553 | 5 | 0.07716 | 77161.782 | 11.0231I | 9.84206 |
| 6 | 0.93000 | 64.58357 | 7.17595 | 14.8263 | 6 | 0.09259 | 92594.138 | 13.22773 | 11.81048 |
| 7 | 1.08500 | 75.34750 | 8.37194 | 17.2974 | 7 | 0.10803 | 108026.495 | 15.43236 | 13.77889 |
| 8 | 1.24000 | 8611143 | 9.56794 | 19.7685 | 8 | 0.12346 | 123458.851 | 17.63698 | 15.74730 |
| 9 | 1.39501 | 96.87536 | 10.76393 | 22.2395 | 9 | 0.13889 | 138891.208 | 19.84160 | 17.71572 |
| CUBIC MEASURE. |  |  |  | Apothecaries' Measure. | Avoirdupors (cont.) |  | Troy Weight. |  | Apothecaries' Weight. |
|  | Cubic decimeters to cubic inches. | Cubic meters to cubic feet. | Cubic meters to cubic yards. | Cub. centimeters to fluid drachms. |  | Milliers or tonnes to tons. | Grams <br> to ounces Troy. | Granis to pennyweights. | Grams to scruples. |
| 1 | 61.02390 | 35.31476 | 1. 30795 | 0.28157 | I | 0.98421 | 0.03215 | 0.64301 | 0.77162 |
| 2 | 122.04781 | 70.62952 | 2.61591 | 0.56314 | 2 | 1.96841 | 0.06430 | 1.28603 | 1.54324 |
| 3 | 183.07171 | 105.94428 | 3.92386 | 0.84471 | 3 | 2.95262 | 0.09645 | I. 92904 | 2.31485 |
| 4 | 244.09561 | 141.25904 | 5.23182 | 1.12627 | 4 | 3.93683 | 0.12860 | 2.57206 | 3.08647 |
| 5 | 305.11952 | 176.57379 | 6.53977 | 1.40784 | 5 | 4.92103 | 0. 16075 | 3.21507 | 3.85809 |
| 6 | 366.14342 | 211.88855 | 7.84772 | 1.6894 I | 6 | 5.90524 | 0.19290 | 3.85809 | 4.62971 |
| 7 | 427.16732 | 247.20331 | 9.15568 | 1.97098 | 7 | 6.88944 | 0.22506 | 4.50110 | 5.40132 |
| 8 | 488.19123 | 282.51807 | 10.46363 | 2.25255 | 8 | 7.87365 | 0.25721 | 5.14412 | 6.17294 |
| 9 | 549.21513 | 317.83283 | 11.77159 | 2.53412 | 9 | 8.85786 | 0.28936 | 5.78713 | 6.94456 |

Smithsonian Tables.

## LINEAR MEASURE.

I inch . . . . . $=\{25.400$ milli-
I foot ( I 2 in .) . $=0.304 \mathrm{So}$ meter.
I YARD ( 3 ft. .).$=0.914399$ "
I pole ( $5 \frac{1}{2} \mathrm{yd}$. ) . $=5.0292$ meters.
$\left.\begin{array}{c}\text { I chain (22 yd. or } \\ \text { Ioo links) }\end{array}\right\}=20.1168$ "
I furlong ( 220 yd .) $=201.168$ "
I mile ( 1,760 yd. $)=\left\{\begin{array}{l}1.6093 \text { kilo. } \\ \text { meters. }\end{array}\right.$

## SQUARE MEASURE.

$$
\text { I rood }(40 \text { perches })=\quad 10.117 \text { ares. }
$$

$$
\text { I ACRE }(4840 \text { sq. yd. })=0.40468 \text { hectare. }
$$

$$
\text { i sq. mile }(640 \text { acres })=\{259.00 \text { hectares. }
$$

## CUBIC MEASURE.

I cub. inch $=16.387$ cub. centimeters.
$\left.\begin{array}{l}\text { I cub. foot } \\ \text { cub. in.) }\end{array}\right)=\left\{\begin{array}{c}0.028317 \text { cub. me- } \\ \text { ter, or } 28.317 \\ \text { cub. decimeters. }\end{array}\right.$
$\begin{aligned} & \begin{array}{l}\text { CUB. YARD } \\ \text { cub. ft.) }\end{array}\end{aligned}(27\}=0.76455$ cub. meter.

## APOTHECARIES' MEASURE.

$\left.\begin{array}{l}\text { I gallon (8 pints or } \\ \text { 160 fluid ounces })\end{array}\right\}=4.545963$ I liters.
I fluid ounce, $f$ 3 $\}=\{28.4123$ cubic (8 drachms) $\}=\left\{\begin{array}{c}\text { centimeters. }\end{array}\right.$
I fluid drachm, f $\left.\begin{array}{c}\text { ( } 60 \text { minims } \text { ) }\end{array}\right\}=\left\{\begin{array}{c}3.5515 \text { cubic } \\ \text { centimeters. }\end{array}\right.$ $\left.\underset{\text { grain weight) }}{\operatorname{minim}, \mathrm{m}_{\text {(0.9rit }}}\right\}\left\{=\left\{\begin{array}{c}0.05919 \mathrm{cubic} \\ \text { centimeters. }\end{array}\right.\right.$
Note. - The Apothecaries' gallon is of the same capacity as the 1 mperial gallon.

$$
\begin{aligned}
& \text { I square inch . } \quad=\left\{\begin{array}{l}
6.45 \mathrm{I} 6 \mathrm{sq.} \text {. cen- } \\
\text { timeters. }
\end{array}\right. \\
& \text { I sq. ft. ( } 144 \mathrm{sq} . \mathrm{in} .)=\left\{\begin{array}{c}
9.2903 \text { sq. } \text {. deci } \\
\text { meter. }
\end{array}\right. \\
& \text { meters. } \\
& \text { I SQ. } \operatorname{YaRD}(9 \mathrm{sq} . \mathrm{ft} .)=\left\{\begin{array}{c}
0 . \mathrm{Sj}_{\mathrm{j}} \mathrm{rI26} \mathrm{~s} \\
\text { meters. }
\end{array}\right. \\
& \text { I perch ( } \left.30 \frac{1}{4} \text { sq. yd. }\right)=\left\{\begin{array}{c}
25.293 \text { sq. me- } \\
\text { ters. }
\end{array}\right.
\end{aligned}
$$

```
MEASURE OF CAPACITY.
I gill . . . . . . \(=\mathbf{I} .42\) deciliters.
I pint ( 4 gills) . . \(=0.568\) liter.
I quart ( 2 pints) . . \(=1.136\) liters.
I Gallon ( 4 quarts) \(=4.545963^{1}\) ""
I peck (2 galls.) . . \(=9.092\)
I bushel ( 8 galls.) . \(=3.637\) dekaliters.
I quarter ( 8 bushels) \(=2.909\) hectoliters.
```


## AVOIRDUPOIS WEIGHT.

${ }^{1}$ grain . . . $=\left\{\begin{array}{c}64.8 \mathrm{~m} \mathrm{i} 11 \\ \text { grams. }\end{array}\right.$
I 'ram . . . . . $=1.772$ grams.
r ounce ( 16 dr.) . . $=28.350$
1 pouxir(16 oz. or $\}=0.45359243$ kilogr.
istone ( $\mathrm{I}+\mathrm{lb}$. ) . $=6.350 \quad$ "
$\begin{aligned} & \text { I quarter ( } 28 \mathrm{lb} .) \\ & \text { I hundredweight }\end{aligned} .=\begin{gathered}12.70 \\ 50.80\end{gathered}$
$\left.\underset{(\text { II } 2 \mathrm{lb} .)}{ }{ }^{\text {I hundredweight }}\right\}=\left\{\begin{array}{c}50.80 \\ 0.50 \text { So quintal. } " . ~\end{array}\right.$ $I$ ton (20 cwt.) $=\left\{\begin{array}{l}\text { I.01 } 60 \text { tonnes } \\ \text { or rion } 6 \text { k:lo- } \\ \text { grams. }\end{array}\right.$

## TROY WEIGHT.

$\left.\begin{array}{c}\text { Troy ounce }(480 \\ \text { frains avoir.) }\end{array}\right\}=3$ 1.1035 grams. I pemimweight $(24\}=1.5552$ " grains)
Notr. - The Troy grain is of the same weight as the Avoirdupois grain.

## APOTHECARIES' WEIGHT.

I ounce ( 8 drachms) $=31.1035$ grams.
$\underset{\text { ples) }}{\text { I drachm, }} 3 \mathrm{i}$ ( 3 scru- $\}=3.888$
$\begin{aligned} & \text { I scruple, } \\ & \text { grains) }\end{aligned} 9^{i}(20\}=1.296 \quad$ " grains)
Note. - The Apothecaries' ounce is of the same weight as the Troy ounce. The Apothecaries' grain is also of the same weight as the Avoirdupois grain.

Note. - The Yard is the length at $62^{\circ}$ Fahr., marked on a bronze bar deposited with the Board of Trade.
The Pound is the weight of a piece of platinum weighed in vacuo at the temperature of $o^{\circ} \mathrm{C}$., and which is also deposited with the Board of Trade.

The Gailon contaius to lb . weight of distilled water at the temperature of $62^{\circ}$ Fahr., the barometer being at 30 inches.

EQUIVALENTS OF BRITISH IMPERIAL AND METRIC WEIGHTS AND MEASURES.
(4) IMPERIAL TO METRIC.
(For U.S. Weights and Measures, see Table 3.)

|  | LINEAR MEASURE. |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { Feet } \\ \text { to } \\ \text { meters. } \end{gathered}$ | $\begin{gathered} \text { Yards } \\ \text { to } \\ \text { meters. } \end{gathered}$ | Miles to kile. meters. |
| 1 | 2.539998 | 0.30480 | 0.91440 | 1.60934 |
| 2 | 5.079996 | 0.60960 | 1.82880 | 3.21869 |
| 3 | 7.619993 | 0.91440 | 2.74320 | 4.82803 |
| 4 | 10.159991 | 1.21920 | 3.65760 | 6.43737 |
| 5 | 12.699989 | 1.52400 | 4.57200 | 8.0467 I |
| 6 | 15.239987 | 1.82880 | 5.48640 | 9.65606 |
| 7 | 17.779984 | 2.13360 | 6.400 So | I 1. 26540 |
| 8 | 20.319982 | 2.43840 | $7 \cdot 31519$ | 12.87474 |
| 9 | 22.3599 So | 2.74320 | 8.22959 | 14.48 .40 S |

SQUARE MEASURE.

|  | $\begin{gathered} \text { Square } \\ \text { inches } \\ \text { to square } \\ \text { centimeters. } \end{gathered}$ | Square feet to square decimeters. | Square <br> yards to square meters. | Acres to hectares. |
| :---: | :---: | :---: | :---: | :---: |
| I | 6.45159 | 9.29029 | 0.83613 | 0.40 .468 |
| 2 | 12.90318 | 18.58058 | 1.67225 | 0.80937 |
| 3 | 19.35477 | 27.87056 | 2.50835 | 1.21405 |
| 4 | 25.50636 | 37.16115 | $3 \cdot 34450$ | 1.61874 |
| 5 | 32.25794 | 46.45144 | 4.18063 | 2.02342 |
| 6 | $3^{8.70953}$ | 55.74173 | 5.01676 | 2.42SII |
| 7 | 45.16112 | 65.03201 | 5.85288 | 2.83279 |
| S | 51.61271 | 74.32230 | 6.68901 | 3.23745 |
| 9 | 58.06430 | 83.61259 | 7-52513 | 3.642 I 6 |

CUBIC MEASURE.

|  | Cubic <br> inches <br> to cubic <br> centimeters. | Cubic feet <br> to <br> cubic <br> meters. | Cubic <br> yards <br> to cubic <br> meters. | Fluid <br> drachms <br> to cubic <br> centi- <br> meters. |
| :---: | :---: | :---: | :---: | :---: |
|  | 16.38702 | 0.02832 | 0.76455 | .3 .55153 |
| 2 | 32.77404 | 0.05663 | 1.52911 | 7.10307 |
| 3 | 49.16106 | 0.08495 | 2.29366 | 10.65460 |
| 4 | 65.54808 | 0.11327 | 3.05821 | 14.20613 |
| 5 | 81.93511 | 0.14158 | 3.82276 | 17.75767 |
| 6 | 98.32213 | 0.16990 | 4.58732 | 21.30920 |
| 7 | 114.70915 | 0.19822 | 5.35187 | 24.86074 |
| 8 | 131.09617 | 0.22653 | 6.11642 | 28.41227 |
| 9 | 147.48319 | 0.25485 | 6.88098 | 31.96380 |
|  |  |  |  |  |

LINEAR MEASURE.

Smithsonian Tables.

MEASURE OF CAPACITY.

|  | Quarts <br> to <br> liters. | Gallons <br> to <br> liters. | Bushels <br> to <br> dekaliters. | Quarters <br> to <br> hectoliters. |
| :---: | :---: | ---: | ---: | ---: |
|  | 1.13649 | 4.54596 | 3.63677 | 2.90942 |
| 2 | 2.27298 | 9.09193 | 7.27354 | 5.81883 |
| 3 | 3.40947 | 13.63789 | 10.9103 I | 8.72825 |
| 4 | 4.54596 | 15.18385 | 14.54708 | 11.63767 |
| 5 | 5.68245 | 22.72982 | 18.18385 | 14.54708 |
| 6 | 6.81894 | 27.27578 | 21.82062 | 17.45650 |
| 7 | 7.95544 | 31.82174 | 25.45739 | 20.36591 |
| 8 | 9.09193 | 36.36770 | 29.09416 | 23.27533 |
| 9 | 10.22842 | 40.91367 | 32.73093 | 26.18475 |

WEIGHT (Avolrdupors).

|  | Grains to milligrams. | Ounces to grams. | Pounds to ki:ugrams. | Hundred. weights to quintals. |
| :---: | :---: | :---: | :---: | :---: |
| I | 64.79892 | 28.34953 | 0.45359 | $0.50 \mathrm{SO2}$ |
| 2 | I 29.59784 | 56.69905 | 0.90718 | 1.01605 |
| 3 | $19+39675$ | $85.045^{\circ}$ | 1.36078 | 1.52407 |
| 4 | 259.19567 | 113.39811 | 1.81437 | 2.03209 |
| 5 | 323.99459 | 141.74763 | 2.26796 | 2.54012 |
| 6 | 388.79351 | 170.09716 | 2.72155 | 3.04814 |
| 7 | 453.59243 | 198.44669 | 3.17515 | 3.55616 |
| 3 | 518.39135 | 226.79621 | 3.62874 | 4.06419 |
| 9 | 583.19026 | 255.14574 | 4.0 S 233 | $4 \cdot 57221$ |



* See also accompanying table of derivatives. For example : $\int \cos . x d x=\sin . x+$ constant.

$$
\begin{align*}
(x+y)^{n}=x^{n}+\frac{n}{1} \cdot x^{n-1} y+\frac{n(n-1)}{2!} x^{n-2} y^{2}+\ldots \\
\frac{n(n-1) \ldots(n-m+1)}{m!} x^{n-m} y^{m}+\ldots \tag{2}
\end{align*}
$$

$(\mathrm{I} \pm x)^{n}=\mathrm{I} \pm n x+\frac{n(n-\mathrm{I}) x^{2}}{2!} \pm \frac{n(n-\mathrm{I})(n-2) x^{2}}{3!}+\ldots+\frac{( \pm \mathrm{I})^{k} n!x^{k}}{(n-k)!k!}+\ldots\left(x^{2}<\mathrm{I}\right)$ $(\mathrm{I} \pm x)^{-n}=\mathrm{I} \mp n x+\frac{n(n+\mathrm{I})}{2!} x^{2} \mp \frac{n(n+1)(n+2) x^{3}}{3!}+\ldots$

$$
\begin{equation*}
(\mp \mathrm{I}) k^{\frac{(n+k-1}{} \frac{1}{} x^{k}}(n-1)!k! \tag{2}
\end{equation*}
$$

$(1 \pm x)^{-1}=1 \mp x+x^{2} \mp x^{3}+x^{4} \mp x^{5}+\ldots$
$(1 \pm x)^{-2}=1 \mp 2 x+3 x^{2} \mp 4 x^{3}+5 x^{4} \mp 6 x^{5}+\ldots$
( $x^{2}<1$ )

$$
\begin{array}{rlr}
f(x+h) & =f(x)+h f^{\prime}(x)+\frac{h^{2}}{2!} f^{\prime \prime}(x)+\ldots+\frac{h^{n}}{n!} f^{(n)}(x)+\ldots & \begin{array}{r}
\text { Taylor’s } \\
\text { series. }
\end{array} \\
f(x) & =f(o)+\frac{x}{1} f^{\prime}(o)+\frac{x^{2}}{2!} f^{\prime \prime}(o)+\ldots \frac{x^{n}}{n!} f(n)(o)+\ldots & \text { Maclaurin's } \\
\text { series. }
\end{array}
$$

$$
e=\lim \left(\mathrm{I}+\frac{\mathrm{I}}{n}\right)^{n}=\mathrm{I}+\frac{\mathrm{I}}{\mathrm{I}!}+\frac{\mathrm{I}}{2!}+\frac{\mathrm{I}}{3!}+\frac{\mathrm{I}}{4!}+\ldots
$$

$$
\begin{equation*}
e^{x}=1+x+\frac{x^{2}}{2!}+\frac{x^{3}}{3!}+\frac{x^{4}}{4!}+\cdots \tag{2}
\end{equation*}
$$

$$
\begin{equation*}
a^{x}=\mathrm{I}+x \log a+\frac{(x \log a)^{2}}{2!}+\frac{(x \log a)^{3}}{3!}+\ldots \tag{2}
\end{equation*}
$$

$$
\left.\left.\left.\begin{array}{rl}
\log x & =\frac{x-1}{x}+\frac{1}{2}\left(\frac{x-1}{x}\right)^{2}+\frac{1}{3}\left(\frac{x-1}{x}\right)^{3}+\ldots \\
& =(x-1)-\frac{1}{2}(x-1)^{2}+\frac{1}{3}(x-1)^{3}-\ldots \\
& =2\left[\frac{x-1}{x+1}+\frac{1}{3}\left(\frac{x-1}{x+1}\right)^{3}+\frac{1}{5}(x-1\right.  \tag{x>0}\\
x+1
\end{array}\right)^{5}+\ldots\right]\right] .
$$

$\log (1+x)=x-\frac{1}{2} x^{2}+\frac{1}{3} x^{3}-\frac{1}{4} x^{4}+\ldots$.

$$
\sin x=\frac{1}{2 i}\left(e^{2 x}-e^{-1 x}\right)=x-\frac{x^{3}}{3!}+\frac{x^{5}}{5!}-\frac{x^{7}}{7!}+\ldots
$$

$$
\left(x^{2}<x\right)
$$

$$
\begin{array}{ll}
\cos x=\frac{1}{2}\left(e^{2 x}+e^{-i x}\right)=1-\frac{x^{2}}{2!}+\frac{x^{4}}{4!}-\frac{x^{6}}{6!}+\ldots=\mathrm{I}-\operatorname{versin} x & \left(x^{2}<x\right) \\
\tan x=x+\frac{x^{3}}{3}+\frac{2 x^{5}}{15}+\frac{17 x^{7}}{3^{1} 5}+\frac{62}{2835} x^{9}+\ldots & \left(x^{2}<\frac{\pi^{2}}{4}\right) \tag{2}
\end{array}
$$

$\sin ^{-1} x=\frac{\pi}{2}-\cos ^{-1} x=x+\frac{x^{3}}{6}+\frac{1}{2} \cdot \frac{3}{4} \cdot \frac{x^{5}}{5}+\frac{1}{2} \cdot \frac{3}{4} \cdot \frac{5}{6} \cdot \frac{x^{7}}{7}+\ldots$
$\tan ^{-1} x=\frac{\pi}{2}-\cot .^{-1} x=x-\frac{1}{3} x^{3}+\frac{1}{5} x^{5}-\frac{1}{7} x^{7}+\cdots$

$$
\begin{equation*}
=\frac{\pi}{2}-\frac{1}{x}+\frac{1}{3 x^{3}}-\frac{1}{5 x^{5}}+\ldots \tag{2}
\end{equation*}
$$

$\sinh x=\frac{1}{2}\left(e^{x}-e^{-x}\right)=x+\frac{x^{3}}{3!}+\frac{x^{5}}{5!}+\frac{x^{7}}{7!}+\cdots$

$$
\begin{aligned}
& \cosh x=\frac{1}{2}\left(e^{x}+e_{n}^{-x}\right)=1+\frac{x^{2}}{2!}+\frac{x^{4}}{4!}+\frac{x^{6}}{6!}+\ldots \\
& \tanh x=x-\frac{1}{3} x^{3}+\frac{2}{15} x^{5}-\frac{17}{315} x^{7}+\ldots \\
& \sinh ^{-1} x=x-\frac{1}{2} \frac{x^{3}}{3}+\frac{1}{2} \cdot \frac{3}{4} \cdot \frac{x^{5}}{5}-\frac{1}{2} \cdot \frac{3}{4} \cdot \frac{5}{6} \frac{x^{7}}{7}+\ldots \\
& =\log 2 x+\frac{1}{2} \frac{1}{2 x^{2}}-\frac{1}{2} \frac{3}{4} \frac{1}{4 x^{4}}+\frac{1}{2} \frac{3}{4} \frac{5}{6} \frac{1}{6 x^{6}}-\ldots \\
& \left(x^{2}<\infty\right) \\
& \left(x^{2}<1\right) \\
& \left(x^{2}>1\right) \\
& \cosh ^{-1} x=\log 2 x-\frac{1}{2} \frac{1}{2 x^{2}}-\frac{1}{2} \frac{3}{4} \frac{1}{4 x^{4}} \cdots-\frac{1}{2} \frac{3}{4} \frac{5}{6} \frac{1}{6 x^{6}}-\ldots \\
& \tanh ^{-1} x=x+\frac{1}{3} x^{3}+\frac{1}{5} x^{5}+\frac{1}{7} x^{7}+\cdots \\
& \operatorname{gd} x=\phi=x-\frac{1}{6} x^{3}+\frac{1}{24} \cdot x^{5}-\frac{61}{5040} x^{7}+\ldots \\
& \text { ( } x \text { small) } \\
& =\frac{\pi}{2}-\operatorname{sech} . x-\frac{1}{2} \frac{\operatorname{sech}^{3} x}{3}-\frac{3}{2} \frac{3}{4} \frac{\operatorname{sech}^{5} x}{5}-\ldots \\
& \text { ( } x \text { large) } \\
& x=\mathrm{gd}^{-1} \phi=\phi+\frac{1}{6} \phi^{3}+\frac{1}{24} \phi^{5}+{ }_{5040}^{61} \phi^{7}+\ldots \\
& f(x)=\frac{1}{2} \mathrm{~b}_{0}+\mathrm{b}_{1} \cos \frac{\pi x}{c}+\mathrm{b}_{2} \cos \frac{2 \pi x}{c}+\ldots \\
& +a_{1} \sin \frac{\pi x}{c}+a_{2} \cos \frac{2 \pi x}{c}+\ldots(-c<x<c) \\
& \mathrm{a}_{m}=\frac{1}{c} \int_{-c}^{+c} f(x) \sin \frac{m}{c} \frac{\pi x}{c} d x \\
& \mathrm{~b}_{m}=\frac{\mathrm{I}}{c} \int_{-c}^{+c} f(x) \cos { }_{c}^{m \pi} d x
\end{aligned}
$$

TABAE 8.-MATHEMATICAL CONSTANTS.

| $e=2.7182818285$ | $\begin{gathered} \text { Numbers. } \\ \pi=3.145926536 \end{gathered}$ | $\begin{gathered} \text { Logarithms. } \\ 0.4971498727 \end{gathered}$ |
| :---: | :---: | :---: |
| $e^{-1}=0.3678794412$ | $\pi^{2}=9.8696044011$ | 0.9942997454 |
| $\mathrm{M}=\log _{10} 0^{\circ}=0.4342944819$ | $\frac{1}{\pi}=0.3183098862$ | 9.50285.01273 |
| $(\mathrm{M})^{-1}=\log _{e} 10=2.3025^{8} 50930$ | $\sqrt{ } \pi=1.7724538509$ $\sqrt{ } \pi$ | 0.2485749363 |
| $\log _{10} \log _{100}=9.6377843113$ | $\frac{\sqrt{\pi}}{2}=0.8862269255$ | 9.9475449407 |
| $\log _{10} 2=0.3010299957$ | $\frac{1}{\sqrt{ } \pi}=0.5641895835$ | 9.7514250637 |
| $\log _{e} 2=0.6931471806$ | $\frac{2}{\sqrt{\pi}}=1.1283791671$ | 0.0524550593 |
| $\log _{10} x=$ M. $\log _{e} x$ | $\sqrt{\frac{\pi}{2}}=1.2533141373$ | 0.0980599385 |
| $\log _{B} x=\log _{e} x \cdot \log _{B} e$ | $V^{\frac{2}{\pi}}=0.7978845608$ | 9.9019400615 |
| $=\log _{e} x \div \log _{e} \mathrm{~B}$ | $\frac{\pi}{4}=0.785398_{1} 634$ | 9.8950898814 |
| $\log _{e} \pi=1.1447298858$ | $\frac{\sqrt{\pi}}{4}=0.44311 \quad 34627$ | $9.6465^{1} 49450$ |
| $\rho=0.4769362762$ | $\frac{4}{3} \pi=4.1887902048$ | 0.62208 \$6093 |
| $\log \rho=9.6784603565$ | $\frac{e}{V \pi}=1.0844375514$ | 0.0352045477 |

VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, OF NATURAL NUMBERS.

| $n$ | 1000. $\frac{1}{11}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } 1$ | $n$ | $1000 . \frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } \times$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 10 | 100.000 | 100 | 1000 | 3.1623 | 65 | 15.3846 | 4225 | 274625 | 8.0623 |
| 11 | 90.9091 | 121 | 1331 | $3 \cdot 3166$ | 66 | 15.1515 | 4356 | 287496 | 8.1240 |
| 12 | 83.3333 | 144 | 1728 | $3 \cdot 4641$ | 67 | 14.9254 | 4489 | 300763 | 8.1854 |
| 13 | 76.9231 | 169 | 2197 | 3.6056 | 68 | 14.7059 | 4624 | 314432 | 8.2462 |
| 14 | 71.4286 | 196 | 2744 | 3.7417 | 69 | 14.4928 | 4761 | 328509 | 8.3066 |
| 15 | 66.6667 | 225 | 3375 | 3.8730 | 70 | 14.2857 | 4900 | 343000 | 8.3666 |
| 16 | 62.5000 | 256 | 4096 | 4.0000 | 71 | 14.0845 | 5041 | 357911 | 8.4261 |
| 17 | 58.8235 | 289 | 4913 | 4.1231 | 72 | 13.8889 | 5184 | 373248 | 8.4853 |
| 18 | $55 \cdot 5556$ | 324 | 5832 | 4.2426 | 73 | 13.6986 | 5329 | 389017 | 8.5440 |
| 19 | 52.6316 | 361 | 6859 | $4 \cdot 3589$ | 74 | 13.5135 | 5476 | 405224 | 8.6023 |
| 20 | 50.0000 | 400 | Sooo | 4.4721 | 75 | 13.3333 | 5625 | 421875 | 8.6603 |
| 21 | 47.6190 | 44 I | 9261 | 4.5826 | 76 | 13.1579 | 5776 | 438976 | 8.7178 |
| 22 | $45.45+5$ | 484 | 10648 | 4.6904 | 77 | 12.9870 | 5929 | 456533 | 8.7750 |
| 23 | 43.4783 | $5 \div 9$ | 12167 | 4.7958 | 78 | 12.8205 | 6084 | 474552 | 8.8318 |
| 24 | 41.6667 | 576 | $13^{82} 4$ | 4.8990 | 79 | 12.6582 | 6241 | 493039 | 8.8882 |
| 25 | 40.0000 | 625 | 15625 | 5.0000 | 80 | 12.5000 | 6400 | 512000 | 8.9443 |
| 26 | 38.4615 | 676 | 17576 | 5.0990 | 81 | 12.3457 | 6561 | 531441 | 9.0000 |
| 27 | 37.0370 | 729 | 19683 | 5.1962 | 82 | 12.1951 | 6724 | 551368 | 9.0554 |
| 28 | 35.7143 | 784 | 21952 | 5.2915 | 83 | 12.0482 | 6889 | 571787 | 9.1504 |
| 29 | 34.4828 | 841 | 24389 | $5 \cdot 3852$ | 84 | 11.9048 | 7056 | 592704 | 9.1652 |
| 30 | 33.3333 | 900 | 27000 | 5.4772 | 85 | 11.7647 | 7225 | 614125 | 9.2195 |
| 31 | 32.2581 | 961 | 29791 | 5.5678 | 86 | 1 I .6279 | 7396 | 636056 | 9.2736 |
| 32 | 31.2500 | 1024 | 32768 | 5.6569 | 87 | 11.4943 | 7569 | 658503 | 9.3274 |
| 33 | 30.3030 | 1089 | 35937 | 5.7446 | 88 | 11.3636 | 7744 | 681472 | 9.3808 |
| 34 | 29.4118 | 1156 | 39304 | 5.8310 | 89 | 11.2360 | 7921 | 704969 | 9.4340 |
| 35 | 28.5714 | 1225 | 42875 | 5.9161 | 90 | 11.1111 | Sioo | 729000 | 9.4868 |
| 36 | 27.7778 | I 296 | 46656 | 6.0000 | 91 | 10.9890 | 828I | 753571 | 9.5394 |
| 37 | 27.0270 | 1 369 | 50653 | 6.0828 | 92 | 10.8696 | 8464 | 778688 | 9.5917 |
| 38 | 26.3158 | 1444 | 54872 | 6.1644 | 93 | 10.7527 | 8649 | 804357 | 9.6437 |
| 39 | 25.6410 | 152 I | 59319 | 6.2450 | 94 | 10.6383 | 8836 | 830584 | 9.6954 |
| 40 | 25.0000 | 1600 | 64000 | 6.3246 | 95 | 10.5263 | 9025 | S57375 | 9.7468 |
| 41 | 24.3902 | I681 | 68921 | 6.4031 | 96 | 10.4167 | 9216 | 884736 | 9.7980 |
| 42 | 23.8095 | 1764 | 74088 | 6.4807 | 97 | 10.3093 | 9409 | 912673 | 9.8489 |
| 43 | 23.2558 | 1849 | 79507 | 6.5574 | 98 | $10.20+1$ | 9604 | 941192 | 9.8995 |
| 44 | 22.7273 | 1936 | S5I84 | 6.6332 | 99 | 10.1010 | 980 I | 970299 | 9.9499 |
| 45 | 22.2222 | 2025 | 91125 | 6.7082 | 100 | 10.0000 | 10000 | 1000000 | 10.0000 |
| 46 | 2 I .7391 | 2116 | 97336 | 6.7823 | 101 | 9.90099 | 10201 | 1030301 | 10.0499 |
| 47 | 21.2766 | 2209 | 103823 | 6.8557 | 102 | 9.80392 | 10.104 | 106ı 208 | 10.0995 |
| 48 | 20.8333 | 2304 | 110592 | 6.9282 | 103 | 9.70874 | 10609 | 1092727 | 10.1489 |
| 49 | 20.4082 | 2401 | 117649 | 7.0000 | 104 | 9.61538 | 10816 | I 124864 | 10.1980 |
| 50 | 20.0000 | 2500 | 125000 | 7.0711 | 105 | 9.52381 | 11025 | 1157625 | 10.2470 |
| 51 | 19.6078 | 2601 | ${ }_{1} 32651$ | 7.1414 | 106 | 9.43396 | 11236 | 1191016 | 10.2956 |
| 52 | 19.2308 | 2704 | 140608 | 7.2111 | 107 | $9 \cdot 34579$ | 11449 | 1225043 | 10.3441 |
| 53 | 18.8679 | 2809 | 148877 | 7.2801 | 108 | 9.25926 | 11664 | 1259712 | 10.3923 |
| 54 | 18.5185 | 2916 | I 57464 | $7 \cdot 3485$ | 109 | 9.17431 | 11881 | 1295029 | 10.4403 |
| 55 | 18.1818 | 3025 | 166375 | 7.4162 | 110 | 9.09091 | 12100 | 1331000 | 10.4881 |
| 56 | 17.8571 | 3136 | 175616 | 7.4833 | 111 | 9.00901 | 12321 | 1367631 | 10.5357 |
| 57 | 17.5439 | 3249 | 185193 | 7.5498 | 112 | 8.92857 | 12544 | 1404928 | 10.5830 |
| 58 | 17.2414 16.9492 | 3364 | 195112 | 7.6158 | 113 | 8.84956 | 12769 | 1442897 | 10.6301 |
| 59 | 16.9492 | 3481 | 205379 | 7.6811 | 114 | 8.77193 | 12996 | 1481544 | 10.6771 |
| 60 | 16.6667 | 3600 | 216000 | 7.7460 | 115 | 8.69565 | 13225 | 1520875 | 10.7238 |
| 61 | 16.3934 | 3721 | 226981 | 7.8102 | 116 | 8.62069 | 13456 | 1560896 | 10.7703 |
| 62 | 16.1290 15.8730 | 3844 | 238328 250047 | 7.8740 | 117 118 | 8.54701 | 13689 | 1601613 | 10.8167 |
| 63 64 | 15.8730 15.6250 | 3969 4096 | 250047 262144 | 7.9373 8.0000 | 118 119 | 8.47458 8.40336 | 13924 14161 | 1643032 1685159 | 10.8628 |
| 64 | 15.6250 | 4096 | 262144 | 8.0000 | 119 | 8.40336 | 14161 | 1685159 | 10.9087 |

TABLE 9 (continued).
VALUES OF RECIPROCALS, SQUARES, CUBES, SQUARE ROOTS, OF NATURAL NUMBERS.

| $n$ | 1000. ${ }_{n}^{1}$ | $n^{2}$ | $n^{8}$ | $\sqrt{ } \times$ | $n$ | $1000 \cdot \frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } 1$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 120 | 8.33333 | 14400 | 1728000 | 10.9545 | 175 | 5.71429 | 30625 | 5359375 | 13.2288 |
| 12 | 8.26446 | 14641 | 1771561 | 11.0000 | 176 | 5.68182 | 30976 | 5451776 | 13.2665 |
| 122 | 8.19672 | 14884 | 1815848 | I 1.0454 | 177 | 5.64972 | 31329 | 5545233 | ${ }^{1} 3.3041$ |
| 123 | 8.13008 | 15129 | 1860867 | 11.0905 | 178 | 5.61798 | 31684 | 5639752 | I 3.3417 |
| 124 | 8.06452 | 15376 | 1906624 | I 1.1355 | 179 | $5 \cdot 58659$ | 32041 | 5735339 | 1 3.3791 |
| 125 | 8.00000 | 15625 | 1953125 | II.1803 | 180 | 5.55556 | 32400 | 5S32000 | 13.4164 |
| 126 | 7.93651 | 15876 | 2000376 | $11.225^{\circ}$ | 181 | 5.52486 | 32761 | 5929741 | 13.4536 |
| 127 | 7.87402 | 16129 | 2048383 | 11.2694 | 182 | 5.49451 | 33124 | 6028568 | 13.4907 |
| 128 | 7.81250 | 16384 | 2097152 | 11.3137 | 183 | 5.46448 | 33489 | 6128487 | 13.5277 |
| 129 | 7.75194 | 16641 | 2146689 | 11.3578 | 184 | 5.43478 | 33856 | 6229504 | I 3.5647 |
| 130 | 7.69231 | 16900 | 2197000 | II. 4018 | 185 | $5 \cdot 40541$ | 34225 | 6331625 | 13.6015 |
| 131 | 7.63359 | 17161 | 2248091 | 11.4455 | 186 | $5 \cdot 37634$ | 34596 | 6434856 | 13.6382 |
| 132 | 7.57576 | 17424 | 2299968 | 11.4891 | 187 | 5.34759 | 34969 | 6539203 | 13.6748 |
| 133 | 7-51880 | 17689 | 2352637 | 11.5326 | 188 | 5.31915 | 35344 | 6644672 | 13.7113 |
| 134 | 7.46269 | I 7956 | 2406104 | $11.575^{8}$ | 189 | 5.29101 | 3572 I | 6751269 | 13.7477 |
| 135 | 7-40741 | 18225 | 2460375 | 11.6190 | 190 | 5.26316 | 36100 | 6859000 | 13.7840 |
| 136 | $7 \cdot 35294$ | 18496 | 2515456 | 11.6619 | 191 | 5.23560 | 36481 | 6967871 | 13.8203 |
| 137 | 7.29927 | 18769 | 2571353 | 11.7047 | 192 | 5.20833 | 36864 | 7077888 | 13.8564 |
| 138 | 7.24638 | 19044 | 2628072 | 11.7473 | 193 | 5.18135 | 37249 | 7189057 | 13.8924 |
| 139 | 7.19424 | 1932 I | 2685619 | 11.7898 | 194 | 5.15464 | 37636 | 7301384 | 13.9284 |
| 140 | 7.14286 | 19600 | 2744000 | 11.8322 | 195 | 5.12821 | 38025 | 7414875 | 13.9642 |
| 141 | 7.09220 | 1988 I | 2 SO 322 I | I 1.8743 | 196 | 5.10204 | 38416 | 7529536 | 14.000 |
| 142 | 7.04225 | 20164 | 2863288 | 11.9164 | 197 | 5.07614 | 38809 | 7645373 | 14.0357 |
| 143 | 6.99301 | 20449 | 2924207 | 11.9583 | 198 | 5.05051 | 39204 | 7762392 | 14.0712 |
| 144 | 6.94444 | 20736 | 2985984 | 12.0000 | 199 | 5.02513 | 39601 | 7880599 | 14.1067 |
| 145 | 6.89655 | 21025 | 3048625 | 12.0416 | 200 | 500000 | 40000 | 8000000 | I4.142I |
| 146 | 6.84932 | 21316 | 3112136 | 12.0830 | 201 | 4.97512 | 40401 | 8120601 | 14.1774 |
| 147 | 6.80272 | 21609 | 3176523 | 12.1244 | 202 | 4.95050 | 40804 | 8242408 | 14.2127 |
| 148 | 6.75676 | 21904 | 3241792 | 12.1655 | 203 | 4.92611 | 41209 | 8365427 | 14.2478 |
| 149 | 6.71141 | 22201 | 3307949 | 12.2066 | 204 | 4.90196 | 41616 | 8489664 | 14.2829 |
| 150 | 6.66667 | 22500 | 3375000 | 12.2474 | 205 | 4.87805 | 42025 | 8615125 | 14.3178 |
| 151 | 6.62252 | 22801 | 3442951 | 12.2882 | 206 | 4.85437 | 42436 | 8741816 | 14.3527 |
| 152 | 6.57895 | 23104 | 3511808 | 12.3288 | 207 | 4.83092 | 42849 | 8869743 | 14.3875 |
| I 53 | 6.53595 | 23409 | 3581577 | 12.3693 | 208 | 4.80769 | 43264 | 8998912 | 14.4222 |
| 154 | 6.4935 I | 23716 | 3652264 | 12.4097 | 209 | 4.78469 | 4368 I | 9129329 | 14.4568 |
| 155 | 6.45161 | 24025 | 3723875 | 12.4499 | 210 | 4.76190 | 44100 | 9261000 |  |
| ${ }^{1} 56$ | 6.41026 | 24336 | 3796416 | 12.4900 | 211 | 4.73934 | 44521 | 9393931 | 14.5258 |
| 157 | 6.36943 | 24649 | 3869893 | I 2.5300 | 212 | 4.71698 | 44944 | 9528128 | 14.5602 |
| 158 | 6.32911 | 24964 | 3944312 | 12.569 S | 213 | 4.69484 | 45369 | 9663597 | 14.5945 |
| 159 | 6.28931 | 2528 I | 4019679 | 12.6095 | 214 | 4.67290 | 45796 | 9800344 | 14.6287 |
| 160 | 6.25000 | 25600 | 4096000 | 12.6491 | 215 | 4.65116 | 46225 | 9938375 | 14.6629 |
| 161 | 6.21118 | 25921 | 4173281 | 12.6886 | 216 | 4.62963 | 46656 | 10077696 | 14.6969 |
| 162 | 6.17284 | 26244 | 4251528 | 12.7279 | 217 | 4.60829 | 47089 | 10218313 | 14.7309 |
| 163 | 6.1 3497 | 26569 | 4330747 | 12.7671 | 218 | 4.58716 | 47524 | 10360232 | 14.7648 |
| 164 | 6.09756 | 26896 | 4410944 | 12.8062 | 219 | 4.56621 | 47961 | 10503459 | 14.7986 |
| 165 | 6.06061 | 27225 |  | $12.845^{2}$ | 220 |  | 48400 | 10648000 | $14.8324$ |
| 166 | 6.02410 | 27556 | 4574296 | 12.8841 | 221 | 4.52489 | 48841 | 10793861 | 14.8661 |
| 167 | 5.98802 | 27889 | 4657463 | 12.9228 | 222 | 4.50450 | 49284 | 10941048 | 14.8997 |
| 168 | 5.95238 | 28224 | 4741632 | 12.9615 | 223 | 4.48430 | 49729 | 11089567 | I 4.9332 |
| 169 | 5.91716 | 28561 | 4826809 | 13.0000 | 224 | 4.46429 | 50176 | 11239424 | 14.9666 |
| 170 | 5.88235 | 28900 | 4913000 | 13.0384 | 225 | 4.44444 | 50625 | 11390625 | 15.0000 |
| 171 | 5.84795 | 29241 | 5000211 | 13.0767 | 226 | 442478 | 51076 | 11543176 | 15.0333 |
| 172 | 5.81395 | 29584 | 5088448 | 13.1149 | 227 | 4.40529 | 51529 | 11697083 | 15.0665 |
| 173 174 | 5.78035 | 29929 | 5177717 | 13.1529 | 228 | 4.38596 | 51984 | 11852352 | 15.0997 |
| 174 | 5.74713 | 30276 | 5268024 | 13.1909 | 229 | 4.3668 I | 52441 | 12008989 | 15.1327 |

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS, OF NATURAL NUMBERS.

| $n$ | $1000 . \frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\checkmark n$ | $n$ | $1000 \cdot{ }_{n}^{1}$ | $n^{2}$ | $n^{3}$ | $\sqrt{n}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 230 | 4.34783 | 52900 | 12167000 | 15.1658 | 285 | 3.50877 | 81225 | 23149125 | 16.8819 |
| 231 | 4.32900 | 53361 | 12326391 | 15.1987 | 286 | 3.49650 | 81796 | 23393656 | 16.9115 |
| 232 | 4.31034 | 53824 | 12487168 | I 5.23I 5 | 287 | $3 \cdot 48432$ | 82369 | 23639903 | 16.9411 |
| 233 | 4.29185 | 54289 | 12649337 | I 5.2643 | 288 | 3.47222 | 82944 | 23887872 | 16.9706 |
| 234 | 4.27350 | 54756 | I2812904 | I 5.297 I | 289 | $3 \cdot 46021$ | 83521 | 24137569 | 17.0000 |
| 235 | 4.25532 | 55225 | 12977875 | I 5.3297 | 290 | 3.44828 | 84100 | 24389000 | 17.0294 |
| 236 | 4.23729 | 55696 | 13144256 | 15.3623 | 291 | 343643 | 8.4681 | 24642171 | 17.0587 |
| 237 | 4.21941 | 56169 | I 3312053 | 15.3948 | 292 | 3.42466 | 85264 | 24897088 | 17.0880 |
| 238 | 4.20168 | 56644 | 13481272 | 15.4272 | 293 | 3. 41297 | 85849 | 25153757 | 17.1172 |
| 239 | 4.18410 | 57121 | 13651919 | 15.4596 | 294 | $3 \cdot 40136$ | 86436 | 25412184 | 17.1464 |
| 240 | 4.16667 | 57600 | 13824000 | 15.4919 | 295 | $3 \cdot 38983$ | 87025 | 25672375 | 17.1756 |
| 241 | 4.14938 | 58081 | 13997521 | 15.5242 | 296 | $3 \cdot 37838$ | 87616 | 25934336 | 17.2047 |
| 242 | 4.13223 | 58564 | 14172488 | ${ }^{1} 5.5563$ | 297 | $3 \cdot 36700$ | 88209 | 26198073 | 17.2337 |
| 243 | 4.11523 | 59049 | 14348907 | 15.5885 | 298 | 3.35570 | 88804 | 26463592 | 17.2627 |
| 244 | 4.09836 | 59536 | 14526784. | 15.6205 | 299 | $3 \cdot 34448$ | S940I | 26730899 | 17.2916 |
| 245 | 4.08163 | 60025 | 14706125 | 15.6525 | 300 | $3 \cdot 33333$ | 90000 | 27000000 | 17.3205 |
| 246 | 4.06504 | 60516 | 14886936 | 15.6844 | 301 | $3 \cdot 32226$ | 90601 | 27270901 | $17 \cdot 3494$ |
| 247 | 4.04858 | 6 r 009 | I 5069223 | 15.7162 | 302 | 3-31126 | 91204 | 27543608 | 17.3781 |
| 248 | 4.03226 | 61504 | 15252992 | 15.7480 | 303 | $3 \cdot 30033$ | 91809 | 27818127 | 17.4069 |
| 249 | 4.01606 | 62001 | 15438249 | 15.7797 | 304 | 3.28947 | 92416 | 28094464 | 17.4356 |
| 250 | 4.00000 | 62500 | 15625000 | 15.8114 | 305 | 3.27869 | 93025 | 28372625 | 17.4642 |
| 251 | 3.98406 | 63001 | 15813251 | 15.8430 | 306 | 3.26797 | 93636 | 28652616 | 17.4929 |
| 252 | 3.96825 | 63504 | 16003008 | 15.8745 | 307 | 3.25733 | 94249 | 28934443 | 17.5214 |
| 253 | 3.95257 | 64009 | 16194277 | 15.9060 | 308 | 3. 2.4675 | 94864 | 29218112 | 17.5499 |
| 254 | 3.93701 | 64516 | 16387064 | I 5.9374 | 309 | 3.23625 | 95.481 | 29503629 | 17.5784 |
| 255 | 3.92157 | 65025 | 16581375 | 15.9687 | 310 | 3.22581 | 96100 | 29791000 | 17.6068 |
| 256 | 3.90625 | 65536 | 16777216 | 16.0000 | 311 | 3.21543 | 96721 | 30080231 | 17.6352 |
| 257 | 3.89105 | 66049 | 16974593 | 16.0312 | 312 | 3.20513 | 97344 | 3037.1328 | 17.6635 |
| 258 | 3.87597 | 66564 | 17173512 | 16.0624 | 313 | 3.19489 | 97969 | 30664297 | 17.6918 |
| 259 | 3.86100 | 67081 | 17373979 | 16.0935 | 314 | 3.18471 | 98596 | 30959144 | 17.7200 |
| 260 | 3.84615 | 67600 | 17576000 | 16.1245 | 315 | 3.17460 | 99225 | 31255875 | 17.7482 |
| 261 | 3.83142 | 68121 | 17779581 | 16.1555 | 316 | 3.16456 | 99856 | 31554496 | 17.7704 |
| 262 | 3.81679 | 68644 | 17984728 | 16.1864 | 317 | 3.15457 | 100489 | 31855013 | 17.8045 |
| 263 | 3.80228 | 69169 | 18191447 | 16.2173 | 318 | 3.14465 | 101124 | 32157432 | 17.8326 |
| 264 | 3.78788 | 69696 | 18399744 | 16.248 I | 319 | 3.13480 | 101761 | 32461759 | 17.8606 |
| 265 | 3.77358 | 70225 | 18609625 | 16.2788 | 320 | 3.12500 | 102400 | 32768000 | 17.8885 |
| 266 | 3.75940 | 70756 | 18821096 | 16.3095 | 321 | 3.1156 | 103041 | 33076161 | 17.9165 |
| 267 | 3.74532 | 71289 | 19034163 | 16.3401 | 322 | 310559 | 103684 | 33386248 | 17.9444 |
| 268 | 3.73134 | 71824 | 19248832 | 163707 | 323 | 3.09598 | 104329 | 33698267 | 17.9722 |
| 269 | 3.71747 | 72361 | 19465109 | 16.4012 | 324 | 3.08642 | 104976 | 34012224 | 18.0000 |
| 270 | 3.70370 | 72900 | 19683000 | 16.4317 | 325 | 3.07692 | 105625 | 34328125 | 18.0278 |
| 271 | 3.69004 | 73441 | 19902511 | 16.4621 | 326 | 3.06748 | 106276 | 34645976 | 18.0555 |
| 272 | 367647 | 73984 | 20123648 | 16.4924 | 327 | 3.05810 | 106929 | 34965783 | 18.0831 |
| 273 | 3.66300 | 74529 | 20346417 | 16.5227 | 328 | 3.04878 | 107584 | 35287552 | 18.1108 |
| 274 | 3.64964 | 75076 | 20570824 | 16.5529 | 329 | 3.03951 | 108241 | 35611289 | 18.1384 |
| 275 | 3.63636 | 75625 | 20796875 | 16.5831 | 330 | 3.03030 | 108900 | 35937000 | 18.1659 |
| 276 | 3.62319 | 76176 | 21024576 | 16.6132 | 331 | 3.02115 | 109561 | 36264601 | I8.1934 |
| 277 | 3.61011 | 76729 | 21253933 | 16.6433 | 332 | 3.01205 | 110224 | 36594368 | 18.2209 |
| 278 | 3.59712 | 77284 | 21484952 | 16.6733 | 333 | 3.00300 | $1 \mathrm{IOS89}$ | 36926037 | 18.2483 |
| 279 | $3 \cdot 58423$ | 77841 | 21717639 | 16.7033 | 334 | 2.99401 | I 11556 | 37259704 | 18.2757 |
| 280 | 3.57143 | 78400 | 21952000 | 16.7332 | 335 | 2.98507 | I 12225 |  | 18.3030 |
| 281 | 3.55872 | 78961 | 22188041 | 16.7631 | 336 | 2.97619 | 112896 | 3793.3056 | $18.3303$ |
| 282 | $3 \cdot 54610$ | 79524 | 22425768 | 16.7929 | 337 | 2.96736 | 11.3569 | 38272753 | $18.3576$ |
| $283$ | 3.53357 | 80089 | 22665187 | 16.8226 | 338 | 2.95858 | II 4244 | 38614472 38958219 | $18.3^{8} 48$ |
| 284 | 3.52113 | 80656 | 22906304 | 16.8523 | 339 | 2.94985 | I I 492 I | 38958219 | 18.4120 |

## VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS

 OF NATURAL NUMBERS.| $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{n}$ | $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } \times$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 340 | 2.94118 | 115600 | 39304000 | 18.4391 | 395 | 2.53165 | 156025 | 61629875 | 19.8746 |
| 341 | 2.93255 | $1162 S$ I | 39651821 | 18.4662 | 396 | 2.52525 | 156816 | 62099136 | 19.8997 |
| 342 | 2.92398 | 116964 | 40001688 | 18.4932 | 397 | 2.51889 | 157609 | 62570773 | 19.9249 |
| 343 | 2.91545 | I 17649 | 40353607 | 18.5203 | 398 | 2.51256 | 158404 | 63044792 | 19.9499 |
| 344 | 2.90698 | 118336 | 40707584 | 18.5472 | 399 | 2.50627 | I 59201 | 63521199 | 19.9750 |
| 345 | 2.89855 | 119025 | 41063625 | 18.5742 | 400 | 2.50000 | 160000 | 64000000 | 20.0000 |
| 346 | 2.89017 | 119716 | 41421736 | 18.6011 | 401 | 2.49377 | 160801 | 64481201 | 20.0250 |
| 347 | 2.88184 | 120409 | 41781923 | 18.6279 | 402 | 2.48756 | 161604 | 64964808 | 20.0499 |
| 348 | 2.87356 | 121104 | 42144192 | $18.654{ }^{3}$ | 403 | 2.48139 | 162409 | 65450827 | 20.0749 |
| 349 | 2.86533 | 121801 | 42508549 | 18.68 I 5 | 404 | 2.47525 | 163216 | 65939264 | 20.0998 |
| 350 | 2.85714 | 122500 | 42875000 | 18.7083 | 405 | 2.46914 | 164025 | 66430125 | 20.1246 |
| 351 | 2.84900 | 123201 | 43243551 | 18.7350 | 406 | 2.46305 | 164836 | 66923416 | 20.1494 |
| 352 | 2.84091 | 123904 | 43614208 | 18.7617 | 407 | 2.45700 | 165649 | 67419143 | 20.1742 |
| 353 | 2.83286 | 124609 | 43986977 | 18.7883 | 408 | 2.45098 | 166464 | 67917312 | 20.1990 |
| 354 | 2.82486 | 125316 | 44361864 | 18.8149 | 409 | 2.44499 | 167281 | 68417929 | 20.2237 |
| 355 | 2.81690 | 126025 | 44738875 | 18.8414 | 410 | 2.43902 | 168100 | 68921000 | 20.2485 |
| 356 | 2.80899 | 126736 | $45^{118016}$ | 18.8680 | 411 | 2.43309 | 16892 I | 69426531 | 20.2731 |
| 357 | 2.80112 | 127449 | 45499293 | 18.8944 | 412 | 2.42718 | 169744 | 69934528 | 20.2978 |
| 358 | 2.79330 | 128164 | 45852712 | 18.9209 | 413 | 2.42131 | 170569 | 70444997 | 20.3224 |
| 359 | $2.7855^{2}$ | 128881 | 46268279 | 18.9473 | 414 | 2.41546 | 171396 | 70957944 | 20.3470 |
| 360 | 2.77778 | 129600 | 46656000 | 18.9737 | 415 | 2.40964 | 172225 | 71473375 | 20.3715 |
| 361 | 2.77008 | 130321 | 4704588 I $^{\circ}$ | 19.0000 | 416 | 2.40385 | 173056 | 71991296 | 20.3961 |
| 362 | 2.76243 | 131044 | 47437928 | 19.0263 | 417 | 2.39808 | 173889 | 72511713 | 20.4206 |
| 363 | 2.75482 | 131769 | 47832147 | 19.0526 | 418 | 2.39234 | 174724 | 73034632 | 20.4450 |
| 364 | 2.74725 | 132496 | 48228544 | 19.0788 | 419 | 2.38663 | 175561 | 73560059 | 20.4695 |
| 365 | 2.73973 | 133225 | 48627125 | 19.1050 | 420 | 2.38095 | 176400 | 74088000 | 20.4939 |
| 366 | 2.73224 | 1 33956 | 49027896 | 19.1311 | 42 I | 2.37530 | 177241 | 74618461 | 20.5183 |
| 367 | 2.72480 | 134689 | 49430863 | 19.1572 | 422 | 2.36967 | 178084 | 75151448 | 20.5426 |
| 368 | 2.71739 | ${ }^{1} 35424$ | 49836032 | 19.1833 | 423 | 2.36407 | 178929 | 75686967 | 20.5670 |
| 369 | 2.71003 | 136161 | 50243409 | 19.2094 | 42.4 | 2.35849 | 179776 | 76225024 | 20.5913 |
| 370 | 2.70270 | I 36900 | 50653000 | 19.2354 | 425 | 2.35294 | 180625 | 76765625 |  |
| 371 | 2.69542 | 137641 | 51064811 | 19.2614 | 426 | 2.34742 | 181476 | 77308776 | 20.6398 |
| 372 | 2.68817 | 138384 | 51478848 | 19.2873 | 427 | 2.34192 | 182329 | 77854483 | 20.6640 |
| 373 | 2.68097 | 139129 | 51895117 | 19.3132 | 428 | 2.33645 | 183184 | 78402752 | 20.6882 |
| 374 | 2.67380 | I 39876 | 52313624 | 19.3391 | 429 | 2.33100 | 184041 | 78953589 | 20.7123 |
| 375 | 2.66667 | 140625 | 52734375 | 19.3649 | 430 | 2.32558 | 184900 | 79507000 |  |
| 376 | 2.65957 | 141376 | 53157376 | 19.3907 | 431 | 2.32019 | 185761 | 80062991 | $20.7605$ |
| 377 | 2.65252 | 142129 | 53582633 | 19.4165 | 432 | 2.3148 r | 186624 | 80621568 | $20.7846$ |
| 378 | 2.64550 | 142884 | 54010152 | 19.4422 | 433 | 2.30947 | 187489 | 81182737 81746504 | 20.8087 20.8327 |
| 379 | 2.63852 | 143641 | 54439939 | 19.4679 | 434 | 2.30415 | 188356 | 81746504 | 20.8327 |
| 380 | 2.63158 | 144400 | 54872000 | 19.4936 19.5192 | 435 |  | 189225 190096 |  | $20.8567$ $20.8806$ |
| 381 | 2.62467 | 145161 | 55306341 | 19.5192 | 436 | 2.29358 | 190096 | 82881856 83453453 | 20.8806 20.9045 |
| 382 | 2.61780 | 145924 | 55742968 | 19.5448 | 437 | 2.28833 | 190969 | 83453453 84027672 | 20.9045 20.9284 |
| 383 | 2.61097 | 146689 | 56181887 | 19.5704 | 438 | 2.28311 | 191844 | 84027672 84604519 | 20.9284 20.9523 |
| 384 | 2.60417 | 147456 | 56623104 | 19.5959 | 439 | 2.27790 | 192721 | 84604519 | 20.9523 |
| 385 | 2.59740 | 148225 | 57066625 | 19.6214 | 440 | 2.27273 | 193600 | $85184000$ | 20.9762 |
| 386 | 2.59067 | 148996 | 57512456 | 19.6469 | 441 | 2.26757 | 194481 | 85766121 | 21.0000 |
| 387 | 2.58398 | 149769 | 57960603 | 19.6723 | 442 | 2.26244 | 195364 | 86350888 86938307 | $21.0238$ |
| 388 | 2.57732 | 150544 | 58411072 | 19.6977 | 443 | 2.25734 | 196249 | 86938307 8752834 | 21.0476 21.0713 |
| 389 | 2.57069 | 151321 | 58863869 | 19.7231 | 444 | 2.25225 | 197136 | 87528384 | 21.0713 |
| 390 | 2.56410 | 152100 | 59319000 | 19.7484 | 445 | 2.24719 | 198025 | 88121125 | 21.0950 |
| 391 | 2.55754 | I 5288I | 59776471 | 19.7737 | 446 | 2.24215 | 198916 | 88716536 | 21.1187 |
| 392 | 2.55102 | ${ }^{1} 53664$ | 60236288 | 19.7990 | 447 | 2.23714 | 199809 | 89314623 | 21.1424 |
| 393 | 2.54453 | I 54449 | 60698457 | 19.8242 | 448 | 2.23214 | 200704 | 89915392 90518849 | 21.1660 21.1896 |
| 394 | 2.53807 | 155236 | 61162984 | 19.8494 | 449 | 2.22717 | 201601 | 90518849 | 21.1896 |

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS
OF NATURAL NUMBERS.

| $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } n$ | $n$ | $1000 . \frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\checkmark n$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 450 | 2.22222 | 202500 | 91125000 | 21.2132 | 505 | 1.98020 | 255025 | 128787625 | 22.4722 |
| 451 | 2.21729 | 203401 | 91733851 | 21.2368 | 506 | 1. 97628 | 256036 | 129554216 | 22.4944 |
| 452 | 2.21239 | 204304 | 92345408 | 21.2603 | 507 | 1.97239 | 257049 | 130323843 | 22.5167 |
| 453 | 2.20751 | 205209 | 92959677 | 21.2838 | 508 | 1.96850 | 258064 | 131096512 | 22.5389 |
| 454 | 2.20264 | 206116 | 93576664 | 21.3073 | 509 | 1.96464 | 259081 | 131872229 | 22.5610 |
| 455 | 2.19780 | 207025 | 94196375 | 21.3307 | 510 | 1.96078 | 260100 | 132651000 | 22.5832 |
| 456 | 2.19298 | 207936 | 94818816 | 21.3542 | 511 | I. 95695 | 261121 | 133432831 | 22.6053 |
| 457 | 2.18818 | 208849 | 95443993 | 21.3776 | 512 | 1.95312 | 262144 | 134217728 | 22.6274 |
| 458 | 2.18341 | 209764 | 96071912 | 21.4009 | 513 | 1.94932 | 263169 | I 35005697 | 22.6495 |
| 459 | 2.17865 | 21068I | 96702579 | 21.4243 | 514 | 1.94553 | 264196 | I 35796744 | 22.6716 |
| 460 | 2.17391 | 211600 | 97336000 | 21.4476 | 515 | 1.94175 | 265225 | 1 36590875 | 22.6936 |
| 461 | 2.16920 | 212521 | 97972181 | 21.4709 | 516 | 1.93798 | 266256 | 137388096 | 22.7156 |
| 462 | 2.16450 | 213444 | 98611128 | 21.4942 | 517 | 1.93424 | 267289 | 138188413 | 22.7376 |
| 463 | 2.15983 | 214369 | 99252847 | 21.5174 | 518 | 1.93050 | 268324 | 138991832 | 22.7596 |
| 464 | 2.15517 | 215296 | 99897344 | 21.5407 | 519 | I. 92678 | 269361 | I 39798359 | 22.7816 |
| 465 | 2.15054 | 216225 | 100544625 | 21.5639 | 520 | 1. 92308 | 270400 | 140608000 | 22.8035 |
| 466 | 2.14592 | 217156 | 101194696 | 21.5870 | 521 | I.91939 | 271441 | 141420761 | 22.8254 |
| 467 | 2.14133 | 218089 | 101847563 | 21.6102 | 522 | 1.9157 I | 272484 | 142236648 | 22.8473 |
| 468 | 2.13675 | 219024 | 102503232 | 21.6333 | 523 | I.91205 | 273529 | 143055667 | 22.8692 |
| 469 | 2.13220 | 219961 | 103161709 | 21.6564 | 524 | 1.90840 | 274576 | 143877824 | 22.8910 |
| 470 | 2.12766 | 220900 | 103823000 | 21.6795 | 525 | 1.90476 | 275625 | 144703125 | 22.9129 |
| 47 I | 2.12314 | 221841 | 104487111 | 21.7025 | 526 | 1.90114 | 276676 | 145531576 | 22.9347 |
| 472 | 2.11864 | 222784 | 105154048 | 21.7256 | 527 | I. 89753 | 277729 | 146363183 | 22.9565 |
| 473 | 2.11416 | 223729 | 105823817 | 21.7486 | 528 | I. 89394 | 278784 | 147197952 | 22.9783 |
| 474 | 2.10970 | 224676 | 106496424 | 21.7715 | 529 | 1.89036 | 279841 | 148035889 | 23.0000 |
| 475 | 2.10526 | 225625 | 107171875 | 21.7945 | 530 | 1.88679 | 280900 | 148877000 | 23.0217 |
| 476 | 2.10084 | 226576 | 107850176 | 21.8174 | 531 | 1.88324 | 281961 | 149721291 | 23.0434 |
| 477 | 2.09644 | 227529 | 108531333 | 21.8403 | 532 | 1.87970 | 283024 | I 50568768 | 23.0651 |
| 478 | 2.09205 | 228484 | 109215352 | 21.8632 | 533 | 1. 87617 | 284089 | 151419437 | 23.0868 |
| 479 | 2.08768 | 229441 | 109902239 | 21.8861 | 534 | 1.87266 | 285156 | 152273304 | 23.1084 |
| 480 | 2.08333 | 230400 | 110592000 | 21.9089 | 535 | 1.86916 | 286225 | ${ }^{1} 53130375$ | 23.1301 |
| 481 | 2.07900 | 231361 | III284641 | 21.9317 | 536 | 1. 86567 | 287296 | I 53990656 | 23.1517 |
| 482 | 2.07469 | 232324 | 111980168 | 21.9545 | 537 | 1.86220 | 288369 | 154854153 | 23.1733 |
| 483 | 2.07039 | 233289 | I 1 2678587 | 21.9773 | 538 | 1. 85874 | 289444 | 155720872 | 23.1948 |
| 484 | 2.06612 | 234256 | 113379904 | 22.0000 | 539 | $1.855^{29}$ | 290521 | I 56590819 | 23.2164 |
| 485 | 2.06186 | 235225 | 114084125 | 22.0227 | 540 | 1.85185 | 291600 | I 57464000 | 23.2379 |
| 486 | 2.05761 | 236196 | $11479125^{6}$ | 22.0454 | 541 | 1. 84843 | 292681 | 15834042 I | 23.2594 |
| 487 | 2.05339 | 237169 | 115501303 | 22.0681 | 542 | 1.84502 | 293764 | 159220088 | 23.2809 |
| 488 | 2.04918 | 238144 | 116214272 | 22.0907 | 543 | 1.84162 | 294849 | 160103007 | 23.3024 |
| 489 | 2.04499 | 239121 | 116930169 | 22.1133 | 544 | 1. 83824 | 295936 | 160989184 | 23.3238 |
| 490 | 2.04082 | 240100 | 117649000 | 22.1359 | 545 | 1. 83486 | 297025 | 161878625 | 23.3452 |
| 491 | 2.03666 | 241081 | 118370771 | 22.1585 | 546 | 1.83150 | 298116 | 162771336 | 23.3666 |
| 492 | 2.03252 | 242064 | 119095488 | 22.1811 | 547 | 1.82815 | 299209 | 163667323 | 23.3880 |
| 493 | 2.02840 | 243049 | 119823157 | 22.2036 | 548 | 1. 82482 | 300304 | 164566592 | 23.4094 |
| 494 | 2.02429 | 244036 | 120553784 | 22.2261 | 549 | 1.82149 | 301401 | 165469149 | 23.4307 |
| 495 | 2.02020 | 245025 | 121287375 | 22.2486 | 550 | 1.8ı8ı8 | 302500 | 166375000 | 23.452 I |
| 496 | 2.01613 | 246016 | 122023936 | 22.2711 | 551 | I. 81488 | 303601 | 167284151 | 23.4734 |
| 497 | 2.01207 | 247009 | 122763473 | 22.2935 | 552 | ı. SII 59 | 304704 | 168196608 | 23.4947 |
| 498 | 2.00803 | 248004 | 123505992 | 22.3159 | 553 | 1.80832 | 305809 | 169142377 | 23.5160 |
| 499 | 2.00401 | 249001 | 124251499 | 22.3383 | 554 | 1.80505 | 306916 | 170031464 | 23.5372 |
| 500 | 2.00000 | 250000 | 125000000 | 22.3607 | 555 | 1.80180 | 308025 | 170953875 | 23.5584 |
| 501 | 1.99601 | 251001 | 125751501 | 22.3830 | 556 | 1. 79856 | 309136 | 171879616 | 23.5797 |
| 502 | 1.99203 | 252004 | 126506008 | 22.4054 | 557 | 1.79533 | 310249 | 172808693 | 23.6008 |
| 503 | 1.98807 | 253009 | 127263527 | 22.4277 | 558 | 1.79211 | 311364 | 173741112 | $23.6220$ |
| 504 | r.98413 | 254016 | 128024064 | 22.4499 | 559 | 1.78891 | 31248r | 174676879 | 23.6432 |

## Smithsonian Tables.

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

| $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } 1$ | $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ } \times$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 560 | 1.78571 | 313600 | 175616000 | 23.6643 | 615 | 1.62602 | 378225 | 232608375 | 24.7992 |
| 561 | 1.78253 | 314721 | 176558481 | 23.6854 | 616 | 1.62338 | 379456 | 233744896 | 24.8193 |
| 562 | 1.77936 | 315844 | 177504328 | 23.7065 | 617 | 1.62075 | 380689 | 234885113 | 24.8395 |
| 563 | 1.77620 | 316969 | 178453547 | 23.7276 | 618 | 1.61812 | $3^{81924}$ | 236029032 | 24.8596 |
| 564 | 1.77305 | 318096 | 179406144 | 23.7487 | 619 | $1.6155^{1}$ | 383161 | 237176659 | 24.8797 |
| 565 | 1.76991 | 319225 | 180362125 | 23.7697 | 620 | 1.61290 | 384400 | 238328000 | 24.8998 |
| 566 | 1.76678 | 320356 | 181321496 | 23.7908 | 621 | 1.61031 | $3^{8} 5641$ | 239483061 | 24.9199 |
| 507 | 1.76367 | 321489 | 182284263 | 23.8118 | 622 | 1.60772 | 386884 | 240641848 | 24.9399 |
| 568 | 1.76056 | 322624 | 153250432 | 23.8328 | 623 | 1.60514 | 388129 | 241804367 | 24.9600 |
| 569 | 1.75747 | 323761 | 184220009 | 23.8537 | 624 | 1.60256 | 389376 | 242970624 | 24.9800 |
| 570 | 1.75439 | 324900 | 185193000 | 23.8747 | 625 | 1.60000 | 390625 | 244140625 | 25.0000 |
| 57 I | 1.75131 | 326041 | 186169411 | 23.8956 | 626 | 1. 59744 | 391876 | 245314376 | 25.0200 |
| 572 | 1.74825 | 327184 | 187149248 | 23.9165 | 627 | 1.59490 | 393129 | 246491883 | 25.0400 |
| 573 | 1.74520 | 328329 | 188132517 | 23.9374 | 628 | 1.59236 | 394384 | 247673152 | 25.0599 |
| 574 | 1.74216 | 329476 | 189119224 | 23.9583 | 629 | 1.58983 | 395641 | 248858189 | 25.0799 |
| 575 | 1.73913 | 330625 | 190109375 | 23.9792 | 630 | 1.58730 | 396900 | 250047000 | 25.0998 |
| 576 | 1.73611 | 331776 | 191102976 | 24.0000 | 631 | 1.58479 | 398161 | 251239591 | 25.1197 |
| 577 | 1.73310 | 332929 | 192100033 | 24.0208 | 632 | 1.58228 | 399424 | 252435968 | 25.1396 |
| 578 | 1.73010 | 334084 | 193100552 | 24.0416 | 633 | 1.57978 | 400689 | 253636137 | 25.1595 |
| 579 | 1.72712 | 335241 | 194104539 | 24.0624 | 634 | 1. 57729 | 401956 | 254840104 | 25.1794 |
| 580 | 1.72414 | 336400 | 195112000 | 24.0832 | 635 | 1.57480 | 403225 | 256047875 | 25.1992 |
| 581 | 1.72117 | 337561 | 196122941 | 24.1039 | 636 | 1.57233 | 404496 | 257259456 | 25.2190 |
| 582 | 1.71821 | 33 S724 | 197137368 | 24.1247 | 637 | 1. 56986 | 405769 | 258474853 | 25.2389 |
| 583 | 1.71527 | 3398S9 | 198155287 | 24.1454 | 638 | 1.56740 | 407044 | 259694072 | 25.2587 |
| 584 | 1.71233 | 341056 | 199176704 | 24.166I | 639 | I. 56495 | 408321 | 260917119 | 25.2784 |
| 585 | 1.70940 | 342225 | 200201625 | 24.1868 | 640 | I. 56250 | 409600 | 262144000 | 25.2982 |
| 586 | 1.70648 | 343396 | 201230056 | 24.2074 | 641 | 1.56006 | 410881 | 263374721 | 25.3180 |
| 587 | 1.70358 | 344569 | 202262003 | 24.2281 | 642 | 1.55763 | 412164 | 264609288 | 25.3377 |
| 588 | 1.70068 | 345744 | 203297472 | 24.2487 | 643 | 1.5552 I | 413449 | 265847707 | 25.3574 |
| 589 | 1.69779 | 346921 | 204336469 | 24.2693 | 644 | 1.55280 | 414736 | 267089984 | $25.377^{2}$ |
| 590 | 1. 69492 | 348100 | 205379000 | 24.2899 | 645 | 1. 55039 | 416025 | 268336125 | 25.3969 |
| 591 | 1.69205 | 349281 | 206425071 | 24.3105 | 646 | I. 54799 | 417316 | 269586136 | 25.4165 |
| 592 | 1.68919 | 350464 | 207474688 | 24.3311 | 647 | 1. 54560 | 418609 | 270840023 | 25.4362 |
| 593 | 1. 68634 | 351649 | 208527857 | 24.3516 | 648 | 1.54321 | 419904 | 272097792 | 25.4558 |
| 594 | 1.68350 | 352836 | 209584584 | 24.3721 | 649 | 1.54083 | 421201 | 273359449 | 25.4755 |
| 595 | 1. 68067 | 354025 | 210644875 | 24.3926 | 650 | I. 53846 | 422500 | 274625000 | 25.4951 |
| 596 | 1. 67785 | 355216 | 211708736 | 24.4 I 31 | 651 | 1.53610 | 423801 | 275894451 | 25.5147 |
| 597 | 1.67504 | 356409 | 212776173 | 24.4336 | 652 | 1. 53374 | 425104 | 277167808 | 25.5343 |
| 598 | 1.67224 | 357604 | 213847192 | 24.4540 | 653 | 1.53139 | 426409 | 278445077 | 25.5539 |
| 599 | 1.66945 | 358801 | 214921799 | 24.4745 | 654 | 1.52905 | 427716 | 279726264 | 25.5734 |
| 600 | 1. 66667 | 360000 | 216000000 | 24.4949 | 655 | 1. 52672 | 429025 | 281011375 | 25.5930 |
| 601 | 1.66389 | 361201 | 217081801 | 24.5153 | 656 | I. 52439 | 430336 | 282300416 | 25.6125 |
| 602 | 1.66113 | 362404 | 218167208 | 24.5357 | 657 | 1.52207 | 431649 | 283593393 | 25.6320 |
| 603 | 1. 65837 | 363609 | 219256227 | 24.5561 | 658 | 1.51976 | 432964 | 284890312 | 25.6515 |
| 604 | 1. 65563 | 364816 | 220348864 | 24.5764 | 659 | 1.51745 | 43428 I | 286191179 | 25.6710 |
| 605 | 1. 65289 | 366025 | 221445125 | 24.5967 | 660 | I. 51515 | 435600 | 287496000 | 25.6905 |
| 606 | 1. 65017 | 367236 | 222545016 | 24.6171 | 661 | 1.51286 | 436921 | 288804781 | 25.7099 |
| 607 | I. 64745 | 368449 | 223648543 | 24.6374 | 662 | 1. 51057 | 438244 | 290117528 | 25.7294 |
| 608 | 1.64474 | 369664 | 224755712 | 24.6577 | 663 | 1.50830 | 439569 | 291434247 | 25.7488 |
| 609 | 1.64204 | 370881 | 225866529 | 24.6779 | 664 | 1.50602 | 440896 | 292754944 | 25.7682 |
| 610 | 1.63934 | 372100 | 226981000 | 24.6982 | 665 | 1. 50376 | 442225 | 294079625 | 25.7876 |
| 611 | 1. 63666 | 37332 I | 228099131 | 24.7184 | 666 | 1. 50150 | 443556 | 295408296 | 25.8070 |
| 612 | 1.63399 | 374544 | 229220928 | 24.7386 | 667 | I. 49925 | 444889 | 296740963 | 25.8263 |
| 613 | 1.63132 | 375769 | 230346397 | 24.7588 | 668 | 1.49701 | 446224 | 298077632 | 25.8457 |
| 614 | 1.62866 | 376996 | 231475544 | 24.7790 | 669 | 1.49477 | 447561 | 299418309 | 25.8650 |

VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

| $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\downarrow n$ | $n$ | 1000. $\frac{1}{n}$ | $n^{2}$ | $n^{3}$ | $\checkmark n$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 670 | I. 49254 | 448900 | 300763000 | 25.8844 | 725 | I.3793I | 525625 | 381078125 | 26.9258 |
| 671 | 1.49031 | 450241 | 302111711 | 25.9037 | 726 | 1.37741 | 527076 | 382657176 | 26.9444 |
| 672 | 1.48810 | 451584 | 303464448 | 25.9230 | 727 | 1. 37552 | 52 S 529 | 384240583 | 26.9629 |
| 673 | I. 48588 | 452929 | 304821217 | 25.9422 | 728 | 1.37363 | 529984 | 385828352 | 26.9815 |
| 674 | 1. 48368 | 454276 | 306182024 | 25.9615 | 729 | 1. 37174 | 53144 I | 387420489 | 27.0000 |
| 675 | I. 48148 | 455625 | 307546875 | 25.9808 | 730 | 1.36986 | 532900 | 389017000 | 27.0185 |
| 676 | 1.47929 | 456976 | 308915776 | 26.0000 | 731 | I. 36799 | 534361 | 390617891 | 27.0370 |
| 677 | 1.47710 | 458329 | 310288733 | 26.0192 | 732 | 1.36612 | 535824 | 392223168 | 27.0555 |
| 678 | 1.47493 | 459684 | 311665752 | 26.0384 | 733 | 1. 36426 | 537289 | 393832837 | 27.0740 |
| 679 | 1.47275 | 461041 | 313046839 | 26.0576 | 734 | 1. 36240 | 538756 | 395446904 | 27.0924 |
| 680 | I. 47059 | 462400 | 314432000 | 26.0768 | 735 | 1.36054 | 540225 | 397065375 | 27.1 109 |
| 681 | 1.46843 | 463761 | 315821241 | 26.0960 | 736 | 1.35870 | 541696 | 398688256 | 27.1293 |
| 682 | 1. 46628 | 465124 | 317214568 | 26.1151 | 737 | 1.35685 | 543169 | 400315553 | 27.1477 |
| 683 | I. 46413 | 466489 | 318611987 | 26.1343 | 738 | 1.3550I | 544644 | 401947272 | 27.1662 |
| 684 | I.46199 | 467856 | 320013504 | 26.1534 | 739 | 1.35318 | 546121 | 403583419 | 27.1846 |
| 685 | 1.45985 | 469225 | 321419125 | 26.1725 | 740 | I. 35135 | 547600 | 405224000 | 27.2029 |
| 686 | 1.45773 | 470596 | 322828856 | 26.1916 | 741 | 1. 34953 | 549081 | 406869021 | 27.2213 |
| 687 | I. 45560 | 471969 | 324242703 | 26.2107 | 742 | 1.34771 | 550564 | 408518488 | 27.2397 |
| 688 | I. 45349 | 473344 | 325660672 | 26.2298 | 743 | 1. 34590 | 552049 | 410172407 | 27.2580 |
| 689 | 1.45138 | 474721 | 327082769 | 26.2488 | 744 | 1. 34409 | 553536 | 411830784 | 27.2764 |
| 690 | I. 44928 | 476100 | 328509000 | 26.2679 | 745 | I. 34228 | 555025 | 413493625 | 27.2947 |
| 691 | 1.44718 | 477481 | 329939371 | 26.2869 | 746 | 1. 34048 | 556516 | 415160936 | 27.3130 |
| 692 | 1. 44509 | 478864 | 331373888 | 26.3059 | 747 | 1.33869 | 558009 | 416832723 | 27.3313 |
| 693 | 1.44300 | 480249 | 332812557 | 26.3249 | 748 | 1.33690 | 559504 | 418508992 | $27 \cdot 3496$ |
| 694 | 1.44092 | 481636 | 334255384 | 26.3439 | 749 | 1.3351I | 561001 | 420189749 | 27.3679 |
| 695 | 1. 43885 | 483025 | 335702375 | 26.3629 | 750 | 1. 33333 | 562500 | 421875000 | 27.3861 |
| 696 | 1. 43678 | 484416 | 337153536 | 26.3818 | 751 | -. 33156 | 564001 | 423564751 | 27.4044 |
| 697 | 1. 43472 | 485809 | 338608873 | 26.4008 | 752 | 1. 32979 | 565504 | 425259008 | 27.4226 |
| 698 | 1. 43266 | 487204 | 340368392 | 26.4197 | 753 | 1. 32802 | 567009 | 426957777 | 27.4408 |
| 699 | 1.43062 | 488601 | 341532099 | 26.4386 | 754 | I. 32626 | 568516 | 428661064 | 27.4591 |
| 700 | I. 42857 | 490000 | 343000000 | 26.4575 | 755 | 1. 32450 | 570025 | 430368875 | 27.4773 |
| 701 | I. 42653 | 491401 | 344472101 | 26.4764 | 756 | I. 32275 | 571536 | 432081216 | 27.4955 |
| 702 | 1.42450 | 492804 | $3459+8408$ | 26.4953 | 757 | 1. 32100 | 573049 | 433798093 | 27.5136 |
| 703 | I. 42248 | 494209 | 347428927 | 26.5141 | 758 | 1.31926 | 574564 | 435519512 | 27.5318 |
| 704 | I. 42045 | 495616 | 348913664 | 26.5330 | 759 | 1.31752 | 57608 I | 437245479 | 27.5500 |
| 705 | I. 41844 | 497025 | 350402625 | 26.5518 | 760 | 1.31579 | 577600 | 438976000 | 27.5681 |
| 706 | 1.41643 | 498436 | 351895816 | 26.5707 | 761 | 1.31406 | 579121 | 440711081 | 27.5862 |
| 707 | I. 41443 | 499849 | 353393243 | 26.5895 | 762 | 1.31234 | 580644 | 442450728 | 27.6043 |
| 708 | I. 41243 | 501264 | 354894912 | 26.6083 | 763 | 1.31062 | 582169 | 444194947 | 27.6225 |
| 709 | I. 41044 | 502681 | 356400829 | 26.6271 | 764 | 1.30890 | 583696 | 445943744 | 27.6405. |
| 710 | I. 40845 | 504100 | 357911000 | 26.6458 | 765 | 1.30719 | 585225 | 447697125 | 27.6586 |
| 711 | I. 40647 | 50552 I | 359425431 | 26.6646 | 766 | 1.30548 | 586756 | 449455096 | 27.6767 |
| 712 | 1.40449 | 506944 | 360944128 | 26.6833 | 767 | 1.30378 | 588289 | 451217663 | 27.6948 |
| 713 | I. 40252 | 508369 | 362467097 | 26.7021 | 768 | I. 30208 | 589824 | 452984832 | 27.7128 |
| 714 | 1.40056 | 509796 | 363994344 | 26.7208 | 769 | 1.30039 | 591361 | 454756609 | 27.7308 |
| 715 | I. 39860 | 511225 | 365525875 | 26.7395 | 770 | 1. 29870 | 592900 | 456533000 | 27.7489 |
| 716 | I. 39665 | 512656 | 367061696 | 26.7582 | 771 | 1.29702 | 594441 | 458314011 | 27.7669 |
| 717 | 1. 39470 | 514089 | 368601813 | 26.7769 | 772 | I. 29534 | 595984 | 460099648 | 27.7849 |
| 718 | I. 39276 | 515524 | 370146232 | 26.7955 | 773 | I. 29366 | 597529 | 461889917 | 27.8029 |
| 719 | 1.39082 | 516961 | 371694959 | 26.8142 | 774 | 1.29199 | 599076 | 463684824 | 27.8209 |
| 720 | 1.38889 | 518400 | 373248000 | 26.8328 | 775 | 1.29032 | 600625 | 465484375 | 27.8388 |
| 721 | 1. 38696 | 519841 | 374805361 | 26.8514 | 776 | I. 28866 | 602176 | 467288576 | 27.8568 |
| 722 | 1.38504 | 521284 | 376367048 | 26.8701 | 777 | I. 28700 | 603729 | 469097433 | 27.8747 |
| 723 | I. 383 I 3 r .38 I 22 | 522729 524176 | 377933067 379503424 | 26.8887 | 778 | I. 28535 | 605284 | 470910952 | 27.8927 |
| 724 | 1.38122 | 524176 | 379503424 | 26.9072 | 779 | 1.28370 | 606841 | 472729139 | 27.9106 |

Smithsonian Tables.

TABLE 9 (continued).

## VALUES OF RECIPROCALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

| $n$ | 1000. ${ }^{1}$ | $n^{2}$ | $n^{3}$ | $\sqrt{ }{ }^{\prime}$ | $n$ | 1000. ${ }_{n}$ | $n^{2}$ | $n^{8}$ | $\sqrt{ } n$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 780 | 1.28205 | 608400 | 474552000 | 27.9285 | 835 | 1.19760 | 697225 | 582182875 | 28.8964 |
| 781 | 1.280 .41 | 609961 | 476379541 | 27.9464 | 836 | 1.19617 | 698896 | 584277056 | 28.9137 |
| 782 | 1.27877 | 611524 | 478211768 | 27.9643 | 837 | I.19474 | 700569 | 586376253 | 28.9310 |
| 783 | 1.27714 | 6130089 | 480048687 | 27.9821 | 838 | 1.19332 | 702244 | 588.450472 | 28.9482 |
| 784 | 1.27551 | 614656 | 481890304 | 28.0000 | 839 | 1.19190 | 703921 | 590589719 | 28.9655 |
| 785 | 1.27389 | 616225 | 483736625 | 28.0179 | 840 | 1.19048 | 705600 | 592704000 | 28.9828 |
| 786 | 1.27226 | 617796 | 485587656 | 28.0357 | 841 | 1.18906 | 707281 | 594823321 | 29.0000 |
| 787 | 1.27065 | 619369 | 457443403 | 28.0535 | 842 | 1.18765 | 708964 | 596947688 | 29.0172 |
| 788 | 1.26904 | 620944 | 489303872 | 28.0713 | 843 | 1.18624 | 710649 | 599077107 | 29.0345 |
| 789 | 1.26743 | 622521 | 491169069 | 28.0891 | 844 | I. 18483 | 712336 | 601211584 | 29.0517 |
| 790 | 1.26582 | 624100 | 493039000 | 28.1069 | 845 | 1.18343 | 714025 | 603351125 | 29.0689 |
| 791 | 1.26422 | 625681 | 494913671 | 28:12.47 | 846 | 1.18203 | 715716 | 605495736 | 29.0861 |
| 792 | 1.26263 | 627264 | 496793088 | 28.1425 | 847 | 1.18064 | 717409 | 607645423 | 29.1033 |
| 793 | 1.26103 | 628849 | 498677257 | 28.1603 | 848 | 1.17925 | 719104 | 609800192 | 29.1204 |
| 794 | I. 25945 | 630436 | 500566184 | 28.1780 | S49 | 1.17786 | 720801 | 6ı1960049 | 29.1376 |
| 795 | 1. 25786 | 632025 | 502459875 | 28.1957 | 850 | I. 17647 | 722500 | 614125000 | 29.1548 |
| 796 | 1.25628 | 633616 | 504358336 | 28.2135 | $8_{51}$ | 1.17509 | 724201 | 616295051 | 29.1719 |
| 797 | 1. 2547 I | 635209 | 506261573 | 28.2312 | 852 | 1.17371 | 725904 | 618470208 | 29.1890 |
| 798 | 1.25313 | 636804 | 508169592 | 28.2489 | 853 | I. 17233 | 727609 | 620650477 | 29.2062 |
| 799 | 1.25156 | 638401 | 510082399 | 28.2666 | 854 | 1.17096 | 729316 | 622835864 | 29.2233 |
| 800 | 1.25000 | 640000 | 512000000 | 28.2843 | 855 | I. 16959 | 731025 | 625026375 | 29.2404 |
| SoI | 1. 24844 | 641601 | 513922401 | 28.3019 | 856 | 1.16822 | 732736 | 627222016 | 29.2575 |
| 802 | 1. 24688 | 643204 | 515849603 | 28.3196 | 857 | I. 16686 | 734449 | 629422793 | 29.2746 |
| 803 | 1.24533 | 644809 | 517781627 | 28.3373 | 858 | 1.16550 | 736164 | 631628712 | 29.2916 |
| 804 | 1. 24378 | 646416 | 519718464 | 28.3549 | 859 | 1.16414 | 73788 I | 633839779 | 29.3087 |
| 805 | 1.24224 | 648025 | 521660125 | 2 S .3725 | 860 | 1.16279 | 739600 | 636056000 | 29.3258 |
| 806 | 1. 24069 | 649636 | 523606616 | 28.3901 | 861 | 1.16144 | 741321 | 638277381 | 29.3428 |
| 807 | 1.23916 | 651249 | 525557943 | 28.4077 | 862 | 1.16009 | 743044 | 640503928 | 29.3598 |
| 808 | 1.23762 | 652864 | 527514112 | 28.4253 | 863 | I.15875 | 744769 | 642735647 | 29.3769 |
| 809 | 1.23609 | 65448 I | 529475129 | 28.4429 | 864 | 1.15741 | 746496 | 644972544 | 29.3939 |
| 810 | 1.23457 | 656100 | 531441000 | 28.4605 | 865 | I. 15607 | 748225 | 647214625 | 29.4109 |
| 811 | 1.23305 | 657721 | 533411731 | 28.4781 | 866 | I.I 5473 | 749956 | 649461896 | 29.4279 |
| 812 | 1.23153 | 659344 | 535387328 | 28.4956 | 867 | I. I 5340 | 751589 | 651714363 | 29.4449 |
| 8 I 3 | 1.23001 | 660969 | 537367797 | 28.5132 | 868 | 1.15207 | 753424 | 653972032 | 29.4618 |
| 814 | I. 22850 | 662596 | 539353144 | 28.5307 | 869 | I.I 5075 | 755161 | 656234909 | 29.4788 |
| 815 | 1. 22699 | 664225 | 541343375 | 28.5482 | 870 | I.I4943 | 756900 | 658503000 | 29.4958 |
| 816 | 1.22549 | 665856 | 543338496 | 28.5657 | 871 | 1.14811 | 758641 | 660776311 | 29.5127 |
| 817 | 1.22399 | 667489 | 545338513 | 28.5832 | 872 | I.14679 | 760384 | 663054848 | 29.5296 |
| 818 | 1. 22249 | 669124 | 547343432 | 28.6007 | 873 | 1.14548 | 762129 | 665338617 | 29.5466 |
| . 819 | 1.22100 | 670761 | 549353259 | 28.6182 | 874 | 1.14416 | 763876 | 667627624 | 29.5635 |
| 820 | 1.21951 | 672400 | 551368000 | 28.6356 | 875 | I. 14286 | 765625 | 669921875 | 29.5804 |
| 821 | 1.21803 | 674041 | 553387661 | 28.6531 | 876 | 1.14155 | 767376 | 672221376 | 29.5973 |
| 822 | 1.21655 | 675684 | 555412248 | 28.6705 | 877 | I.14025 | 769129 | 674526133 | 29.6142 |
| 823 | 1.21507 | 677329 | 557441767 | 28.6880 | 878 | 1.13895 | 770884 | 676836152 | 29.6311 |
| 824 | 1.21359 | 678976 | 559476224 | 28.7054 | 879 | I. 13766 | 772641 | 679151439 | 29.6479 |
| 825 | 1.21212 | 680625 | 561515625 | 28.7228 | 880 | 1.13636 | 774400 | 681472000 | 29.6648 |
| 826 | 1.21065 | 682276 | 563559976 | 28.7402 | 881 | I.13507 | 776161 | 683797841 | 29.6816 |
| 827 | 1. 20919 | 683929 | 565609283 | 28.7576 | 882 | I.13379 | 777924 | 686128968 | 29.6985 |
| 828 | 1.20773 | 685584 | 567663552 | 28.7750 | 883 | 1.13250 | 779689 | 688465387 | 29.7153 |
| 829 | 1.20627 | 687241 | 569722789 | 28.7924 | 884 | 1.13122 | 781456 | 690807104 | 29.7321 |
| 830 | I. 20482 | 688900 | 571787000 | 28.8097 | 885 | I.I2994 | 783225 | 693154125 | 29.7489 |
| 831 | 1.20337 | 69056 I | 573856191 | 28.8271 | 886 | 1.12867 | 784996 | 695506456 | 29.7658 |
| 832 | I. 20192 | 692224 | 575930368 | 28.8444 | 887 | 1.12740 | 786769 | 697864103 | 29.7825 |
| 833 834 | I. 20048 | 693889 | 578009537 | 28.8617 | 888 | 1.12613 | 788544 | 700227072 | 29.7993 |
| 834 | 1.19904 | 695556 | 580093704 | 28.8791 | 889 | I.12486 | 790321 | 702595369 | 29.8161 |

VALUES OF RECIPROGALS, SQUARES, CUBES, AND SQUARE ROOTS OF NATURAL NUMBERS.

| $n$ | $1000 . \frac{1}{12}$ | $n^{2}$ | $n^{3}$ | $\downarrow n$ | $n$ | 1000. ${ }_{n}$ | $n^{2}$ | $n^{3}$ | $\checkmark n$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 890 | I. 12360 | 792100 | 704969000 | 29.8329 | 945 | 1.05820 | 893025 | 843908625 | 30.7409 |
| 891 | 1.12233 | 793881 | 707347971 | 29.8496 | 946 | I. 05708 | 894916 | 846590536 | 30.757 I |
| 892 | 1.12108 | 795664 | 709732288 | 29.8664 | 947 | I. 05597 | 896809 | 849278123 | 30.7734 |
| 893 | 1.11982 | 797449 | 712121957 | 29.8831 | 948 | I. 05485 | 898704 | 851971392 | 30.7896 |
| 894 | 1.11857 | 799236 | 714516984 | 29.8998 | 949 | I. 05374 | 900601 | 854670349 | 30.8058 |
| 895 | 1.11732 | 801025 | 716917375 | 29.9166 | 950 | 1.05263 | 902500 | 857375000 | 30.8221 |
| 896 | 1.11607 | 802816 | 719323136 | 29.9333 | 951 | 1.05152 | 904401 | 860085351 | 30.8383 |
| 897 | 1.11483 | S04609 | 721734273 | 29.9500 | 952 | 1.05042 | 906304 | 862801408 | 30.8545 |
| 898 | I.11359 | 806404 | 724150792 | 29.9666 | 953 | 1. 04932 | 908209 | 865523177 | 30.8707 |
| 899 | I.11235 | 808201 | 726572699 | 29.9833 | 954 | 1.04822 | 910116 | 868250664 | 30.8869 |
| 900 | 1.11111 | 810000 | 729000000 | 30.0000 | 955 | 1.04712 | 912025 | 870983875 | 30.9031 |
| 901 | 1.10988 | 8ıi80ı | 731432701 | 30.0167 | 956 | 1.04603 | 913936 | 873722816 | 30.9192 |
| 902 | 1.10865 | 813604 | 733870808 | 30.0333 | 957 | 1.04493 | 915849 | 876467493 | 30.9354 |
| 903 | 1.10742 | 815409 | 736314327 | 30.0500 | 958 | 1.04384 | 917764 | 879217912 | 30.9516 |
| 904 | 1.10619 | 817216 | 738763264 | 30.0666 | 959 | 1.04275 | 91.968 I | 881974079 | 30.9677 |
| 905 | 1.10497 | 819025 | 741217625 | 30.0832 | 960 | 1.04167 | 921600 | 884736000 | 30.9839 |
| 906 | 1.10375 | 820836 | 743677416 | 30.0998 | 961 | $1.0405^{8}$ | 923521 | 887503681 | 31.0000 |
| 907 | I. 10254 | 822649 | 746142643 | 30.11 64 | 962 | 1.03950 | 925444 | 890277128 | 3 I .0161 |
| 908 | 1.10132 | 824464 | 748613312 | 30.1330 | 963 | 1.03842 | 927369 | 893056347 | 31.0322 |
| 909 | I.100II | 826281 | 751089429 | 30.1496 | 964 | 1.03734 | 929296 | 895841344 | 31.0483 |
| 910 | 1.09890 | -828100 | 753571000 | 30.1662 | 965 | I. 03627 | 931225 | 898632125 | 31.0644 |
| 911 | 1.09769 | 829921 | 756058031 | 30.1828 | 966 | 1.03520 | 933156 | 901428696 | 31.0805 |
| 912 | I. 09649 | 831744 | 758550528 | 30.1993 | 967 | 1.03413 | 935089 | 904231063 | 31.0966 |
| 913 | 1.09529 | 833569 | 761048497 | 30.2159 | 968 | 1.03306 | 937024 | 907039232 | 31.1127 |
| 914 | 1.09409 | 835396 | 763551944 | 30.2324 | 969 | 1.03199 | 938961 | 909853209 | 31.1288 |
| 915 | 1.09290 | 837225 | 766060875 | 30.2490 | 970 | 1.03093 | 940900 | 912673000 | 31.1448 |
| 916 | 1.09170 | 839056 | 768575296 | 30.2655 | 971 | 1.02987 | 942841 | 915498611 | 31.1609 |
| 917 | I. 09051 | 840889 | 771095213 | 30.2820 | 972 | 1.02881 | 944784 | 918330048 | 31.1769 |
| 918 | 1.08932 | 842724 | 773620632 | 30.2985 | 973 | 1.02775 | 946729 | 921167317 | 31.1929 |
| 919 | 1.08814 | 844561 | 776151559 | 30.3150 | 974 | 1.02669 | 948676 | 924010424 | 31.2090 |
| 920 | 1.08696 | 846400 | 778688000 | 30.3315 | 975 | 1.02564 | 950625 | 926859375 | 31.2250 |
| 921 | 1. 08578 | 848241 | 781229961 | 30.3480 | 976 | I. 02459 | 952576 | 929714176 | 31.2410 |
| 922 | 1.08460 | 850084 | 783777448 | 30.3645 | 977 | 1.02354 | 954529 | 932574833 | 31.2570 |
| 923 | 1.08342 | 851929 | 786330467 | 30.3809 | 978 | I.02249 | 956484 | 935441352 | 31.2730 |
| 924 | 1.08225 | 853776 | 788889024 | 30.3974 | 979 | 1.02145 | 958441 | 93 ¢ 3 I 3739 | 31.2890 |
| 925 | 1.08108 | 855625 | 791453125 | 30.4138 | 980 | 1.02041 | 960400 | 941192000 | 31.3050 |
| 926 | 1.07991 | 857476 | 794022776 | 30.4302 | 981 | 1.01937 | 962361 | 944076141 | 31.3209 |
| 927 | 1.07875 | 859329 | 796597983 | 30.4467 | 982 | 1.01833 | 964324 | 946966168 | 31.3369 |
| 928 | 1.07759 | 86II84 | 799178752 | 30.4631 | 983 | 1.01729 | 966289 | 949862087 | 31.3528 |
| 929 | 1.07643 | 863041 | So17650S9 | 30.4795 | 984 | 1.01626 | 968256 | 952763904 | 31.3688 |
| 930 | 1.07527 | 864900 | So4357000 | 30.4959 | 985 | 1.01523 | 970225 | 955671625 | 31.3847 |
| 931 | 1.07411 | 866761 | 806954491 | 30.5123 | 986 | 1.01420 | 972196 | 958585256 | 31.4006 |
| 932 | 1.07296 | 868624 | 809557568 | 30.5287 | 987 | 1.01317 | 974169 | 961504803 | 31.4166 |
| 933 | 1.07181 | 870489 | S12166237 | 30.5450 | 988 | I.OI215 | 976144 | 964430272 | 3 I .4325 |
| 934 | 1.07066 | 872356 | 814780504 | 30.5614 | 989 | 1.OIII2 | 978121 | 967361669 | 31.4484 |
| 935 | 1.06952 | 874225 | 817400375 | 30.5778 | 990 | 1.01010 | 9Soroo | 970299000 | 31.1643 |
| 936 | 1.06838 | 876096 | 820025856 | 30.5941 | 991 | 1.00908 | 9820 I | 973242271 | 31.4802 |
| 937 | 1.06724 | 877969 | 822656953 | 30.6105 | 992 | 1.00806 | 984064 | 976191488 | 31.4960 |
| 938 | 1.06610 | 879844 | 825293672 | 30.6268 | 993 | 1.00705 | 986049 | 979146657 | 31.5119 |
| 939 | 1.06496 | 881721 | 827936019 | 30.6431 | 994 | 1.00604 | 988036 | 982107784 | 31.5278 |
| 940 | 1.06383 | 883600 | 830584000 | 30.6594 | 995 | 1.00503 | 990025 | $985074875$ | 31.5436 |
| 941 | 1.06270 | 885481 | 833237621 | 30.6757 | 996 | 1.00402 | 992016 | 988047936 | 31.5595 |
| 942 | 1.06157 | 887364 | 835896888 | 30.6920 | 997 | I. 00301 | 994009 | 991026973 | 31.5753 |
| 943 | 1.06045 | 889249 | ${ }_{8} 38561807$ | 30.7083 | 998 | 1.00200 | 996004 | 994011992 | 3 I .5911 |
| 944 | 1.05932 | 891136 | 841232384 | 30.7246 | 999 | 1.00100 | 998001 | 997002999 | 31.6070 |

## Smithsonian Tables.

LOGARITHMS.

| $\mathbf{N}$. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 100 | 0000 | 0004 | 0009 | 0013 | 0017 | 0022 | 0026 | 0030 | 0035 | 0039 | 0043 |
| 101 | 0043 | 0048 | 0052 | 0056 | 0060 | 0065 | 0069 | 0073 | 0077 | 0082 | 0086 |
| 102 | 0086 | 0090 | 0095 | 0099 | OIO3 | 0107 | OIII | OII 6 | 0120 | 0124 | 0128 |
| 103 | OI 28 | OI 33 | -137 | O14 1 | OI 45 | OI 49 | O1 54 | OI 58 | 0162 | or66 | 0170 |
| 104 | or 70 | O175 | OI79 | 0183 | 0187 | OI9I | OI95 | Or99 | 0204 | 0208 | 0212 |
| 105 | 0212 | 0216 | 0220 | 0224 | 0228 | 0233 | 0237 | 0241 | 0245 | 0249 | 0253 |
| 106 | 0253 | 0257 | 0261 | 0265 | 0269 | 0273 | 0278 | 0282 | 0286 | 0290 | 0294 |
| 107 | 0294 | 0298 | 0302 | 0306 | 0310 | 0314 | 0318 | 0322 | 0326 | 0330 | 0334 |
| 108 | 0334 | 0338 | 0342 | -346 | -350 | 0354 | -358 | 0362 | 0366 | 0370 | 0374 |
| 109 | 0374 | 0378 | 0382 | -386 | 0390 | 0394 | 0398 | 0402 | 0406 | 0410 | 0414 |
| 110 | 0414 | 0418 | 0422 | 0426 | 0430 | 04.34 | 0438 | 0441 | 0445 | 0449 | 0453 |
| III | 0453 | 0457 | 046I | 0465 | 0469 | 0473 | 0477 | 048I | 0484 | 0488 | 0492 |
| 112 | 0492 | 0496 | 0500 | 0504 | 0508 | 0512 | 0515 | 0519 | 0523 | 0527 | 0531 |
| 113 | 0531 | O535 | 0538 | 0542 | 0546 | 0550 | 0554 | 0558 | 0561 | 0565 | 0569 |
| 114 | 0569 | 0573 | 0577 | 0580 | 0584 | 0588 | 0592 | 0596 | 0599 | 0603 | 0607 |
| 115 | 0607 | 0611 | 06I 5 | 0618 | 0622 | 0626 | 0630 | 0633 | 0637 | 0641 | 0645 |
| 116 | 0645 | 0648 | 0652 | 0656 | 0660 | 0663 | 0667 | 067 I | 0674 | 0678 | 0682 |
| 117 | 0682 | 0686 | 0689 | 0693 | 0697 | 0700 | 0704 | 0708 | 0711 | 0715 | 0719 |
| 118 | 0719 | 0722 | 0726 | 0730 | 0734 | 0737 | 0741 | 0745 | 0748 | 0752 | 0755 |
| 119 | 0755 | 0759 | 0763 | 0766 | 0770 | 0774 | 0777 | 078 I | 0785 | 0788 | 0792 |
| 120 | 0792 | 0795 | 0799 | 0803 | 0806 | 0810 | 0813 | 08i7 | 0821 | 0824 | 0828 |
| 121 | 0828 | 0831 | 0835 | 0839 | 0842 | 0846 | 0849 | 0853 | 0856 | 0860 | 0864 |
| 122 | 0864 | 0867 | 0871 | 0874 | 0878 | 0881 | -8S 5 | o888 | 0892 | 0896 | 0899 |
| 123 | 0899 | 0903 | 0906 | 0910 | 0913 | 0917 | 0920 | 0924 | 0927 | 0931 | 0934 |
| 124 | 0934 | 0938 | 0941 | 0945 | 0948 | 0952 | 0955 | 0959 | 0962 | 0966 | 0969 |
| 125 | 0969 | 0973 | 0976 | 0980 | 0983 | 0986 | 0990 | 0993 | 0997 | 1000 | 1004 |
| 126 | 1004 | 1007 | 1011 | IOI 4 | 1017 | 1021 | 1024 | 1028 | 1031 | 1035 | 1038 |
| 127 | 1038 | 1041 | 1045 | 1048 | 1052 | 1055 | 1059 | 1062 | 1065 | 1069 | 1072 |
| 128 | 1072 | 1075 | 1079 | 1082 | 1086 | 1089 | 1092 | 1096 | 1099 | 1103 | 1106 |
| 129 | 1106 | 1109 | III3 | I I 16 | 1119 | 1123 | 1126 | I 129 | 1133 | 1136 | 1139 |
| 130 | 1139 | 1143 | II 46 | I 149 | 1153 | 1156 | II 59 | 1163 | 1166 | 1169 | 1173 |
| ${ }^{1} 31$ | 1173 | 1176 | 1179 | 1183 | 1186 | 1189 | I 193 | 1196 | 1199 | 1202 | 1206 |
| 132 | 1206 | 1209 | 1212 | 1216 | 1219 | 1222 | 1225 | 1229 | 1232 | 1235 | 1239 |
| 133 | 1239 | 1242 | 1245 | 1248 | 1252 | 1255 | I 258 | 1261 | 1265 | 1268 | 1271 |
| 134 | 127 I | 1274 | 1278 | 1281 | 1284 | 1287 | 1290 | 1294 | 1297 | 1300 | 1303 |
| 135 | 1303 | 1307 | 1310 | 1313 | 1316 | 1319 | 1323 | 1326 | 1329 | 1332 | 1335 |
| 136 | I 335 | 1339 | 1342 | I 345 | 1348 | 1351 | I 355 | 1358 | 1361 | 1 364 | 1367 |
| 137 | 1367 | 1370 | I 374 | 1377 | 1380 | 1383 | I 386 | I 389 | 1392 | I 396 | 1399 |
| 138 | I 399 | 1402 | 1405 | 1408 | 1411 | 1414 | 1418 | 142 I | 1424 | 1427 | 1430 |
| 139 | 1430 | 1433 | 1436 | 1440 | 1443 | 1446 | $1449{ }^{-}$ | 1452 | 1455 | 1458 | 1461 |
| 140 | 1461 | 1464 | 1467 | 1471 | 1474 | 1477 | 1480 | 1483 | 1486 | 1489 | 1492 |
| 141 | 1492 | 1495 | 1498 | 1501 | 1504. | 1508 | 1511 | 1514 | 1517 | 1520 | 1523 |
| 142 | I 523 | 1526 | 1529 | 1532 | 1535 | 1538 | 1541 | I 544 | 1547 | I 550 | I 553 |
| 143 | 1553 | I 556 | I 559 | 1562 | 1565 | 1569 | 1572 | 1575 | I 578 | I 581 | I 584 |
| 144 | 1584 | 1587 | 1590 | I 593 | 1596 | I 599 | 1602 | 1605 | 1608 | 1611 | 1614 |
| 145 | 1614 | 1617 | 1620 | 1623 | 1626 | 1629 | 1632 | 1635 | 1638 | 1641 | 1644 |
| 146 | 1644 | 1647 | 1649 | 1652 | 1655 | 1658 | 1661 | 1664 | 1667 | 1670 | 1673 |
| 147 | 1673 | 1676 | 1679 | 1682 | 1685 | 1688 | 1691 | 1694 | 1697 | 1700 | 1703 |
| 148 | 1703 | 1706 | 1708 | 1711 | 1714 | 1717 | 1720 | 1723 | 1726 |  | 1732 |
| 149 | 1732 | 1735 | 1738 | 1741 | 1744 | 1746 | 1749 | 1752 | 1755 | $75^{8}$, | 1761 |

## Smithsonian Tables.

LOGARITHMS.

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 150 | 1761 | 1764 | 1767 | 1770 | 1772 | 1775 | 1778 | 1781 | 1784 | 1787 | 1790 |
| 151 | 1790 | 1793 | 1796 | 1798 | 1801 | 1804 | 1807 | 1810 | 1813 | 1816 | 1818 |
| 152 | 1818 | 182 I | 1824 | 1827 | 1830 | 1833 | 1836 | 1838 | 184 1 | 1844 | 1847 |
| I 53 | 1847. | 1850 | 1853 | 1855 | 1858 | 1861 | 1864 | 1867 | 1870 | 1872 | 1875 |
| I 54 | 1875 | 1878 | 1881 | 1884 | 1886 | 1889 | 1892 | 1895 | 1898 | 1901 | 1903 |
| 155 | 1903 | 1906 | 1909 | 1912 | 1915 | 1917 | 1920 | 1923 | 1926 | 1928 | 1931 |
| 156 | 1931 | 1934 | 1937 | 1940 | 1942 | 1945 | 1948 | 1951 | 1953 | 1956 | 1959 |
| 157 | 1959 | 1962 | 1965 | 1967 | 1970 | 1973 | 1976 | 1978 | 1981 | 1984 | 1987 |
| 158 | 1987 | 1989 | 1992 | 1995 | 1998 | 2000 | 2003 | 2006 | 2009 | 2011 | 2014 |
| 159 | 2014 | 2017 | 2019 | 2.022 | 2025 | 2028 | 2030 | 2033 | 2036 | 2038 | 2041 |
| 160 | 2041 | 2044 | 2047 | 2049 | 2052 | 2055 | 2057 | 2060 | 2063 | 2066 | 2068 |
| 161 | 2068 | 2071 | 2074 | 2076 | 2079 | 2082 | 2084 | 2087 | 2090 | 2092 | 2095 |
| 162 | 2095 | 2098 | 2101 | 2103 | 2106 | 2109 | 2111 | 2114 | 2117 | 2119 | 2122 |
| 163 | 2122 | 2125 | 2127 | 2130 | 2133 | 2135 | 2138 | 2140 | 2143 | 2146 | 2148 |
| 164 | 2148 | 2151 | 2154 | 2156 | 2159 | 2162 | 2164 | 2167 | 2170 | 2172 | 2175 |
| 165 | 2175 | 2177 | 2180 | 2183 | 2185 | 2188 | 2191 | 2193 | 2196 | 2198 | 2201 |
| 166 | 2201 | 2204 | 2206 | 2209 | 2212 | 2214 | 2217 | 2219 | 2222 | 2225 | 2227 |
| 167 | 2227 | 2230 | 2232 | 2235 | 2238 | 2240 | 2243 | 2245 | 2248 | 2251 | 2253 |
| 168 | 2253 | 2256 | 2258 | 2261 | 2263 | 2266 | 2269 | 2271 | 2274 | 2276 | 2279 |
| 169 | 2279 | 2281 | 2284 | 2287 | 2289 | 2292 | 2294 | 2297 | 2299 | 2302 | 2304 |
| 170 | 2304 | 2307 | 2310 | 2312 | 2315 | 2317 | 2320 | 2322 | 2325 | 2327 | 2330 |
| 171 | 2330 | 2333 | 2335 | 2338 | 2340 | 2343 | 2345 | 2348 | 2350 | 2353 | 2355 |
| 172 | 2355 | 2358 | 2360 | 2363 | 2365 | 2368 | 2370 | 2373 | 2375 | 2378 | 2380 |
| 173 | 2380 | 2383 | 2385 | 2388 | 2390 | 2393 | 2395 | 2398 | 2400 | 2403 | 2.405 |
| 174 | 2405 | 2408 | 2410 | 2413 | 2415 | 2418 | 2420 | 2423 | 2425 | 2428 | 2430 |
| 175 | 2430 | 2433 | 2435 | 2438 | 2445 | 2443 | 2445 | 2448 | 2450 | 2453 | 2455 |
| 176 | 2455 | 2458 | 2460 | 2463 | 2465 | 2467 | 2470 | 2472 | 2475 | 2477 | 2480 |
| 177 | 2480 | 2482 | 2485 | 2487 | 2490 | 2492 | 2494 | 2497 | 2499 | 2502 | 2504 |
| 178 | 2504 | 2507 | 2509 | 2512 | 2514 | 2516 | 2519 | 2521 | 2524 | 2526 | 2529 |
| 179 | 2529 | 2531 | 2533 | 2536 | 2538 | 2541 | 2543 | 2545 | 2548 | 2550 | 2553 |
| 180 | 2553 | 2555 | 2558 | 2560 | 2562 | 2565 | 2567 | 2570 | 2572 | 2574 | 2577 |
| 181 | 2577 | 2579 | 2582 | 2584 | 2586 | 2589 | 2591 | 2594 | 2596 | 2598 | 2601 |
| 182 | 2601 | 2603 | 2605 | 2608 | 2610 | 2613 | 2615 | 2617 | 2620 | 2622 | 2625 |
| 183 | 2625 | 2627 | 2629 | 2632 | 2634 | 2636 | 2639 | 2641 | 2643 | 2646 | 2648 |
| 184 | 2648 | 2651 | 2653 | 2655 | 2658 | 2660 | 2662 | 2665 | 2667 | 2669 | 2672 |
| 185 | 2672 | 2674 | 2676 | 2679 | 2681 | 2683 | 2686 | 2688 | 2690 | 2693 | 2695 |
| 186 | 2695 | 2697 | 2700 | 2702 | 2704 | 2707 | 2709 | 2711 | 2714 | 2716 | 2718 |
| 187 | 2718 | 2721 | 2723 | 2725 | 2728 | 2730 | 2732 | 2735 | 2737 | 2739 | 2742 |
| 188 | 2742 | 2744 | 2746 | 2749 | 2751 | 2753 | 2755 | 2758 | 2760 | 2762 | 2765 |
| 189 | 2765 | 2767 | 2769 | 2772 | 2774 | 2776 | 2778 | 2781 | 2783 | 2785 | 2788 |
| 190 | .2788 | 2790 | 2792 | 2794 | 2797 | 2799 | 2801 | 2804 | 2806 | 2808 | 2810 |
| 191 | 2810 | 2813 | 2815 | 2817 | 2819 | 2822 | 2824 | 2826 | 2828 | 2831 | 2833 |
| 192 | 2833 | 2835 | 2838 | 2840 | 2842 | 2844 | 2847 | 2849 | 2851 | 2853 | 2856 |
| 193 | 2856 | 2858 | 2860 | 2862 | 2865 | 2867 | 2869 | 2871 | 2874 | 2876 | 2878 |
| 194 | -2878 | 2880 | 2882 | 2885 | 2887 | 2889 | 2891 | 2894 | 2896 | 2898 | 2900 |
| 195 | 2900 | 2903 | 2905 | 2907 | 2909 | 2911 | 2914 | 2916 | 2918 | 2920 | 2923 |
| 196 | 2923 | 2925 | 2927 | 2929 | 2931 | 2934 | 2936 | 29.38 | 2940 | 2942 | 2945 |
| 197 | 2945 | 2947 | 2949 | 2951 | 2953 | 2956 | 2958 | 2960 | 2962 | 2964 | 2967 |
| 198 | 2967 | 2969 | 2971 | 2973 | 2975 | 2978 | 2980 | 2982 | 2984 | 2986 | 2989 |
| 199 | 2989 | 2991 | 2993 | 2995 | 2997 | 2999 | 3002 | 3004 | 3006 | 3008 | 3010 |

Smithsonian Tables.

Table 11.
LOGARITHMS.

| $\mathbf{N}$ | 0 | 1 | . 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | P. P. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  | 1 | 2 | 3 | 4 | 5 |
| 10 | 0000 | 0043 | 0086 | 0128 | 0170 | 0212 | 0253 | 0294 | 0334 | 0374 | 4 | 8 | 12 | 17 | 21 |
| 11 | 0414 | 0453 | 0492 | 0531 | 0569 | 0607 | 0645 | 0682 | 0719 | 0755 | 4 | 8 | 11 | 15 | 19 |
| 12 | 0792 | 0828 | 0864 | 0899 | 0934 | 0969 | 1004 | 1038 | 1072 | 1106 | 3 | 7 | 10 | 14 | 17 |
| 13 | 1139 | 1173 | 1206 | 1239 | 1271 | 1303 | 1335 | 1367 | 1399 | 1430 | 3 | 6 | 10 | 13 | 16 |
| 14 | 1461 | 1492 | 1523 | 1553 | 1584 | 1614 | 1644 | 1673 | 1703 | 1732 | 3 | 6 | 9 | 12 | 15 |
| 15 | 1761 | 1790 | 1818 | 1847 | 1875 | 1903 | 1931 | 1959 | 1987 | 2014 | 3 | 6 | 8 | II | 14 |
| 16 | 2041 | 2068 | 2095 | 2122 | 2148 | 2175 | 2201 | 2227 | 2253 | 2279 | 3 | 5 | 8 | 11 | 13 |
| 17 | 2304 | 2330 | 2355 | 2380 | 2405 | 2430 | 2455 | 2480 | 2504 | 2529 | 2 | 5 | 7 | 10 | 12 |
| 18 | 2553 2788 | 2577 2810 | 2601 | 2625 2856 | 2648 | 2672 | 2695 | 2718 | 2742 | 2765 | 2 | 5 | 7 | 9 | 12 |
| 19 | 2788 | 2810 | 2833 | 2856 | 2878 | 2900 | 2923 | 2945 | 2967 | 2989 | 2 | 4 | 7 | 9 | II |
| 20 | 3010 | 3032 | 3054 | 3075 | 3096 | 3118 | $3^{1} 39$ | 3160 | 318I | 3201 | 2 | 4 | 6 | 8 | II |
| 21 | 3222 | 3243 | 3263 | 3284 | 3304 | 3324 | 3345 | 3365 | 3385 | 3404 | 2 | 4 | 6 | 8 | 10 |
| 22 | 3424 | 3444 | 3464 | 3483 | 3502 | 3522 | 3541 | 3560 | 3579 | 3598 | 2 | 4 | 6 | 8 | 10 |
| 23 | 3617 | 3636 | 3655 | 3674 | 3692 | 3711 | 3729 | 3747 | 3766 | 3784 | 2 | 4 | 5 | 7 | 9 |
| 24 | 3802 | 3820 | 3838 | 3856 | 3874 | 3892 | 3909 | 3927 | 3945 | 3962 | 2 | 4 | 5 | 7 | 9 |
| 25 | 3979 | 3997 | 4014 | 4031 | 4048 | 4065 | 4082 | 4099 | 4116 | 4133 | 2 | 3 | 5 | 7 | 9 |
| 26 | 4150 | 4166 | 4183 | 4200 | 4216 | 4232 | 4249 | 4265 | 4281 | 4298 | 2 | 3 | 5 | 7 | 8 |
| 27 | 4314 | 4330 | 4346 | 4362 | 4378 | 4393 | 4409 | 4425 | 4440 | 4456 | 2 | 3 | 5 | 6 | 8 |
| 28 | 4472 4624 | 4487 | 4502 | 4518 4669 | 4533 | 4548 | 4564 | 4579 | 4594 | 4609 | 2 | 3 | 5 | 6 | 8 |
| 29 | 4624 | 4639 | 4654 | $4669$ | 4683 | 4698 | 4713 | 4728 | 4742 | 4757 | 1 | 3 | 4 | 6 | 7 |
| 30 | 4771 | 4786 | 4800 | 4814 | 4829 | 4843 | $4 S_{57}$ | 4871 | 4886 | 4900 | I | 3 | 4 | 6 | 7 |
| 31 | 4914 | 4928 | 4942 | 4955 | 4969 | 4983 | 4997 | 5011 | 5024 | 5038 | I | 3 | 4 | 6 | 7 |
| 32 | 5051 | 5065 | 5079 | 5092 | 5105 | 5119 | 5132 | 5145 | 5159 | 5172 | 1 | 3 | 4 | 5 | 7 |
| 33 | 5185 | 5198 | 52 II | 5224 | 5237 | 5250 | 5263 | 5276 | 5289 | 5302 | I | 3 | 4 | 5 | 6 |
| 34 | 5315 | 5328 | 5340 | 5353 | 5366 | 5378 | 5391 | 5403 | 5416 | 5428 | I | 3 | 4 | 5 | 6 |
| 35 | 5441 | 5453 | 5465 | 5478 | 5490 | 5502 | 5514 | 5527 | 5539 | 5551 | I | 2 | 4 | 5 | 6 |
| 36 | 5563 | 5575 | 5587 | 5599 | 5611 | 5623 | 5635 | 5647 | 5658 | 5670 | I | - | 4 | 5 | 6 |
| 37 | 5682 | 5694 | 5705 | 5717 | 5729 | 5740 | 5752 | 5763 | 5775 | 5786 | 1 | 2 | 3 | 5 | 6 |
| 38 | 5798 | 5809 | 5821 | 5832 | 5843 | 5855 | 5866 | 5877 | 5888 | 5899 | 1 | 2 | 3 | 5 | 6 |
| -39 | 59 II | 5922 | 5933 | 5944 | 5955 | 5966 | 5977 | 5988 | 5999 | 6010 | 1 | 2 | 3 | 4 | 6 |
| 40 | 6021 | 6031 | 6042 | 6053 | 6064 | 6075 | 6085 | 6096 | 6107 | 6117 | I | 2 | 3 | 4 | 5 |
| 41 | 6128 | ${ }_{61} 3^{8}$ | 6149 | 6160 | 6170 | 6180 | 6191 | 6201 | 6212 | 6222 | I | 2 | 3 | 4 | 5 |
| 42 | 6232 | 6243 | 6253 | 6263 | 6274 | 6284 | 6294 | 6304 | 6314 | 6325 | I | 2 | 3 | 4 | 5 |
| 43 | 6335 | 6345 | 6355 | 6365 | 6375 | 6385 | 6395 | 6405 | 6415 | 6425 | I | 2 | 3 | 4 | 5 |
| 44 | 6435 | 6444 | 6454 | 6464 | 6474 | 6484 | 6493 | 6503 | 6513 | 6522 | 1 | 2 | 3 | 4 | 5 |
| 45 | 6532 | 6542 | 6551 | 6561 | 6571 | 6580 | 6590 | 6599 | 6609 | 6618 | 1 | 2 | 3 | 4 | 5 |
| 46 | 6628 | 6637 | 6646 | 6656 | 6665 | 6675 | 6684 | 6693 | 6702 | 6712 | I | 2 | 3 | 4 | 5 |
| 47 | 6721 | 6730 | 6739 | 6749 | 6758 | 6767 | 6776 | 6785 | 6794 | 6803 | 1 | 2 | 3 | 4 | 5 |
| 48 | 6812 | 682 I | 6830 | 6839 | 6848 | 6857 | 6866 | 6875 | 6884 | 6893 | 1 | 2 | 3 | 4 | 4 |
| 49 | 6902 | 6911 | 6920 | 6928 | 6937 | 6946 | 6955 | 6964 | 6972 | 6981 | 1 | 2 | 3 | 4 | 4 |
| 50 | 6990 | 6998 | 7007 | 7016 | 7024 | 7033 | 7042 | 7050 | 7059 | 7067 | 1 | 2 | 3 | 3 | 4 |
| 51 | 7076 | 7084 | 7093 | 7101 | 7110 | 7118 | 7126 | 7135 | 7143 | 7152 | 1 | 2 | 3 | 3 | 4 |
| 52 | 7160 | 7168 | 7177 | 7185 | 7193 | 7202 | 7210 | 7218 | 7226 | 7235 | 1 | 2 | 2 | 3 | 4 |
| 53 | 7243 | 7251 | 7259 | 7267 | 7275 | 7284 | 7292 | 7300 | 7308 | 7316 | 1 | 2 | 2 | 3 | 4 |
| 54 | 7324 | 7332 | 7340 | 7348 | 7356 | 7364 | 7372 | 7380 | 7388 | 7396 | 1 | 2 | 2 | 3 | 4 |

Emithsonian Tables.

LOGARITHMS.

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | P. P. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  | 1 | 2 | 3 | 4 | 5 |
| 55 | 7404 | 7412 | 7419 | 7427 | 7435 | 7443 | 7451 | 7459 | 7466 | 7474 | 1 | 2 | 2 | 3 | 4 |
| 56 | 7482 | 7490 | 7497. | 7505 | 7513 | 7520 | 7528 | 7536 | 7543 | 7551 | 1 | 2 | 2 | 3 | 4 |
| 57 | 7559 | 7566 | 7574 | 7582 | 7589 | 7597 | 7604 | 7612 | 7619 | 7627 | 1 | 2 | 2 | 3 | 4 |
| 58 | 7634 | 7642 | 7649 | 7657 | 7664 | 7672 | 7679 | 7686 | 7694 | 7701 | I | 1 | 2 | 3 | 4 |
| 59 | 7709 | 7716 | 7723 | 7731 | 7738 | 7745 | 7752 | 7760 | 7767 | 7774 | I | I | 2 | 3 | 4 |
| 60 | 7782 | 7789 | 7796 | 7803 | 7810 | 7818 | 7825 | 7832 | 7839 | 7846 | I | 1 | 2 | 3 | 4 |
| 61 | 7853 | 7860 | 7868 | 7875 | 7882 | 7889 | 7896 | 7903 | 7910 | 7917 | 1 | 1 | 2 | 3 | 4 |
| 62 | 7924 | 7931 | 7938 | 7945 | 7952 | 7959 | 7966 | 7973 | 7980 | 7987 | I | 1 | 2 | 3 | 3 |
| 63 | 7993 | 8000 | 8007 | 8014 | 8021 | 8028 | 8035 | 8041 | 8048 | 8055 | I | 1 | 2 | 3 | 3 |
| 64 | 8062 | 8069 | 8075 | 8082 | 8089 | 8096 | 8102 | 8109 | 8116 | 8122 | 1 | 1 | 2 | 3 | 3 |
| 65 | 8129 | 8136 | 8142 | 8149 | 8 I 56 | 8162 | 8169 | 8176 | 8182 | 8189 | I | 1 | 2 | 3 | 3 |
| 66 | 8195 | 8202 | 8209 | 8215 | 8222 | 8228 | 8235 | 8241 | 8248 | 8254 | I | 1 | 2 | 3 | 3 |
| 67 | 8261 | 8267 | 8274 | 8280 | 8287 | 8293 | 8299 | 8306 | 8312 | 8319 | I | 1 | 2 | 3 | 3 |
| 68 | 8325 | 833 I | 8338 | 8344 | 835 I | 8357 | 8363 | 8370 | 8376 | 8382 | I | 1 | 2 | 3 | 3 |
| 69 | 8388 | 8395 | 8401 | 8407 | 8414 | 8420 | 8426 | 8432 | 8439 | 8445 | I | 1 | 2 | 3 | 3 |
| 70 | 8451 | 8457 | 8463 | 8470 | 8476 | 8482 | 8488 | 8494 | 8500 | 8506 | 1 | I | 2 | 2 | 3 |
| 71 | 8513 | 8519 | 8525 | 8531 | 8537 | 8543 | 8549 | 8555 | 8561 | 8567 | 1 | 1 | 2 | 2 | 3 |
| 72 | 8573 | 8579 | 8585 | 8591 | 8597 | 8603 | 8609 | 8615 | 8621 | 8627 | I | 1 | 2 | 2 | 3 |
| 73 | 8633 | 8639 | 8645 | 8651 | 8657 | 8663 | 8669 | 8675 | 8681 | 8686 | I | I | 2 | 2 | 3 |
| 74 | 8692 | 8698 | 8704 | 8710 | 8716 | 8722 | 8727 | 8733 | 8739 | 8745 | I | 1 | 2 | 2 | 3 |
| 75 | 8751 | 8756 | 8762 | 8768 | 8774 | 8779 | 8785 | 8791 | 8797 | 8802 | I | 1 | 2 | 2 | 3 |
| 76 | 8808 | 8814 | 8820 | 8825 | 8831 | 8837 | 8842 | 8848 | 8854 | 8859 | I | I | 2 | 2 | 3 |
| 77 | 8865 | 8871 | 8876 | 8882 | 8887 | 8893 | 8899 | 8904 | 8910 | 8915 | 1 | I | 2 | 2 | 3 |
| 78 | 8921 | 8927 | 8932 | 8938 | 8943 | 8949 | 8954 | 8960 | 8965 | 8971 | I | I | 2 | 2 | 3 |
| 79 | 8976 | 8982 | 8987 | 8993 | 8998 | 9004 | 9009 | 9015 | 9020 | 9025 | I | I | 2 | 2 | 3 |
| 80 | 9031 | 9036 | 9042 | 9047 | 9053 | 9058 | 9063 | 9069 | 9074 | 9079 | I | I | 2 | 2 | 3 |
| 81 | 9085 | 9090 | 9096 | 9101 | 9106 | 9112 | 9117 | 9122 | 9128 | 9133 | I | 1 | 2 | 2 | 3 |
| 82 | 9138 | 9143 | 9149 | 9154 | 9159 | 9165 | 9170 | 9175 | 9180 | 9186 | 1 | I | 2 | 2 | 3 |
| 83 | 9191 | 9196 | 9201 | 9206 | 9212 | 9217 | 9222 | 9227 | 9232 | 9238 | I | 1 | 2 | 2 | 3 |
| 84 | 9243 | 9248 | 9253 | 9258 | 9263 | 9269 | 9274 | 9279 | 9284 | 9289 | I | I | 2 | 2 | 3 |
| 85 | 9294 | 9299 | 9304 | 9309 | 9315 | 9320 | 9325 | 9330 | 9335 | 9340 | I | 1 | 2 | 2 | 3 |
| 86 | 9345 | 9350 | 9355 | 9360 | 9365 | 9370 | 9375 | 9380 | 9385 | 9390 | 1 | I | 2 | 2 | 3 |
| 87 | 9395 | 9400 | 9405 | 9410 | 9415 | 9420 | 9425 | 9430 | 9435 | 9440 | 0 | 1 | 1 | 2 | 2 |
| 88 | 9445 | 9450 | 9455 | 9460 | 9465 | 9469 | 9474 | 9479 | 9484 | 9489 | 0 | 1 | 1 | 2 | 2 |
| 89 | 9494 | 9499 | 9504 | 9509 | 9513 | 95IS | 9523 | 9528 | 9533 | 9538 | 0 | I | 1 | 2 | 2 |
| $\bigcirc 90$ | 9542 | 9547 | 9552 | 9557 | 9562 | 9566 | 9571 | 9576 | 9581 | 9586 | 0 | 1 | 1 | 2 | 2 |
| 91 | 9590 | 9595 | 9600 | 9605 | 9609 | 9614 | 9619 | 9624 | 9628 | 9633 | - | 1 | 1 | 2 | 2 |
| 92 | ,9638 | 9643 | 9647 | 9652 | 9657 | 9661 | 9666 | 9671 | 9675 | 9680 | 0 | 1 | I | 2 | 2 |
| 93 | 9685 | 9689 | 9694 | 9699 | 9703 | 9708 | 9713 | 9717 | 9722 | 9727 | 0 | 1 | 1 | 2 | 2 |
| 94 | 9731 | 9736 | 9741 | 9745 | 9750 | 9754 | 9759 | 9763 | 9768 | 9773 | 0 | 1 | 1 | 2 | 2 |
| 95 | 9777 | 9782 | 9786 | 9791 | 9795 | 9800 | 9 SO 5 | 9809 | 9814 | 9818 | 0 | 1 | 1 | 2 | 2 |
| 96 | 9823 | 9827 | 9832 | 9836 | 9841 | 9845 | 9850 | 9854 | 9859 | 9863 | 0 | I | I | 2 | 2 |
| 97 | 9868 | 9872 | 9877 | 9881 | 9886 | 9890 | 9894 | 9899 | 9903 | 9908 | $\bigcirc$ | I | 1 | 2 | 2 |
| 98 | 9912 | 9917 | 9921 | 9926 | 9930 | 9934 | 9939 | 9943 | 9948 | 9952 | 0 | I | 1 | 2 | 2 |
| 99 | 9956 | 9961 | 9965 | 9969 | 9974 | 9978 | 9983 | 9987 | 9991 | 9996 | 0 | 1 | 1 | 2 | 2 |

Smithsonian Tables.

ANTILOGARITHMS.

|  | 0 | 1 | - 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | P. P. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  | 1 | 2 | 3 | 4 | 5 |
| . 00 | 1000 | 1002 | 1005 | 1007 | 1009 | 1012 | 1014 | 1016 | 1019 | 1021 | 0 | 0 | 1 | 1 | 1 |
| . OI | 1023 | 1026 | 1028 | 1030 | 1033 | 1035 | 1038 | 1040 | 1042 | 1045 | - | 0 | 1 | 1 | 1 |
| . 02 | 1047 | 1050 | 1052 | 1054 | 1057 | 1059 | 1062 | 1064 | 1067 | 1069 | - | $\bigcirc$ | I | 1 | 1 |
| . 03 | 1072 | 1074 | 1076 | 1079 | 1081 | 1084 | 1086 | 1089 | 109I | 1094 | - | $\bigcirc$ | 1 | I | I |
| . 04 | 1096 | 1099 | 1102 | 1104 | 1107 | 1109 | 1112 | III4 | 1117 | III9 | $\bigcirc$ | I | 1 | 1 | 1 |
| . 05 | 1122 | 1125 | 1127 | 1130 | 1132 | 1135 | 1138 | 1140 | 1143 | 1146 | $\bigcirc$ | 1 | 1 | 1 | 1 |
| . 06 | 1148 | 1151 | 1153 | 1156 | 1159 | 1161 | 1164 | 1167 | 1169 | 1172 | $\bigcirc$ | 1 | 1 | 1 | 1 |
| . 07 | 1175 | 1178 | 1180 | 1183 | 1186 | 1189 | 1191 | 1194 | 1197 | 1199 | $\bigcirc$ | 1 | I | 1 | 1 |
| . 08 | 1202 | 1205 | 1208 | 1211 | 1213 | 1216 | 1219 | 1222 | 1225 | 1227 | $\bigcirc$ | 1 | 1 | 1 | 1 |
| . 09 | 1230 | 1233 | 1236 | 1239 | 1242 | 1245 | 1247 | 1250 | 1253 | 1256 | $\bigcirc$ | 1 | I | 1 | 1 |
| . 10 | 1259 | 1262 | 1265 | 1268 | 1271 | 1274 | 1276 | 1279 | 1282 | 1285 | 0 | 1 | 1 | I | 1 |
| . 11 | 1288 | 1291 | 1294 | 1297 | 1300 | 1303 | 1306 | 1309 | 1312 | 1315 | $\bigcirc$ | 1 | 1 | 1 | 2 |
| . 12 | ${ }^{1} 318$ | 1321 | 1324 | 1327 | 1330 | 1334 | 1337 | 1340 | 1343 | 1346 | $\bigcirc$ | 1 | 1 | 1 | 2 |
| . 13 | 1349 | 1352 | 1355 | 1358 | 1361 | 1365 | 1368 | 1371 | 1374 | 1377 | 0 | 1 | 1 | 1 | 2 |
| . 14 | I 380 | 1384 | 1387 | 1390 | 1393 | 1396 | 1400 | 1403 | 1406 | 1409 | 0 | 1 | 1 | 1 | 2 |
| . 15 | 1413 | 1416 | 1419 | 1422 | 1426 | 1429 | 1432 | 1435 | 1439 | 1442 | $\bigcirc$ | 1 | 1 | I | 2 |
| . 16 | 144.5 | 1449 | 1452 | 1455 | 1459 | 1462 | I 466 | 1469 | 1472 | 1476 | $\bigcirc$ | 1 | 1 | 1 | 2 |
| .17 | 1479 | 1483 | 1486 | 1489 | 1493 | 1496 | 1500 | 1503 | 1507 | 1510 | 0 | 1 | 1 | 1 | 2 |
| .18 | 1514 | 1517 | 1521 | 1524 | 1528 | 1531 | 1535 | 1538 | 1542 | 1545 | 0 | 1 | 1 | 1 | 2 |
| . 19 | 1549 | 1552 | 1556 | 1560 | 1563 | I 567 | 1570 | 1574 | 1578 | 1581 | 0 | I | 1 | 1 | 2 |
| . 20 | 1585 | 1589 | 1592 | 1596 | 1600 | 1603 | 1607 | 1611 | 1614 | 1618 | 0 | 1 | 1 | 1 | 2 |
| . 21 | 1622 | 1626 | 1629 | 1633 | 1637 | 1641 | 1644 | 1648 | 1652 | 1656 | 0 | 1 | 1 | 2 | 2 |
| . 22 | 1660 | 1663 | 1667 | 1671 | 1675 | 1679 | 1683 | 1687 | 1690 | 1694 | $\bigcirc$ | 1 | 1 | 2 | 2 |
| . 23 | 1698 | 1702 | 1706 | 1710 | 1714 | 1718 | 1722 | 1726 | 1730 | 1734 | 0 | I | 1 | 2 | 2 |
| . 24 | 1738 | 1742 | 1746 | 1750 | 1754 | 1758 | 1762 | 1766 | 1770 | 1774 | - | 1 | 1 | 2 | 2 |
| . 25 | 1778 | 1782 | 1786 | 1791 | 1795 | I799 | 1803 | 1807 | 1811 | 1816 | 0 | 1 | 1 | 2 | 2 |
| . 26 | 1820 | 1824 | 1828 | 1832 | 1837 | 1841 | 1845 | 1849 | 1854 | 1858 | 0. | 1 | 1 | 2 | 2 |
| . 27 | 1862 | 1866 | 1871 | 1875 | 1879 | 1884 | 1888 | 1892 | 1897 | 1901 | $\bigcirc$ | I | I | 2 | 2 |
| . 28 | 1905 | 1910 | 1914 | I919 | 1923 | 1928 | 1932 | 1936 | 1941 | 1945 | - | I | 1 | 2 | 2 |
| . 29 | 1950 | 1954 | 1959 | 1963 | 1968 | 1972 | 1977 | 1982 | 1986 | - 1991 | 0 | 1 | 1 | 2 | 2 |
| . 30 | 1995 | 2000 | 2004 | 2009 | 2014 | 2018 | 2023 | 2028 | 2032 | 2037 | 0 | I | I | 2 | 2 |
| . 31 | 2042 | 2046 | 2051 | 2056 | 2061 | 2065 | 2070 | 2075 | 2080 | 2084 | - | I | 1 | 2 | 2 |
| . 32 | 2089 | 2094 | 2099 | 2104 | 2109 | 2113 | 2118 | 2123 | 2128 | 2133 | $\bigcirc$ | 1 | 1 | 2 | 2 |
| . 33 | 2138 | 2143 | 2148 | 2153 | 2158 | 2163. | 2168 | 2173 | 2178 | 2183 | 0 | 1 | 1 | 2 | 2 |
| $\cdot 34$ | 2188 | 2193 | 2198 | 2203 | 2208 | 2213 | 2218 | 2223 | 2228 | 2234 | I | 1 | 2 | 2 | 3 |
| . 35 | 2239 | 2244 | 2249 | 2254 | 2259 | 2265 | 2270 | 2275 | 2280 | 2286 | 1 | 1 | 2 | 2 | 3 |
| . 36 | 2291 | 2296 | 2301 | 2307 | 2312 | 2317 | 2323 | 2328 | 2333 | 2339 | 1 | I | - | 2 | 3 |
| . 37 | 2344 | 2350 | 2355 | 2360 | 2366 | 2371 | 2377 | 2382 | 2388 | 2393 | I | 1 | 2 | 2 | 3 |
| - 38 | 2399 | 2404 | 2410 | 2415 | 2421 | 2427 | 2432 | 2438 | 2443 | 2449 | 1 | I | 2 | 2 | 3 |
| . 39 | 2455 | 2460 | 2466 | 2472 | 2477 | 2483 | 2489 | 2495 | 2500 | 2506 | 1 | 1 | 2 | 2 | 3 |
| . 40 | 2512 | 2518 | 2523 | 2529 | 2535 | 2541 | 2547 | 2553 | 2559 | 2564 | I | 1 | 2 | 2 | 3 |
| . 41 | 2570 | 2576 | 2582 | 2588 | 2594 | 2600 | 2606 | 2612 | 2618 | 2624 | I | 1 |  | 2 | 3 |
| .42 | 2630 | 2636 | 2642 | 2649 | 2655 | 2661 | 2667 | 2673 | 2679 | 2685 | I | 1 | 2 | 2 | $\stackrel{3}{3}$ |
| - 43 | 2692 | 2698 | 2704 | 2710 | 2716 | 2723 | 2729 | 2735 | 2742 | 2748 | I | 1 | 2 | 3 | 3 |
| .44 | 2754 | 2761 | 2767 | 2773 | 2780 | 2786 | 2793 | 2799 | 2805 | 2812 | 1 | 1 | 2 | 3 | 3 |
| . 45 | 2818 | 2825 | 2831 | 2838 | 2844 | 2851 | 2858 | 2864 | 2871 | 2877 | 1 | 1 | 2 | 3 | 3 |
| . 46 | 2884 | 2891 | 2897 | 2904 | 291I | 2917 | 2924 | 2931 | 2938 | 2944 | I | 1 | 2 | 3 | 3 |
| - 47 | 2951 | 2958 | 2965 | 2972 | 2979 | 2985 | 2992 | 2999 | 3006 | 3013 | I | I | 2 | 3 | 3 |
| . 48 | 3020 | 3027 | 3034 | 3041 | 3048 | 3055 | 3062 | 3069 | 3076 | 3083 3155 | 1 | 1 | 2 | 3 | 4 |
| -49 | 3090 | 3097 | 3105 | 3112 | 3119 | 3126 | 3133 | 3141 | 3148 | 3155 | 1 | 1 | 2 | 3 | 4 |

Smithsonian Tables.

ANTILOGARITHMS.

|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | P. P. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  | 1 | 2 | 3 | 4 | 5 |
| . 50 | 3162 | 3170 | 3177 | 3184 | 3192 | 3199 | 3206 | 3214 | 3221 | 3228 | I | 1 | 2 | 3 | 4 |
| . 51 | 3236 | 3243 | 3251 | 3258 | 3266 | 3273 | 3281 | 3289 | 3296 | 3304 | I | 2 | 2 | 3 | 4 |
| . 52 | 3311 | 3319 | 3327 | 3334 | 3342 | 3350 | 3357 | 3365 | 3373 | 3381 | I | 2 | 2 | 3 | 4 |
| . 53 | 3388 | 3396 | 3404 | 3412 | 3420 | 3428 | 3436 | 3443 | 3451 | 3459 | I | 2 | 2 | 3 | 4 |
| . 54 | 3467 | 3475 | 3483 | 3491 | 3499 | 3508 | 3516 | 3524 | 3532 | 3540 | I | 2 | 2 | 3 | 4 |
| . 55 | 3548 | 3556 | 3565 | 3573 | 358r | 3589 | 3597 | 3606 | 3614 | 3622 | 1 | 2 | 2 | 3 | 4 |
| . 56 | 3631 | 3639 | 3648 | 3656 | 3664 | 3673 | 3681 | 3690 | 3698 | 3707 | I | 2 | 3 | 3 | 4 |
| . 57 | 3715 | 3724 | 3733 | 3741 | 3750 | 3758 | 3767 | 3776 | 3784 | 3793 | I | 2 | 3 | 3 | 4 |
| . 58 | $3802{ }^{\circ}$ | 3811 | 3819 | 3828 | 3837 | 3846 | 3855 | 3864 | 3873 | 3882 | I | 2 | 3 | 4 | 4 |
| . 59 | 3890 | 3899 | 3908 | 3917 | 3926 | 3936 | 3945 | 3954 | 3963 | 3972 | I | 2 | 3 | 4 | 5 |
| . 60 | 3981 | 3990 | 3999 | 4009 | 4018 | 4027 | 4036 | 4046 | 4055 | 4064 | I | 2 | 3 | 4 | 5 |
| .61 .62 | 4074 4169 | 4083 | 4093 | 4102 | 4111 | 4121 | 4130 | 4140 | 4150 | 4159 | I | 2 | 3 | 4 | 5 |
| . 62 | 4169 | 4178 | 4188 | 4198 | 4207 | 4217 | 4227 | 4236 | 4246 | 4256 | I | 2 | 3 | 4 | 5 |
| . 63 | 4266 | 4276 | 4285 | 4295 | 4305 | 4315 | 4325 | 4335 | 4345 | 4355 | I | 2 | 3 | 4 | 5 |
| . 64 | 4365 | 4375 | 4385 | 4395 | 4406 | 4416 | 4426 | 4436 | 4446 | 4457 | I | 2 | 3 | 4 | 5 |
| . 65 | 4467 | 4477 | 4487 | 4498 | 4508 | 4519 | 4529 | 4539 | 4550 | 4560 | I | 2 | 3 | 4 | 5 |
| . 66 | 4571 | 4581 | 4592 | 4603 | 4613 | 4624 | 4634 | 4645 | 4656 | 4667 | I | 2 | 3 | 4 | 5 |
| . 67 | 4677 | 4688 | 4699 | 4710 | 4721 | 4732 | 4742 | 4753 | 4764 | 4775 | 1 | 2 | 3 | 4 | 5 |
| . 65 | 4786 | 4797 | 4808 | 4819 | 4831 | 4842 | 4853 | 4864 | 4875 | 4887 | I | 2 | 3 | 4 | 6 |
| . 69 | 4898 | 4909 | 4920 | 4932 | 4943 | 4955 | 4966 | 4977 | 4989 | 5000 | I | 2 | 3 | 5 | 6 |
| . 70 | 5012 | 5023 | 5035 | 5047 | 5058 | 5070 | 5082 | 5093 | 5105 | 5117 | I | 2 | 4 | 5 | 6 |
| . 71 | 5129 | 5140 | 5152 | 5164 | 5176 | 5188 | 5200 | 5212 | 5224 | 5236 | I | 2 | 4 | 5 | 6 |
| . 72 | 5248 | 5260 | 5272 | 5284 | 5297 | 5309 | 5321 | 5333 | 5346 | 5358 | I | 2 | 4 | 5 | 6 |
| . 73 | 5370 | 5383 | 5395 | 5408 | 5420 | 5433 | 5445 | 5458 | 5470 | 5483 | I | 3 | 4 | 5 | 6 |
| . 74 | 5495 | 5508 | 552 I | 5534 | 5546 | 5559 | 5572 | $55^{8} 5$ | 5598 | 5610 | I | 3 | 4 | 5 | 6 |
| .75 .76 | 5623 | 5636 5768 | 5649 | 5662 | 5675 5808 | 5689 | 5702 | 5715 | 5728 | 5741 | I | 3 | 4 | 5 | 7 |
| .76 .77 | 5754 5888 | 5768 | 5781 5916 | 5794 5929 | 5808 | 5821 | 5834 5970 | 5848 | 5861 | 5875 6012 | I | 3 | 4 | 5 | 7 7 |
| .78 .78 | 6026 | 6039 | 6053 | 6067 | 6943 | 6957 | 5970 6109 | 6124 | 5998 6138 | 6152 | I | 3 | 4 | 5 | 7 |
| . 79 | 6166 | 6180 | 6r94 | 6209 | 6223 | 6237 | 6252 | 6266 | 6281 | 6295 | I | 3 | 4 | 6 | 7 |
| . 80 | 6310 | 6324 | 6339 | 6353 | 6368 | 6383 | 6397 | 6412 | 6427 | 6442 | I | 3 | 4 | 6 | 7 |
| . 81 | 6457 | 6471 | 6486 | 6501 | 6516 | 6531 | 6546 | 6561 | 6577 | 6592 | 2 | 3 | 5 | 6 | 8 |
| . 82 | 6607 | 6622 | 6637 | 6653 | 6668 | 6683 | 6699 | 6714 | 6730 | 6745 | 2 | 3 | 5 | 6 | 8 |
| . 83 | 6761 | 6776 | 6792 | 6808 | 6823 | 6839 | 6855 | 6871 | 6887 | 6902 | 2 | 3 | 5 | 6 | 8 |
| . 84 | 6918 | 6934 | 6950 | 6966 | 6982 | 6998 | 7015 | 7031 | 7047 | 7063 | 2 | 3 | 5 | 6 | 8 |
| . 85 | 7079 | 7096 | 7112 | 7129 | 7145 | 7161 | 7178 | 7194 | 7211 | 7228 | 2 | 3 | 5 | 7 | 8 |
| . 86 | 7244 | 7261 | 7278 | 7295 | 7311 | 7328 | 7345 | 7362 | 7379 | 7396 | 2 | 3 | 5 | 7 | 8 |
| . 87 | 7413 | 7430 | 7447 | 7464 | 7482 | 7499 | 7516 | 7534 | 7551 | 7568 | 2 | 3 | 5 | 7 | 9 |
| . 88 | 7586 | 7603 | 7621 | 7638 | 7656 | 7674 | 7691 | 7709 | 7727 | 7745 | 2 | 4 | 5 | 7 | 9 |
| . 89 | 7762 | 7780 | 7798 | 7816 | 7834 | 7852 | 7870 | 7889 | 7907 | 7925 | 2 | 4 | 5 | 7 | 9 |
| . 90 | 7943 | 7962 | 7980 | 7998 | 8017 | 8035 | 8054 | 8072 | SogI | 8ilo | 2 | 4 | 6 | 7 | 9 |
| .91 | 8128 | 8147 | 8166 | 8185 | 8204 | 8222 | 8241 | 8260 | 8279 | 8299 | 2 | 4 | 6 | 8 | 9 |
| . 92 | 8318 | 8337 | 8356 | S375 | 8395 | 8414 | 8433 | 8453 | 8472 | 8492 | 2 | 4 | 6 | 8 | 10 |
| . 93 | 8511 8710 | 8531 8730 | 8551 8750 | 8570 8770 | 8590 8790 | 8610 8810 | 8630 8831 | 8650 8851 | 8670 8872 | 8690 8892 | 2 | 4 | 6 | 8 | 10 |
| .94 | 8710 | 8730 | 8750 | 8770 | 8790 | 88ı0 | 8831 | 8851 | 8872 | 8892 | 2 | 4 | 6 | 8 | 10 |
| . 95 | 8913 | 8933 | 8954 | 8974 | 8995 | 9016 | 9036 | 9057 | 9078 | 9099 | 2 | 4 | 6 | 8 | 10 |
| . 96 | 9120 | 9141 | 9162 | 9183 | 9204 | 9226 | 9247 | 9268 | 9290 | 9311 | 2 | 4 | 6 | 8 | II |
| . 97 | 9333 | 9354 | 9376 | 9397 | 9419 | 944 I | 9462 | 9484 | 9506 | 9528 | 2 | 4 | 7 | 9 | II |
| . 98 | 9550 | 9572 | 9594 | 9616 | 9638 | 9661 | 9683 | 9705 | 9727 | 9750 | 2 | 4 | 7 | 9 | II |
| . 99 | 9772 | 9795 | 9817 | 9840 | 9863 | 9886 | 9908 | 9931 | 9954 | 9977 | 2 | 5 | 7 | 9 | 11 |

Smithsonian Tables.

|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| . 900 | 7943 | 7945 | 7947 | 7949 | 7951 | 7952 | 7954 | 7956 | 7958 | 7960 | 7962 |
| . 901 | 7962 | 7963 | 7965 | 7967 | 7969 | 7971 | 7973 | 7974 | 7976 | 7978 | 7980 |
| . 902 | 7980 | 7982 | 7984 | 7985 | 7987 | 7989 | 7991 | 7993 | 7995 | 7997 | 7998 |
| . 903 | 7998 | 8000 | 8002 | 8004 | 8006 | So08 | 8009 8028 | 8011 | 8013 | 8015 | 8017 |
| . 904 | 8017 | 8019 | 8020 | S022 | 8024 | 8026 |  | 8030 | 8032 | 8033 | 8035 |
| . 905 | 8035 | 8037 | 8039 | 8041 | 8043 | 8045 | 8046 | 8048 | 8050 | 8052 | 8054 |
| . 906 | So54 | So56 | 8057 | 8059 | 8061 | 8063 | 8065 | 8067 | 8069 | So70 | 8072 |
| . 907 | 8072 | 8074 | 8076 | 8078 | 8080 | 8082 | 8084 | 8085 | 8087 | 8089 | 8091 |
| . 908 | So91 | 8093 | 8095 | 8097 | 8098 | 8100 | 8102 | 8104 | 8106 | 8108 | 8110 |
| . 909 | Silo | 8111 | 8113 | 8115 | 8117 | 8119 | SI2I | 8123 | 8125 | 8126 | 8128 |
| . 910 | S128 | 8130 | 8132 | 8134 | 8136 | 8138 | 8140 | 8141 | 8143 | 8145 | 8147 |
| .911 | 8147 | 8149 | 8151 | 8153 | 8155 | 8156 | 8158 | 8160 | 8162 | 8164 | 8166 |
| . 912 | 8166 | 8168 | 8170 | 8171 | 8173 | 8175 | 8177 | 8179 | 8181 | 8183 | 8185 |
| .913 | 8185 | 8187 | 8188 | 8190 | 8192 | 8194 | 8196 | 8198 | 8200 | 8202 | 8204 |
| . 914 | 8204 | 8205 | 8207 | 8209 | 82II | 8213 | 8215 | 8217 | 8219 | 8221 | 8222 |
| . 915 | S222 | 8224 | 8226 | 8228 | 8230 | 8232 | 8234 | 8236 | 8238 | 8239 | 8241 |
| . 916 | 8241 | 8243 | 8245 | 8247 | 8249 | 8251 | 8253 | 8255 | 8257 | 8258 | 8260 |
| . 917 | 8260 | 8262 | 8264 | 8266 | 8268 | 8270 | 8272 | 8274 | 8276 | 8278 | 8279 |
| .918 | 8279 | 8281 | 8283 | 8285 | 8287 | 8289 | 8291 | 8293 | 8295 | 8297 | 8299 |
| .919 | 8299 | 8300 | 8302 | 8304 | 8306 | 8308 | 8310 | 8312 | 8314 | 8316 | 8318 |
| . 920 | 8318 | 8320 | 8321 | 8323 | 8325 | 8327 | 8329 | 8331 | 8333 | 8335 | 8337 |
| . 921 | 8337 | 8339 | 8341 | 8343 | 8344 | 8346 | 8348 | 8350 | 8352 | 8354 | 8356 |
| . 922 | 8356 | 8358 | 8360 | 8362 | 8364 | 8366 | 8368 | 8370 | 8371 | 8373 | 8375 |
| . 923 | 8375 | 8377 | 8379 | ${ }_{8}^{831}$ | 8383 | 8385 | 8387 | 8389 | 8391 | 8393 | 8395 |
| . 924 | 8395 | 8397 | 8398 | 8400 | 8402 | 8404 | 8406 | 8408 | 8410 | 8412 | 8414 |
| . 925 | 8414 | 8416 | 8418 | 8420 | 8422 | 8424 | 8426 | 8428 | 8429 | 8431 | 8433 |
| . 926 | 8433 | 8435 | 8437 | $8+39$ | 8441 | 8443 | 8445 | 8447 | 8449 | 8451 | 8453 |
| . 927 | 8453 | 8455 | 8457 | 8459 | 8461 | 8463 | 8464 | 8466 | 8468 | 8470 | 8472 |
| . 928 | 8472 | 8474 | ${ }_{8}^{8} 476$ | 8478 | 8480 | 8482 | 8484 | 8486 | 8488 | 8490 | 8492 |
| . 929 | 8492 | 8494 | 8496 | 8498 | 8500 | 8502 | 8504 | 8506 | 8507 | 8509 | 8511 |
| . 930 | 8511 | 8513 | 8515 | 8517 | 8519 | 8521 | 8523 | 8525 | 8527 | 8529 | 8531 |
| . 931 | 8531 | 8533 | 8535 | 8537 | 8539 | 8541 | 8543 | 8545 | 8547 | 8549 | 8551 |
| . 932 | 8551 | 8553 | 8555 | 8557 | 8559 | 8561 | 8562 | 8564 | 8566 | 8568 | 8570 |
| -933 | 8570 | 8572 | 8574 |  |  | 8580 8600 | 8582 8602 | ${ }_{8}^{854}$ | 8586 8606 | 8588 8608 | - 590 |
| . 934 | 8590 | 859? | 8594 | 8596 | 8598 | 8600 | 8602 | 8604 | 8606 | 8608 | 8610 |
| . 935 | 8610 | 8612 | 8614 | 8616 | 8618 | 8620 | 8622 | 8624 | 8626 | 8628 | 8630 |
| . 936 | 8630 | 8632 | 8634 | 8636 | 8638 | 8640 | 8642 | 8644 | 8646 | 8648 | 8650 |
| . 937 | 8650 | 8652 | 8654 | 8656 | 8658 | 8660 | 8662 | 8664 | 8666 | 8668 | 8670 |
| . 938 | 8670 | 8672 | 8674 | 8676 | 8678 | 8680 | 8682 | 8684 | 8686 | 8688 | 8690 |
| . 939 | 8690 | 8692 | 8694 | 8696 | 8698 | 8700 | 8702 | 8704 | 8706 | 8708 | 8710 |
| . 940 | 8710 | 8712 | 8714 | 8716 | 8718 | 8720 | 8722 | 8724 | 8726 | 8728 | 8730 |
| .941 | 8730 | 8732 | 8734 | 8736 | 8738 | 8740 | 8742 | 8744 | 8746 | 8748 | 8750 |
| . 942 | 8750 | 8752 | 8754 | 8756 | 8758 | 8760 | 8762 | 8764 | 8766 | 8768 | 8770 |
| . 943 | 8770 | 8772 | 8774 | 8776 | 8778 | 8780 | 8782 | 8784 | 8786 | 8788 | 8790 |
| . 944 | 8790 | 8792 | 8794 | 8796 | 8798 | 8800 | 8802 | 8804 | 8806 | 8808 | 8810 |
| . 945 | 88 ı | 8813 | 8815 | 8817 | 8819 | 8821 | 8823 | 8825 | 8827 | 8829 | 8831 |
| . 946 | 8831 | 8833 | 8835 | 8837 | 8839 | 8841 | 8843 | 8845 | 8847 | 8849 | 8851 |
| . 947 | 8851 8872 | 8853 8874 | 8855 8876 | 8857 8878 | 8859 8880 | 8861 8882 | 8863 8884 | 8865 8886 | 8867 8888 | 8870 8890 | 8872 8892 88 |
| . 949 | 8892 | 8894 | 8896 | 8898 | 8900 | 8902 | 8904 | 8906 | 8908 | 8910 | 8913 |

Table 13 (continued).
ANTILOGARITHMS.

|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| . 950 | 8913 | 8915 | 8917 | 8919 | 8921 | 8923 | 8925 | 8927 | 8929 | 8931 | 8933 |
| . 951 | S933 | 8935 | 8937 | 8939 | 8941 | 8943 | 8945 | 8947 | 8950 | 8952 | 8954 |
| . 952 | 8954 | 8956 | 8958 | 8960 | 8962 | 8964 | 8966 | 8968 | S970 | 8972 | 8974 |
| . 953 | 8974 | 8976 | 8978 | 8980 | 8983 | 8985 | 8987 | 8989 | 8991 | 8993 | 8995 |
| . 954 | 8995 | 8997 | 8999 | 9001 | 9003 | 9005 | 9007 | 9009 | 9012 | 9014 | 9016 |
| . 955 | 9016 | 9018 | 9020 | 9022 | 9024 | 9026 | 9028 | 9030 | 9032 | 9034 | 9036 |
| . 956 | 9036 | 9039 | 9041 | 9043 | 9045 | 9047 | 9049 | 9051 | 9053 | 9055 | 9057 |
| . 957 | 9 C 57 | 9059 | 9061 | 9064 | 9066 | 9068 | 9070 | 9072 | 9074 | 9076 | 9078 |
| . 958 | 9078 | 9080 | 9082 | 9084 | 9087 | 9089 | 9091 | 9093 | 9095 | 9097 | 9099 |
| . 959 | 9099 | 9101. | 9103 | 9105 | 9108 | 9110 | 9112 | 9114 | 9116 | 9118 | 9120 |
| . 960 | 9120 | 9122 | 9124 | 9126 | 9129 | 9131 | 9133 | 9135 | 9137 | 9139 | 9141 |
| .961 | 9141 | 9143 | 9145 | 9147 | 9150 | 9152 | 9154 | 9156 | 9158 | 9160 | 9162 |
| . 962 | 9162 | 9164 | 9166 | 9169 | 9171 | 9173 | 9175 | 9177 | 9179 | 9181 | 9183 |
| . 963 | 9183 | 9185 | 9188 | 91.90 | 9192 | 9194 | 9196 | 9198 | 9200 | 9202 | 9204 |
| . 964 | 9204 | 9207 | 9209 | 92 II | 9213 | 9215 | 9217 | 9219 | 922 I | 9224 | 9226 |
| . 965 | 9226 | 9228 | 9230 | 9232 | 9234 | 9236 | 9238 | 9241 | 9243 | 9245 | 9247 |
| . 966 | 9247 | 9249 | 9251 | 9253 | 9256 | 9258 | 9260 | 9262 | 9264 | 9266 | 9268 |
| . 967 | 9268 | 9270 | 9273 | 9275 | 9277 | 9279 | 9281 | 9283 | 9285 | 9288 | 9290 |
| . 968 | 9290 | 9292 | 9294 | 9296 | 9298 | 9300 | 9303 | 9305 | 9307 | 9309 | 9311 |
| . 969 | 9311 | 9313 | 9315 | 9318 | 9320 | 9322 | 9324 | 9326 | 9328 | 9330 | 9333 |
| . 970 | 9333 | 9335 | 9337 | 9339 | 9341 | 9343 | 9345 | 9348 | 9350 | 9352 | 9354 |
| . 971 | 9354 | 9356 | 9358 | 936 I | 9363 | 9365 | 9367 | 9369 | 9371 | 9373 | 9376 |
| . 972 | 9376 | 9378 | 9380 | 9382 | 9384 | 9386 | 9389 | 9391 | 9393 | 9395 | 9397 |
| . 973 | 9397 | 9399 | 9402 | 9404 | 9406 | 9408 | 9410 | 9412 | 9415 | 9417 | 9419 |
| . 974 | 9419 | 942 i | 9423 | 9425 | 9428 | 9430 | 9432 | 9434 | 9436 | 9438 | 9441 |
| . 975 | 9441 | 9443 | 9445 | 9447 | 9449 | 9451 | 9454 | 9456 | 9458 | 9460 | 9462 |
| . 976 | 9462 | 9465 | 9467 | 9469 | 9471 | 9473 | 9475 | 9478 | 9480 | 9482 | 9484 |
| . 977 | 9484 | 9486 | 9489 | 9491 | 9493 | 9495 | 9497 | 9499 | 9502 | 9504 | 9506 |
| . 978 | 9506 | 9508 | 9510 | 9513 | 9515 | 9517 | 9519 | 9521 | 9524 | 9526 | 9528 |
| . 979 | 9528 | 9530 | 9532 | 9535 | 9537 | 9539 | 9541 | 9543 | 9546 | 9548 | 9550 |
| 980 | 9550 | 9552 | 9554 | 9557 | 9559 | 9561 | 9563 | 9565 | 9568 | 9570 | 9572 |
| . 98 I | 9572 | 9574 | 9576 | 9579 | 9581 | 9583 | 9585 | 9587 | 9590 | 9592 | 9594 |
| . 982 | 9594 | 9596 | 9598 | 9601 | 9603 | 9605 | 9607 | 9609 | 9612 | 9614 | 9616 |
| .983 | 9616 | 9618 | 9621 | 9623 | 9625 | 9627 | 9629 | 9632 | 9634 | 9636 | 9638 |
| .984 | 9638 | 9641 | 9643 | 9645 | 9647 | 9649 | 9652 | 9654 | 9656 | 9658 | 966 I |
| . 985 | 9661 | 9663 | 9665 | 9667 | 9669 | 9672 | 9674 | 9676 | 9678 | 968 I | 9683 |
| . 986 | 9683 | 9685 | 9687 | 9689 | 9692 | 9694 | 9696 | 9698 | 9701 | 9703 | 9705 |
| . 987 | 9705 | 9707 | 9710 | 97 I 2 | 9714 | 9716 | 9719 | 9721 | 9723 | 9725 | 9727 |
| . 988 | 9727 | 9730 | 9732 | 9734 | 9736 | 9739 | 9741 | 9743 | 9745 | 9748 | 9750 |
| . 989 | 9750 | 9752 | 9754 | 9757 | 9759 | 976 I | 9763 | 9766 | 9768 | 9770 | 9772 |
| . 990 | 9772 | 9775 | 9777 | 9779 | 9781 | 9784 | 9786 | 9788 | 9790 | 9793 | 9795 |
| .991 | 9795 | 9797 | 9799 | 9802 | 9804 | 9806 | 9808 | 98 II | $9{ }^{8} \mathrm{I} 3$ | 9815 | 9817 |
| . 992 | 9817 | 9820 | 9822 | 9824 | 9827 | 9829 | 9831 | 9833 | 9836 | 9838 | 9840 |
| . 993 | 9840 | 9842 | 9845 | 9847 | 9849 | 985 I | 9854 | 9856 | 9858 | 9861 | 9863 |
| . 994 | 9863 | 9865 | 9867 | 9870 | 9872 | 9874 | 9876 | 9879 | 9881 | 9883 | 9886 |
| . 995 | 9886 | 9888 | 9890 | 9892 | 9895 | 9897 | 9899 | 9901 | 9904 | 9906 | 9908 |
| . 996 | 9908 | 991 I | 9913 | 9915 | 9917 | 9920 | 9922 | 9924 | 9927 | 9929 | 9931 |
| . 997 | 993 I | 9933 | 9936 | 9938 | 9940 | 9943 | 9945 | 9947 | 9949 | 9952 | 9954 |
| . 998 | 9954 | 9956 9979 | 9959 9982 | 9961 9984 | 9963 9986 | 9966 9988 | 9968 999 I | 9970 9993 | 9972 9995 | 9975 9998 | 9977 0000 |
| . 999 | 9977 | 9979 | 9982 | 9984 | 9986 | 9988 | 9991 | 9993 | 9995 | 9998 | 0000 |

Smithsonian Tables.

## CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

(Taken from B. O. Peirce's "Short Table of Integrals," Ginn \& Co.)

|  |  | SINES. |  | COSINES. |  | TANGENTS. |  | COTANGENTS. |  | $90^{\circ} 00^{\prime}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |  |
| 0.0000 | $0^{\circ} 0^{\prime}$ | . 0000 | $\infty$ | 1.0000 | 0.0000 | . 0000 | $\infty$ | $\cdots$ | $\infty$ |  | 1. 5708 |
| 0.0029 | 10 | . 0029 | 7.4637 | 1.0000 | . 0000 | . 0029 | 7.4637 | 343.77 | 2.5363 | 50 | I. 5679 |
| 0.0058 | 20 | .0058 | . 7648 | 1.0000 | . 0000 | . 0058 | . 7648 | 171.89 | . 2352 | 40 | I. 5650 |
| 0.0087 | 30 | . 0087 | . 9408 | 1.0000 | . 0000 | . 0087 | . 9409 | I 14.59 | .0591 | 30 | I. 562 I |
| 0.0116 | 40 | . 0116 | S.0658 | . 9999 | . 0000 | . 1116 | 8.0658 | 85.940 | 1.9342 | 20 | 1.5592 |
| 0.0145 | 50 | . 0145 | . 1627 | . 9999 | . 0000 | . 0145 | . 1627 | 68.750 | . 8373 | 10 | 1.5563 |
| 0.0175 | $\mathrm{I}^{\circ} 0^{\prime}$ | . 0175 | 8.2419 | . 9998 | 9.9999 | . 0175 | 8.2419 | 57.290 | 1.758 I | $89^{\circ} 00^{\prime}$ | I. 5533 |
| 0.0204 | 10 | . 0204 | . 3088 | . 9998 | . 9999 | . 0204 | . 3089 | 49.104 | . 6911 | 50 | I. 5504 |
| 0.0233 | 20 | . 0233 | . 3668 | . 9997 | . 9999 | . 0233 | -3669 | 42.964 | . 6331 | 40 | I. 5475 |
| 0.0262 | 30 | . 0262 | .4179 | . 9997 | . 9999 | . 0262 | . 4181 | 38.188 | . 5819 | 30 | I. 5446 |
| 0.029I | 40 | .0291 | .4637 | . 9996 | . 9998 | .0291 | .4638 | 34.368 | . 5362 | 20 | I. 5417 |
| 0.0320 | 50 | .0320 | . 5050 | . 9995 | . 9998 | . 0320 | . 5053 | 31.242 | . 4947 | 10 | I. 5388 |
| 0.0349 | $2^{\circ} 00^{\prime}$ | . 0349 | 8.5428 | -9994 | 9.9997 | . 0349 | 8.543 I . | 28.636 | 1.4569 | $88^{\circ} 0^{\prime}$ | I. 5359 |
| 0.0378 | 10 | . 0378 | . 5776 | . 9993 | . 9997 | . 0378 | . 5779 | 26.432 | . 422 I | 50 | 1.5330 |
| 0.0407 | 0 | . 0407 | . 6097 | . 9992 | . 9996 | . 0407 | .6101 | 24.542 | . 3899 | 40 | 1.53301 |
| 0.0436 | 30 | . 0436 | . 6397 | . 9990 | . 9996 | . 0437 | . 6401 | 22.904 | . 3599 | 30 | 1.5272 |
| 0.0465 | 40 | . 0465 | . 6677 | . 9989 | . 9995 | . 0466 | . 6682 | 21.470 | -3318 | 20 | 1. 5243 |
| 0.0495 | 50 | . $0+49$ | . 6940 | . 9988 | . 9995 | . 0495 | . 6945 | 20.206 | - 3055 | 0 | 1.5213 |
| 0.0524 | $3^{\circ} 0^{\prime}$ | . 0523 | 8.7188 | . 9986 | 9.9994 | . 0524 | 8.7194 | 19.081 | 1.2806 | $87^{\circ} 00^{\prime}$ | I. 5184 |
| 0.0553 | 10 | . 0552 | . 7423 | . 9985 | . 9993 | . 0553 | . 7429 | 18.075 | . 2571 | 50 | 1.5155 |
| 0.0582 | 20 | .0581 | . 7645 | .9983 | . 9993 | .0582 | .7652 | 17.169 | . 2348 | 40 | 1.5126 |
| 0.0611 | 30 | . 0610 | .7857 | . 9981 | . 9992 | . 0612 | .7865 | 16.350 | . 2135 | 30 | 1. 5097 |
| 0.0640 | 40 | . 0640 | . 8059 | . 9980 | .999I | . 0641 | . 8067 | 15.605 | . 1933 | 20 | 1. 5068 |
| 0.0669 | 50 | . 0669 | .8251 | . 9978 | . 9990 | . 0670 | .826I | 14.924 | .1739 | 10 | 1.5039 |
| 0.0698 | $4^{\circ} 00^{\prime}$ | . 0698 | 8.8436 | . 9976 | 9.9989 | . 0699 | 8.8446 | 14.301 | 1.1554 | $86^{\circ} 00^{\prime}$ | 1. 5010 |
| 0.0727 | 10 | . 0727 | .8613 | . 9974 | . 9989 | . 0729 | . 8624 | 13.727 | .1376 | 50 | 1.4981 |
| 0.0756 | 20 | . 0756 | . 8783 | . 9971 | . 9988 | . 0758 | . 8795 | 13.197 | . 1205 | 40 | 1. 4952 |
| 0.0785 | 30 | . 0785 | . 8946 | . 9969 | . 9987 | . 0787 | . 8960 | 12.706 | . 1040 | 30 | I. 4923 |
| 0.0814 | 40 | .08I4 | . 9104 | . 9967 | . 9986 | .0816 | .9118 | 12.251 | . 0882 | 20 | 1.4893 |
| 0.0844 | 50 | . 0843 | . 9256 | . 9964 | . 9985 | . 0846 | . 9272 | 11.826 | . 0728 | 10 | 1.4864 |
| 0.0873 | $5^{\circ} 00^{\prime}$ | . 0872 | 8.9403 | . 9962 | 9.9983 | . 0875 | 8.9420 | 11.430 | 1.0580 | $85^{\circ} 00^{\prime}$ | I. 4835 |
| 0.0902 | 10 | . 0901 | . 9545 | . 9959 | . 9982 | . 0904 | . 9563 | 11.059 | . 0437 | 50 | 1.4806 |
| 0.0931 | 20 | . 0929 | . 9682 | . 9957 | .998I | . 0934 | . 9701 | 10.712 | .0299 | 40 | 1.4777 |
| 0.0960 | 30 | . 0958 | .9816 | . 9954 | . 9980 | . 0963 | .9836 | 10.385 | . 0164 | 30 | 1.4748 |
| 0.0989 | 40 | . 0987 | . 9945 | . 9951 | . 9979 | . 0992 | . 9966 | 10.078 | . 0034 | 20 | 1.4719 |
| 0.1018 | 50 | . 1016 | 9.0070 | . 9948 | . 9977 | . 1022 | 9.0093 | 9.7882 | 0.9907 | 10 | 1.4690 |
| 0.1047 | $6^{\circ} 00$ | . 1045 | 9.0192 | . 9945 | 9.9976 | . 1051 | 9.0216 | 9.5144 | 0.9784 | $84^{\circ} 0^{\prime}$ | I. 4661 |
| 0.1076 | 10 | .1074 | . 0311 | . 9942 | . 9975 | . 1080 | .0336 | 9.2553 | . 9664 | 50 | 1.4632 |
| 0.1105 | 20 | . 1103 | . 0426 | . 9939 | . 9973 | . 11110 | . 0453 | 9.0098 | . 9547 | 40 | 1.4603 |
| 0.1134 | 30 | .1132 | . 0539 | . 9936 | . 9972 | . 1139 | . 0567 | 8.7769 | . 9433 | 30 | I. 4574 |
| 0.1164 | 40 | .1161 | . 0648 | . 9932 | . 9971 | . 1169 | . 0678 | 8.5555 | .9322 | 20 | 1.4544 |
| 0.1193 | 50 | . 1190 | . 0755 | . 9929 | . 9969 | . 1198 | . 0786 | 8.3450 | .9214 | 10 | 1.4515 |
| 0.1222 | $7^{\circ} 00^{\prime}$ |  | 9.0859 | . 9925 | 9.9968 | . 1228 | 9.089 I | 8.1443 | 0.9109 | $83^{\circ} 0^{\prime}$ | I. 4486 |
| 0.1251 | 10 | . 1248 | .0961 | . 9922 | . 9966 | . 1257 | . 0995 | 7.9530 | . 9005 | 50 | I. 4457 |
| 0.1280 | 20 | . 1276 | . 1060 | .9918 | . 9964 | . 1287 | . 1095 | 7.7704 | . 8904 | 40 | 1.4428 |
| 0.1309 | 30 | . 1305 | . 1157 | . 9914 | . 9963 | .1317 | . 1194 | 7.5958 | . 8806 | 30 | I. 4399 |
| 0.1338 | 40 | . 1334 | .1252 | . 9911 | . 9961 | . 1346 | .1291 | 7.4287 | . 8709 | 20 | I.4370 |
| 0.1367 | 50 | . 1363 | . 1345 | . 9907 | . 9959 | . 1376 | . 1385 | 7.2687 | .86I 5 | 10 | I. 4341 |
| 0.1396 | $8^{\circ} 00^{\prime}$ | .1392 | 9.1436 | . 9903 | 9.9958 | . 1405 | 9.1478 | 7.1154 | $0.8522$ | $82^{\circ} 00^{\prime}$ | I. 4312 |
| 0.1425 | 10 | .142I | . 1525 | . 9899 | . 9956 | . 1435 | . 1569 | 6.9682 | .843I | 50 | 1.4283 |
| 0.1454 | 20 | .1449 | .1612 | . 9894 | . 9954 | . 1465 | .1658 | 6.8269 | .8342 | 40 | 1.4254 |
| 0.1484 | 30 | .1478 | .1697 | . 9890 | . 9952 | . 1495 | .1745 | 6.6912 | . 8255 | 30 | 1.4224 |
| 0.1513 | 40 | .1507 | .1781 | . 9888 | . 9950 | . 1524 | .1831 | 6.5606 | 8169 8085 | 20 | 1.4195 |
| 0.1542 | 50 | .1536 | . 1863 | .988I | . 9948 | . 1554 | .1915 | 6.4348 | . 8085 | 10 | 1.4166 |
| 0.1571 | $9^{\circ} 00^{\prime}$ | . 1564 | 9.1943 | . 9877 | 9.9946 | . 1584 | 9.1997 | 6.3138 | 0.8003 | $81^{\circ} 00^{\prime}$ | 1.4137 |
|  |  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. | 空 |  |
|  |  | COSINES. |  | SINES. |  | COTANGENTS. |  | TANGENTS. |  |  |  |

Table 14 (continued).
CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

|  |  | SINES. |  | COSINES. |  | TANGENTS. |  | COTANGENTS. |  | $81^{\circ}{ }^{\circ}{ }^{\prime}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |  |
| 0.1571 | $9^{\circ} 00^{\prime}$ | . 1564 | 9.1943 | . 9877 | 9.9946 | .1584 | 9.1997 | 6.3138 | 0.8003 |  | 1.4137 |
| 0.1600 | 10 | . 1593 | . 2022 | . 9872 | . 9944 | .1614 | . 2078 | 6.1970 | . 7922 | 50 | 1.4108 |
| 0.1629 | 20 | . 1622 | . 2100 | . 9868 | . 9942 | . 1644 | . 2158 | 6.0844 | .7842 | 40 | 1. 4079 |
| 0.1658 | 30 | . 1650 | . 2176 | .9863 | . 9940 | . 1673 | . 2236 | 5.9758 | .7764 | 30 | 1.4050 |
| 0.1687 | 40 | .1679 | . 2251 | .9858 | .9938 | .1703 | .2313 | 5.8708 | .7687 | 20 | 1.4021 |
| 0.1716 | 50 | .1708 | . 2324 | . 9853 | .9936 | . 1733 | . 2389 | 5.7694 | .7611 | 10 | 1. 3992 |
| 0.1745 | $10^{\circ} 0^{\prime}$ | .1736 | 9.2397 | . 9848 | 9.9934 | .1763 | 9.2463 | 5.6713 | 0.7537 | $80^{\circ} 00^{\prime}$ | 1.3963 |
| 0.1774 | 10 | . 1765 | . 2468 | . 9843 | . 9931 | . 1793 | . 2536 | $5 \cdot 5764$ | . 7464 | 50 | 1.3934 |
| 0.1804 | 20 | . 1794 | . 2538 | . 9838 | . 9929 | . 1823 | . 2609 | 5.4845 | . 7391 | 40 | 1.3904 |
| 0.1833 | 30 | .1822 | . 2606 | . 9833 | . 9927 | .1853 | . 2680 | $5 \cdot 3955$ | . 7320 | 30 | I. 3875 |
| 0.1862 | 40 | .1851 | . 2674 | . 9827 | . 9924 | . 1883 | . 2750 | $5 \cdot 3093$ | . 7250 | 20 | I. 3846 |
| 0.1891 | 50 | . 1880 | . 2740 | . 9822 | . 9922 | .1914 | .2819 | 5.2257 | .7181 | 10 | 1.3817 |
| 0.1920 | $\mathrm{II}^{\circ} \mathrm{OO}{ }^{\prime}$ | . 1908 | 9.2806 | .9816 | 9.9919 | . 1944 | 9.2887 | 5.1446 | 0.7113 | $79^{\circ} 00^{\prime}$ | I. 3788 |
| 0.1949 | 10 | . 1937 | . 2870 | .98II | . 9917 | . 1974 | . 2953 | 5.0658 | . 7047 | 50 | I. 3759 |
| 0.1978 | 20 | . 1965 | . 2934 | . 9805 | . 9914 | . 2004 | . 3020 | 4.9894 | . 6980 | 40 | I. 3730 |
| 0.2007 | 30 | . 1994 | . 2997 | . 9799 | .9912 | . 2035 | . 3085 | 4.9152 | .6915 | 30 | 1.3701 |
| 0.2036 | 40 | . 2022 | .3058 | . 9793 | $\cdot .9909$ | . 2065 | .3149 | 4.8430 | . 6851 | 20 | I. 3672 |
| 0.2065 | 50 | . 2051 | -3119 | . 9787 | . 9907 | . 2095 | .3212 | 4.7729 | . 6788 | 10 | I. 3643 |
| 0.2094 | $12^{\circ} \mathrm{OO}{ }^{\prime}$ | . 2079 | 9.3179 | .9781 | 9.9904 | . 2126 | 9.3275 | 4.7046 | 0.6725 | $8^{\circ} 00^{\prime}$ | I. 3614 |
| 0.2123 | 10 | . 2108 | . 3238 | . 9775 | .9901 | . 2156 | . 3336 | 4.6382 | . 6664 | 50 | 1.3584 |
| 0.2153 | 20 | . 2136 | - 3296 | . 9769 | . 9899 | . 2186 | - 3397 | 4.5736 | . 6603 | 40 | I. 3555 |
| 0.2182 | 30 | . 2164 | . 3353 | .9763 | . 9896 | . 2217 | - 3458 | 4.5107 | .6542 | 30 | 1.3526 |
| 0.2211 | 40 | . 2193 | . 3410 | . 9757 | . 9893 | . 2247 | -3517 | 4.4494 | .6483 | 20 | I. 3497 |
| 0.2240 | 50 | . 2221 | -3466 | . 9750 | . 9890 | . 2278 | -3576 | $4 \cdot 3897$ | . 6424 | 10 | I. 3468 |
| 0.2269 | $13^{\circ} 0^{\prime}$ | . 2250 | 9.3521 | . 9744 | 9.9887 | . 2309 | 9.3634 | 4.3315 | 0.6366 | $77^{\circ} 0^{\prime}$ | 1.3439 |
| 0.2298 | 10 | . 2278 | . 3575 | :9737 | . 9884 | . 2339 | . 3691 | 4.2747 | . 6309 | 50 | 1.3410 |
| 0.2327 | 20 | . 2306 | . 3629 | . 9730 | . 988 I | . 2370 | - 3748 | 4.2193 | . 6252 | 40 | 1.3381 |
| 0.2356 | 30 | . 2334 | - 3682 | . 9724 | .9878 | . 2401 | -3804 | 4.1653 | . 6196 | 30 | I. 3352 |
| 0.2385 | 40 | . 2363 | - 3734 | . 9717 | .9875 | . 2432 | - 3859 | 4.1126 | . 6141 | 20 | 1.3323 |
| 0.2414 | 50 | . 2391 | . 3786 | . 9710 | .9872 | . 2462 | -3914 | 4.0611 | . 6086 | 10 | 1.3294 |
| 0.2443 | $14^{\circ} 0^{\prime}$ | . 2419 | 9.3837 | . 9703 | 9.9869 | . 2493 | 9.3968 | 4.0108 | 0.6032 | $76^{\circ} 00^{\prime}$ | 1. 3265 |
| 0.2473 | 10 | . 2447 | . 3887 | . 9696 | . 9866 | . 2524 | . 4021 | 3.9617 | . 5979 | 50 | 1.3235 |
| 0.2502 | 20 | . 2476 | - 3937 | . 9689 | . 9863 | . 2555 | .4074 | 3.9136 | . 5926 | 40 | 1.3206 |
| 0.253 I | 30 | . 2504 | - 3986 | . 968 I | .9859 | . 2586 | .4127 | 3.8667 | . 5873 | 30 | 1.3177 |
| 0.2560 | 40 | . 2532 | . 4035 | . 9674 | . 9856 | . 2617 | . 4178 | 3.8208 | . 5822 | 20 | 1.3148 |
| 0.2589 | 50 | . 2560 | .4083 | . 9667 | .9853 | . 2648 | .4230 | 3.7760 | . 5770 | 10 | 1.3119 |
| 0.2618 | $15^{\circ} 00^{\prime}$ | . 2588 | 9.4130 | . 9659 | 9.9849 | . 2679 | 9.4281 | 3.7321 | 0.5719 | $75^{\circ} \mathrm{OO}$ | I. 3090 |
| 0.2647 | 10 | . 2616 | . 4177 | . 9652 | . 9846 | .2711 | $.4331$ | 3.6891 | . 5669 | 50 | 1.3061 |
| 0.2676 | 20 | . 2644 | .4223 | . 9644 | . 9843 | . 2742 | . 4381 | 3.6470 | . 5619 | 40 | 1.3032 |
| 0.2705 | 30 | . 2672 | . 4269 | . 9636 | . 9839 | . 2773 | . 4430 | 3.6059 | . 5570 | 30 | 1.3003 |
| 0.2734 | 40 | . 2700 | . 4314 | . 9628 | .9836 | . 2805 | .4479 | 3.5656 | . 5521 | 20 | 1.2974 |
| 0.2763 | 50 | . 2728 | .4359 | .962 I | .9832 | .2836 | .4527 | 3.5261 | . 5473 | 10 | 1. 2945 |
| 0.2793 | $16^{\circ} 00^{\prime}$ | .2756 | 9.4403 | .9613 | 9.9828 | . 2867 | 9.4575 | 3.4874 | 0.5425 | $74^{\circ} \mathrm{OO}$ | 1.2915 |
| 0.2822 | 10 | .2784 | . 4447 | .9605 | .9825 | . 2899 | . 4622 | 3.4495 | . 5378 | 50 | $1.2886$ |
| 0.2851 | 20 | . 2812 | .449I | . 9596 | .982I | . 293 I | .4669 | 3.4124 | . 5331 | 40 | I. 2857 |
| 0.2880 | 30 | . 2840 | .4533 | . 9588 | $\cdot .9817$ | . 2962 | .4716 | 3.3759 | . 5284 | 30 | 1.2828 |
| 0.2909 | 40 | . 2868 | .4576 | . 9580 | .9814 | . 2994 | .4762 | $3 \cdot 3402$ | . 5238 | 20 | 1.2799 |
| 0.2938 | 50 | . 2896 | .4618 | . 9572 | .9810 | . 3026 | . 4808 | $3 \cdot 3052$ | . 5192 | 10 | 1.2770 |
| 0.2967 | $17^{\circ} 00^{\prime}$ | . 2924 | 9.4659 | . 9563 | 9.9806 | . 3057 | 9.4853 | 3.2709 | 0.5147 | $73^{\circ} 00 \prime$ | 1.2741 |
| 0.2996 | 10 | . 2952 | . 4700 | . 9555 | . 9802 | . 3089 | . 4898 | 3.237 I | . 5102 | 50 | 1.2712 |
| 0.3025 | 20 | . 2979 | .4741 | . 9546 | . 9798 | -3121 | .4943 | 3.2041 | . 5057 | 40 | 1.2683 |
| 0.3054 | 30 | - 3007 | . 4781 | . 9537 | . 9794 | . 3153 | . 4987 | 3.1716 | . 5013 | 30 | 1.2654 |
| 0.3083 | 40 | .3035 | . 4821 | . 9528 | . 9790 | . 3185 | . 5031 | 3.1397 | . 4969 | 20 | 1.2625 |
| 0.3113 | 50 | - 3062 | .4861 | . 9520 | . 9786 | . 3217 | . 5075 | 3.1084 | .4925 | 10 | 1.2595 |
| 0.3142 | $18^{\circ} 00^{\prime}$ | . 3090 | 9.4900 | .9511 | 9.9782 | . 3249 | 9.5118 | 3.0777 | 0.4882 | $72^{\circ} 00^{\prime}$ | I. 2566 |
|  |  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. | ) |  |
|  |  | CoS | INES |  | ES. |  | AN- | TANG | ENTS | R10 | 穴苋 |

Smithsonian Tables.

CIRCULAR（TRIGONOMETRIC）FUNCTIONS．

| $\begin{aligned} & \text { 家苋 } \\ & \text { 品 } \end{aligned}$ |  | SINES． |  | COSINES． |  | TANGENTS． |  | COTANGENTS． |  | $72^{\circ} 00^{\prime}$ | 1.2566 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Nat． | Log． | Nat． | Log． | Nat． | Log． | Nat． | Log． |  |  |
| 0.3142 | $18^{\circ} 00^{\prime}$ | － 3090 | 9.4900 | ． 9511 | 9.9782 | ． 3249 | 9．5118 | 3.0777 | 0.4882 |  |  |
| 0.3171 | 10 | ．3118 | .4939 | ． 9502 | ． 9778 | －3281 | ．516I | 3.0475 | ． 4839 | 50 | 1.2537 |
| 0.3200 | 20 | －3145 | ． 4977 | ． 9492 | ． 9774 | ． 3314 | ． 5203 | 3.0178 | ． 4797 | 40 | 1． 2508 |
| 0.3229 | 30 | ． 3173 | － 5015 | ． 9483 | ． 9770 | － 3346 | ． 5245 | 2.9887 | ． 4755 | 30 | 1.2479 |
| 0.3258 | 40 | ． 3201 | ． 5052 | ． 9474 | .9765 | ． 3378 | ． 5287 | 2.9600 | ． 4713 | 20 | I． 2450 |
| 0.3287 | 50 | －3228 | － 5090 | ． 9465 | ． 9761 | －3411 | ． 5329 | 2.9319 | ．467 I | 10 | 1.2421 |
| 0.3316 | $19^{\circ} 00^{\prime}$ | ． 3256 | 9．5126 | ． 9455 | 9.9757 | ． 3443 | 9.5370 | 2.9042 | 0.4630 | $71^{\circ} 00^{\prime}$ | 1.2392 |
| 0.3345 | 10 | ． 3283 | ． 5163 | ． 9446 | ． 9752 | ． 3476 | ． 54111 | 2.8770 | ． 4589 | 50 | 1.2363 |
| 0.3374 | 20 | ．3311 | ． 5199 | ． 9436 | ． 9748 | －3508 | －5451 | 2.8502 | ． 4549 | 40 | 1.2334 |
| 0.3403 | 30 | －3338 | ． 5235 | ． 9426 | ． 9743 | －354 1 | －5491 | 2.8239 | ． 4509 | 30 | 1.2305 |
| 0.3432 | 40 | － 3365 | ． 5270 | .9417 | ． 9739 | －3574 | ． 5531 | 2.7980 | ． 4469 | 20 | 1.2275 |
| 0.3462 | 50 | ． 3393 | ． 5306 | ． 9407 | ． 9734 | ． 3607 | ． 5571 | 2.7725 | ． 4429 | 10 | 1.2246 |
| 0.3491 | $20^{\circ} 00^{\prime}$ | ． 3420 | 9．5341 | ． 9397 | 9.9730 | ． 3640 | 9．5611 | 2.7475 | 0.4389 | $70^{\circ} 00^{\prime}$ | 1.2217 |
| 0.3520 | 10 | － 3448 | ． 5375 | .9387 | ． 9725 | ． 3673 | ． 5650 | 2.7228 | ． 4350 | 50 | 1.2188 |
| 0.3549 | 20 | － 3475 | － 5409 | ． 9377 | ． 9721 | ． 3706 | ． 5689 | 2.6985 | ．4311 | 40 | 1.2159 |
| 0.3578 | 30 | ． 3502 | ． 5443 | ． 9367 | ．9716 | ． 3739 | ． 5727 | 2.6746 | ． 4273 | 30 | 1.2130 |
| 0.3607 | 40 | ． 3529 | ． 5477 | ． 9356 | ． 9711 | ． 3772 | ． 5766 | 2.6511 | ． 4234 | 20 | 1.2101 |
| 0.3636 | 50 | －3557 | ． 5510 | ． 9346 | ． 9706 | ． 3805 | ． 5804 | 2.6279 | ．4196 | 10 | 1.2072 |
| 0.3665 | $21^{\circ} 0^{\prime \prime}$ | ． 3584 | 9.5543 | ． 9336 | 9.9702 | ． 3839 | 9.5842 | 2.6051 | 0.4158 | $69^{\circ} 00^{\prime}$ | 1.2043 |
| 0.3694 | IO | －3611 | ． 5576 | .9325 | ． 9697 | ． 3872 | ． 5879 | 2.5826 | ． 412 I | 50 | 1.2014 |
| 0.3723 | 20 | ． 3638 | ． 5609 | .9315 | .9692 | － 3906 | ． 5917 | 2.5605 | .4083 | 40 | 1． 1985 |
| 0.3752 | 30 | ． 3665 | ． 5641 | ． 9304 | ． 9687 | ． 3939 | ． 5954 | 2.5386 | ． 4046 | 30 | 1.1956 |
| 0.3782 | 40 | ． 3692 | .5673 | ． 9293 | ． 9682 | ． 3973 | ． 5991 | 2.5172 | .4009 | 20 | 1．1926 |
| 0.3811 | 50 | ． 3719 | ． 5704 | ． 9283 | ． 9677 | ． 4006 | ． 6028 | 2.4960 | ． 3972 | 10 | 1．1897 |
| 0.3840 | $22^{\circ} 0^{\prime}$ | ． 3746 | 9.5736 | ． 9272 | 9.9672 | ． 4040 | 9.6064 | 2.4751 | 0.3936 | $68^{\circ}{ }^{\circ}{ }^{\prime}$ | I． 1868 |
| 0.3869 | 10 | － 3773 | ． 5767 | ． 9261 | ． 9667 | ． 4074 | ． 6100 | 2.4545 | ． 3900 | 50 | I． 1839 |
| 0.3898 | 20 | ． 3800 | ． 5798 | ． 9250 | ． 9661 | .4108 | ．6136 | 2.4342 | ． 3864 | 40 | 1.1810 |
| 0.3927 | 30 | ． 3827 | ． 5828 | ． 9239 | ． 9656 | .4142 | ． 6172 | 2.4142 | －3828 | 30 | 1.1781 |
| 0.3956 | 40 | .3854 | ． 5859 | ． 9228 | ． 9651. | ． 4176 | ． 6208 | 2.3945 | ． 3792 | 20 | 1．1752 |
| 0.3985 | 50 | ． 3881 | ． 5889 | ． 9216 | ． 9646 | ． 4210 | ． 6243 | 2.3750 | ． 3757 | IO | 1.1723 |
| 0.4014 | $23^{\circ} 00^{\prime}$ | － 3907 | 9．5919 | ． 9205 | 9.9640 | ． 4245 | 9.6279 | 2.3559 | 0.3721 | $67^{\circ} 00^{\prime}$ | 1.1694 |
| 0.4043 | 10 | － 3934 | － 5948 | ． 9194 | .9635 | ． 4279 | .6314 | 2.3369 | ． 3686 | 50 | 1.1665 |
| 0.4072 | 20 | －3961 | ． 5978 | ． 9182 | ． 9629 | .4314 | ． 6348 | 2.3183 | － 3652 | 40 | 1.1636 |
| 0.4102 | 30 | － 3987 | ． 6007 | ．9171 | ． 9624 | －4348 | .6383 | 2.2998 | ． 3617 | 30 | 1． 1606 |
| 0.4131 | 40 | ． 4014 | ． 6036 | ．9159 | ．9618 | .4383 | .6417 | 2.2817 | $\cdot 3583$ | 20 | $\text { 1. } 1577$ |
| 0.4160 | 50 | ． 4041 | ． 6065 | ．9147 | .9613 | ． 4417 | .6452 | 2.2637 | ． 3548 | 10 | $1.1548$ |
| 0.4189 | $24^{\circ} 0^{\prime}$ | ． 4067 | 9.6093 | ． 9135 | 9.9607 | ． 4452 | 9.6486 | 2.2460 | 0.3514 | $66^{\circ} 00^{\prime}$ | I．1519 |
| 0.4218 | 10 | ． 4094 | ．612I | ．9124 | ． 9602 | ． 4487 | ． 6520 | 2.2286 | ． 3480 | 50 | 1.1490 |
| 0.4247 | 20 | ． 4120 | ．6149 | ．9112 | ． 9596 | ． 4522 | .6553 | 2.2113 | ． 3447 | 40 | 1.146 I |
| 0.4276 | 30 | ． 4147 | ． 6177 | .9100 | ． 9590 | ． 4557 | .6587 | 2.1943 | .3413 | 30 | 1.1432 |
| 0.4305 | 40 | .4173 | ． 6205 | ． 9088 | ． 9584 | ． 4592 | ． 6620 | 2.1775 | ． 3380 | 20 | 1.1403 |
| 0.4334 | 50 | ． 4200 | ． 6232 | ． 9075 | ． 9579 | ． 4628 | ． 6654 | 2.1609 | ． 3346 | 10 | 1.1374 |
| 0.4363 | $25^{\circ} 00^{\prime}$ | ． 4226 | 9.6259 | ． 9063 | 9.9573 | ． 4663 | 9.6687 | 2.1445 | 0.3313 | $65^{\circ}{ }^{\circ} 0^{\prime}$ | 1.1345 |
| 0.4392 | 10 | ． 4253 | ． 6286 | ．9051 | ． 9567 | ． 4699 | ． 6720 | 2.1283 | ． 3280 | 50 | I．1316 |
| 0.4422 | 20 | ． 4279 | ． 6313 | ． 9038 | ． 9561 | ． 4734 | ． 6752 | 2.1123 | －3248 | 40 | 1.1286 |
| 0.4451 | 30 | ． 4305 | ． 6340 | ． 9026 | ． 9555 | ． 4770 | ． 6785 | 2.0965 | －3215 | 30 | 1.1257 |
| 0.4480 | 40 | ．4331 | ． 6366 | ． 9013 | ． 9549 | ． 4806 | ．6817 | 2.0809 | －3183 | 20 | 1.1228 |
| 0.4509 | 50 | ． 4358 | ． 6392 | ． 9001 | ．9543 | ． 4841 | ． 6850 | 2.0655 | ．3150 | 10 | 1.1199 |
| 0.4538 | $26^{\circ} 00^{\prime}$ | ． 4384 | 9.6418 | ． 8988 | 9.9537 | ． 4877 | 9.6882 | 2.0503 | 0.3118 | $64^{\circ} \mathrm{OO}$ | 1.1170 |
| 0.4567 | 10 | ． 4410 | ． 6444 | ． 8975 | ． 95330 | ． 4913 | ． 6914 | 2.0353 | $\cdot 3086$ | 50 | I．1141 |
| 0.4596 | 20 | .4436 | ． 6470 | ． 8962 | ． 9524 | ． 4950 | ． 6946 | 2.0204 | － 3054 | 40 | 1.1112 |
| 0.4625 | 30 | ． 4462 | ． 6495 | ． 8949 | ．9518 | ． 4986 | ． 6977 | 2.0057 | － 3023 | 30 | 1.1083 |
| 0.4654 | 40 | $.4488$ | .6521 | ． 8936 | .9512 | $.5022$ | .7009 | 1.9912 | ． 2991 | 20 | 1.1054 |
| 0.4683 | 50 | ． 4514 | ． 6546 | ． 8923 | ． 9505 | －50．59 | ． 7040 | 1.9768 | ． 2960 | 10 | 1.1025 |
| 0.4712 | $27^{\circ} 00^{\prime}$ | ． 4540 | 9.6570 | ． 8910 | 9.9499 | ． 5095 | 9.7072 | 1.9626 | 0.2928 | $63^{\circ}{ }^{\circ}{ }^{\prime}$ | 1.0996 |
|  |  | Nat． | Log． | Nat． | Log． | Nat． | Log． | Nat． | Log． | ¢1 |  |
|  |  | COSI | NES． | SIN | NES． | $\begin{aligned} & \text { COT } \\ & \text { GEN } \end{aligned}$ | $\begin{aligned} & \text { rAN- } \\ & \text { NTS. } \end{aligned}$ | TANG | ENTS． |  | «K |

TABLE 14 (continued).
CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

| $\begin{aligned} & \frac{1}{8} \dot{8} \\ & \sum_{4}^{2} \end{aligned}$ |  | SINES. | COSINES. | TANGENTS. | COTANGENTS. | $63^{\circ} 00^{\prime}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Nat. Log. | Nat. Log. | Nat. Log. | Nat. Log. |  |  |
| 0.4712 | $27^{\circ} 00^{\prime}$ | . 45409.6570 | . 89109.9499 | . 50959.7072 | 1.96260 .2928 |  | 1.0996 |
| 0.4741 | 10 | . 4566.6595 | . 8897 . 9492 | .5132 .7103 | 1.9486 .2897 | 50 | 1.0966 |
| 0.4771 | 20 | . 4592.6620 | . 8884 . 9486 | $.5169 \quad .7134$ | 1.9347 . 2866 | 40 | 1.0937 |
| 0.4800 | 30 | .4617 . 6644 | . 8870.9479 | .5206 .7165 | 1.9210 .2835 | 30 | 1.0908 |
| 0.4829 | 40 | .4643 . 6668 | .8857 . 9473 | .5243 .7196 | 1.9074 .2804 | 20 | 1.0879 |
| 0.4858 | 50 | .4669 .6692 | . 8843 . 9466 | .5280 .7226 | 1.8940 .2774 | 10 | 1.0850 |
| 0.4887 | $28^{\circ} 00^{\prime}$ | . 46959.6716 | . 88299.9459 | $\begin{array}{ll}.5317 & 9.7257\end{array}$ | 1.88070 .2743 | $62^{\circ} 00^{\prime}$ | I. 0821 |
| 0.4916 | 10 | .4720 . 6740 | .8816 .9453 | . 5354 .7287 | 1.8676 .2713 | 50 | 1.0792 |
| 0.4945 | 20 | . 4746 . 6763 | .8802 .9446 | . 5392 .7317 | 1.8546 . 2683 | 40 | 1.0763 |
| 0.4974 | 30 | .4772 6787 | . 8788 .9439 | .5430 | 1.8418 . 2652 | 30 | 1.0734 |
| 0.5003 | 40 | .4797 .6810 | . 8774 .9432 | . 5467 . 7378 | 1.8291 . 2622 | 20 | 1.0705 |
| 0.5032 | 50 | .4823 .6833 | . 8760.9425 | .5505 .7408 | 1.8165 . 2592 | 10 | 1.0676 |
| 0.5061 | $29^{\circ} 00^{\prime}$ | .4848 9.6856 | . 8746 . 9.9418 | . 5543 9.7438 | $\begin{array}{lll}1.8040 & 0.2562\end{array}$ | $61^{\circ} \mathrm{O}{ }^{\prime}$ | 1.0647 |
| 0.5091 | 10 | . 4874 . 6878 | . 8732.9411 | . 5581 | 1.7917 .2533 | 50 | 1.0617 |
| 0.5120 | 20 | .4899 .6901 | . 8718.9404 | .5619 .7497 | 1.7796 .2503 | 40 | 1.0588 |
| 0.5149 | 30 | .4924, 6923 | . 8704.9397 | . 5658 . 7526 | 1.7675 . 2474 | 30 | 1.0559 |
| 0.5178 | 40 | .4950 .6946 | . 8689.9390 | .5696 .7556 | 1.7556 . 2444 | 20 | 1.0530 |
| 0.5207 | 50 | . 4975.6968 | . 5675.9383 | . 5735 .7585 | 1.7437 .2415 | 10 | I. 0501 |
| 0.5236 | $30^{\circ} 00^{\prime}$ | . 50009.6990 | . 86609.9375 | . 57749.7614 | 1.73210 .2386 | $60^{\circ} 00^{\prime}$ | 1.0472 |
| 0.5265 | 10 | .5025 . 7012 | . 8646 . 9368 | .5812 | 1.7205 . 2356 | 50 | 1.0443 |
| 0.5294 | 20 | $.5050 \cdot 7033$ | . 8631 .9361 | .5851 .7673 | 1.7090 .2327 | 40 | 1.0414 |
| 0.5323 | 30 | .5075 .7055 | . 8616.9353 | . 5890 .7701 | 1.6977 . 2299 | 30 | 1.0385 |
| 0.5352 | 40 | .5100 .7076 | . 8601.9346 | .5930 .7730 | 1.6864 . 2270 | 20 | 1.0356 |
| 0.5381 | 50 | . 5125 .7097 | .8587 .9338 | . $5969 \quad .7759$ | 1.6753 .2241 | 10 | 1.0327 |
| 0.5411 | $31^{\circ} 00^{\prime}$ | . 51509.7118 | . 85729.933 I | . 60097.7788 | 1.66430 .2212 | $59^{\circ} 00^{\prime}$ | 1.0297 |
| 0.5440 | 10 | .5175 .7139 | . 8557.9323 | . 6048 .7816 | $1.6534-2184$ | 50 | 1.0268 |
| 0.5469 | 20 | .5200 .7160 | .8542 .9315 | . 6088 .7845 | 1. 6426 .2155 | 40 | 1.0239 |
| 0.5498 | 30 | . 5225 .718I | . 8526 -9308 | . 6128 .7873 | 1.6319 .2127 | 30 | 1.0210 |
| 0.5527 | 40 | .5250 .7201 | . 8511.9300 | .6168 .7902 | 1.6212 .2098 | 20 | 1.0181 |
| -. 5556 | 50 | . 5275 .7222 | . 8496.9292 | .6208 .7930 | 1.6107 . 2070 | 10 | 1.0152 |
| 0.5585 | $32^{\circ} 00^{\prime}$ | -5299 9.7242 | $.8480 \quad 9.9284$ | 6249 9.7958 | 1.60030 .2042 | $5^{8}{ }^{\circ} 00^{\prime}$ | 1.0123 |
| 0.5614 | 10 | . 5324 .7262 | $.8465 \quad .9276$ | . 6289.7986 | 1.5900 .2014 | 50 | 1.0094 |
| 0.5643 | 20 | . 5348 .7282 | . 8450.9268 | . 6330 . 8014 | I. 5798 . 1986 | 40 | 1.0065 |
| 0.5672 | 30 | .5373 .7302 | .8434 .9260 | . 6371 . 8042 | I. 5697 . 1958 | 30 | 1.0036 |
| 0.5701 | 40 | . 5398 . 7322 | .8418 . 9252 | . 6412 . 8070 | 1.5597 . 1930 | 20 | 1.0007 |
| 0.5730 | 50 | . 5422.7342 | . 8403.9244 | . 6453 . 8097 | 1.5497 . 1903 | 10 | 0.9977 |
| 0.5760 | $33^{\circ 00}{ }^{\prime}$ | . 5446 9.7361 | . 83878 | . 6494 9:8125 | I. 53990.1875 | $57^{\circ} \mathrm{O} 0^{\prime}$ | $0.99+8$ |
| 0.5789 | 10 | . 5471 I .7380 | . 8371 I 9228 | .6536 .8153 | 1.5301 .1847 | 50 | 0.9919 |
| 0.5818 | 20 | .5495 .7400 | . 8355 .9219 | . 6577 .8180 | 1.5204 . 1820 | 40 | 0.9890 |
| 0.5847 | 30 | .5519 .7419 | . 8339 .9211 | . 6619 . 8208 | 1.5108 . 1792 | 30 | 0.9861 |
| 0.5876 | 40 | .5544 .7438 | .8323 .9203 | .6661 . 8235 | $1.5013 \quad .1765$ | 20 | 0.9832 |
| 0.5905 | 50 | . 5568 .7457 | . 8307.9194 | . 6703.8263 | 1.4919 .1737 | 10 | 0.9803 |
| 0.5934 | $34^{\circ} 00^{\prime}$ | . 55929.7476 | . 82909.9186 | . 67459.8290 | 1.48260 .1710 | $5^{6}{ }^{\circ} 0^{\prime}$ | 0.9774 |
| 0.5963 | 34 | . 5616 .7494 | . 8274 .9177 | . 6787 | 1.4733 .1683 | 50 | 0.9745 |
| 0.5992 | 20 | $.5640 \quad .7513$ | . 8258 . 9169 | $.6830 \quad .8344$ | 1.4641 | 40 | 0.9716 |
| 0.6021 | 30 | . 5664 .7531 | .8241 9160 | .6873 . 837 I | 1.4550 . 1629 | 30 | 0.9687 |
| 0.6050 | 40 | .5688 .7550 | . 8225 .9151 | .6916 . 8398 | I. 4460 . 1602 | 20 | 0.9657 |
| 0.6080 | 50 | . 5712 . 7568 | . 8208 .9142 | . 6959.8425 | 1.4370 . 1575 | 10 | 0.9628 |
| 0.6109 | $35^{\circ} 00^{\prime}$ | . 57369.7586 | .8192 9.9134 | .70029 .8452 | 1.428 I | $55^{\circ} 0^{\prime}$ | 0.9599 |
| 0.6138 | 10 | $.5760 \quad .7604$ | . $8175 \quad .9125$ | .7046 .8479 | 1.4193 .1521 | 50 | 0.9570 |
| 0.6167 | 20 | $.5783 \quad .7622$ | .8158 .9116 | $.7089 \quad .8506$ | 1.4106 .1494 | 40 | 0.9541 |
| 0.6196 | 30 | .5807 . 7640 | $\begin{array}{ll}.8141 & .9107\end{array}$ | $.7133-8533$ | 1.4019 .1467 | 30 | $0.9512$ |
| 0.6225 | 40 | . 583 ll | .8124 .9098 | .7177 | $1.3934-1441$ | 20 | 0.9483 |
| 0.6254 | 50 | .5854 .7675 | 8107 .9089 | 7221858 | 1.3848 . 1414 | 10 | 0.9454 |
| 0.6283 | $36^{\circ} 00^{\prime}$ | $\begin{array}{ll}.5878 & 9.7692\end{array}$ | 8090 9.9080 | $\begin{array}{lll}.7265 & 9.8613\end{array}$ | 1.37640 .1387 | $54^{\circ} 00^{\prime}$ | 0.9425 |
|  |  | Nat. Log. | Nat. Log. | Nat. Log. | Nat. Log. |  |  |
|  |  | COSINES. | SINES. | COTANGENTS. | TANGENTS. |  | ¢ |

Smithsonian Tables.

TABLE 14 (continued).
CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

|  |  | SINES. |  | COSINES. |  | TANGENTS. |  | COTANGENTS. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |  |
| 0.6283 | $36^{\circ} 00^{\prime}$ | .5878 | 9.7692 | . 8090 | 9.9080 | .7265 | 9.8613 | 1. 3764 | 0.1387 | $54^{\circ} 00^{\prime}$ | 0.9425 |
| 0.6312 | 10 | . 5901 | . 7710 | . 8073 | . 9070 | . 7310 | . 8639 | r. 3680 | .1361 | 50 | 0.9396 |
| 0.634 I | 20 | . 5925 | . 7727 | . 8056 | . 9061 | . 7355 | . 8666 | I. 3597 | . 1334 | 40 | 0.9367 |
| 0.6370 | 30 | . 5948 | . 7744 | . 8039 | .9052 | . 7400 | . 8692 | 1.3514 | - 308 | 30 | 0.9338 |
| 0.6400 | 40 | . 5972 | .7761 | . $\mathrm{SO2} 1$ | . 9042 | . 7445 | . 8718 | 1.3432 | . 1282 | 20 | 0.9308 |
| 0.6429 | 50 | . 5995 | . 7778 | . 8004 | . 9033 | . 7490 | . 8745 | 1.3351 | . 1255 | 10 | 0.9279 |
| 0.6458 | $37^{\circ} 00^{\prime}$ | . 6018 | 9.7795 | . 7986 | 9.9023 | . 7536 | 9.8771 | 1.3270 | 0.1229 | $53^{\circ}{ }^{\circ} 0^{\prime}$ | 0.9250 |
| 0.6487 | 10 | . 6041 | .7811 | .7969 | . 9014 | . 7581 | . 8797 | 1.3190 | . 1203 | 50 | 0.9221 |
| 0.6516 | 20 | . 6065 | . 7828 | .7951 | . 9004 | . 7627 | . 8824 | 1.3111 | .ri76 | 40 | 0.9192 |
| 0.6545 | 30 | . 6088 | . 7844 | . 7934 | . 8995 | .7673 | . 8850 | I. 3032 | .1150 | 30 | 0.9163 |
| 0.6574 | 40 | .61II | .7861 | . 7916 | . 8985 | . 7720 | . 8876 | I. 2954 | . 1124 | 20 | 0.9134 |
| 0.6603 | 50 | .6134 | . 7877 | .7898 | . 8975 | . 7766 | . 8902 | 1. 2876 | .1098 | 10 | 0.9105 |
| 0.6632 | $38^{\circ} 00^{\prime}$ | . 6157 | 9.7893 | .7880 | 9.8965 | . 7813 | 9:8928 | 1.2799 | 0.1072 | $5^{\circ}{ }^{\circ} 0^{\prime}$ | 0.9076 |
| 0.666I | 10 | .6180 | .7910 | . 7862 | . 8955 | . 7860 | . 8954 | 1.2723 | . 1046 | 50 | 0.9047 |
| 0.6690 | 20 | . 6202 | . 7926 | . 7844 | . 8945 | . 7907 | . 8980 | I. 2647 | . 1020 | 40 | 0.9018 |
| 0.6720 | 30 | . 6225 | .794I | . 7826 | . 8935 | . 7954 | . 9006 | 1. 2572 | . 0994 | 30 | 0.8988 |
| 0.6749 | 40 | . 6248 | . 7957 | . 7808 | . 8925 | . 8002 | .9032 | 1.2497 | . 0968 | 20 | 0.8959 |
| 0.6778 | 50 | . 6271 | . 7973 | . 7790 | . 8915 | . 8050 | . 9058 | 1.2423 | . 0942 | 10 | 0.8930 |
| 0.6807 | $39^{\circ} 0^{\prime}$ | . 6293 | 9.7989 | . 7771 | 9.8905 | . 8098 | 9.9084 | 1. 2349 | 0.0916 | $51^{\circ} \mathrm{OO}$ | 0.8901 |
| 0.6836 | 10 | . 6316 | . 8004 | . 7753 | . 8895 | . 8146 | .9110 | 1.2276 | .0890 | 50 | 0.8872 |
| 0.6865 | 20 | . 6338 | . 8020 | . 7735 | . 8884 | .8195 | . 9135 | 1.2203 | . 0865 | 40 | 0.8843 |
| 0.6894 | 30 | . 6361 | . 8035 | .7716 | . 8874 | . 8243 | -9161 | 1.2131 | . 0839 | 30 | 0.88 r 4 |
| 0.6923 | 40 | .6383 | . 8050 | . 7698 | . 8864 | . 8292 | .9187 | 1.2059 | .0813 | 20 | 0.8785 |
| 0.6952 | 50 | . 6406 | . 8066 | . 7679 | . 8853 | . 8342 | . 9212 | 1.1988 | . 0788 | 10 | 0.8756 |
| 0.698 I | $40^{\circ} 00^{\prime}$ | . 6428 | 9.8081 | . 7660 | 9.8843 | .8391 | 9.9238 | r.1918 | 0.0762 | $50^{\circ} 00^{\prime}$ | 0.8727 |
| 0.7010 | 10 | . 6450 | . 8096 | . 7642 | . 8832 | . 844 I | .9264 | 1.1847 | . 0736 | 50 | 0.8698 |
| 0.7039 | 20 | . 6472 | .8111 | . 7623 | .8821 | . 8491 | . 9289 | 1.1778 | . 07 I I | 40 | 0.8668 |
| 0.7069 | 30 | . 6494 | .8125 | .760.4 | .88ı0 | . 8541 | . 9315 | 1.1708 | . 0685 | 30 | 0.8639 |
| 0.7098 | 40 | . 6517 | .8140 | . 7585 | . 8800 | . 8591 | . 934 I | 1.1640 | . 0659 | 20 | 0.8610 |
| 0.7127 | 50 | . 6539 | .81 55 | . 7566 | . 8789 | . 8642 | . 9366 | 1.1571 | . 0634 | 10 | 0.8581 |
| 0.7156 | $4 \mathrm{I}^{\circ} 00^{\prime}$ | .6561 | 9.8169 | . 7547 | 9.8778 | . 8693 | 9.9392 | I. 1504 | 0.0608 | $49^{\circ} 00^{\prime}$ | $0.855^{2}$ |
| 0.7185 | 10 | . 6583 | .8184 | . 7528 | . 8767 | . 8744 | . 9417 | 1.1436 | . 0583 | 50 | 0.8523 |
| 0.7314 | 20 | . 6604 | . 8198 | . 7509 | . 8756 | . 8796 | . 9443 | 1.1369 | . 0557 | 40 | 0.8494 |
| 0.7243 | 30 | . 6626 | .8213 | . 7490 | . 8745 | . 8847 | . 9468 | I. 1303 | .0532 | 30 | 0.8465 |
| 0.7272 0.7301 | 40 | . 6648 | .8227 .8241 | . 7470 | . 8733 | . 8899 | . 9494 | I. 1237 | . 0506 | 20 | 0.8436 |
| 0.7301 | 50 | . 6670 | . 8241 | .745 | . 8722 | . 8952 | .9519 | 1.1171 | .0481 | 10 | 0.8407 |
| 0.7330 | $42^{\circ} 00^{\prime}$ | .669r | 9.8255 | .743I | . 9.8711 | -9004 | 9.9544 | I.I 106 | 0.0456 | $8^{\circ} 00^{\prime}$ | 0.8378 |
| 0.7359 | 10 | . 6713 | . 8269 | .7412 | . 8699 | .9057 | . 9570 | I. 1041 | . 0430 | 50 | 0.8348 |
| 0.7389 | 20 | . 6734 | . 8283 | . 7392 | . 8688 | -9110 | . 9595 | 1.0977 | .0405 | 40 | 0.8319 |
| 0.7418 | 30 | . 6756 | . 8297 | . 7373 | . 8676 | .9163 | . 9621 | 1.0913 | .0379 | 30 | 0.8290 |
| 0.7447 | 40 | . 6777 | .83II | . 7353 | . 8665 | . 9217 | .9646 | 1.0850 | . 0354 | 20 | $0.826 \mathbf{I}$ |
| 0.7476 | 50 | . 6799 | . 8324 | . 7333 | . 8653 | . 9271 | . 9671 | 1.0786 | . 0329 | 10 | 0.8232 |
| 0.7505 | $43^{\circ} 00^{\prime}$ | . 6820 | 9.8338 | .7314 | 9.864 I | . 9325 | 9.9697 | 1.0724 | 0.0303 | $47^{\circ} \mathrm{O} 0^{\prime}$ | 0.8203 |
| 0.7534 | 10 | . 6841 | . 8351 | . 7294 | . 8629 | . 9380 | . 9722 | 1.0661 | . 0278 | 50 | 0.8174 |
| 0.7563 | 20 | . 6862 | . 8365 | . 7274 | . 8618 | . 9435 | . 9747 | 1.0599 | .0253 | 40 | 0.8145 |
| 0.7592 | 30 | . 6884 | . 8378 | . 7254 | . 8606 | . 9490 | - 9772 | 1.0538 | . 0228 | 30 | 0.8116 |
| 0.7621 | 40 | . 6905 | .8391 | . 7234 | .8594 8582 | . 9545 | . 9798 | 1.0477 | . 0202 | 20 | 0.8087 |
| 0.7650 | 50 | . 6926 | . 8405 | . 7214 | . 8582 | . 9601 | .9823 | 1.0416 | . 0177 | 10 | 0.8058 |
| 0.7679 | $44^{\circ} 0^{\prime}$ | . 6947 | 9.8418 | .7193 | 9.8569 | .9657 | 9.9848 | 1.0355 | 0.0152 | $46^{\circ} 00^{\prime}$ | 0.8029 |
| 0.7709 | 10 | . 6967 | . 8431 | . 7173 | . 8557 | . 9713 | . 9874 | I. 0295 | . 0126 | 50 | 0.7999 |
| 0.7738 | 20 | . 6988 | . 8444 | . 7153 | . 8545 | . 9770 | .9899 | 1.0235 | . 0101 | 40 | 0.7970 |
| 0.7767 | 30 | . 7009 | . 8457 | . 71133 | .8532 | . 9827 | . 9924 | 1.0176 | . 0076 | 30 | 0.7941 |
| 0.7796 | 40 | . 7030 | . 8469 | .7112 | . 8520 | . 9884 | . 9949 | 1.0117 | .0051 | 20 | 0.7912 |
| 0.7825 | 50 | . 7050 | . 8482 | .7092 | . 8507 | . 9942 | .9975 | 1.0058 | . 0025 | 10 | 0.7883 |
| 0.7854 | $45^{\circ} 00^{\prime}$ | .7071 | 9.8495 | .7071 | 9.8495 | 1.0000 | 0.0000 | 1.0000 | 0.0000 | $45^{\circ} \mathrm{O}{ }^{\prime}$ | 0.7854 |
|  |  | Nat. | Log. | Nat | Log. | Nat. | Log. | Nat. | Log. |  |  |
|  |  | COSI | NES. |  | ES. | COT | $\begin{aligned} & \text { CAN- } \\ & \text { NTS } \end{aligned}$ | TANG | ENTS. | Aㅚㅚ |  |

TABLE 15.
CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

| 岂 | SINES. |  | COSINES. |  | TANGENTS |  | COTANGENTS. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 0.00 | 0.00000 | - $\infty$ | 1.00000 | 0.00000 | $\infty$ | - | $\infty$ | $\infty$ | 00 ${ }^{\circ} 0{ }^{\prime}$ |
| . 01 | . 01000 | 7.99999 | 0.99995 | 9.99998 | 0.01000 | 8.00001 | 99.997 | 1. 99999 | OO 34 |
| . 02 | . 02000 | 8.30100 | . 99980 | .99991 | . 02000 | . 30109 | 49.993 | .69891 | OI 09 |
| . 03 | . 03000 | . 47706 | . 99955 | . 99980 | . 03001 | -47725 | 33.323 | - 52275 | OI 43 |
| . 04 | . 03999 | . 60194 | . 99920 | . 99965 | . 04002 | . 60229 | 24.987 | .39771 | 0218 |
| 0.05 | 0.04998 | 8.69879 | 0.99875 | 9.99946 | 0.05004 | 8.69933 | 19.983 | 1.30067 | $02^{\circ} 5^{\prime \prime}$ |
| . 06 | . 05996 | . 77789 | . 99820 | . 99922 | . 06007 | . 77867 | 16.647 | . 22133 | 0326 |
| . 07 | . 06994 | . 84474 | . 99755 | . 99894 | . 07011 | . 84581 | 14.262 | . 15419 | 04 OI |
| . 08 | . 07991 | . 90263 | . 99680 | . 99861 | .08017 | . 90402 | 12.473 | . 09598 | 0435 |
| . 09 | . 08988 | . 95366 | . 99595 | . 99824 | . 09024 | . 95542 | 11.081 | . 04458 | 0509 |
| 0.10 | 0.09983 | 8.99928 | 0.99500 | 9.99782 | 0.10033 | 9.00145 | 9.9666 | 0.99855 | $05^{\circ} 44^{\prime}$ |
| . I 1 | . 10978 | 9.04052 | . 99396 | . 99737 | . 11045 | . 04315 | 9.0542 | . 95685 | 0618 |
| . 12 | . 11971 | .07814 | . 99281 | . 99687 | . 12058 | . 08127 | 8.2933 | .91873 | 0653 |
| . 13 | . 12963 | . 11272 | .99156 | . 99632 | . 13074 | .11640 | 7.6489 | .88360 | 0727 |
| . 14 | . 13954 | . 14471 | . 99022 | . 99573 | . 14092 | . 14898 | 7.0961 | .85102 | 08 or |
| 0.15 | 0.14944 | 9.17446 | 0.98877 | $9.995^{10}$ | 0.15114 | 9.17937 | 6.6166 | 0.82063 | $0^{\circ} 8^{\circ} 6^{\prime}$ |
| . 16 | . 15932 | . 20227 | . 98723 | . 99442 | .16138 | . 20785 | 6.1966 | . 79215 | 09 IO |
| .17 | . 16918 | . 22836 | . 98558 | . 99369 | .17166 | . 23466 | 5.8256 | .76534 | 0944 |
| . 18 | . 17903 | . 25292 | . 98384 | . 99293 | .18197 | . 26000 | 5.4954 | . 74000 | 1019 |
| . 19 | . 18886 | .27614 | . 98200 | .99211 | . 19232 | . 28402 | 5.1997 | . 71598 | 1053 |
| 0.20 | 0.19867 | 9.29813 | 0.98007 | 9.99126 | 0.20271 | 9.30688 | 4.9332 | 0.69312 | $\mathrm{II}^{\circ}{ }_{2} 8^{\prime}$ |
| . 21 | . 20846 | . 31902 | . 97803 | . 99035 | . 21314 | . 32867 | 4.6917 | . 67133 | 1202 |
| . 22 | . 21823 | . 33891 | . 97590 | . 98940 | . 22362 | -34951 | 4.4719 | . 65049 | $\begin{array}{ll}12 & 36\end{array}$ |
| . 23 | . 22798 | . 35789 | . 97367 | .9884I | . 23414 | -36948 | 4.2709 | .63052 | 1311 |
| . 24 | . 23770 | . 37603 | .97134 | .98737 | . 24472 | . 38866 | 4.0864 | .61134 | 1345 |
| 0.25 | 0.24740 | 9.39341 | 0.96891 | 9.98628 | 0.25534 | 9.40712 | 3.9163 | 0.59288 | $14^{\circ} 19^{\prime}$ |
| . 26 | . 25708 | . 41007 | . 96639 | . 98515 | . 26602 | .42491 | 3.7592 | . 57509 | 1454 |
| . 27 | . 26673 | . 42607 | . 96377 | . 98397 | . 27676 | .44210 | 3.6133 | . 55790 | 1528 |
| . 28 | . 27636 | .44147 | .96106 | . 98275 | . 28755 | . 45872 | 3.4776 | . 54128 | 1603 |
| . 29 | . 28595 | . 45629 | . 95824 | .98148 | . 2984 I | .47482 | $3 \cdot 3511$ | .52518 | 1637 |
| 0.30 | 0.29552 | 9.47059 | 0.95534 | 9.98016 | 0.30934 | 9.49043 | 3.2327 | 0.50957 | ${ }_{17} 7^{\circ} \mathrm{II}^{\prime}$ |
| .31 | . 30506 | . 48438 | . 95233 | . 97879 | . 32033 | .50559 | 3.1218 | . 4944 I | 1746 |
| . 32 | -31457 | . 4977 I | . 94924 | . 97737 | -33139 | - 52034 | 3.0176 | -47966 | 1820 |
| . 33 | - 32404 | . 51060 | . 94604 | . 97591 | . 34252 | . 53469 | 2.9195 | .46531 | 1854 |
| . 34 | -33349 | . 52308 | . 94275 | . 97440 | $\cdot 35374$ | . 54868 | 2.8270 | .45132 | 1929 |
| 0.35 | 0.34290 | 9.53516 | 0.93937 | 9.97284 | 0.36503 | 9.56233 | 2.7395 | 0.43767 | $20^{\circ} \mathrm{O}^{\prime}$ |
| . 36 | . 35227 | . 54688 | . 93590 | . 97123 | . 37640 | . 57565 | 2.6567 | . 42435 | 2038 |
| . 37 | . 36162 | . 55825 | . 93233 | . 96957 | .38786 | . 58868 | 2.5782 | .41132 | 2112 |
| . 38 | . 37092 | . 56928 | . 92866 | . 96786 | . 39941 | . 60142 | 2.5037 | -39858 | 2146 |
| . 39 | . 38019 | . 58000 | .92491 | . 96610 | .41105 | .61390 | 2.4328 | . 38610 | 22 21 |
| 0.40 | 0.38942 | 9.59042 | 0.92106 | 9.96429 | 0.42279 | 9.62613 | 2.3652 | 0.37387 | $22^{\circ} 55^{\prime}$ |
| . 41 | -39861 | . 60055 | .91712 | . 96243 | . 43463 | . 63812 | 2.3008 | -36188 | 2329 |
| . 42 | .40776 | .61041 | .91309 | . 96051 | . 44657 | . 64989 | 2.2393 | -35011 | 2404 |
| . 43 | . 41687 | . 62000 | . 90897 | . 95855 | . 45862 | . 66145 | 2.1804 | . 33855 | 2438 |
| . 44 | .42594 | . 62935 | . 90475 | . 95653 | . 47078 | .67282 | 2.1241 | -32718 | 2513 |
| 0.45 | 0.43497 | 9.63845 | 0.90045 | 9.95446 | 0.48306 | 9.68400 | 2.0702 | 0.31600 | $25^{\circ} 47^{\prime}$ |
| . 46 | . 44395 | . 64733 | . 89605 | .95233 | .49545 | - 69500 | 2.0184 | . 30500 | 2621 |
| . 47 | . 45289 | . 65599 | . 89157 | . 95015 | . 50797 | .70583 | 1.9686 | . 29417 | 2656 |
| . 48 | .46178 .47063 | . 66443 | .88699 .88233 | .94792 .94563 | .52061 .53339 | .71651 .72704 | 1.9208 1.8748 | .28349 .27296 | 2730 2804 |
| . 49 | .47063 | . 67268 | . 88233 | $\cdot 94563$ | . 53339 | .72704 | 1.8748 | . 27296 | 2804 |
| 050 | 0.47943 | 9.68072 | 0.87758 | 9.94329 | 0.54630 | 9.73743 | 1. 8305 | 0.26257 | $28^{\circ} 39^{\prime}$ |

CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

| $$ | SINES. ${ }^{\circ}$ |  | COSINES. |  | TANGENTS |  | COTANGENTS. |  | $\begin{aligned} & \text { win } \\ & \text { M1 } \\ & \text { Mr } \\ & 0 \\ & \text { M } \\ & \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 0.50 | 0.47943 | 9.68072 | 0.87758 | 9.94329 | 0.54630 | 9.73743 | I. 8305 | 0.26257 | $28^{\circ} 39^{\prime}$ |
| . 51 | . 48818 | . 68858 | . 87274 | . 94089 | . 55936 | . 74769 | . 7878 | .2523I | 2913 |
| . 52 | . 49688 | . 69625 | . 86782 | . 93843 | . 57256 | . 75782 | .7465 | . 24218 | 2948 |
| . 53 | - 50553 | . 70375 | .86281 | .93591 | . 58592 | . 76784 | . 7067 | . 23216 | 3022 |
| . 54 | -514 4 | .71108 | . 8577 I | . 93334 | - 59943 | . 77774 | . 6683 | . 22226 | 3056 |
| 0.55 | 0.52269 | 9.71824 | 0.85252 | 9.93071 | 0.61311 | 9.78754 | 1.6310 | 0.21246 | $31^{\circ} 3 \mathrm{I}^{\prime}$ |
| . 56 | . 53119 | . 72525 | . 84726 | .92801 | . 62695 | . 79723 | . 5950 | . 20277 | 3205 |
| . 57 | . 53963 | .73210 | . 84190 | .92526 | .64097 | . 80684 | . 5601 | . 19316 | 3240 |
| . 58 | . 54802 | . 73880 | . 83646 | . 92245 | .65517 | . 81635 | . 5263 | .18365 | 3314 |
| . 59 | . 55636 | .74536 | . 83094 | .91957 | . 66956 | . 82579 | . 4935 | .1742 I | 3348 |
| 0.60 | 0.56464 | 9.75177 | 0.82534 | 9.91663 | 0.68414 | 9.83514 | I. 4617 | 0.16486 | $34^{\circ} 23^{\prime}$ |
| . 61 | . 57287 | . 75805 | . 81965 | .91363 | . 69892 | . 84443 | . 4308 | . 15557 | 3457 |
| . 62 | .58104 | .76420 | . 81388 | . 91056 | . 71391 | . 85364 | . 4007 | . 14636 | 3531 |
| . 63 | .589:4 | . 77022 | .80803 | . 90743 | .72911 | . 86280 | -3715 | . 13720 | 3606 |
| . 64 | - 59720 | .77612 | . 80210 | . 90423 | . 74454 | . 87189 | -343I | . 28811 | 3640 |
| 0.65 | 0.60519 | 9.78I89 | 0.79608 | 9.90096 | 0.76020 | 9.88093 | I.3154 | 0.11907 | $37^{\circ} \mathrm{I} 5^{\prime}$ |
| . 66 | .61312 | . 78754 | . 78999 | . 89762 | .77610 | . 88992 | . 2885 | . 11008 | 3749 |
| . 67 | . 62099 | .79308 | .78382 | . $89+22$ | . 79225 | . 89886 | . 2622 | . 10114 | 38.23 |
| . 68 | . 62879 | .79851 | . 77757 | . 89074 | . 80866 | . 90777 | . 2366 | . 09223 | 3858 |
| . 69 | . 63654 | .80382 | .77125 | . 88719 | . 82534 | .91663 | . 2116 | . 08337 | 3932 |
| 0.70 | 0.64422 | 9.80903 | 0.76484 | 9.88357 | 0.84229 | 9.92546 | 1.1872 | 0.07454 | $40^{\circ} 06^{\prime}$ |
| . 71 | . 65183 | . 81414 | .75836 | . 87988 | . 85953 | . 93426 | . 1634 | . 06574 | 4041 |
| . 72 | . 65938 | . 81914 | . 75181 | . 87611 | . 87707 | .94303 | . 1402 | . 05697 | 4115 |
| . 73 | . 66687 | .82404 | . 74517 | . 87226 | . 89492 | .95178 | . 1174 | . 04822 | 4150 |
| . 74 | . 67429 | . 82885 | .73847 | . 86833 | .91309 | .96051 | . 0952 | . 03949 | 4224 |
| 0.75 | 0.68164 | 9.83355 | 0.73169 | 9.86433 | 0.93160 | 9.96923 | 1.0734 | 0.03077 | $42^{\circ} 5^{\prime \prime}$ |
| . 76 | . 68892 | . 83517 | . 72484 | . 86024 | . 95045 | . 97793 | .0521 | . 02207 | 4333 |
| . 77 | . 69614 | . 84269 | . 71791 | . 85607 | . 96967 | . 98662 | .0313 | . 01338 | 4407 |
| . 78 | .70328 .71035 | . 847 I 3 | .71091 | . 85182 | . 98926 | 9.99531 | 1.0109 | . 00469 | 4441 |
| . 79 | . 71035 | . 85147 | .70385 | . 84748 | 1.0092 | 0.00400 | 0.99084 | 9.99600 | 4516 |
| 0.80 | 0.71736 | 9.85573 | 0.69671 | 9.84305 | 1.0296 | 0.01268 | 0.97121 | 9.98732 | $45^{\circ} 5^{\prime}$ |
| .81 | . 72429 | . 85991 | . 68950 | . 83853 | . 0505 | . 02138 | .95197 | . 97862 | 4625 |
| . 82 | .73115 | . 86400 | . 68222 | . 83393 | . 0717 | .03008 | .93309 | . 96992 | 4659 |
| . 83 | .73793 | . 86802 | . 67488 | . 82922 | . 0934 | .03879 | .91455 | .9612 | 4733 |
| . 84 | . 74464 | . 87195 | . 66746 | . 82443 | .1156 | . 04752 | . 89635 | $\cdot 95248$ | 4808 |
| 0.85 | 0.75128 | 9.87580 | 0.65998 | 9.81953 | 1.1383 | 0.05627 | 0.87848 | 9.94373 | $48^{\circ}{ }^{2} 2^{\prime}$ |
| . 86 | . 75784 | . 87958 | . 65244 | .81454 | . 1616 | .06504 | . 86091 | . 93496 | 4916 |
| . 87 | .76433 | . 88328 | . 64483 | . 80944 | .1853 | . 07384 | . 84365 | .92616 | 49 51 |
| . 88 | .77074 | . 88691 | . 63715 | . 80424 | . 2097 | . 08266 | . 82668 | -91734 | 5025 |
| . 89 | . 77707 | . 89046 | .6294I | . 79894 | . 2346 | .09153 | . 80998 | . 90847 | 5100 |
| 0.90 | 0.78333 | 9.89394 | 0.62161 | 9.79352 | 1. 2602 | 0.10043 | 0.79355 | 9.89957 | $51^{\circ} 34^{\prime}$ |
| . 91 | . 78950 | . 89735 | .61375 | . 78799 | . 2864 | . 10937 | . 77738 | . 89063 | 5208 |
| . 92 | . 79560 | . 90070 | . 60582 | .78234 | . 3133 | .11835 | . 76146 | .88165 | 5243 |
| . 93 | . 80162 | .90397 | . 59783 | . 77658 | - 3409 | . 12739 | . 74578 | . 87261 | 5317 |
| . 94 | . 80756 | .90717 | . 58979 | . 77070 | $\cdot 3692$ | .13648 | . 73034 | .86352 | 53 51 |
|  | 0.81342 | 9.91031 | 0.58168 | 9.76469 | 1. 3984 | 0.14563 | 0.71511 | 9.85437 | $54^{\circ} 26^{\prime}$ |
| . 96 | .81919 | .91339 | . 57352 | . 75855 | . 4284 | . 15484 | . 70010 | . 84516 | 5500 |
| . 97 | . 82489 | .91639 | . 56530 | . 75228 | . 4592 | .16412 | . 68531 | . 83588 | 5535 |
| . 98 | .83050 .83603 | .91934 | . 55702 | .74587 .73933 | . 4910 | .17347 .18289 | . 6707 I | .82653 .8 I 7 II | $56 \quad 09$ 5643 |
| . 99 | . 83603 | . 92222 | - 54869 | . 73933 | . 5237 | .18289 | .6563I | .81711 | 5643 |
| 1.00 | 0.84147 | 9.92504 | 0.54030 | 9.73264 | 1. 5574 | 0.19240 | 0.64209 | 9.80760 | $57^{\circ} \mathrm{I} 8^{\prime}$ |

Smithsonian Tables.

TAble 15 (continued).
CIRCULAR (TRIGONOMETRIC) FUNCTIONS.

|  | SINES. |  | COSINES. |  | TANGENTS. |  | COTANGENTS. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 1.00 | 0.84147 | 9.92504 | 0.54030 | 9.73264 | 1. 5574 | -. 19240 | 0.64209 | 9.80760 | $57^{\circ} 18^{\prime}$ |
| . 01 | . 84683 | . 92780 | . 53186 | . 72580 | . 5922 | . 20200 | . 62806 | . 79800 | 5752 |
| . 02 | . 85211 | . 93049 | . 52337 | .71881 | . 6281 | . 21169 | . 61420 | .7883I | 5827 |
| . 03 | . 85730 | .93313 | . 51482 | .71165 | . 6652 | . 22148 | . 60051 | .77852 | 59 O1 |
| . 04 | . 86240 | .9357 I | . 50622 | .70434 | .7036 | .23137 | . 58699 | .76863 | 5935 |
| 1.05 | 0.86742 | 9.93823 | 0.49757 | 9.69686 | 1.7433 | 0.24138 | 0.57362 | 9.75862 | $60^{\circ} 10^{\prime}$ |
| . 06 | . 87236 | . 94069 | . 48887 | . 68920 | . 7844 | . 25150 | . 56040 | . 74850 | 6044 |
| . 07 | . 87720 | .94310 | . 48012 | .68135 | . 8270 | . 26175 | . 54734 | .73825 | 6118 |
| . 08 | .88ı 96 | . 94545 | . 47133 | . 67332 | . 8712 | . 27212 | . 53441 | . 72788 | 6153 |
| . 09 | . 88663 | . 94774 | . 46249 | .66510 | .9171 | . 28264 | . 52162 | .71736 | 6227 |
| 1.10 | 0.89121. | 9.94998 | 0.45360 | 9.65667 | 1.9648 | 0.29331 | 0.50897 | 9.70669 | $63^{\circ} \mathrm{O} 2^{\prime}$ |
| . 11 | . 89570 | . 95216 | . 44466 | . 64803 | 2.0143 | . 30413 | . 49644 | . 69587 | 6336 |
| . 12 | -90010 | . 95429 | . 43568 | . 63917 | . 0660 | -31512 | . 48404 | . 68488 | 6410 |
| . 13 | . 9044 I | . 95637 | . 42666 | . 63008 | .1 198 | . 32628 | . 47175 | . 67372 | 6445 |
| . 14 | .90863 | . 95839 | .41759 | . 62075 | . 1759 | .33763 | . 45959 | . 66237 | 6519 |
| 1.15 | 0.91276 | 9.96036 | 0.40849 | 9.61118 | 2.2345 | 0.34918 | 0.44753 | 9.65082 | $65^{\circ} 53^{\prime}$ |
| . 16 | . 91680 | . 96228 | . 39934 | .60134 | . 2958 | . 36093 | . 43558 | . 63907 | 6628 |
| . 17 | . 92075 | .96414 | -39015 | . 59123 | . 3600 | -37291 | . 42373 | . 62709 | 6702 |
| . 18 | .92461 | . 96596 | .38092 | .58084 | .4273 | -38512 | .41199 | .61488 | 6737 |
| .19 | . 92837 | . 96772 | . 37166 | . 57015 | . 4979 | -39757 | .40034 | $.602+3$ | 68 I I |
| 1.20 | 0.93204 | 9.96943 | 0.36236 | 9.55914 | 2.5722 | 0.41030 | 0.38878 | 9.58970 | $68^{\circ} 45^{\prime}$ |
| . 21 | . 93562 | .97110 | - 35302 | . 54780 | . 6503 | . 42330 | . 37731 | . 57670 | 6920 |
| . 22 | . 93910 | . 9727 I | . 34365 | . 53611 | .7328 | . 43660 | . 36593 | . 56340 | 6954 |
| .23 | . 94249 | . 97428 | - 33424 | - 52406 | . 8198 | . 45022 | - 35463 | - 54978 | 7028 |
| . 24 | -94578 | . 97579 | . 32480 | .51161 | .9119 | .46418 | -3434 ${ }^{\text {I }}$ | . 53582 | 7103 |
| 1.25 | 0.94898 | 9.97726 | 0.31532 | 9.49875 | 3.0096 | 0.47850 | 0.33227 | 9.52150 | $71^{\circ} 37^{\prime}$ |
| . 26 | . 95209 | . 97868 | . 30582 | . 48546 | .1133 | . 49322 | .32121 | . 50678 | 7212 |
| . 27 | . 95510 | . 98005 | . 29628 | . 47170 | . 2236 | . 50835 | -3102 I | .49165 | 7246 |
| . 28 | .95802 | .98137 | .28672 | . 45745 | .3413 | . 52392 | . 29928 | . 47608 | 7320 |
| . 29 | .96084 | . 98265 | . 27712 | .44267 | .4672 | - 53998 | . 28842 | .46002 | 7355 |
| 1. 30 | 0.96356 | 9.98388 | 0.26750 | 9.42732 | 3.6021 | 0.55656 | 0.27762 | 9.44344 | $74^{\circ} 29^{\prime}$ |
| . 31 | .966ı 8 | .98506 | . 25785 | .41137 | . 747 I | . 57369 | . 26687 | . 42631 | 7503 |
| - 32 | .96872 | . 98620 | . 24818 | -39476 | .9033 | - 59144 | . 25619 | . 40856 | 7538 |
| - 33 | .97115 | .98729 | .23848 | - 37744 | 4.0723 | . 60984 | .24556 | .39016 | 7612 |
| - 34 | . 97348 | .98833 | . 22875 | . 35937 | . 2556 | .62896 | .23498 | .37104 | 7647 |
| I. 35 | 0.97572 | 9.98933 | 0.21901 | 9.34046 | 4.4552 | 0.64887 | 0.22446 | 9.35113 | $77^{\circ} 21^{\prime}$ |
| - 36 | . 97786 | . 99028 | . 20924 | -32064 | . 6734 | . 66964 | . 21398 | . 33036 | 7755 |
| - 37 | .97991 | .99119 | . 19945 | .29983 | .9131 | .69135 | . 20354 | -30865 | 7830 |
| - 38 | .98185 | -99205 | .IS964 | .27793 | 5.1774 | .71411 | .19315 | .28589 | 7904 |
| . 39 | .98370 | . 99286 | . 17981 | . 25482 | . 4707 | .73804 | . 8279 | .26196 | 7938 |
| I. 40 | 0.98545 | 9.99363 | 0.16997 | 9.23036 | 5.7979 | 0.76327 | 0.17248 | 9.23673 | $80^{\circ} 13^{\prime}$ |
| . 41 | .98710 | . 99436 | . 16010 | . 20440 | 6.1654 | .78996 | . 16220 | . 21004 | 8047 |
| . 42 | . 98865 | . 99504 | . 15023 | .17674 | 6.5811 | . 81830 | .15195 | .18170 | S1 22 |
| . 43 | . 99010 | . 99568 | .14033 | .14716 | 7.0555 | . 84853 | .14173 | . 15147 | 8156 |
| . 44 | .99146 | . 99627 | . 3042 | .11536 | 7.6018 | . 88092 | . 13155 | . 11908 | 8230 |
| 1.45 | 0.99271 | 9.99682 | 0.12050 | 9.08100 | 8.2381 | 0.91583 | 0.12139 | 9.08417 | $83^{\circ} 05^{\prime}$ |
| .46 | . 99387 | . 99733 | . 11057 | . 04364 | 8.9886 | .95369 | . 11125 | . 04631 | 8339 |
| . 47 | . 99492 | . 99779 | . 10063 | . 00271 | 9.8874 | . 99508 | . 10114 | . 00492 | S+13 |
| . 48 | . 999588 | .99821 | . 09067 | 8.95747 .00692 | 10.983 | 1.04074 | .09105 | 8.95926 | $\mathrm{S}_{4} 48$ |
| . 49 | . 99674 | .99858 | .0807 I | .90692 | 12.350 | .09166 | .08097 | . 90834 | 8522 |
| I. 50 | 0.99749 | 9.99891 | 0.07074 | 8.84965 | 14.10I | 1.14926 | 0.07091 | 8.85074 | $85^{\circ} 57^{\prime}$ |

Smithsonian Tables.

TABLE 15 (continued), Oircular (Trigonometric) Functions.

|  | SINES. |  | COSINES. |  | TANGENTS. |  | COTANGENTS. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log | Nat. | Log | Nat. | Log. | Nat. | Log. |  |
| 1.50 | 0.99749 | 9.99891 | 0.07074 | 8.84965 | 14.101 | I. 14926 | 0.07091 | 8.85074 | $85^{\circ} 57^{\prime}$ |
| . 51 | .99SI 5 | . 99920 | . 06076 | .78361 | 16.428 | .21559 | . 06087 | .78441 | 8631 |
| .52 | .9987 1 | . 99944 | . 05077 | .70565 | 19.670 | . 29379 | . 05084 | .70621 | 8705 |
| . 53 | . 99917 | . 99964 | . 04079 | . 61050 | 24.498 | -38914 | . 04082 | . 61086 | 8740 |
| . 54 | . 99953 | . 99979 | . 03079 | .48843 | 32.461 | . 51136 | .0308I | .43864 | 8814 |
| 1.55 | 0.9997 S | 9.99991 | 0.02079 | 8.31796 | 48.078 | 1.68195 | 0.02080 | 8.31805 | $88^{\circ} 49^{\prime}$ |
| . 56 | 0.99994 | 9.99997 | . 01080 | 8.03327 | 92.621 | I. 9667 I | . 01080 | 8.03329 | S9 23 |
| . 57 | 1.00000 | 0.00000 | .00080 | 6.90109 | 1255.8 | 3.09891 | . 00080 | 6.90109 | 8957 |
| . $5^{8}$ | 0.99996 | 9.99998 | -. 000920 | $7.96396 n$ | 108.65 | 2.03603 | -. 000920 | $7.96397 n$ | 9032 |
| . 59 | 0.99982 | 9.99992 | -. 01920 | S.28336n | 52.067 | 1.71656 | -.01921 | $8.28344 n$ | 9106 |
| 1.60 | 0.99957 | 9.9998 I | -0.02920 | $8.46538 n$ | 34.233 | 1. 53444 | -0.02921 | 8.46556 n | $91^{\circ} 40^{\prime}$ |

$90^{\circ}=1.5707963$ radians.

TABLE 16.-Logarithmic Factorials.
Logarithms of the products $1.2 .3 . \ldots . . n, n$ from $I$ to 100 .
See Table 18 for Factorials I to 20.
See Table 32 for log. $\Gamma(n+1)$, values of $n$ between I and 2 .

| $n$ | $\log (n!)$ | $n$ | $\log (n!)$ | $n$ | $\log (n!)$ | $n$. | $\log (n!)$ |
| ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 0.000000 | 26 | 26.605619 | 51 | 66.190645 | 76 | 111.275425 |
| 1 | 0 | 0.301030 | 27 | 28.036983 | 52 | 67.906648 | 77 |
| 113.161916 |  |  |  |  |  |  |  |
| 3 | 0.778151 | 28 | 29.484141 | 53 | 69.630924 | 78 | 115.054011 |
| 4 | 1.380211 | 29 | 30.946539 | 54 | 71.363318 | 79 | 116.951638 |
| 5 | 2.079181 | 30 | 32.423660 | 55 | 73.103681 | 80 | 118.854728 |
| 6 | 2.857332 | 31 | 33.915022 | 56 | 74.851869 | 81 | 120.763213 |
| 7 | 3.702431 | 32 | 35.420172 | 57 | 76.607744 | 82 | 122.677027 |
| 8 | 4.605521 | 33 | 36.938686 | 58 | 78.371172 | 83 | 124.596105 |
| 9 | 5.559763 | 34 | 38.470165 | 59 | 80.142024 | 84 | 126.520384 |
| 10 | 6.559763 | 35 | 40.014233 | 60 | 81.920175 | 85 | 128.449803 |
|  |  |  |  |  |  |  |  |
| 11 | 7.601156 | 36 | 41.570535 | 61 | 83.705505 | 86 | 130.384301 |
| 12 | 8.680337 | 37 | 43.138737 | 62 | 85.497896 | 87 | 132.323821 |
| 13 | 9.794280 | 38 | 44.718520 | 63 | 87.297237 | 88 | 134.268303 |
| 14 | 10.940408 | 39 | 46.309585 | 64 | 89.103417 | 89 | 136.217693 |
| 15 | 12.116500 | 40 | 47.911645 | 65 | 90.916330 | 90 | 138.171936 |
| 16 | 13.320620 | 41 | 49.524429 | 66 | 92.735874 | 91 | 140.130977 |
| 17 | 14.551069 | 42 | 51.147678 | 67 | 94.561949 | 92 | 142.094765 |
| 18 | 15.806341 | 43 | 52.781147 | 68 | 96.394458 | 93 | 144.063248 |
| 19 | 17.085095 | 44 | 54.424599 | 69 | 98.233307 | 94 | 146.036376 |
| 20 | 18.386125 | 45 | 56.077812 | 70 | 100.078405 | 95 | 148.014099 |
| 21 | 19.708344 | 46 | 57.740570 | 71 | 101.929663 | 96 | 149.996371 |
| 22 | 21.050767 | 47 | 59.412668 | 72 | 103.786996 | 97 | 151.983142 |
| 23 | 22.412494 | 48 | 61.093909 | 73 | 105.650319 | 98 | 153.974368 |
| 24 | 23.792706 | 49 | 62.784105 | 74 | 107.519550 | 99 | 155.970004 |
| 25 | 25.190646 | 50 | 64.483075 | 75 | 109.394612 | 100 | 157.970004 |


| u | sinh. u |  | cosh. u |  | tanh. u |  | coth. u |  | gd u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 0.00 | 0.00000 | - $\infty$ | 1.00000 | 0.00000 | 0.00000 | $-\infty$ | $\infty$ | $\infty$ | $0^{\circ} 0^{\prime}$ |
| . 01 | . 01000 | 8.00001 | . 00005 | . 00002 | . 01000 | 7.99999 | 100.003 | 2.00001 | - 34 |
| . 02 | . 02000 | . 30106 | . 00020 | . 00009 | . 02000 | 8.30097 | 50.007 | 1.69903 | 109 |
| . 03 | . 03000 | . 47719 | . 00045 | . 00020 | . 02999 | . 47699 | 33.343 | 1.52301 | I 43 |
| . 04 | . 04001 | . 60218 | . 00080 | . 00035 | .03998 | . 60183 | 25.013 | 1.39817 | 217 |
| 0.05 | 0.05002 | 8.69915 | 1.00125 | 0.00054 | 0.04996 | 8.6986I | 20.017 | 1.30139 | 252 |
| . 06 | . 06004 | .7784 I | . 00180 | . 00078 | . 05993 | .77763 | 16.687 | . 22237 | 326 |
| . 07 | . 07006 | . 84545 | . 00245 | . 00106 | . 06989 | . 84439 | 14.309 | . 15561 | 400 |
| . 08 | . 08009 | . 90355 | . 00320 | .001 39 | . 07983 | . 90216 | 12.527 | . 09784 | 435 |
| . 09 | . 09012 | .95483 | . 00405 | . 00176 | . 08976 | . 95307 | II.14I | . 04693 | 509 |
| 0.10 | 0.10017 | 9.00072 | 1.00500 | 0.00217 | 0.09967 | 8.99856 | 10.0333 | I.00144 | 543 |
| . 11 | . 11022 | . 04227 | . 00606 | . 00262 | . 10956 | 9.03965 | 9.1275 | 0.96035 | 617 |
| .12 | . 12029 | . 08022 | . 0072 I | . 00312 | . 11943 | . 07710 | 8.3733 | . 92290 | 652 |
| .13 | .13037 | . 11517 | . 00846 | . 00366 | . 12927 | .1115 ${ }^{\text {I }}$ | 7.7356 | . 88849 | 726 |
| . 14 | .14046 | .14755 | . 00982 | . 00424 | . 13909 | . 14330 | 7.1895 | .85670 | 800 |
| 0.15 | 0.15056 | 9.17772 | 1.OI 127 | 0.00487 | 0.14889 | 9.17285 | 6.7166 | 0.82715 | 834 |
| . 16 | . 16068 | . 20597 | . 01283 | . 00554. | . 5865 | . 20044 | 6.3032 | . 79956 | 9 OS |
| .17 | . 17082 | . 23254 | . 01448 | . 00625 | .16838 | . 22629 | 5.9389 | -7737 ${ }^{\text {I }}$ | 942 |
| .18 | .18097 | . 25762 | . 01624 | . 00700 | .17808 | . 25062 | 5.6154 | .74938 | 1015 |
| .19 | .1915 5 | .28136 | .01810 | . 00779 | . 18775 | . 27357 | $5 \cdot 3263$ | .72643 | IO 49 |
| 0.20 | 0.20134 | 9.30392 | 1.02007 | 0.00863 | -. 19738 | 9.29529 | 5.0665 | 0.7047 I | 1123 |
| . 21 | .21155 | -32541 | . 02213 | . 00951 | . 20697 | -31590 | 4.8317 | . 68410 | II 57 |
| .22 | . 22178 | -34592 | . 02430 | . 01043 | .21652 | -33549 | 4.6186 | . 6645 I | 1230 |
| .23 | . 23203 | - 36555 | . 02657 | . 01139 | . 22603 | -35416 | 4.4242 | .64584 | 1304 |
| . 24 | .2423I | . 38437 | . 02894 | . 01239 | . 23550 | . 37198 | 4.2464 | . 62802 | 1337 |
| 0.25 | 0.25261 | 9.40245 | 1.03141 | 0.01343 | 0.24492 | 9.38902 | 4.0830 | 0.61098 | 14 II |
| . 26 | . 26294 | . 41986 | . 03399 | . 01452 | . 25430 | . 40534 | 3.9324 | . 59466 | 1444 |
| . 27 | . 27329 | .43663 | . 03667 | . 01564 | . 26362 | -42099 | 3.7933 | . 57901 | 1517 |
| . 28 | . 28367 | . 45282 | . 03946 | .0168I | . 27291 | .43601 | 3.6643 | - 56399 | 1550 |
| .29 | . 29408 | .46847 | . 04235 | .orsor | .28213 | .45046 | $3 \cdot 5444$ | -54954 | 1623 |
| 0.30 | 0.30452 | 9.48362 | 1.04534 | 0.01926 | 0.29131 | 9.46436 | 3.4327 | 0.53564 | 1656 |
| .31 | . 31499 | . 498.30 | . 04344 | . 02054 | . 30044 | . 47775 | . 3285 | . 52225 | 1729 |
| $\cdot 32$ | . 32549 | . 51254 | .05164 | . 02187 | -30951 | -49067 | . 2309 | - 50933 | I8 02 |
| $\cdot 33$ | . 33602 | . 52637 | . 05495 | . 02323 | . 31852 | .50314 | . 1395 | . 49686 | 1834 |
| . 34 | .34659 | . 5398 I | . 05836 | . 02463 | -32748 | .51518 | . 0536 | .48482 | 1907 |
| 0.35 | 0.35719 | 9.55290 | 1.06188 | 0.02607 | 0.33638 | 9.52682 | 2.9729 | 0.47318 | 1939 |
| $\cdot \cdot 36$ | .36783 | . 56564 | . 06550 | .02755 | -34521 | $.53 \mathrm{So9}$ | . 8968 | .46191 | 2012 |
| - 37 | -37850 | . 57807 | . 06923 | .02907 | -35399 | . 54899 | . 8249 | -45101 | 2044 |
| - 38 | . 38921 | . 59019 | . 07307 | .03063 | -3627I | . 55956 | . 7570 | . 44044 | 2116 |
| - 39 | . 39996 | . 60202 | . 07702 | . 03222 | .37136 | . 56980 | . 6928 | . 43020 | 2148 |
| 0.40 | 0.41075 | 9.61358 | 1.08107 | 0.03385 | 0.37995 | 9.57973 | 2.6319 | 0.42027 | 2220 |
| . 41 | . 42158 | . 62488 | .08523 | .03552 | . 38847 | . 58936 | . 5742 | . 41064 | 2252 |
| .42 | . 43246 | .63594 | . 08950 | . 03723 | - 39693 | .59871 | . 5193 | . 40129 | $23 \quad 23$ |
| . 43 | . 44337 | .64677 | . 09388 | . 03897 | . 40532 | . 60780 | . 4672 | . 39220 | 2355 |
| - 44 | : 45434 | . 65738 | .09837 | . 04075 | .41364 | . 61663 | . 4175 | .38337 | 2426 |
| 0.45 | 0.46534 | 9.66777 | 1. 102970 | . 04256 | 0.42190 | 9.62521 | 2.3702 | 0.37479 | 2457 |
| . 46 | . 47640 | . 67797 | . 10768 | . 04441 | . 43008 | . 63355 | .3251 | . 36645 | $25 \quad 28$ |
| . 47 | . 48750 | . 68797 | . 11250 | .04630 | . 43820 | .64167 | . 2821 | . 35833 | 2559 |
| .48 | . 49865 | . 69779 | . 11743 | . 04822 | . 44624 | . 64957 | .2409 | -35043 | 2630 |
| . 49 | . 50984 | . 70744 | . 12247 | . 05018 | . 45422 | .65726 | . 2016 | - 34274 | 27 or |
| 0.50 | 0.52110 | 9.71692 | 1.12763 | 0.05217 | 0.46212 | 9.66475 | 2.1640 | 0.33525 | 27 31 |

Table 17 (continued).
HYBERBOLIC FUNCTIONS.

| u | sinh. u |  | cosh. u |  | tanh. u |  | coth. u |  | gd u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 0.50 | 0.52110 | 9.71692 | 1.12763 | 0.05217 | 0.46212 | 9.66475 | 2.1640 | 0.33525 | $27^{\circ} 3^{1}{ }^{\prime}$ |
| . 51 | . 53240 | . 72624 | . 13289 | .05419 | . 46995 | . 67205 | . 1279 | . 32795 | 2802 |
| . 52 | . 54375 | . 73540 | . 13827 | . 05625 | . 47770 | . 67916 | . 0934 | -32084 | $28 \quad 32$ |
| . 53 | . 55516 | . 74442 | . 14377 | .05834 | . 48538 | .68608 | . 0602 | . 31392 | 2902 |
| . 54 | - 56663 | . 75330 | . 14938 | .06046 | . 49299 | . 69284 | . 0284 | . 30716 | 2932 |
| - . 55 | 0.57815 | 9.76204 | 1.15510 | 0.06262 | 0.50052 | 9.69942 | 1.9979 | 0.30058 | 3002 |
| .56 | . 58973 | .77065 | . 16094 | .06481 | . 50798 | .70584 | . 9686 | .29416 | 3032 |
| . 57 | . 60137 | .77914 | . 16690 | . 06703 | .51536 | . 71211 | . 9404 | .28789 | 3 I or |
| . 58 | .61307 | .78751 | . 17297 | . 06929 | . 52267 | .71822 | .9133 | .28178 | $3 \mathrm{I} 3^{1}$ |
| . 59 | . 62483 | .79576 | .17916 | .07157 | . 52990 | .72419 | . 8872 | .27581 | 3200 |
| 0.60 | 0.63665 | 9.80390 | 1.18547 | 0.07389 | 0.53705 | 9.73001 | 1. 8620 | 0.26999 | 3229 |
| .6I | . 64854 | . 81194 | . 19189 | . 07624 | . 54413 | . 73570 | . 8378 | . 26430 | 3258 |
| . 62 | . 66049 | . 81987 | . 19844 | .07861 | . 55113 | . 74125 | .8I45 | .25875 | 3327 |
| 63 | . 67251 | . 82770 | . 20510 | .08102 | . 55805 | . 74667 | . 7919 | . 25333 | 3355 |
| . 64 | .68459 | . 83543 | .21189 | .08346 | . 56490 | .75197 | .7702 | . 24803 | 3424 |
| 0.65 | 0.69675 | 9.84308 | 1.21879 | 0.08593 | 0.57167 | 9.75715 | 1.7493 | 0.24285 | 3452 |
| . 66 | . 70897 | . 85063 | . 22582 | .08843 | . 57836 | . 76220 | . 7290 | . 23780 | 3520 |
| . 67 | . 72126 | . 85809 | . 23297 | . 09095 | . 58498 | . 76714 | . 7095 | . 23286 | 3548 |
| . 68 | .73363 | . 86548 | . 24025 | .09351 | . 59152 | . 77197 | . 6906 | . 22803 | 3616 |
| . 69 | . 74607 | . 87278 | . 24765 | . 09609 | . 59798 | .77669 | . 6723 | .2233 I | 3644 |
| 0.70 | 0.75858 | 9.88000 | 1.25517 | 0.09870 | 0.60437 | 9.78130 | 1.6546 | 0.21870 | 3711 |
| . 71 | . 77117 | . 88715 | . 26282 | .10134 | .61068 | .78581 | . 6375 | . 21419 | 3738 |
| .72 | . 78384 | . 89423 | . 27059 | . 10401 | .61691 | . 79022 | . 6210 | . 20978 | 3805 |
| . 73 | . 79659 | .90123 | .27849 | . 10670 | . 62307 | . 79453 | . 6050 | . 20547 | 3832 |
| . 74 | . 80941 | .90817 | .28652 | .10942 | . 62915 | .79875 | .5895 | . 20125 | 3859 |
| 0.75 | 0.82232 | 9.91504 | 1.29468 | 0.11216 | $0.635^{15}$ | 9.80288 | 1.5744 | 0.19712 | 3926 |
| . 76 | . 83530 | .92185 | . 30297 | . 11493 | . 64108 | . 80691 | . 5599 | .19309 | 39 52 |
| . 77 | . 84838 | . 92859 | . 31139 | .11773 | . 64693 | . 81086 | . 5458 | .18914 | 4019 |
| . 78 | . 86153 | . 93527 | . 31994 | . 12055 | . 6527 I | . 81472 | . 5321 | . 18528 | 4045 |
| . 79 | . 87478 | .94190 | . 32862 | . 12340 | . 65841 | . 81850 | .5188 | .18150 | 4111 |
| 0.80 | 0.88811 | 9.94846 | 1.33743 | $0.12627^{\circ}$ | 0.66404 | 9.82219 | 1.5059 | 0.17781 | 4137 |
| . 81 | .901 52 | . 95498 | . 34638 | . 12917 | . 66959 | . 82581 | . 4935 | . 17419 | 4202 |
| . 82 | .91503 | . 96144 | . 35547 | . 13209 | . 67507 | . 82935 | .4813 | .17065 | 4228 |
| . 83 | . 92863 | .96784 | . 36468 | . 13503 | .68048 | . 83281 | . 4696 | . 16719 | 4253 |
| . 84 | . 94233 | . 97420 | . 37404 | .13800 | .6858 I | . 83620 | . 4581 | .16380 | 4318 |
| 0.85 | 0.95612 | 9.98051 | 1.38353 | 0.14099 | 0.69107 | 9.83952 | 1.4470 | 0.16048 | 4343 |
| . 86 | . 97000 | . 98677 | . 39316 | . 14400 | . 69626 | . 84277 | . 4362 | . 15723 | 44 o8 |
| . 87 | . 98398 | . 99299 | . 40293 | . 14704 | .70137 | . 84595 | . 4258 | . 15405 | 4432 |
| . 88 | . 99806 | . 99916 | . 41284 | . 15009 | . 70642 | . 84906 | .4156 | . 15094 | 4457 |
| . 89 | 1.01224 | 0.00528 | . 42289 | . 55317 | . 71139 | . 85211 | . 4057 | . 14789 | 4521 |
| 0.90 | 1.02652 | 0.01137 | 1. 43309 | 0.15627 | 0.71630 | 9.85509 | 1.3961 | 0.14491 | 4545 |
| . 91 | . 04090 | . 01741 | . 44342 | . 15939 | . 72113 | . 85801 | . 3867 | . 14199 | $46 \quad 09$ |
| . 92 | . 05539 | . 02341 | . 45390 | .16254 | . 72590 | . 86088 | . 3776 | . 13912 | 4633 |
| . 93 | . 06998 | . 02937 | .46453 | . 16570 | . 73059 | . 86368 | . 3687 | . 13632 | 4656 |
| . 94 | . 08468 | . 03530 | . 47530 | . 16888 | .73522 | . 86642 | . 3601 | . 13358 | 4720 |
| 0.95 | 1.09948 | 0.04119 | 1.48623 | 0.17208 | 0.73978 | 9.86910 | 1. 3517 | 0.13090 |  |
| . 96 | . 11440 | .04704 | . 49729 | .17531 | . 74428 | . 87173 | . 3436 | . 12827 | 4806 |
| . 97 | . 12943 | . 05286 | . 50851 | .17855 | . 74870 | . 87431 | . 3356 | . 12569 | 4829 |
| . 98 | . 14457 | . 05864 | . 51988 | .18181 | .75307 | . 87683 | -3279 | .12317 | 4851 |
| .99 | . 5988 | . 06439 | . 5314 I | .18509 | .75736 | . 87930 | . 3204 | . 12070 | 4914 |
| 1.00 | 1.17520 | 0.07011 | 1. 54308 | 0.18839 | 0.76159 | 9.88172 | 1.3130 | 0.11828 | 4936 |

TABLE 17 (continued). HYPERBOLIC FUNCTIONS.

| u | sinh. u |  | cosh. u |  | $\tanh . \mathrm{u}$ |  | coth u |  | gd u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 1.00 | I.17520 | 0.07011 | 1. 54308 | 0.18839 | 0.76159 | 9.88172 | 1.3130 | 0.11828 | $49^{\circ} 36^{\prime}$ |
| . 01 | . 19069 | . 07580 | . 55491 | .19171 | . 76576 | . 88409 | . 3059 | . 11591 | 4958 |
| . 02 | . 20630 | . 08146 | - 56689 | . 19504 | .76987 | . 88642 | .2989 | . 11358 | 5021 |
| . 03 | . 22203 | .08708 | . 57904 | .19839 | .77391 | . 88869 | . 2921 | . 11131 | 5042 |
| . 04 | . 23788 | . 09268 | . 59134 | . 20176 | .77789 | .89092 | . 2855 | . 10908 | 5104 |
| 1.05 | 1.25386 | 0.09825 | 1.60379 | 0.20515 | 0.78181 | 9.89310 | 1.2791 | 0.10690 | 5126 |
| . 06 | . 26996 | .10379 | .61641 | . 20855 | . 78566 | . 89524 | . 2728 | . 10476 | 5147 |
| . 07 | .28619 | . 10930 | . 62919 | .21197 | . 78946 | . 89733 | . 2667 | . 10267 | 5208 |
| . 08 | . 30254 | . 11479 | . 64214 | . 21541 | . 79320 | . 89938 | . 2607 | . 10062 | 5229 |
| . 09 | . 31903 | . 12025 | . 65525 | .21886 | . 79688 | .90139 | . 2549 | .09861 | 5250 |
| 1.10 | 1. 33565 | 0.12569 | 1.66852 | 0.22233 | 0.80050 | 9.90336 | 1. 2492 | 0.09664 | 53 II |
| . 11 | . 35240 | .13111 | . 68196 | . 22582 | . 80406 | . 90529 | . 2437 | . . 0947 I | 53 31 |
| . 12 | -36929 | . 13649 | . 69557 | . 22931 | . 80757 | . 90718 | .2383 | . 09282 | 5352 |
| .13 | . 38631 | . 14186 | . 70934 | . 23283 | .81102 | .90903 | .2330 | . 09097 | 54 I 2 |
| .14 | . 40347 | . 14720 | . 72329 | .23636 | .8I44I | .91085 | . 2279 | . 08915 | 5432 |
| 1.15 | 1.42078 | 0.15253 | 1.73741 | 0.23990 | 0.81775 | 9.91262 | 1.2229 | 0.08738 | 5452 |
| . 16 | . 43822 | . 15783 | . 75171 | . 24346 | . 82104 | . 91436 | . 2180 | .08564 | 55 II |
| .17 | -45581 | . 16311 | .76618 | . 24703 | . 82427 | .91607 | .2132 | . 08393 | 553 I |
| .18 | . 47355 | .16836 | . 78083 | . 25062 | . 82745 | .91774 | . 2085 | . 08226 | 5550 |
| .19 | . 49143 | .17360 | .79565 | .25422 | . 83058 | .9193 ${ }^{3}$ | . 2040 | . 08062 | 5609 |
| 1.20 | 1. 50946 | 0.17882 | 1.81066 | 0.25784 | 0.83365 | 9.92099 | I. 1995 | 0.07901 | 5629 |
| . 21 | . 52764 | .18402 | . 82584 | .26146 | . 83665 | . 92256 | . 1952 | . 07744 | 5647 |
| . 22 | . 54598 | . 18920 | . 84121 | . 26510 | . 83965 | .92410 | . 1910 | . 07590 | 5706 |
| .23 | . 56447 | . 19437 | . 85676 | . 26876 | . $8+258$ | .92561 | . 1868 | . 07439 | 5725 |
| . 24 | . 58311 | .19951 | . 87250 | .27242 | . 84546 | . 92709 | . 1828 | .07291 | 5743 |
| 1.25 | 1.60192 | 0.20464 | 1.88842 | 0.27610 | 0.84828 | 9.92854 | 1.1789 | 0.07146 | 5802 |
| . 26 | . 62088 | . 20975 | . 90454 | . 27979 | . 85106 | . 92996 | . $175^{\circ}$ | . 07004 | 5820 |
| . 27 | . 64001 | $.214 S^{5}$ | .92084 | .28349 | . 85380 | .93135 | .1712 | . 06865 | 5838 |
| . 28 | . 65930 | .21993 | . 93734 | .28721 | . 85648 | .93272 | .1676 | . 06723 | 5855 |
| . 29 | . 67876 | . 22499 | .95403 | .29093 | . 85913 | . 93406 | .1640 | . 06594 | 59 I 3 |
| 1.30 | 1.69838 | 0.23004 | 1.97091 | 0.29467 | 0.86172 | 9.93537 | 1.1605 | 0.06463 |  |
| $\cdot 31$ | .71818 | . 23507 | . 98800 | . 29842 | . 86428 | . 93665 | . 1570 | . 06335 | 5948 |
| - 32 | .73814 | . 24009 | 2.00528 | . 30217 | . 86678 | .93791 | . 1537 | . 06209 | 6005 |
| . 33 | .75828 | .24509 | . 02276 | . 30594 | . 86925 | .93914 | . 1504 | .06086 | 6022 |
| - 34 | . 77860 | . 25008 | . 04044 | . 30972 | . 87167 | . 94035 | . 1472 | . 05965 | 6039 |
| 1.35 | 1.79909 | 0.25505 | 2.05833 | 0.31352 | 0.87405 | 9.94154 | 1.1441 | 0.05846 | 6056 |
| $\cdot 36$ | .81977 | . 26002 | . 07643 | . 31732 | . 87639 | . 94270 | . 1410 | . 05730 | 6113 |
| . 37 | . 84.4062 | .26496 | . 09473 | .32113 | . 87869 | . 94384 | .1381 | .05616 | 6129 |
| . 38 | . 86166 | . 26990 | .11324 | . 32495 | .8S095 | . 94495 | .1351 | . 05505 | 6145 |
| $\cdot 39$ | .88289 | .27482 | . 13196 | . 32878 | . 88317 | .94604 | .1323 | . 05396 | 6202 |
| 1. 40 | 1.90430 | 0.27974 | 2.15090 | 0.33262 | 0.88535 | 9.94712 | 1.1295 | 0.05288 | 6218 |
| .41 | .92591 | .28464 | . 17005 | . 33647 | . 88749 | .94817 | . 1268 | .05183 | 6234 |
| .42 | . 94770 | .28952 | .18942 | . 34033 | . 88960 | . 94919 | .1241 | .0508I | 6249 |
| . 43 | . 96970 | . 29440 | . 20900 | . 34420 | . 89167 | . 95020 | .1215 | .04980 | 6305 |
| . 44 | .99188 | . 29926 | .22881 | .34807 | . 89370 | .95119 | .1189 | .0488I | 6320 |
| 1.45 | 2.01427 | 0.30412 | 2.24884 | 0.35196 | 0.89569 | 9.95216 | 1.1165 | 0.04784 | 6336 |
| . 46 | . 03686 | . 30896 | . 26910 | . 35585 | . 89765 | .95311 | .1140 | . 04689 | 63 51 |
| . 47 | . 05965 | -31379 | . 28958 | . 35976 | . 89958 | . 95404 | . 1116 | . 04596 | 6406 |
| . 48 | . 08265 | -31862 | . 31029 | $\cdot 36367$ | . 90147 | . 95495 | .1093 | . 04505 | 6421 |
| . 49 | . 10586 | -32343 | .33123 | .36759 | .90332 | .95584 | . 1070 | .04416 | 6436 |
| 1.50 | 2.12928 | 0.32823 | 2.35241 | $0.37{ }^{151}$ | 0.90515 | 9.95672 | 1. 1048 | 0.0432 S | 6451 |

HYPERBOLIC FUNCTIONS.

| u | sinh. u |  | cosh. u |  | tanh. u |  | coth. u |  | gd. u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 1.50 | 2.12928 | 0.32823 | 2.35241 | 0.37151 | 0.90515 | 9.95672 | I.1048 | 0.04328 | $64^{\circ}{ }_{51}{ }^{\prime}$ |
| . 51 | . 15291 | . 33303 | . 37382 | . 37545 | . 90694 | . 95758 | . 1026 | . 04242 | $65 \quad 05$ |
| . 52 | . 17676 | -33781 | - 39547 | - 37939 | . 90870 | . 95842 | . 1005 | . 04158 | 6520 |
| . 53 | . 20082 | . 34258 | . 41736 | . 38334 | . 91042 | . 95924 | . 0984 | . 04076 | 6534 |
| . 54 | . 22510 | - 34735 | -43949 | - 38730 | . 91212 | . 96005 | . 0963 | . 03995 | 6548 |
| 1.55 | 2.24961 | 0.35211 | 2.46186 | 0.39126 | 0.91379 | 9.96084 | I. 0943 | 0.03916 | $66 \quad 02$ |
| . 56 | . 27434 | . 35686 | . 48448 | . 39524 | .91542 | .96162 | . 0924 | . 03838 | 6616 |
| . 57 | . 29930 | . 36160 | . 50735 | -39921 | . 91703 | . 96238 | . 0905 | . 03762 | 6630 |
| . 58 | -32449 | . 36633 | . 53047 | . 40320 | . 91860 | . 96313 | . 0886 | . 03687 | 6643 |
| - 59 | -34991 | . 37105 | -55384 | .40719 | . 92015 | . 96386 | . 0868 | .03614 | $66 \quad 57$ |
| 1.60 | 2.37557 | 0.37577 | 2.57746 | 0.41119 | 0.92167 | 9.96457 | 1.0850 | 0.03543 | 67 10 |
| .61 | 40146 | . 38048 | . 60135 | . 41520 | . 92316 | . 96528 | . 0832 | . 03472 | $67 \quad 24$ |
| . 62 | . 42760 | . 38518 | . 62549 | . 41921 | . 92462 | . 96597 | . 0815 | . 03403 | $67 \quad 37$ |
| . 63 | . 45397 | . 38987 | . 64990 | . 42323 | . 92606 | . 96664 | . 0798 | . 03336 | 6750 |
|  | . 48059 | -3945 | . 67457 | . 42725 | -92747 | .96730 | . 0782 | .03270 | $68 \quad 03$ |
| 1.65 | 2.50746 | 0.39923 | 2.69951 | 0.43129 | 0.92886 | 9.96795 | 1.0766 | 0.03205 | $68 \quad 15$ |
| . 66 | . 53459 | . 40391 | . 72472 | . 43532 | . 93022 | . 96858 | . 0750 | .03142 | 68 28 |
| . 67 | . 56196 | . 40857 | . 75021 | -43937 | .93155 | . 96921 | . 0735 | . 03079 | $68 \quad 41$ |
| . 68 | . 58959 | .41323 | . 77596 | -44341 | . 93286 | . 96982 | . 0720 | . 03018 | $68 \quad 53$ |
| . 69 | . 61748 | . 41788 | . 80200 | -44747 | . 93415 | . 97042 | . 0705 | . 02958 | $69 \quad 05$ |
| 1.70 | 2.64563 | 0.42253 | 2.82832 | 0.45153 | 0.93541 | 9.97100 | 1.0691 | 0.02900 | 6918 |
| . 71 | . 67405 | . 42717 | . 85491 | . 45559 | . 93665 | .97158 | . 0676 | . 02842 | 6930 |
| . 72 | . 70273 | . 43180 | . 88180 | . 45966 | . 93786 | . 97214 | . 0663 | . 02786 | 6942 |
| . 73 | . 73168 | . 43643 | . 90897 | . 46374 | -93906 | -97269 | . 0649 | . 02731 | $69 \quad 54$ |
| .74 | .76091 | . 44105 | . 93643 | . 46782 | . 94023 | . 97323 | . 0636 | . 02677 | $70 \quad 05$ |
| 1.75 | 2.79041 | 0.44567 | 2.96419 | 0.47191 | 0.94138 | 9.97376 | 1.0623 | 0.02624 | $70 \quad 17$ |
| . 76 | . 82020 | . 45028 | . 99224 | . 47600 | . 94250 | . 97428 | . 0610 | . 02572 | $70 \quad 29$ |
| . 77 | . 85026 | -45488 | 3.02059 | . 48009 | .94361 | . 97479 | . 0598 | . 02521 | 7040 |
| . 78 | . 88061 | -45948 | . 04925 | . 48419 | . 94470 | . 97529 | . 0585 | . 02471 | $70 \quad 51$ |
| . 79 | .91125 | . 46408 | . 07821 | . 48830 | . 94576 | . 97578 | . 0574 | . 02422 | 7103 |
| 1.80 | 2.94217 | 0.46867 | 3. 10747 | 0.49241 | 0.94681 | 9.97626 | 1.0562 | 0.02374 | 7114 |
| . 81 | . 97340 | . 47325 | . 13705 | . 49652 | . 94783 | . 97673 | . 0550 | . 02327 | $71 \quad 25$ |
| . 82 | 3.00492 | . 47783 | . 16694 | - 50064 | -94884 | . 97719 | . 0539 | . 022281 | $\begin{array}{ll}71 & 36 \\ 71 & 46\end{array}$ |
| . 83 | . 03674 | . 48241 | .19715 .22768 | . 50476 | -94983 | . 97764 | . 0528 | . 02236 | 7146 |
|  | . 06886 |  |  |  |  |  |  | . 02 | 715 |
| I. 85 | 3.10129 | 0.49154 | 3.25853 | 0.51302 | 0.95175 | 9.97852 | 1.0507 | 0.02148 | 7208 |
| . 86 | .1.3403 | . 49610 | . 28970 | . 51716 | . 95268 | . 97895 | . 0497 | . 02105 | 72 |
| . 87 | . 16709 | . 50066 | -32121 | . 52130 | -95359 | . 97936 | . 0487 | . 02064 | 72 |
| . 88 | . 20046 | . 50521 | - 35305 | . 52544 | -95449 | . 97977 | . 0477 | . 02023 | $72 \quad 39$ |
| . 89 | . 23415 | . 50976 | - 38522 | . 52959 | -95537 | .98017 | . 0467 | . 01983 | $72 \quad 49$ |
| 1.90 | 3.26816 | 0.51430 | 3.41773 | 0.53374 | 0.95624 | 9.98057 | 1.0458 | 0.01943 | 7259 |
| .91 | ${ }^{-} .30250$ | . 51884 | . 45058 | . 53789 | . 95709 | . 98095 | . 0448 | . $01905^{\circ}$ | 73 09 |
| . 92 | - 33718 | . 52338 | - 48378 | . 54205 | . 95792 | .98133 | . 0439 | .01867 | $\begin{array}{ll}73 & 19\end{array}$ |
| . 93 | -37218 | . 52791 | . 51733 | . 54621 | . 95873 | .98170 | . 0430 | .01830 | $73 \quad 29$ |
| . 94 | -40752 | . 53244 | -551.23 | . 55038 | . 95953 | . 98206 | . 0422 | . 01794 | $73 \quad 39$ |
| 1.95 | 3.44321 | 0.53696 | 3.58548 | 0.55455 | 0.96032 | 9.98242 | 1.0413 | 0.01758 | 73 |
| . 96 | . 47923 | . 54148 | . 62009 | . 555872 | . 966109 | . 988276 | . 0405 | . 01724 | $73 \quad 58$ |
| . 97 | . 51561 | - 54600 | . 65507 | - 56290 | . 96685 | . 983111 | . 0397 | . 01689 | 74 |
| . 98 | -55234 | . 55051 | . 69041 | . 56707 | . 96259 | . 98344 | . 0389 | . 01656 | $\begin{array}{ll}74 & 17\end{array}$ |
| . 99 | . 58942 | - 55502 | . 72611 | . 57126 | . $9633{ }^{1}$ | . 98377 | . 0381 | . 01623 | $74 \quad 26$ |
| 2.00 | 3.62686 | 0.55953 | 3.76220 | 0.57544 | 0.96403 | 9.98409 | 1.0373 | 0.01591 | $74 \quad 35$ |

TABLE 17 (continued).
HYPERBOLIC FUNCTIONS.

| u | sinh. u |  | cosh. u |  | tanh. u |  | coth. u. |  | gd. u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 2.00 | 3.62686 | 0.55953 | 3.76220 | 0.57544 | 0.96403 | 9.98409 | 1.0373 | 0.01591 | $74^{\circ} 35^{\prime}$ |
| . 01 | . 66466 | . 56403 | . 79865 | . 57963 | . 96473 | . 98440 | . 0366 | . 01560 | 7444 |
| . 02 | . 70283 | . 56853 | . 83549 | . 58382 | . 96541 | . 9847 I | . 0358 | . 01529 | 7453 |
| . 03 | .74138 | . 57303 | . 87271 | . 58802 | . 96609 | . 98502 | . 0351 | . 01498 | 7502 |
| . 04 | . 78029 | . 57753 | .91032 | -59221 | . 96675 | .98531 | . 0344 | . 01469 | 75 II |
| 2.05 | 3.81058 | 0.58202 | 3.94832 | 0.59641 | 0.96740 | 9.98560 | 1. 0337 | 0.01440 | 7520 |
| . 06 | . 85926 | . 58650 | . 9867 I | . 60061 | . 96803 | .98589 | . 0330 | .01411 | 7528 |
| . 07 | . 89932 | . 59099 | 4.02550 | . 60482 | . 96865 | . 98617 | . 0324 | . 01383 | 7537 |
| . 08 | . 93977 | - 59547 | . 06470 | . 60903 | . 96926 | . 98644 | . 0317 | . 13356 | 7545 |
| . 09 | .9806I | . 59995 | . 10430 | .6I324 | . 96986 | . 9867 I | .0311 | . 01329 | 7554 |
| 2.10 | 4.02186 | 0.60443 | 4.14431 | 0.61745 | 0.97045 | 9.98697 | 1. 0304 | 0.01303 | 7602 |
| . 11 | . 06350 | . 60890 | . 18474 | . 62167 | . 97103 | . 98723 | . 0298 | . 01277 | 7610 |
| . 12 | . 10555 | .61337 | . 22558 | . 62589 | .971 59 | .98748 | . 0292 | . 01252 | 7619 |
| . 13 | .14801 | .61784 | . 26685 | .63011 | . 97215 | .98773 | . 0286 | . 01227 | $76 \quad 27$ |
| .14 | . 19089 | .6223I | -30855 | . 63433 | . 97269 | . 98798 | .028I | . 01202 | 7635 |
| 2.15 | 4.23419 | 0.62677 | 4.35067 | 0.63856 | 0.97323 | 9.98821 | 1.0275 | 0.01179 | 7643 |
| . 16 | .27791 | .63123 | . 39323 | . 64278 | . 97375 | . 98845 | . 0270 | . 01155 | 7651 |
|  | . 32205 | . 63569 | . 43623 | . 64701 | . 97426 | . 98868 | . 0264 | . 011132 | 7658 |
| .I8 | . 36663 | . 64015 | . 47967 | .65125 | . 97477 | . 98890 | . 0259 | . 01110 | 7706 |
| .19 | . 41165 | . 64460 | . 52356 | . 65548 | . 97526 | .98912 | . 0254 | . 01088 | $77 \quad 14$ |
| 2.20 | 4.457 II | 0.64905 | 4.56791 | 0.65972 | 0.97574 | 9.98934 | 1.0249 | 0.01066 | 7721 |
| . 21 | . 50301 | . 65350 | . 61271 | . 66396 | . 97622 | . 98955 | . 0244 | .01045 | $77 \quad 29$ |
| . 22 | . 54936 | . 65795 | . 65797 | . 66820 | . 97668 | . 98975 | . 0239 | . 01025 | $77 \quad 36$ |
| .23 | . 59617 | . 66240 | . 70370 | . 67244 | . 97714 | . 98996 | . 0234 | .01004 | 7744 |
| .24 | . 64344 | . 66684 | . 74989 | . 67668 | . 97759 | .99016 | . 0229 | . 00984 | 77 51 |
| 2.25 | 4.69117 | 0.67128 | 4.79657 | 0.68093 | 0.97803 | 9.99035 | 1. 0225 | 0.00965 | $77 \quad 58$ |
| . 26 | . 73937 | . 67572 | . 84372 | . 68518 | .97846 | . 99054 | . 0220 | . 00946 | 7805 |
| . 27 | . 78804 | . 68016 | .891 36 | . 68943 | . 97888 | . 99073 | . 0216 | . 00927 | 78 12 |
| . 28 | . 83720 | . 68459 | . 93948 | . 69368 | . 97929 | .99091 | . 0211 | . 00909 | 7819 |
| . 29 | . 88684 | . 68903 | .98810 | . 69794 | . 97970 | .99109 | . 0207 | .00891 | $78 \quad 26$ |
| 2.30 | 4.93696 | 0.69346 | 5.03722 | 0.70219 | 0.98010 | 9.99127 | 1.0203 | 0.00873 | 7833 |
| . 31 | . 98758 | . 69789 | . 08684 | . 70645 | . 98049 | . 99144 | . 0199 | .00856 | 7840 |
| .32 | 5.03870 | .70232 | . 13697 | . 71071 | . 98087 | .9916I | . 0195 | .00839 | 7846 |
| - 33 | . 09032 | . 70675 | . 18762 | .71497 | .98124 | .99178 | . 0191 | . 00822 | 7853 |
| - 34 | . 14245 | .71117 | .23878 | .71923 | .98161 | .99194 | . 1818 | .00806 | 7900 |
| 2.35 | 5.19510 | 0.71559 | 5.29047 | 0.72349 | 0.98197 | 9.99210 | I.OI84 | 0.00790 | 7906 |
| . 36 | . 24827 | . 72002 | -34269 | . 72776 | .98233 | .99226 | . 0180 | . 00774 | 7913 |
| - 37 | . 30196 | . 72444 | . 39544 | .73203 | . 98267 | . 99241 | . 0176 | . 00759 | 7919 |
| . 38 | . 35618 | .72885 | . 44873 | .73630 | . 9830 I | . 99256 | . 0173 | .00744 | 7925 |
| - 39 | .41093 | .73327 | . 50256 | .74056 | . 98335 | . 9927 I | .0169 | . 00729 | $793^{2}$ |
| 2.40 | 5.46623 | 0.73769 | $5 \cdot 55695$ | 0.74484 | 0.98367 | 9.99285 | 1.0166 | 0.00715 | 7938 |
| . 41 | . 52207 | .74210 | . 61189 | .74911 | . 98400 | . 99299 | . 0163 | .00701 | 7944 |
| .42 | . 57847 | .74652 | . 66739 | .75338 | . 98431 | . 99313 | . 0159 | . 00687 | 7950 |
| . 43 | . 63542 | .75093 | .72346 | .75766 | . 98462 | . 99327 | . Or 56 | . 00673 | 7956 |
| . 44 | . 69294 | .75534 | . 78010 | .76194 | . 98492 | . 99340 | . 1153 | . 00660 | 8002 |
| 2.45 | 5.75103 | 0.75975 | 5.83732 | 0.76621 | 0.98522 | 9.99353 | 1.0150 | 0.00647 | So os |
| . 46 | . 80969 | .76415 | . 89512 | .77049 | . 98551 | . 99366 | . 0147 | . 00634 | 8014 |
| . 47 | .86893 | .76856 | . 953352 | . 77477 | .98579 | . 99379 | .oI44 | . 0062 I | 8020 |
| .48 | . 92876 | .77296 | 6.01250 | . 77906 | . 98607 | -99391 | . 0141 | . 00609 | 8026 |
| . 49 | .98918 | . 77737 | . 07209 | .78334 | .98635 | . 99403 | . 0138 | . 00597 | So 3I |
| 2.50 | 6.05020 | 0.78177 | 6.13229 | 0.78762 | 0.9866I | 9.99415 | 1.0136 | 0.00585 | 8o 37 |

Smithsonian tables.

TABLE 17 (continued).
HYPERBOLIC FUNCTIONS.

| 1 | sinh. u |  | cosh. u |  | tanh. u |  | coth. u |  | gd. u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 2.50 | 6.05020 | 0.78177 | 6.13229 | 0.78762 | 0.98661 | 9.99415 | 1.0136 | 0.00585 | $80^{\circ} \quad 37^{\prime}$ |
| . 51 | .11183 | .78617 | . 19310 | .79191 | . 98688 | . 99426 | . 0133 | . 00574 | 8042 |
| . 52 | . 17407 | . 79057 | . 25453 | .79619 | . 98714 | . 99438 | . 0130 | . 00562 | 8048 |
| . 53 | . 23692 | . 79497 | .31658 | . 80048 | . 98739 | . 99449 | . 0128 | . 00551 | So 53 |
| . 54 | -30040 | . 79937 | -37927 | . 80477 | . 98764 | . 99460 | . 0125 | . 00540 | $80 \quad 59$ |
| 2.55 | 6.36451 | 0.80377 | 6.44259 | 0.80906 | 0.98788 | 9.99470 | 1.0123 | 0.00530 | 81 |
| . 56 | . 42926 | .80816 | - 50656 | .81 335 | .98812 | .99481 | . 0120 | .00519 | 81 10 |
| . 57 | . 49464 | . 81256 | . 57118 | .81764 | .98835 | .99491 | . 0118 | . 00509 | 8 I 15 |
| . 58 | . 56068 | . 81695 | . 63646 | .82194 | . 98858 | .9950 I | . 0115 | . 00499 | 8120 |
| . 59 | . 62738 | .82134 | . 70240 | . 82623 | .98881 | . 99511 | . 0113 | . 00489 | 81 25 |
| 2.60 | 6.6947 .3 | 0.82573 | 6.76901 | 0.83052 | 0.98903 | 9.99521 | 1.0111 | 0.00479 | 8 I 30 |
| . 61 | . 76276 | .83c12 | . 83629 | . 83482 | .98924 | . 99530 | .0109 | . 00470 | 8 I 35 |
| . 62 | . 83146 | . 83451 | . 90426 | . 83912 | . 98946 | . 99540 | .0107 | . 00460 | 8140 |
| .63 | . $900{ }^{5} 5$ | . 83890 | . 97292 | . 84341 | . 98966 | . 99549 | . 0104 | .00451 | 81 45 |
| . 64 | .97092 | . 84329 | 7.04228 | . 84771 | .98987 | . 99558 | .0102 | . 00442 | 8I 50 |
| 2.65 | 7.04169 | 0.84768 | 7.11234 | 0.85201 | 0.99007 | 9.99566 | 1.0100 | 0.00434 | 8 I 55 |
| . 66 | .11317 | . 85206 | . 18312 | . 85631 | . 99026 | . 99575 | . 0098 | . 00425 | 8200 |
| . 67 | . 18536 | . 85645 | . 25461 | . 86061 | . 99045 | . 99583 | .0096 | . 00417 | 8205 |
| . 68 | .25S27 | . 86083 | . 32683 | . 86492 | . 99064 | . 99592 | . 0094 | . 00408 | 8209 |
| . 69 | -33190 | .86522 | -39978 | . 86922 | . 99083 | . 99600 | . 0093 | . 00400 | $82 \quad 14$ |
| 2.70 | 7.40626 | 0.86960 | 7.47347 | 0.87352 | 0.99101 | 9.99608 | 1.0091 | 0.00392 | $82 \quad 19$ |
| . 71 | .48137 | . 87398 | . 5479 I | . 87783 | .99118 | . 99615 | .0089 | .00385 | $82 \quad 23$ |
| . 72 | - 55722 | . 87836 | . 62310 | . 88213 | .99136 | . 99623 | . 0087 | . 00377 | 8228 |
| .73 | .63383 | . 88274 | . 69905 | . 88644 | .99153 | . 9963 I | . 0085 | . 00369 | 8232 |
| . 74 | .7112 | .88-12 | . 77578 | . 89074 | .99170 | .99638 | . 0084 | .00362 | 8237 |
| 2.75 | 7.78935 | 0.89150 | 7.85328 | 0.89505 | 0.99186 | 9.99645 | 1.0082 | 0.00355 | 8241 |
| . 76 | . 86828 | . 89588 | . 93157 | . 89936 | . 99202 | . 99652 | . 0080 | .00348 | 8245 |
| . 77 | . 94799 | . 90026 | 8.01065 | . 90367 | -99218 | . 99659 | . 0079 | .00341 | 8250 |
| .78 | 8.02849 | . 90463 | . 09053 | . 90798 | .99233 | . 99666 | . 0077 | .00334 | $8254$ |
| . 79 | . 10980 | .90901 | . 17122 | .91229 | . 99248 | .99672 | . 0076 | . 00328 | 8258 |
| 2.80 | 8.19192 | 0.91339 | 8.25273 | 0.91660 | 0.09263 | 9.99679 | 1.0074 | 0.0032 I | $83 \quad 02$ |
| .81 | . 27486 | . 91776 | . 33506 | .92091 | . 99278 | . 99685 | . 0073 | .00315 | 8307 |
| . 82 | . 35862 | .92213 | .41823 | .92522 | . 99292 | . 99691 | . 0071 | . 00309 | 83 II |
| . 83 | . 44322 | .92651 | . 50224 | -92953 | . 99306 | . 99698 | . 0070 | . 00302 | 8315 |
| . 84 | . 52867 | . 93088 | . 58710 | . 93385 | . 99320 | .99704 | . 0069 | . 00296 | 8319 |
| 2.85 | 8.61497 | 0.93525 | 8.67281 | 0.93816 | 0.99333 | 9.99709 | 1.0067 | 0.00291 | $83 \quad 23$ |
| . 86 | .70213 | .93963 | . 75940 | . 94247 | . 99346 | . 99715 | . 0066 | . 00285 | $83 \quad 27$ |
| . 87 | . 79016 | . 94400 | . 84686 | . 94679 | . 99359 | . 99721 | . 0065 | . 00279 | 83.31 |
| . 58 | . 87907 | . 94837 | . 93520 | .95110 | . 99372 | . 99726 | . 0063 | . 00274 | $83^{\circ} 34$ |
| . 89 | .96887 | .95274 | 9.02444 | . 95542 | . 99384 | .99732 | . 0062 | . 00268 | $83 \quad 38$ |
| 2.90 | 9.05956 | 0.957 I I | 9.11458 | 0.95974 | 0.99396 | 9.99737 | 1.0061 | 0.00263 | 8342 |
| .91 | .15116 | . 96148 | . 20564 | . 96405 | . 99408 | . 99742 | . 0060 | . 00258 | 8346 |
| .92 | . 24368 | .96584 | . 29761 | . 96837 | . 99420 | . 99747 | .0058 | . 00253 | 8350 |
| . 93 | . 33712 | . 97021 | . 39051 | . 97269 | . 99531 | . 99752 | . 0057 | . 00248 | 8353 |
| . 94 | . 43149 | . 97458 | . 48436 | . 97701 | . 99443 | . 99757 | . 0056 | . 00243 | 8357 |
| 2.95 | 9.52681 | 0.97895 | 9.57915 | 0.98133 | 0.99454 | 9.99762 | 1.0055 | 0.00238 | 8400 |
| . 96 | . 62308 | .9833I | . 67490 | . 98565 | . 99464 | . 99767 | . 0054 | . 00233 | 84 |
| . 97 | . 72031 | . 98768 | . 77161 | . 98997 | . 99475 | . 9977 I | . 0053 | . 00229 | 84 |
| . 98 | .81851 | . 99205 | . 86930 | . 99429 | . 99485 | .99776 | . 0052 | . 00224 | 84 II |
| . 99 | .91770 | .9964 I | . 96798 | .99861 | . 99496 | .99780 | . 0051 | . 00220 | $84 \quad 15$ |
| 3.00 | 10.01787 | 1.00078 | 10.06766 | 1.00293 | 0.99505 | 9.99785 | 1.0050 | 0.00215 | $84 \quad 18$ |

Smithsonian tables.

HYPERBOLIC FUNCTIONS.

| u | sinh. u |  | cosh. u |  | tanh. u |  | coth. u |  | gd. u |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Nat. | Log. | Nat. | Log. | Nat. | Log. | Nat. | Log. |  |
| 3.0 | 10.0179 | 1.00078 | 10.0677 | 1.00293 | 0.99505 | 9.99785 | 1.0050 | 0.00215 | $84^{\circ} \mathrm{I} 8^{\prime}$ |
| . 1 | 11.0765 | . 04440 | 11.1215 | .04616 | . 99595 | . 99824 | . 0041 | . 00176 | 8450 |
| . 2 | 12.2459 | . 08799 | I 2.2866 | . 08943 | . 99668 | . 99856 | . 0033 | .00144 | 8520 |
| . 3 | 1 3.5379 | .13155 | 13.5748 | . 13273 | . 99728 | . 99882 | . 0027 | . 00118 | 8547 |
| . 4 | 14.9654 | . 17509 | 14.9987 | . 17605 | . 99777 | .99903 | . 0022 | . 00097 | 86 II |
| $3 \cdot 5$ | 16.5426 | 1.21860 | 16.5728 | 1.21940 | 0.99818 | 9.9992 I | 1.001S | 0.00079 | 8632 |
| . 6 | 18.2855 | . 26211 | 18.3128 | . 26275 | . 99851 | . 99935 | .0015 | . 00065 | 8652 |
| $\cdot 7$ | 20.2113 | . 30559 | 20.2360 | . 30612 | . 99878 | . 99947 | . 0012 | . 00053 | 8710 |
| . 8 | 22.3394 | . 34907 | 22.3618 | .34951 | . 99900 | . 99957 | .0010 | . 00043 | 8726 |
| . 9 | .24.69II | - 39254 | 24.7113 | -39290 | . 99918 | . 99964 | . 0008 | . 00036 | 87 4I |
| 4.0 | 27.2899 | 1.43600 | 27.3082 | 1.43629 | 0.99933 | 9.99971 | 1.0007 | 0.00029 | 8754 |
| . I | 30.1619 | . 47946 | 30.1784 | . 47970 | . 99945 | . 99976 | . 0005 | . 00024 | 8806 |
| . 2 | 33.3357 | . 52291 | 33.3507 | . 52310 | . 99955 | .99980 | . 0004 | . 00020 | 8817 |
| -3 | 36.8431 | .56636 | 36.8567 | . 56652 | . 99963 | . 99984 | . 0004 | . 00016 | 88 88 |
| . 4 | 40.7193 | .60980 | 40.7316 | . 60993 | . 99970 | .99987 | . 0003 | . 00013 | 8836 |
| 4.5 | 45.0030 | 1.65324 | 45.0141 | 1. 65335 | 0.99975 | 9.99989 | 1.0002 | 0.00011 | 8844 |
| . 6 | 49.7371 | . 69668 | 49.7472 | . 69677 | . 99980 | .99991 | . 0002 | . 00009 | 88 51 |
| .7 | 54.9690 | .74012 | 54.9781 | .74019 | .99983 | . 99993 | . 0002 | . 00007 | 8857 |
| . 8 | 60.7511 | .78355 | 60.7593 | .78361 | . 99986 | . 99994 | .0001 | . 00006 | 8903 |
| . 9 | 67.1412 | . 82699 | 67.1486 | . 82704 | .99989 | .99995 | .0001 | . 00005 | 8909 |
| 5.0 | 74.2032 | 1. 87042 | 74.2099 | 1.87046 | 0.99991 | 9.99996 | 1.0001 | 0.00004 | 89 I 4 |

TABLE 18.-Factorials.
See Table 16 for logarithms of the products 1.2.3. . . . $n$ from I to 100.
See Table 32 for log. $\Gamma(n+1)$ for values of $n$ between 1.000 and 2.000 .

| $n$ | $\frac{1}{n!}$ | $n:=1.2 \cdot 3 \cdot 4 \cdots n$ | $n$ |
| :---: | :---: | :---: | :---: |
| I | 1. | 1 | I |
| 2 | 0.5 | 2 | 2 |
| 3 | . 1666666666666666666666667 | 6 | 3 |
| 4 | .04166 66666666666666666667 | 24 | 4 |
| 5 | . 0083333333333333333333333 | 120 | 5 |
| 6 | 0.00138 88888888888888888889 | 720 | 6 |
| 7 | .00019 84126 98412 69841 26984 | 5040 | 7 |
| 8 | .00002 48015873015873015873 | 40320 | 8 |
| 9 | .00000 27557319223985890653 | 362880 368800 | 9 |
| 10 | .00000 02755731922398589065 | 3628800 | 10 |
| II | 0.0000000250521083854417188 | 39916800 | 1 I |
| 12 | . 0000000020876756987868099 | 4790 O1600 | 12 |
| 13 | .00000 00001 60590438.3682161 | 6227020800 | 13 |
| 14 | . 00000000001147707455977297 | 87178291200 | 14 |
| 15 | .00000 0000000764 71637 31820 | 1307674368000 | 15 |
| 16 | 0.0000000000000477947733239 | 2092 27898 88000 | 16 |
| 17 | . 0000000000000028114572543 | 355687428096000 | ${ }^{1} 7$ |
| 18 | . 0000000000000001561920697 | 6402373705728000 | 18 |
| 19 | . 0000000000000000082206352 | 121645100408832000 | 19 |
| 20 | .00000 00000 00000 00041 10318 | 243290200 8ı766 40000 | 20 |

Table 19.
EXPONENTIAL FUNCTION.

| $x$ | $\log _{10}(e x)$ | ex | - $x$ | $x$ | $\log _{10}(e x)$ | ex | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.00 | 0.00000 | 1.0000 | 1.000000 | 0.50 | 0.21715 | 1. 6487 | 0.606531 |
| . 01 | . 00434 | . 0101 | 0.990050 | . 51 | . 22149 | . 6653 | . 600496 |
| . 02 | . 00869 | . 0202 | .980199 | . 52 | .22583 | . 6820 | .594521 |
| . 03 | .01303 | . 0305 | . 970446 | . 53 | . 23018 | . 6989 | . 588605 |
| . 04 | . 01737 | . 0408 | .960789 | . 54 | . 23452 | .7160 | . 582748 |
| 0.05 | 0.02171 | 1.0513 | 0.951229 | 0.55 | 0.23886 | 1.7333 | 0.576950 |
| .o6 | . 02606 | . 0618 | . 941765 | . 56 | . 24320 | .7507 | . 571209 |
| . 07 | . 03040 | . 0725 | . 932394 | . 57 | . 24755 | . 7683 | . 565525 |
| .OS | . 03474 | .0833 | .923116 | . 58 | . 25189 | . 7860 | -559898 |
| . 09 | . 03909 | . 0942 | .913931 | . 59 | . 25623 | . 8040 | . 554327 |
| 0.10 | 0.04343 | 1.1052 | 0.904837 | 0.60 | 0.26058 | 1.8221 | 0.548812 |
| . 11 | . 04777 | . 1163 | . 895834 | .61 | . 26492 | . 8404 | .543351 |
| . 12 | .05212 | . 1275 | . 886920 | . 62 | . 26926 | . 8589 | . 537944 |
| . 13 | . 05646 | . 1388 | . 878095 | . 63 | .27361 | . 8776 | . 532592 |
| . 14 | .06080 | . 1503 | . 869358 | . 64 | . 27795 | . 8965 | . 527292 |
| 0.15 | 0.06514 | 1.1618 | 0.860708 | 0.65 | 0.28229 | 1.9155 | 0.522046 |
| .16 | . 06949 | . 1735 | . 85.52144 | . 66 | . 28663 | . 9348 | . 516851 |
| .17 | .07383 | .1853 | . 843665 | . 67 | . 29098 | . 9542 | . 511709 |
| . 18 | :07817 | . 1972 | . 835270 | . 68 | . 29532 | . 9739 | . 506617 |
| . 19 | . 08252 | . 2092 | . 826959 | . 69 | . 29966 | .9937 | . 501576 |
| 0.20 | 0.08686 | 1.2214 | 0.818731 | 0.70 | 0.30401 | 2.0138 | 0.496585 |
| 21 | .09120 | . 2337 | . 810584 | . 71 | . 30835 | . 0340 | . 491644 |
| . 22 | . 09554 | . 2461 | . 802519 | . 72 | . 31269 | . 0544 | .486752 |
| . 23 | . 09989 | . 2586 | .794534 | . 73 | . 31703 | . 0751 | .481909 |
| . 24 | . 10423 | .2712 | .786628 | . 74 | . 32138 | . 0959 | -477114 |
| 0.25 | 0.10857 | 1.2840 | 0.778801 | 0.75 | 0.32572 | 2.1170 | 0.472367 |
| . 26 | . 11292 | . 2969 | .771052 | . 76 | . 33006 | . 1383 | . 467666 |
| .27 | . 11726 | . 3100 | .763379 | . 77 | - 33441 | . 1598 | . 463013 |
| . 28 | .12160 | -3231 | . 755784 | . 78 | . 33875 | .1815 | . 458406 |
| . 29 | .12595 | . 3364 | . 748264 | . 79 | -34309 | . 2034 | .453845 |
| 0.30 | 0.13029 | 1.3499 | 0.740818 | 0.80 | 0.34744 | 2.2255 | 0.449329 |
| . 31 | . 13463 | . 3634 | . 733447 | . 81 | . 35178 | . 2479 | . 444858 |
| $\cdot 32$ | . 3897 | -3771 | . 726149 | . 82 | . 35612 | . 2705 | . 440432 |
| . 33 | . 14332 | . 3910 | . 718924 | . 83 | - 36046 | . 2933 | . 436049 |
| . 34 | . 14766 | . 4049 | .711770 | . 84 | . 36481 | . 3164 | . 431711 |
| 0.35 | 0.15200 | 1.4191 | 0.704688 | 0.85 | 0.36915 | 2.3396 | 0.427415 |
| . 36 | . 15635 | . 4333 | . 697676 | . 86 | . 37349 | . 3632 | .423162 |
| - 37 | . 16069 | . 44777 | .690734 .683865 | . 87 | . .37784 .38218 | - 3869 | . 418952 |
| - 39 | . 16937 | . 4770 | . 677057 | . 89 | ${ }^{-} .38652$ | .4351 | . 410656 |
| 0.40 | 0.17372 | 1.4918 | 0.670320 | 0.90 | 0.39087 | 2.4596 | 0.406570 |
| . 41 | . 17806 | . 5068 | . 663650 | .91 | -39521 | . 4843 | . 402524 |
| . 42 | . 18240 | . 5220 | . 657047 | . 92 | . 39955 | . 5093 | -398519 |
| . 43 | . 18675 | . 5373 | . 650509 | .93 | . 40389 | . 5345 | -. 394554 |
| . 44 | .19109 | . 5527 | . 644036 | . 94 | . 40824 | . 5600 | -390628 |
| 0.45 | 0. 19543 | 1. 5683 | 0.637628 | 0.95 | 0.41258 | 2.5857 | 0.386741 |
| . 46 | . 19978 | . 584 l | . 631284 | . 96 | . 41692 | . 6117 | -382893 |
| . 47 | . 20412 | . 6000 | . 625002 | . 97 | . 42127 | . 6379 | -379083 |
| . 48 | . 20846 | . 6161 | . 618783 | . 98 | . 42561 | . 6645 | -3753II |
| . 49 | .21280 | . 6323 | . 612626 | . 99 | . 42995 | . 6912 | -371577 |
| 0.50 | 0.21715 | 1.6487 | 0.606531 | 1.00 | 0.43429 | 2.7183 | 0.367879 |

EXPONENTIAL FUNCTION.

| $x$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ | $x$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.00 | 0.43429 | 2.7183 | 0.367879 | 1.50 | 0.65144 | 4.4817 | 0.223130 |
| . 01 | . 43864 | . 7456 | . 364219 | . 51 | . 65578 | . 5267 | .220910 |
| . 02 | . 44298 | . 7732 | . 360595 | . 52 | . 66013 | . 5722 | . 218712 |
| . 03 | . 44732 | .8011 | - 357007 | . 53 | . 66447 | . 6182 | . 216536 |
| . 04 | .45167 | . 8292 | -353455 | -54 | .6688I | . 6646 | . 214381 |
| 1.05 | 0.45601 | 2.8577 | 0.349938 | 1. 55 | 0.67316 | 4.7115 | 0.212248 |
| . 06 | . 46035 | . 8864 | . 346456 | . 56 | -. 67750 | . 7588 | .210136 |
| . 07 | . 46470 | .9154 | -343009 | . 57 | . 68184 | . 8066 | . 208045 |
| . 08 | . 46904 | . 9447 | . 339596 | . 58 | .68619 | . 8550 | . 205975 |
| . 09 | -47338 | . 9743 | . 336216 | . 59 | . 69053 | . 9037 | . 203926 |
| 1.10 | 0.47772 | 3.0042 | 0.332871 | 1.60 | 0.69487 | 4.9530 | 0.201897 |
| . 11 | . 48207 | . 0344 | $\cdot 329559$ | . 61 | . 6992 I | 5.0028 | . 199888 |
| . 12 | . 48641 | . 0649 | . 326280 | . 62 | . 70356 | .0531 | . 197899 . |
| . 13 | . 49075 | . 0957 | . 323033 | . 63 | . 70790 | .1039 | . 195930 |
| . 14 | .49510 | . 1268 | -3198ı9 | . 64 | . 71224 | . 1552 | .193980 |
| 1.15 | 0.49944 | 3.1582 | 0.316637 | 土. 65 | 0.71659 | 5.2070 | 0.192050 |
| .16 | . 50378 | .18999 | . 313486 | . 66 | . 72093 | . 2593 | .190139 |
| .17 | -50812 | . 2220 | . 310367 | . 67 | . 72527 | . 3122 | . 188247 |
| . 18 | -51247 | . 2544 | - 307279 | . 68 | .72961 | . 3656 | . 186374 |
| . 19 | . 51681 | . 2871 | . 304221 | . 69 | .73396 | .4195 | . 184520 |
| 1.20 | 0.52115 | 3.3201 | 0.301194 | 1.70 | 0.73830 | 5.4739 | 0.182684 |
| . 21 | . 52550 | - 3535 | .298197 | . 71 | . 74264 | . 5290 | . 180866 |
| . 22 | -52984 | -3872 | . 295230 | .72 | . 74699 | . 5845 | . 179066 |
| . 23 | -53418 | .4212 | . 292293 | . 73 | . 75133 | . 6407 | . 177284 |
| . 24 | . 53853 | . 4556 | . 289384 | . 74 | . 75567 | . 6973 | . 175520 |
| 1.25 | 0.54287 | $3 \cdot 4903$ | 0.286505 | 1.75 | 0.76002 | 5.7546 | 0.173774 |
| . 26 | . 54721 | . 5254 | . 283654 | . 76 | . 76436 | . 8124 | .172045 |
| .27 | . 55155 | . 5609 | . 280832 | . 77 | . 76870 | . 8709 | .170333 |
| . 28 | . 55590 | . 5966 | . 278037 | . 78 | . 77304 | . 9299 | .168638 |
| . 29 | . 56024 | .6328 | . 27527 I | .79 | . 77739 | . 9895 | . 166960 |
| 1.30 | 0.56458 | 3.6693 | 0.272532 | 1.80 | 0.78173 | 6.0496 | 0.165299 |
| . 31 | . 56893 | . 7062 | . 269820 | .81 | . 78607 | .1104 | . 163654 |
| . 32 | . 57327 | . 7434 | . 267135 | . 82 | . 79042 | . 1719 | . 162026 |
| .33 | .5776I | .7810 | . 264477 | . 83 | . 79476 | . 2339 | . 160414 |
| . 34 | .58195 | .8190 | .261846 | . 84 | . 79910 | . 2965 | . 588817 |
| I. 35 | 0.58630 | 3.8574 | 0.259240 | 1. 85 | 0.80344 | 6.3598 | 0. 157237 |
| . 36 | . 59064 | . 8962 | . 256661 | . 86 | . 80779 | . 4237 | . 155673 |
| -37 | - 59498 | . 9354 | . 254107 | . 87 | . 81213 | .4883 | .154124 |
| . 38 | . 59933 | . 9749 | .251579 | . 88 | . 81647 | . 5535 | . 152590 |
| - 39 | . 60367 | 4.0149 | . 249075 | . 89 | . 82082 | .6194 | .151072 |
| 1.40 | 0.60801 | 4.0552 | 0.246597 | 1.90 | 0.82516 | 6.6859 | 0.149569 |
| . 41 | .61236 | . 0960 | .244143 | . 91 | . 82950 | .7531 | . 148080 |
| . 42 | .61670 | . 1371 | . 241714 | . 92 | . 83385 | . 8210 | . 146607 |
| . 43 | . 62104 | .1787 | .239309 | . 93 | . 83819 | .8895 | .145148 |
| . 44 | . 62538 | . 2207 | . 236928 | .94 | . 84253 | . 9588 | . 143704 |
|  | 0.62973 | 4.2631 | 0.234570 |  | 0.84687 | 7.0287 |  |
| . 46 | . 63407 | . 3060 | . 232236 | . 96 | . 85122 | . 0993 | . 140858 |
| . 47 | . 63841 | - 3492 | . 229925 | . 97 | . 85556 | .1707 | . 139457. |
| . 48 | .64276 | - 3929 | .227638 | . 98 | . 85990 | . 2427 | . 138069 |
| . 49 | . 64710 | .437 I | . 225373 | . 99 | . 86425 | -3155 | . 136695 |
| 1. 50 | 0.65144 | $4 \cdot 4817$ | 0.223130 | 2.00 | 0.86859 | $7 \cdot 3891$ | -. 135335 |

Smithsonian Tables.

EXPONENTIAL FUNCTION.

| $x$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ | $x$ | $\log _{10}\left(e^{x}\right)$ | ${ }^{x}$ | ${ }^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2.00 | 0.86859 | $7 \cdot 3891$ | 0.135335 | 2.50 | 1.08574 | 12.182 | 0.082085 |
| . 01 | . 87293 | . 4633 | . 133989 | . 51 | . 09008 | . 305 | .081268 |
| . 02 | . 87727 | . 5383 | . 132655 | . 52 | . 09442 | . 429 | . 080460 |
| . 03 | . 88162 | . 6141 | . 131336 | . 53 | . 09877 | . 554 | . 079659 |
| . 04 | . 88596 | . 6906 | . 130029 | . 54 | .103 I I | . 680 | . 078866 |
| 2.05 | 0.89030 | 7.7679 | 0.128735 | 2.55 | 1.10745 | 12.807 | 0.078082 |
| . 06 | . 89465 | . 8460 | . 127454 | . 56 | . 11179 | . 936 | . 077305 |
| . 07 | . 89899 | . 9248 | . 126186 | . 57 | .11614 | 13.066 | . 076536 |
| . 08 | .90333 | 8.0045 | . 124930 | . 58 | .12048 | . 197 | . 075774 |
| . 09 | . 90768 | . 0849 | . 123687 | . 59 | .12482 | . 330 | . 075020 |
| 2.10 | 0.91202 | 8.1662 | 0.122456 | 2.60 | 1.12917 | 13.464 | 0.074274 |
| . 11 | . 91636 | . 2482 | . 121238 | . 61 | . 13351 | . 599 | . 073535 |
| . 12 | . 92070 | . 3311 | . 120032 | . 62 | . 13785 | .736 | . 072803 |
| 13 | . 92505 | . 4149 | . 118837 | .63 | . 14219 | . 874 | . 072078 |
| . 14 | . 92939 | . 4994 | . 117655 | . 64 | . 14654 | 14.013 | . 071361 |
| 2.15 | 0.93373 | 8.5849 | 0.116484 | 2.65 | 1.15088 | 14.154 | 0.070651 |
| .16 | . 93808 | . 6711 | . 115325 | . 66 | . 15522 | . 296 | . 069948 |
| . 17 | . 94242 | .758 | . 114178 | . 67 | . 15957 | . 440 | . 069252 |
| . 18 | . 94676 | . 8463 | . 113042 | . 68 | . 16391 | . 585 | . 068563 |
| . 19 | .951 10 | .9352 | .111917 | . 69 | . 16825 | .732 | .067881 |
| 2.20 | 0.95545 | 9.0250 | 0.110803 | 2.70 | 1.17260 | 14.880 | 0.067206 |
| . 21 | . 95979 | . 1557 | .109701 | . 71 | .17694 | 15.029 | . 066537 |
| . 22 | . 96413 | . 2073 | . 108609 | . 72 | . 18128 | .180 | . 065875 |
| . 23 | . 96848 | . 2999 | . 107528 | .73 | .18562 | . 333 | . 065219 |
| . 24 | . 97282 | - 3933 | . 106459 | . 74 | . 18997 | .487 | . 064570 |
| 2.25 | 0.97716 | 9.4877 | -. 105399 | 2.75 | 1.19431 | 15.643 | 0.063928 |
| . 26 | . 98151 | . 5831 | . 104350 | . 76 | . 19865 | . 800 | . 063292 |
| . 27 | . 98585 | . 6794 | . 103312 | . 77 | . 20300 | . 959 | . 062662 |
| . 28 | . 99019 | .7767 | .102284 | . 78 | . 20734 | 16.119 | . 062039 |
| . 29 | . 99453 | . 8749 | . 101266 | . 79 | .21168 | .28I | .06142I |
| 2.30 | 0.99888 | 9.9742 | 0.100259 | 2.80 | 1.21602 | 16.445 | 0.060810 |
| . 31 | 1.00322 | 10.074 | .099261 | .81 | . 22037 | . 610 | . 060205 |
| . 32 | . 00756 | .176 | . 098274 | . 82 | . 22471 | . 777 | . 059606 |
| . 33 | . 01191 | . 278 | . 097296 | . 83 | . 22905 | . 945 | .059013 |
| . 34 | . 01625 | . 381 | .096328 | . 84 | . 23340 | 17.116 | . 058426 |
| 2.35 | - 1.02059 | 10.486 | 0.095369 | 2.85 | 1.23774 | 17.288 | 0.057844 |
| . 36 | . 02493 | . 591 | . 094420 | . 86 | . 24208 | . 462 | . 057269 |
| . 37 | . 02928 | . 697 | . 09348 I | . 87 | . 24643 | . 637 | . 056699 |
| . 38 | . 03362 | . 805 | . 092551 | . 88 | . 25077 | .814 | . 055135 |
| . 39 | . 03796 | . 913 | . 091630 | . 89 | .255 ${ }^{1}$ | . 993 | . 055576 |
| 2.40 | 1.04231 | 11.023 | 0.090718 | 2.90 | 1.25945 | 18.174 | 0.055023 |
| .41 | . 04665 | . 34 | . 089815 | .91 | . 26380 | -357 | . 054476 |
| . 42 | . 05099 | . 246 | . 088922 | . 92 | . 26814 | -541 | . 053934 |
| . 43 | . 05534 | . 359 | . 088037 | . 93 | . 27248 | . 728 | . 053397 |
| . 44 | . 05968 | . 473 | .08716ז | . 94 | . 27683 | .916 | . 052866 |
|  | 1.06402 | 11.588 | 0.086294 |  | 1.28117 | 19.106 | 0.052340 |
| . 46 | . 06836 | . 705 | . 085435 | . 96 | . 28551 | . 298 | . 051819 |
| . 47 | . 07271 | . 82.2 | . 084585 | . 97 | . 28985 | . 492 | . 051303 |
| . 48 | . 07705 | . 941 | . 083743 | . 98 | . 29420 | . 688 | . 050793 |
| . 49 | .08139 | 12.061 | . 082910 | . 99 | . 29854 | . 886 | . 050287 |
| 2.50 | 1.08574 | 12.182 | 0.082085 | 3.00 | 1.30288 | 20.086 | 0.049787 |

Smithsonian Tables.

EXPONENTIAL FUNCTION.

| $x$ | $\log _{10}(e x)$ | ex | $e^{-x}$ | $x$ | $\log _{10}(e x)$ | $e x$ | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3.00 | 1.30288 | 20.086 | 0.049787 | $3 \cdot 50$ | 1.52003 | 33.115 | 0.030197 |
| . 01 | . 30723 | .287 | . 049292 | . 51 | . 52437 | . 448 | . 029897 |
| . 02 | -31157 | -491 | .04880I | . 52 | -52872 | .784 | . 029599 |
| . 03 | . 31591 | . 697 | . 048316 | . 53 | . 53306 | 34.124 | . 029305 |
| . 04 | . 32026 | .905 | . 047835 | . 54 | -53740 | . 467 | . 029013 |
| 3.05 | 1. 32460 | 21.115 | 0.047359 | 3.55 | 1. 54175 | 34.813 | 0.028725 |
| . 06 | . 32894 | -328 | . 046888 | . 56 | . 54609 | 35.163 | . 028439 |
| . 07 | . 33328 | - 542 | .04642I | - 57 | - 55043 | . 517 | .028I 56 |
| . 08 | .33763 | . 758 | . 045959 | . 58 | . 55477 | . 874 | . 027876 |
| . 09 | -34197 | . 977 | . 044502 | - 59 | . 55912 | 36.234 | . 027598 |
| 3.10 | 1.34631 | 22.198 | 0.045049 | 3.60 | 1. 56346 | 36.598 | 0.027324 |
| . 11 | . 35066 | . 421 | . 044601 | .61 | . 56780 | . 966 | . 027052 |
| .12 | -35500 | . 646 | . 044157 | . 62 | . 57215 | $37 \cdot 338$ | . 026783 |
| . 13 | -35934 | . 874 | . 043718 | . 63 | . 57649 | . 713 | . 026516 |
| . 14 | . 36368 | 23.104 | . 043283 | . 64 | . 58083 | 38.092 | . 026252 |
| 3.15 | 1.36803 | 23.336 | 0.042852 | 3.65 | 1.58517 | 38.475 | 0.025991 |
| . 16 | . 37237 | . 571 | .042426 | . 66 | . 58952 | .861 | . 025733 |
| .17 | -37671 | . 807 | . 042004 | . 67 | . 59386 | 39.252 | . 025476 |
| . 18 | .38106 | 24.047 | . 041586 | . 68 | . 59820 | . 646 | . 025223 |
| . 19 | . 38540 | . 288 | .041172 | . 69 | . 60255 | 40.045 | . 024972 |
| 3.20 | 1.38974 | 24.533 | 0.040762 | 3.70 | 1.60689 | 40.447 | 0.024724 |
| . 21 | -39409 | . 779 | . 040357 | . 71 | . 61123 | . 854 | . 024478 |
| . 22 | -39843 | 25.028 | . 039955 | .72 | .61 558 | 41.264 | . $02+234$ |
| . 23 | . 40277 | . 280 | . 039557 | . 73 | .61992 | . 679 | . 023993 |
| . 24 | .407 II | . 534 | .039164 | .74 | . 62426 | 42.098 | . 023754 |
| 3.25 | 1.41146 | 25.790 | 0.038774 | 3.75 | 1.62860 | 42.521 | 0.023518 |
| . 26 | .41580 | 26.050 | . 038388 | . 76 | . 63295 | . 948 | . 023284 |
| . 27 | . 42014 | -3II | .038006 | . 77 | . 63729 | 43.380 | . 023052 |
| . 28 | . 42449 | . 576 | . 037628 | .78 | . 64163 | . 816 | .022823 |
| . 29 | .42883 | . 843 | . 037254 | .79 | . 64598 | 44.256 | . 022596 |
| $3 \cdot 30$ | 1.43317 | 27.113 | 0.036883 | 3.80 | 1.65032 | 44.701 | 0.022371 |
| . 31 | .43751 | .385 | .036516 | . 81 | . 65466 | 45.150 | .022148 |
| - 32 | .44186 | . 660 | .036153 | . 82 | . 65900 | . 604 | .021928 |
| . 33 | . 44620 | . 938 | . 035793 | . 83 | . 66335 | 46.063 | . 021710 |
| . 34 | . 45054 | 28.219 | . 035437 | . 84 | . 66769 | . 525 | . 021494 |
| $3 \cdot 35$ | 1.45489 | 28.503 | 0.035084 | 3.85 | 1.67203 |  | 0.021280 |
| . 36 | . 45923 | . 789 | . 034735 | . 86 | . 67638 | 47.465 | . 021068 |
| - 37 | . 46357 | 29.079 | . 034390 | . 87 | . 68072 | . 942 | .020S58 |
| - 38 | . 46792 | . 371 | . 034047 | . 88 | . 68506 | 48.424 | . 020651 |
| -39 | . 47226 | . 666 | . 033709 | . 89 | .68941 | .911 | . 020445 |
| 3.40 | 1.47660 | 29.964 | 0.033373 | 3.90 | 1. 69375 | 49.402 | 0.020242 |
| .41 | -48094 | 30.265 | . 033041 | .91 | . 69809 | . 899 | .020041 |
| . 42 | . 48529 | . 569 | . 032712 | . 92 | .70243 | 50.400 | . 019841 |
| . 43 | . 48963 | . 877 | .032387 | . 93 | . 70678 | . 907 | .OI9644 |
| . 44 | . 49397 | 31.187 | . 032065 | . 94 | .71112 | 51.419 | . 019448 |
| 3.45 | I. 49832 | 31.500 | 0.031746 |  | 1.71546 |  |  |
| . 46 | . 50266 | . 17 | .031430 | . 96 | .71981 | 52.457 | $.019063$ |
| -47 | . 50700 | 32.137 | . 031117 | . 97 | .72415 | .985 | . 188873 |
| .48 .49 | .51134 .51569 | . 460 | . 030807 | . 98 | . 72849 | 53.517 | . 018686 |
| . 49 | . 51569 | .786 | .030501 | . 99 | .73283 | 54.055 | .018500 |
| $3 \cdot 50$ | 1.52003 | 33.115 | 0.030197 | 4.00 | 1.73718 | 54.598 | 0.018316 |

EXPONENTIAL FUNCTION.

| $\boldsymbol{x}$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ | $\boldsymbol{x}$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4.00 | 1.73718 | 54.598 | 0.018316 | 4.50 | 1.95433 | 90.017 | 0.011109 |
| . 01 | .74152 | 55.147 | .OI8133 | . 51 | . 95867 | . 922 | . 010998 |
| . 02 | .74586 | .701 | . 017953 | . 52 | . 96301 | 91.836 | . 010889 |
| . 03 | . 75021 | 56.261 | . 017774 | . 53 | . 96735 | 92.759 | .010781 |
| . 04 | . 75455 | . 826 | . 017597 | . 54 | . 97170 | 93.691 | . 010673 |
| 4.05 | 1.75889 | 57.397 | 0.017422 | 4.55 | 1.97604 | 94.632 | 0.010567 |
| . 06 | . 76324 | . 974 | . 017249 | . 56 | . 98038 | 95.583 | . 010462 |
| . 07 | . 76758 | 58.557 | . 017077 | . 57 | . 98473 | 96.544 | . 010358 |
| . 08 | . 77192 | 59.145 | .016907 | . 58 | . 98907 | 97.514 | . 010255 |
| . 09 | .77626 | . 740 | . 016739 | . 59 | . 99341 | 98.494 | . 010153 |
| 4.10 | 1.7806I | 60.340 | 0.016573 | 4.60 | 1.99775 | 99.484 | 0.010052 |
| . 11 | . 78495 | . 947 | . 016408 | .6I | 2.00210 | 100.48 | . 009952 |
| . 12 | . 78929 | 61.559 | . 016245 | . 62 | . 00644 | 101.49 | . 009853 |
| .13 | . 79364 | 62.178 | . 016083 | . 63 | .01078 | 102.51 | . 009755 |
| . 14 | . 79798 | . 803 | . 015923 | . 64 | .OI513 | 103.54 | . 009658 |
| 4.15 | 1. 80232 | 63.434 | 0.015764 | 4.65 | 2.01947 | 104.58 | $0.009562$ |
| .16 | . 80667 | 64.072 | . 115608 | . 66 | .02381 | 105.64 | $.009466$ |
| . 17 | . 81 il 101 | . 715 | . 015452 | . 67 | . 02816 | 106.70 | . 009372 |
| . 18 | .81 535 | 65.366 | . 015299 | . 68 | . 03250 | 107.77 | . 009279 |
| . 19 | .81969 | 66.023 | .015146 | . 69 | . 03684 | 108.85 | .009187 |
| 4.20 | 1. 82404 | 66.686 | 0.014996 | 4.70 | 2.04118 | 109.95 | 0.009095 |
| . 21 | . 82838 | 67.357 | . 014846 | . 71 | . 04553 | 111.05 | . 009005 |
| . 22 | . 83272 | 68.033 | . Or 4699 | .72 | . 04987 | 112.17 | .008915 |
| . 23 | . 83707 | . 717 | . 014552 | .73 | . 05421 | 113.30 | . 008826 |
| . 24 | .84141 | 69.408 | . 014408 | . 74 | . 05856 | 114.43 | . 008739 |
| 4.25 | 1. 84575 | 70.105 | 0.014264 | 4.75 | 2.06290 | 115.58 | 0.008652 |
| . 26 | . 85009 | . 810 | . 014122 | . 76 | . 06724 | 116.75 | . 008566 |
| . 27 | . 85444 | 71.522 | .OI3982 | . 77 | . 07158 | 117.92 | . 008480 |
| . 28 | . 85878 | 72.240 | . 013843 | .78 | . 07593 | 119.10 | . 008396 |
| . 29 | . 86312 | . 966 | . 013705 | . 79 | . 08027 | 120.30 | . 008312 |
| $4 \cdot 30$ | 1.86747 | 73.700 | 0.013569 | 4.80 | 2.08461 | 121.51 | 0.008230 |
| .31 | . 87181 | 74.440 | . 113434 | . 81 | .08896 | 122.73 | .008148 |
| .32 | . 87615 | 75.189 | . 013300 | . 82 | .09330 | 123.97 | . 008067 |
| . 33 | .88050 | . 944 | . 013168 | . 83 | . 09764 | 125.21 | . 007987 |
| . 34 | . 88484 | 76.708 | . 013037 | . 84 | . 10199 | 126.47 | . 007907 |
| $4 \cdot 35$ | 1.88918 | 77.478 | 0.012907 | 4.85 | 2.10633 | 127.74 | 0.007828 |
| . 36 | . 89352 | 78.257 | .012778 | . 86 | . 11067 | 129.02 | . 007750 |
| . 37 | . 89787 | 79.044 | . 012651 | . 87 | .11501 | 130.32 | . 007673 |
| . 38 | .90221 | 79.838 | . 012525 | . 88 | . 11936 | 131.63 | . 007597 |
| . 39 | . 90655 | 80.640 | . 012401 | . 89 | . 12370 | 132.95 | . 007521 |
| 4.40 | 1.91090 | 8 I .451 | 0.012277 | 4.90 | 2.12804 | 134.29 | 0.007447 |
| . 41 | .91524 | 82.269 | . 012155 | .91 | .13239 | 135.64 | . 007372 |
| . 42 | . 91958 | 83.096 | . 012034 | . 92 | . 13673 | 137.00 | . 007299 |
| . 43 | . 92392 | .931 | .OII914 | . 93 | .14107 | 138.38 | . 007227 |
| . 44 | . 92827 | 84.775 | . 011796 | . 94 | .14541 | 139.77 | . 007155 |
|  | 1.93261 | 85.627 | 0.011679 |  | 2.14976 | 141.17 | 0.007083 |
| . 46 | . 93695 | 86.488 | . 011562 | . 96 | . 15410 | 142.59 | . 007013 |
| . 47 | . 94130 | 87.357 | . 0111447 | . 97 | . 5844 | 144.03 | .006943 |
| .48 | . 94564 | 88.235 | . 011333 | . 98 | .16279 | 145.47 | .006874 |
| . 49 | . 94998 | 89.12I | .OII22I | . 99 | .16713 | 146.94 | .006806 |
| $4 \cdot 50$ | 1.95433 | 90.017 | 0.011109 | 5.00 | 2.17147 | 148.41 | 0.006738 |

EXPONENTIAL FUNCTION.

| $\boldsymbol{x}$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ | $x$ | $\log _{10}\left(e^{x}\right)$ | $e^{x}$ | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5.00 | 2.17147 | 148.41 | 0.006738 | 5.0 | 2.17147 | 148.41 | 0.006738 |
| . OI | . 17582 | 149.90 | . 006671 | I | . 21490 | 164.02 | . 006097 |
| . 02 | .18016 | 151.41 | . 006605 | 2 | .25833 | 181.27 | . 005517 |
| . 03 | .18450 | 152.93 | . 006539 | $\cdot 3$ | -30176 | 200.34 | . 004992 |
| . 04 | . 18884 | I 54.47 | . 006474 | . 4 | -34519 | 221.41 | . 004517 |
| 5.05 | 2.19319 | ${ }_{1} 56.02$ | 0.006409 | $5 \cdot 5$ | 2.38862 | 244.69 | 0.004087 |
| . 06 | . 19753 | 157.59 | . 006346 | . 6 | . 43205 | 270.43 | . 003698 |
| . 07 | . 20187 | 159.17 | . 006282 | . 7 | . 47548 | 298.87 | . 003346 |
| . 08 | . 20622 | 160.77 | . 006220 | . 8 | . 51891 | 330.30 | . 003028 |
| . 09 | . 21056 | 162.39 | .006I 58 | . 9 | . 56234 | 365.04 | . 002739 |
| 5.10 | 2.21490 | 164.02 | 0.006097 | 6.0 | 2.60577 | 403.43 | 0.002479 |
| . 11 | . 21924 | 165.67 | .006036 | . 1 | . 64920 | 445.86 | . 002243 |
| . 12 | . 22359 | 167.34 | . 005976 | 2 | . 69263 | 492.75 | . 002029 |
| . 13 | . 22793 | 169.02 | . 005917 | $\cdot 3$ | .73606 | $544 \cdot 57$ | . 001836 |
| . 14 | . 23227 | 170.72 | . 005858 | . 4 | .77948 | 601.85 | . 001662 |
| 5.15 | 2.23662 | 172.43 | 0.005799 | 6.5 | 2.82291 | 665.14 | 0.001503 |
| . 16 | . 24096 | 174.16 | . 005742 | . 6 | . 86634 | 735.10 | . 001360 |
| . 17 | . $2453{ }^{\circ}$ | 175.91 | . 005685 | .7 | . 90977 | 8 I 2.41 | . 001231 |
| . .18 | . 24965 | 177.68 | . 005628 | . 8 | . 95320 | 897.85 | .OOIII4 |
| . 19 | . 25399 | 179.47 | . 005572 | $\cdot 9$ | . 99663 | 992.27 | .001008 |
| 5.20 | 2.25833 | 181127 | 0.005517 | 7.0 | 3.04006 | 1096.6 | 0.000912 |
| . 21 | . 26267 | 183.09 | . 005462 | . I | . 08349 | 1212.0 | . 000825 |
| . 22 | . 26702 | 184.93 | . 005407 | . 2 | . 12692 | 1339.4 | . 000747 |
| .23 | . 27136 | 186.79. | . 005354 | $\cdot 3$ | .17035 | 1480.3 | . 000676 |
| . 24 | .27570 | 188.67 | . 005300 | . 4 | .21378 | 1636.0 | .0006I I |
| 5.25 | 2.28005 | 190.57 | 0.005248 | $7 \cdot 5$ | 3.25721 | 1808.0 | 0.000553 |
| . 26 | . 28439 | 192.48 | . 005195 | . 6 | . 30064 | 1998.2 | . 000500 |
| . 27 | . 28873 | 194.42 | .005144 | .7 | . 34407 | 2208.3 | . 000453 |
| . 28 | . 29307 | 196.37 | .005092 | . 8 | . 38750 | 2440.6 | . 000410 |
| . 29 | . 29742 | 198.34 | . 005042 | . 9 | . 43093 | $2697 \cdot 3$ | . 000371 |
| $5 \cdot 30$ | 2.30176 | 200.34 | 0.004992 | 8.0 | 3.47436 | 2981.0 |  |
| $\cdot 31$ | . 30610 | 202.35 | . 004942 | . 1 | . 51779 | 3294.5 | . 000304 |
| $\cdot 32$ | -31045 | 204.38 | . 004893 | . 2 | -56121 | 3641.0 | . 000275 |
| . 33 | -31479 | 206.44 | . 004844 | - 3 | . 60464 | 4023.9 | . 000249 |
| . 34 | -31913 | 208.51 | . 004796 | . 4 | . 64807 | 4447.I | . 000225 |
| $5 \cdot 35$ | 2.32348 | 210.61 | 0.004748 | 8.5 | 3.69150 | 4914.8 | 0.000203 |
| . 36 | . 32782 | 212.72 | . 004701 | . 6 | . 73493 | 5431.7 | . 000184 |
| . 37 | . 33216 | 214.86 | . 004654 | .7 | .77836 | 6002.9 | . 000167 |
| . 38 | . 33650 | 217.02 | .004608 | . 8 | . 82179 | 6634.2 | . 000151 |
| . 39 | . 34085 | 219.20 | . 004562 | . 9 | . 86522 | 7332.0 | .000136 |
| $5 \cdot 40$ | 2.34519 | 221.41 | 0.004517 | 9.0 | 3.90865 | 8ro3.r | 0.000123 |
| . 41 | - 34953 | 223.63 | . 004472 | . 1 | . 95208 | $8955 \cdot 3$ | . 000112 |
| . 42 | -35388 | 225.88 | . 004427 | . 2 | .99551 | 9897.1 | .000IOI |
| . 43 | -35822 | 228.15 | . 004383 | $\cdot 3$ | 4.03894 | 10938. | .000091 |
| . 44 | . 36256 | 230.44 | . 004339 | . 4 | . 08237 | 12088. | .000083 |
| 5.45 | 2.36690 | 232.76 | 0.004296 | $9 \cdot 5$ | 4.12580 | 13360. | 0.000075 |
| . 46 | . 37125 | 235.10 | . 004254 | . 6 | . 16923 | 14765. | . 000068 |
| . 47 | . 37559 | 237.46 | . 004211 | .7 | . 21266 | 16318. | .00006I |
| . 48 | . 37993 | 239.85 | . 004169 | . 8 | .25609 | 18034. | . 000055 |
| . 49 | . 38428 | 242.26 | . 004128 | -9 | . $2995{ }^{2}$ | 19930. | . 000050 |
| 5.50 | 2.38862 | 244.69 | 0.004087 | 10.0 | $4 \cdot 34294$ | 22026. | 0.000045 |

EXPONENTIAL FUNCTIONS.
Value of $e^{2}$ and $e^{-x^{2}}$ and their logarithms.

| $x$ | $r^{2}$ | $\log e^{x^{2}}$ | $e^{-x^{2}}$ | $\log e^{-x^{2}}$ |
| :---: | :---: | :---: | :---: | :---: |
| 0.1 | $1 . \mathrm{OIOI}$ | 0.00434 | 0.99005 | İ. 99566 |
| 2 | 1.0408 | 01737 | 96079 | 98263 |
| 3 | 1.0942 | 03909 | 91393 | 96091 |
| 4 | 1.1735 | 06949 | 85214 | 93051 |
| 5 | 1.2840 | 10857 | 77880 | 89143 |
| 0.6 | 1.4333 | -. 15635 | 0.69768 | $\overline{\mathrm{I}} .84365$ |
|  | 1.6323 | 21280 | 61263 | 78720 |
| 8 | I. 8965 | 27795 | 52729 | 72205 |
| 9 | 2.2479 | 35178 | 44486 | 64822 |
| 1.0 | 2.7183 | 43429 | 36788 | 5657 I |
| 1.1 | $3 \cdot 3535$ | 0.52550 | 0.29820 | İ. 47450 |
| 2 | 4.2207 | 62538 | 23693 | 37462 |
| 3 | 5.4195 | 73396 | 18452 | 26604 |
| 4 | 7.0993 | 85122 | 14086 | 14878 |
| 5 | 9.4877 | 97716 | 10540 | 02284 |
| 1.6 | 1. $2936 \times 10$ | I.1II79 | $0.77305 \times 10^{-1}$ | $\overline{2.88821}$ |
| 7 | 1.7993 " | 25511 | 55576 | 74489 |
| 8 | 2.5534 | 40711 | 39164 " | 59289 |
| 9 | 3.6966 | 56780 | 27052 " | 43220 |
| 2.0 | 5.4598 " | 73718 | 18316 | 26282 |
| 2.1 | 8.2269 " | 1.91524 | $0.12155 \times$ | 2. 2.08476 |
| 2 | $1.2647 \times 10^{2}$ | 2.10199 | $79071 \times 10^{-2}$ | $\overline{3} .89801$ |
| 3 | 1.9834 " | 29742 | 50418 "، | 70258 |
| 4 | 3.1735 | 50154 | $3 \mathrm{5II}$ "، | 49846 |
| 5 | 5.1801 " | 71434 | 19305 | 28566 |
| 2.6 | 8.6264 " | 2.93583 | $0.11592 \times$ | 3'.06417 |
| 7 | $1.4656 \times 10^{3}$ | 3.10601 | $68233 \times 10^{10}$ | 4.83399 |
| 8 | 2.5402 " | 40487 | 39367 ": | 59513 |
| 9 | 4.49 I 8 " | 65242 | 22263 " | 34758 |
| 3.0 | 8.103I " | 90865 | 12341 " | 09135 |
| 3.1 | $1.4913 \times 10^{4}$ | 4.17357 | $0.67055 \times 10^{10}{ }^{-4}$ | - $\overline{5} .82643$ |
| 2 | 2.8001 " | 44718 | 35713 " | 55282 |
| 3 | $5.3637 \times{ }^{\text {" }}$ | 72947 | I8644 $\times{ }^{\text {" }}$ | 27053 |
| 4 | ${ }_{1.0482 \times 10}{ }_{10}{ }^{5}$ | 5.02044 | $95402 \times 10^{10} 9$ | 6.97956 |
| 5 | 2.0898 " | 32011 | $47^{8} 5 \mathrm{I}$ " | 67989 |
| 3.6 | 4.2507 | 5.62846 | 0.23526 " | 6.37154 |
|  | $8.8205 \times{ }^{\text {" }}$ | 94549 | 11337 " ${ }^{\text {" }}$ | -05451 |
| 8 | ${ }_{1} .8673 \times 1{ }^{10}$ | 6.27121 | $53553 \times 10^{-6}$ | 7.72879 |
| 9 | 4.0329 " | 60562 | 24796 " | 39438 |
| 4.0 | 8.886 I I | 94871 | 11254 " | 05129 |
| 4.1 | $1.9975 \times 10^{7}$ |  | $0.50062 \times 10^{-7}$ | 8.69951 |
| 2 | $4.5809 \times$ | 66095 | $21830 \times{ }^{\text {a }}$ | -33905 |
| 3 | $1.0718 \times 10^{8}$ | 8.03010 | $93303 \times 10^{10}$ | 9.96990 |
| 4 | 2.5582 " | 40794 | 39089 ، | 59206 |
| 5 | 6.2296 " | 79446 | 16052 。" | 20554 |
| 4.6 | $1.5476 \times 10^{9}$ | 9.18967 | $0.64614 \times 10^{-9}$ | 10.81033 |
|  | $3.9225$ | 59357 | $25494 \text { " }$ | $-40643$ |
| 8 | 1.0142 $\times 1{ }^{10} 10$ | 10.00614 | $98595 \times 10^{-10}$ | 11.99386 |
| 9 | 2.6755 | 42741 | 37376 | 57259 |
| 5.0 | 7.2005 " | 85736 | 13888 " | 14264 |

Smithsonian Tables.

EXPONENTIAL FUNCTIONS.
Values of $e^{\frac{\pi}{4} x}$ and $e^{-\frac{\pi}{4} x}$ and their logarithms.

| $\boldsymbol{x}$ | $e^{\frac{\pi}{4} x}$ | $\log e^{\frac{\pi}{4} x}$ | $e^{-\frac{\pi}{4} x}$ | $\log e^{-\frac{\pi}{4} x}$ |
| :---: | :---: | :---: | :---: | :---: |
| 1 | 2.1933 | 0.34109 | 0.45594 | T. 65891 |
| 2 | 4.8105 | . 68219 | . 20788 | -31781 |
| 3 | ${ }_{1} .0551 \times 10$ | 1.02328 | $.94780 \times 10^{-1}$ | 2. 97672 |
| 4 | 2.3141 " | - 36438 | .43214 " | . 63562 |
| 5 | 5.0754 " | . 70547 | .19703 " | . 29453 |
| 6 | $1.1132 \times 10^{2}$ | 2.04656 | $0.89833 \times 10^{-2}$ | $\overline{3} \cdot 95344$ |
| 7 8 | 2.4415 5.3 | . $3^{8766}$ | . $40957{ }^{\text {c }}$ | . 61234 |
| 8 | $5.3549 \times$ | . 72875 | .18674 " | . 27125 |
| ${ }_{10}^{9}$ |  | 3.06985 | $._{.85144} \times 10{ }^{10}{ }^{-3}$ | 4.93015 <br> .58006 |
|  |  |  |  |  |
| 11 | 5.6498 " | 3.75203 | 0.17700 " | 4.24797 |
| 12 | $1.2392 \times 10^{4}$ | 4.09313 | . $80700 \times 10^{-4}$ | 5.90687 |
| 13 | 2.7178 " | . 43422 | .36794 " | . 56578 |
| 14 | 5.9610 " | . 77532 | .16776 " | . 22468 |
| 15 | ${ }_{1.3074 \times 10}$ | 5.11641 | $.76487 \times 10^{-5}$ | 6.88359 |
| 16 | 2.8675 " | 5.45751 | $0.3+873$ " | $\overline{6} .54249$ |
| 17 | 6.2893 " | . 79860 | .15900 " | - 20140 |
| 18 | ${ }^{1.3794 \times 10}{ }^{6}$ | 6.13969 | $.72+95 \times 10^{10}{ }^{-6}$ | $\overline{7} .86031$ |
| 19 20 | 3.0254 6.6356 | .48079 .82188 | . 33053 " | . 51921 |

Table 22.

## EXPONENTIAL FUNCTIONS.

Values of $e^{\frac{\sqrt{ } \bar{\pi}}{4} x}$ and $e^{-\frac{\sqrt{\pi} x}{4} x}$ and their logarithms.

| $\boldsymbol{x}$ | $e^{\frac{\sqrt{\pi}}{4} x}$ | $\log e^{\frac{\sqrt{ } \pi}{4} x}$ | $e^{-\frac{\sqrt{4} x}{4}}$ | $\log e^{-\frac{\sqrt{\pi}}{x} x}$ |
| :---: | :---: | :---: | :---: | :---: |
| 1 | 1. 5576 | 0.19244 | 0.64203 | -1. 80756 |
| 2 | 2.4260 | -38488 | . 41221 | .61512 |
| 3 | 3.7786 | . 57733 | . 26465 | . 42267 |
| 4 | 5.8853 | . 76977 | .16992 | .23023 |
| 5 | 9.1666 | . 96221 | . 10909 | . 03779 |
| 6 | 14.277 | I.15465 | 0.070041 | $\overline{2} .84535$ |
| 7 | 22.238 | . 34709 | . 044968 | . 65291 |
| 8 | 34.636 | - 53953 | . 028871 | . 46047 |
| 9 | 53.948 | .73198 | .o18536 | .26802 |
| 10 | 84.027 | . 92442 | . 011901 | . 07558 |
| 11 | 130.88 | 2.11686 | 0.0076408 | $\overline{3} .88314$ |
| 12 | 203.85 | . 30930 | . 0049057 | . 69070 |
| 13 | 317.50 | . 50174 | . 0031496 | . 49826 |
| 14 | 494.52 | . 69418 | . 0020222 | -30582 |
| 15 | 770.24 | . 88663 | . 0012983 | . 11337 |
| 16 | 1199.7 | 3.07907 | 0.00083355 | 4.92093 |
| 17 | 1868.6 | . 27151 | . 00053517 | . 72849 |
| 18 | 2910.4 | . 46395 | . 00034360 | . 53605 |
| 19 | 4533.1 | . 65639 | . 00022060 | -34361 |
| 20 | 7060.5 | .84883 | . 00014163 | .15117 |

Tables 23 and 24.
EXPONENTIAL FUNCTIONS AND LEAST SQUARES.
TABLE 23.-Exponential Functions.
Value of $e^{x}$ and $e^{-x}$ and their logarithms.

| $x$ | $e^{x}$ | $\log e^{x}$ | $e^{-x}$ | $x$ | $\iota^{x}$ | $\log e^{x}$ | $e^{-x}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1/64 | 1.0157 | 0.00679 | 0.98450 | 1/3 | 1.3956 | 0.14476 | 0.71653 |
| 1/32 | .0317 | . 01357 | . 96923 | $1 / 2$ | . 6487 | .21715 | . 60653 |
| 1/16 | . 0645 | . 02714 | . 9394 I | 3/4 | 2.1170 | . 32572 | . 47237 |
| $1 / 10$ | . 1052 | . 04343 | .90484 | 1 | . 7183 | . 43429 | $\cdot 36788$ |
| I/9 | . 1175 | . 04825 | . 89484 | 5/4 | 3.4903 | - 54287 | . 28650 |
| $1 / 8$ | I.1331 | 0.05429 | 0.88250 | 3/2 | 4.4817 | 0.65144 | 0.22313 |
| $1 / 7$ | .1536 | . 06204 | . 86688 | 7/4 | 5.7546 | .76002 | . 17377 |
| 1/6 | .1814 | .07238 | . 84648 |  | 7.3891 | . 86859 | . 13534 |
| 1/5 | .2214 | . 08686 | . 81873 | 9/4 | $9 \cdot 4877$ | . 97716 | . 10540 |
| I/ 4 | .2840 | . 10857 | . 77880 | 5/2 | 12.1825 | 1.08574 | . 08208 |

TABLE 24.-Least Squares.
Values of $\mathrm{P}=\frac{2}{\sqrt{\pi}} \int_{o}^{h x} e^{-(h x)^{2}} d(h x)$.
This table gives the value of P , the probability of an observational error having a value positive or negative equal to or less than $x$ when $h$ is the measure of precision, $\mathrm{P}=\frac{2}{\sqrt{\pi}} \int_{o}^{h x} e^{-(h x)^{2}}$ $d(h x)$. For values of the inverse function see the table on Diffusion.

| $h x$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.0 |  | . 01128 | . 02256 | . 03384 | . 0451 I | . 05637 | . 06762 | . 07886 | . 09008 | . 10128 |
| . I | . 11246 | . 12362 | . 13476 | . 14587 | . 15695 | . 16800 | . 17901 | . 18999 | . 20094 | . 21184 |
| . 2 | . 22270 | . 23352 | . 24430 | . 25502 | . 26570 | . 27633 | . 28690 | . 29742 | . 30788 | . 31828 |
| $\cdot 3$ | . 32863 | . 33891 | . 34913 | - 35928 | . 36936 | 37938 | .38933 | . 3992 I | . 40901 | . 41874 |
| . 4 | . 42839 | . 43797 | . 44747 | -45689 | . 46623 | . 47548 | . 48466 | . 49375 | - 50275 | .51167 |
| 0.5 | . 52050 | . 52924 | - 53790 | . 54646 | . 55494 | . 56332 | . 57162 | . 57982 | . 58792 | -59594 |
| . 6 | . 60386 | .61168 | . 61941 | . 62705 | . 63459 | . 64203 | . 64938 | . 65663 | . 66378 | . 67084 |
| . 7 | . 67780 | . 68467 | . 69143 | .69810 | . 70468 | .71116 | . 71754 | .72382 | . 73001 | . 73610 |
| . 8 | . 74210 | .74800 | . 75381 | .75952 | . 76514 | .77067 | .77610 | .78144 | . 78669 | . 79184 |
| . 9 | .79691 | . 80188 | . 80677 | .81156 | . 81627 | . 82089 | . 82542 | . 82987 | . 83423 | . 83851 |
| 1.0 | . 84270 | . 8468 r | . 85084 | . 85478 | . 85865 | . 86244 | . 86614 | . 86977 | . 87333 | .87680 |
| . 1 | . 88021 | . 88353 | . 88679 | . 88997 | . 89308 | . 89612 | .89910 | . 90200 | .90484 | . 90761 |
| . 2 | .9103I | . 91296 | .91553 | .91805 | .92051 | . 92290 | . 92524 | .92751 | . 92973 | . 93190 |
| $\cdot 3$ | .93401 | .93606 | .93807 | . 94002 | .94191 | . 94376 | . 94556 | . 94731 | . 94902 | . 95067 |
| -4 | . 95229 | .95385 | . 95538 | . 95686 | .95830 | . 95970 | . 96105 | . 96237 | . 96365 | . 96490 |
| 1.5 | .96611 | . 96723 | . 9684 I | . 96952 | . 97059 | . 97162 | . 97263 | -97360 | . 97455 | . 97546 |
| . 6 | . 97635 | . 97721 | .97804 | . 97884 | . 97962 | . 98038 | .981ı0 | .98181 | . 98249 | . 98315 |
| . 7 | . 98379 | . 98441 | .98500 | . 98558 | . 98613 | . 98667 | . 98719 | . 98769 | .98817 | . 98864 |
| . 8 | . 98909 | . 98952 | . 98994 | . 99035 | . 99074 | .991II | . 99147 | .99182 | . 99216 | . 99248 |
| . 9 | . 99279 | . 99309 | . 99338 | . 99366 | . 99392 | . 99418 | . 99443 | . 99466 | . 99489 | .99511 |
| 2.0 | . 995.32 | . 99552 | . 99572 | .99591 | . 99609 | . 99626 | . 99642 | . 99658 | . 99673 | . 99688 |
| . 1 | . 99702 | . 99715 | . 99728 | . 99741 | . 99753 | . 99764 | . 99775 | . 99785 | . 99795 | . 99805 |
| . 2 | . 99814 | . 99822 | . 9983 I | . 99839 | . 99846 | . 99854 | . 99861 | . 99867 | . 99874 | . 99880 |
| $\cdot 3$ | . 99886 | .99891 | . 99997 | . 99902 | . 99906 | .9991 I | . 99915 | . 99920 | . 99924 | . 99928 |
| . 4 | .99931 | . 99935 | . $99933^{8}$ | . 9994 I | . 99944 | . 99947 | . $99950^{\circ}$ | . 99952 | . 99955 | . 99957 |
| 2.5 | . 99959 | . 99961 | . 99963 | . 99965 | . 99967 | . 99969 | .9997 I | . 99972 | . 99974 | . 99975 |
| . 6 | . 99976 | . 99978 | . 99979 | . 99988 | .9998I | . 99982 | . 99983 | . 99984 | . 99985 | . 99986 |
| . 7 | . 99987 | . 99987 | . 99988 | . 99989 | . 99989 | . 99990 | . 99991 | - 99991 | . 99992 | . 99992 |
| . 8 | . 99992 | . 99993 | . 99993 | . 99994 | . 99994 | . 99994 | . 99995 | . 99995 | . 99995 | . 99996 |
| . 9 | . 99996 | . 99996 | . 99996 | . 99997 | . 99997 | . 99997 | . 99997 | . 99997 | . 99997 | . 99998 |
| 3.0 | .99998 | . 99999 | . 99999 | 1.00000 |  |  |  |  |  |  |

Taken from a paper by Dr. James Burgess 'on the Definite Integral $\frac{2}{\sqrt{ } \pi} \int_{0}^{t} e^{-t^{2}} d t$, with Ex. tended Tables of Values.' Trans. Roy. Soc. of Edinburgh, vol. xxxix, i900, p. 257.

LEAST SQUARES.
This table gives the values of the probability P , as defined in last table, corresponding to different values of $x / r$ where $r$ is the "probable error." The probable error $r$ is equal to $0.47694 / \mathrm{h}$.

| $\frac{\boldsymbol{x}}{\boldsymbol{r}}$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.0 | . 00000 | . 00538 | . 01076 | .016I4 | . 02152 | . 02690 | . 03228 | . 03766 | . 04303 | . 0.4840 |
| 0.1 | . 05378 | . 05914 | .06451 | . 06987 | . 07523 | . 08059 | .08594 | .09129 | . 09663 | . 10197 |
| 0.2 | .10731 | . 11264 | . 11796 | . 12328 | . 12860 | 13391 | . 1392 I | . 14451 | . 14980 | . 15508 |
| 0.3 | . 16035 | .16562 | . 17088 | .17614 | .18ı38 | . 18662 | .19185 | . 19707 | . 20229 | . 20749 |
| 0.4 | . 21268 | .21787 | . 22304 | .22821 | . 23336 | . 23851 | . 24364 | . 24876 | . 25388 | . 25898 |
| 0.5 | . 26407 | . 26915 | . 2742 I | . 27927 | . 28431 | . 28934 | . 29436 | . 29936 | - 30435 | - 30933 |
| 0.6 | . 31430 | . 31925 | . 32419 | .3291 1 | . 33402 | . 33892 | -34380 | -34866 | $\cdot 35352$ | - 35835 |
| 0.7 | $\cdot 36317$ | $\cdot 36798$ | . 37277 | - 37755 | -38231 | -38705 | -39178 | -39649 | -401 I8 | . 40586 |
| 0.3 | . 41052 | .41517 | . 41979 | . 42440 | . 42899 | . 43357 | .43813 | .44:67 | -44719 | . 45169 |
| 0.9 | .45618 | . 46064 | . 46509 | .46952 | . 47393 | . 47832 | . 48270 | . 48705 | . 49139 | . 49570 |
| 1.0 | - 50000 | - 50428 | . $50 \mathrm{~S}_{53}$ | -51277 | . 51699 | . 52119 | . 52537 | . 52952 | . 53366 | . 53778 |
| 1.1 | . 54188 | . 54595 | . 55001 | . 55404 | . 55806 | . 56205 | . 56602 | . 56998 | . 57391 | . 57782 |
| 1.2 | .58171 | . 58558 | . 58942 | . 59325 | . 59705 | . 60083 | . 60460 | . 60833 | . 61205 | . 61575 |
| 1.3 | . 61942 | . 62308 | . 6267 I | . 63032 | .63391 | . 63747 | . 64102 | . 64454 | . 64804 | .65152 |
| 1.4 | . 65498 | . 65841 | . 66182 | . 6652 I | . 66858 | .67193 | . 67526 | .67856 | . 68184 | . 68510 |
| 1.5 | . 68833 | . 69155 | . 69474 | . 69791 | . 70106 | .70419 | . 70729 | . 71038 | . 71344 | . 71648 |
| 1.6 | . 71949 | .72249 | . 72546 | . 72841 | .73134 | . 73425 | . 73714 | . 74000 | . 74285 | . 74567 |
| 1.7 | .74847 | .75124 | . 75400 | .75674 | . 75945 | . 76214 | .76481 | .76746 | . 77009 | . 77270 |
| 1.8 | .77528 | . 77785 | .78039 | .78291 | . 78542 | . 78790 | .79036 | . 79280 | . 79522 | . 79761 |
| I. 9 | . 79999 | . 80235 | . 80469 | . 80700 | . 80933 | .81158 | . 81383 | . 81607 | . 81828 | . 82048 |
| 2.0 | . 82266 | . 8248 I | . 82695 | . 82907 | . 83117 | . 83324 | . 83530 | . 83734 | . 83936 | . 84137 |
| 2.1 | . 84335 | .84531 | . 84726 | . 84919 | . 85109 | . 85298 | . 85486 | . 8567 I | . 85854 | . 86036 |
| 2.2 | . 86216 | . 86394 | . 86570 | . 86745 | . 86917 | . 87088 | . 87258 | . 87425 | . 87591 | . 87755 |
| 2.3 | . 87918 | . 88078 | . 88237 | . 88395 | . 88550 | . 88705 | . 88857 | . 89008 | . 89157 | . 89304 |
| 2.4 | . 89450 | . 89595 | . 89738 | . 89879 | .90019 | .90157 | . 90293 | .90428 | . 90562 | . 90694 |
| 2.5 | . 90825 | -90954 | . 91082 | . 91208 | .91332 | .91456 | .91578 | . 91698 | .91817 | . 91935 |
| 2.6 | . $9205^{1}$ | .92266 | . 92280 | . 92392 | . 92503 | .92613 | . 92721 | . 92828 | . 92934 | . 93038 |
| 2.7 | .93I41 | . 93243 | . 93344 | .93443 | .9354 | .93638 | . 93734 | .93828 | . 93922 | -9.4014 |
| 2.8 | .94105 | .94195 | . 94284 | . 9437 I | . 94445 | $\cdot 94543$ | . 94627 | -947 I I | . 94793 | . 94874 |
| 2.9 | . 94954 | $\cdot 95033$ | .9511 1 | $\cdot 95187$ | $\cdot 95263$ | -9533 ${ }^{\circ}$ | . 95412 | $\cdot 95484$ | -95557 | .95628 |
|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 3 | . 95698 | . 96346 | .96910 | . 97397 | . 97817 | .98ı 76 | . 98482 | .98743 | . 98962 | . 99147 |
| 4 | . 99302 | . 99431 | . 99539 | 99627 | . 99700 | . 99760 | . 99808 | . 99848 | . 99859 | . 99905 |
| 5 | . 99926 | . 99943 | . 99956 | . 99966 | . 99974 | . 99980 | . 99985 | -99988 | . 99991 | . 99993 |

Table 26.
LEAST SQUARES.
Values of the factor $0.6745 \sqrt{\frac{1}{n-1}}$.
This factor occurs in the equation $r_{\mathrm{s}}=0.6745 \sqrt{\frac{\sum v^{2}}{n-1}}$ for the probable error of a single observation, and other similar equations.

| $\boldsymbol{n}$ | $\mathbf{0}$ | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | $\mathbf{6}$ | $\mathbf{7}$ | $\mathbf{8}$ | $\mathbf{9}$ |
| :---: | :---: | :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| $\mathbf{0 0}$ |  |  | 0.6745 | 0.4769 | 0.3894 | 0.3372 | 0.3016 | 0.2754 | 0.2549 | 0.2385 |
| 10 | 0.2248 | 0.2133 | .2034 | .1947 | .1871 | .1803 | .1742 | .1686 | .1636 | .1590 |
| 20 | .1547 | .1508 | .1472 | .1438 | .1406 | .1377 | .1349 | .1323 | .1298 | .1275 |
| 30 | .1252 | .1231 | .1211 | .1192 | .1174 | .1157 | .1140 | .1124 | .1109 | .094 |
| 40 | .1080 | .1066 | .1053 | .1041 | .1029 | .1017 | .1005 | .0994 | .0984 | .0974 |
| 50 | 0.0964 | 0.0954 | 0.0944 | 0.0935 | 0.0926 | 0.0918 | 0.0909 | 0.0901 | 0.0893 | 0.0886 |
| 60 | .0878 | .0871 | .0864 | .0857 | .0850 | .0843 | .0837 | .0830 | .0824 | .0818 |
| 70 | .0812 | .0806 | .0800 | .0795 | .0789 | .0784 | .0779 | .0774 | .0769 | .0764 |
| 80 | .0759 | .0754 | .0749 | .0745 | .0740 | .0736 | .0727 | .0727 | .0723 | .07199 |
| 90 | .0715 | .0711 | .0707 | .0703 | .0699 | .0696 | .0692 | .0688 | .0685 | .0681 |

## 8 mithsonian Tables.

TAble 27.-LEAST SQUARES.
Values of the factor $0.6745 \sqrt{\frac{1}{u(u-1)}}$.
This factor occurs in the equation $r_{0}=0.6745 \sqrt{\frac{\Sigma v^{2}}{u(n-1)}}$ for the probable error of the arithmetic mean.

| $\boldsymbol{n}=$ |  | $\mathbf{1}$ | $\mathbf{2}$ | $\mathbf{3}$ | $\mathbf{4}$ | $\mathbf{5}$ | $\mathbf{6}$ | $\mathbf{7}$ | $\mathbf{8}$ | $\mathbf{9}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathbf{0 0}$ |  |  | 0.469 | 0.2754 | 0.1947 | 0.1508 | 0.1231 | 0.1041 | 0.0901 | 0.0795 |
| 10 | 0.0711 | 0.0643 | .0587 | .0540 | .0500 | .0465 | .0435 | .0409 | .0386 | .0365 |
| 20 | .0346 | .0329 | .0314 | .0300 | .0287 | .0275 | .0265 | .0255 | .0245 | .0237 |
| 30 | .0229 | .0221 | .0214 | .0208 | .0201 | .0196 | .0190 | .0185 | .0180 | .0175 |
| 40 | .0171 | .0167 | .0163 | .0159 | .0155 | .0152 | .0148 | .0145 | .0142 | .0139 |
| 50 | 0.0136 | 0.0134 | 0.0131 | 0.0128 | 0.0126 | 0.0124 | 0.0122 | 0.0119 | 0.0117 | 0.01155 |
| 60 | .0113 | .0111 | .0110 | .0108 | .0106 | .0105 | .0103 | .0101 | .0100 | .0098 |
| 70 | .0097 | .0096 | .0094 | .0093 | .0092 | .00911 | .0089 | .0088 | .0087 | .0086 |
| 80 | .0085 | .0084 | .0083 | .0082 | .0081 | .0080 | .0079 | .0078 | .0077 | .0076 |
| 90 | .0075 | .0075 | .0074 | .0073 | .0072 | .0071 | .0071 | .0070 | .0069 | .0068 |

TABLE 28. - LEAST SQUARES.

$$
\text { Values of the factor } 0.8453 \sqrt{\frac{1}{n(n-1)}} \text {. }
$$

This factor occurs in the approximate equation $r=0.8453 \sqrt{\frac{\sum v^{2}}{n(n-1)}}$ for the probable error of a single observation.

|  | $=$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 00 |  |  | 0. 5978 | 0.3451 | 0.2440 | 0.1890 | 0.1543 | 0.1304 | 0.1130 | 0.0996 |
| 10 | 0.0891 | 0.0806 | . 0736 | . 0677 | . 0627 | . 0583 | . 0546 | . 0513 | . 0483 | . 0457 |
| 20 | . 0434 | . 0412 | . 0393 | . 0376 | . 0360 | . 0345 | . 0332 | .0319 | . 0307 | . 0297 |
| 30 | . 0287 | . 0277 | . 0268 | . 0260 | . 0252 | . 0245 | . 0238 | . 0232 | . 0225 | . 0220 |
| 40 | . 0214 | . 0209 | . 0204 | . 0199 | . 0194 | . 0190 | . 0186 | . 0182 | . 0178 | . 0174 |
| 50 | 0.0171 | 0.0167 | 0.0164 | 0.0161 | 0.0158 | 0.0155 | 0.0152 | 0.0150 | 0.0147 | 0.0145 |
| 60 | . 0142 | . 0140 | .OI37 | .OI35 | . 0133 | . 0131 | . 0129 | . 0127 | . 0125 | . 0123 |
| 70 | . 0122 | . 0120 | . 0118 | . 0117 | . 1115 | . 0113 | . 1112 | . 0111 | . 0109 | . 0108 |
| 80 | . 0106 | . 0105 | . 0104 | . 0102 | . 0101 | . 0100 | . 0099 | .0098 | . 0097 | . 0096 |
| 90 | . 0094 | . 0093 | . 0092 | .0091 | .0090 | .0089 | . 0089 | .0088 | . 0087 | . 0086 |

TAble 29. - LEAST SQUARES.
Values of $0.8453 \frac{1}{n \sqrt{n-1}}$.
This factor'occurs in the approximate equation $r_{0}=0.8453 \frac{\Sigma \nu}{n \sqrt{n-1}}$ for the probable error of the arithmetical mean.

|  | = | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 00 |  |  | 0.4227 | 0.1993 | 0.1220 | 0.0845 | 0.0630 | 0.0493 | 0.0399 | 0.0332 |
| 10 | 0.0282 | 0.0243 | . 0212 | . 0188 | . 0167 | . 0151 | . 0136 | . 0124 | . 0114 | . 0105 |
| 20 | . 0097 | . 0090 | . 0084 | . 0078 | . 0073 | . 0069 | . 0065 | .006I | . 0058 | . 0055 |
| 30 | . 0052 | . 0050 | . 0047 | . 0045 | . 0043 | .004I | . 0040 | .00,38 | . 0037 | . 0035 |
| 40 | . 0034 | . 0033 | .0031 | . 0030 | . 0029 | . 0028 | . 0027 | . 0027 | . 0026 | . 0025 |
| 50 | 0.0024 | 0.0023 | 0.0023 | 0.0022 | 0.0022 | 0.0021 | 0.0020 | 0.0020 | 0.0019 | 0.0019 |
| 60 | . 0018 | . 0018 | . 0017 | . 0017 | . 0017 | . 0016 | . 0016 | . 0016 | . 0015 | . 0015 |
| 70 | . 0015 | .0014 | . 0014 | . 0014 | .0013 | . 0013 | . 0013 | .0013 | . 0012 | . 0012 |
| 80 | . 0012 | . 0012 | . 0011 | . 0011 | . 0011 | . 011 | .0011 | . 0010 | . 0010 | . 010 |
| 90 | . 0010 | . 0010 | . 0010 | . 0009 | . 0009 | . 0009 | . 0009 | . 0009 | . 0009 | . 0009 |

Observation equations :

$$
\begin{aligned}
& a_{1} z_{1}+b_{1} z_{2}+\ldots l_{1} z_{q}=M_{1} \text {, weight } p_{1} \\
& a_{2} z_{1}+b_{2} z_{2}+\ldots \cdot l_{2} z_{q}=M_{2} \text {, weight } p_{2} \\
& a_{n} z_{1}+b_{n} z_{2}+\ldots . i_{n} z_{q}=M_{n}, \text { weight } p_{n} .
\end{aligned} .
$$

Auxiliary equations:

$$
\begin{aligned}
& {[\mathrm{paa}]=p_{1} a_{1}^{2}+p_{2} a_{2}^{2}+\cdots p_{n} a_{n}^{2}} \\
& {[\mathrm{pab}]=p_{1} a_{1} b_{1}+p_{2} a_{2} b_{2}+\cdots p_{n} a_{n 1} b_{n}} \\
& {[p a M]=p_{1} a_{1} \dot{M}_{1}+\ddot{p}_{2} a_{2} \dot{M}_{2}+\cdots \dot{p}_{n} a_{n} \dot{M}_{n}}
\end{aligned}
$$

Normal equations:

$$
\begin{aligned}
& {[\text { paa }] z_{1}+[\text { pab }] z_{2}+\cdots[\text { pal }] z_{q}=[\text { paM }]} \\
& {[\text { pab }] z_{1}+[\text { pbb }] z_{2}+\cdots[\text { pbl }] z_{q}=[\text { pbM }]} \\
& {[\text { pla }] z_{1}+[\text { plb }] z_{2}+\cdots \cdot[\text { pll }] z_{q}=[\text { plM }] .}
\end{aligned}
$$

Solution of normal equations in the form,

$$
\begin{aligned}
\mathrm{z}_{1} & =\mathrm{A}_{1}[\mathrm{paM}]+\mathrm{B}_{1}[\mathrm{pbM}]+\cdots \mathrm{L}_{1}[\mathrm{plM}] \\
\mathrm{z}_{2} & =\mathrm{A}_{2}[\mathrm{paM}]+\mathrm{B}_{2}[\mathrm{pbM}]+\cdots \cdot \mathrm{L}_{2}[\mathrm{plM}] \\
\mathrm{z}_{\mathrm{q}} & =\mathrm{A}_{\mathrm{n}}[\mathrm{paM}]+\mathrm{B}_{\mathrm{n}}[\mathrm{pbM}]+\cdots \cdot \mathrm{L}_{\mathrm{n}}[\mathrm{plM}]
\end{aligned}
$$

gives :

$$
\begin{aligned}
& \text { weight of } z_{1}=\mathrm{p}_{\mathrm{z}_{1}}=\left(\mathrm{A}_{1}\right)^{-1} ; \text { probable error of } \mathrm{z}_{1}=\frac{\mathrm{r}}{\sqrt{\mathrm{p}_{z_{1}}}} \\
& \text { weight of } \mathrm{z}_{2}=\mathrm{pz}_{2}=\left(\mathrm{B}_{2}\right)^{-1} ; \text { probable error of } \mathrm{z}_{2}=\frac{\mathrm{r}^{2}}{\sqrt{\mathrm{p}_{z_{2}}}} \\
& \text { • } \cdot \cdot \cdot \cdot \cdot \cdot \cdot \\
& \text { weight of } \mathrm{z}_{\mathrm{q}}=\mathrm{p}_{z_{\mathrm{q}}}=\left(\mathrm{L}_{\mathrm{n}}\right)^{-1} ; \text { probable error of } z_{\mathrm{q}}=\frac{\cdot}{\sqrt{\mathrm{p}_{\mathrm{z}_{\mathrm{q}}}}}
\end{aligned}
$$

wherein

$$
\begin{aligned}
\mathrm{r} & =\text { probable error } \text { of observation of weight unity } \\
& =0.6745 \sqrt{\frac{\Sigma p v^{2}}{n-q}} \cdot \text { (q unknowns.) }
\end{aligned}
$$

Arithmetical mean, n observations:

$$
\begin{aligned}
& r=0.6745 \sqrt{\frac{\Sigma v^{2}}{n-1}}=\frac{0.8453 \Sigma v}{\sqrt{n(n-1)}} . \quad \begin{array}{r}
\text { (approx.) }=\text { probable error of ob- } \\
\text { servation of weight unity. }
\end{array} \\
& r_{0}=0.6745 \sqrt{\frac{\Sigma v^{2}}{n(n-1)}}=\frac{0.8453 \Sigma v}{n \sqrt{n-1}} . \quad \text { (approx.) = probable error } \\
& \text { of mean. }
\end{aligned}
$$

Weighted mean, n observations:

$$
\mathrm{r}=0.6745 \sqrt{\frac{\Sigma \mathrm{pv}^{2}}{\mathrm{n}-\mathrm{I}}} ; \mathrm{r}_{\mathrm{o}}=\frac{\mathrm{r}}{\sqrt{\Sigma \mathrm{p}}}=0.6745 \sqrt{\frac{\Sigma \mathrm{pv}^{2}}{(\mathrm{n}-\mathrm{I}) \Sigma \mathrm{p}}}
$$

Probable error (R) of a function (Z) of several observed quantities $z_{1}, z_{2}, \ldots$ whose probable errors are respectively, $\left.r_{1}, r_{2}, \ldots, \ldots\right)$

$$
\mathrm{R}^{2}=\binom{\partial Z}{\partial Z_{1}}^{2} \mathrm{r}_{1}^{2}+\left(\frac{\partial Z}{\partial Z_{2}}\right)^{2} \mathrm{r}_{2}^{2}+\ldots
$$

Examples:

$$
\begin{array}{ll}
\mathrm{Z}=\mathrm{z}_{1} \pm \mathrm{z}_{2}+\cdots \\
\mathrm{Z}=\mathrm{Az}_{1} \pm \mathrm{Bz}_{2} \pm \cdots \\
\mathrm{Z}=\mathrm{z}_{1} \mathrm{z}_{2} . & \mathrm{R}^{2}=\mathrm{r}_{1}^{2}+\mathrm{r}_{2}^{2}+\cdots \\
\mathrm{R}^{2}=\mathrm{A}^{2} \mathrm{r}_{1}^{2}+\mathrm{B}^{2} \mathrm{r}_{2}^{2}+\cdots \\
\mathrm{R}^{2}=\mathrm{z}_{1}^{2} \mathrm{r}_{2}^{2}+\mathrm{z}_{2}{ }^{2} \mathrm{r}_{1}^{2} .
\end{array}
$$

## Table 31. <br> DIFFUSION.

Inverse * values of $v / c=1-\frac{2}{\sqrt{\pi}} \int_{0}^{q} e^{-q^{2}} d q$
$\log x=\log (2 q)+\log \sqrt{\overline{k t} .} \quad t$ expressed in seconds.
$\begin{array}{lc}=\log \delta+\log \sqrt{k t .} & t \text { expressed in days. } \\ =\log \gamma+\log \sqrt{k t .} & \text { "" " years. }\end{array}$
$k=$ coefficient of diffusion. $\dagger$
$c=$ initial concentration.
$v=$ concentration at distance $x$, time $t$.

| $v / c$ | $\log 2 q$ | 29 | $\log \delta$ | $\delta$ | $\log \gamma$ | $\gamma$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.00 | $+\infty$ | $\infty$ | $+\infty$ | $+\infty$ | $\infty$ | $\infty$ |
| . O | 0.56143 | 3.6428 | 3.02970 | 1070.78 | 4.31098 | 20463. |
| . 02 | . 51719 | 3.2900 | 2.98545 | 967.04 | . 26674 | 1848 I . |
| . 03 | .48699 | 3.0690 | . 95525 | 902.90 | . 23654 | 17240. |
| . 04 | . 46306 | 2.9044 | .93132 | 853.73 | . 21261 | 16316. |
| 0.05 | 0.44276 | 2.7718 | 2.91102 | 814.74 | 4.19231 | I 557 I . |
| . 06 | . 42486 | 2.6598 | .89311 | 78 r .83 | . 17440 | 14942. |
| . 07 | . 40865 | 2.5624 | . 87691 | 753.20 | . 15820 | 14395. |
| . 08 | . 39372 | $2.475^{8}$ | .86198 | 727.75 | . 14327 | 13908. |
| . 09 | - 37979 | 2.3977 | . 84804 | 704.76 | . 12933 | 13469. |
| 0.10 | 0.36664 | 2.3262 | 2.83490 | 683.75 | 4.11619 | 13067. |
| . 11 | . 35414 | 2.2602 | . 82240 | $66+36$ | .10369 | 12697. |
| . 12 | -34218 | 2.1988 | . 81044 | 646.31 | . 09173 | 12352. |
| .13 | . 33067 | 2.1413 | .79893 | 629.40 | . 08022 | 12029. |
| . 14 | . 31954 | 2.087 I | . 78780 | 613.47 | . 06909 | 11724. |
| 0.15 | 0.30874 | 2.0358 | 2.77699 | 598.40 | 4.05828 | 11436. |
| . 16 | . 29821 | 1.9871 | . 76647 | 584.08 | . 04776 | II 162. |
| .17 | . 28793 | 1.9406 | .75619 | 570.41 | . 03748 | 1090. |
| . 18 | . 27786 | 1.8961 | .74612 | $557 \cdot 34$ | . 02741 | 10652. |
| . 19 | . 26798 | 1.8534 | . 73624 | 544.80 | . 01753 | 10412. |
| 0.20 | 0.25825 | I. SI 24 | 2.72651 | 532.73 | 4.00780 | IOI8I. |
| . 2 I | . 24866 | 1.7728 | .71692 | 521.10 | 3.99821 | 9958.9 |
| . 22 | . 23919 | 1.7346 | . 70745 | 509.86 | . 98874 | 9744. I |
| . 23 | . 22983 | 1.6976 | .69808 | 498.98 | . 97937 | 9536.2 |
| . 24 | . 22055 | 1.6617 | .68880 | 488.43 | . 97010 | 9334.6 |
| 0.25 | 0.21134 | 1.6268 | 2.67960 | 478.19 | 3.96089 | 9138.9 |
| . 26 | . 20220 | I. 5930 | . 67046 | 468.23 | . 95175 | 8948.5 |
| . 27 | .19312 | 1.5600 | .661 37 | 458.53 | . 94266 | S763.2 |
| . 28 | . 18407 | 1.5278 | . 65232 | 449.08 | . 93361 | S582.5 |
| . 29 | . 17505 | I. 4964 | .64331 | 439.85 | .92460 | 8406.2 |
| 0.30 | 0.16606 | I. 4657 | 2.63431 | 430.84 | 3.91560 | 8233.9 |
| . 31 | . 5708 | 1.4357 | . 62533 | 422.02 | . 90662 | 8065.4 |
| $\cdot 32$ | .14810 | 1.4064 | . 61636 | 413.39 | . 89765 | 7900.4 |
| . 33 | .13912 | 1.3776 | . 60738 | 404.93 | . 88867 | 7738.8 |
| . 34 | .13014 | I. 3494 | . 59840 | 396.64 | . 87969 | 7580.3 |
| 0.35 | O.121I4 | 1.3217 | 2.58939 | 388.50 | 3.87068 | 7424.8 |
| . 36 | . 11211 | I. 2945 | . 58037 | 380.51 | . 86166 | 7272.0 |
| $\cdot 37$ | .10305 | 1. 2678 | -57131 | 372.66 | . 85260 | 7122.0 |
| $\cdot 38$ | . 09396 | I. 2415 | . 56222 | 364.93 | . 84351 | 6974.4 |
| . 39 | . 08482 | 1.2157 | -55308 | $357 \cdot 34$ | . 83437 | 6829.2 |
| 0.40 | 0.07563 | 1.1902 | 2.54389 | 349.86 | 3.82518 | 6686.2 |
| $\cdot 41$ | . 06639 | 1.1652 | . 53464 | 342.49 | . 81593 | 6545.4 |
| .42 | . 05708 | 1.1405 | . 52533 | 335.22 | . 80662 | 6406.6 |
| . 43 | . 04770 | 1.1161 | . 51595 | 328.06 | .79724 | 6269.7 |
| . 44 | . 03824 | 1.0920 | . 50650 | 320.99 | . 78779 | 6134.6 |
| 0.45 | 0.02870 | 1.0683 | 2.49696 | 314.02 | 3.77825 | 6001.3 |
| .46 | . 01907 | I. 0449 | . 48733 | 307.13 | . 76862 | 5869.7 |
| . 47 | . 00934 | 1.0217 | . 47760 | 300.33 | .75889 | $5739 \cdot 7$ |
| .48 | 9.99951 | 0.99886 | . 46776 | 293.60 | . 74905 | 5611.2 |
| . 49 | . 93956 | 0.97624 | -45782 | 286.96 | .7391 I | 5484.I |
| 0.50 | 9.97949 | 0.95387 | 2.44775 | 280.38 | 3.72904 | 5358.4 |

$\dagger$ Kelvin, Mathematical and Physical Papers, vol. III. p. 428 ; Becker, Am. Jour. of Sci. vol. III. 1897, p. 280 .
*For direct values see table 24.
Smithsonian Tables.

DIFFUSION.

| $v / c$ | $\log 2 q$ | $2 q$ | $\log \delta$ | $\delta$ | $\log \gamma$ | $\gamma$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.50 | 9.97949 | 0.95387 | 2.44775 | 280.38 | 3.72904 | 5358.4 |
| . 51 | . 96929 | . 93174 | . 43755 | 273.87 | . 71884 | 5234.1 |
| . 52 | . 95896 | .90983 | . 42722 | 267.43 | . 70851 | 5111.0 |
| . 53 | . 94848 | . 88813 | . 41674 | 261.06 | . 69803 | 4989.I |
| . 54 | . 93784 | . 86665 | . 40610 | 254.74 | . 68739 | 4868.4 |
| 0.55 | 9.92704 | 0.84536 | 2.39530 | 248.48 | 3.67659 | 4748.9 |
| . 56 | .91607 | . 82426 | . 38432 | 242.28 | .66561 | 4630.3 |
| . 57 | . 90490 | . 80335 | -37316 | 236.13 | . 65445 | 4512.8 |
| . 58 | . 89354 | . 78260 | -36180 | 230.04 | . 64309 | 4396.3 |
| . 59 | .88197 | . 76203 | $\cdot 35023$ | 223.99 | .63152 | 4280.7 |
| 0.60 | 9.87018 | 0.74161 | 2.33843 | 217.99 | 3.61973 | 4166.1 |
| . 61 | . 85815 | .72135 | . 32640 | 212.03 | . 60770 | 4052.2 |
| . 62 | . 84587 | .70124 | .31412 | 206.12 | . 59541 | 3939.2 |
| . 63 | . 83332 | .68126 | -30157 | 200.25 | . 58286 | 3827.0 |
| . 64 | . 82048 | . 66143 | . 28874 | 19.42 | . 57003 | 3715.6 |
| 0.65 | 9.80734 | 0.64172 | 2.27560 | 188.63 | 3.55689 | 3604.9 |
| . 66 | . 79338 | . 62213 | . 26214 | 182.87 | . 54343 | 3494.9 |
| . 67 | .7S008 | . 60266 | . 24833 | 177.15 | . 52962 | 3385.4 |
| . 68 | . 76590 | .58331 | . 23416 | 171.46 | . 51545 | 3276.8 |
| . 69 | .751.33 | . 56407 | . 21959 | 165.80 | . 50088 | 3168.7 |
| 0.70 | 9.73634 | 0.54493 | 2.20459 | 160.17 | 3.48588 | 306I.r |
| . 71 | . 72089 | . 52588 | .18915 | I 54.58 | . 47044 | 2954.2 |
| .72 | . 70495 | - 50694 | .17321 | 149.01 | -45450 | 2847.7 |
| . 73 | . 68849 | -48808 | . 15675 | 143.47 | .43804 | 2741.8 |
| . 74 | .67146 | -4693I | - 13972 | I 37.95 | -42101 | 2636.4 |
| 0.75 | 9.65381 | 0.45062 | 2.12207 | 132.46 | 3.40336 | 2531.4 |
| . 76 | . 63550 | -43202 | . 10376 | 126.99 | -38505 | 2426.9 |
| . 77 | . 61646 | . 41348 | .0847 1 | 121.54 | -36600 | 2322.7 |
| . 78 | . 59662 | . 39502 | . 06487 | II6.11 | -34616 | 2219.0 |
| . 79 | . 57590 | . 37662 | . 04416 | 110.70 | -32545 | 2115.7 |
| 0.80 | 9.55423 | 0.35829 | 2.02249 | 105.31 | 3.30378 | 2012.7 |
| . 8 I | . 53150 | .34001 | I. 99975 | 99.943 | .28104 | 1910.0 |
| . 82 | . 50758 | -32180 | . 97584 | 94.589 | . 25713 | 1807.7 |
| .83 | . 48235 | $\cdot 30363$ | .95061 | 89.250 | .23190 | 1705.7 |
| . 84 | . 45564 | .28552 | .92389 | 83.926 | .20518 | 1603.9 |
| 0.85 | 9.42725 | 0.26745 | I. 8955 I | 78.615 | 3.17680 | I 502.4 |
| . 86 | . 39695 | . 24943 | . 8652 I | 73.317 | . 14650 | 1401.2 |
| . 87 | -36445 | .23145 | . 83271 | 68.032 | . 11400 | 1300.2 |
| . 88 | -32940 | .21350 | . 79766 | 62.757 | . 07895 | 1199.4 |
| . 89 | .29135 | . 19559 | . 75961 | 57.492 | 3.04090 | 1098.7 |
| 0.90 | 9.24972 | 0.17771 | 1.71797 | 52.236 | 2.99926 | 998.31 |
| .91 | . 20374 | . 15986 | . 67200 | 46.989 | . 95329 | 898.03 |
| . 92 | . 15239 | . 14203 | . 62065 | 41.750 | .90194 | 797.89 |
| . 93 | . 09423 | .12423 | . 56249 | 36.516 | . 43378 | 697.88 |
| . 94 | 9.02714 | . 10645 | . 49539 | 31.289 | . 77668 | 597.98 |
| 0.95 | 8.94783 | 0.08868 | 1.41609 | 26.067 | 2.69738 | $49^{8.17}$ |
| . 96 | . 85082 | . 07093 | - 31907 | 20.848 | . 60036 | 398.44 |
| . 97 | . 72580 | .05319 | . 19406 | 15.633 | .47535 | 298.78 |
| . 98 | .54965 .24859 | .0 .3545 .01773 | .01791 0.71684 | 10.421 5.21007 | $\begin{array}{r}.29920 \\ \hline .09813\end{array}$ | 199.16 99.571 |
| . 99 | .24559 | . 01773 | 0.71684 | 5.21007 | I. 99813 | 99.571 |
| 1.00 | $-\infty$ | 0.00000 | $-\infty$ | 0.00000 | $-\infty$ | 0.000 |

Smithsonian Tables.

Table 32.
GAMMA FUNCTION.*
Value of $\log \int_{0}^{\infty} e^{-z} x^{n-1} d x+10$.
Values of the logarithms + ro of the "Second Eulerian Integral" (Gamma function) $\int_{0}^{\infty} e^{-x} x^{n-1} d x 0 \log \Gamma(n)+10$ for values of $n$ between $x_{1}$ and 2 . When $n$ has values not lying between 1 and 2 the value of the $f 1$ nction can be readily calculated from the equation $\Gamma(n+1)=n \Gamma(n)=n(n-1) \ldots(n-r) \Gamma(n-r)$.

| $n$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.00 | 9.99 | 97497 | 95001 | 92512 | 90030 | 87555 | 85087 | 82627 | 80173 | 77727 |
| I. OI | 75287 | 72855 | 70430 | 6801 I | 65600 | 63196 | 60798 | 58.08 | 56025 | 53648 |
| 1.02 | 51279 | 48916 | 46561 | 44212 | 41870 | 395.35 | 37207 | 34886 | 32572 | 30265 |
| 1.03 | 27964 | 25671 | 23384 | 21104 | 18831 | 16564 | 14305 | 12052 | 09806 | 07567 |
| 1.04 | 05334 | 03108 | 00889 | $\overline{98677}$ | $\overline{96471}$ | $\overline{94273}$ | 92080 | 89895 | 87716 | 85544 |
| 1.05 | 9.9883379 | SI 220 | 79068 | 76922 | 74783 | 72651 | 70525 | 68406 | 66294 | 64188 |
| 1.06 | 62089 | 59996 | 57910 | 55830 | 53757 | 51690 | 49630 | 47577 | 45530 | 43489 |
| 1.07 | 41455 | 39428 | 37407 | 35392 | 33384 | 31382 | 29387 | 27398 | 25415 | 23439 |
| 1.08 | 21469 | 19506 | 17549 | 15599 | 13655 | 11717 | 09785 | 07860 | 0594 I | 04029 |
| 1.09 | 02123 | 00223 | 98329 | 96442 | $\underline{94561}$ | 92686 | 90818 | 88956 | 87100 | 85250 |
| 1.10 | 9.9783407 | 81570 | 79738 | 77914 | 76095 | 74283 | 72476 | 70676 | 68882 | 67095 |
| I. I I | 65.313 | 63538 | 61768 | 60005 | 58248 | 56497 | 54753 | 53014 | 51281 | 49555 |
| I.I2 | 47834 | 46120 | 44411 | 42709 | 41013 | 39323 | 37638 | 35960 | 34288 | 32622 |
| 1.13 | 30962 | 29308 | 27659 | 26017 | 24381 | 22751 | 21126 | 19508 | 17896 | 16289 |
| 1.14 | 14689 | 13094 | 11505 | 09922 | 08345 | 06774 | 05209 | 03650 | 02096 | 00549 |
| 1.15 | 9.9699007 | 97471 | 95941 | 94417 | 92898 | 91386 | 89879 | 88378 | 86883 | 85393 |
| 1.16 | 83910 | 82432 | 80960 | 79493 | 78033 | 76578 | 75129 | 73686 | 72248 | 70816 |
| 1.17 | . 69390 | 67969 | 66554 | 65145 | 63742 | 62344 | 60952 | 59566 | 58185 | 56810 |
| 1.18 | 55440 | 54076 | 52718 | 51366 | 50019 | 48677 | 4734 I | 46011 | 44687 | 43368 |
| 1.19 | 42054 | 40746 | 39444 | $3^{81} 47$ | 36856 | 35570 | 34290 | 33016 | 31747 | 30483 |
| 1.20 | 9.9629225 | 27973 | 26725 | 25484 | 24248 | 23017 | 21792 | 20573 | 19358 | 18150 |
| 1.21 | 16946 | 15748 | 14556 | 13369 | 12188 | $\underline{11011}$ | 09841 | 08675 | 07515 | 06361 |
| 1.22 | 05212 | 0.4068 | 02930 | 01796 | 00669 | 99546 | 98430 | 97318 | 96212 | 95111 |
| 1.23 | 594015 | 92925 | 91840 | 90760 | 89685 | 88616 | 87553 | 86494 | 85441 | S4393 |
| 1.24 | 83350 | 82313 | 81280 | 80253 | 79232 | 78215 | 77204 | 76198 | 75197 | 74201 |
| 1.25 | 9.957321 .1 | 72226 | 71246 | 70271 | 69301 | 68337 | 67377 | 66423 | 65474 | 64530 |
| 1.26 | 63592 | 62658 | 61730 | 60806 | 59888 | 58975 | 58067 | 57165 | 56267 | 55374 |
| 1.27 | 54487 | 53604 | 52727 | 51855 | 50988 | 50126 | 49268 | 48416 | 47570 | 46728 |
| 1.28 | 45891 | 45059 | 44232 | 43410 | 42593 | 41782 | 40975 | 40173 | 39376 | 38585 |
| 1.29 | 37798 | 37016 | 36239 | 35467 | 34700 | 33938 | 33181 | 32429 | 31682 | 30940 |
| 1.30 | 9.9530203 | 29470 | 28743 | 28021 | 27303 | 26590 | 25883 | 25180 | 24482 | 23789 |
| 1.31 | 23100 | 22417 | 21739 | 21065 | 20396 | 19732 | 19073 | 18419 | 17770 | 17125 |
| 1.32 | 16.485 | ${ }^{1} 5850$ | 15230 | 14595 | I 3975 | 13359 | 12748 | 12142 | 11541 | 10944 |
| 1.33 | 10353 | 09766 | 09184 | 08606 | 08034 | 07466 | 06903 | 06344 | 05791 | 05242 |
| 1.34 | 04698 | 04158 | 03624 | 03094 | 02568 | 02048 | OI 532 | O102I | 00514 | 00012 |
| 1.35 | 9.9499515 | 99023 | 98535 | 98052 | 97573 | 97100 | 96630 | 96166 | 95706 | 95251 |
| I. 36 | 94800 | 94355 | 93913 | 93477 | 93044 | 92617 | 92194 | 91776 | 91362 | 90953 |
| 1.37 | 90549 | 90149 | 89754 | 89363 | 88977 | 88595 | 88218 | 87846 | 87478 | 87115 |
| 1.38 | 86756 | 86402 | 86052 | 85707 | 85366 | 85030 | 84698 | 84371 | 84049 | 83731 |
| 1.39 | 83417 | 83108 | S2803 | 82503 | 82208 | 8ı916 | 81630 | 81 348 | 81070 | 80797 |
| 1.40 | 9.9480528 | 80263 | 80003 | 79748 | 79497 | 79250 | 79008 | 78770 | 78537 | 78308 |
| 1.41 | 78084 | 77864 | 77648 | 77437 | 77230 | 77027 | 76829 | 76636 | 76446 | 76261 |
| 1.42 | 76081 | 75905 | 75733 | 75565 | 75402 | 75243 | 75089 | 74939 | 74793 | 74652 |
| I. 43 | 74515 | 74382 | 74254 | 74130 | 74010 | 73894 | 73783 | 73676 | 73574 | 73476 |
| I. 44 | 73382 | 73292 | 73207 | 73125 | 73049 | 72976 | 72908 | 72844 | 72784 | 72728 |

[^8]
## Smithsonian Tables.

GAMMA FUNCTION.

| $\boldsymbol{\sim}$ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.45 | 9.9472677 | 72630 | 72587 | 72549 | 72514 | 72484 | 72459 | 724.37 | 72419 | 72406 |
| 1.46 | 72397 | 72393 | 72392 | 72396 | 72404 | 72416 | 72432 | 72452 | 72477 | 72506 |
| I. 47 | 72539 | 72576 | 72617 | 72662 | 72712 | 72766 | 72824 | 72886 | 72952 | 73022 |
| I. 48 | 73097 | 73175 | 73258 | 73345 | 73436 | $7353{ }^{\text {I }}$ | 73630 | 73734 | 73841 | 73953 |
| I. 49 | 74068 | 74188 | 74312 | 74440 | 74572 | 74708 | 74848 | 74992 | 75141 | 75293 |
| 1.50 | 9.9475449 | 75610 | 75774 | 75943 | 76116 | 76292 | 76473 | 76658 | 76847 | 77040 |
| 1.51 | - 77237 | $774{ }^{-}$ | 77642 | 77851 | 78064 | 78281 | 78502 | 78727 | 78956 | 79189 |
| 1.52 | 79426 | 79667 | 79912 | S0161 | 80414 | 80671 | 80932 | 81196 | 81465 | 81738 |
| 1.53 | 82015 | 82295 | 82580 | 82868 | 83161 | 83457 | 83758 | 84062 | 84370 | 84682 |
| 1.54 | 84998 | S5318 | 85642 | 85970 | 86302 | 86638 | 86977 | 87321 | 87668 | 88019 |
| 1.55 | 9.9488374 | 88733 | 89096 | 89463 | 89834 | 90208 | 90587 | 90969 | 91355 | 91745 |
| 1. 56 | 92139 | 92537 | 92938 | 93344 | 93753 | 94166 | 94583 | 95004 | 95429 | 95857 |
| 1.57 | 96289 | 96725 | 97165 | 97609 | 98056 | 98508 | 98963 | 99422 | 99885 | 00351 |
| 1.58 | 500822 | 01296 | 01774 | 02255 | 02741 | 03230 | 03723 | 04220 | 04720 | 05225 |
| I. 59 | 05733 | 06245 | 06760 | 07280 | 07803 | 08330 | 08860 | 09395 | 09933 | 10475 |
| 1.60 | 9.9511020 | 11569 | 12122 | 12679 | 13240 | I 3804 | 14372 | 14943 | I 5519 | 16098 |
| 1.61 | 16680 | 17267 | 17857 | 1845 I | 19048 | 19649 | 20254 | 20862 | 21475 | 22091 |
| 1.62 | 22710 | 23333 | 23960 | 24591 | 25225 | 25863 | 26504 | 27149 | 27798 | 28451 |
| 1.63 | 29107 | 29766 | 30430 | 31097 | 31767 | 32442 | 33120 | 33801 | 34486 | 35175 |
| 1.64 | 35867 | 36563 | 37263 | 37966 | 38673 | 39383 | 40097 | 40815 | 41536 | 42260 |
| 1.65 | 9.9542989 | 43721 | 44456 | 45195 | 45938 | 46684 | 47434 | 48187 | 48944 | 49704 |
| 1.66 | 50468 | 51236 | 52007 | 52782 | 53560 | 54342 | 55127 | 55916 | 56708 | 57504 |
| 1.67 | 58303 | 59106 | 59913 | 60723 | 61536 | 62353 | 63174 | 63998 | 64825 | 65656 |
| 1.68 I. 69 | 66491 | 67329 75001 | 68170 -6777 | 69015 | 69864 | 70716 | 71571 | 72430 | 73293 | 74159 |
| 1.69 | 75028 | 75901 | 76777 | 77657 | 78540 | 79427 | So317 | 8I2II | 82108 | 83008 |
| 1.70 | 9.9583912 | 84820 | 85731 | 86645 | 87563 | 88484 | 89409 | 90337 | 21268 | 22203 |
| 1.71 | 93I4I | 94083 | 95028 | 95977 | 96929 | 97884 | 98843 | 99805 | 00771 | 01740 |
| 1.72 | 602712 | 03688 | 0.4667 | 05650 | 06636 | 07625 | 08618 | 09614 | 1061 3 | 11616 |
| 1.73 | 12622 | 13632 | 14645 | 15661 | 1668 I | 17704 | 18730 | 19760 | 20793 | 21830 |
| 1.74 | 22869 | 23912 | 24959 | 26009 | 27062 | 28118 | 29178 | 30241 | 31308 | 32377 |
| 1.75 | 9.9633451 | 34527 | 35607 | 36690 | 37776 | 38866 | 39959 | 41055 | 42155 | 43258 |
| 1.76 | 44364 | 45473 | 46586 | 47702 | 48821 | 49944 | 51070 | 52199 | 53331 | 54467 |
| 1.77 | 55606 | 56749 | 57894 | 59043 | 60195 | 61350 | 62509 | 63671 | 64836 | 66004 |
| 1.78 | 67176 | 68351 | 69529 | 70710 | 71895 | 73082 | 74274 | 75468 | 76665 | 77866 |
| 1.79 | 79070 | 80277 | 81488 | 82701 | 83918 | S5138 | 86361 | 87588 | S88IS | 90051 |
| 1.80 | 9.9691287 | 92526 | 93768 | 95014 | 96263 | 97515 | 98770 | 00029 | $\underline{1291}$ | 02555 |
| I. 81 | 703823 | 05095 | 06369 | 07646 | 08927 | IO211 | 11498 | 12788 | 14082 | 15375 |
| I. 82 | 16678 | 17981 | 19287 | 20596 | 21908 | 23224 | 24542 | 25864 | 27189 | 28517 |
| 1.83 | 29848 | 31182 | 32520 | 33860 | 35204 | 36551 | 37900 | 39254 | 40610 | 41969 |
| 1.84 | 43331 | 44697 | 46065 | 47437 | 48812 | 50190 | 51571 | 52955 | 54342 | 55733 |
| 1.85 | 9.9757126 | 58522 | 59922 | 61325 | 62730 | 64139 | 65551 | 66966 | 68384 | 69805 |
| 1.86 | 71230 | 72657 | 74087 | 75521 | 76957 | 78397 | 79839 | 81285 | 82734 | 84186 |
| 1. 87 | S5640 | 87098 | 88559 | 90023 | 91490 | 92960 | 94433 | 95909 | 97389 | 98871 |
| 1.88 | 800356 | O1844 | 03335 | 04830 | 06327 | 07827 | 09331 | 10837 | 12346 | 13859 |
| ז. 89 | 15374 | 16893 | 18414 | 19939 | 21466 | 22996 | 24530 | 26066 | 27606 | 29148 |
| 1.90 | 9.9830693 | 32242 | 33793 | 35348 | 36905 | 38465 | 40028 | 41595 | 43164 | 44736 |
| I.91 | 46311 | 47890 | 4947 I | 51055 | 52642 | 54232 | 55825 | 5742 I | 59020 | 60621 |
| 1.92 | 62226 | ${ }_{6} 6834$ | 65445 | ${ }^{6} 7058$ | 68675 | 70294 | 71917 | 73542 | 75170 | 76802 |
| 1.93 | 78436 | 80073 | 81713 | 83356 | 85002 | 86651 | 88302 | S9957 | $\underline{91614}$ | 23275 |
| 1.94 | 94938 | 96605 | 98274 | 99946 | 01621 | 03299 | 04980 | 06663 | 08350 | 10039 |
| 1.95 | 9.9911732 | 13427 | 15125 | 16826 | 18530 | 20237 | 21947 | 23659 | 25375 | 27093 |
| I. 96 | 28815 | 30539 | 32266 | 33995 | 35728 | 37464 | 39202 | 40943 | 42688 | 44435 |
| 1.97 | 46155 | 47937 | 49693 | 51451 | 53213 | 54977 | 56744 | 58513 | 60286 | 62062 |
| I. 98 | 63840 | 65621 | 67405 | 69192 | 70982 | 72774 | $7457{ }^{\circ}$ | 76368 | 78169 | 79972 |
| I. 99 | 8ı779 | 83588 | 85401 | 87216 | 89034 | 90854 | 92678 | 94504 | 96333 | 98165 |

Smithsonian Tables.

ZONAL SPHERICAL HARMONICS.*

| Degrees | $\mathrm{P}_{1}$ | $\mathrm{P}_{2}$ | $\mathrm{P}_{3}$ | $\mathrm{P}_{4}$ | $\mathrm{P}_{5}$ | $\mathrm{P}_{6}$ | $\mathrm{P}_{7}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | +1.0000 | +1.0000 | +1.0000 | +1.0000 | +1.0000 | +1.0000 | +1.0000 |
| 1 | . 9998 | . 9995 | .9991 | . 9985 | . 9977 | . 9968 | . 9957 |
| 2 | . 9994 | .9982 | . 9963 | . 9939 | . 9909 | . 9872 | . 9830 |
| 3 | . 9986 | . 9959 | .9918 | . 9863 | . 9795 | . 9714 | . 9620 |
| 4 | . 9976 | . 9927 | . 9854 | . 9758 | . 9638 | . 9495 | . 9329 |
| 5 | +0.9962 | + 0.9886 | + 0.9773 | +0.9623 | +0.9437 | +0.9216 | +0.8962 |
| 6 | . 9945 | .9836 | . 9674 | . 9459 | .9194 | . 8881 | . 8522 |
| 7 | . 9925 | . 9777 | . 9557 | . 9267 | .89II | . 8492 | . 8016 |
| 8 | . 9903 | . 9709 | . $9+23$ | . 9048 | .8589 | . 8054 | . 7449 |
| 9 | .9877 | .9633 | . 9273 | . 8803 | . 8232 | . 7570 | . 6830 |
| 10 | +0.9848 | +0.9548 | +0.9106 | +0.8532 | +0.7840 | +0.7045 | +0.6164 |
| 11 | .98i6 | . 9454 | . 8923 | . 8238 | . 7417 | . 6483 | . 5462 |
| 12 | . 978 I | . 9352 | . 8724 | .7920 | . 6966 | .5891 | . 4731 |
| 13 | . 9744 | . 9241 | . 8511 | . 7582 | . 6489 | .5273 | . 3980 |
| 14 | .9703 | .9122 | .8283 | . 7224 | . 5990 | . 4635 | -3218 |
| 15 | +0.9659 | +0.8995 | +0.8042 | + 0.6847 | +0.5471 | +0.3983 | +0.2455 |
| 16 | .9613 | . 8860 | .7787 | . 6454 | . 4937 | . 3323 | + .1700 |
| 17 | .9563 | . 8718 | .7519 | . 6046 | . 4391 | . 2661 | + .0961 |
| 18 | . 9511 | . 8568 | . 7240 | . 5624 | . 3836 | . 2002 | + . 0248 |
| 19 | . 9455 | . 8410 | . 6950 | . 5192 | . 3276 | .1353 | -. 0433 |
| 20 | +0.9397 | +0.8245 | + 0.6649 | +0.4750 | +0.2715 | +0.0719 | $-0.1072$ |
| 21 | .9336 | . 8074 | . 6338 | . 4300 | . 2156 | + .0106 | . 1664 |
| 22 | . 9272 | .7895 | . 6019 | - 3845 | . 1602 | -.0481 | . 2202 |
| 23 | . 9205 | . 7710 | . 5692 | .3386 | . 1057 | -.1038 | . 2680 |
| 24 | .9135 | .7518 | . 5357 | . 2926 | . 0525 | - . 1558 | . 3094 |
| 25 | $+0.9063$ | +0.7321 | +0.5016 | +0.2465 | +0.0009 | -0.2040 | -0.344I |
| 26 | . 8988 | .7117 | . 4670 | . 2007 | - . 0489 | . 2478 | . 3717 |
| 27 | . 8910 | . 6908 | .4319 | . 1553 | -. 0964 | . 2869 | . 3922 |
| 28 | . 8829 | . 6694 | . 3964 | . 1105 | -.1415 | -3212 | . 4053 |
| 29 | . 8746 | . 6474 | . 3607 | . 0665 | -. 1839 | . 3502 | .4143 |
| 30 | +0.8660 | +0.6250 | +0.3248 | +0.0234 | -0.2233 | -0.3740 | -0.4102 |
| 31 | . 8572 | . 6021 | .2887 | -. .0185 | . 2595 | . 3924 | . 4022 |
| 32 | . 8480 | . 5788 | . 2527 | -.0591 | . 2923 | . 4053 | . 3877 |
| 33 | . 8387 | . 5551 | . 2167 | - . 0982 | - 3216 | .4127 | -3671 |
| 34 | . 8290 | . 5310 | .1809 | -.1357 | - 3473 | .4147 | . 3409 |
| 35 | +0.8192 | +0.5065 | +0.1454 | -0.1714 | --0.3691 | -0.4114 | -0.3096 |
| 36 | . 8090 | . 4818 | . 1102 | .2052 | . 3871 | . 4031 | .2738 |
| 37 | . 7986 | .4567 | . 0755 | . 2370 | . 4011 | . 3898 | .2343 |
| 38 | . 7880 | . 4314 | . 0413 | . 2666 | .4112 | . 3719 | .1918 |
| 39 | .777 I | . 4059 | . 0077 | . 2940 | .4174 | - 3497 | . 1470 |
| 40 | +0.7660 | +0.3802 | -0.0252 | -0.3190 | -0.4197 | $-0.3236$ | -0.1006 |
| 41 | . 7547 | . 3544 | . 0574 | . 3416 | .4181 | . 2939 | -. 0535 |
| 42 | .7431 | -3284 | .0887 | . 3616 | .4128 | . 2610 | -. 0064 |
| 43 | .7314 | . 3023 | . 1191 | . 3791 | . 4038 | . 2255 | +.0398 |
| 44 | .7193 | .2762 | .1485 | - 3940 | . 3914 | . 1878 | +.0846 |
| 45 | +0.7071 | + 0.2500 | -0.1768 | $-0.4063$ | -0.3757 | -0.1484 | +0.1271 |
| 46 | . 6947 | .2238 | . 2040 | . 4158 | $.3568$ | -.1078 | . 1667 |
| 47 | . 6820 | . 1977 | . 2300 | .4227 | . 3350 | -. .0665 | . 2028 |
| 48 | . 6691 | .1716 | . 2547 | . 4270 | . 3105 | -.0251 | . 2350 |
| 49 | .6561 | .1456 | .2781 | . 4286 | .2836 | +.0161 | . 2626 |
| 50 | + 0.6428 | +0.1198 | -0.3002 | -0.4275 | -0.2545 | + 0.0564 | +0.2854 |

* Calculated by Mr. C. E. Van Orstrand for this publication.

Smithsonian Tables.

Table 33 (continued).
ZONAL SPHERICAL HARMONICS.

| Degrees | $\mathrm{P}_{1}$ | $\mathrm{P}_{2}$ | $\mathrm{P}_{3}$ | $\mathrm{P}_{4}$ | $\mathrm{P}_{5}$ | $\mathrm{P}_{6}$ | $\mathrm{P}_{7}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 50 | +0.6428 | +0.1198 | -0.3002 | -0.4275 | -0.2545 | +0.0564 | +0.2854 |
| 51 | . 6293 | . 0941 | . 3209 | .4239 | . 2235 | . 0954 | . 3031 |
| 52 | . 6157 | . 0686 | . 3401 | .4178 | .1910 | .1326 | -3154 |
| 53 | . 6018 | . 0433 | . 3578 | . 4093 | . 1571 | . 1677 | . 3221 |
| 54 | .5878 | . 0182 | . 3740 | - 3984 | . 1223 | . 2002 | . 3234 |
| 55 | $+0.5736$ | -0.0065 | -0.3886 | -0.3852 | -0.0868 | + 0.2297 | +0.3191 |
| 56 | - 5592 | .0310 | . 4016 | . 3698 | -. 0509 | . 2560 | . 3095 |
| 57 | - 5446 | . 0551 | .4131 | . 3524 | -. 0150 | .2787 | . 2947 |
| 58 | - 5299 | . 0788 | . 4229 | -3331 | $+.0206$ | . 2976 | . 2752 |
| 59 | .5150 | .1021 | .4310 | -3119 | +.0557 | .3125 | .2512 |
| 60 | +0.5000 | -0.1250 | -0.4375 | -0.2891 | +0.0898 | +0.3232 | +0.2231 |
| 61 | . 4848 | . 1474 | . 4423 | . 2647 | . 1229 | . 3298 | . 1916 |
| 62 | . 4695 | . 1694 | . 4455 | . 2390 | . 1545 | . 3321 | . 1572 |
| 63 | . 4540 | .1908 | . 447 I | . 2121 | . 1844 | . 3302 | . 1203 |
| 64 | . 4384 | .2117 | . 4470 | .1841 | . 2123 | - 3240 | .0818 |
| 65 | + 0.4226 | -0.2321 | -0.4452 | -0.1552 | +0.2381 | +0.3138 | +0.0422 |
| 66 | . 4067 | .2518 | . 4419 | . 1256 | .2615 | . 2997 | + .0022 |
| 67 | . 3907 | . 2710 | . 4370 | . 0955 | . 2824 | .2819 | - . 0375 |
| 68 | . 3746 | . 2895 | . 4305 | . .0651 | . 3005 | . 2606 | -. .0763 |
| 69 | . 3584 | . 3074 | . 4225 | . 0344 | . 3158 | .2362 | -. .1135 |
| 70 | +0.3420 | -0.3245 | -0.4130 | $-0.0038$ | +0.3281 | +0.2089 | $-0.1485$ |
| 71 | .3256 | .3410 | . 4021 | + .0267 | . 3373 | . 1791 | . 1808 |
| 72 | - 3090 | . 3568 | . 3898 | . 0568 | - 3434 | . 1472 | . 2099 |
| 73 | . 2924 | . 3718 | .3761 | . 0864 | $\cdot 3463$ | .1136 | .2352 |
| 74 | . 2756 | . 3860 | .3611 | . 1153 | .3461 | . 0788 | .2563 |
| 75 | + 0.2588 | -0.3995 | -0.3449 | +0.1434 | +0.3427 | +0.0431 | $-0.2730$ |
| 76 | . 2419 | .4122 | . 3275 | .1705 | . 3362 | $\pm .0070$ | $.2850$ |
| 77 | . 2250 | .4241 | -3090 | .1964 | . 3267 | - . 0290 | . 2921 |
| 78 | . 2079 | . 4352 | .2894 | . 2211 | -3143 | - . 0644 | . 2942 |
| 79 | . 1908 | . 4454 | . 2688 | . 2443 | . 2990 | -. 0990 | . 2913 |
| 80 | +0.1736 | -0.4548 | -0.2474 | +0.2659 | + 0.2810 | -0.1321 | -0.2835 |
| 8 I | .1564 | . 4633 | . 2251 | . 2859 | . 2606 | .1635 | . 2708 |
| 82 | . 1392 | . 4709 | . 2020 | . 3040 | . 2378 | . 1927 | .2536 |
| 83 84 | .1219 .1045 | .4777 | .1783 | .3203 | .2129 | .2193 | .2321 |
| 84 | . 1045 | .4836 | . 1539 | . 3345 | .1861 | . 2431 | . 2067 |
|  | $+0.0872$ | -0.4886 | -0.1291 | +0.3468 | +0.1577 | -0.2638 | -0.1778 |
| 86 | $.0698$ | .4927 | .1038 | .3569 | . 1278 | .2810 | . 1460 |
| 87 | .0523 | .4959 | . 0781 | . 3648 | . 0969 | . 2947 | . 1117 |
| 88 | . 0349 | .4982 | .0522 | . 3704 | . 0651 | -3045 | . 0755 |
| 89 | . 0175 | . 4995 | . 0262 | -3739 | . 0327 | $\cdot 3105$ | . 0381 |
| 90 | +0.0000 | $-0.5000$ | -0.0000 | $+0.375^{\circ}$ | + 0.0000 | -0.3125 | -0.0000 |

smithsonian tables.

CYLINDRICAL HARMONICS OF THE OTH AND 1st ORDERS
Values when $n=0$ and I of the Bessel function $J_{n}(x)$

$$
=\frac{x^{n}}{2^{n} \Gamma(n+1)}\left\{1-\frac{x^{2}}{2^{2}(n+1)}+\frac{x^{4}}{2^{4} 2!(n+1)(n+2)} \ldots\right\} . \quad J_{1}(x)=-J_{0}^{\prime}(x)=\frac{d J_{0}(x)}{d x} .
$$

| $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J_{1}(x)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| . 00 | unity | zero | . 50 | . 938470 | . 242268 | 1.00 | . 765198 | . 440051 | 1.50 | . 511828 | . 557937 |
| . O | . 999975 | . 005000 | . 51 | . 936024 | . 246799 | . OI | .760781 | . 443286 | . 51 | . 506241 | . 559315 |
| . 02 | . 999900 | . 010000 | . 52 | . 933534 | . 251310 | . 02 | . 756332 | . 446488 | . 52 | . 500642 | . 560653 |
| . 03 | . 999775 | . 014998 | -53 | . 930998 | . 255803 | . 03 | -751851 | . 449658 | . 53 | . 495028 | .561951 |
| . 04 | .999600 | . 019996 | . 54 | .928418 | . 260277 | . 04 | . 747339 | .452794 | - 54 | . 489403 | . 563208 |
| . 05 | . 999375 | . 024992 | . 55 | . 925793 | . 264732 | 1.05 | . 742796 | . 455897 | 1.55 | . 483764 | . 564424 |
| . 06 | . 999100 | . 029987 | . 56 | . 923123 | . 269166 | . 06 | . 73822 I | . 458966 | . 56 | .478114 | . 565600 |
| . 07 | . 998775 | . 034979 | $\cdot 57$ | . 920410 | .273581 | . 07 | .7336ı6 | . 462001 | . 57 | . 472453 | . 566735 |
| . 0 | . 998401 | . 039968 | . 58 | .917652 | . 277975 | . 08 | . 72898 I | . 465003 | . 58 | . 466780 | . 567830 |
| . 09 | .997976 | . 044954 | . 59 | .914850 | . 282349 | . 09 | . 724316 | . 467970 | . 59 | .461096 | . 568883 |
| . 1 | . 997502 | . 049938 | . 60 | .912005 | . 286701 | 1.10 | . 719622 | . 470902 | 1.60 | . 455402 | . 569896 |
| . 11 | . 996977 | . 054917 | . 61 | . 909116 | . 291032 | . II | . 714898 | . 473800 | . 61 | . 449698 | . 570868 |
| . 1 | . 996403 | .059892 | . 62 | .005184 | . 295341 | . 12 | . 710146 | .476663 | . 62 | . 443985 | . 571798 |
| . 13 | . 995779 | . 064863 | . 63 | .903209 | . 299628 | . 13 | . 705365 | . 479491 | . 63 | . 438262 | . 572688 |
| . 14 | .995106 | . 069829 | . 64 | .900192 | . 303893 | 14 | . 700556 | .482284 | . 64 | . 43253 I | . 573537 |
| . 1 | . 99438 | . 07478 | . 65 | .897132 | .308135 | 1.15 | . 695720 | . 48504 I | 1.65 | . 426792 | . 574344 |
| . 1 | . 993610 | . 079744 | . 66 | . 894029 | -312355 | 6 | . 690856 | . 487763 | . 66 | . 421045 | . 575111 |
| . 17 | . 992788 | . 084693 | . 67 | . 890885 | -316551 | .17 | . 685965 | . 490449 | . 67 | .415290 | . 575836 |
| . 18 | .991916 | .089636 | . 68 | . 887698 | - 320723 | . 18 | .681047 | . 493098 | . 68 | . 409528 | . 576520 |
| . 19 | .990995 | . 094572 | . 69 | . 884470 | . 32487 I | . 19 | .676103 | . 495712 | . 69 | . 403760 | . 577163 |
| . 20 | . 99 | . 099501 | . 70 | .88I 201 | . 328996 | 1.20 | . 671133 | . 498289 | 1.70 | . 397985 | . 577765 |
| . 21 | . 989005 | . 104422 | . 71 | . 877890 | . 333096 | . 21 | .6661 37 | . 500830 | . 71 | - 392204 | . 578326 |
| . 2 | . 987937 | . 109336 | . 72 | . 874539 | -337170 | . 22 | .66ı 116 | . 503334 | . 72 | - 386418 | . 578845 |
| . 23 | .9868I9 | .11424 | . 73 | . 871147 | .341220 | . 23 | . 656071 | .505801 | . 73 | . 380628 | . 579323 |
| . 24 | .985652 | .199138 | . 74 | . 867715 | - 345245 | . 24 | . 651000 | . 50823 I | . 74 | - $37483^{2}$ | . 579760 |
| . 25 | . 984436 | . 124026 | . 75 |  | . 349244 | 1.25 | . 645906 | . 510623 | 1.75 | . 369033 | . 580156 |
| . 26 | .983171 | . 128905 | . 76 | . 860730 | . 353216 | . 26 | . 640788 | . 512979 | . 76 | . 363229 | . 580511 |
| . 27 | .981858 | . 133774 | . 77 | . 857178 | . 357163 | . 27 | . 635647 | .515296 | . 77 | . 357422 | . 580824 |
| . 2 | . 980496 | . 138632 | . 78 | . 853587 | -361083 | . 28 | . 630482 | .517577 | .78 | -351613 | .581096 |
| . 29 | .979085 | .143481 | . 79 | . 849956 | . 364976 | . 29 | . 625295 | .519819 | . 79 | . 345801 | .581327 |
| . 30 | . 977 | . 148319 | . 80 | . 846287 | . 368842 | 1.30 | . 620086 | . 522023 | 1.80 | - 339986 | $.581517$ |
| . 31 | .97611 | . 153146 | . 81 | . 842580 | . 372681 | -31 | .614855 | . 524189 | . 8 r | . 334170 | . 581666 |
| . 32 | .974563 | . 157961 | . 82 | . 838834 | . 376492 | . 32 | . 609602 | . 526317 | . 82 | - 328353 | -581773 |
| . 33 | . 972960 | . 162764 | . 83 | . 835050 | . 380275 | . 33 | . 604329 | . 528407 | . 83 | - 322535 | .581840 |
| . 34 | .971308 | . 167555 | . 84 | .831228 | . 384029 | - 34 | . 599034 | . 530458 | . 84 | . 316717 | .581865 |
| . 35 |  | . 172334 | . 85 | . 827369 | . 387755 | 1.35 | . 593720 | . 532470 | 1.85 | . 310898 | $.58 \mathrm{I} 849$ |
| -36 | .96786I | . 177100 | . 86 | . 823473 | . 391453 | . 36 | . 588385 | . 534444 | . 86 | -305080 | . 581793 |
| . 37 | . 966067 | .181852 | . 87 | .81954 I | . 395121 | - 37 | - 583031 | . 536379 | . 87 | . 299262 | -581695 |
| . 38 | . 964224 | .186591 | . 88 | .815571 | . 398760 | . 38 | - 577658 | . 538274 | . 88 | . 293446 | -581557 |
| . 39 | . 962335 | .191316 | . 89 | .8II565 | . 402370 | . 39 | . 572266 | . 540131 | . 89 | . 286631 | .581377 |
| . 40 | .9603 | . 196027 | . 90 | . 807524 | . 405950 | 1.40 | . 566855 | . 541948 | 1.90 | .281819 | .581157 |
| . 41 | . 958414 | . 200723 | . 91 | . 803447 | . 409499 | . 41 | . 561427 | . 543726 | . 91 | . 276008 | . 580896 |
| . 42 | . 956384 | .205403 | . 92 | . 799334 | .413018 | . 42 | -555981 | . 545464 | . 92 | . 270201 | . 580595 |
| . 43 | . 954306 | . 210069 | $\cdot 93$ | . 795186 | .416507 | . 43 | -550518 | . 547162 | $\cdot 93$ | . 264.397 | . 580252 |
| . 44 | .952183 | . 214719 | . 94 | .791004 | . 419965 | . 44 | . 545038 | . 548821 | -94 | . 258596 | . 579870 |
| . 45 | .950012 | . 219353 | . 95 | .786787 | . 423392 | 1.45 | . 53954 I | . 55044 I | 1.95 | . 252799 | . 579446 |
| . 46 | . 947796 | . 223970 | . 96 | . 782536 | . 426787 | . 46 | . 534029 | . 552020 | . 96 | . 247007 | . 578983 |
| . 47 | . 945533 | . 22857 I | . 97 | . 778251 | .430151 | . 47 | -528501 | . 553559 | - 97 | . 241220 | . 578478 |
| . 48 | . 943224 | . 233154 | .98 | . 773933 | . 433483 | -48 | - 522958 | . 555059 | .98 | .235438 | . 577934 |
| . 49 | . 940870 | . 237720 | . 99 | . 769582 | .436783 | . 49 | .517400 | . 556518 | . 99 | . 229661 | . 577349 |
| . 50 | . 938470 | . 242268 | 1.00 | .765198 | . 440051 | 1.50 | . 511828 | . 557937 | 2.00 | .223891 | . 576725 |

CYLINDRICAL HARMONICS OF THE OTh AND 1st ORDERS.
$J_{1}(x)=-J_{0^{\prime}}(x)$. Other orders may be obtained from the relation, $J_{n+1}(x)=\frac{2 n}{x} J_{n}(x)-J_{n-1}(x)$.
$J_{-n}(x)=(-1)^{n} J_{n}(x)$.

| $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J_{1}(x)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2.00 | . 2238891 | . 576725 | 2.50 | -. 048384 | . 497094 | 3.00 | -. 260052 | - 339059 | 3.50 | -380128 | .I37378 |
| . Or | . 218127 | . 576060 | . 51 | -. 053342 | . 494606 | . OI | -. 263424 | -335319 | . 51 | -.381481 | .133183 |
| . 0 | . 212370 | . 575355 | . 52 | -. 058276 | . 492086 | . 02 | -. $26675^{8}$ | .331563 | . 52 | -.382791 | . 128989 |
| . 03 | . 206620 | . 574611 | . 53 | -. 063184 | . 489535 | .03 | -. 270055 | -327789 | . 53 | -. 384060 | . 124795 |
| . 04 | . 200878 | . 573827 | . 54 | -. 068066 | . 486953 | . 04 | -. 273314 | . 323998 | . 54 | $-.385287$ | . 120601 |
| 2.05 | . 195143 | . 573003 | 2.55 | -. 072923 | . 484340 | 3.05 | -. 276535 | 320191 | 3.55 | $-.386472$ | .116408 |
| . 06 | . 189418 | 572139 | . 56 | -.077753 | .481696 | -6 | -. 279718 | . 316368 | . 56 | $-.387615$ | . 112216 |
| . 07 | . 183701 | .571236 | . 57 | -.082557 | .47902 1 | . 07 | -. 282862 | . 312529 | . 57 | -.388717 | .108025 |
| . 08 | .177993. | . 570294 | . 58 | -.087333 | -476317 | . 08 | -. 285968 | . 308675 | . 58 | $-.389776$ | .103836 |
| . 09 | . 172295 | -5693 I3 | . 59 | -.092083 | . 473582 | . 09 | -. 289036 | . 304805 | . 59 | -. 390793 | . 099650 |
| 2.10 | . 166607 | . 568292 | 2.60 | -. 096805 | 4708I8 | 3.10 | -. 292064 | . 30092 I | 3.60 | -.391769 | . 095466 |
| . 11 | . 160929. | . 567233 | . 61 | -.IOI499 | . 468025 | . 11 | $-.295054$ | 297023 | . 61 | $-.392703$ | .091284 |
| . 12 | . 555262 | . 566134 | . 62 | -.106I65 | . 465202 | . 12 | -. 298005 | . 293110 | . 62 | -. 393595 | . 087106 |
| .13 | . 149607 | . 564997 | . 63 | -.110803 | . 462350 | .13 | -.300916 | . 289184 | . 63 | -. 394445 | .08293I |
| . 14 | . 143963 | . 56382 I | . 64 | -.115412 | . 459470 | . 14 | $-.303788$ | $.285244$ | . 64 | $-.395^{253}$ | . 078760 |
| 2.15 | . 138330 | . 562607 | 2.65 | -.II9992 | . 45656 I | 3.15 | $-.306621$ |  | 3.65 | $-.396020$ | . 074593 |
| 6 | . 132711 | . 561354 | . 66 | -. 124543 | . 453625 | . 16 | -.309414 | . 277326 | . 66 | -. 396745 | . 07043 I |
| . 17 | . 127104 | . 560063 | . 67 | -. 129065 | . 450660 | . 17 | -.312168 | . 273348 | . 67 | -. 397429 | . 066274 |
| . 18 | . 121509 | . 558735 | . 68 | -. 133557 | -447668 | . 18 | -.31488I | . 269358 | . 68 | -.398071 | . 062122 |
| . 19 | .II5929 | . 557368 | . 69 | -.138018 | . 444648 | . 19 | -.317555 | . 265356 | . 69 | -.39867I | . 057975 |
| 2.20 | . 110362 | . 555963 | 2.70 | -.I42449 | . 441601 | 3.20 | -.320188 | . 261343 | 3.70 | -. 399230 | . 053834 |
| . 21 | . 104810 | . 55452 I | . 71 | -. 146850 | . 438528 | . 21 | -.322781 | . 257319 | . 71 | -. 399748 | . 049699 |
| . 22 | . 099272 | . 55304 I | . 72 | -. 151220 | . 435428 | . 22 | -. 325335 | . 253284 | . 7 | -. 400224 | . 04557 I |
| .23 | . 093749 | -551524 | . 73 | -. 155559 | . 432302 | .23 | -. 327847 . | . 249239 . | . 73 | -. 400659 | . 041450 |
| . 24 | . 088242 | . 549970 | . 74 | -. 59866 | . 429150 | . 24 | -.330319 | . 245184 | . 74 | -.401053 | .037336 |
| 2.25 | . 082750 | . 548378 | 2.75 | -.164141 | . 425972 | 3.25 | -.332751. |  | 3.75 | -. 401406 | . 033229 |
| . 26 | . 077274 | . 546750 | . 76 | -.168385 | . 422769 | . 26 | $-.335142$ | . 237046 | . 76 | -.401718 | .02913I |
| . 27 | . 071815 | . 545085 | . 77 | -. 172597 | -41954 | . 27 | -.337492 | . 232963 | . 77 | -.401989 | . 025040 |
| .28 | . 066373 | . 543384 | . 78 | -. 176776 | . 416288 |  | -.339801. | . 228871 | .78 | $-.402219$ | .020958 |
| . 29 | . 060947 | -541646 | . 79 | -.180922 | .41301 I | . 29 | -.342069. | .22477I | . 79 | $-.402408$ | . 016885 |
| 2.30 | . 055540 | . 539873 | 2.80 | -.185036 | . 409709 | 3.30 | -.344296 | . 220663 | 3.80 | -. 402556 | . 012821 |
| . 31 | . 050150 | . 538063 | . 8 I | -.189117 | . 406384 | . 31 | -. 346482 | . 216548 | . 8 I | -. 402664 | .008766 |
| - 32 | . 044779 . | . 536217 | . 82 | -.193164 | -403035 | - 32 | -.348627 | . 212425 | . 82 | -. 402732 | . 004722 |
| - 33 | .039426 | - 534336 | . 83 | -.197177 | -399662 | $\cdot 33$ | -.35073 1 . | . 208296 | . 83 | -. 402759 | . 000687 |
| - 34 | .034092 | -532419 | . 84 | -.201157. | . 396267 | - 34 | -.352793 | . 204160 | . 84 | $-.402746$ | -.003337 |
| 2.35 | . 028778 . | . 530467 | 2.85 | -. 205102 | - 392849 | 3.35 | -.354814 | . 200018 | 3.85 | -.402692 | -. 007350 |
| -36 | .023483. | -528480 | . 86 | -.209014 | - 389408 | . 36 | -.356793. | . 195870 | . 86 | -. 402599 | -. O11352 |
| -37 | . 018208 | . 526458 | . 87 | -. 212890 | . 385945 |  | -.358731. | .191716 | . 87 | -. 402465 | -. O1 5343 |
| . 38 | . 012954. | -524402 | . 88 | -.216733. | -38246I | . 38 | -.360628 | .187557 | . 88 | -.402292 | -. 019322 |
| . 39 | . 007720 | . 5223 I I | . 89 | -. 220540 | . 378955 | - 39 | -.362482 . | . 183394 | . 89 | -.402079 | -. 023289 |
| 2.40 | . 002508 | . 520185 | 2.90 | 224312 | -375427 | 3.40 | -. 364296 | . 779226 | 3.90 | -.401826 | -. 027244 |
| . 41 | -.002683 | -518026 | -9 | -. 228048 | -371879 |  | -. 366067. | . 175054 | . 91 | -.401534 | $-.031186$ |
|  | -.007853 | . 515833 | -92 | -. 231749 | -368311 |  | -. 367797 . | . 170878 | . 92 | -. 401202 | -.035115 |
| $\cdot 43$ | . 013000 | . 513606 | . 93 | $-.235414$ | $.364722$ |  | $-.369485 \mid$ | $.166699$ | . 93 | -.400832 | -.039031 |
|  | 25 | -5 I 1346 | . 94 | -. 239043 | -361113 | . 44 | $-.371 \mathrm{I} 3 \mathrm{I}$ | .162516 | . 94 | $-.400422$ | -. 042933 |
| 2. | -. 023227 | -509052 | 2.95 | -. 242636 | . 357485 | 3.45 | -. 372735 | . 15833 I | 3.95 | -. 399973 | -. 04682 I |
|  | -. 028306 | . 506726 | . 96 | -.246193 | . 353837 | . 46 | -. 374297 . | .154144 | . 96 | -. 399485 | -. 050695 |
| .47 | -.033361 | -504366 | . 97 | -. 249713 | -350170 | . 47 | $-.375818$ | . 149954 | . 97 | -. 398959 | -. 054555 |
| . 48 | -. 038393 | -501974 | . 98 | $-.253196$ | -346484 | $.48$ | $-.377296$ | $.145763$ | . 98 | $-.398394$ | -. 058400 |
| . 49 | 43401 | . 499550 | -99 | -. 256643 | -342781 | . 49 | -. 378733 . | .141571 | . 99 | -.397791 | -. 062229 |
| 2.50 | $-.048384$ | . 497094 | 3.00 | $-.260052$ | . 339059 | 3.50 | -.380128 | . 137378 | 4.00 | -.397150 | . 066043 |

TABLE 35. - 4-place Values for $x=4.0$ to 15.0 .

| $x$ | $J_{0}(x)$ | $J_{1}(x)$ | $x$ | $J_{0}(x)$ | $J^{\prime}(x)$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 4.0 | - - . 3972 | -. 0660 |  | -. 1939 | +. 1613 |
| , | 1 -.3887 | $-.1033$ |  | -. 2090 | . 1395 |
|  | -. 3766 | -. I386 |  | -. 2218 | . 1166 |
| 3 | $3-.3610$ | -. 1719 |  | $-.2323$ | . 0928 |
| . 4 | $4-.3423$ | -. 2028 | . 9 | -. 2403 | . 0684 |
|  | $5-.3205$ | -. 23 II | 10.0 | -. 2459 | . 0435 |
| . 6 | 6-. 2961 | -. 2566 | - | -. 2490 | +. 0184 |
|  | 7-. 2693 | -. 279 I | . 2 | -. 2496 | -. 0066 |
|  | 8-. 2404 | $-.2985$ |  | -. 2477 | -.0313 |
| . 9 | 9-. 2097 | -. 3147 | . 4 | -. 2434 | -. 0555 |
| 5.0 | - - 1776 | -. 3276 | 10.5 | -. 2366 | $-.0789$ |
| . | I - . 4443 | -. 3371 | . 6 | -. 2276 | -. IOI 2 |
| . 2 | -. 1103 | -. 3432 | . 7 | -. 2164 | -. 1224 |
| $\cdot 3$ | 3-.0758 | -. 3460 |  | -. 2032 | -. 1422 |
| 4 | 4-.0412 | -. 3453 | . 9 | -. 1881 | -. 1603 |
| $5 \cdot 5$ | 5-.0068 | -. 3414 | 1.0 | -. 1712 | -. I768 |
| . 6 | + +.0270 | -. 3343 | 1 | -. I5 28 | -. 1913 |
| . 7 | 7 . 0599 | -. 324 I | - | -. 1330 | -. 2039 |
| . 8 | 8.0917 | -.3110 | $\cdot 3$ | - . II 21 | -. 2143 |
| -9 | 9 . 1220 | -. 2951 |  | -. 0902 | -. 2225 |
| 6.0 | - . 1506 | -. 2767 | II 5 | -. 0677 | -. 2284 |
| . I | . 1773 | -. 2559 | . 6 | -. 0446 | -. 2320 |
| . 2 | 2.2017 | -. 2329 |  | -. 0213 | -. 2333 |
| - 3 | 3.2238 | -. 208I | . 8 | 20 | -. 2323 |
| . 4 | 4.2433 | 18 | . 9 | . 0250 | -. 2290 |
| 6.5 | 5 . 2601 | -. 1538 | 12.0 | . 0477 | -. 2234 |
| . 6 | 6 . 2740 | -. 1250 | . 1 | . 0697 | -. 2157 |
| - 7 | 7.285 I | -. 0953 | . 2 | . 0908 | -. 2060 |
| . 8 | 8.2931 | -. 0652 | - 3 | . 1108 | - . 1943 |
| . 9 | 9 . 298I | -. 0349 | . 4 | . 1296 | -. 1807 |
| 7.0 | - .3001 | -. 0047 | 12.5 | . 1469 | -. 1655 |
| . I | . 2991 | +.0252 | . 6 | . 1626 | -. 1487 |
| . 2 | 2 . 2951 | . 0543 | . 7 | . 1766 | -. I307 |
| - 3 | 3.2882 | . 0826 | . 8 | . 1887 | -. III4 |
| . 4 | 4.2786 | . 1096 | . 9 | . 1988 | -. 0912 |
| $7 \cdot 5$ | 5 . 2663 | . 1352 | 13.0 | . 2069 | -. 0703 |
| . 6 | 6.2516 | . 1592 | . 1 | . 2129 | -. 0489 |
| - 7 | 7 . 2346 | .18I3 | . 2 | . 2167 | -. 027 I |
| . 8 | 8 . 2154 | . 2014 | $\cdot 3$ | . 2183 | -.0052 |
| -9 | 9 . 1944 | . 2192 | . 4 | . 2177 | +.0166 |
| 8.0 | - 1717 | . 2346 | 13.5 | . 2150 | . 0380 |
| . 1 | 1.1475 | . 2476 | . 6 | . 2101 | . 0590 |
| . 2 | . 1222 | . 2580 | - 7 | . 2032 | . 0791 |
| - 3 | 3 .0960 | . 2657 | . 8 | . 1943 | . 0984 |
| . 4 | 4.0692 | . 2708 | . 9 | . 1836 | . 1165 |
| 8.5 | 5 .0419 | . 2731 | 14.0 | . 1711 | . 1334 |
| . 6 | $6 . .0146$ | . 2728 | . 1 | . 1570 | . 1488 |
|  | $7-.0125$ | . 2697 | . 2 | . 1414 | . 1626 |
|  | 8-.0392 | . 2641 | . 3 | . 1245 | . 1747 |
|  | 9-.0653 | . 2559 | . 4 | . 1065 | . 1850 |
|  | -0-.0903 | . 2453 | 14.5 | . 0875 | . 1934 |
|  | $1-.1142$ | . 2324 | . 6 | . 0679 | . 1999 |
|  | $2-.1367$ | . 2174 | . 7 | . 0476 | . 2043 |
|  | $3-.1577$ | . 2004 | . 8 | . 0271 | . 2066 |
|  | $4-.1768$ | . 1816 | . 9 | . 0064 | . 2069 |
| $9 \cdot 5$ | $5-.1939$ | . 1613 | I5.0 | -. 0142 | . 2051 |

TABLE 36. - Roots.
(a) ist Io roots of $J_{0}(x)=0$

Higher roots may be calculated to better than I part in 10,000 by the approximate formula
$R_{m}=R_{m-1}+\pi$
$R_{1}=2.404826$
$R_{2}=5.520078$
$R_{3}=8.653728$
$R_{4}=$ II. 791534
$R_{5}=14.930918$
$R_{6}=18.071064$
$R_{7}=21.211637$
$R_{8}=24.352472$
$R_{9}=27.493479$
$R_{10}=30.634606$
(b) Ist $I_{5}$ roots of $J_{1}(x)=\frac{d J_{0}(x)}{d x}=0$ with corresponding values of maximum or or minimum values of $J_{6}(x)$.

| No. of root ( $n$ ) | Root $=x_{n}$. | $J_{0}\left(x_{n}\right)$. |
| :---: | :---: | :---: |
| I | 3.831706 | -. 402759 |
| 2 | 7.015587 | $+.300116$ |
| 3 | 10.173468 | -. 249705 |
| 4 | 13.323692 | +.218359 |
| 5 | 16.470630 | -. 196465 |
| 6 | 19.615859 | +. 180063 |
| 7 | 22.760084 | -. 167185 |
| 8 | 25.903672 | +.156725 |
| 9 | 29.046829 | -. 148011 |
| 10 | 32.189680 | +. 140606 |
| II | 35.332308 | -. I342II |
| 12 | 38.474766 | +.128617 |
| 13 | 41.617094 | -. 123668 |
| 14 | 44.759319 | +.119250 |
| 15 | 47.901461 | -. II5274 |

Higher roots may be obtained as under (a).
Notes. $y=J_{n}(x)$ is a particular solution of Bessel's equation,

$$
x^{2} \frac{d^{2} y}{d x^{2}}+x \frac{d y}{d x}+\left(x^{2}-n^{2}\right) y=0
$$

The general formula for $J_{n}(x)$ is
or

$$
\begin{aligned}
J_{n}(x) & =\sum_{0}^{\infty} \frac{(-1)^{s} x^{n+2 s}}{2^{n+2 s} \pi s} \pi(n+s) \\
& =\sum_{0}^{\infty} \frac{(-1)^{8} x^{n+2 s}}{2^{n+2 s} s!(n+s)!}
\end{aligned}
$$

when $n$ is an integer and
and

$$
J_{n+1}(x)=\frac{2 n}{x} J_{n}(x)-J_{n-1}(x),
$$

$$
J_{1}(x)=\frac{d J_{0}(x)}{d x}
$$

$$
J_{-n}(x)=(-\mathrm{I})^{n} J_{n}(x)
$$

Tables 35 to 36 are based upon Gray and Matthews' reprints from Dr. Meissel's tables. See also Reports of British Association, 1907-1916.

## ELLIPTIC INTEGRALS.

Values of $\int_{0}^{\frac{\pi}{2}}\left(1-s \sin ^{2} \theta \sin ^{2} \phi\right)^{ \pm \frac{1}{2}} d \phi$.
This table gives the values of the integrals between o and $\pi / 2$ of the function $\left(1-\sin ^{2} \theta \sin ^{2} \phi\right)^{ \pm \frac{1}{2}} d \phi$ for different val.
ues of the modulus corresponding to each degree of $\theta$ between o and 90 .

| $\theta$ | $\int_{0}^{\frac{\pi}{2}} \frac{d \phi}{\left(1-\sin ^{2} \theta \sin ^{2} \phi^{\frac{1}{2}}\right.}$ |  | $\int_{0}^{\bullet \frac{\pi}{2}}\left(\mathrm{I}-\sin ^{2} \theta \sin ^{2} \phi\right)^{\frac{1}{2}} d \phi$ |  | $\theta$ | $\int_{0}^{\frac{\pi}{2}} \frac{d \phi}{\left(1-\sin ^{2} \theta \sin ^{2} \phi\right)^{\frac{2}{2}}}$ |  | $\int_{0}^{\frac{\pi}{2}}\left(1-\sin ^{2} \theta \sin ^{2} \phi\right)^{\frac{1}{3}} d \phi$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Number. | Log. | Number. | Log. |  | Number. | Log. | Number. | Log. |
| $0^{\circ}$ | 1.5708 | 0.196120 | I. 5708 | 0.196120 | $45^{\circ}$ | I. 854 I | 0.268127 | I. 3506 | 0.130541 |
| 1 | 5709 | 196153 | 5707 | 196087 | 6 | 8691 | 271644 | 3418 | 127690 |
| 2 | 5713 | 196252 | 5703 | 195988 | 7 | 8848 | 275267 | 3329 | 124788 |
| 3 | 5719 | 196418 | 5697 | 195822 | 8 | 9011 | 279001 | 3238 | 121836 |
| 4 | 5727 | 196649 | 5689 | 195591 | 9 | 9180 | 282848 | 3147 | I 18836 |
| $5^{\circ}$ | 1. 5738 | 0.196947 | I. 5678 | 0.195993 | $50^{\circ}$ | I. 9356 | 0.28681 I | I. 3055 | 0.115790 |
| 6 | 5751 | 197312 | 5665 | 194930 | 1 | 9539 | 290895 | 2963 | I 12698 |
| 7 | 5767 | 197743 | 5649 | 194500 | 2 | 9729 | 295101 | 2870 | 109563 |
| 8 | 5785 | 198241 | 5632 | 194004 | 3 | 9927 | $299+35$ | 2776 | 106386 |
| 9 | 5805 | 198806 | 5611 | 193442 | 4 | 2.0133 | 303901 | 2681 | 103169 |
| $10^{\circ}$ | 1.5828 | 0.199438 | 1. 5589 | 0.192815 | $55^{\circ}$ | 2.0347 | 0.308504 | 1. 2587 | 0.099915 |
| 1 | 5854 | 200137 | 5564 | 192121 | 6 | 0571 | 313247 | 2492 | 096626 |
| 2 | 5882 | 200904 | 5537 | 191362 | 7 | 0804 | 318138 | 2397 | 093303 |
| 3 | 5913 | 201740 | 5507 | 190537 | 8 | 1047 | 323182 | 2301 | 089950 |
| 4 | 5946 | 202643 | 5476 | 189646 | 9 | 1300 | 328384 | 2206 | 086569 |
| $15^{\circ}$ | 1.598I | 0.203615 | 1. 5442 | 0.188690 | $60^{\circ}$ | 2.1565 | 0.333753 | 1.2111 | 0.083164 |
| 6 | 6020 | 204657 | 5405 | 187668 | I | 1842 | 339295 | 2015 | 079738 |
| 7 | 6061 | 205768 | 5367 | 18658 I | 2 | 2132 | 345020 | 1920 | 076293 |
| 8 | 6105 | 206948 | 5326 | 185428 | 3 | 2435 | 350936 | 1826 | 072834 |
| 9 | 6151 | 208200 | 5283 | 184210 | 4 | 2754 | 357053 | 1732 | 069364 |
| $20^{\circ}$ | 1.6200 | 0.209522 | I. 5238 | 0.182928 | $65^{\circ}$ | 2.3088 | 0.363384 | 1.1638 | 0.065889 |
| I | 6252 | 210916 | 5191 | 181580 | 6 | 3439 | 369940 | 1545 | 062412 |
| 2 | 6307 | 212382 | 5141 | 180163 | 7 | 3809 | 376736 | 1453 | 058937 |
| 3 | 6365 | 213921 | 5090 | 178691 | 8 | 4198 | 383787 | 1362 | 055472 |
| 4 | 6426 | 215533 | 5037 | 177150 | 9 | 4610 | 391112 | 1272 | -52020 |
| $25^{\circ}$ | 1. 6490 | 0.217219 | I.498I | 0.175545 | $70^{\circ}$ | 2.5046 | 0.398730 | I. 1184 | 0.048589 |
| 6 | 6557 | 218981 | 4924 | 173876 | I | 5507 | 406665 | 1096 | $045{ }^{183}$ |
| 7 | 6627 | 220818 | 4864 | 172144 | 2 | 5998 | $4149+3$ | 1011 | 041812 |
| 8 | 6701 | 222732 | 4803 | 170348 | 3 | 652 I | 423596 | 0927 | 038481 |
| 9 | 6777 | 224723 | 4740 | 168489 | 4 | 7081 | 432660 | 0844 | 035200 |
| $30^{\circ}$ | 1. 6858 | 0.226793 | 1. 4675 | 0.166567 | $75^{\circ}$ | 2.7681 | 0.442176 | 1.0764 | 0.031976 |
| 1 | 6941 | 228943 | 4608 | 164583 | 6 | 8327 | 452196 | 0686 | 028819 |
| 2 | 7028 | 231173 | 4539 | 162537 | 7 | 9026 | 462782 | 0611 | 025740 |
| 3 | 7119 | 233485 | 4469 | 160429 | 8 | 9786 | 474008 | 0538 | 022749 |
| 4 | 7214 | 235880 | 4397 | 158261 | 9 | 3.0617 | 485967 | 0468 | 019858 |
| $35^{\circ}$ | 1.7312 | 0.238359 | I. 4323 | 0.156031 | $80^{\circ}$ | 3.1534 | 0.498777 | I. 0401 | 0.017081 |
| 6 | 7415 | 240923 | 4248 | I 53742 | 1 | 2553 | 512591 | 0338 | OI 4432 |
| 7 | 7522 | 243575 | 4171 | 151393 | 2 | 3699 | 527613 | 0278 | OII927 |
| 8 | 7633 | 246315 | 4092 | 148985 | 3 | 5004 | 544120 | 0223 | 009584 |
| 9 | 7748 | 249146 | 4013 | 146519 | 4 | 6519 | 562514 | 0172 | 007422 |
| $40^{\circ}$ | I. 7868 | 0.252068 | I. 393 I | 0. 143995 | 85 ${ }^{\circ}$ | 3.8317 | 0.583396 | 1. 0127 | 0.005465 |
| 1 | 7992 | 255085 | 3849 | 141414 | 6 | 4.0528 | 607751 | 0086 | 003740 |
| 2 | 8122 | 258197 | 3765 | 138778 | 7 | 3387 | 637355 | 0053 | 002278 |
| 3 | 8256 | 261406 | 3680 | 136086 | 8 | 7427 | 676027 | 0026 | 001121 |
| 4 | 8396 | 264716 | 3594 | 133340 | 9 | 5.4349 | 735192 | 0008 | 000326 |
| $45^{\circ}$ | I. 8541 | 0.268127 | I. 3506 | 0.130541 | $90^{\circ}$ | $\infty$ | $\infty$ | 1.0000 |  |

## MOMENTS OF INERTIA, RADII OF GYRATION, AND WEIGHTS.

In each case the axis is supposed to traverse the centre of gravity of the body. The axis is one of symmetry. The mass of a unit of volume is $v$.

| Body. | Axis. | Weight. | Moment of Inertia $\mathrm{I}_{0}$. | Square of Radius of Gyration $\rho_{0}^{2}$. |
| :---: | :---: | :---: | :---: | :---: |
| Sphere of radius $r$ | Diameter | $\frac{4 \pi z u r^{3}}{3}$ | $\frac{8 \pi z u r^{5}}{15}$ | $\frac{2 r^{2}}{5}$ |
| Spheroid of revolution, polar axis $2 a$, equatorial diameter $2 r$ | Polar axis | $\frac{4 \pi w a r^{2}}{3}$ | $\frac{8 \pi w a r^{4}}{\text { I5 }}$ | $\frac{2 r^{2}}{5}$ |
| Ellipsoid, axes $2 a, 2 b, 2 c$ | Axis 2a | $\frac{4 \pi w a b c}{3}$ | $\frac{4 \pi z v a b c\left(b^{2}+c^{2}\right)}{15}$ | $\frac{b^{2}+c^{2}}{5}$ |
| Spherical shell, external radius $r$, internal $r^{\prime}$ | Diameter | $\frac{\begin{array}{c} 3 \\ 4 \pi \pi\left(r^{3}-r^{\prime 3}\right) \end{array}}{3}$ | $\frac{\begin{array}{c} I 5 \\ \\ 8 \pi w\left(r^{5}-r^{\prime 5}\right) \end{array}}{I 5}$ | $\frac{2\left(r^{5}-r^{\prime 5}\right)}{5\left(r^{3}-r^{\prime 3}\right)}$ |
| Ditto, insensibly thin, radius $r$, thickness $d r$ | Diameter | $4 \pi z u r^{2} d r$ | $\frac{8 \pi w r^{4} d r}{3}$ | $\frac{2 r^{2}}{3}$ |
| Circular cylinder, length $2 a$, radius $r$ | Longitudinal axis $2 a$ | $2 \pi w a r^{2}$ | $\pi w a r^{4}$ | $\frac{r^{2}}{2}$ |
| Elliptic cylinder, length $2 a$, transverse axes $2 b, 2 c$ | Longitudinal axis $2 a$ | $2 \pi z w a b c$ | $\frac{\pi w a b c\left(b^{2}+c^{2}\right)}{2}$ | $\frac{b^{2}+c^{2}}{4}$ |
| Hollow circular cylinder, length $2 a$, external radius $r$, internal $r^{\prime}$ | Longitudinal axis $2 a$ | $2 \pi w a\left(r^{2}-r^{\prime 2}\right)$ | $\pi w a\left(r^{4}-r^{4}\right)$ | $\frac{r^{2}+r^{\prime 2}}{2}$ |
| Ditto, insensibly thin, thickness $d r$ | Longitudinal axis $2 a$ | $4 \pi$ ruardr | $4 \pi w a r^{3} d r$ | $r^{2}$ |
| Circular cylinder, length $2 a$, radius $r$ | Transverse diameter | $2 \pi w a r^{2}$ | $\frac{\pi z a r^{2}\left(3 r^{2}+4 a^{2}\right)}{6}$ | $\frac{r^{2}}{4}+\frac{a^{2}}{3}$ |
| Elliptic cylinder, length $2 a$, transverse axes $2 a, 2 b$ | Transverse axis $2 b$ | $2 \pi w a b c$ | $\frac{\pi w a b c\left(3 c^{2}+4 a^{2}\right)}{6}$ | $\frac{c^{2}}{4}+\frac{a^{2}}{3}$ |
| Hollow circular cylinder, length $2 a$, external radius $r$, internal $r^{\prime}$ | Transverse diameter | $2 \pi \tau v a\left(r^{2}-r^{\prime 2}\right)$ | $\frac{\pi z a}{6}\left\{\begin{array}{c} 3\left(r^{4}-r^{\prime 4}\right) \\ +4 a^{2}\left(r^{2}-r^{\prime 2}\right) \end{array}\right\}$ | $\frac{r^{2}+r^{\prime 2}}{4}+\frac{a^{2}}{3}$ |
| Ditto, insensibly thin, thickness $d r$ | Transverse diameter | $4 \pi$ wardr | $\pi w a\left(2 r^{3}+\frac{4}{3} a^{2} r\right) d r$ | $\frac{r^{2}}{2}+\frac{a^{2}}{3}$ |
| Rectangular prism, dimensions $2 a, 2 b, 2 c$ | Axis $2 a$ | Swabc | $\frac{8 w a b c\left(b^{2}+c^{2}\right)}{3}$ | $\frac{b^{2}+c^{2}}{3}$ |
| Rhombic prism, length $2 a$, diagonals $2 b, 2 c$ | Axis $2 a$ | $4 w a b c$ | $2 w a b c\left(b^{2}+c^{2}\right)$ | $\frac{b^{2}+c^{2}}{6}$ |
| Ditto | Diagonal $2 b$ | $4 w a b c$ | $\frac{2 w a b c\left(c^{2}+2 a^{2}\right)}{3}$ | $\frac{c^{2}}{6}+\frac{a^{2}}{3}$ |

(Taken from Rankine.)

For further mathematical data see Smithsonian Mathematical Tables, Becker and Van Orstrand (Hyperbolic, Circular and Exponential Functions); Functionentafeln, Jahnke und Emde (xtgx, $x^{-1} \operatorname{tgx}$, Roots of Transcendental Equations, $a+b i$ and $r^{\vartheta i}$, Exponentials, Hyperbolic Functions, $\int_{0}^{x} \frac{\sin u}{u} d u, \int_{x}^{+\infty} \frac{\cos u}{u} d u, \int_{\infty}^{-x} \frac{e^{-u}}{u} d u$, Fresnel Integral, Gamma Function, Gauss Integral $\frac{2}{\sqrt{\pi}} \int_{0}^{x} e^{-x^{2}} d x$, Pearson Function $e^{-\frac{1}{2} \pi \nu} \int_{0}^{\pi} \sin r \mathrm{e}^{\nu x} d x$, Elliptic Integrals and Functions, Spherical and Cylindrical Functions, etc.). For further references see under Tables, Mathematical, in the IIthed. Encyclopædia Britannica. See also Carr's Synopsis of Pure Mathematics and Mellor's Higher Mathematics for Students of Chemistry and Physics.
Smithsonian tables.

Table 39.
INTERNATIONAL ATOMIC WEIGHTS. VALENCIES.
The International Atomic Weights are quoted from the report of the International Committee on Atomic Weights (Journal American Chemical Society, 39, 42, p. 9, 1920).

| Substance. | Symbol. | Relative atomic wt. Oxygen $=16$. | Valency. | Substance. | Symbol. | Relative atomic wt. Oxygen $=16$. | Valency. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum | Al | 27.1 | 3. | Mercury | Hg | 200.6 | I, 2. |
| Antimony | Sb | 120.2 | 3, 5. | Molybdenum | Mo | 96.0 | 4,6. |
| Argon. | A | 39.9 | 0. | Neodymium | Nd | 144.3 | 3. |
| Arsenic | As | 74.96 | 3, 5. | Neon | Ne | 20.2 | 0. |
| Barium | Ba | 1 37.37 | 2. | Nickel | Ni | 58.68 | 2,3 . |
| Bismuth | Bi | 208.0 | 3, 5. | Niton(Raeman- | Nt . | 222.4 | - |
| Boron | B | 10.9 | 3. | Nitrogen | N | 14.008 | 3, 5. |
| Bromine | Br | 79.92 | 1. | Osmium | Os | 190.9 | 6,8. |
| Cadmium | Cd | 112.40 | 2. | Oxygen | O | 16.00 | 2. |
| Cæsium | Cs | 132.81 | I. | Palladium | Pd | 106.7 | 2, 4 . |
| Calcium | Ca | 40.07 | 2. | Phosphorus | P | 31.04 | 3, 5 . |
| Carbon | C | 12.005 | 4. | Platinum | Pt | 195.2 | 2, 4. |
| Cerium | Ce | 140.25 | 3, 4. | Potassium | K | 39.10 | 1. |
| Chlorine | ${ }^{\mathrm{Cl}}$ | 35.46 | I. | Praseodymium | Pr | 140.9 | 3. |
| Chromium | Cr | 52.0 | 2, 3, 6. | Radium | Ra | 226.0 | 2. |
| Cobalt | Co | 58.97 | 2, 3 . | Rhodium | Rh | 102.9 | 3. |
| Columbium | Cb | 93.1 | 5. | Rubidium | Rb | 85.45 | 1. |
| Copper | Cu | 63.57 | I, 2. | Ruthenium | Ru | 101.7 | 6, 8. |
| Dysprosium | Dy | 162.5 | 3. | Samarium | Sa | 150.4 | 3. |
| Erbium | Er | 167.7 | 3. | Scandium | Sc | 45.1 | 3. |
| Europium | Eu | 152.0 | 3. | Selenium | Se | 79.2 | 2, 4, 6. |
| Fluorine | F | 19.0 | 1. | Silicon | Si | 28.3 |  |
| Gadolinium | Gd | 157.3 | 3. | Silver | Ag | 107.88 | 1. |
| Galliumı | Ga | 70.1 | 3. | Sodium | Na | 23.00 | 1. |
| Germanium | Ge | 72.5 | 4. | Strontium | Sr | 87.63 | 2. |
| Glucinum | Gl | 9.1 | 2. | Sulphur | S | 32.06 | 2, 4, 6 . |
| Gold | Au | 197.2 | I, 3 . | Tantalum | Ta | 181.5 |  |
| Helium | He | 4.00 | o. | Tellurium | Te | 127.5 | 2, 4, 6. |
| Holmium | Ho | 163.5 | 3. | Terbium | Tb | 159.2 |  |
| Hydrogen | H | 1.008 | 1. | Thallium | Tl | 204.0 | 1,3. |
| Indium | In | 114.8 |  | Thorium | Th | 232.15 | 4. |
| Iodine | I | 126.92 | I. | Thulium | Tm | 168.5 | 3. |
| Iridium | Ir | 193.1 | 4. | Tin | Sn | 118.7 | 2, 4 . |
| Iron | Fe | 55.84 | 2, 3 . | Titanium | 'Ti | 48.I | 4. |
| Krypton | Kr | 82.92 | o. | Tungsten Uranium | W | 184.0 | 6. $4,6$. |
| Lanthanum | La | 139.0 | 3. |  |  |  |  |
| Lead | Pb | 207.20 | 2, 4 . | Vanadium | V | 51.0 | 3, 5 . |
| Lithium | Li | 6.94 | I. | Xenon | Xe | 130.2 | 0. |
| Lutecium |  | 175.0 | 3. | Ytterbium: | Yb | 173.5 | 3. |
| Magnesium | $\mathrm{Mg}^{\mathrm{Mg}}$ | 24.32 | 2. | Yttrium | Yt | 89.33 | 3. |
| Manganese | Mn | 54.93 | 2, 3, 7 . | Zinc Zirconium | Zn Zr | $\begin{aligned} & 65 \cdot 37 \\ & 90.6 \end{aligned}$ | 2. |

Smithsonian Tables.

## VOLUME OF A GLASS VESSEL FROM THE WEIGHT OF ITS EQUIVALENT VOLUME OF MERCURY OR WATER.

If a glass vessel contains at $t^{\circ} \mathrm{C}, P$ grammes of mercury, weighed with brass weights in air at 760 mm . pressure, then its volume in c. cm .
at the same temperature, $t,: V=P R=P \frac{p}{d}$,
at another temperature, $t_{1},: V=P R_{1}=P p / d\left\{\mathrm{I}+\gamma\left(t_{1}-t\right)\right\}$
$p=$ the weight, reduced to vacuum, of the mass of mercury or water which, weighed with brass weights, equals 1 gram ;
$d=$ the density of mercury or water at $t^{\circ} \mathrm{C}$,
and $\gamma=0.000025$, is the cubical expansion coefficient of glass.

| $\begin{aligned} & \text { Temper- } \\ & \text { ature } \end{aligned}$ | WATER. |  |  | MERCURY. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | ${ }^{*}$. | $R_{1}, t_{1}=10^{\circ}$. | $R_{1}, t_{1}=20^{\circ}$. | $R$. | $R_{1}, t_{1}=10^{\circ}$. | $R_{1}, t_{1}=20^{\circ}$. |
| $0^{\circ}$ | 1.001192 | 1.001443 | 1.001693 | 0.0735499 | 0.0735683 | 0.0735867 |
| 1 | 1133 | 1358 | 1609 | 5633 | 5798 | 5982 |
| 2 | 1092 | 1292 | I 542 | 5766 | 5914 | 6098 |
| 3 | 1068 | 1243 | 1493 | 5900 | 6029 | 6213 |
| 4 | 1060 | 1210 | 1460 | 6033 | 6144 | 6328 |
| 5 | 1068 | 1193 | 1443 | 6167 | 6259 | 6443 |
| 6 | 1.001092 | 1.001192 | 1.001442 | 0.0736301 | 0.0736374 | 0.0736558 |
|  | 1131 | 1206 | 1456 | 6434 | 6490 | 6674 |
| 8 | 1184 | 1234 | 1485 | 6568 | 6605 | 6789 |
| 9 | 1253 | 1277 | 1527 | 6702 | 6720 | 6904 |
| 10 | ${ }^{1} 333$ | 1333 | 1584 | 6835 | 6835 | 7020 |
| 11 | 1.001428 | 1.001 403 | 1.001 653 | 0.0736969 | 0.0736951 | 0.0737135 |
| 12 | 1536 | 1486 | 1736 | 7103 | 7066 | 7250 |
| 13 | 1657 | 1582 | 1832 | 7236 | 7181 | 7365 |
| 14 | 1790 | 1690 | 1940 | 7370 | 7297 | 7481 |
| 15 | 1935 | ISIO | 2060 | 7504 | 7412 | 7596 |
| 16 | 1.002092 | 1.001942 | 1.002193 | 0.0737637 | 0.0737527 | 0.0737711 |
| 17 | 2261 | 2086 | 2337 | - 7771 | 7642 | 7826 |
| 18 | 2441 | 22.15 | 2491 | 7905 | 7757 | 7941 |
| 19 | 2633 | 2407 | 2658 | So39 | 7872 | 8057 |
| 20 | 2835 | 2584 | 2835 | 8172 | 7988 | 8172 |
| 21 | 1.003048 | 1.002772 | 1.003023 | 0.0738306 | 0.0738103 | 0.0738288 |
| 22 | 3271 | 2970 | 3220 | 8440 | 8218 | 8403 |
| 23 | 3504 | 3178 | 3429 | 8573 | 8333 | 8518 |
| 24 | 3748 | 3396 | 3647 | 8707 | 8449 | 8633 |
| 25 | 4001 | 3624 | 3875 | 8841 | 8564 | 8748 |
| 26 | 1.004264 | 1.003862 | I.004113 | 0.0738974 | 0.0738679 | 0.0738864 |
| 27 | 4537 | 4110 | 4361 | 9108 | 8794 | 8979 |
| 28 | 4818 | 4366 | 4616 | 9242 | 8910 | 9094 |
| 29 | 5110 | 4632 | 4884 | 9376 | 9025 | 9210 |
| 30 | 5410 | 4908 | 5159 | 9510 | 9140 | 9325 |

Taken from Landolt, Börnstein, and Meyerhoffer's Physikalisch-Chemische Tabellen.

## Smithsonian Tables.

REDUCTIONS OF WEIGHINGS IN AIR TO VACUO.
table 41.
When the weight M in grams of a body is determined in air, a correction is necessary for the buoyancy of the air equal to $M \delta\left(\mathrm{I} / \mathrm{d}-\mathrm{I} / \mathrm{d}_{1}\right)$ where $\delta=$ the density ( wt . of Icm in grams $=0.0012$ ) of the air during the weighing, $d$ the density of the body, $\mathrm{d}_{1}$ that of the weights. $\delta$ for various barometric values and humidities may be determined from Tables 153 to 155. The following table is computed for $\delta=0.0012$. The corrected weight $=\mathrm{M}+\mathrm{kM} / \mathrm{r} 000$.

| Density of body weighed d. | Correction factor, k . |  |  | Density of body weighed d. | Correction factor, k . |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Pt. Ir. weights $\mathrm{d}_{1}=2 \mathrm{t} .5$. | Brass weights 8.4 . | Quartz or A. weights 2.65. |  | $\begin{gathered} \text { Pt. Ir. } \\ \text { weights } \\ \mathrm{d}_{1}=2 \mathrm{I} .5 . \end{gathered}$ | Brass weights 8.4 . | $\begin{aligned} & \text { Quartz or } \\ & \text { Al. weights } \\ & 2.65 \text {. } \end{aligned}$ |
| . 5 | +2.34 | + 2.26 | +1.95 | 1.6 | $+0.69$ | +0.6r | $+0.30$ |
| . 6 | +1.91 | + 1.86 | +1.55 | 1.7 | $+.65$ | + 56 | +.25 |
| $\cdot 7$ | +1.66 | $+1.57$ | +1.26 | 1.8 | + . 62 | $+.52$ | $+.2 \mathrm{I}$ |
| .75 | +1.55 | +1.46 | +1.15 | 1.9 | $+.58$ | $+.49$ | + .18 |
| . 80 | +1.44 | +1.36 | +1.05 | 2.0 | + . 54 | $+.46$ | +.15 |
| . 85 | $+1.36$ | +1.37 | + 0.96 | 2.5 | + +.43 | + 34 | $+.03$ |
| . 90 | +1.28 | +1.19 | + . 88 | 3.0 | + . 34 | +. 26 | -. 05 |
| . 95 | +1.21 | +1.12 | $+.88$ | 4.0 | + .24 | $+.16$ | -. 15 |
| 1.00 | +1.14 | +1.06 | -. 75 | 6.0 | +.14 | +..06 | -. 25 |
| I.I | +1.04 | + 0.95 | -. 64 | 8.0 | $+. .09$ | + . O | -. 30 |
| 1.2 | +0.94 | + . 86 | . 55 | 10.0 | $+.06$ | -. .02 | -. 33 |
| 1.3 | $+.87$ | $+.78$ | - . 47 | 15.0 | $+. .03$ | - . 06 | -. 37 |
| 1.4 | -. .8o | + .71 | -. 40 | 20.0 | $+.004$ | -.08 | -. 39 |
| 1.5 | +.75 | $+.66$ | -. 35 | 22.0 | -.001 | - . 09 | -. 40 |

## TABLE 42.-Reductions of Densities in Air to Vacuo.

(This correction may be accomplished through the use of the above table for each separate weighing.)

If $s$ is the density of the substance as calculated from the uncorrected weights, $S$ its true density, and $L$ the true density of the liquid used, then the vacuum correction to be applied to the uncorrected density, s, is 0.0012 ( $\mathrm{I}-\mathrm{s} / \mathrm{L}$ ).

Let $\mathrm{W}_{\mathrm{s}}=$ uncorrected weight of substance, $\mathrm{W}_{l}=$ uncorrected weight of the liquid displaced by the substance, then by definition, $\mathrm{s}=\mathrm{LW}_{\mathrm{s}} / \mathrm{W}_{1}$. Assuming D to be the density of the balance of weights, $\mathrm{V}_{\mathrm{s}}\{\mathrm{I}+0.0012(\mathrm{I} / \mathrm{S}-\mathrm{I} / \mathrm{D})\}$ and $\mathrm{W}_{1}\{1+0.0012(1 / \mathrm{L}-\mathrm{I} / \mathrm{D})\}$ are the true weights of the substance and liquid respectively (assuming that the weighings are made under normal atmospheric corrections, so that the weight of I cc. of air is 0.0012 gram).
Then the true density $\mathrm{S}=\frac{\mathrm{W}_{\mathrm{s}}\{\mathrm{I}+0.0012(\mathrm{I} / \mathrm{S}-\mathrm{I} / \mathrm{D})\}}{\mathrm{W}_{1}\{\mathrm{I}+0.0012(\mathrm{I} / \mathrm{L}-\mathrm{I} / \mathrm{D})\}} \mathrm{L}$.
But from above $\mathrm{W}_{\mathrm{s}} / \mathrm{W}_{1}=\mathrm{s} / \mathrm{L}$, and since L is always large compared with 0.0012 ,

$$
\mathrm{S}-\mathrm{s}=0.0012(\mathrm{r}-\mathrm{s} / \mathrm{L}) .
$$

The values of $0.0012(1-s / L)$ for densities up to 20 and for liquids of density 1 (water), 0.852 (xylene) and 13.55 (mercury) follow:
(See reference below for discussion of density determinations).

| Density of substance s. | Corrections. |  |  | Density of substance s | Corrections. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{L}=\mathrm{I}$ <br> Water. | $\begin{aligned} & \mathrm{L}=0.852 \\ & \text { Xylene. } \end{aligned}$ | $\begin{aligned} & \mathrm{L}=13.55 \\ & \text { Mercury. } \end{aligned}$ |  | $\mathrm{L}=\mathrm{I}$ <br> Water. | $\begin{aligned} & L=13.55 \\ & \text { Mercury. } \end{aligned}$ |
| 0.8 | $+0.00024$ | - | - | II. | -0.0120 | $+0.0002$ |
| 0.9 | $+.00012$ | - | - | 12. | -.0132 | + .0001 |
| 1. | 0.0000 | -0.0002 | +0.0011 | 13. | -. .0144 | 0.0000 |
| 2. | -.OOI 2 | -.0016 | $+.0010$ | 14. | -. .OI 56 | 0.0000 |
| 3. | -. .0024 | -. .0030 | $+.0009$ | 15. | -. .0168 | -. .0001 |
| 4. | - . 0036 | -. .0044 | + .0008 | 16. | -. .0180 | -. 0002 |
| 5. | -. .0048 | -. .0058 | + .0008 | 17. | -. .OI92 | -. .0003 |
| 6. | -. .0060 | -. 0073 | +.0007 | 18. | -. .0204 | -. .0004 |
| 7. | -. 0072 | -. 0087 | $+.0006$ | 19. | -. .0216 | -. .0005 |
| 8. | -..0084 | -.oror | $+.0005$ | 20. | -. 0228 | -. .0006 |
| 9. | -. .0096 | -.OII5 | $+.0004$ |  |  |  |
| 10. | -..0108 | -.0129 | +..0003 |  |  |  |

* Compiled from various sources by Harvey A. Anderson, C.E., Assistant Engineer Physicist, U. S. Bureau of Standards.

The mechanical properties of most materials vary between wide limits; the following figures are given as being representative rather than what may be expected from an individual sample. Figures denoting such properties are commonly given either as specification or experimental values. Unless otherwise shown, the values below are experimental. Credit for information included is due the U. S. Bureau of Standards; the Am. Soc. for Testing Materials; the Soc. of Automotive Eng.; the Motor Transport Corps, U.S. War Dept.; the Inst. of Mech. Eng.; the Inst. of Metals; Forest Products Lab.; Dept. of Agriculture (Bull. 556); Moore's Materials of Engineering; Hatfield's Cast Iron; and various other American, English and French authorities.

The specified properties shown are indicated minimums as prescribed by the Am. Soc. for Testing Materials, U. S. Navy Dept., Panama Canal, Soc. of Automotive Eng., or Intern. Aircraft Standards Board. In the majority of cases, specifications show a range for chemical constituents and the average value only of this range is quoted. Corresponding average values are in general given for mechanical properties. In general, tensile test specimens were 12.8 mm ( 0.505 in .) diameter and 50.8 mm ( 2 in .) gage length. Sizes of compressive and transverse specimens are generally shown accompanying the data.

All data shown in these tables are as determined at ordinary room temperature, averaging $20^{\circ} \mathrm{C}$ ( $68^{\circ} \mathrm{F}$.). The properties of most metals and alloys vary considerably from the values shown when the tests are conducted at higher or lower temperatures.

The following definitions govern the more commonly confused terms shown in the tables. In all cases the stress referred to in the definitions is equal to the total load at that stage of the test divided by the original cross-sectional area of the specimen (or the corresponding stress in the extreme fiber as computed from the flexure formula for transverse tests).

Proportional Limit (abbreviated P-limit). - Stress at which the deformation (or deflection) ceases to be proportional to the load (determined with extensometer for tension, compressometer for compression and deflectometer for transverse tests).

Elastic Limit. - Stress which produces a permanent elongation (or shortening) of o.oor per cent of the gage length, as shown by an instrument capable of this degree of precision (determined from set readings with extensometer or compressometer). In transverse tests the extreme fiber stress at an appreciable permanent deflection.

Yield Point. - Stress at which marked increase in deformation (or deflection) of specimen occurs without increase in load (determined usually by drop of beam or with dividers for tension, compression or transverse tests).

Ultimate Strength in Tension or Compression. - Maximum stress developed in the material during test.
Modulus of Rupture. - Maximum stress in the extreme fiber of a beam tested to rupture, as computed by the empirical application of the flexure formula to stresses above the transverse proportional limit.

Modulus of Elasticity (Young's Modulus). - Ratio of stress within the proportional limit to the corresponding strain, - as determined with an extensometer. Note: All moduli shown are obtained from tensile tests of materials, unless otherwise stated.

Brinell Hardness Numeral (abbreviated B. h. n.). - Ratio of pressure on a sphere used to indent the material to be tested to the area of the spherical indentation produced. The standard sphere used is a romm diameter hardened steel ball. The pressures used are 3000 kg for steel and 500 kg for softer metals, and the time of application of pressure is 30 seconds. Values shown in the tables are based on spherical areas computed in the main from measurements of the diameters of the spherical indentations, by the following formula:

$$
\text { B. h. n. }=P \div \pi t D=P \div \pi D\left(D / 2-\sqrt{D^{2} / 4-d^{2} / 4}\right)
$$

$P=$ pressure in $\mathrm{kg}, t=$ depth of indentation, $D=$ diameter of ball, and $d=$ diameter of indentation, - all lengths being expressed in mm . Brinell hardness values have a direct relation to tensile strength, and hardness determinations may be used to define tensile strengths by employing the proper conversion factor for the material under consideration.

Shore Scleroscope Hardness. - Height of rebound of diamond pointed hammer falling by its own weight on the object. The hardness is measured on an empirical scale on which the average hardness of martensitic high carbon steel equals roo. On very soft metals a "magnifier" hammer is used in place of the commonly used "universal" hammer and values may be converted to the corresponding "universal" value by multiplying the reading by ${ }_{7}^{4}$. The scleroscope hardness, when accurately determined, is an index of the tensile elastic limit of the metal tested.

Erichsen Value. - Index of forming quality of sheet metal. The test is conducted by supporting the sheet on a circular ring and deforming it at the center of the ring by a spherical pointed tool. The depth of impression (or cup) in mm required to obtain fracture is the Erichsen value for the metal. Erichsen standard values for trade qualities of soft metal sheets are furnished by the manufacturer of the machine corresponding to various sheet thicknesses. (See Proc. A. S. T. M. 17, part 2, p. 200, 1917.)

Alloy steels are commonly used in the heat treated condition, as strength increases are not commensurate with increases in production costs for annealed alloy steels. Corresponding strength values are accordingly shown for annealed alloy steels and for such steels after having been given certain recommended heat treatments of the Society of Automotive Engineers. The heat treatments followed in obtaining the properties shown are outlined on the pages immediately following the tables on steel. It will be noted that considerable latitude is allowed in the indicated drawing temperatures and corresponding wide variations in physical propertics may be obtained with each heat treatment. The properties vary also with the size of the specimens heat treated. The drawing temperature is shown with the letter denoting the heat treatment, wherever the information is available.

TABLE 44. - Ferrous Metals and Alloys - Iron and Iron Alloys.

| Metal. | 믈. |  | 可: : |  |  |  | Hardness. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  | rine | Sclero- |
|  | Tension. $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension <br> $\mathrm{lb} / \mathrm{in}^{2}$ |  | Per cent. |  | kg | scope. |
| Iron |  |  |  |  |  |  |  |  |
| Electrolytic* (remelt): as forged.... | 34.0 | 38.5 | 48,500 | 55,000 |  | 83.0 | $95{ }^{\dagger}$ | 18 |
|  | 12.5 | 27.0 | 18,000 | 38,000 | 52.0 | 87.0 | $75 \dagger$ |  |
| Gray cast $\ddagger$ (19 mm diam. bars) . . . | ndet. | $\left\{\begin{array}{l}17.5 \\ 26.5\end{array}\right.$ | indet. | $\left\{\begin{array}{l}25,000 \\ 38,000\end{array}\right.$ | negli | gible | $\left\{\begin{array}{l}100 \\ 150\end{array}\right.$ | $\left\{\begin{array}{l}24 \\ 40\end{array}\right.$ |
| Malleable cast, American (after Hatfield) | \{ 14.0 | $\{24.5$ | 20,000 | \{35,000 | $\{15.0$ | $\{15.0$ |  |  |
|  | 31.5 | 40.0 | 45,000 | \{57,000 | $\{4.5$ | 4.5 | - | - |
| European (after Am. Malleable Castings Ass.) <br> (run of 24 successive heats, 1919)§ Commercial wrought. | 19:0 | ( 29.5 | 27,000 | $\{42,000$ | 6.0 | \{ 6.0 | - | - |
|  | \{28.0 | \{45.5 | 40,000 | \{65,000 | $\{2.0$ |  | - |  |
|  | - | 40.8 | - | 58,000 | 21.6 | - | - | - |
|  | $\left\{\begin{array}{l}19.5\end{array}\right.$ | $\{34.0$ | $\{28,000$ | $\{48,000$ | $\{40.0$ | $\{45.0$ |  | $\left\{\begin{array}{l}25 \\ \hline\end{array}\right.$ |
| Silicon alloys\|| Si 0.01 : as forged... | 22.5 | 37.0 | [ 32,000 | [53,000 | 30.0 | 35.0 |  | 30 |
|  | 29.5 | 31.5 | 41,800 | 45,200 | 35.0 | 78.0 | - |  |
| (Melted in vacuo) ann. $970^{\circ} \mathrm{C}$ <br> (Note: C max. o.or per cent) | 11.0 | 24.5 | 16,000 | 34,900 | 53.0 | 81.5 | - | - |
| (Note: C max. o.or per cent) <br> Si 1.71 : as forged... | 48.0 | 53.5 | 68,100 | 76,300 | 37.0 | 82.0 | - | - |
| Si 4.40 annealed $970^{\circ} \mathrm{C}$. . . . . | 25.0 | 38.0 | 35,800 | 54,200 | 50.0 | 90.6 | - | - |
| Si 4.40 : as forged. . annealed $970^{\circ} \mathrm{C}$ | 66.0 | 74.0 | 94,000 | 105,000 | 6.0 | $7 \cdot 5$ | - | - |
|  | 51.0 | 64.5 | 72,900 | 91,600 | 24.0 | 25.1 |  | - |
| Aluminum alloys $\mathbb{T}$ Al 0.00 : as forged | 35.5 | 38.5 | 50,700 | 54,700 | 26.0 | 84.3 | - | - |
| (Melted in vacuo) ann. $1000^{\circ} \mathrm{C}$ <br> (Note: C max. o.or per cent) | 12.5 | 24.5 | 17,600 | 34,900 | 60.0 | 93.5 |  |  |
| Al 3.08: as forged | 48.0 | 54.5 | 68,200 | 77,500 | 21. | 76.4 | - | - |
| A1 6.24 : as forged | 22.5 | 37.5 | 31,800 | 53,400 | 51.0 | 85.3 | - | - |
|  | 54.5 | 60.5 | 77,700 | 86,000 | 28.0 | 74.7 | - | - |
| , | $37 \cdot 5$ | 49.0 | 53,400 | 69,800 | 27.0 | 55.5 |  |  |

Composition, approximate:
Electrolytic, C 0.0125 per cent; other impurities less than 0.05 per cent.
Cast, gray: Graphitic, $\mathrm{C} 3.0, \mathrm{Si} 1.3$ to $2.0, \mathrm{Mn} 0.6$ to 0.9, S max. o.1, P max. I.2.
A. S. T. M. Spec. A48 to 18 allows S max. o.ro, except $S$ max. o.1 2 for heavy castings.

Malleable: American "Black Heart," C 2.8 to 3.5, Si 0.6 to 0.8 , Mn max. $0.4, \mathrm{~S}$ max. 0.07 , P max. 0.2 .
European "Steely Fracture," C 2.8 to 3.5, Si 0.6 to 0.8, Mn 0.15, S max. 0.35, P max. 0.2.
Compressive Strengths [Specimens tested: 25.4 mm ( I in .) diam. cylinders 76.2 mm ( 3 in.) long].
Electrolytic iron $56.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $80,000 \mathrm{ib} / \mathrm{in}^{2}$.
Gray and malleable cast iron 56.5 to $84.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or 80,000 to $120,000 \mathrm{lb} / \mathrm{in}^{2}$.
Wrought iron, approximately equal to tensile yield point (slightly above P-limit).
Density:
Electrolytic iron............. $7.8 \mathrm{~g} / \mathrm{cm}^{3}$ or $487 \mathrm{lb} / \mathrm{ft}^{3}$ Malleable iron............... $7.6 \mathrm{~g} / \mathrm{cm}^{3}$ or $474 \mathrm{lb} / \mathrm{ft}^{3}$
Cast iron..................... $7.2 \mathrm{~g} / \mathrm{cm}^{3}$ or $449 \mathrm{lb} / \mathrm{ft}^{3}$ Wrought iron................. $7.85 \mathrm{~g} / \mathrm{cm}^{3}$ or $490 \mathrm{lb} / \mathrm{ft}^{3}$
Ductility: - Normal Erichsen values for good trade quality sheets, 0.4 mm ( 0.0156 in .)


Modulus of elasticity in tension and compression:
Electrolytic iron.... $17,500 \mathrm{~kg} / \mathrm{mm}^{2}$ or $25,000,000 \mathrm{lb} / \mathrm{in}^{2}$ Malleable iron... $17,500 \mathrm{~kg} / \mathrm{mm}^{2}$ or $25,000,000 \mathrm{lb} / \mathrm{in}^{2}$
Cast iron......... $10,500 \mathrm{~kg} / \mathrm{mm}^{2}$ or $15,000,000 \mathrm{lb} / \mathrm{in}^{2}$ Wrought iron.... $\mathrm{I}_{7}, 500 \mathrm{~kg} / \mathrm{mm}^{2}$ or $25,000,000 \mathrm{lb} / \mathrm{in}^{2}$
Modulus of elasticity in shear:
Electrolytic iron...... $7030 \mathrm{~kg} / \mathrm{mm}^{2}$ or $10,000,000 \mathrm{lb} / \mathrm{in}^{2}$ Cast iron $\ldots . . .8850 . \mathrm{kg} / \mathrm{mm}^{2}$ or $12,000,000 \mathrm{lb} / \mathrm{in}^{2}$ Wrought iron...................... $7030 \mathrm{~kg} / \mathrm{mm}^{2}$ or $10,000,000 \mathrm{lb} / \mathrm{in}^{2}$
Scleroscope hardness values shown are as determined with the Shore Universal hammer.
Strength in Shear:

Electrolytic (remelt)
P-limit............... $\quad 8.4 \mathrm{~kg} / \mathrm{mm}^{2}$ or $12,000 \mathrm{lb} / \mathrm{in}^{2}$
Ultimate strength...... $21.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or $30,000 \mathrm{lb} / \mathrm{in}^{2}$
Transverse strength, from flexure formula:
Gray cast iron
". Modulus of rupture, $33.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $47,000 \mathrm{lb} / \mathrm{in}^{2}$
"Arbitration Bar," 31.8 mm (I $\frac{1}{4} \mathrm{in}$.) diameter, or 304.8 mm ( I 2 in .) span; minimum central load at rupture 1130 to 1500 kg ( 2500 to 3300 lb .); minimum central deflection at rupture 2.5 mm ( 0.1 in ), (A.S. T. M. Spec. A 48-18).

* Properties of Swedish iron (impurities less than r per cent) approximate those of electrolytic iron.
$\dagger$ These two values of B. h. n. only are as determined at 500 kg pressure.
$\ddagger$ U.S. Navy specifies minimum tensile strength of $14.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or $20,000 \mathrm{lb} / \mathrm{in}^{2}$.
§ Averages for a U. S. foundry.
|| From T. D. Yensen, University of Illinois, Engr. Exp. Station, Bulletin No. 83, 1915 (shows Si 4.40 as alloy of maximum strength).

I From T. D. Yensen, University of Illinois, Engr. Exp. Station, Bulletin No. 95, 1917.
Smithsonian Tables.

## MECHANICAL PROPERTIES OF MATERIALS.

## TABLE 45. - Carbon Steels - Commercial Experimental Values.

S. A. E. (Soc. of Automotive Eng., U. S. A.) classification scheme used as basis for steel groupings. First two digits S. A. E. Spec. No. show steel group number, and last two (or three in case of five figures) show carbon content in hundredths of one per cent.

The first lines of properties for each steel show values for the rolled or forged metal in the annealed or normalized condition. Comparative heat-treated values show properties after receiving modified S. A. E. heat treatment as shown below (Table 46). The P-limit and ductility of cast steel average slightly lower and the ultimate strength io to 15 per cent higher than the values shown for the same composition steel in the annealed condition. The properties of rolled steel (raw) are approximately equal to those shown for the annealed condition, which represents the normalized condition of the metal rather than the soft annealed state.

The data for heat-treated strengths are average values for specimens for heat treatment ranging in size from $\frac{1}{2}$ to $I^{\frac{1}{2}}$ in. diameter. The final drawing or quenching temperature for the properties shown is indicated in degreas C with the heat treatment letter, wherever the information is available. In general, specimens were drawn near the lower limit of the indicated temperature range.


Structural Steel: Rolled: S max. 0.05; P-Bess. max. o.10; -O-H. max. 0.06
Tension: Yield Point min. $=0.5$ ultimate; ultimate $=38.7$ to $45.7 \mathrm{~kg} / \mathrm{mm}^{2}$ or 55,000 to $65,000 \mathrm{lb} / \mathrm{in}^{2}$ with $22 \% \mathrm{~min}$. elongation in 50.8 mm (2 in.).

* Average carbon contents: steel castings, C 0.30 to 0.40 ; structural steel, C 0.15 to 0.30 (mild carbon or medium hard steel).


## TABLE 46. - Explanation of Heat Treatment Letters used in Table of Steel Data.

Motor Transport Corps Modified S. A. E. Heat Treatments for Steels. (S. A. E. Handbook, Vol. i, pp. 9 d and 9 e , 1915, q. v. for alternative treatments.)

Heat Treatment A. - After forging or machining (1) carbonize at a tomperature between 870 and $930^{\circ} \mathrm{C}$. ( 1600 and $1700^{\circ} \mathrm{F}$.); (2) cool slowly; (3) reheat to 760 to 820 C . ( 1400 to $1500^{\circ} \mathrm{F}$.) and quench in oil.

Heat Treatment D. - After forging or machining: (1) heat to 820 to $840^{\circ} \mathrm{C}$. ( 1500 to $1550^{\circ} \mathrm{F}$.) ; (2) quench; (3) reheat to 790 to $820^{\circ} \mathrm{C}$. ( 1450 to $1500^{\circ} \mathrm{F}$.); (4) quench; (5) reheat to 320 to $650^{\circ} \mathrm{C}$. ( 600 to $1200^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment F. - After shaping or coiling: (1) heat to 775 to $800^{\circ} \mathrm{C}$. ( 1425 to $1475^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to 200 to $480^{\circ} \mathrm{C}$. ( 400 to $900^{\circ} \mathrm{F}$.) in accordance with degree of temper required and cool slowly.

Heat Treatment H. - After forging or machining: (I) heat to 820 to $840^{\circ} \mathrm{C}$. ( 1500 to $1550^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to 230 to $650^{\circ} \mathrm{C}$. ( 450 to $1200^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment L. - After forging or machining: (1) carbonize at a temperature between 870 and $950^{\circ} \mathrm{C}$. ( 1600 and $1750^{\circ} \mathrm{F}$.), preferably between 900 and $930^{\circ} \mathrm{C}$. ( 1650 and 1700 F .); (2) cool slowly in carbonizing material; (3) reheat to 790 to $820^{\circ} \mathrm{C}$. ( 1450 to $1500^{\circ} \mathrm{F}$.); (4) quench; (5) reheat to 700 to $760^{\circ} \mathrm{C}$. ( 1300 to $1400^{\circ} \mathrm{F}$.); (6) quench; (7) reheat to 120 to $260^{\circ} \mathrm{C}$. ( 250 to 500 F .) and cool slowly.

Heat Treatment M. - After forging or machining: (I) heat to 790 to $820^{\circ} \mathrm{C}$. ( 1450 to $1500^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to between 260 and $680^{\circ} \mathrm{C}$. ( 500 and $1250^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment P. - After forging or machining: (I) heat to 790 to $820^{\circ} \mathrm{C}$. (I 450 to $1500^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to 750 to $770^{\circ} \mathrm{C}$. ( 1375 to $1425^{\circ} \mathrm{F}$.); (4) quench; (5) reheat to 260 to $650^{\circ} \mathrm{C}$. ( 500 to $1200^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment T. - After forging or machining: (1) heat to 900 to $950^{\circ} \mathrm{C}$. ( 1650 to $1750^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to 260 to $700^{\circ} \mathrm{C}$. ( 500 to $1300^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment U. - After forging: (I) heat to 830 to $870^{\circ} \mathrm{C}$. ( 1525 to $1600^{\circ} \mathrm{F}$.), hold half an hour; (2) cool slowly; (3) reheat to 900 to $930^{\circ} \mathrm{C}$. ( 1650 to $1700^{\circ} \mathrm{F}$.); (4) quench; (5) reheat to 180 to $290^{\circ} \mathrm{C}$. ( 350 to $550^{\circ} \mathrm{F}$.) and cool slowly.

Heat Treatment V. - After forging or machining. (1) heat to 900 to $950^{\circ} \mathrm{C}$. ( 1650 to $1750^{\circ} \mathrm{F}$.); (2) quench; (3) reheat to between 200 and $650^{\circ} \mathrm{C}$. ( 400 and $1200^{\circ} \mathrm{F}$.) and cool slowly.

EDITOR's Note: Oil quenching is recommended wherever the instructions specify "quench," inasmuch as the data in the table are taken from tests of automobile parts which must resist considerable vibration and which are usually small in section. The quenching medium must always be carefully considered.
Smithsonian tables.

MECHANICAL PROPERTIES.
TABLE 47. - Alloy Steels - Commercial Experimental Values.


General Note. - Table on steels after Motor Transport Corps, Metallurgical Branch of Engineering Division, Table No. 88.

Maximum allowable P 0.045 or less, maximum allowable S 0.05 or less
Silicon contents were not determined by Motor Transport Corps in preparing table, except for silico-manganese steels. Compressive strengths:

For all steels approx. equal to yield point in tension (slightly above P-limit).
Density:
Steel weighs about $7.85 \mathrm{~g} / \mathrm{cm}^{3}$ or $490 \mathrm{lb} / \mathrm{ft}^{3}$
Ductility, Erichsen values:
0.75 mm ( 0.029 in .) thick, low carbon soft annealed sheet (B. S.), depth of indentation 12.0 mm or 0.472 in .
I. 30 mm ( 0.050 in .) thick, low carbon soft annealed sheet (B.S.), depth of indentation 12.5 mm or 0.492 in .

Modulus of elasticity in tension and compression:
For all steels approx. $21,000 \mathrm{~kg} / \mathrm{mm}^{2}=30,000,000 \mathrm{lb} / \mathrm{in}^{2}$.
Modulus of elasticity in shear:
For all steels approx. $8400 \mathrm{~kg} / \mathrm{mm}^{2}=12,000,000 \mathrm{lb} / \mathrm{in}^{2}$.
Scleroscope hardness values shown are as determined with the Shore Universal hammer.
Strength in shear:
P-limit and ultimate strength each about 70 per cent corresponding tensile values.

## Smithsonian Tables.

## TABLE 48．－Steel Wire－Specification Values．

（After I．A．S．B．Specification 3Si2，Sept．，1917，for High－strength Steel Wire．）
S．A．E．Carbon Steel，No．1050 or higher number specified（see Carbon steels above）．Steel used to be manufac－ tured by acid open－hearth process，to be rolled，drawn，and then uniformly coated with pure tin to solder readily．

| American B．and S wire gage． | Diameter． |  | Req＇d twists in 203.2 mm or 8 in ． | Weight． |  | Req＇d bends thru $90^{\circ}$ | Spec．minimum tensile strength． |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | in． |  | kg／room | $\begin{gathered} \mathrm{lb} / \mathrm{Ioo} \\ \mathrm{ft} . \end{gathered}$ |  | kg | lb． | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| 6 | 4． 115 | 0.162 | 16 | 10.44 | 7.01 | 5 | 2040 | 4500 | 154 | 219，000 |
| 7 | 3.665 | ． 144 | 19 | 8.28 | $5 \cdot 56$ | 6 | 1680 | 3700 | 161 | 229，000 |
| 8 | 3.264 | ． 129 | 21 | 6.55 | 4.40 | 8 | 1360 | 3000 | 164 | 233，000 |
| 9 | 2.906 | ． 114 | 23 | 5.21 | 3.50 | 9 | 1135 | 2500 | 172 | 244，000 |
| 10 | 2.588 | ． 102 | 26 | 4.12 | 2.77 | II | 910 | 2000 | 172 | 244，000 |
| 11 | 2.305 | ．091 | 30 | 3.28 | 2.20 | 14 | 735 | 1620 | 179 | 254，000 |
| 12 | 2.053 | ．08I | 33 | 2.60 | I． 74 | 17 | 590 | 1300 | 177 | 252，000 |
| 13 | I． 828 | ． 072 | 37 | 2.06 | I． 38 | 21 | 470 | 1040 | 179 | 255，000 |
| 14 | I． 628 | ． 064 | 42 | I． 64 | I．IO | 25 | 375 | 830 | 18 I | 258，000 |
| 15 | 1.450 | .057 | 47 | I． 30 | 0.87 | 29 | 300 | 660 | 182 | 259，000 |
| 16 | 1． 291 | ．051 | 53 | I． 03 | 0.69 | 34 | 245 | 540 | I86 | 264，000 |
| 17 | I． 150 | ． 045 | 60 | 0.8 I | 0.55 | 42 | 195 | 425 | 188 | 267，000 |
| 18 | 1.024 | ． 040 | 67 | 0.65 | 0.43 | 52 | 155 | 340 | 190 | 270，000 |
| 19 | 0.912 | ． 036 | 75 | 0.51 | 0.34 | 70 | 125 | 280 | 193 | 275，000 |
| 20 | 0.812 | ． 032 | 85 | 0.41 | 0.27 | 85 | 100 | 225 | 197 | 280，000 |
| 2 I | 0.723 | ． 028 | 96 | 0.32 | 0.22 | 105 | 80 | 175 | 200 | 284，000 |

Note．－Number of $90^{\circ}$ bends specified above to be obtained by bending sample about 4.76 mm （ 0.188 in ．）radius， alternately，in opposite directions．
（Above specification corresponds to U．S．Navy Department Specification 22W6，Nov．1，1916，for tinned，galvan－ ized or bright aaroplane wire．）

TABLE 49．－Steel Wire－Experimental Values．
（Data from tests at General Electric Company laboratories．）＂Commercial Steel Music Wire（Hardened）．＇

| Diameter． |  | Ultimate strength． |  |
| :---: | :---: | :---: | :---: |
| mm | in． | kg／m | $\mathrm{lb} / \mathrm{in}^{2}$ |
| 12.95 | 0.051 | 226.0 | 321，500 |
| 11.70 | ． 046 | 249.0 | 354，000 |
| 9.15 | ． 036 | 253.0 | 360，000 |
| 7.60 | ． 030 | 260.0 | 370，000 |
| 6.35 | ． 025 | 262.0 | 372，500 |
| 4．55＊ | ． 018 | 265.5 | 378，000 |
| 2．55＊＊ | ． 010 | 386.5 | 550，000 |
| 1.65 4.55 | ． .018 | 527.0 49.2 | 750,000 70,000 |

＊For 4.55 mm wire drawn cold to indicated sizes．$\quad \dagger$ For 4.55 mm （ 0.018 in．）wire annealed in $\mathrm{H}_{2}$ at $850^{\circ} \mathrm{C}$ ．

## TABLE 50．－Semi－steel．

Test results at Bureau of Standards on $155-\mathrm{mm}$ shell，Jan． 1919.
Microstructure－matrix resembling pearlitic steel，embedded in which are flakes of graphite．
Composition－Comb．Co．60 to 0．76，Mn 0．88，Po．42 to 0.43 ， S 0.077 to 0.088 ， Si 1.22 to 1．23，graphitic C 2.84 to 2.94 ．

| Metal． |  |  | 官 | 㝕至 |  |  | 菏 |  | Hardness． |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  | Brinell （B） 3000 kg | Sclero－ scope． |
|  | Tension $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension $\mathrm{lb} / \mathrm{in}^{2}$ |  | Compression $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Compression $\mathrm{lb} / \mathrm{in}^{2}$ |  |  |  |
| Semi－steel： |  |  |  |  |  |  |  |  |  |  |
| Graph．C 2.85 | 7.9 | 19.8 | 11，200 | 28，200 | 24.3 | 72.6 | 34，500 | 103，000 | 176 | － |
| Graph．C ${ }^{2} .92$ Comb． C 0.60 | 4.2 | 14.9 | 6，000 | 21，200 | 18.3 | 61.4 | 26，000 | 87，300 | 170 | － |

Tension specimens $12.7 \mathrm{~mm}(0.5 \mathrm{in}$ ．）diameter， $50.8 \mathrm{~mm}(2 \mathrm{in}$ ．）gage length；elorgation and reduction of area negligible．

Compression specimens 20.3 mm （ 0.8 in ．）diameter， 61.0 mm （ 2.4 in ．）long；failure occurring in shear．
Tension set readings with extensometer showed elastic limit of $2.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or $3000 \mathrm{lb} / \mathrm{in}^{2}$ ．
Modulus of elasticity in tension－ $9560 \mathrm{~kg} / \mathrm{mm}^{2}$ or $13,600,000 \mathrm{lb} / \mathrm{in}^{2}$ ．
Smithsonian Tables．

Cast steel wire to be of hard crucible steel with minimum tensile strength of $155 \mathrm{~kg} / \mathrm{mm}^{2}$ or $220,000 \mathrm{lb} / \mathrm{in}^{2}$ and minimum elongation of 2 per cent in 254 mm (10 in.).

Plow steel wire to be of hard crucible steel with minimum tensile strength of $183 \mathrm{~kg} / \mathrm{mm}^{2}$ or 260,000 $\mathrm{lb} / \mathrm{in}^{2}$ and minimum elongation of 2 per cent in 254 mm ( 10 in .)

Annealed steel wire to be of crucible cast steel, annealed, with minimum tensile strength of $77 \mathrm{~kg} / \mathrm{mm}^{2}$ or $110,000 \mathrm{lb} / \mathrm{in}^{2}$ and minimum elongation of 7 per cent in 254 mm ( 10 in .).

Type A: 6 strands with hemp core and 19 wires to a strand ( $=6 \times 19$ ), or 6 strands with hemp core and 18 wires to a strand with jute, cotton or hemp center.
Type B: 6 strands with hemp core, and 12 wires to a strand with hemp center.
Type C: 6 strands with hemp core, and 14 wires to a strand with hemp or jute center.
Type AA: 6 strands with hemp core, and 37 wires to a strand ( $=6 \times 37$ ) or 6 strands with hemp core and 36 wires to a strand with jute, cotton or hemp center.

| Description. | Diameter. |  | Approx. weight. |  | Minimum strength. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | in. | kg/m | $\mathrm{lb} / \mathrm{ft}$ | kg | 1 l . |
| Galv. cast steel, Type A | $9 \cdot 5$ | $\frac{3}{8}$ | 0.31 | 0.2I | 3,965 | 8,740 |
| "6 " " ${ }^{\text {6 }}$ " | 12.7 | $\frac{1}{2}$ | 0.55 | 0.37 | 6,910 | 15,230 |
| " " | 25.4 | 1 | 2.23 | 1. 50 | 27,650 | 60,960 |
| "alv cast steel, Typ | 38.1 | $1{ }^{1}$ | 5.06 | 3.40 | 63,485 | I39,960 |
| Galv. cast steel, Type AA. | 9.5 | $\frac{3}{8}$ | 0.35 | 0.22 | 3,840 | 8,460 |
|  | 12.7 | $\frac{1}{2}$ | 0.58 | - 0.39 | 7,410 | 16,330 |
| " ${ }^{\text {، }}$ " 6 " 6 " 6 | 25.4 | ${ }_{1}$ | 2.23 | 1. 50 | 27,650 | 60,960 |
| " " " ${ }^{\text {" }}$ | 38.1 | $\mathrm{I}^{\frac{1}{2}}$ | 5.28 | $3 \cdot 55$ | 59,735 | 1 31,690 |
| Galv. cast steel, Type ${ }_{6}$ B | 9.5 | $\frac{3}{8}$ | 0.25 | -.17 | 2,995 | 6,600 |
|  | 12.7 | $\frac{1}{2}$ | 0.42 | 0.28 | 5,210 | 11,500 |
| " " " " " | 25.4 | I | I. 68 | 1.13 | 20,890 | 46,060 |
| Galv cast steel Type C | 38.1 | $1{ }^{1}$ | 3.94 | 2.65 | 47,965 | 105,740 |
| Galv. cast steel, Type C | 25.4 | ${ }_{\text {I }}^{1}$ | I. 59 | 1.07 | 18,825 | 41,500 |
|  | 41.3 | 15 <br> 8 <br> 3 | 4.35 | 2.92 | 51,575 | 113,700 |
| Galv. plow steel, Type ${ }_{6}{ }_{6}$ | $\begin{array}{r}9.5 \\ \hline 12.7\end{array}$ | $\frac{3}{8}$ $\frac{1}{2}$ | 0.31 | 0.21 | 4,690 | 10,340 |
| "، "، ، ${ }^{\text {، }}$ " ${ }^{\text {، }}$ | 12.7 | $\frac{1}{2}$ | 0.55 | 0.37 | 8,165 | 18,000 |
| " ، " ، | 25.4 36.4 | ${ }^{7}$ | 2.23 | 1.50 | 32,675 | 72,040 |
| Galv. plow steel, Type Ȧ | 36.5 | ${ }_{\substack{1 \\ \frac{1}{6} 6}}$ | 4.66 | 3.13 | 69,140 | 152,430 |
| "6. plow steel, Type Ax | 9.5 +2.7 | $\frac{1}{2}$ | -. 58 | 0.32 | 8,750 | 19,300 |
| " ${ }^{\text {" }}$ " ${ }^{\text {a }}$ | 25.4 | 1 | 2.35 | 1. 58 | 32,250 | 71,100 |
| " " ، ${ }^{\text {6 }}$ | 41.3 | $\mathrm{I}^{5}$ | 6.18 | 4.15 | 83,010 | 183,000 |

## TABLE 52. - Plow Steel Hoisting Rope (Bright).

(After Panama Canal Specification No. 302, 1912.)
Wire rope to be of best plow steel grade, and to be composed of 6 strands, 19 wires to the strand, with hemp center. Wires entering into construction of rope to have an elongation in 203.2 mm or 8 in . of about $2 \frac{1}{2}$ per cent.

| Diameter. |  | Spec. minimum strength. |  | Diameter. |  | Spec. minimum strength. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| mm | in. | kg | lb . | mm | in. | kg | lb . |
| 9.5 | $\frac{3}{8}$ | 5,2i5 | 1 1,500 | 38.1 | $\mathrm{I}^{\frac{1}{2}}$ | 74,390 | 164,000 |
| 12.7 | $\frac{1}{2}$ 3 | 9,070 | 20,000 | 50.8 | 2 | 127,000 | 280,000 |
| 19.0 | $\frac{3}{4}$ | 20,860 | 46,000 | 63.5 | $2 \frac{1}{2}$ | 207,740 | 458,000 |
| 25.4 | I | 34,470 | 76,000 | 69.9 | $2 \frac{3}{4}$ | 249,350 | 550,000 |

TABLE 53. - Steel-wire Rope - Experimental Values.
(Wire rope purchased under Panama Canal Spec. 302 and tested by U. S. Bureau of Standards, Washington, D. C.)

| Description and analysis. | Diameter. |  | Ultimate strength. |  | Ultimate strength (net area). |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | in. | kg | 1 b . | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| Plow Steel, 6 strands $\times$ i9 wires |  |  |  |  |  |  |
| C 0.90, S 0.034, P 0.024, Mn $0.48, \mathrm{Si} 0.172$.. | 50.8 | 2 | 137,900 | 304,000 | 129.5 | 184,200 |
| Plow Steel, 6 strands $\times 25$ wires |  |  | - | 304,000 |  |  |
| C 0.77, S 0.036, P 0.027, Mn 0.46 , Si $0.152 \ldots$ | 69.9 | $2 \frac{3}{4}$ | 314,800 | 694,000 | 151.2 | 214,900 |
| Plow Steel, $6 \times 37$ plus $6 \times 19$ C 0.58, S 0.032, P 0.033, Mn $0.41, \mathrm{Si} 0.160$. | 82.6 | $3^{\frac{1}{4}}$ | 392,800 | 866,000 | 132.2 | 187,900 |
| Monitor Plow Steel, $6 \times 6$ m plus |  |  |  |  |  |  |
| $6 \times$ 19, C 0.82, S 0.025, P o.019, Mn 0.23, Si o.169.............. | 82.6 | $3^{\frac{1}{4}}$ | 425,000 | 937,000 | 142.5 | 202,400 |

Recommended allowable load for wire rope running over sheave is one fifth of specified min. strength.

TABLE 54.- Aluminum.

| Metal, approx. composition, per cent. | Condition. | Density or weight. |  | 葆 |  | $\stackrel{\ddot{E}}{\stackrel{E}{E}}$ |  |  |  | Hardness. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  | $\begin{array}{\|l\|l\|} \hline \text { gm } & \text { ler } \\ \text { per } & \text { lb.per } \\ \mathrm{ft}^{3} \end{array}$ |  |  | Tension, $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension, lb./in ${ }^{2}$ |  | Per cent. |  |
| Aluminum: <br> Av. Al 99.3 <br> Imp., Fe and Si. . . | Cast, sand at $700^{\circ}$ C...... . <br> Cast, sand and heat treated Ann. $500^{\circ} \mathrm{C}$, air cooled Cast, chill Sheet, ann. Sheet, hard. Bars, hard Wire, hard. | $2.57$ |  |  |  |  |  |  |  |  |  |  |
|  |  |  | 160.5 | 6.0 to | 8.0 to | 8,500 to | 12,000 to |  |  |  |  |
|  |  |  |  | 7.0 | 9.8 | 10,000 | 14,000 | 15 | 22 |  | 5 |
|  |  | - | - | - | 8.9 to | - | 12,600 to | 28 to | 30 to | 25 to | 4 to |
|  |  | - | - | - | 9.6 | - | 13,600 |  | 22 |  | 5 |
|  |  | 2.57 2.69 | 160.5 168.0 | 6.0 6.0 | 9.0 9.0 | 8,000 | 13,000 13,500 |  | 25.c |  | 5 |
|  |  | 2.70 | 168.5 | 14.0 | 21.0 | 20,000 | 13,500 |  |  | 二 | 14 |
|  |  | 2.70 | 168.5 | 15.0 | 23.0 | 22,000 | 33,000 |  | 35.0 |  | - |
|  |  | 2.70 | 168.5 | 21.0 | 28.0 | 30,000 | 40,000 |  |  |  |  |

Compressive strength: cast, yield point $13.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $18,000 \mathrm{lb} / \mathrm{in}^{2}$; ultimate strength 47.0 $\mathrm{kg} / \mathrm{mm}^{2}$ or $67,000 \mathrm{lb} / \mathrm{in}^{2}$.

Modulus of elasticity: cast, $6900 \mathrm{~kg} / \mathrm{mm}^{2}$ or $9,8 \mathrm{IO}, 000 \mathrm{lb} / \mathrm{in}^{2}$ at $17^{\circ} \mathrm{C}$.

TABLE 55.- Aluminum Sheet.
(a) Grade A (Al min. 99.0) Experimental Erichsen and Scleroscope Hardness Values.
[From tests on No. 18 B. \& S. Gage sheet rolled from 6.3 mm ( 0.25 in .) slab. Iron Age v. ror, page 950].

| Heat treatment annealed. | Thickness, mm | Indentation, mm | Scleroscope hardness. |
| :---: | :---: | :---: | :---: |
| None (as rolled). | 1.08 | 6.83 | 4.0 |
| ( $200^{\circ} \mathrm{C}, 2$ hours | 1.09 | 8.86 | 8.0 |
| (a) $300^{\circ} \mathrm{C}, 2$ hours | 1. 07 | 10.17 | 4.5 |
| (a) $400^{\circ} \mathrm{C}, 2$ hours | 1.08 | 9.40 | 4.5 |
| (a) $200^{\circ} \mathrm{C}, 30 \mathrm{~min}$. | 1.07 | 7.97 0.80 | 11.8 |
| (a) $400^{\circ} \mathrm{C}, 30 \mathrm{~min}$. |  | 9.80 | . 5 |

(b) Specification Values. - (1) Cast: U. S. Navy 49 Al, July 1, 1915; Al min. 94, Cu max. 6, Fe max. 0.5, Si max. 0.5, Mn max. 3.

Minimum tensile strength $12.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $18,000 \mathrm{lb} / \mathrm{in}^{2}$ with minimum elongation of 8 per cent in 50.8 mm ( 2 in .).
(2) Sheet, Grade A: A. S. T. M. 25 to 18 T; Al min. 99.0; minimum strengths and elongations.

| Gage, sheet thicknesses. |  |  | Temper, No. hardness. | Tensile strength. |  | Elong. in 50.8 mm or 2 in . per cent. | Sheets of temper No. I to withstand being bent double in any direction and hammered flat; temper No. 2 to bend $180^{\circ}$ about radius equal to thickness without cracking. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (B. \& S.) | mm | in. |  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |  |  |
| 12 to 16 incl. | 2. 052 to | 0.0808 to | $\begin{cases}1 & \text { Soft, Ann }\end{cases}$ | 8.8 | 12,500 | 30 |  |
|  | 1.293 |  | 3 Hard | 12.5 15.5 | 18,000 22,000 | 7 |  |
| 17 to | 1. 152 to | . 0453 to | I Soft, Ann. | 8.8 | 12,500 | 20 |  |
| 22 incl. | 0.643 | . 0253 | 2 Half-hard | 12.5 | 18,000 | 5 |  |
|  |  |  | 3 Hard | 17.5 | 25,000 | 2 |  |
| 23 to 26 incl. | $\begin{aligned} & 0.574 \text { to } \\ & 0.404 \end{aligned}$ | $\begin{aligned} & .0226 \text { to } \\ & .0159 \end{aligned}$ | $\left\{\begin{array}{l}\text { 1 Soft, Ann. } \\ 2 \text { Half-hard }\end{array}\right.$ | $\begin{array}{r}8.8 \\ 12.5 \\ \hline 2.5\end{array}$ | 12,500 18,000 | 10 5 |  |
|  |  |  | ${ }_{3}$ Hard | 12.5 21.0 | 30,000 | 5 |  |

Note. - Tension test specimen to be taken parallel to the direction of cold rolling of the sheet. Smithsonian tables.

ALUMINUM ALLOY．

| Alloy，approx． composition per cent． | Condition， per cent reduction． | Density or weight． |  |  |  | : |  |  | 烒 | Hard | ness． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\underset{\mathrm{cm}^{3}}{\mathrm{gm} /}$ | $\begin{aligned} & \mathrm{lb} / \mathrm{ft}^{3} \end{aligned}$ | Tension， $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension， $\mathrm{lb} / \mathrm{in}^{2}$ |  | per cent． |  |  |  |
| Aluminum－Copper． <br> $\mathrm{Al}_{98 \mathrm{Cu} \text { I Imp．max．} \mathrm{I}}$ | Cast，chill．．．． | － | 二 | 5．3 | 10.5 | 7，500 | $\left\lvert\, \begin{aligned} & 15,000 \\ & 30,000\end{aligned}\right.$ | 24.0 | 34.0 | － | 二 |
|  | Rolled， $70 \%$ <br> Cast，chill． <br> Rolled， $70 \%$ ． <br> Cast，chill． <br> Rolled， $70 \%$ ． <br> Cast，sand．．． | 二 | 二 | $\begin{array}{r} 19.0 \\ 8.1 \\ 25.0 \end{array}$ | $1 \begin{aligned} & 21.0 \\ & 13.7 \\ & 28.8\end{aligned}$ | $\begin{aligned} & 27,000 \\ & \text { I 1,500 } \end{aligned}$ |  | 12．0 | 21.0 |  |  |
| $\mathrm{Al}_{96} \mathrm{Cu}_{3}$ Imp．max．I |  |  |  |  |  |  |  |  |  | － | － |
| $\mathrm{Al}_{94} \mathrm{Cu} 5$ Imp．max． I |  | 二 | 二 | $\begin{aligned} & 25.0 \\ & 10.0 \end{aligned}$ | $1 \begin{aligned} & 28.8 \\ & 15.0\end{aligned}$ | $\begin{aligned} & 35,000 \\ & 14,500 \end{aligned}$ | $\begin{aligned} & 41,000 \\ & 21,500 \end{aligned}$ | $\begin{aligned} & 5.5 \\ & 7.0 \end{aligned}$ | 14.0 | － | 二 |
| Al 92 Cu 8 ：Alloy No． |  | 2.88 | 180 | $\begin{aligned} & 23.0 \\ & 7.7 \text { to } \\ & 10.5 \end{aligned}$ | $\left\lvert\, \begin{aligned} & 27.0 \\ & 10.5 \text { to } \\ & 16.2 \end{aligned}\right.$ | $\begin{aligned} & 33,000 \\ & \text { II, }, 000 \text { to } \end{aligned}$ | $\left\|\begin{array}{l} 38,000 \\ 15,000 \text { to } \\ 23,000 \end{array}\right\|$ | 6.0 | － | － |  |
| Al 92 Cul 8：Alloy No． 12．．．．．．．．．．．． Al |  |  |  |  |  | $\begin{aligned} & \text { I1 ,000 to } \\ & 15,000 \end{aligned}$ |  | ${ }_{\text {None }}$ | None |  | ${ }_{18}^{13}$ to |
|  | Cast＊ | 2.9 | 181 |  | 12.7 | － | 18,000 |  | － |  |  |
| Copper，Magnesium． | Cast at $700^{\circ} \mathrm{C}$ ． | 2．9 |  | 3.2 to | 0.6 to | 4，500 to |  | 2.0 to | 0.5 to |  | ${ }_{18}^{17}$ tc |
|  | Ann． $500^{\circ}$ | 2.8 |  |  | 13.3 17.3 | 6,500 6,500 | 18，900 | ${ }^{\circ} \mathrm{O}$ | ${ }^{\circ} \mathrm{I}$. |  |  |
| Duralumin or | Ann．． |  | 174 | $\begin{array}{r} 4.0 \\ 25.0 \\ 53.0 \end{array}$ | $\left\lvert\, \begin{aligned} & 12.0 \\ & 42.0 \\ & 56.0 \end{aligned}\right.$ | $\begin{aligned} & 35,100 \\ & 75,400 \end{aligned}$ | $\begin{aligned} & 59,500 \\ & 79,600 \end{aligned}$ | 21.14.0 | $\begin{aligned} & 29.5 \\ & 13.2 \end{aligned}$ | － | － |
|  | Rolled 70 |  |  |  |  |  |  |  |  |  |  |
|  | tr＇d $\dagger$ | － | － | $23.4$ | $39.0$ | $\left\lvert\, \begin{aligned} & 13,400 \\ & 33,400 \end{aligned}\right.$ | $55,300$ | $25.5$ | 26.0 | － | － |
| Copper，Manganese． | Cast，chill |  |  | 10．0． | 14.0 | 14，300 | 20，300 | 5.0 | － |  |  |
| $\mathrm{Al}^{96} \mathrm{Cu} 2 \mathrm{Mn}_{2}$ | Rolled， 20 mm | 2.8 |  | 19.0 | 27.0 | 27，100 | 38，200 | 16.0 | 28.0 |  |  |
| $\mathrm{Al}_{96} \mathrm{Cu} 3 \mathrm{Mn}$ | Cast，chill |  | ${ }^{175}$ |  | 19.0 | 16，200 |  | 14.0 |  |  |  |
| Naval Gun Factory | Cast，sand |  |  | $15 \frac{1.3}{14.0}$ |  | 19，500 | $\begin{aligned} & 20,000 \\ & 27,800 \end{aligned}$ | 12.0 |  |  |  |
|  |  | － | － |  |  |  | 18，000 | $\left\lvert\, \begin{array}{r} 12.0 \\ 8.0 \end{array}\right.$ | － | － |  |
| max． $3 . \ldots \ldots$ | Mini |  |  | － | 12.7 | － |  |  |  |  | － |
| Copper，Nickel，Mg Mn | ast | - | $\begin{aligned} & - \\ & - \end{aligned}$ | $3.5 \text { to }$ | 17.9 to |  | 25，500 to | 6.0 to | 8.5 to | 54 to | 9 to |
|  |  |  |  |  | $\left\lvert\, \begin{aligned} & 23.2 \\ & 14.5\end{aligned}\right.$ |  | $\left\lvert\, \begin{aligned} & 33,000 \\ & 20,600 \text { to } \end{aligned}\right.$ | $\begin{gathered} 1.5 \\ 6.0 \text { to } \end{gathered}$ |  |  | 25 |
| Copper，Nickel Mn | Cast at $700^{\circ} \mathrm{C}$ ． | － | 二 | 9.8 |  | 14，000 |  |  | $\begin{aligned} & \text { r.O } \\ & \text { II.O to } \end{aligned}$ |  |  |
| $\mathrm{Al}_{94.2} \mathrm{Cu}_{3} \mathrm{Ni} 2 \mathrm{Mn}$ o．8． |  |  |  |  | 21.4 |  | 30，50 | 1.0 | 2.0 | 91 | 27 |
| Magnesium：${ }_{\text {Magnalium }}{ }^{\text {Al }} 05 \mathrm{Mg}$ |  | $\begin{aligned} & 2.5 \\ & 2.4 \text { to } \end{aligned}$ | $\begin{aligned} & 156 \\ & 150 \text { to } \\ & 160 \\ & 160 \end{aligned}$ | 5.6 | $15.5 \text { to }$ | 8，000 | $\begin{aligned} & 22,000 \\ & 42,000 \text { to } \end{aligned}$ |  |  |  |  |
| $\mathrm{Al}_{77-98, \mathrm{Mg}}^{23-2 . .}$ | Cast，ch |  |  |  |  |  |  | 7.0 | 8.5 | 二 | 二 |
|  |  |  |  |  |  |  | I4，900 | 21.0 | 36.0 | － |  |
| Nickel ${ }^{\text {Al }} 97 \mathrm{Ni} 2 . . .$. | $\left\{\begin{array}{l}\text { Cast，chill } \ldots \\ \text { Drawn，cold } . . \\ \text { Rolled，hot．} \\ \text { Cast，chill } \\ \text { Drawn，cold } \ldots \\ \text { Rolled，hot．}\end{array}\right.$ |  | 二 |  | $\begin{aligned} & 11.0 \\ & 16.0 \\ & 10 \end{aligned}$ | 5，800 |  |  |  |  |  |
|  |  | 二 |  |  |  | $\begin{aligned} & \text { 19,700 } \\ & \text { I 1,900 } \end{aligned}$ | $\begin{aligned} & 22,700 \\ & 18,200 \end{aligned}$ | $\left\lvert\, \begin{aligned} & 13.0 \\ & 28.0 \end{aligned}\right.$ | $\begin{aligned} & 37.0 \\ & 52.0 \end{aligned}$ | － | 二 |
|  |  | － | 二 | $\begin{array}{r} 14.0 \\ 8.0 \\ 6.0 \end{array}$ | $\begin{aligned} & 15.0 \\ & 20.0 \end{aligned}$ | $\left\lvert\, \begin{array}{r} 9,000 \\ 22,900 \end{array}\right.$ | $\begin{aligned} & 21,700 \\ & 27,900 \end{aligned}$ | 9.08.0 | 11.024.0 | 二 二 |  |
| Al 95 Ni 5. |  |  |  | $\begin{array}{r} 6.0 \\ 16.0 \end{array}$ |  |  |  |  |  |  | － |
|  |  |  |  |  | 16.0 | 13，500 | 22，300 | 22.0 | 36.0 |  |  |
| Al 93.5 Ni 5.5 Cu r | Cast，chill |  |  | 7.0 | 17.0 | 10，700 | 24，800 | 6.0 | 8.0 |  |  |
| $\mathrm{Al}_{91.5} \mathrm{Ni}_{4.5} \mathrm{Cu}_{4}$. | Cast，chill |  |  | 7.0 | 18.0 | 9，900 | 25，200 | 4.0 | 5.0 |  |  |
| $\mathrm{Al}_{92} \mathrm{Ni} 5_{5} 5 \mathrm{Cu} 2$ | Drawn，co | － | － | 22.0 | 27.0 | 31，700 | 37，800 | 8.0 | 15.0 |  |  |
| Zinc，Copper： |  |  | － | $\begin{aligned} & 4.7 \\ & 4.4 \\ & 9.8 \\ & 9.8 \end{aligned}$ | 22.0 | 18，200 | 31，500 | 16.0 | 24.0 |  |  |
| Al 88.6 Cu 3 |  | － |  |  | $\begin{aligned} & 18.5 \\ & 20.2 \\ & 24.7 \\ & 29.0 \end{aligned}$ | $\begin{array}{r} 6,700 \\ 6,200 \\ \text { I4,00 } \\ \text { I4, } 4,00 \end{array}$ |  | 8.0 | 7.5 | 50 | 10 |
|  | Ann． $500^{\circ} \mathrm{C}$ ．${ }^{\text {c }}$ |  | － |  |  |  | $28,800$ | 8.0 | 7.5 | 50 | 10 |
| Al 8 I .1 Cu 3 Zn 15.9. | Cast at $700^{\circ} \mathrm{C}$ ． | 3.1 | 193 |  |  |  | $35,100$ | 2.0 | 2.0 | 74 | 15 |
|  |  |  |  |  |  |  | $41,200$ | 4.0 | 4.0 | 70 | r 5 |

[^9]| Metal and approx. composition. Per cent. | Condition. | Density or weight. |  |  |  | Tension, $\mathrm{lb} / \mathrm{in}^{2}$ |  |  |  | Hardness. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |
|  |  | $\underset{\mathrm{cm}^{3}}{\mathrm{gm} /}$ | $\begin{aligned} & \mathrm{lb} / \\ & \mathrm{ft}^{3} \end{aligned}$ |  |  |  |  |  |  |
| Copper: | Ann. $200^{\circ} \mathrm{C} . . .$. . | 8.89 | 555 | 6.0 | 27.0 | 8,50010,000 | 38,000 |  | 50.060.0 |  | 7 |
| Cu 99.6...... . | Cast. . . . . . . . . | 8.85 | 552 | 7.0 | 18.0 |  |  | 50.0 20.0 |  | 80 |  |
| Rolled. | \% Hard, $40 \%$ reduct | 8.89 | 555 | 14.0 | 35.0 | 20,000 | $\begin{aligned} & 50,000 \\ & 35,000 \end{aligned}$ | 5.0 | 8.060.0 | 94 | 6 |
| Rolled. | Ann. at $500^{\circ} \mathrm{C}$. ${ }^{\circ}$ | 8.90 | 556 | indet. | 25.0 |  |  | 50.0 |  |  |  |
|  | reduct....... | - | - | 26.0 | 35.0 | 37,000 | 50,000 | 9.0 | - | - | 18 |
| Cu 99.9*...... | No Ann. ( $96 \%$ reduction)....... . | - | - | - | $47 \cdot 3$ | 37,00 | 67,400 | 0.8 | 64.5 | - | - |
|  | Ann. $750^{\circ} \mathrm{C}$ after drawing cold. | - | - | - | 21.9 | - | 31,200 | 0.8 24.5 | 64.5 76.0 | - | - |
| Cu 99.9†....... | Drawn hot ( $64 \%$ reduction)..... | - | - | - | 33.0 | - | 46,800 | 4.3 | 70.5 | - | - |

* Wire drawn cold from 3.18 mm ( 0.125 in .) to 0.64 mm ( 0.025 in.) Bull. Am. Inst. Min. Eng., Feb., 1919.
$\dagger$ Wire drawn at $150^{\circ} \mathrm{C}$ from 0.79 mm ( 0.031 in .) to 0.64 mm ( 0.025 in .) (Jeffries, loc. cit.).
Compression, cast copper, Ann. 15.9 mm ( 0.625 in .) diam. by 50.8 mm (2 in.) long cylinders.
Shortened 5 per cent at $22.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $31,300 \mathrm{lb} / \mathrm{in}^{2} \mathrm{log}_{6}$.

$$
\begin{array}{lllllll}
" 10 & \text { 10 } & \text { " } & \text { " } & 29.0 \mathrm{~kg} / \mathrm{mm}^{2} & \text { " } & 4 \mathrm{r}, 200 \mathrm{lb} / \mathrm{in}^{2}
\end{array} \text { " }
$$

Shearing strength, cast copper $21.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $30,000 \mathrm{lb} / \mathrm{in}^{2}$
Modulus of elasticity, electrolytic $12,200 \mathrm{~kg} / \mathrm{mm}^{2}$ or $17,400,000 \mathrm{lb} / \mathrm{in}^{2}$
"" "" " cast $7,700 \mathrm{~kg} / \mathrm{mm}^{2}$ or $11,000,000 \mathrm{lb} / \mathrm{in}^{2}$
drawn, hard $12,400 \mathrm{~kg} / \mathrm{mm}^{2}$ or $17,600,000 \mathrm{lb} / \mathrm{in}^{2}$
TABLE 58. - Rolled Copper - Specification Value.
Specification values: U. S. Navy Dept., 47 C 2 , minimums for rolled copper, -Cu min. 99.5

| Description, temper and thickness. | Tensile strength. |  | Elong. in 50.8 or 2 in . - per cent. |
| :---: | :---: | :---: | :---: |
|  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |  |
| Rods, bars, and shapes: |  |  |  |
| Soft.. | 21.0 | 30,000 | 25 |
| Hard: to $9.5 \mathrm{~mm}\left(\frac{3}{8} \mathrm{in}\right.$.) incl. . | 35.0 | 50,000 | 10 |
| Hard: 9.5 mm to 25.4 mm ( I in.) | 31.5 | 45,000 | 12 |
| Hard: 25.4 mm to 50.8 mm ( 2 in .) | 28.0 | 40,000 | 15 |
| Hard: over 50.8 mm (2 in.). | 24.5 | 35,000 | 20 |
| Sheets and plates: Soft. . . . . . . . | 21.0 to 28.0 | 30,000 to 40,000 |  |
| Hard. | 24.5 | 30,00, | 18 |

TABLE 59. - Copper Wire - Specification Values.
Specific Gravity 8.89 at $20^{\circ} \mathrm{C}\left(68^{\circ} \mathrm{F}\right)$.
Copper wire: Hard Drawn (and Hard-rolled flat copper of thicknesses corresponding to diameters of wire) Specification values. (A.S. T. M. Bi-15, and U. S. Navy Dept., 22 W3, Mar. 1, 1915.)

| Diameter. |  | Minimum tensile strength. |  | Maximum elongation, per cent in 254 mm ( 10 in .). |
| :---: | :---: | :---: | :---: | :---: |
| mm | in. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |  |
| 11.68 | . 460 | 34.5 | 49,000 | 2.75 |
| 10.41 | . 410 | 35.9 | 51,000 | 3.25 |
| 9.27 | . 365 | 37.1 | 52,800 | 2.80 |
| 8.25 | . 325 | 38.3 | 54,500 | 2.40 |
| 7.34 6.55 | . 289 | 39.4 40.5 | 56,100 57,600 | 2.17 1.98 |
| 5.82 | . 229 | 4 I .5 | 59,000 | 1.79 |
| 5.18 |  |  | 60,100 | in 1524 mm ( 60 in.$)$ |
| ${ }_{4.62}$ | .204 .182 | 42.2 43.0 | 60,100 | 1.24 1.18 |
| 4.12 | . 162 | 43.7 | 62,100 | 1.14 |
| 3.66 | . 144 | 44.3 | 63,000 | 1.09 |
| 3.25 | . 128 | 44.8 | 63,700 | 1.06 |
| 2.90 | . 114 | 45.2 | 64,300 | 1.02 |
| 2.59 | . 102 | 45.7 | 64,900 | $1 . \infty$ |
| 2.31 | .09r | 46.0 | 65,400 | 0.97 |
| 2.06 1.83 | . 081 | 46.2 46.3 | 65,700 65,900 | 0.95 0.92 |
| I. 63 | . 064 | 46.5 | 66,200 | 0.92 0.90 |
| 1.45 | . 057 | 46.7 | 66,400 | -. 89 |
| 1.30 | . 051 | 46.8 | 66,600 | 0.87 |
| 1.14 | . 045 | 47.0 | 66,800 67,000 | 0.86 0.85 |
| 1.02 | . 040 | 47.1 | 67,000 | 0.85 |

P-limit of hard-drawn copper wire must average 55 per cent of ultimate tensile strength for four largest sized wires in table, and 60 per cent of tensile strength for smaller sizes.
Smithsonian Tables.

TABLE 60. - Copper Wire - Medium Hard-drawn.
(A. S. T. M. $\mathrm{B}_{2}-15$ ) Minimum and Maximum Strengths.

| Diameter. |  | Tensile strength. |  |  |  | Elongation, minimum per cent in 254 mm ( $\mathrm{Io} \mathrm{in),}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Minimum. |  | Maximum. |  |  |
| mm | in. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $1 \mathrm{l} / \mathrm{in}^{2}$ | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |  |
| 11.70 | 0.460 | 29.5 | 42,000 | 34.5 | 49,000 | 3.75 |
| 6.55 | .258 | 33.0 | 47,000 | 38.0 | 54,000 | $\begin{gathered} 2.50 \\ \text { in } 1524 \mathrm{~mm}(60 \mathrm{in} .) \end{gathered}$ |
| 4.12 | . 162 | 34.5 | 49,000 | 39.5 | 56,000 | 1.15 |
| 2.59 | . 102 | 35.5 | 50,330 | 40.5 | 57,330 | 1.04 |
| 1.02 | . 040 | 37.0 | 53,000 | 42.0 | 60,000 | 0.88 |

Representative values only from table in specifications are shown above. P-limit of medium hard-drawn copper averages 50 per cent of ultimate strength.

TABLE 61. - Copper Wire - Soft or Annealed.
(A. S. T. M. B3-15) Minimum Values.

| Diameter. |  | Minimum tensile strength. |  | Elongation in 254 mm ( 10 in. ), per cent. |
| :---: | :---: | :---: | :---: | :---: |
| mm | i:. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{i} \mathrm{n}^{2}$ |  |
| II. 70 to 7.37 | 0.460 to 0.290 | $25 \cdot 5$ | 36,000 | 35 |
| 7.34 to 2.62 | 0.289 to 0.103 | 26.0 | 37,000 | 30 |
| 2.59 to 0.53 | 0.102 to 0.021 | 27.0 | 38,500 | 25 |
| 0.51 to 0.08 | 0.020 to 0.003 | 28.0 | 40,000 | 20 |

Note. - Experimental res.lts show tensile strength of concentric-lay copper cable to approximate 90 per cent of combined strengths of wires forming the cable.

TABLE 62. - Copper Plates.
(A. S. T. M. Bir-18) for Locomotive Fire Boxes. Specification Values.

| Minimum requirements. | Tensile strength. |  | Elong. in 203.2 mm (8 in.), per cent. |
| :---: | :---: | :---: | :---: |
|  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $1 \mathrm{~b} / \mathrm{in}^{2}$ |  |
| Copper, Arsenical, As $0.25-0.50$ Impurities, max. 0.12........ Copper Non-arsenical: | 22.0 | 31,000 | 35 |
| Impurities, max. O.I2 | 21.0 | 30,000 | 30 |

Note. - Copper to be fire-refined or electrolytic, hot-rolled from suitable cakes.
TABLE 63.- Copper Alloys.
The general system of nomenclature employed has been to denominate all simple copperzinc alloys as brasses, copper-tin alloys as bronzes, and three or more metals alloys composed primarily of either of these two combinations as alloy brasses or bronzes, e.g., "Zinc bronze" for U.S. Government composition " G " Cu 88 per cent, Sn ro per cent, Zn 2 per cent. Alloys of the third type noted above, together with other alloys composed mainly of copper, have been called copper alloys, with the alloying elements other than minor impurities listed as modifying copper in the order of their relative percentages.
In some instances, the scientific name used to denote an alloy is based upon the deoxidizer used in its preparation, which may appear either as a minor element of its composition or not at all, e.g., phosphor bronze.

Commercial names are shown below the scientific names. Care should be taken to specify the chemical composition of a commercial alloy, as the same name frequently applies to widely varying compositions.

TABLE 64．－Copper－zinc Alloys or Brasses；Tin Alloys or Bronzes．

| Metal and approx． composition， per cent． | Condition． | Density or weight． |  | 㵄 |  | 茄 |  |  |  | Har | dness． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\frac{\mathrm{gm}}{\mathrm{cm}^{3}}$ | $\frac{\mathrm{lb}}{\mathrm{ft}^{3}}$ | Tension， $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension， $1 \mathrm{~b} / \mathrm{in}^{2}$ |  | Per cent． |  | ［． | 辰 |
| Brass： <br> Cu 90 Zn го†． |  |  |  |  |  |  |  |  |  |  |  |
|  | $\left\{\begin{array}{l}\text { Sand cast．．．．} \\ \text { Cold rolled，}\end{array}\right.$ | － | － | － | 20.0 39.0 | 二 | 29，000＊ | 22 ＊ | － | 60 | － 20 |
|  | Cold rolled，soft． | 8.7 | 543 | － | 26.0 | － | 37，000＊ | 40＊ | 70 | 47 | 10 |
| $\mathrm{Cu} 80, \mathrm{Zn} 20 \ddagger$. | $\left\{\begin{array}{l}\text { Sand cast．．．．} \\ \text { Cold rolled，hard }\end{array}\right.$ | － | － | － | 25.0 53.0 | － | 35，000 | 31 | 32 | － 75 | － |
|  | Cold rolled，soft． | 8.6 | 537 | － | 29.0 | － | 42，000＊ | 50＊ | 85 | 75 46 | 12 |
| $\mathrm{Cu} 70, \mathrm{Zn} 30$ ． Cu 66 Zn 34 Std． sheet ．．．．．．．． | Sand cast．．．．．． | 8.4 | 52.4 | － | 28.0 | － | 40，000 | 35 ＊ |  | 37 | － |
|  | Cold rolled，hard | 8.5 | 530 | － | 42.0 | － | 60，000 | 5＊ | － | 758 | 26 |
|  | Cold rolled，soft． | 8.4 | 524 | － | 34.0 | － | 48，000＊ | 50＊ | 85 | 45 | 12 |
| $\mathrm{Cu} 60, \mathrm{Zn} 40 .$.Muntz metal．． | Sand cast．．．．． | － | － | 15.5 | 32.2 | 21，800 | 45，800 | 15 | 22 | － | － |
|  | Cold rolled，hard | 18.4 | 522 | 31.5 | 49.0 | 45，000 | 70，000 | 30 | 50 | － | － |
| Bronze： Cu 97．7，Sn 2．3． |  |  |  |  |  |  |  |  |  |  |  |
|  | Cast． | － | － | 6.0 | 19.5 | 8，500 | 28，000 | 20 | － | － | － |
|  | （Rolled | － | － | 7.6 | 34.0 | 10，800 | 48，000 | 55 | 75 |  | － |
| Cu 90，Sn 10．．． | $\left\{\begin{array}{ccc}\text { Cast or } & \text { gun } \\ \text { bronze or } & \text { bell } \\ \text { metal．} \ldots . & .\end{array}\right.$ | 8.78 | 548 | 7.2 | 23.0 | 10，300 | 33，000 | 10 | － | － | 23 |
| $\mathrm{Cu} 80, \mathrm{Sn} 20 .$. | Cast．．．．．．．．．．． | 8.81 | 550 | 7.1 | 22.5 | 10，100 | 32，000 | 1.5 | － | － | － |
| Cu 70，Sn 30．．． | Cast．．．．．．．．．．． | 8.84 | 552 | 1.4 | 5.0 | 2，000 | 7，000 | 0.5 |  | － | － |

Compressive Strengths，Brasses：
$\mathrm{Cu} 90, \mathrm{Zn}$ 10，cast $21.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $30,000 \mathrm{lb} / \mathrm{in}^{2}$ $\mathrm{Cu} 80, \mathrm{Zn} 20$ ，cast $27.4 \mathrm{~kg} / \mathrm{mm}^{2}$ or $39,000 \mathrm{lb} / \mathrm{in}^{2}$ $\mathrm{Cu} 70, \mathrm{Zn} 30$ ，cast $42.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $60,000 \mathrm{lb} / \mathrm{in}^{2}$ $\mathrm{Cu} 60, \mathrm{Zn} 40$ ，cast $52.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $75,000 \mathrm{lb} / \mathrm{in}^{2}$ $\mathrm{Cu} 50, \mathrm{Zn} 50$ ，cast $77.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $110,000 \mathrm{lb} / \mathrm{in}^{2}$

Modulus of elasticity，－cast brass，－average $9100 \mathrm{~kg} / \mathrm{mm}^{2}$ or $13,000,000 \mathrm{lb} / \mathrm{in}^{2}$
Erichsen values：Soft slab， 1.3 mm （ 0.05 in．）thick，no rolling，depth of impression 13.8 mm （ 0.55 in ．）．
Hard sheet， I .3 mm ，rolled $38 \%$ reduction，depth of impression 7.3 mm （ 0.29 in. ）．
Hard sheet， 0.5 mm ，rolled $60 \%$ reduction，depth of impression 3.7 mm （ 0.15 in ．）．
Compressive Ultimate Strengths，Cast Bronzes：
$\mathrm{Cu} 97.7, \mathrm{Sn} 2.3$ to $24.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $34,000 \mathrm{lb} / \mathrm{in}^{2}$
$\mathrm{Cu} 90, \mathrm{Sn} 10$ to $39.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $56,000 \mathrm{lb} / \mathrm{in}^{2}$
$\mathrm{Cu} 80, \mathrm{Sn} 20$ to $83.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $118,00 \mathrm{lb} / \mathrm{in}^{2}$
$\mathrm{Cu} 70, \mathrm{Sn} 30$ to $105.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $150,000 \mathrm{lb} / \mathrm{in}^{2}$

Specification value，A．S．T．M．，B ${ }_{22-18}$ T，for specimen $=$ cylinder $645 \mathrm{sq} . \mathrm{mm}(\mathrm{r} \mathrm{sq} . \mathrm{in}$ ．）area， 25.4 mm （ I in ．） long．

Cu $80, \mathrm{Sn} 20$ ：minimum compressive elastic limit $=17.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $24,000 \mathrm{lb} / \mathrm{in}^{2}$
Modulus of elasticity for bronzes varies from $7000 \mathrm{~kg} / \mathrm{mm}^{2}$ or $10,000,000 \mathrm{lb} / \mathrm{in}^{2}$ to $10,000 \mathrm{~kg} / \mathrm{mm}^{2}$ or $15,500,00$ or $\mathrm{lb} / \mathrm{in}^{2}$
＊Values marked thus are S．A．E．Spec．values．（See S．A．E．Handbook，Vol．I，p．13a，rev．December， 1913.
$\dagger$ Red metal．$\ddagger$ Low brass or bell metal．
8 A．S．T．M．Spec．Brg－18T requires B．h．n．of $51-65 \mathrm{~kg} / \mathrm{mm}^{2}$＠ 5000 kg pressure for $70: 30$ annealed sheet brass．

## Foot notes to Table 65，Page 85.

[^10]
## Smithsonian Tableg．

Table 65.
MECHANICAL PROPERTIES.
TABLE 65. - Copper Alloys - Three (or more) Components.


For Footnotes see page 84.

TABLE 65. - Copper Alloys - Three (or more) Components.


Bronze, Phosphor: spring wir2, hard-drawn or hard-rolled (U. S. Navy Spec. 22 W5, Dec. 1, 1915). Cu 94 , Sn min. $4.5, \mathrm{Zn} \max 0.3$, Fe max. $0.1, \mathrm{~Pb}$ max. $0.2 . \mathrm{P} 0.05$ to 0.50 ; max. elong. in $203 \mathrm{~mm}(8 \mathrm{in})=$.4 per cent.

| Diameter (group limits). | Min. tensile strength. |  | Diameter (group limits). |  | Min. tensile strength. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | kg/mm ${ }^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | mm | in. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| Up to 1.59 mm or 0.0625 in . Over 1.59 mm to 3.17 mm ( 0.125 in .)... | 85.0 | $\begin{aligned} & 135,000 \\ & 125,000 \end{aligned}$ | to 6.35 to 9.52 | $\begin{aligned} & \text { to } 0.250 \\ & \text { to } 0.375 \end{aligned}$ | 77.5 74.0 | $\begin{aligned} & 110,000 \\ & 105,000 \end{aligned}$ |

* Specification Values, Rolled Brass, $\mathrm{Cu}_{62}, \mathrm{Zn}_{37}, \mathrm{Sn} 1$, min. properties after U. S. Navy Spec., 1918 .
$\dagger$ Specification Values: Jan. 3, 1916, Vanadium Bronze Castings, Cu 6r, $\mathrm{Zn} 38, \mathrm{Sn}$ max. I (incl. V). Mimima.
$\ddagger$ Compressive P-limit $15.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $22,000 \mathrm{lb} / \mathrm{in}^{2}$
8 Compressive P-limit $10.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or ${ }_{15,000} \mathrm{lb} / \mathrm{in}^{2}$ and 28 per cent set for $70 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$
i| Ulimate compressive strength, $54.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or $77,100 \mathrm{lb}^{2} \mathrm{in}^{2}(\mathrm{Cu} 76, \mathrm{Sn} 7, \mathrm{~Pb} 13, \mathrm{Zn} 4)$.
TI Compressive P-limit 8.8 to $9.1 \mathrm{Ikg} / \mathrm{mm}^{2}$ or 12,500 to $13,000 \mathrm{lb} / \mathrm{in}^{2}$, and 34 to 35 per cent set for $70 \mathrm{~kg} / \mathrm{mm}^{2}$
** Compression: ultimate strength $49.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $70,500 \mathrm{lb} / \mathrm{in}^{2}$
\# Modulus of Elasticity: (I) $12,200 \mathrm{~kg} / \mathrm{mm}^{2}$ or $17,300,000 \mathrm{lb} / \mathrm{in}^{2}$; (2) $10,500 \mathrm{~kg} / \mathrm{mm}^{2}$ or $14,900,000 \mathrm{lb} / \mathrm{in}^{2}$
$\ddagger$ Compressive P-limit 17.6 to $28.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or 25,000 to $40,000 \mathrm{lb} / \mathrm{in}^{2}$ and 6 to ro per cent set for $70 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$ load.

Specification Values: U. S. Navy 46 B sc, Mar. 1, 1917, Cu 85 to $90, \mathrm{Sn} 6$ to 11, Zn max. 4: Cast, Grade 1. - Im-
purities max. 0.8 ; min. tensile strength $31.6 \mathrm{~kg} / \mathrm{mm}^{2}$ or $45,000 \mathrm{lb} / \mathrm{in}^{2}$ with 20 per cent elong. in 50.8 mm ( 2 in .).
II Grade 2.-Impurities max. $1.6 ; \min$. tensile strength $21.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or $30,000 \mathrm{lb} / \mathrm{in}^{2}$ with 15 per cent elong. in 50.8 mm ( 2 in .).

88 Specification Values: U. S. Navy 46B 14b, Mar. 1, 1916, Cu min. 94, Sn min. 3.5, P o.50, rolled or drawn.
ifil Minimum yield points specified: for P-limits assume 66 per cent of valuea chown.

## MECHANICAL PROPERTIES.

TABLE 65. - Copper Alloys - Three (or more) Components.


* Gov't. Bronze: $\mathrm{Cu} 88, \mathrm{Sn} 10, \mathrm{Zn} 2$ (values shown are averages for 30 specimens from five foundries tested at the Bureau of Standards).

Compressive P-limit $10.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $15,000 \mathrm{lb} / \mathrm{in}^{2}$ with 29 per cent set for $70 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$ load.
$\ddagger$ Values from same series of tests as first values for " $88-10-2$," averages for 26 specimens from five foundries tested at Bureau of Standards.
§ Compressive P-limit $9.1 \mathrm{xg} / \mathrm{mm}^{2}$ or $13,000 \mathrm{lb} / \mathrm{in}^{2}$ with 34 per cent set for $70 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2} \mathrm{load}$.
|| Specification minimums: U. S. Navy 46 Br 7 , Dec. 2, I918, for hot-rolled aluminum bronze, Cu 85 to 87 , Al 7 to $9, \mathrm{Fe} 2.5$ to 4.5 . Specification values under P-limit are for yield point.

TTwo and six tenths per cent increase in strength up to 762 mm ( 30 in .) width. load.

+ Compressive P-limit: cast, 12.7 to $14.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or 18,000 to $20,000 \mathrm{lb} / \mathrm{in}^{2}$ with 13 to 15 per cent set at $700 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$ load.
$\ddagger \ddagger$ Modulus of elasticity $14,800 \mathrm{~kg} / \mathrm{mm}^{2}$ or $21,150,000 \mathrm{lb} / \mathrm{in}^{2}$
88 Compressive P-limit $8.4 \mathrm{~kg} / \mathrm{mm}^{2}$ or ${ }^{12,000 ~ l b / \mathrm{in}^{2}}$ with 36 per cent set for $70.3 \mathrm{~kg} / \mathrm{mm}^{2}$, or $100,000 \mathrm{lb} / \mathrm{in}^{2} \mathrm{load}$.
II $\|$ High values are after Jean Escard "'L'Aluminum dans L'Industrie," Paris, 1918. Compressive P-limit 13.5


TABLE 66. - Miscellaneous Metals and Alloys.


Antimony: Modulus of Elasticity $7960 \mathrm{~kg} / \mathrm{mm}^{2}$ or $\mathrm{II}_{1,320,000 \mathrm{lb} / \mathrm{in}^{2} \text { (Bridgman). }}^{\text {I }}$

* Compressive strength: cast and annealed, $86.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $122,000 \mathrm{lb} / \mathrm{in}^{2}$.

Comm'c'l. comp., C 0.06 , cast, tensile, ultimata, $42.8 \mathrm{~kg} / \mathrm{mm}^{2}$ or $61,000 \mathrm{lb} / \mathrm{in}^{2}$, with 20 per cent elongation in 50.8 or 2 in . Compression, ultimate $123.0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $175,000 \mathrm{lb} / \mathrm{in}^{2}$

Stellite, $\mathrm{Co} 59.5, \mathrm{MO}{ }_{22.5}, \mathrm{Cr} 10.8, \mathrm{Fe} 3 . \mathrm{I}, \mathrm{Mn} 2.0, \mathrm{C} 0.9, \mathrm{Si} 0.8$. Brinell hardness 512 at 3000 kg .
$\dagger$ Modulus of elasticity, cast or rolled, $492 \mathrm{~kg} / \mathrm{mm}^{2}$ or $700,000 \mathrm{lb} / \mathrm{in}^{2}$; drawn hard $703 \mathrm{~kg} / \mathrm{mm}^{2}$ or $\mathrm{I}, 000,000 \mathrm{lb} / \mathrm{in}^{2}$
$\ddagger$ For compressive test data on lead-base babbitt metal, see table following zinc.
8 Modulus of elasticity $15,800 \mathrm{~kg} / \mathrm{mm}^{2}$ or $22,500,000 \mathrm{lb} / \mathrm{in}^{2}$.
II Specification values, U. S. Navy, Monel metal, Ni min. 60 , $\mathrm{Cu} \min .23, \mathrm{Fe}$ max. 3.5, Mn max. 3.5, C + Si max. .8, Al max. o.5.
\& Values shown are subject to slight modifications dependent on shapes and thicknesses.
** Values are for yield point.
\# Compressive strength: cast, $4.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $6,400 \mathrm{lb} / \mathrm{in}^{2}$
Modulus of elasticity: cast av. $2,810 \mathrm{~kg} / \mathrm{mm}^{2}$ or $4,000,000 \mathrm{lb} / \mathrm{in}^{2}$; rolled av. $40 \pi .0 \mathrm{~kg} / \mathrm{mm}^{2}$ or $5,700,000 \mathrm{lb} / \mathrm{in}^{2}$

Table 67.
MECHANICAL PROPERTIES．
TABLE 67．－Miscellaneous Metals and Alloys．
（a）Tungsten and Zinc．

| Metal or alloy approx． comp． per cent． | Condition． | Density or weight． |  | 号 |  | $\begin{aligned} & \text { 品 } \\ & \text { 品 } \end{aligned}$ |  |  |  | Hardness． |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} & \mathrm{gm} \\ & \text { per } \\ & \mathrm{cm}^{3} \end{aligned}$ | $\begin{aligned} & \text { lb. } \\ & \text { per } \\ & \mathrm{ft}^{3} \end{aligned}$ | Tension， $\mathrm{kg} / \mathrm{mm}^{2}$ |  | Tension， $\mathrm{lb} / \mathrm{in}^{2}$ |  | Per cent |  |  | 竒号苞 |
| Tungsten， W 99.2 ＊ | $\left(\begin{array}{l}\text { Ingot sintered，} \\ \mathrm{D}=5.7 \mathrm{~mm} \text { or } 0.22 \mathrm{in} . \\ \text { Swaged rod，} \\ \mathrm{D}=0.7 \mathrm{~mm} \text { or } 0.03 \mathrm{in} . \\ \text { Drawn hard，} \\ \text { D }\end{array}\right.$ | 18.0 | 1124 | － | 12.7 151.0 | － | 18,000 215,000 | 0.0 | 0.0 28.0 | － | － |
|  | $\left\{\begin{array}{ccc} \mathrm{D}=0.029 & \mathrm{~mm} & \text { or } \\ 0.001414 i n . . . . & \\ \text { 0wnoed and drawn } \end{array}\right.$ | － | － |  | 415.0 | － | 590，000 | － | 65.0 | － | － |
|  | $\left\|\begin{array}{c} \text { Swaged and drawn hot } \\ 97.5 \% \text { reductiont... } \\ \text { Same as above and } \end{array}\right\|$ | － | － | － | 164．0 | － | 233，500 | 3.2 | 14.0 | － | － |
|  | $\left(\begin{array}{l}\text { equiaxed at } 200{ }^{\circ} \mathrm{C} \\ \text { in } \mathrm{H}_{2} \ddagger \ldots \ldots \ldots \ldots \ldots\end{array}\right.$ | － | － |  | 118.0 |  | 168，000 | 0.0 | 0.0 | － | － |
| Zinc，§Zn： | $\left\{\begin{array}{l}\text { Cast．．．．．．．．．．．．．．．．．} \\ \text { Coarse crystailine．．．．} \\ \text { Fine crystalline．．．．．．} \\ \text { Rolled（with grain or } \\ \text { direction of roilling）．} \\ \text { Rolled（across grain or } \\ \text { direction of rolling）．} \\ \text { Drawn hard．．．．．．．．}\end{array}\right.$ | 7.0 | 437 | （Impurities $\mathrm{Pb}, \mathrm{Fe}$ and Cd ） |  |  |  | － | － | － | － |
|  |  | 二 | － |  | 2.8 8.4 |  | $\underset{\text { 12，000 }}{4,000}$ | 二 | 二 | $4_{48}^{42} \text { to }$ | $\begin{aligned} & 8 \text { to } \\ & \text { 10 } \end{aligned}$ |
|  |  | － | － | 2.0 | 19.0 | 2，900 | 27，000 | － | － | － | － |
|  |  | － | － | 4.1 | 25.3 | 5，800 | 36，000 | － | － | － | － |
|  |  | 7.1 | 443 |  | 7.0 |  | 10，000 |  |  |  |  |

＊Commercial composition for incandescent electric lamp filaments containing thoria（ $\mathrm{ThO}_{2}$ ）approx．o． 75 per cent after Z Jeffries Am．Inst．Min．Eng．Bulletin 138，June， 1918.
$\dagger$ After Z Jefiries Am．Inst．Min．Eng．Bulletin 149，May，I919
$\ddagger$ Ordinary annealing treatment makes $W$ brittle，and severe working，below recrystallization or equiaxing tempera－ ture，produces ductility W rods which have been worked and recrystallized are stronger than sintered rods．The equiaxing temperature of worked tungsten，with a $5-\mathrm{min}$ ．exposure，varies from $2200^{\circ} \mathrm{C}$ for a work rod with 24 per cent reduction，to $1350^{\circ} \mathrm{C}$ tor a fine wire with 100 per cent reduction．Tungsten wire， $\mathrm{D}=0.635 \mathrm{~mm}$ or 0.025 in ．
§ Compression on cylinder 25.4 mm （ 1 in ．）by 65.1 mm （ 2.6 in ．），at 20 per cent deformation：
For spelter（cast zinc）free from Cd，av． $17.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or $24,500 \mathrm{lb} / \mathrm{in}^{2}$ ．
For spelter with Cd 0．26，av． $27.4 \mathrm{~kg} / \mathrm{mm}^{2}$ or $39,000 \mathrm{lb} / \mathrm{in}^{2}$ ．（See Proc．A．S．T．M．，Vol．13，pl．19．）
Modulus of rupture averages twice the corresponding tensile strength．
Shearing strength：rolled，averages $13.6 \mathrm{~kg} / \mathrm{mm}^{2}$ or $194,000 \mathrm{lb} / \mathrm{in}^{2}$ ．
Modulus of elasticity：cast， $7,750 \mathrm{~kg} / \mathrm{mm}^{2}$ or $11,025,000 \mathrm{lb} / \mathrm{in}^{2}$
Modulus of elasticity．rolled， $8450 \mathrm{~kg} / \mathrm{mm}^{2}$ or $\mathrm{I} 2,000000 \mathrm{lb} / \mathrm{in}^{2}$ ．（Moore，Bulletin 52，Eng．Exp．Sta．Univ．of Ill．）
（b）White Metal Bearing Alloys（Babbitt Metal）．
A．S．T．M．vol．xviii，I，p． 49 I.
Experimental permanent deformation values from compression tests on cylinders 31.8 mm （ $1_{\frac{1}{4}} \mathrm{in}$ ．）diam．by 63.5 mm （ $2 \frac{1}{2} \mathrm{in}$ ．）long，tested at $21^{\circ} \mathrm{C}$（ $70^{\circ} \mathrm{F}$ ．）（Set readings after removing loads．）

| $\begin{array}{\|l} \text { Al- } \\ \text { loy } \\ \text { No } \end{array}$ | Formula， per cent． |  |  |  | Pouring temp． |  | Weight． |  | Permanent deformation＠ $21^{\circ} \mathrm{C}$ |  |  |  |  |  | Hardness． |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | $\begin{aligned} & (@) 454 \mathrm{~kg} \\ & =1000 \mathrm{lb} . \end{aligned}$ | $\begin{aligned} & @ 2268 \mathrm{~kg} \\ & =5000 \mathrm{lb} . \end{aligned}$ |  | $\begin{aligned} & \text { @) } 4536 \mathrm{~kg} \\ & \stackrel{10,000 \mathrm{lb} .}{ } \end{aligned}$ |  |  |  |
|  | Sn |  | Cu | Pb |  |  | C | F． | $\mathrm{g} / \mathrm{cm}^{3}$ |  |  | lb．／ft ${ }^{3}$ | mm | in． | mm | in． | mm | in． |
|  | Tin Base． |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{2}$ 2 | 89.0 | 7.5 | 4.5 35 | 二 | 432 | 808 | 7.34 7.39 | 46 x | ． 0.000 | 0．0000 | ． 0.025 | －0．0010 | 0.380 .305 | 0.0150 .0120 | 28.6 28.3 | 12.8 12.7 |
| 3 | 83.3 | 8.3 | 8.3 | － | 491 | 916 | 7.46 | 465 | ． 025 | ． 0010 | ． 114 | ． 0045 | ． 180 | ． 070 | 34.4 | 15.7 |
| 4 5 | 75.0 65.0 | 12.0 |  | 10.0 | 360 350 | 680 | 7.52 7.75 | 469 484 | ． 013 | ． .0005 | ． 064 | ． 0025 | .230 .230 | ．0090 | 29.6 | 12.8 It． 8 |
|  |  | Lead B | Base． |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6 | 20.0 | 15.0 | 1.5 | 63.5 | 337 | 638 | 9.33 | 582 | ． 038 | ． 0015 | ． 127 | ． 0050 | ． 457 | ． 0180 | 24.3 | II．I |
| 7 | 10.0 | 15.0 |  | 75.0 | 329 | 625 | 9.73 | 607 | ． 025 | ． 010 | ． 127 | ． 0050 | ． 583 | ． 0230 | 24.1 | 11.7 |
|  |  | 15.0 |  | 80.0 | 329 | 625 | 10.04 |  | ． 051 | ． 0020 | ． 229 | ． 0090 | 1.575 | ． 0620 | 20.9 | 10.3 |
| ${ }^{9}$ | 5.0 | 10.0 | － | 85.0 | 319 | 616 | 10.24 | 640 | ． 102 | ． 0040 | ． 305 | ． 0120 | 2.130 | ． 0840 | 19.5 | 8.6 |
| 11 |  | 15.0 | 二 | 83．0 | 325 | 625 625 | 10.07 | 629 642 | .025 .025 | ． 0010 | ． 254 | ． .10100 | 3.910 3.020 | ． 1540 | 17.0 | 8.9 |
| 12 | － | 10.0 | － | 90.0 | 334 | 634 | 10.67 | 666 | 0.064 | 0.0025 | 0.432 | 0.0170 | 7.240 | 0.2850 | 14.3 | 6.9 6.4 |

[^11]Smithsonian Tables．

MECHANICAL PROPERTIES.
table 68. - Cement and Concrete.

## (a) Cement.

Cement: Specification Values (A.S. T. M. C9 to 17, Сio to o9, and C9 to 16T).
Minimum strengths based on tests of $645 \mathrm{~mm}^{2}$ ( $\mathrm{I} \mathrm{in}^{2}$ ) cross section briquettes for tension, and cylinders $50.8 \mathrm{~mm}(2 \mathrm{in}$.) diameter by 101.6 mm ( 4 in .) length for compression. Mortar, composed of 1 part cement to 3 parts Ottawa sand by volume; specimens kept in damp closet for first 24 hours and in water from then on until tested.

| Cement <br> (r: 3 mortar tested). | Specific gravity. | Age, days. | Tension. |  | Compression. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| Std. Portland. | 3.10 | 7 | 0.16 | 200 | 0.85 | 1,200 |
| White Portland. | 3.07 | 28 | . 24 | 300 | 1.60 | 2,000 |
| Natural Av. | 2.85 | ${ }_{8}^{7}$ | . 03 | 50 | - | - |
| Natural. | - | 28 | 0.09 | 125 | - | - |

(b) Cement and Cement Mortars.

Cement and Cement Mortars. - Bureau of Standards Experimental Values. Compressive Strengths of Portland cement mortars of uniform plastic consistency. Data from tests on $50.8 \mathrm{~mm}(2 \mathrm{in}$.) cubes stored in water. Sand: Potomac River, representative concrete sand.

| Cement. | Sand. | Water, per cent. | Age, days. | Compressive strength. |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Proportions by volume. |  |  |  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| I | $\bigcirc$ | 30.0 | 728 | 4.20 | 5,970 |
|  |  |  |  | 6.40 | 9,120 |
| I | I | 16.0 | 728 | 3.10 | 4,440 |
|  |  |  |  | 4.75 | 6,750 |
| I | 2 | 13.6 | 7 | 2.05 | 2,900 |
|  |  |  | 28 | 3.10 | 4,440 |
| I | 3 | 13.9 | 728 | I. 25 | 1,780 |
|  |  |  |  | 2.05 | 2,890 |
| I | 9 | I5. I | 728 | -. 10 | 120 |
|  |  |  |  | O. 15 | 200 |

Note. - (From Bureau of Standards Tech. Paper 58.) Neat cement briquettes mixed at plastic consistency (water 2 I per cent) show $0.52 \mathrm{~kg} / \mathrm{mm}^{2}$ or $740 \mathrm{lb} / \mathrm{in}^{2}$ tensile strength at 28 days' age;
I Cement: 3 Ottawa sand-mortar briquettes, mixed at plastic consistency (water 9 per cent) show $0.28 \mathrm{~kg} / \mathrm{mm}^{2}$ or $400 \mathrm{lb} / \mathrm{in}^{2}$ tensile strength at 28 days' age.

Smithsonian Tables.

TABLE 68 (continued).
(c) Concrett.

Concrete: Compressive strengths. Experimental values for various mixtures. Results compiled by Joint Committee on Concrete and Reinforced Concrete. Final Report adopted by the Committee July 1, 1916. Data are based on tests of cylinders 203.2 mm ( 8 in .) diameter and 406.4 mm ( x 6 in .) long at 28 days age. American Standard Concrete Compressive Strengths.

| Aggregate. | Units. | Mix. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 1:3 | 1: $4 \frac{1}{2}$ | 1: 6 | 1:731 | 1:9 |
| Granite, trap rock. . . . . . . <br> Gravel, hard limestone and hard sandstone. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $2 \cdot 3$ | 2.0 | I. 5 | 1.3 | 1.0 |
|  | $\mathrm{lb} / \mathrm{in}^{2}$ | 3300 | 2800 | 2200 | 1800 | 1400 |
|  | $\mathrm{kg} / \mathrm{mm}^{2}$ | 2.1 | 1.8 | 1.4 | I. 1 | 0.9 |
|  | $\mathrm{lb} / \mathrm{in}^{2}$ | 3000 | 2500 | 2000 | 1600 | 1300 |
| Soft limestone and soft sandstone. | $\mathrm{kg} / \mathrm{mm}^{2}$ | I. 5 | 1.3 | I.I | 0.8 | 0.7 |
|  | $\mathrm{lb} / \mathrm{in}^{2}$ | 2200 | 1800 | 1500 | 1200 | 1000 |
| Cinders. . . . . . . . . . . . . . . | $\mathrm{kg} / \mathrm{mm}^{2}$ | 0.6 | 0.5 | 0.4 | 0.4 | 0.3 |
|  | $\mathrm{lb} / \mathrm{ln}^{2}$ | 800 | 700 | 600 | 500 | 400 |

Note. - Mix shows ratio of cement (Portland) to combined volume of fine and coarse aggregate (latter as shown).

Committee recommends certain fractions of tabular values as safe working stresses in reinforced concrete design, which may be summarized as follows:
Bearing, 35 per cent of compressive strength;
Compression, extreme fiber, 32.5 per cent of compressive strength;
Vertical shearing stress 2 to 6 per cent of compressive strength, depending on reinforcing;
Bond stress, 4 and 5 per cent of compressive strength, for plain and deformed bars, respectively.
Modulus of Elasticity to be assumed as follows:

| For concrete with strength. |  | Assume modulus of elasticity. |  |
| :---: | :---: | :---: | :---: | :---: |
| $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | $\mathrm{~kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| up to 0.6 | up to 800 | 530 | 750,000 |
| 0.6 to 1.5 | 800 to 2200 | 1400 | $2,000,000$ |
| I .5 to 2.0 | 2200 to 2900 | 1750 | $2,500,000$ |
| over 2.0 | over 2900 | 2100 | $3,000,000$ |

## (See Joint Committee Report, Proc. A. S. T. M. v. XVII, 1917, p. 201.)

Edrtor's Note. - The values shown in the table above are probably fair values for the compressive strengths of concretes made with average commercial material, although higher results are usually obtained in laboratory tests of specimens with high grade aggregates. Observed values on $1: 2: 4$ gravel concrete show moduliof elasticity up to $3 \times 60 \mathrm{~kg} / \mathrm{mm}^{2}$ or $4,500,000 \mathrm{lb} / \mathrm{in}^{2}$ and compressive strengths to $4.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or $6000 \mathrm{lb} / \mathrm{in}^{2}$

Tensile strengths average ro per cent of values shown from compressive strengths.
Shearing strengths average from 75 to 125 per cent of the compressive strengths; the larger percentage representing the shear of the leaner mixtures (for direct shear, Hatt gives 60 to 80 per cent of crushing strength).
Compressive strengths of natural cement concrete average from 30 to 40 per cent of that of Portland cement concrete of the same proportioned mix.
Transverse strength: modulus of rupture of $1: 2 \frac{1}{2}: 5$ concrete at r and 2 months equal to one sixth crushing strength at same age (Hatt).
Weight of granite, gravel and limestone, $\mathrm{I}: 2: 4$ concretes averages about $2.33 \mathrm{~g} / \mathrm{cm}^{3}$ or $145 \mathrm{lb} / \mathrm{ft}^{3}$; that of cinder concrete of same mix is about $1.85 \mathrm{~g} / \mathrm{cm}^{3}$ or $115 \mathrm{lb} / \mathrm{ft}^{3}$

> Concrete, 1:2:4 Mix, Compressive Strengths at Various Ages.

Experimental Values: one part cement, two parts Ohio River sand and four parts of coarse aggregate as shown. Compressive tests madeon 203.2 mm ( 8 in .) diameter cylinders, 406.4 mm ( I 6 in .) long. (After Pittsburgh Testing Laboratory Results. See Rwy Age, vol. 64, Jan. 18, 1918, pp. 165-166.)


Note. - Maximum and minimum test results varied about 5 per cent above or below average values shown above. Smithsonian Tables.

TABLE 69．－Stone and Clay Products．

| Stone． | Weight， average． |  | Compression． Ultimate strength． |  |  | Flexure． Modulus ofrupture． |  |  | Shear． Ulimate strength |  |  | Flexure， modulus of elasticity |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Average． |  |  | Average． |  |  | Average． |  |  | Average． |  |  |
|  | $\stackrel{\square}{E}$ | $\stackrel{3}{3}$ | 耍 | $\stackrel{\square}{\square}$ |  |  | 号 |  | \％ | \＃ |  |  | $\mathrm{lb} / \mathrm{in}^{2}$ |  |
| Granite．． | 2.6 | 165 |  | 20，200 |  |  | 1600 | 30 | I． 60 |  |  |  | 7，500，000 | 25 |
| Marble．． | 2.7 | 170 | 8.85 | 12，600 | 25 | I． 05 | 1500 | 50 | 0.90 | 1300 | 25 |  | 8，200，000 | 50 |
| Limestone | 2.6 | 160 | 6.30 | 9，000 | 95 | 0.85 | 1200 | 100 | I． 00 | 1400 | 45 | 5900 | 8，400，000 | 65 |
| Sandstone． |  | I35 | 8.80 | 12，500 |  | I． 05 | 1500 | 55 | I． 20 | 1700 | 45 | 2300 | 3，300，000 | 100 |
| ＊Values based on tests of American building stones from upwards of twenty－five localities， made at Watertown（Mass．）Arsenal（Moore，p．184）．Each value shown under＂Range＂ is one half the difference between maximum and minimum locality averages expressed as a percentage of the average for the stone． |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

（b）Strength and Stiffness of Bavarian Building Stone．＊

| Stone． | Weight， average． |  | Compression． Ultimate strength． |  |  | Flexure． Modulus of rupture． |  |  | Shear． Ultimate Strength．$\dagger$ |  |  | Flexure． Modulus of elasticity． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Average． |  |  | Average． |  |  | Average． |  |  | Average． |  |  |
|  | $\frac{\pi}{8}$ | $\frac{\cong}{3}$ | $\begin{aligned} & \text { \# } \\ & \frac{1}{g} \\ & \text { Eq } \end{aligned}$ | $\stackrel{\text { E }}{\text { ¢ }}$ |  | 首 B B | $\xrightarrow{\text { an }}$ |  | \％ E E B | $\stackrel{\ddot{E}}{\cong}$ |  | $\begin{aligned} & \text { In } \\ & E \\ & \text { n } \end{aligned}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |  |
| Granite．． | 2.66 | 165 | 13.70 | 19，500 |  | 0.90 | 1300 | 5 | 1．00 | 1420 | $\bigcirc$ | 1600 | 2，300，000 | 30 |
| Marble $\ddagger$. | 2.16 | 135 | 5.60 | 8，000 | 15 | 0． 30 | 450 | － | 0.45 | 620 | 50 | 3450 | 4，900，000 |  |
| Limestone | 2.48 | ${ }^{155}$ | 8．10 | II，500 | 5 | т．ro | 1550 | 45 | 0.60 | 870 | 20 | 2350 | 3，350，000 | 90 |
| Sandstone | 2.30 | 145 | 8.10 | 11，500 | 75 | 0.45 | 650 | 55 | 0．50 | 680 | 35 | 2500 | 3，550，000 | 35 |

＊Values based on careful tests by Bauschinger，＂Communications，＂Vol．ıо．
$\dagger$ Shearing strength determined perpendicular to bed of stone．
$\ddagger$ Values are for Jurassic limestone．

General Notes．－i．Later transverse strength（flexure）tests on Wisconsin building stones （Johnson＇s＂Materials of Construction，＂1918 ed．，p．255）show moduli of rupture as follows： Granite， 1.90 to $2.75 \mathrm{~kg} / \mathrm{mm}^{2}$ or 2710 to $3910 \mathrm{lb} / \mathrm{in}^{2}$ ；limestone， 0.80 to $3.30 \mathrm{~kg} / \mathrm{mm}^{2}$ or 1160 to $4660 \mathrm{lb} / \mathrm{in}^{2}$ ；sandstone， 0.25 to $0.95 \mathrm{~kg} / \mathrm{mm}^{2}$ or 360 to $1320 \mathrm{lb} / \mathrm{in}^{2}$ ．

2．Good slate has a modulus of rupture of $4.90 \mathrm{~kg} / \mathrm{mm}^{2}$ or $7000 \mathrm{lb} / \mathrm{in}^{2}$（loc．cit．，p．257）．

[^12]| Brick - description. | $\begin{gathered} \text { Absorption } \\ \text { average } \\ \text { per cent. } \end{gathered}$ | Compression. Min. ult. strength. |  | Flexure. <br> Min. modulus rupture |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| Class A (Vitrified). . | 5 | 3.50 | 5000 | 0.65 | 900 |
| Class B (Hard burned). | 12 | 2.45 | 3500 | 0.40 | 600 |
| Class C (Common firsts) | 18 | 1.40 | 2000 | 0.30 | 400 |
| Class D (Common). | - | 1.05 | 1500 | 0.20 | 300 |

* After A. S. T. M. Committee C-3, Report 1913, and University laboratories' tests for Committee $\mathrm{C}-3$ (Johnson, p. 28I).
(d) Strength in Compression of Brick Piers and of Terra-cotta Block Piers.

Tabular values are based on test data from Watertown Arsenal, Cornell University, U. S. Bureau of Standards, and University of Ill. (Moore, p. 185).

| Brick or block used. | Mortar. | Compression.* Av. ult. strength. |  |
| :---: | :---: | :---: | :---: |
|  |  | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| Vitrified brick. | I part P. $\dagger$ cement $: 3$ parts sand. | 1.95 | 2800 |
| Pressed (face) brick. | x part $P$. cement $: 3$ parts sand | r. 40 | 2000 |
| Pressed (face) brick. | I part lime: 3 parts sand. | 1.00 | 1400 |
| Common brick. | I part P. cement : 3 parts sand. | 0.70 | 1000 |
| Common brick | I part lime : 3 parts sand. | 0.50 | 700 |
| Terra-cotta brick | x part P. cement : 3 parts sand. | 2.10 | 3000 |

[^13](e) Strength of Compression of Various Bricks.

Reasonable minimum average compressive strengths for other types of brick than building brick are noted by Johnson, "Materials of Construction," pp. 289 ff ., as follows:

| Brick. | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ |
| :---: | :---: | :---: |
| sand-lime | 2.10 | 3000 |
| sand-lime (German) | I. 53 | 2 L 0 (av. 255 tests) |
| paving | 5.60 | 8000 |
| acid-refractory | 0.70 | 1000 |
| silica-refractory | 1.40 | 2000 |

The specific gravity of brick ranges from I .9 to 2.6 (corresponding to 120 to $\mathrm{I} 60 \mathrm{lb} / \mathrm{ft}^{3}$ ).
Building tile: hollow clay blocks of good quality, - minimum compressive strength: $0.70 \mathrm{~kg} / \mathrm{mm}^{2}$ or $1000 \mathrm{lb} / \mathrm{in}^{2}$. Tests made for A. S. T. M. Committee C-io (A. S. T. M. Proc. XVII, I, p. 334) show compressive strengths ranging from 0.45 to $8.70 \mathrm{~kg} / \mathrm{mm}^{2}$ or 640 to $12,360 \mathrm{lb} / \mathrm{in}^{2}$ of net section, corresponding to 0.05 to $4.20 \mathrm{~kg} / \mathrm{mm}^{2}$ or 95 to 6000 $\mathrm{lb} / \mathrm{in}^{2}$ of gross section. Recommended safe loads (Marks, "Mechanical Engineers' Handbook," p. 625) for effective bearing parts of hollow tile: hard fire-clay tiles $0.06 \mathrm{~kg} / \mathrm{mm}^{2}$ or $80 \mathrm{lb} . / \mathrm{in}^{2}$; ordinary clay tiles $0.04 \mathrm{~kg} / \mathrm{mm}^{2}$ or $60 \mathrm{lb} / \mathrm{in}^{2}$; porous terracotta tiles $0.03 \mathrm{~kg} / \mathrm{mm}^{2}$ or $40 \mathrm{lb} / \mathrm{in.}^{2}$ The specific gravity of tile ranges from 1.9 to 2.5 corresponding to a weight of 120 to $155 \mathrm{lb} / \mathrm{ft}^{3}$.

Table 70.
MECHANICAL PROPERTIES.
TABLE 70. - Rubber and Leather.
(a) Rubber, - Sheet.*

| Grade. | Ultimate strength. |  |  |  | Ult, elongation. |  | Set. $\ddagger$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Longitudinal. $\dagger$ |  | Transverse. |  | Longit. | Transv. | Longit. | Transv. |
|  | kg/mm ${ }^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | $\mathrm{kg} / \mathrm{mm}^{2}$ | $\mathrm{lb} / \mathrm{in}^{2}$ | per cent. |  | per cent. |  |
| I | 1.92 | 2730 | 1.8I | 2575 | 630 | 640 | II. 2 | $7 \cdot 3$ |
| 2 | 1. 45 | 2070 | 1.43 | 2030 | 640 | 670 | 6.0 | 5.0 |
| 3 | 0.84 | 1200 | 0.89 | 1260 | 480 | 555 | 22.1 | 16.3 |
| 4 | 1.30 | 1850 | I. 20 | 1700 | 410 | 460 | 34.0 | 24.0 |
| 5 | 0.48 | 690 | 0.36 | 510 | 320 | 280 | 27.5 | 25.0 |
| 6 | 0.62 | 880 | 0.48 | 690 | 315 | 315 | $34 \cdot 3$ | 25.9 |

* Data from Bureau of Standards Circular 38.
$\dagger$ Longitudinal indicates direction of rolling through the calendar.
$\ddagger$ Set measured after 300 per cent elongation for I minute with I minute rest.
The specific gravity of rubber averages from 0.95 to I .25 , corresponding to an average weight of 60 to $80 \mathrm{lb} / \mathrm{ft}^{3}$.

Four-ply rubber belts show an average ultimate tensile strength of 0.63 to $0.65 \mathrm{~kg} / \mathrm{mm}^{2}$ or 890 to $930 \mathrm{lb} . / \mathrm{in}^{2}$ (Benjamin), and a working tensile stress of 0.07 to $0.11 \mathrm{~kg} / \mathrm{mm}^{2}$ or 100 to 150 $\mathrm{lb} . / \mathrm{in}^{2}$ is recommended (Bach).

> (b) Leather, - Belting.

Oak tanned leather from the center or back of the hide:
$\underset{\text { (Marks, p. } 622 \text { ) }}{\text { Minimum tensile strengths of belts }}\left\{\begin{array}{l}\text { single } 2.8 \mathrm{~kg} / \mathrm{mm}^{2} \text { or } 4000 \mathrm{lb} . / \mathrm{in}^{2} \\ \text { double } 2.5 \mathrm{~kg} / \mathrm{mm}^{2} \text { or } 3600 \mathrm{lb} . / \mathrm{in}^{2}\end{array}\right.$
Maximum elongation for one hour application of $\{$ single 13.5 per cent $1.6 \mathrm{~kg} / \mathrm{mm}^{2}$ or $2250 \mathrm{lb} . / \mathrm{in}^{2}$ stress $\quad\left\{\begin{array}{l}\text { double } 12.5 \text { per cent. }\end{array}\right.$

Modulus of elasticity of leather varies from an average value of $12.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $17,800 \mathrm{lb} / \mathrm{in}^{2}$ (new) to $22.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $32,000 \mathrm{lb} . / \mathrm{in}^{2}$ (old).
Chrome leather has a tensile strength of 6.0 to $9.1 \mathrm{~kg} / \mathrm{mm}^{2}$ or 8500 to $12,900 \mathrm{lb} / \mathrm{in}^{2}$.
The specific gravity of leather varies from 0.86 to r .02 , corresponding to a weight of 53.6 to $63.6 \mathrm{lb} . / \mathrm{ft}^{3}$.

## MECHANICAL PROPERTIES.

TABLE 71. - Manila Rope.
Manila Rope, Weight and Strength - Specification Values. From U. S. Government Standard Specifications adopted April 4, 1918.

Rope to be made of manila or Abaca fiber with no fiber of grade lower than U. S. Government Grade I, to be three-strand, ${ }^{*}$ medium-laid, with maximum weights and minimum strengths shown in the table below, lubricant content to be not less than 8 nor more than 12 per cent of the weight of the rope as sold.

| Approximate diameter. |  | Circumference. |  | Maximum net weight. |  | Minimum breaking strength. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| mm | in. | mm | in. | kg/m | $\mathrm{lb} / \mathrm{ft}$. | kg | lb . |
| 6.3 | $\frac{1}{4}$ | 19.1 | $\frac{3}{4}$ | 0.029 | 0.0196 | 320 | 700 |
| 7.9 | ${ }^{5}$ | 25.4 | 1 | 0.044 | 0.0286 | 540 | 1,200 |
| 9.5 | $\frac{3}{8}$ | 28.6 | I $\frac{1}{8}$ | 0.061 | 0.0408 | 660 | 1,450 |
| II.I | $\frac{7}{16}$ | 31.8 | $1{ }^{\frac{1}{4}}$ | 0.080 | 0.0539 | 790 | 1,750 |
| II. 9 | $\frac{1}{3} \frac{5}{2}$ | 34.9 | $1 \frac{3}{8}$ | 0.095 | 0.0637 | 950 | 2,100 |
| 12.7 | $\frac{3}{2}$ | 38.1 | $1 \frac{1}{2}$ | -. 109 | 0.0735 | 1, i Io | 2,450 |
| 14.3 | $\frac{9}{16}$ | 44.5 | 1 ${ }^{\frac{3}{4}}$ | -. 153 | 0.1029 | 1,430 | 3,150 |
| 15.9 | $\frac{5}{8}$ | 50.8 | 2 | -. 195 | 0.1307 | ェ,8ı0 | 4,000 |
| 19.1 | $\frac{3}{4}$ | 57.2 | $2 \frac{1}{4}$ | 0.24 I | -.16I7 | 2,220 | 4,900 |
| 20.6 | ${ }_{1}^{13}$ | 63.5 | $2 \frac{1}{2}$ | 0. 284 | 0.1911 | 2,680 | 5,900 |
| 22.2 | $\frac{7}{8}$ | 69.9 | $2 \frac{3}{4}$ | 0.328 | 0.2205 | 3,170 | 7,000 |
| 25.4 | 1 | 76.2 | 3 | 0. 394 | 0. 2645 | 3,720 | 8,200 |
| 27.0 | I 16 | 82.6 | $3^{\frac{1}{4}}$ | 0.459 | 0.3087 | 4,310 | 9,500 |
| 28.6 | $1 \frac{1}{8}$ | 88.9 | $3^{\frac{1}{2}}$ | 0.525 | -. 3528 | 4,990 | 11,000 |
| 31.8 | $\mathrm{I}^{\frac{1}{4}}$ | 95.2 | $3^{\frac{3}{4}}$ | 0.612 | 0.4115 | 5,670 | 12,500 |
| $33 \cdot 3$ | ${ }_{1}{ }_{16}^{5}$ | IOI. 6 | 4 | 0.700 | 0.4703 | 6,440 | 14,200 |
| 34.9 | $1{ }^{3}$ | 108.0 | $4^{\frac{1}{4}}$ | 0.787 | -. 5290 | 7,260 | 16,000 |
| 38.1 | $1 \frac{1}{2}$ | 114.3 | $4^{\frac{1}{2}}$ | 0.875 | 0. 5879 | 7,940 | 17,500 |
| 39.4 | $\mathrm{I}_{19}{ }^{9}$ | 120.7 | $4^{\frac{3}{4}}$ | 0.984 | 0.6615 | 8,840 | 19,500 |
| 41.2 | 15 | 127.0 | 5 | 1.094 | -. 7348 | 9,750 | 21,500 |
| $44 \cdot 5$ | I ${ }^{3}$ | 140.0 | $5^{\frac{1}{2}}$ | 1.312 | -.88ı8 | 11,550 | 25,500 |
| 50.8 | 2 | I 52.4 | 6 | I. 576 | 1.059 | 13,610 | 30,000 |
| 52.4 | $2 \frac{1}{16}$ | 165.1 | $6 \frac{1}{2}$ | 1.823 | I. 225 | 15,420 | 34,000 |
| 57.2 | $2 \frac{1}{4}$ | 177.8 | 7 | 2.144 | $1.44{ }^{1}$ | 17,460 | 38,500 |
| 63.5 | $2 \frac{1}{2}$ | 190.5 | $7 \frac{1}{2}$ | 2.450 | I. 646 | 19,730 | 43,500 |
| 66.7 | $2 \frac{5}{8}$ | 203.2 | 8 | 2.799 | 1.88 r | 22,220 | 49,000 |
| 73.0 | $2 \frac{7}{8}$ | 215.9 | 81 $\frac{1}{2}$ | 3.136 | 2. 107 | 24,940 | 55,000 |
| 76.2 | 3 | 228.6 | 9 | $3 \cdot 543$ | 2.38 I | 27,670 | 61,000 |
| 79.4 | $3 \frac{1}{8}$ 。 | 241.3 | $9^{\frac{1}{2}}$ | 3.936 | 2.645 | 30,390 | 67,000 |
| 82.5 | $3{ }^{\frac{1}{4}}$ | 254.0 | 10 | 4.375 | 2.940 | 33,1 10 | 73,000 |

* Four-strand, medium-laid rope when ordered may run up to $7 \%$ heavier than three-strand rope of the same size, and must show $95 \%$ of the strength required for three-strand rope of the same size.

| Common and botanical name. | Specific gravity, oven-dry, based on |  | Static bending. |  |  | Impact bending. |  | Compression. |  |  | Shear. | Tension. | Hardness. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | $\underbrace{\text { En }}_{\substack{\text { En }}}$ |  | Parallel to grain. |  |  | $\begin{aligned} & \text { Parallel to grain } \\ & \text { ult. st. } \mathrm{kg} / \mathrm{mm}^{2} \end{aligned}$ |  | Load to $\frac{1}{2}$ imbed II. 3 mm <br> d. ball |  |
|  | vol. when green. | vol. ovendry. |  |  |  | $\frac{:-3}{1}$ |  | limit <br> kg / | $\mathrm{nm}^{2}$ |  |  |  | $\begin{gathered} \text { end } \\ \mathbf{k g} \end{gathered}$ | $\begin{aligned} & \text { side } \\ & \text { kg } \end{aligned}$ |
| 1 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Alder (Al | 0.37 | 0.43 | 2.65 | 4.55 | 8.30 | 5.60 | 0.56 | 1. 85 | 2.10 | 0.22 | 0.54 | 0.27 | 250 | 20 |
| Ash, black. . . . . . (Fraxinus nigra) | 0.46 | 0.53 | 1.85 | 4.20 | 720 | 5.10 | 0.8 I | 1.15 | 1. 60 | 0.31 | 0.61 | 0.35 | 270 | 250 |
| Ash, white (forest grown) (Fraxinus americana) | 0.52 | 0.60 | 3.45 | 6.4 | 950 | 8.25 | 0.91 | 2.30 | 2.70 | 0.57 | 0.89 | 0.44 | 455 | 401 |
| Ash, white (second growth) (Fraxinus americana) | 0.58 | 0.71 | 4.30 | 7.60 | 1150 | 9.70 | 1.19 | 2.70 | 2.90 | 0.56 | r. 13 | 0. 56 | 515 | 490 |
| Aspen. (Populus tremuloides) | 0.36 | 0.42 | 2.05 | $3 \cdot 75$ | 590 | 4.85 | 0.71 | 1.10 | 1.50 | 0.14 | 0.44 | 0.13 | 120 | 145 |
| Basswood............. <br> (Tilia americana) | 0.33 | 0.40 | 1.90 | 3.50 | 725 | $4 \cdot 35$ | 0.43 | 1.20 | 1. 55 | 0.15 | 0.43 | 0.20 | 125 | 115 |
| Beech. (Fagus atropunicea) | 0.54 | 0.66 | 3.15 | 5.80 | 875 | 7.30 | 1.02 | 1.80 | 2.30 | 0.43 | 0.85 | 0.56 | 430 | 370 |
| Birch, paper. <br> (Betula papyrifera) | 0.47 | 0.60 | 2.05 | 4.10 | 710 | $5 \cdot 50$ | 1.14 | 1.20 | 1. 55 | 0.21 | -. 56 | 0.27 | 180 | 220 |
| Birch, yellow. (Betula lutea) | 0.54 | 0.66 | 3.25 | 6.05 | 1080 | 8.25 | 1.02 | 1.90 | 2.40 | 0.32 | 0.78 | 0.34 | 370 | 340 |
| Butternut.................. . . <br> (Juglans cinerea) | 0.36 | 0.40 | 2.05 | 3.80 | 680 | 5.15 | 0.61 | 1.40 | 1.70 | 0.19 | -. 53 | 0.30 | 185 | 175 |
| Cherry, black. (Prunus serotina) | 0.47 | 0. 53 | 2.95 | 5.65 | 920 | 7.20 | 0.84 | 2.10 | 2.50 | 0.31 | 0.80 | 0.40 | 340 | 300 |
| Chestnut................... . . (Castanea dentata) | 0.40 | 0.46 | 2.20 | 3.95 | 655 | 5.55 | -.6I | I. 45 | 1.75 | 0.27 | 0.56 | 0.30 | 240 | 190 |
| Cottonwood. <br> (Populus deltoides) | 0.37 | 0.43 | 2.05 | 3.75 | 710 | 5.05 | 0. 53 | 1.25 | 1. 60 | 0.17 | 0.48 | 0.29 | 175 | 155 |
| Cucumber tree............. . <br> (Magnolia acuminata) | 0.44 | 0.52 | 2.95 | 5.20 | 1100 | 6.55 | 0.76 | 1.95 | 2.20 | 0.29 | 0.70 | 0.31 | 270 | 235 |
| Dogwood (flowering)...... (Cornus florida) | 0.64 | 0.80 | 3.40 | 6.20 | 830 | 5.00 | 1.47 | - | 2.55 | 0.73 | 1.07 | - | 640 | 640 |
| Elm, cork. . . . . . . . . . . . . . . <br> (Ulmus rasemosa) | 0.58 | 0.66 | 3.25 | 6.70 | 840 | 7.75 | I. 27 | 2.00 | 2.70 | -0. 53 | 0.89 | 0.47 | 445 | 450 |
| Elm, white. <br> (Ulmus americana) | 0.44 | 0.54 | 2.55 | 4.85 | 725 | 5.70 | 0.86 | 1.60 | 2.00 | 0.28 | 0.65 | 0.39 | 275 | 250 |
| Gum, blue. <br> (Eucalyptus globulus) | 0.62 | 0.80 | 5.35 | 7.85 | 1430 | 10.00 | 1.02 | 3.40 | 3.70 | 0.72 | 1.09 | 0.45 | 595 | 610 |
| Gum, cotton. . . . . . . . . . . . <br> (Nyssa aquatica) | 0.46 | 0.52 | 2.95 | 5.15 | 740 | 6.30 | 0.76 | 1.95 | 2.40 | 0.42 | 0.84 | 0.42 | 365 | 320 |
| Gum, red. <br> (Liquidambar styraciflua) | 0.44 | 0.53 | 2.60 | 4.80 | 810 | 7.05 | 0.84 | 1.70 | 1.95 | 0.32 | 0.75 | 0.36 | 285 | 235 |
| Hickory pecan............. <br> (Hicoria pecan) | 0.60 | 0.69 | 3.65 | 6.90 | 960 | 8.65 | 1.35 | 2.15 | 2.80 | 0.63 | 1.04 | 0.48 | 575 | 595 |
| Hickory, shagbark . . . . . . . . <br> (Hicoria ovata) | 0.64 | - | 4.15 | 7.75 | 1105 | 10.10 | 1.88 | 2.40 | 3.20 | 0.70 | 0.93 | - | - | - |
| Holly, American . . . . . . . . . <br> (Ilex opaca) | 0. 50 | 0.61 | 2.40 | 4.55 | 630 | 6.25 | 1.30 | 1.40 | 1.85 | 0.43 | 0.80 | 0.43 | 390 | 360 |
| Laurel, mountain . . . . . . . . . <br> (Kalmia latifolia) | 0.62 | 0.74 | 4.10 | 5.90 | 650 | 7.20 | 0.8I | - | 3.00 | 0.78 | 1.18 | - | 635 | 590 |
| Locust, black. <br> (Robinia pseudacacia) | 0.66 | 0.71 | 6.20 | 9.70 | 1300 | 12.90 | I. 12 | 4.40 | 4.80 | 1.OI | 1.24 | 0.54 | 740 | 715 |
| Locust, honey. (Gleditsia triacanthos) | 0.60 | 0.67 | 3.95 | 7.20 | 910 | 8.30 | 1.20 | 2.35 | 3.10 | 1.00 | I. 17 | 0.66 | 655 | 630 |
| Magnolid (evergreen)...... <br> (Magnolia foetida) | 0.46 | 0.53 | 2.55 | 4.80 | 780 | 6.20 | 1.37 | 1. 55 | 1.90 | 0.42 | 0.73 | 0.43 | 355 | 335 |
| Maple, silver. . . . . . . <br> (Acer saccharinum) | 0.44 | 0.51 | 2.20 | 4.10 | 660 | 4.80 | 0.74 | I. 35 | 1.75 | 0.32 | 0.74 | 0.39 | 305 | 270 |
| Maple, sugar........ <br> (Acer saccharum) | 0.56 | 0.66 | 3.50 | 6.40 | 1040 | 8.50 | 0.91 | 2.20 | 2.80 | 0.53 | 0.97 | 0.54 | 455 | 415 |
| Oak, canyon live.......... . (Quercus chrysolepsis) | 0.70 | 0.84 | 4.45 | 7.45 | 945 | 7.90 | 1. 20 | 2.85 | $3 \cdot 30$ | 1.04 | 1.20 | 0.63 | 720 | 715 |
| Oak, red................... . . <br> (Quercus rubra) | 0.56 | 0.65 | 2.60 | 5.40 | 910 | 7.30 | 1.04 | 1.65 | 2.25 | 0.51 | 0.79 | 0. 52 | 465 | $430^{\circ}$ |
| Oak, white. $\qquad$ (Quercus alba) | 0.60 | 0.71 | 3.30 | 5.85 | 880 | 7.55 | 1.07 | 2.10 | 2.50 | 0.59 | 0.88 | 0.54 | 510 | 480 |
| Persimmon................. . <br> (Diospyros virginiana) | 0.64 | 0.78 | 3.95 | 7.05 | 965 | 8.50 | I. 04 | 2.15 | 2.95 | 0.78 | 1.03 | 0.54 | 565 | 580 |
| Poplar, yellow. . . . . . . . . . . <br> (Liriodendron tulipifera) | 0.37 | 0.42 | 2.25 | 3.95 | 850 | 5.65 | 0.43 | 1.40 | 1.80 | 0.22 | 0.56 | 0.32 | 190 | 155 |
|  <br> (Platanus occidentalis) | 0.46 | 0.54 | 2.30 | 4.60 | 745 | 6.20 | 0.84 | 1.70 | 2.00 | 0.32 | 0.71 | 0.44 | 320 | 275 |
| Walnut, black. (Juglans nigra) | 0.51 | 0.56 | 3.80 | 6.70 | 1000 | 8.40 | 0.94 | 2.55 | 3.05 | 0.42 | 0.86 | 0.43 | 435 | 410 |
| Willow, black.............. . (Salix nigra) | 0.34 | 0.41 | 1.25 | 2.75 | 395 | 3.60 | 0.91 | 0.70 | 1.05 | 0.15 | 0.44 | 0.30 | 160 | 165 |


| Common and botanical name． | Specific gravity， oven－dry， based on |  | Static bending． |  |  | Impact bend－ ing． |  | Compression |  |  | Shear | Ten－ sion． | Hardness． |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | $\begin{aligned} & \text { 关 } \\ & \text { 을 } \\ & \frac{0}{7} 60 \end{aligned}$ |  |  |  | $\begin{aligned} & \mathrm{Pa} \\ & \text { to } \end{aligned}$ | $\begin{aligned} & \text { allel } \\ & \text { rain. } \end{aligned}$ |  |  |  |  | do <br> bed <br> mm <br> all |
|  | when green． | oven－ dry． | $\frac{B}{A}$ | 发鹪 |  | $\frac{\tilde{A}}{A}$ | Ny | $\frac{\operatorname{limi}}{\mathrm{k}}$ |  |  |  |  | $\begin{gathered} \text { end } \\ \mathrm{kg} \end{gathered}$ | side kg |
|  | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| Cedar，incense． $\qquad$ （Libocedrus decurrens） | 0.35 | 0.36 | 2.75 | $4 \cdot 35$ | 590 | 5.15 | 0.43 | 2.00 | 2.20 | 0.32 | 0.53 | 0.20 | 260 | 175 |
| Cedar，Port Orford，．．．．．． | 0.41 | 0.47 | 2.75 | 4.80 | 1055 | 6.55 | 0.64 | 2.10 | 2.30 | 0.27 | 0.62 | 0.17 | 255 | 220 |
| （Chamaecyparis lawsoniana） Cedar，western red．．．．．．．． <br> （Thuja plicata） | 0.31 | 0.34 | 2.30 | 3.65 | 670 | 5.05 | 0.43 | 1.75 | 2.00 | 0.22 | 0.51 | 0.15 | 195 | I18 |
| Cedar，white <br> （Thuja occidentalis） | 0.29 | 0.32 | r． 85 | 2.95 | 450 | 3.75 | 0.38 | 1.00 | 1． 40 | 0.20 | 0.44 | 0.17 | 145 | 104 |
| Cypress，bald． $\qquad$ <br> （Taxodium distichum） | 0.41 | 0.47 | 2.80 | 4.80 | 835 | 5.60 | 0.61 | 2.20 | 2.45 | 0.33 | 0.58 | 0.20 | 215 | 175 |
| Fir，amabilis． <br> （Abies amabilis） | 0.37 | 0.42 | 2.75 | 4.45 | 915 | 5.50 | 0.53 | 1.70 | 2.00 | 0.22 | 0.47 | 0.17 | 165 | 140 |
| Fir，balsam． （Abies balsamea） | 0.34 | 0.41 | 2.10 | 3.45 | 675 | 4.85 | 0.41 | －1． 55 | 1.70 | 0.15 | 0.43 | 0.23 | 135 | 135 |
| Fir，Douglas（I）．． （Pseudotsuga taxifolia） | 0.45 | 0.52 | 3.50 | $5 \cdot 50$ | Irio | 6.60 | 0.63 | 2.40 | 2.80 | 0.37 | 0.64 | 0.14 | 230 | 215 |
| Fir，Douglas（2）．．．．．．．．．．． <br> （Pseudotsuga taxifolia） | 0.40 | 0.44 | 2.55 | 4.50 | 830 | 6.45 | 0.51 | 1.80 | 2． 10 | 0.32 | 0.62 | 0.25 | 205 | I80 |
| Fir，grand．．．．．．．．．．．．．．．． （Abies grandis） | 0.37 | 0.42 | 2.55 | $4 \cdot 30$ | 915 | 5.70 | －． 56 | 1.90 | 2.10 | 0.24 | 0.53 | 0．16 | 190 | 165 |
| Fir，noble． <br> （Abies nobilis） | 0.35 | 0.41 | 2.40 | 4.00 | 900 | 5.55 | 0． 5 r | 1.70 | 1.90 | 0.22 | 0.49 | －． 13 | 135 | II5 |
| Fir，white． （Abies concolor） | 0.35 | 0.44 | 2.75 | 4.20 | 795 | 5.05 | 0.46 | 1.85 | 1.95 | 0.31 | 0.51 | －．18 | 175 | 150 |
| Hemlock，eastern． <br> （Tsuga canadensis） | 0.38 | 0.44 | 2.95 | 4.70 | 790 | 5.55 | 0.51 | 1.90 | 2.30 | 0.35 | 0.62 | 0.18 | 230 | 185 |
| Hemlock，western （Tsuga heterophylla） | 0.38 | 0.43 | 2.40 | 4.30 | 835 | 5.50 | 0.51 | r． 60 | 2.05 | 0.25 | 0.57 | 0．18 | 245 | 195 |
| Larch，western． <br> （Larix occidentalis） | 0.48 | 0.59 | 3.25 | 5.25 | 950 | 6.60 | 0.6 r | 2.30 | 2.70 | 0.39 | 0.65 | 0．16 | 215 | 205 |
| Pine，Cuban． <br> （Pinus heterophylla） | －． 58 | 0.68 | 3.95 | ${ }^{\circ} 6.20$ | II 50 | 7.95 | 0.94 | 2.80 | 3.15 | 0.41 | 0.72 | 0.20 | 260 | 285 |
| Pine，loblolly． <br> （Pinus taeda） | 0.50 | 0.59 | 3.10 | $5 \cdot 30$ | 970 | 6.70 | 0.8 r | 2.00 | 2.50 | 0.39 | 0.63 | 0.20 | I85 | 205 |
| Pine，lodgepole． <br> （Pinus contorta） | 0.38 | 0.44 | 2.10 | 3.85 | 760 | 5.05 | 0．51 | I． 50 | 1． 85 | 0.22 | 0.49 | 0.15 | 145 | 150 |
| Pine，longleaf ．．．．．．．．．．．．．． <br> （Pinus palustris） | 0.55 | 0.64 | 3.80 | 6.10 | I150 | 7.60 | 0.86 | 2.70 | 3.10 | 0.42 | 0.75 | 0.20 | 250 | 270 |
| Pine，Norway $\qquad$ <br> （Pinus resinosa） | 0.44 | 0.51 | 2.60 | 4.50 | 970 | 5.35 | 0.71 | 1.75 | 2.20 | 0.25 | 0.55 | 0.13 | 165 | 155 |
| Pine，pitch． <br> （Pinus rigida） | 0.47 | 0． 54 | 2.60 | 4.70 | 790 | 6.40 | 0.74 | 1.50 | 2.15 | 0.36 | 0.67 | 0.25 | 210 | 220 |
| Pine，shortleaf． （Pinus echinata） | 0.50 | 0.58 | 3.15 | 5.65 | 1020 | 7.90 | 0.99 | 2.50 | 2.70 | 0.34 | 0.63 | 0.23 | 220 | 255 |
| Pine，sugar．．．．．．．．．．．．．． <br> （Pinus lambertiana） | 0.36 | 0.39 | 2.30 | 3.75 | 685 | 4.70 | 0.43 | 1.65 | 1.85 | 0.25 | 0.50 | 0．19 | 150 | 145 |
| Pine，western white．．．．．．． （Pinus monticola） | 0.39 | 0.45 | 2.45 | 4.00 | 935 | 5.35 | 0.58 | 1.95 | 2.15 | 0.21 | 0.50 | －． 18 | 150 | 150 |
| Pine，western yellow．．．．．．． <br> （Pinus ponderosa） | 0.38 | 0.42 | 3.20 | 3.65 | 710 | $4 \cdot 70$ | 0.48 | 1.45 | I． 75 | 0.24 | 0.48 | 0． 20 | 140 | 145 |
| Pine，white． <br> （Pinus strobus） | 0.36 | 0.39 | 2.40 | 3.75 | 750 | 4.55 | 0.46 | 1.65 | 1.90 | 0.22 | 0.45 | 0.18 | 135 | 135 |
| Spruce，red． <br> （Picea rubens） $\qquad$ | 0.48 | 0.41 | 2.40 | 4.00 | 830 | 5.05 | 0.46 | 1.65 | 1.95 | 0.25 | 0.54 | 0.15 | 190 | 160 |
| Spruce，Sitka ．．．．．．．．．．．． <br> （Picea sitchensis） | 0.34 | 0.37 | 2.10 | 3.85 | 830 | 5.05 | 0.74 | 1.60 | 1.85 | 0.23 | 0.55 | 0．16 | 195 | 170 |
| Tamarack．．．．．．．．．．．．．．．．．．．． | 0.49 | 0.56 | 2.95 | 5.05 | 875 | $5 \cdot 50$ | 0.71 | 2.20 | 2.45 | 0.34 | 0.65 | －． 18 | 180 | 170 |
| Yew，western． $\qquad$ <br> （Taxus brevifolia） | 0.60 | 0.67 | 4.55 | 7． 10 | 695 | 9.20 | 0.97 | 2.40 | 3.25 | 0.73 | I． 14 | 0.32 | 610 | 520 |

Note．－The data above are extracted from tests on one hundred and twenty－six species of wood made at the Forest Products Laboratory，Madison，Wisconsin．Bulletin 556 records results of tests on air－dry timber also，but only dita on green timber are shown， as the latter are bascd on a larger number of tests and on tests which are not influenced by variations in moisture conteat．The strength of dry material usually exceeds that of green material，but allowable working stresses in design should be bas，d on strengths of green timber，inasmuch as the increase of strength due to drying is a variable，uncertain factor and likely to be offset by defects． All test specimens were two inches square，by lengths as shown．

Column Notes．－2，Locality where grown，－see Tables 74 and 75；3，Moisture includes all matter volatile at $100^{\circ} \mathrm{C}$ expressed as per cent of ordinary weight；5，Weight，air dry is for wood with 12 percent moisture；for density，see metric unit tables 72 and 73；6－10， 762 mm （ 30 in ．）long specimen on 7 Ir .2 mm （ 28 in ．）span，with load at center．


Nore. - Results of tests on sixty-eight species; test specimens, small clear pieces, 2 by 2 inches in section, 30 inches long tor bending; others, shorter. Tested in a green condition. Data taken from Bulletin 556, Forest Service, U. S. Dept. of Agriculture, containing data on 130,000 tests. See pages 97 and 99 for explanation of columns.
Smithsonian Tables.


Column Notes (continued). - (7) recommended allowable working stress (interior construction): $\frac{1}{5}$ tabular value; experimental results on tests of air-dry timber in small clear pieces average 50 per cent higher; kiln-dry, double tab. lar values; (10) repeated falls of $50-\mathrm{lb}$. hammer from increasing heights; $11-12,203.2-\mathrm{mm}(8 \mathrm{in}$.$) long specimen loaded on ends with deformations$
measured in a $152.4-\mathrm{mm}$ ( 6 in .) gage length; (12) allowable working stress $\frac{1}{2}$ tabular crushing strength; (13) $152.4-\mathrm{mm}(6 \mathrm{in}$.) long block loaded on its side with a central bearing area of $2580.6-\mathrm{mm}^{2}\left(4 \mathrm{in}^{2}\right)$ allowable working stress, $\frac{3}{3}$ tabular value. (14) $50.8-\mathrm{mm}$ by $50.8-\mathrm{mm}$ ( 2 in .) projecting lip sheared from block; allowable working stress, $\frac{1}{8}$ tabular value; (15) $63.5-\mathrm{mm}$ ( $2 \frac{1}{2}$ in.) specimen with $25.4-\mathrm{mm}$ ( I in.) free loaded length; allowable working stress, $\frac{1}{}$ tabular value. ${ }^{(16-17)}$ ) for values in lbs. multiply values of metric tables by 2.2 .

## TABLE 76.-Rigidity Modulus.

If to the four consecutive faces of a cube a tangential stress is applied, opposite in direction on adjacent sides, the modulus of rigidity is obtained by dividing the numerical value of the tangential stress per unit area (kg. per sq. mm.) by the number representing the change of angles on the non-stressed faces, measured in radians.

| Substance. | Rigidity | Reference. | Substance. | Rigidity <br> Modulus. | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum . . | 3350 | 14 | Quartz fibre | 2888 | 20 |
| ". cast | 2550 | 5 | - ". | 2380 | 21 |
| Brass . . | 3550 | 10 | Silver | 2960 | 5 |
| $\cdots$. . . . . . | 3715 | 11 | " . . . . . . | 2650 | 10 |
| . cast, $60 \mathrm{Cu}+12 \mathrm{Sn}$ | 3700 | 5 | " ${ }^{\prime}$. . . . | 2566 | 16 |
| Bismuth, slowly cooled | 12.40 | 5 | " hard-drawn | 2816 | II |
| Rronze, cast, $\mathrm{SS} \mathrm{Cu}+12 \mathrm{Sn}$. | 4060 | 5 | Steel . . . . . . . . | 8290 | 16 |
| Cadmium, cast . . . . . | 2450 | 5 | " cast . . . . . . | 7458 | 15 |
| Copper, cast . . . . . | 47 SO | 5 | " cast, coarse gr. . . | 8070 | 5 |
| " | 4213 | 18 | ${ }^{\text {" }}$ cin, silver- cast ${ }^{\text {a }}$. . . . | 7872 1730 | 11 |
| ". ${ }^{\text {c }}$ - . . . | 4450 4664 | 10 | Tin, cast . . . . . . | 1730 1543 | 5 19 |
| Gold . | 2850 | 5 | Zinc . . . . . . . . | 3880 | 5 |
| - . . . . . . | 3950 | 14 | '* . . . . . . . . . | 3820 | 19 |
| Iron, cast | 5210 | 5 | Platinum . . . . . . | 6630 | 16 |
| " . . . . . . | 6706 | 15 | " | 6220 | 22 |
| " . . . . . | 7975 | 10 | Glass . . | 2350 | - |
| " . . . . . . . | 6940 | 7 | - • - . - | 2730 | - |
| " . . . . . . | Sios | 16 | Clay rock . . . | 1770 | 23 |
| " . . . | 7505 | 14 | Granite . . | 1280 | 23 |
| Magnesium, cast | 1710 | 5 | Marble . . | 1190 | 23 |
| Nickel - . . | 7820 | 5 | Slate | 2290 | 23 |
| l'hosphor bronze | 4359 | 11 |  |  |  |
| Keferences $1-16$, see Table $4 S$. <br> 17 Gratz, W'ied. Am. 28, 1886. <br> 18 Savart, Pogy. Am. 16, 1820. <br> 19 Kiewiet, Diss. (iouttingen, 1886. <br> 20 Threlfall, Philos. Mag. (5) 30, 1890. |  |  | 21 Boys, Philos. Mag. (5) 30, 1890. <br> 22 Thomson, Lord Kelvin. <br> 23 Gray and Milne. <br> 24 Adams-Coker, Carnegie Publ. No. 46, 1906. |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

TABLE 77. - Variation of the Rigidity Modulus with the Temperature.
$n_{t}=n_{0}\left(\mathrm{r}-a t-\beta t^{2}-\gamma t^{3}\right)$, where $t=$ temperature Centigrade.


[^14]TABLE 78.—Interior Friction at Low Temperatures.
C is the damping coefficient for infinitely small oscillations; T , the period of oscillation in seconds; N, the second modulus of elasticity. Guye and Schapper, C. R. 150, p. 963, 1910.

| Substance . . . . . . . . Length of wire in cm. Diameter in mm.... | $\begin{gathered} \mathrm{Cu} \\ 22 \cdot 5 \\ .6+3 \end{gathered}$ | Ni 22.2 .4 II | $\begin{gathered} \mathrm{Au} \\ 22 \cdot 3 \\ .609 \end{gathered}$ | $\begin{gathered} \mathrm{Pd} \\ 22.2 \\ \cdot 553 \end{gathered}$ | $\begin{gathered} \mathrm{Pt} \\ 23.0 \\ .8 \mathrm{I} 2 \end{gathered}$ | $\begin{gathered} \mathrm{Ag} \\ 17.2 \\ .60 \mathrm{I} \end{gathered}$ | $\begin{aligned} & \text { Quartz } \\ & 17.3 \\ & .612 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $100^{\circ} \mathrm{C} \quad \mathrm{C}$ | 24.1 | I. 34 | 27.5 | 1.67 | 2.98 | 55.8 | - |
| T | 2.3815 | 3.83 IS | 3.010 S | 2.579 | I.I43s | 1.808 s | - |
| $\mathrm{N} \times 10^{-11}$ | 3.32 | $7 \cdot 54$ | 2.55 | 5.08 | 5.77 | 2.71 | - |
| $0^{\circ} \mathrm{C} \quad \mathrm{C}$ | 5.88 | . 417 | 4.82 | 1.25 | 4.60 | 7.19 | 4.69 |
|  | 2.336 s | 3.754 s | 2.969 s | 2.571 IS | I. 133 S | 1.759 s | I. 408 s |
| $\mathrm{C}^{\mathrm{N} \times 10^{-11}}$ | 3.45 | 7.85 | 2.62 | 5.12 |  | 2.87 | 2.26 |
| $-195^{\circ} \mathrm{C} \quad \mathrm{C}$ | 3.64 | . 556 | 6.36 | . 744 | 3.02 | I. 64 | 1.02 |
| $\mathrm{T}_{\text {T }}$ | $2.274{ }^{\text {s }}$ | $3 \cdot 577 \mathrm{~s}$ | 2.902 s | 2.552 s | I.IIIS | I. 694 s | I. 425 s |
| $\mathrm{N} \times 10^{-11}$ | 3.64 | 8.65 | 2.74 | 5.19 | 6.10 | 3.18 | 2.20 |

TABLE 79.—Hardness.

| Agate | 7. | Brass | 3-4. | Iridosmium | 7. | Sulphur | 1.5-2.5 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Alabaster | 1.7 | Calamine |  | Iron | 4-5. | Stibnite | 2. |
| Alum | 2-2.5 | Calcite | 3. | Kaolin | 1. | Serpentine | 3-4. |
| Aluminum | 2. | Copper | 2.5-3. | Loess ( $0^{\circ}$ ) | 0.3 | Silver | 2.5-3. |
| Amber | 2-2.5 | Corundum | 9. | Magnetite | 6. | Steel | 5-8.5 |
| Andalusite | $7 \cdot 5$ | Diamond | 10. | Marble | 3-4. | Talc | 1. |
| Anthracite | 2.2 | Dolomite | 3.5-4. | Meerschaum | 2-3. | Tin | 1.5 |
| Antimony | $3 \cdot 3$ | Feldspar | 6. | Mica | 2.8 | Topaz | 8. |
| Apatite | 5. | Flint | 7. | Opal | 4-6. | Tourmaline | 7.3 |
| Aragonite | 3.5 | Fluorite | 4. | Orthoclase | 6. | Wax ( $0^{\circ}$ ) | 0.2 |
| Arsenic | $3 \cdot 5$ | Galena | 2.5 | Palladium | 4.8 | Wood's metal | 3. |
| Asbestos | 5. | Garnet | 7. | Phosphorbronze | 4. |  |  |
| Asphalt | 1-2. | Glass | 4.5-6.5 | Platinum | $4 \cdot 3$ |  |  |
| Augite | 6. | Gold | $2.5-3$. | Platin-iridium | 6.5 |  |  |
| Barite | $3 \cdot 3$ | Graphite | $0.5-1$. | Pyrite | 6.3 |  |  |
| Beryl | 7.8 | Gypsum | 1.6-2. | Quartz | 7. |  |  |
| Bell-metal | 4. | Hematite | 6. | Rock-salt | 2. |  |  |
| Bismuth | 2.5 | Hornblende | $5 \cdot 5$ | Ross' metal | 2.5-3.0 |  |  |
| Boric acid | 3. | Iridium | 6. | Silver chloride | 1.3 |  |  |

From Landolt-Bornstein-Meyerhoffer Tables: Auerbachs, Winklemann, Handb. der Phys. 189 r.
TABLE 80.-Relative Hardness of the Elements.

| C | 10.0 | Ru | 6.5 | Cu | 3.0 | Au | 2.5 | Sn | I .8 | Li | 0.6 |
| :--- | ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| B | 9.5 | Mn | 5.0 | Sb | 3.0 | Te | 2.3 | Sr | I .8 | P | 0.5 |
| Cr | 9.0 | Pd | 4.8 | Al | 2.9 | Cd | 2.0 | Ca | I .5 | K | 0.5 |
| Os | 7.0 | Fe | 4.5 | Ag | 2.7 | S | 2.0 | Ga | I .5 | Na | 0.4 |
| Si | 7.0 | Pt | 4.3 | Bi | 2.5 | Se | 2.0 | Pb | 1.5 | Rb | 0.3 |
| Ir | 6.5 | As | 3.5 | Zn | 2.5 | Mg | 2.0 | In | 1.2 | Cs | 0.2 |

Rydberg, Zeitschr. Phys Chem 33, 1900
TABLE 81.-Ratio, p, of Transverse Contraction to Longitudinal Extension under Tensile Stress. (Poisson's Ratio.)

| Metal | Pb | Au | Pd | Pt | Ag | Cu | Al | Bi | Sn | Ni | Cd | Fe |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\boldsymbol{\rho}$ | 0.45 | 0.42 | 0.39 | 0.39 | 0.38 | 0.35 | 0.34 | 0.33 | 0.33 | 0.31 | 0.30 | 0.28 |

From data from Physikalisch-Technischen Reichsanstalt, 1907.
$\rho$ for: marbles, 0.27 ; granites, 0.24 ; basic-intrusives, 0.26 ; glass, 0.23 . Adams-Coker, 1906 .

The formule were deduced from experiments made on rectangular prismatic bars cut from the crystal. These bars were subjected to cross bending and twisting and the corresponding Elastic Moduli deduced. The symbols ${ }^{\boldsymbol{a}} \beta \boldsymbol{\beta}, a_{1} \beta_{1} \gamma_{1}$ and $a_{2} \beta_{2} \gamma_{2}$ represent the direction cosines of the length, the greater and the less transverse dimensions of the prism with reference to the principal axis of the crystal. $\mathbf{E}$ is the modulus for extension or compression, and T is the modulus for torsional rigidity. The moduli are in grams per square centimeter.

Barite.

$$
\begin{aligned}
& \frac{10^{10}}{\mathrm{E}}=16.13 \alpha^{4}+18.51 \beta^{1}+10.42 \gamma^{4}+2\left(35.75 \beta^{2} \gamma^{2}+15.21 \gamma^{2} \alpha^{2}+5.88 \alpha^{2} \beta^{2}\right) \\
& \frac{10^{10}}{T^{1}}=69.52 \alpha^{4}+117.66 \beta^{4}+116.46 \gamma^{4}+2\left(20.16 \beta^{2} \gamma^{2}+S_{\left.5.29 \gamma^{2} \alpha^{3}+127.35 \alpha^{2} \beta^{2}\right)}^{2}\right.
\end{aligned}
$$

Beryl (Emerald).

$$
\begin{aligned}
& \frac{10^{10}}{\mathrm{E}}=4.325 \sin ^{1} \phi+4.619 \cos ^{3} \phi+13.32 S \sin ^{2} \phi \cos ^{2} \phi \dot{\varphi} \\
& \frac{10^{10}}{\mathrm{~T}}=15.00-3.675 \cos ^{4} \theta_{2}-17.536 \cos ^{2} \phi \cos ^{2} \varphi_{1}
\end{aligned}\left\{\begin{array}{l}
\text { where } \phi \phi_{1} \phi_{2} \text { are the angles which } \\
\text { the length, breadth, and thickness } \\
\text { of the specimen make with the } \\
\text { principal axis of the crystal. }
\end{array}\right.
$$

Fluorite.

$$
\begin{aligned}
& \frac{10^{10}}{\mathrm{E}}=13.05-6.26\left(\alpha^{4}+\beta^{i}+\gamma^{4}\right) \\
& \frac{10^{13}}{\mathrm{~T}}=58.04-50.05\left(\beta^{\prime} \gamma^{\prime}+\gamma^{\prime 2} \alpha^{\prime 2}+\alpha^{\prime 2} \beta^{\prime}\right)
\end{aligned}
$$

## Pyrite.

$$
\begin{aligned}
\frac{10^{10}}{\mathrm{E}} & =5.08-2.24\left(\alpha^{1}+\beta^{\prime}+\gamma^{4}\right) \\
\frac{10^{13}}{\mathrm{~T}} & =18.60-17.95\left(\beta^{\prime} \gamma^{2}+\gamma^{\prime} \alpha^{\prime}+\alpha^{\prime 2} \beta^{\prime}\right)
\end{aligned}
$$

Rock salt.

$$
\begin{aligned}
& \frac{10^{10}}{\mathrm{E}}=33.48-9.66\left(\alpha^{4}+\beta^{4}+\gamma^{1}\right) \\
& \frac{10^{10}}{\mathrm{~T}}=154.58-77.28\left(\beta^{\prime} \gamma^{\prime}+\gamma^{\prime \prime} \alpha^{2}+\alpha^{\prime 2} \beta^{\prime}\right)
\end{aligned}
$$

Sylvite.

$$
\begin{aligned}
& \frac{10^{10}}{\mathrm{E}}=75.1-48.2\left(\alpha^{4}+\beta^{1}+\gamma^{4}\right) \\
& \frac{10^{10}}{\mathrm{~T}}=306.0-192.8\left(\beta^{2} \gamma^{2}+\gamma^{2} \alpha^{2}+\alpha^{2} \beta^{3}\right)
\end{aligned}
$$

Topaz.

$$
\begin{aligned}
\frac{10^{10}}{\mathrm{E}} & =4.341 \alpha^{4}+3.460 \beta^{4}+3.771 \gamma^{4}+2\left(3.879 \beta^{2} \gamma^{2}+2.856 \gamma^{2} \alpha^{2}+2.39 \alpha^{2} \beta^{2}\right) \\
\frac{10^{10}}{\mathrm{~T}} & =14.88 \alpha^{4}+16.54 \beta^{4}+16.45 \gamma^{4}+30.89 \beta^{2} \gamma^{2}+40.89 \gamma^{2} \alpha^{2}+43.51 \alpha^{2} \beta^{2}
\end{aligned}
$$

Quartz.

$$
\begin{aligned}
& \frac{10^{11}}{E^{10}}=12.734\left(1-\gamma^{2}\right)^{2}+16.693\left(1-\gamma^{2}\right) \gamma^{2}+9.705 \gamma^{4}-8.460 \beta \gamma\left(3 \alpha^{2}-\beta^{2}\right) \\
& \left.\frac{10^{10}}{T}=19.665+9.060 \gamma_{2}^{2}+22.984 \gamma^{2} \gamma_{1}^{2}-16.920\left[\left(\gamma \beta_{1}+\beta \gamma_{1}\right)\left(3 \alpha \alpha_{1}-\beta \beta_{1}\right)-\beta_{2} \gamma_{2}\right)\right]
\end{aligned}
$$

*These formulx are taken from Voigt's papers (Wied. Ann. vols. 3r, 34, and 35).

## Smitheonian Tables.

## Table 83. <br> ELASTICITY OF CRYSTALS.

IO3

Some particular values of the Flastic Moduli are here given. Under $\mathbf{E}$ are given moduli for extension or compression in the directions indicated by the subscripts and explained in the notes, and under T the moduli for torsional rigidities round the axes similarly indicated. Moduli in grams per sq. cm.
(a) Isometric System.*

| Substance. | $\mathrm{E}_{\boldsymbol{a}}$ | $\mathrm{E}_{b}$ | $\mathbf{E}_{c}$ | $\mathrm{T}_{a}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Fluorite | $1473 \times 10^{6}$ | $1008 \times 10^{6}$ | $910 \times 10^{6}$ | $345 \times 10^{6}$ | Voigt. $\dagger$ |
| Pyrite | $3530 \times 10^{6}$ | $2530 \times 10^{6}$ | $2310 \times 10^{6}$ | $1075 \times 10^{6}$ |  |
| Rock salt . | $419 \times 10^{6}$ | $349 \times 10^{6}$ | $303 \times 10^{6}$ | ${ }^{129} \times 10^{6}$ |  |
| " | $403 \times 10^{6}$ | $339 \times 10^{6}$ | - | - | Koch. $\ddagger$ |
|  | $401 \times 10^{6}$ | $209 \times 10^{6}$ 196 | - | $655 \times 10^{\text {5 }}$ |  |
| Sodium chlorate | $372 \times 10^{6}$ $405 \times 10^{6}$ | $196 \times 10^{6}$ $319 \times 10^{6}$ | - | $655 \times 10^{6}$ | Voigt. Koch. |
| Potassium alum . | $181 \times 10^{6}$ | $199 \times 10^{6}$ | - | - | Beckenkamp.§ |
| Chromium alum | $161 \times 10^{6}$ | $177 \times 10^{6}$ | - | - |  |
| Iron alum . | $186 \times 10^{6}$ | - | - | - | " |

(/) Orthorhombic System.||


In the Monoclinic System, Coromilas (Zeit. fïr Kryst. vol. i) gives Gypsum $\left\{\begin{array}{l}\mathbf{E}_{\max }=887 \times 10^{6} \text { at } 21.9^{\circ} \text { to the principal axis. } \\ \mathbf{E}_{\min }=313 \times 10^{6} \text { at } 75.4^{\circ} \text { "" " }\end{array}\right.$ Mica $\left\{\mathrm{E}_{\max }=2213 \times 10^{6}\right.$ in the principal axis. $\left\{\mathrm{E}_{\min }={ }^{1} 554 \times 10^{6}\right.$ at $45^{\circ}$ to the principal axis.

In the Hexagonal System, Voigt gives measurements on a beryl crystal (emerald). The subscripts indicate inclination in degrees of the axis of stress to the principal axis of the crystal.

$$
\begin{aligned}
& \mathrm{E}_{0}=2165 \times 10^{66}, \quad \mathrm{E}_{45}=1796 \times 10^{6}, \quad \mathrm{E}_{90}=2312 \times 10^{6}, \\
& \mathrm{~T}_{0}=667 \times 10^{6}, \quad \mathrm{~T}_{90}=883 \times 10^{6} . \quad \text { The smallest cross dimension of the } \\
& \text { prism experimented on (see Table 82), was in the principal axis for this last case. }
\end{aligned}
$$

In the Rhombohedral System, Voigt has measured quartz. The subscripts have the same meaning as in the hexagonal system.

$$
\begin{array}{ll}
\mathrm{E}_{0}=1030 \times 10^{6}, & \mathrm{E}_{-45}=1305 \times 10^{6}, \quad \mathrm{E}_{+45}=850 \times 10^{6}, \quad \mathrm{E}_{90}=785 \times 10^{6}, \\
\mathrm{~T}_{0}=508 \times 10^{6}, & \mathrm{~T}_{90}=348 \times 10^{6} .
\end{array}
$$

Baumgarten $\mathbb{T}$ gives for calcite

$$
\mathrm{E}_{0}=501 \times 10^{9} . \quad \mathrm{E}_{-45}=441 \times 10^{6}, \quad \mathrm{E}_{+45}=772 \times 10^{6}, \quad \mathrm{E}_{90}=790 \times 10^{6} .
$$

[^15]
## Smithsonian Tables.

Tables 84-86
COMPRESSIBILITY OF GASES.
TABLE 84.-Relative Volumes at Various Pressures and Temperatures, the volumes at $0^{\circ} \mathrm{C}$ and at 1 atmosphere being taken as 1000000 .

| Atm. | Oxygen. |  |  | Air. |  |  | Nitrogen. |  |  | Hydrogen. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\bigcirc$ | $99^{\circ} \cdot 5$ | $199^{\circ} \cdot 5$ | $0^{\circ}$ | $99^{\circ} \cdot 4$ | $200^{\circ} \cdot 4$ | $\circ^{\circ}$ | $99^{\circ} \cdot 5$ | 199.6 | $\bigcirc$ | $99^{\circ} \cdot 3$ | $200^{\circ} \cdot 5$ |
| 100 | 9265 | - | - | 9730 | - | - | 9910 | - | - |  |  |  |
| 200 | 4570 | 7000 | 9095 | 5050 | 7360 | 9430 | 5195 | 7445 | 9532 | 5690 | 7567 | 9420 |
| 300 | 3208 | 4843 | 6283 | 3658 | 5170 | 6622 | 3786 | 5301 | 6715 | 4030 | 5286 | 6520 |
| 400 | 2629 | $3^{8} 30$ | 4900 | 3036 | 4170 | 5240 | 3142 | 4265 | 5331 | 3207 | 4147 | 5075 |
| 500 | 2312 | 3244 | 4100 | 2680 | 3565 | 4422 | 2780 | 3655 | 4515 | 2713 | 3462 | 4210 |
| 600 | 2115 | 2867 | 3570 | 2450 | 3180 | 3883 | 2543 | 3258 | 3973 | 2387 | 3006 2680 | 3627 3212 |
| 700 | 1979 | 2610 | 3202 | 2288 | 2904 | 3502 | 2374 | 2980 | 3589 3300 | 2149 | 2680 | 3212 |
| 800 | 1879 | 2417 | 2929 | 2168 | 2699 | 3219 | 2240 | 2775 2616 | 3300 3085 | 1972 1832 |  | 2900 |
| 900 | 1800 | 2268 | 2718 | 2070 | 2544 | 3000 | 2149 | 2616 | 3085 | 1832 1720 | 2244 | 26 |
| 1000 | 1735 | 2151 | - | 1992 | 2415 | 2828 | 2068 | - | - | 1720 | 2093 |  |

Amagat: C. R. 111, p. 878, 1800 ; Ann. chim. phys. (6) 29, pp. 68 and 505, 1893.

TABLE 85.-Ethylene.
$p v$ at $0^{\circ} \mathrm{C}$ and $1 \mathrm{~atm} .=\mathrm{I}$.

| Atm. | $0^{\circ}$ | $10^{\circ}$ | 200 | $30^{\circ}$ | $40^{\circ}$ | $60^{\circ}$ | $80^{\circ}$ | $100^{\circ}$ | $137^{\circ} .5$ | $198^{\circ} .5$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |
| 46 | - | 0.562 | 0.684 | - | - | - | - | - | - | - |
| 48 | - | 0.508 | - | - | - | - | - | - | - | - |
| 50 | 0.176 | 0.420 | 0.629 | 0.731 | 0.814 | 0.954 | 1.077 | 1.192 | 1.374 | $\mathbf{1 . 6 5 2}$ |
| 52 | - | 0.240 | 0.598 | - | - | - | - | - | - | - |
| 54 | - | 0.229 | 0.561 | - | - | - | - | - | - | - |
| 56 | - | 0.227 | 0.524 | - | - | - | - | - | - | - |
| 100 | 0.310 | 0.331 | 0.360 | 0.403 | 0.471 | 0.668 | 0.847 | 1.005 | 1.247 | $\mathbf{1 . 5 8 0}$ |
| 150 | 0.441 | 0.459 | 0.485 | 0.515 | 0.551 | 0.649 | 0.776 | 0.924 | 1.178 | 1.540 |
| 200 | 0.565 | 0.585 | 0.610 | 0.638 | 0.669 | 0.744 | 0.838 | 0.946 | 1.174 | 1.537 |
| 300 | 0.806 | 0.827 | 0.852 | 0.878 | 0.908 | 0.972 | 1.048 | 1.133 | 1.310 | 1.628 |
| 500 | 1.256 | 1.280 | 1.308 | 1.337 | 1.367 | 1.431 | 1.500 | 1.578 | 1.721 | 1.985 |
| 1000 | 2.289 | 2.321 | 2.354 | 2.387 | 2.422 | 2.493 | 2.566 | 2.643 | 2.798 | - |

Amagat, C. R. 111 , p. 871, 1890; 116, p. 946, 1893.

## TABLE 86.-Relative Gas Volumes at Various Pressures.

The following table, deduced by Mr. C. Cochrane, from the PV curves of Amagat and other observers, gives the relative volumes occupied by various gases when the pressure is reduced from the value given at the head of the column to I atmosphere:

| $\begin{gathered} \text { Gas. } \\ \left(\text { Temp. }=16^{\circ} \mathrm{C} .\right) . \end{gathered}$ | Relative volume which the gas will occupy when the pressure is reduced to atmospheric from |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 atm . | 50 atm . | 100 atm . | 120 atm . | 150 atm . | 200 atm . |
| "Perfect" gas | I | 50 | 100 | 120 | 150 | 200 |
| Hydrogen .. | I | 48.5 | 93.6 | 111.3 | 136.3 | 176.4 |
| Nitrogen . | I | 50.5 | 100.6 | 120.0 | 147.6 | 190.8 |
| Air . | I | 50.9 | IOI. 8 | 121.9 | 150.3 | 194.8 |
| Oxygen ...... | 1 | - | 105.2 | - | - | 212.6 |
| Oxygen (at $0^{\circ} \mathrm{C}$.) Carbon dioxide. | I | 52.3 | 107.9 | ${ }^{128.6}$ | 161.9 | 218.8 |
| Carbon dioxide. | I | 69.0 | $477^{*}$ | 485* | 498* | 515* |

* Carbon dioxide is liquid at pressures greater than 90 atmospheres.


## Smithsonian Tables.

## COMPRESSIBILITY OF GASES.

## table 87.-Carbon Dioxide.

| Pressure in meters of mercury. | Relative values of $p v$ at - |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $18^{\circ} .2$ | $35^{\circ} \cdot 1$ |  | $40^{\circ} \cdot 2$ | $50^{\circ} .0$ | 60 ${ }^{\circ}$. | $70^{\circ} .0$ |  |  | $90^{\circ} .0$ | $100^{\circ} .0$ |
| 30 | liquid | 2360 |  | 2460 | 2590 | 2730 | 2870 |  |  | 3120 | 3225 |
| 50 |  | 1725750 |  | 1900 | 2145 | 2330 | 2525 |  |  | 2845 | 2980 |
| 80 | 625 |  |  | 825 | 1200 | 1650 | 1975 |  |  | 2440 | 2635 |
| 110 | 825 | 930 |  | 980 | 1090 | 1275 | 1550 |  |  | 2105 | 2325 |
| 140 | 1020 | 1120 |  | 1175 | 1250 | 1360 | 1525 |  |  | 1950 | 2160 |
| 170 | 1210 | 1310 |  | 1360 | 1430 | 1520 | 1645 |  |  | 1975 | 2135 |
| 200 | 1405 | 1500 |  | 1550 | 1615 | 1705 | 1810 |  |  | 2075 | 2215 |
| 230 | 1590 | 1690 |  | 1730 | 1800 | 1890 | 1990 |  |  | 2210 | 2340 |
| 260 | 1770 | 1870 |  | 1920 | 1985 | 2070 | 2166 |  |  | 2375 | 2490 |
| 290 | 1950 | 2060 |  | $\begin{aligned} & 2100 \\ & 2280 \end{aligned}$ | 2170 | 2260 | 2340 |  |  | 2550 | 2655 |
| 320 | 2135 | 2240 |  |  | 2360 | 2440 | 2525 |  |  | 2725 | 2830 |
| Atm | Relative values of $p v ; p v$ at $o^{\circ} \mathrm{C}$. and $\mathbf{x}$ atm. $=\mathbf{1}$. |  |  |  |  |  |  |  |  |  |  |
|  | $\circ^{\circ}$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $60^{\circ}$ | $80^{\circ}$ | $100^{\circ}$ | $137^{\circ}$ | $198^{\circ}$ | $258^{\circ}$ |
| 50 | 0.105 | 0.114 | 0.680 | 0.775 | 0.750 | 0.984 | 1.096 | 1.206 | 1.380 | - | - |
| 100 | 0.202 | 0.213 | 0.229 | 0.255 | 0.309 | 0.661 | 0.873 | 1.030 | 1.259 | 1. 582 | I. 847 |
| 150 | 0.295 | 0.309 | 0.326 | 0.346 | 0.377 | 0.485 | 0.68 I | 0.878 | 1.159 | 1.530 | 1.818 |
| 300 | 0.559 | 0.578 | 0.599 | 0.623 | 0.649 | 0.710 | 0.790 | 0.890 | 1.108 | I. 493 | 1. 820 |
| 500 | 0.891 | 0.913 | 0.938 | 0.963 | 0.990 | I. 054 | I. 124 | 1.201 | 1.362 | 1. 678 | - |
| 1000 | 1.656 | 1.685 | 1.716 | 1.748 | 1.780 | 1. 848 | 1.921 | 1.999 |  | - | - |

Amagat, C. R. 111, p. 871, 1890; Ann. chim. phys. (5) 22, p. 353, 1881; (6) 29, pp. 68 and 405, 1893.

TABLE 88. - Compressibility of Gases.

| Gas. | $\frac{p . v .\left(\frac{1}{2} \mathrm{~atm} .\right)}{p_{0} v_{0}(\mathrm{I} \text { atm.) }}$. | $\frac{1}{p \cdot v .} \frac{d(p . v .)}{d p}$ $=a$. | $t$ | $\mathrm{t}^{\boldsymbol{a}} \mathrm{o}$ | $\begin{aligned} & \mathrm{Density} \\ & \stackrel{\text { Den }}{ }{ }^{322,{ }^{\circ} \mathrm{C}} \\ & \mathrm{P} \mathrm{com}^{\mathrm{cm}} \mathrm{C} \end{aligned}$ | Density. <br> Very small pressure. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{O}_{2}$ | 1.00038 | -.00076 | $11.2{ }^{\circ}$ | -. 00094 |  | 32. |
| $\mathrm{H}_{2}$ | 0.99974 | +.00052 | 10.7 | +.00053 | 2.015 (160) | 2.0173 |
| $\mathrm{N}_{2}$ | 1.00015 | -. 00030 | 14.9 | -. 000056 | 28.005 | 28016 |
| CO | 1.00026 | -. 00052 | 13.9 | -. 00081 | 28.000 | 28.003 |
| $\mathrm{CO}_{2}$ | I. 00279 | -. 0055 | 15.0 | -. 00668 | 44.268 | 44.014 |
| $\mathrm{N}_{2} \mathrm{O}$ | 1.00327 | -. 00654 | 11.0 | -. 00747 | 44.285 | 43.996 |
| Air | I. 00026 | -. 00046 | 11.4 | - | - |  |
| $\mathrm{NH}_{3}$ | ${ }^{1.006 .32}$ |  |  | - | - | - |

Rayleigl, Zeitschr. Phys. Chem. 52, p. 705, 1905.

TABLE 89. - Compressibility of Air and Oxygen between $18^{\circ}$ and $22^{\circ} \mathrm{C}$.
Pressures in meters of mercury, $p v$, relative.

| Air | $p$ $p v$ | 24.07 26968 | 34.90 26908 | $\begin{array}{r} 45.24 \\ 26791 \end{array}$ | $\begin{array}{r} 55.30 \\ 26789 \end{array}$ | $\begin{array}{r} 64.00 \\ 26778 \end{array}$ | $\begin{array}{r} 72.16 \\ 26792 \end{array}$ | $\begin{aligned} & 8_{4.22} \\ & 26840 \end{aligned}$ | $\begin{array}{r} 101.47 \\ 27041 \end{array}$ | $\begin{aligned} & 214.54 \\ & 29585 \end{aligned}$ | $\begin{aligned} & 304.04 \\ & 32488 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{O}_{2}$ | $p$ $p$ | 24.07 26843 | 34.89 26614 | - | 55.50 26.85 | 64.07 26050 | 72.15 25858 | $\begin{array}{r} 84.19 \\ 25745 \end{array}$ | $\begin{array}{r} \text { ior. } 06 \\ 25639 \end{array}$ | $\begin{array}{r} 214.52 \\ 26536 \end{array}$ | $\begin{gathered} 303.03 \\ 28756 \end{gathered}$ | VOLUME OF SULPHUR DIOXIDE AND AMMONIA.*

TABLE 90.-Sulphur Dioxide.
Original volume $1000 n 0$ under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

|  | Corresponding Volume for Experiments at Temperature - |  |  | Volume. | Pressure in Atmospheres for Experiments at Temperature - |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $5^{8}$. 0 | $99^{\circ} .6$ | $183^{\circ} \cdot 2$ |  | $58^{\circ} .0$ | $99^{\circ} .6$ | $183^{\circ} .2$ |
| 10 | 8560 | 9.440 | - |  |  |  |  |
| 12 | 6360 | 7800 | - | 10000 | - | 9.60 | - |
| 14 | 40.40 | 6420 | - | 9000 | 9.60 | 10.35 | - |
| 16 | - | 5310 | - | 8000 |  |  |  |
| 18 | - | 4405 | - | 8000 | 10.40 | 1155 | - |
| 20 | - | 4030 | - | 7050 | 11.55 | 13.05 | - |
| 24 28 28 | - | 3345 2780 | 3 I 0 | 6000 | 12.30 | 14.70 | - |
| 32 | - | 2305 | 2640 | 5000 | 13.15 | 16.70 | - |
| 36 | - | 1935 | 2260 | 4000 | 14.00 | 20.15 | - |
| 40 | - | 1450 | 20.40 | 3500 | 14.40 | 23.00 | - |
| 50 | - | - | 1640 | 3000 | 4.40 | 23.00 26.40 | 29.10 |
| 60 70 | - | - | 1375 1130 | 2500 | - |  |  |
| So | - | - | 930 |  |  | 30.15 |  |
| 90 | - | _ | 790 | 2000 | - | 35.20 | 40.95 |
| 100 | - | - | 680 | 1500 | - | 39.60 | 55.20 |
| 120 | - | - | 545 | 1000 | - | - | 76.00 |
| 140 160 | - | - | 430 325 | 500 | - | - | 117.20 |

TABLE 91. - Ammonia.
Original volume roooso under one atmosphere of pressure and the temperature of the experiments as indicated at the top of the different columns.

|  | Corresponding Volume for Experiments at Temperature - |  |  | Volume. | Pressure in Atmospheres for Experiments at Temperature - |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $46^{\circ} .6$ | 99.6 | $183^{\circ} .6$ |  | $30^{\circ} .2$ | $46^{\circ} .6$ | $99^{\circ} .6$ | $183^{\circ}$.o |
| 10 | 9500 | - | - | 10000 | 8.85 | 9.50 |  | - |
| 12.5 | 7245 | 7635 | - | 9000 | 9.60 | 10.45 |  | - |
| 15 | 5880 | 6305 |  | 8000 | 10.40 | 11.50 |  | - |
| 20 | - | 4645 | 4875 | 8000 | 10.40 | 11.50 | 12.00 | - |
| 25 | - | 3560 | 3835 | 7000 | 11.05 | 13.00 | 13.60 | - |
| 30 | - | 2875 | 3185 | 6000 | 1 t .80 | 14.75 | I 5.55 | - |
| 35 40 | - | 2440 | 2680 | 5000 | 12.00 | 16.60 | 18.60 | 19.50 |
| 40 45 | - | 2080 1795 | 2345 2035 | 4000 | - | 18.35 | 22.70 | 24.00 |
| 50 | - | 1490 | 1775 | 3500 | - | 18.30 | 25.40 | 27.20 |
| 55 | - | 1250 | I 590 | 3000 | - | - | 29.20 | 31.50 |
| 60 70 | - | 975 | 1450 1245 | 2500 | - | - | 34.25 | 37.35 |
| 80 | - | - | 1245 1125 | 2000 | - | - | 41.45 | $45 \cdot 50$ |
| 90 | - | - | 1035 | 1500 | - | - | 49.70 | 58.00 |
| 100 | - | - | 950 | 1000 | - | - | 59.65 | 93.60 |

[^16]Emithsonian Tables.

## COMPRESSIBILITY OF LIQUIDS.

At the constant temperature $t$, the compressibility $\beta=\left(\mathrm{I} / V_{0}\right)(d V / d P)$. In general as $P$ increases, $\beta$ decreases rapidly at first and then slowly; the change of $\beta$ with $t$ is large at low pressures but very small at pressures above 1000 to 2000 megabars. I megabar $=0.987$ atmosphere $=10^{6}$ dyne/ $\mathrm{cm}^{2}$.

| Substance. |  |  |  |  | Substance. | $\begin{aligned} & \cup \\ & 0 \\ & \dot{\circ} \\ & \underset{H}{0} \end{aligned}$ |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetone. . . . . . . . . ${ }^{6}$ | 14202040 | 23 |  |  | Ethyl ether, ct'd... |  | 1,000 | 61 | I |
|  |  | 500 | 6I | I |  |  |  | 10 | I |
| 6 |  | 1,00c | 52 | 1 | Ethyl iodide. | 20 | 200 | 81 | I6 |
| " |  | 12,000 | 9 | I | 66 | 20 | 400 | 69 | 16 |
|  | 1 | 123 | 88 | 10 | 666. | 20 | 500 | 64 | I |
| " iso... | 20 | 200 | 84 | 16 | 66 | 20 | , | 50 | I |
| 6 6 iSo... |  | 400 | 70 | 16 | $66 \quad 6$ | 20 | 1 2,000 | 8 | I |
| 6 6 | 20 | 500 | 61 | I | Gallium. | 30 | 300 | $3 \cdot 67$ | 6 |
| 6. 6 |  | 1,000 | 46 | I | Glycerine | 15 | 5 | 32 | 12 |
| " 6 |  | 1 2,000 | 8 | I | Hexane. | 20 | 200 | II 7 | 16 |
| 66 |  | 12,000 | 8 | 1 | ، | 20 | 400 | 9 I | 16 |
| Benzene |  | 5 | 89 | 2, 3 | Kerosene. | 20 | 500 | 55 | I |
| " | 17 | 200 | 77 | 16 |  | 20 | 1,000 | 45 | 1 |
| 6 | 20 | 400 | 67 | 16 | 6 . . . . . . . | 20 | 12,000 | 8 | I |
| Bromine |  | 200 | 56 | 16 | ، | 20 | 1 2,000 | S | 13 |
| ${ }_{6}$ | 20 | 400 | 51 | r6 | Merc | 20 | 300 | 3.95 | 7 |
| Butyl alcohol, iso.. | 13 | 8 | 97 | 2 |  | 22 | 500 | 3.97 | S |
| 66 6 iso.. | 20 | 200 | 81 | 16 | 66 | 22 | 1,000 | 3.91 | 8 |
| " 6 iso.. | 20 | 200 | 64 | 16 | 6 | 2 | 12,000 | 2.37 | 8 |
| " 6 iso.. | 20 | 500 | 56 | I | Methyl alcohol | 15 | 23 | 103 | 10 |
| 6 66 iso.. |  | 1,000 | 46 | 1 | 66 6 | 20 | 200 | 95 | 16 |
| 6 6 iso.. | 20 | 12,000 | 8 | 1 | 66 6 | 20 | 4 | 80 | 16 |
| Carbon bisulphide.. | r6 | 12,00 2 I | 86 | 10 | 66 | 20 | 500 | 65 | I |
|  | 20 | 500 | 57 | I | 66 66 | 20 | 1,000 | 54 | I |
| 66 c6 | 20 | 1,000 | 48 | I | 6 6 | 20 | I 2,000 | S | 1 |
| 66 | 20 | 1,000 | 4 | 1 | Nitric acid. | 20 | 12,000 | 32 | I4 |
|  | 20 | 12,000 | 85 | 16 | Cils: Almon' | - | 17 | 32 | 14 |
| $\mathrm{Carb}_{6}$. tetrachoride. |  | 200 400 | 85 73 | I6 | Cils: Amon | I5 | 5 | 53 46 | 12 12 |
|  | 20 | 400 | 73 | 16 | Castor | 15 | 5 | 46 | 12 |
| Chloroform. | 20 | 200 | 83 | 16 | Linsecd | I5 | 5 | 51 | 12 |
|  |  | 400 | 70 | 16 | Oilve. | 15 | 5 | 55 | 12 |
| Dichlorethylsulfide. | 3232 | 1,000 | 3424 | 55 | Rape-seed.... Phosph. trichloride. | 20 | - | 5) | 15 |
|  |  |  |  |  |  | 10 | 250 | 71 | 1 I |
| Ethyl acetate. |  |  | 103 | 10 |  | 20 | うวะ | 03 | I |
| " 6 | 3 |  | 90 | 16 | $\begin{array}{llll}66 & 6 & \cdot\end{array}$ |  | 1,000 | 47 | I |
| 66 |  | 200400 | 75 | I6 |  |  | :2,000 | S | I |
| Cthyl alcohol. | 20 |  |  |  | "6 "6 . |  |  |  |  |
|  | 14 | 23500 | $100$ | 10 | Propyl alcohol, n... | 23 | 200 | $\begin{aligned} & -7 \\ & 67 \end{aligned}$ | 10 |
|  | 20 |  |  | I |  | 20 | 400 |  | 16 |
| 66 | 23 | r $\begin{array}{r}500 \\ 1,000 \\ 12,000\end{array}$ | 548 | 1 |  | 25 |  | 67 | I |
| " ${ }^{6}$...... |  |  |  |  | " ${ }^{6}$ | 20 |  | 47 | 1 |
| Ethyl bromide.... | 20 | \|r $\begin{array}{r}12,000 \\ 200 \\ 400\end{array}$ | 10082 | 16 | 6 6 (n?). | 20 | 12,000 | 7 | 1 |
|  | 20 |  |  | 16 | Toluenc. . . . . . . . . | $2 \bigcirc$ | 200 | 74 | 10 |
| 66 | 20 | 500 | 70 | I |  | ว | 40 | 64 | I6 |
| 66 |  | 1,000 | 548 | 1 | Turpentine. | 2 | 4 | -4 | 15 |
|  | 20 |  |  | 1 |  | 20 | - | ,4 | 15 |
| Ethyl chloride..... | I 20 | 12,000 |  | 1 | Turpentine. . . . . . . | 20 | 13 | 4) | II |
|  |  | \|r $\begin{array}{r}23 \\ 500\end{array}$ | 8 $\times 51$ | 10 | Wat | 20 | 200 | 43 | 16 |
|  | 15 |  | IO2 | I |  | 23 | 400 | 41 | I6 |
| 66 | 20 | 1,000 | 66 | I | 6 | 20 | 500 | 39 | 4 |
| " ${ }^{6}$ | 20 | 12,000 | 8 |  | 6 | 0 | 500 | 38 | 4 |
| Ethyl ether. | $\begin{aligned} & 25 \\ & 20 \end{aligned}$ | 23500 | 18884 | $\begin{array}{r} 10 \\ \mathrm{I} \end{array}$ | 6 |  | 1000 | 33 | 4 |
| 6 6 . . . . . . |  |  |  |  | 6 | 40 | 12,000 | 33 9 | 4 |
|  |  |  |  |  | Xylene, meti | 20 | 200 | 69 | I6 |
|  |  |  |  |  | ${ }^{6}$ | 20 | 400 | 60 | 16 |

For references, see page 108.

## COMPRESSIBILITY OF SOLIDS,

If $V$ is the volume of the material under a pressure $P$ megabars and $V_{0}$ is the volume at atmospheric pressure, then the compressibility $\beta=-\left(\mathrm{I} / V^{\circ}\right)\left(d V^{\gamma} / d P\right)$. Its unit is $\mathrm{cm}^{2} /$ megadynes (reciprocal megabars). $10^{6 / \beta}$ is the bulk modulus in absolute units (dynes $/ \mathrm{cm}^{2}$ ). The following values of $\beta$, arranged in order of increasing compressibility, are for $P=0$ and room temperature. 1 megabar $=10^{6}$ dynes $=1.013 \mathrm{~kg} / \mathrm{cm}^{2}=0.987$ atmosphere.

| Substance. |  | Bulk modulus. dynes $/ \mathrm{cm}^{2}$ $\times 1 \mathrm{ol}^{12}$ | Reference. | Substance. | Compres unit vol. per mega- bar $\times 10^{6}$ | Bulk modulus. $\underset{\times 10^{12}}{\substack{\text { dynes } \\ \times 1 \mathrm{~cm}^{2}}}$ | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tungsten | 0.27 | 3.7 | 2 | Plate glass. | 2.23 | 0. 45 | 4 |
| (inoron. | 0.3 0.32 | 3.15 | 2 | Thallium.. | ${ }_{2.3}^{2.27}$ | 0.44 0.43 | ${ }_{2}{ }^{2}$ |
| Platinum | -. 38 | 2.6 | 2 | Antimony. | 2.4 | -. 42 |  |
| Nickel. | 0.43 | 2.3 | 2 | Quartz. | 2.7 | -. 37 | 1 |
| Molybdenum | $\bigcirc$ | 2.2 | 2 | ${ }_{\text {Magnesium }}$ | 2.9 | -. 34 | 2 |
| Tantalum. | -. 53 | ${ }^{1.9}$ | ${ }_{2}^{2}$ | Bismuth. | 3.0 | -.33 | ${ }_{2}$ |
| Iron.... | 0.54 0.60 | ${ }_{1.6}^{1.9}$ | 3 | Silica glass. | 3.1 | -. 32 | I |
| Gold. | 0.60 | 1. 67 | I, 2 | Sodium chloride... | 4.12 | 0.24 | 1 |
| Pyrite. | 0.7 | 1. 4 | 4 | Arsenic. . | 4.5 | 0.22 | 2 |
| Copper.. | -. 75 | 1. 33 | 1 |  | 5.7 | 0.175 | ${ }_{6}$ |
| Manganese | 0.84 0.80 | I. ${ }_{\text {r }}^{19}$ | ${ }_{1}^{2}$ | Potassium chiorice | 7.4 9.0 | 0.135 0.111 | 2 |
| Chromium | -. 0.9 | I. r 2 |  | Phosphorus (red).. | 9.2 | -.1709 | 2 |
| Silver. | -. 99 | I. Or | 1, 2 | Selenium......... | ${ }_{12}^{12.0}$ | 0.083 | 2 |
| Mg. silicate, crys. | 1.03 | 0.97 | 4 | Sulphur. | ${ }^{12.9}$ | 0.078 | 2 |
| Aluminum...... | 1. 33 | 0.75 | r-3 | Iodine.. | 13.0 | 0.077 | 2 |
| Calcite. | r. 39 | 0.72 | 1 | Sodium........ie. | 15.6 | 0.064 | 2 |
| Zinc. | 1. 74 | 0.57 0.53 0.53 | I | Phosphorus (white) Potassium....... | ${ }^{20.5}$ | 0.049 0.032 | 2 |
| Gailium......... | Y. 89 2.09 | 0.53 0.48 0.48 |  | Potassium......... | 31.7 40.0 | 0.032 0.025 | $\stackrel{2}{2}$ |
| Cadmium........ | ${ }_{2.17}$ | 0.48 0.46 | I, 2 | Calcium | 6 r .0 | 0.016 | 2 |

Note. - Winklemann, Schott, and Straulel (Wied Ann. 6r, 63, r897, 68, 1899) give the following coefficients (among others) for various Jena glasses in terms of the volume decrease divided by the increase of pressure expressed in kilograms per square millimeter:

| No. | Glass. | Compressibility. | No. | Glass. | Compressibility. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 665 |  | 7520 | 2154 | Kalibleisilicat. | 3660 |
| 1299 | Barytborosilicat. | 5800 | S 208 | Heaviest Bleisilicat. | 3550 |
| 16 273 | Natronkalkzinksilicat | 4530 3790 | ( $\begin{array}{r}500 \\ \hline 196\end{array}$ | Very Heavy Bleisilicat......... | 3510 3470 |

The following values in $\mathrm{cm}^{2} / \mathrm{kg}$ of $10^{6} \times$ Compressibility are given for the corresponding temperatures by Grüneisen, Ann. der Phys. 33, p. 65, 1910.

$$
\begin{aligned}
& \mathrm{Al} \text { - } 19 \mathrm{r}^{\circ}{ }^{\circ} \text {, } \mathrm{I} .32 ; 17^{\circ}{ }^{\circ}, \mathrm{I} .46 ; 125^{\circ}, \text { 1.70. } \\
& \mathrm{Cu} \text { - } 191^{\circ}, 0.72 ; 17^{\circ}, 0.77 ; 165^{\circ}, 0.83 \text {. } \\
& \mathrm{Pt}-189^{\circ}, 0.37 ; 17^{\circ}, 0.39 ; 164^{\circ}, 0.40 \text {. } \\
& \mathrm{Fe}=190^{\circ}, 0.61 ; 18^{\circ}, 0.63 ; 165^{\circ}, 0.67 . \\
& \mathrm{Ag} \text { - } 19 \mathrm{I}^{\circ}, 0.7 \mathrm{I} ; 16^{\circ} ; 0.76 ; 166^{\circ}, 0.86 \text {. } \\
& \mathrm{Pb} \text { - } 19 \mathrm{I}^{\mathrm{o}},\left({ }_{(2.5)}\right)_{14}{ }^{\circ},(3.2) \text {. }
\end{aligned}
$$

References to Table 92, p. 107:
(1) Bridgman, Pr. Am. Acad. 49, r, 1913 ;
(2) Roentgen, Ann. Phys. 44, 1, 1891;
(3) Pagliani-Palazzo, Mem. Acad. Lin. 3, 18, 1883 ;
(4) Bridgman, Pr. Am. Acad. 48, 341, 1912 ;
(5) Adams, Williamson, J. Wash. Acad. Sc. 9, Jan. 19, 1919;
(6) Richards, Boyer, Pr. Nat. Acad. Sc. 4, 389, 19IS;
(7) Richards, J. Am. Ch. Soc. $37,1646,1915$;
(8) Bridgman, Pr. Am. Acad. 47, 38r, 1911 ;
(9) Amagat, C. R. 73, 143, $\mathbf{1 8 7 2}$;
(10) Amagat, C. R. 68, 1170 , 1869;
(iI) Amagat, Ann. chim. phys. 29, 68, 505, 1893;
(12) de Metz, Ann. Phys. 41, 663, 1800 ;
(13) Adams, Williamson, Johnston, J. Am. Chem. Soc.
(14) Colla 27, 1919;
(14) Colladon, Sturm, Ann. Phys. 12, 39, 1828;
(15) Quincke, Ann. Phys. 19, 40r, 1883 ;
(16) Kichards et al. J. Am. Ch. Soc. 34, 988, 1912.

## References to Table 93, p. 108:

(r) Adams, Williamson, Johnston, J. Am. Ch. Soc. 4r, 39, 1919;
(2) Richards, ibid. 37, 1646, 1915;
(3) Bridgman, Pr. Am. Acad. 44, 279, 1909; 47, 366, 1911;
(4) Adams, Williamson, unpublished;
(5) Richards, Boyer, Pr. Nat. Acad. Sc. 4, 388, 1918;
(6) Voigt, Ann. Phys. 31, 1887; 36, 1888.

SPECIFIC GRAVITIES CORRESPONDING TO THE BAUMÉ SCALE.
The specific gravities are for $15.56^{\circ} \mathrm{C}\left(60^{\circ} \mathrm{F}\right)$ referred to water at the same temperature as unity For specific gravities less than unity the values are calculated from the formula:

$$
\text { Degrees Baumé }=\frac{140}{\text { Specific Gravity }}-130 .
$$

For specific gravities greater than unity from:

$$
\text { Degrees !3aumé }=145-\frac{145}{\text { Specific Gravity }} .
$$

Specific Gravities less than 1 .

| Specific Gravity. | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Degrees Baumé. |  |  |  |  |  |  |  |  |  |
| 0.60 | 103.33 | 99.5I | 95.8 I | 92.22 | 88.75 | 85.38 | S2.12 | 78.95 | 75.88 | 72.90 |
| . 70 | 70.00 | 67.18 | 64.44 | 61.78 | 59.19 | 56.67 | 54.21 | 51.82 | 49.49 | 47.22 |
| . 80 | 45.00 | 42.84 | 40.73 | 38.68 | 36.67 | 34.71 | 32.79 | 30.92 | 29.09 | 27.30 |
| . 90 | 25.56 | 23.85 | 22.17 | 20.54 | 18.94 | 17.37 | I 5.83 | 14.33 | 12.86 | I I .41 |
| 1.00 | 10.00 |  |  |  |  |  |  |  |  |  |

Specific Cravities greater than 1 .

| Specific Gravity. | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Degrees Baumé. |  |  |  |  |  |  |  |  |  |
| 1.00 | 0.00 | 1.44 | 2.84 | 4.22 | $5 \cdot 58$ | 6.91 | 8.21 | 9.49 | 10.74 | 11.97 |
| 1.10 | 13.18 | 14.37 | I 5.54 | 16.68 | 17.81 | 18.91 | 20.00 | 21.07 | 22.12 | 23.15 |
| 1.20 | 24.17 | 25.16 | 26.15 | 27.11 | 28.06 | 29.00 | 29.92 | 30.83 | 31.72 | 32.60 |
| 1.30 | 33.46 | 34.31 | 35.15 | 35.98 | 36.79 | 37.59 | 38.38 | 39.16 | 39.93 | 40.68 |
| 1.40 | 41.43 | 42.16 | 42.89 | 43.60 | 44.31 | 45.00 | 45.68 | 46.36 | 47.03 | 47.68 |
| 1.50 | 48.33 | 48.97 | 49.60 | 50.23 | 50.34 | 51.45 | 52.05 | 52.64 | 53.23 | 53.80 |
| 1.60 | 54.38 | 54.94 | 55.49 | 56.04 | 56.58 | 57.12 | 57.65 | 58.17 | 58.69 | 59.20 |
| 1.70 | 59.71 | 60.20 | 60.70 | 61.18 | 61.67 | 62.14 | 62.61 | 63.08 | 63.54 | 63.99 |
| 1.80 | 64.44 | 64.89 | 65.33 | 65.76 | 66.20 | 66.62 |  |  |  |  |

Smithsonian Tables.
N. B. The density of a specimen may depend considerably on its state and previous treatment.

| Element. | Physical State. | Grams per cu. cm.* | Temperature ${ }^{\circ} \mathrm{C} . \dagger$ | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Aluminum | commercial h'd d'n wrought | $\begin{aligned} & 2.70 \\ & 2.65-2.80 \end{aligned}$ | $20^{\circ}$ | Wolf, Dellinger, 1910 |
| Antimony | vacuo-distilled | 6.618 | 20 | Kahlbaum, 1902. |
| " | ditto-compressed amorphous | 6.691 6.22 | 20 | Hérard. |
| Argon | liquid | 1. 3845 | 183 -18 | Baly-Donnan. |
| Arsenic | crystallized | 1.4233 5.73 | $\begin{array}{r}\text { r } \\ -189 \\ \hline 14\end{array}$ |  |
| ${ }^{\text {a }}$ | amorph. br.-black | 3.70 |  | Geuther. |
| $\stackrel{\square}{ }$ | yellow | 3.88 |  | Linck. |
| Barium |  | 3.78 |  | Guntz. |
| Bismuth | solid | 9.70-9.90 |  |  |
| " | electrolytic vacuo-distilled | 9.747 9.781 | 20 | Classen, 1890. <br> Kahlbaum, 1902. |
| " | liquid | 10.00 | 271 | Vincentini-Omodei. |
| " ${ }^{\text {c }}$ | solid | 9.67 | 271 |  |
| Boron | crystal | 2.535 |  | Wigand. Moissan. |
| Bromine | liquid | 3.12 |  | Richards-Stull. |
| Cadmium | cast | 8.54-8.57 |  |  |
| " | wrought | ${ }_{8} 8.678$ |  | Kahlb |
| " | solid | 8.37 | 318 | Vincentini-Omodei. |
| " ${ }^{\text {c }}$ | liquid | 7.99 | 318 | " " |
| Cæsium |  | 1.873 | 20 | Richards-Brink. |
| Calcium |  | 1.54 |  | Brink. |
| Carbon | diamond graphite | 3.52 2.25 |  | Wigand. |
| Cerium | electrolytic | 6.79 |  | Muthmann-Weiss. |
|  | pure | 7.02 |  | " " |
| Chlorine Chromium | liquid | I. 507 $6.52-6.73$ | - 33.6 | Drugman-Ramsay. |
|  | pure | 6.92 | 20 | Moissan. |
| Cobalt |  | 8.71 | 1 | Tilden, Ch. C. 1898. |
| Columbium |  | 8.4 | 15 | Muthmann-Weiss. |
| Copper | cast | 8.30-8.95 |  |  |
| " | annealed wrought | ${ }_{8.85}^{8.89} 8$ | 20 | Dellinger, 1911 |
| " | hard drawn | 8.89 |  | " " |
| " | vacuo-distilled | 8.9326 | 20 | Kahlbaum, 1902. |
| " | ditto-compressed | 8.9376 | 20 | " ${ }^{\text {c }}$ |
| Erbium | liquid | 8.217 |  | Roberts-Wrightson. |
| Erbium <br> Fluorine | liquid | 4.77 |  | St. Meyer, Z. Ph. Ch. 37. |
| Gallium | . T quid | 1.14 5.93 | -200 23 | de Boisbaudran. |
| Germanium |  | 5.46 | 20 | Winkler. |
| Glucinum |  | 1.85 |  | Humpidge. |
| Gold | cast | 19.3 |  |  |
| " | wrought | 19.33 |  |  |
| " | vacuo-distifled | 18.88 | 20 | Kahlbaum, 1902. |
| Helium | liquid |  | -269 | Onnes, 1908. |
| Hydrogen Indium | liquid | $\begin{aligned} & 0.070 \\ & 7.28 \end{aligned}$ | -252 | Dewar, Ch. News, 1904. Richards. |

*To reduce to pounds per cu . ft . multiply by 62.4 .
$\dagger$ Where the temperature is not given, ordinary atmospheric temperature is understood.
Compiled from Clarke's Constants of Nature, Landolt-Börnstein-Meyerhoffer's Tables, and other sources. Where no authority is stated, the values are mostly means from varions sources.

DENSITY IN GRAMS PER CUBIC CENTIMETER OF THE ELEMENTS, LIQUID OR SOLID.

| Element. | Physical State | Grams per cu. cmi.* | Temperature ${ }^{\circ} \mathrm{C} . \dagger$ | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Iridium |  | 22.42 | 17 | Deville-Debray |
| Iodine |  | 4.940 | 20 | Richards-Stull |
| Iron | pure | 7.85-7.88 |  |  |
| " | gray cast | 7.03-7.13 |  |  |
| " | white cast | 7.58-7.73 |  |  |
| " | wrought | $7.80-7.90$ |  |  |
| ، | liquid | 688 |  | Roberts-Austen |
| " | steel | 7.60-7.80 |  |  |
| Krypton | liquid | 2.16 | -146 | Ramsay-Travers |
| Lanthanum |  | 6.15 |  | Muthmann-Weiss |
| Lead | vacuo-distilled | 11.342 | 20 | Kahlbaum, 1902 |
| " | ditto-compressed | I 1. 347 | 20 | .. .. |
| " | solid | 11.005 | 325 | Vincentini-Omodei |
| " | liquid | 10.645 | 325 | , |
| " |  | 10.597 | $400^{\circ}$ | Day, Sosman, Hostetter, |
| " | '، | 10.078 | $850^{\circ}$ | 1914 |
| Lithium |  | 0.534 | 20 | Richards-Brink, '07. |
| Magnesium |  | 1.741 |  | Voigt |
| Manganese |  | 7.42 |  | Prelinger |
| Mercury | liquid | 13.596 | $\bigcirc$ | Regnault, Volkmann |
|  |  | 13.546 | 20 |  |
| " | " | 13.690 | -38.8 | Vincentini-Omodei |
| " | solid | 14.193 | -38.8 | Mallet |
| " |  | 14.383 | -188 | Dewar, 1902 |
| Molybdenum |  | 9.01 |  | Moissan . |
| Neodymium |  | 6.96 |  | Muthmann-Weiss |
| Nickel |  | 8.60-3.90 |  |  |
| Nitrogen | liquid | 0.810 0.854 | $\begin{array}{r} \text {-I95 } \\ -205 \end{array}$ | $\underset{64}{ }$ Baly-Donnan, ${ }_{6} 902$ |
| Osmium |  | 22.5 |  | Deville-Debray |
| Oxygen Palladium | liquid | 1.14 12.16 | -184 | Richards-Stull |
| Phosphorus $\ddagger$ | white | 12.16 1.83 |  | Richards-Stull |
| Phosphorus 7 | red | 2.20 |  |  |
| " | metallic | 2.34 | 15 | Hittorf |
| Platinum |  | 21.37 | 20 | Richarcls-Stult |
| Potassium |  | 0.870 | 20 | Richards-Brink, '07 |
| "، | solid liquid | 0.851 | 62.1 | Vincentini-Omodei |
| Præsodymium |  | 6.475 | 62.1 | Muthmann-Weiss |
| Rhodium |  | 12.44 |  | Holborn Henning |
| Rubidium |  | - 1.532 | 20 | Richards-Brink, '0才 |
| Ruthenium |  | 12.06 | - | Toby |
| Samarium |  | 7.7-7.8 |  | Muthmann- Weiss |
| Selenium |  | 4.3-48 |  |  |
| Silicon | cryst. amorph. | 2.42 2.35 | 20 | Richards-Stull-Brink Vigoroux |
| Silver | cast | $\xrightarrow{2.35} 10.42-10.53$ | 15 | Vigoroux |
| " | wrought | 10.6 |  |  |
| " | vacuo-distilled | 10.492 | 20 |  |
| " | ditto-compressed | 10.503 | 20 |  |
| "' | liquid | 9.51 |  | Wrightson , |
| Sodium |  | 0.9712 |  | Richards-Brink, 'ō |
| " | solid liquid | 0.9519 | 97.6 | Vincentini-Omodei |
| " |  | 1.0066 | -188 | 1)ewar |
| Strontium |  | 2.50-2.58 |  | Matthiessen |
| Sulphur | liquid | $\begin{aligned} & 2.0-2.1 \\ & 1.8 \text { II } \end{aligned}$ | 113 | Vincentini-Omodei |

II2 TABLES 95 (continued) AND 96. DENSITY OF VARIOUS SUBSTANCES.
TABLE 95 (continued). - Density in grams per cubic centimeter and pounds per cublo foot of the elements, liquid or solid.

| Element. | Physical State. | Grams per $\mathrm{cu} . \mathrm{cm}$. | Temperature ${ }^{\circ} \mathrm{C}$. | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Tantalum |  | 16.6 |  |  |
| Tellurium | crystallized | 6.25 |  |  |
| ، | amorphous | 6.02 | 20 | Beljankin. |
| Thallium |  | 11.86 |  | Richards-Stull. |
| Thorium |  | 12.16 | 17 | Bolton. |
| Tin | white, cast | 7.29 |  | Matthiessen. |
| ، | " wrought | $7 \cdot 30$ |  |  |
| " | "، crystallized | 6.97-7.1S |  |  |
| " | "' solid | 7.184 | 226 | Vincentini-Omodei |
| " | liquid | 6.99 | 226 | " See Table 65 |
| " ${ }^{\text {Titanium }}$ | gray | 5.8 |  |  |
| Titanium |  | 4.5 | 18 | Mixter. |
| Tungsten |  | 18.6-19.1 |  |  |
| Uranium |  | 18.7 | I 3 | Zimmermann. |
| Vanadium |  | 5.69 |  | Ruff-Martin. |
| Xenon | liquid | 3.52 | 109 | Ramsay-Travers. |
| Yttrium |  | 3.80 |  | St. Meyer. |
| Zinc | cast | 7.04-7.16 |  |  |
| " | wrought | 7.19 |  |  |
| " | vacuo-distilled | 6.92 | 20 | Kablbaum, 1902. |
| " | ditto-compressed liquid | 7.13 6.48 | 20 | Roberts-Wrightson. |
| Zirconium |  | 6.44 |  |  |

TABLE 96. - Density in grams per cubic centimeter and in pounds per cubic foot of different kinds of wood.
The wood is supposed to be seasoned and of average dryuess.

| Wood. | Grams per cubic centimeter. | Pounds per cubic foot. | Wood. | Grams per cubic centimeter. | Pounds per cubic foot. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alder | $0.42-0.65$ | 26-42 | Hazel | $0.60-0.80$ | 37-49 |
| Apple | 0.66-0.84 | $4^{1-52}$ | Hickory | 0.60-0.93 | $37-5^{8}$ |
| Ash | $0.65-0.85$ | 40-53 | Holly | 0.76 |  |
| Bamboo | $0.31-0.40$ | 19-25 | Iron-bark | 1.03 | 64 |
| Basswood. See Linden. |  |  | Juniper | 0.56 | 35 |
| Beech | 0.70-0.90 | 43-56 | Laburnum | 0.92 | 57 |
| Blue gum | 1.00 | 62 | Lancewood | 0.68-1.00 | 42-62 |
| Birch | $0.51-0.77$ | 32-48 | Lignum vita | 1.17-1.33 | $73-83$ |
| Box | 0.95-1.16 | 59-72 | Linden or lime-tree | 0.32-0.59 | 20-37 |
| Bullet-tree | 1.05 | 65 | Locust | 0.67-0.71 | 42-44 |
| Butternut | 0.38 | 24 | Logwood | . 91 | 57 |
| Cedar | 0.49-0.57 | 30-35 | Mahogany, Honduras | 0.66 | 41 |
| Cherry | $0.70-0.90$ | 43-56 | " Spanish | 0.85 | 53 |
| Cork | 0.22-0.26 | 14-16 | Maple | $0.62-0.75$ | 39-47 |
| Dogwood | 0.76 |  | Oak | $0.60-0.90$ | 37-56 |
| Ebony Elm | $1.11-1.33$ $0.54-0.60$ | 69-83 | lear-tree | $0.61-0.73$ | 38-45 |
| Fir or Pine, American | 0.54-0.60 | 34-37 | Plum-tree Poplar | $0.66-0.78$ $0.35-0.5$ | $41-49$ $22-31$ |
| White | 0.35-0.50 | 22-31 | Satinwood | 0.95 |  |
| " Larch | $0.50-0.56$ | $31-35$ | Sycamore | $0.40-0.60$ | 24-37 |
| " Pitch | 0.83-0.85 | 52-53 | Teak, Indian | 0.66-0.88 | 41-55 |
| " $\quad$ Red | $0.48-0.70$ | 30-44 | " African | 0.98 |  |
| " Scotch | $0.43-0.53$ | 27-33 | Walnut | 0.64-0.70 | 40-43 |
| " Spruce | 0.48-0.70 | 30-44 | Water gum | 1.00 | 62 |
| Greenheart ellow | $0.37-0.60$ $0.93-1.04$ | $23-37$ $58-65$ | Willow | 0.40-0.60 | 24-37 |

* Where the temperature is not given, ordinary atmospheric temperature is understood.

Smithsonian Tables.

## DENSITY IN GRAMS PER CUBIC CENTIMETER AND POUNDS PER CUBIC

 FOOT OF VARIOUS SOLIDS.N. B. The density of a specimen depends considerably on its state and previous treatment; especially is this the case with porous materials.

| Material. | Grams per $\mathrm{cu} . \mathrm{cm}$. | Pounds per cu. foot. | Material. | Grams per cu. cm. | Pounds per cu. foot. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Agate | $2.5-2.7$ | 1 56-168 | Gum arabic | 1.3-1.4 | 80-85 |
| Alabaster : |  |  | Gypsum | $2.31-2.33$ | 144-145 |
| Carbonate | 2.69-2.78 | 168-173 | Hematite | 4.9-5.3 | 306-330 |
| Sulphate | 2.26-2.32 | 141-145 | Hornblende | 3.0 | 187 |
| Albite | 2.62-2.65 | 163-165 | Ice | 0.917 | 57.2 |
| Amber | 1.06-I.1 1 | 66-69 | Ilmenite | 4.5-5. | 280-310 |
| Amphiboles | 2.9-3.2 | 180-200 | Ivory | 1.83-1.92 | 114-120 |
| Anorthite | $2.74{ }^{-2.76}$ | $171-172$ | Labradorite | $2.7-2.72$ | 168-170 |
| Anthracite | 1.4-1. ${ }^{\text {- }}$ | 87-112 | Lava : basaltic | 2.8-3.0 | 175-185 |
| Asbestos | 2.0-2.8 | 125-175 | trachytic | 2.0-2.7 | 125-168 |
| Asphalt | 1.1-1.5 | 69-94 | Leather: dry | 0.86 | 54 |
| lasalt | 2.4-3.1 | 150-190 | greased | I. 02 | 64 |
| Beeswax | $0.96-0.97$ | 60-6I | Lime : mortar | 1.65-1.78 | 103-11 I |
| Beryl | 2.69-2.7 | 168-168 | slaked | 1.3-1.4 | 81-87 |
| Biotite | 2.7-3.1 | 170-190 | Limestone | 2.68-2.76 | 167-171 |
| Bone | 1.7-2.0 | 106-125 | Litharge : |  |  |
| Brick | 1.4-2.2 | 87-137 | Artificial | 9.3-9.4 | 580-585 |
| Butter | 0.86-0.87 | 53-54 | Natural | 7.8-8.0 | 490-500 |
| Calamine | 4.1-4.5 | $255-280$ | Magnetite | 4.9-5.2 | 306-324 |
| Caoutchouc | 0.92-0.99 | 57-62 | Malachite | 3.7-4.I | 231-256 |
| Celluloid | 1.4 | 87 | Marble | 2.6-2.84 | 160-177 |
| Cement, set | 2.7-3.0 | 170-190 | Meerschaum | 0.99-1.28 | 62-80 |
| Chalk | 1.9-2.8 | 118-175 | Mica | 2.6-3.2 | 165-200 |
| Charcoal: oak |  | 35-28 | Muscovite | $2.76-3.00$ | $172-225$ |
| pine | $0.28-0.44$ | 18-28 | Ochre | 3.5 | $218$ |
| Chrome yellow | 6.00 | 374 | Oligoclase | 2.65-2.67 | $165-167$ |
| Chromite | 4.32-4.57 | 270-285 | Olivine | 3.27-3.37 | 204-210 |
| Cinnabar | 8.12 | 507 | Opal | 2.2 |  |
| Clay | 1.8-2.6 | 122-162 | Orthoclase | $2.58-2.61$ | 161-163 |
| Coal, soft | 1.2-I.5 | 75-94 | Paper | $0.7-1.15$ | 44-72 |
| Cocoa butter | 0.89-0.91 | 56-57 | Paraffin | 0.87-0.91 | 54-57 |
| Coke | 1.0-1.7 | 62-105 | Peat | 0.84 | 52 |
| Copal | 1.04-1.14 | 65-71 | Pitch | 1.07 | 67 |
| Corundtum | 3.9-4.0 | 245-250 | Porcelain | 2.3-2.5 | $143-156$ |
| Diamond: |  |  | Porphyry | 2.6-2.9 | 162-181 |
| Anthracitic Carbonado | 1. 66 $3.01-3.25$ | 104 $188-203$ | Pyrite | $4.95-5.1$ 2.65 | 309-318 |
| Diorite ${ }^{\text {Carbonado }}$ | $3.01-3.25$ 2.52 | $188-203$ 157 | Quartz | 2.65 2.73 | 165 170 |
| Dolomite | 2.84 | 177 | Resin | 1.07 | 67 |
| Ebonite | 1.15 | 72 | Rock salt | 2.18 | 136 |
| Emery | 4.0 | 250 | Rutile | 6.00-6.5 | 374-406 |
| Epidote | 3.25-3.5 | 203-218 | Sandstone | $2.14-2.36$ | $134-147$ |
| Feldspar | 2.55-2.75 | 159-172 | Serpentine | 2.50-2.65 | $156-165$ |
| Flint | 2.63 | 164 | Slag, furnace | 2.0-3.9 | 125-240 |
| Fluorite | 3.18 | 198 | Slate | $2.6-3 \cdot 3$ | 162-205 |
| Gamboge | 1.2 | 75 | Soapstone | 2.6-2.8 | 162-175 |
| Garnet | 3.15-4.3 | 197-268 | Starch | I. 53 | 95 |
| Gas carbon | I. 88 | 117 | Sugar | 1.61 | 100 |
| Gelatine | 1.27 | 180 | Talc | 2.7-2.8 | 168-174 |
| Glass: common | 2.4-2.8 | 150-175 | Tallow | 0.91-0.97 | 57-60 |
| flint | 2.9-5.9 | 180-370 | Topaz | 3.5-3.6 | 219-223 |
| Glue | 1.27 | So | Tourmaline | 3.0-3.2 | 190-200 |
| Granite | 2.6.4-2.76 | ${ }_{165-172}$ | Zircon | $4.68-4.70$ | 292-293 |
| Graphite | $2.30-2.72$ | 14i-170 |  |  |  |

DENSITY IN GRAMS PER CUBIC CENTIMETER AND POUNDS PER CUBIC FOOT OF VARIOUS ALLOYS.


SMITMSONIIN TABLES.

## Table 99.-DENSITIES OF VARIOUS NATURAL AND ARTIFICIAL MINERALS.

(See also Table 97.)


References: i, Larsen 1909; 2, Day and Shepherd; 3, Shepherd and Rankin, 1909; 4, Allen and White, 1909 ; 5, Allen, Wright and Clement, I906; 6, Day and Allen, 1905; 7, Washington and Wright, i910; 8, Merwin, I9II ; 9, Johnston and Adams, i9I ; 10, Allen and Crenshaw, 1912; 11, Wright, 1908.

All the data of this table are from the Geophysical Laboratory, Washington.

Table 100.- DENSITIES OF MOLTEN TIN AND TIN-LEAD EUTECTIC.

| Temperature | $250^{\circ} \mathrm{C}$ | $300^{\circ}$ | $400^{\circ}$ | $500^{\circ}$ | $600^{\circ}$ | $900^{\circ}$ | $1200^{\circ}$ | $1400^{\circ}$ | $1600^{\circ}$ |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: |
| Molten tin | 6.982 | 6.943 | 6.875 | 6.814 | 6.753 | 6.578 | 6.399 | 6.280 | 6.162 |
| 37 pts. $\mathrm{Pb}, 63$, Sn.* | 8.01 I | 7.965 | 7.879 | 7.800 | 7.73 I | - | - | - | - |

* Melts at 181. Day and Sosman, Geophysical Laboratory, unpublished.

For further densities inorganic substances see table $\begin{array}{cc}219 & 219 . \\ \text { organic } & 220 .\end{array}$

TABLE 101. - Weight of Sheet Metal. (Metric Measure.)
This table gives the weight in grams of a plate one meter square and of the thickness stated in the first column.

| Thickness <br> in thou- <br> sandths of <br> a cm. | Iron. | Copper. | Brass. | Aluminum. | Platinum. | Gold. | Silver. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathbf{y}$ |  | 78.0 | 89.0 | 85.6 | 26.7 | 215.0 | 193.0 | 105.0 |
| $\mathbf{1}$ | 156.0 | 178.0 | 171.2 | 53.4 | 430.0 | 386.0 | 210.0 |  |
| 2 | 234.0 | 267.0 | 256.8 | 80.1 | 6450 | 579.0 | 315.0 |  |
| 3 | 312.0 | 356.0 | 342.4 | 106.8 | 860.0 | 772.0 | 420.0 |  |
| 4 | 390.0 | 445.0 | 428.0 | 133.5 | 1075.0 | 965.0 | 525.0 |  |
| 5 |  |  |  |  |  |  |  |  |
| 6 | 468.0 | 534.0 | 513.6 | 160.2 | 1290.0 | 1158.0 | 630.0 |  |
| 7 | 546.0 | 623.0 | 599.2 | 186.9 | 1505.0 | 1351.0 | 735.0 |  |
| 8 | 624.0 | 712.0 | 684.8 | 213.6 | 1720.0 | 1544.0 | 840.0 |  |
| 9 | 702.0 | 801.0 | 770.4 | 240.3 | 1935.0 | 1737.0 | 945.0 |  |
| 10 | 780.0 | 890.0 | 856.0 | 267.0 | 2150.0 | 1930.0 | 1050.0 |  |

TABLE 102. - Weight of Sheet Metal. (British Measure.)


## DENSITY OF LIQUIDS.

Density or mass in grams per cubic centimeter and in pounds per cubic foot of various liquids.


## Smithsonian Tables.

[Under standard pressure ( 76 cm ), at every tenth part of a degree of the international hydrogen scale from $0^{\circ}$ to $41^{\circ}$ C, in grams per milliliter ${ }^{1}$ ]

| Degrees grade. | Tenths of Degrees. |  |  |  |  |  |  |  |  |  | Mean Differ ences. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |  |
| $\bigcirc$ | 0.999 S681 | S747 | 8812 | S875 | 8936 | 8996 | 9053 | 9109 | 9163 | 9216 | + 59 |
| 1 | 9267 | 9315 | 9363 | 9403 | 9452 | 9494 | 9534 | 9573 | 9610 | 9645 | $+\quad 41$ $+\quad 24$ |
| 2 | 9679 | 9711 | 974 I | 9769 | 9796 | 9821 | 9844 | 9866 | 9887 | 9905 | +24 $+\quad 8$ |
| 3 | 9922 | 9937 | 9951 | +9962 | *9973 | -9981 | *9988 | *9994 | *9998 | *0000 |  |
| 4 | 1.0000000 | *9999 | *9996 | *9992 | *9986 | *9979 | *9970 | *9960 | *9947 | *9934 | 8 |
| 5 | 0.9999919 | 9902 | 9884 | 9864 | 9842 | 9819 | 9795 | 9769 | 9742 | 9713 | - 24 |
| 6 | 9682 | 9650 | 9617 | 9582 | 9545 | 9507 | 9468 | 9427 | 9385 | 9341 | - 39 |
| 7 | 9296 | 9249 | 9201 | 9151 | 9100 | 9048 | 8994 | 8938 | 8881 | 8823 | - 53 |
| 8 | S764 | 8703 | 8641 | 8577 | 8512 | 8445 | 8377 | 8308 | 8237 | 8165 | -67 |
| 9 | So9I | Sol 7 | 7940 | 7863 | 7784 | 7704 | 7622 | 7539 | 7455 | 7369 | - 8I |
| 10 | 7282 | 7194 | 7105 | 7014 | 6921 | 6826 | 6729 | 6632 | 6533 | 6432 | -95 |
| 11 | 6331 | 6228 | 6124 | 6020 | 5913 | 5805 | 5696 | 5586 | 5474 | 5362 | -108 |
| 12 | 52.48 | 5132 | 5016 | 4898 | 4780 | 4660 | 4538 | 4415 | 4291 | 4166 | -121 |
| 13 | 4040 | 3912 | 3784 | 3654 | 3523 | 3391 | 3257 | 3122 | 2986 | 2850 | -133 |
| 14 | 2712 | 2572 | 243 I | 2289 | 2147 | 2003 | 1858 | 1711 | 1564 | 1416 | -145 |
| 15 | 1266 | III4 | 0962 | oSo9 | 0655 | 0499 | 0343 | O185 | 0026 | *9865 | -156 |
| 16 | 0.9989705 | 9542 | 9378 | 9214 | 9048 | 888I | 8713 | 8544 | 8373 | 8202 | -168 |
| 17 | 8029 | 7856 | 7681 | 7505 | 7328 | 7150 | 697 I | 6791 | 6610 | 6427 | -178 |
| 18 | 6244 | 6058 | 5873 | 5686 | 5498 | 5309 | 5119 | 4927 | 4735 | 4541 | -190 |
| 19 | 4347 | 4152 | 3955 | 3757 | 3558 | 3358 | 3158 | 2955 | 2752 | 2549 | -200 |
| 20 | 2343 | 2137 | 1930 | 1722 | 1511 | 1301 | 1090 | 0878 | 0663 | 0449 | -211 |
| 21 | 0233 | 0016 | *9799 | *9580 | *9359 | *9139 | *8917 | *8694 | *8470 | *8245 | -221 |
| 22 | 0.9978019 | 7792 | 7564 | 7335 | 7104 | 6873 | 6641 | 6408 | 6173 | 5938 | -232 |
| 23 | 5702 | 5466 | 5227 | 4988 | 4747 | 4506 | 4264 | 402 I | 3777 | 3531 | -242 |
| 24 | 3286 | 3039 | 2790 | 2541 | 2291 | 2040 | 1788 | 1535 | 1280 | 1026 | -252 |
| 25 | 0770 | 0513 | 0255 | *9997 | *9736 | *9476 | *92I4 | *8951 | *8688 | *8423 | -261 |
| 26 | 0.9968158 | 7892 | 7624 | 7356 | 7087 | 6817 | 6545 | 6273 | 6000 | 5726 | -271 |
| 27 | 5451 | 5176 | 4898 | 4620 | 4342 | 4062 | 3782 | 3500 | 3218 | 2935 | -280 |
| 28 | 2652 | 2366 | 2080 | 1793 | 1505 | 1217 | 0928 | 0637 | 0346 | 0053 | $-289$ |
| 29 | 0.9959761 | 9466 | 9171 | 8876 | S 579 | 8282 | 7983 | 7684 | 7383 | 7083 | -298 |
| 30 | 6780 | 6478 | 6174 | 5869 | 5564 | 5258 | 4950 | 4642 | 4334 | 4024 | -307 |
| 31 | 3714 | 3401 | * 3089 | 2776 $*$ | 2462 $* 9276$ | 2147 $* 8$ | 1832 $* 8630$ | +1515 | 1198 $*$ | * 880 | -315 |
| 32 | 0561 | 0241 | *9920 | *9599 | *9276 | *8954 | *8630 | *8304 | *7979 | $*_{7} 653$ | -324 |
| 33 | 0.9947325 | 6997 | 6668 | 6338 | 6007 | 5676 | 5345 | 5011 | 4678 | 4343 | $-332$ |
| 34 | 4007 | 3671 | 3335 | 2997 | 2659 | 2318 | 1978 | 1638 | 1296 | 0953 | -340 |
| 35 | 0610 | 0267 | *9922 | *9576 | *9230 | *8883 | *8534 | *8186 | *7837 | *7486 | -347 |
| 36 | 0.9937136 3585 | 6784 | 6432 | 6078 | 5725 | 5369 | 5014 | 4658 | 4301 | 3943 | -355 |
| 37 38 | 3585 0.9929960 | 3226 | 2866 | 2505 8859 | 2144 8490 | ${ }_{1}^{1782}$ | 1419 | 1055 | 0691 | 0326 | $-362$ |
| 38 39 | 0.9929960 6263 | 9593 5800 | 9227 5516 | 8859 5140 | 8490 4765 | 8120 | 7751 | 7380 | 7008 | 6636 | -370 -377 |
| 39 | 6263 | 5890 | 5516 | 5140 | 4765 | 4389 | 4011 | 3634 | 3255 | 2876 | -377 |
| 40 41 | 2497 0.9918661 | 2116 | 1734 | 1352 | 0971 | 0587 | 0203 | *9818 | *9433 | *9047 | $-384$ |

${ }^{1}$ According to $P$. Chappuis, Bureau international des Poids et Mesures, Travaux et Mémoires, 13; 1907.

[^17]VOLUMEIN CUBIC CENTIMETERS AT VARIOUS TEMPERATURES OF A CUBIC CENTIMETER OF WATER FREE FROM AIR AT THE TEMPERATURE OF MAXIMUM DENSITY. $0^{\circ}$ TO $40^{\circ} \mathrm{C}$.

Hydrogen Thermometer Scale.

| $\underset{\text { C. }}{\text { Temp. }}$ | . 0 | . 1 | . 2 | -3 | . 4 | - 5 | . 6 | . 7 | . 8 | -9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\bigcirc$ | 1.000132 | 125 | 118 | 112 | 106 | 100 | 095 | 089 | 084 | 079 |
| 1 | 073 | 069 | 064 | 059 | 055 | 051 | 047 | 043 | 039 | 035 |
| 2 | 032 | 029 | 026 | 023 | 020 | 018 | 0.6 | 013 | OII | 009 |
| 3 | 008 | 006 | 005 | 004 | 003 | 002 | 001 | 001 | 000 | Q00 |
| 4 | 000 | 000 | 00 | OOI | 0 OI | 002 | 003 | 004 | 005 | 007 |
| 5 | 008 | 010 | 012 | Or 4 | 016 | OI 8 | 021 | 023 | 026 | 029 |
| 6 | 032 | 035 | 039 | 042 | 046 | 050 | 054 | 058 | 062 | 066 |
| 7 | 070 | 075 | 080 | 085 | 090 | 095 | 101 | 106 | 112 | 118 |
| 8 | 124 | 130 | 137 | 142 | 149 | 156 | 162 | 169 | 176 | 184 |
| 9 | ${ }^{191}$ | 198 | 206 | 214 | 222 | 230 | 238 | 246 | 254 | 263 |
| 10 | 272 | 281 | 290 | 299 | 308 | 317 | 327 | 337 | 347 | 357 |
| 11 | 367 | 377 | 388 | 398 | 409 | 420 | 430 | 441 | 453 | 464 |
| 12 | 476 | 487 | 499 | 511 | 522 | 534 | 547 | 559 | 57 I | 584 |
| 13 | 596 | 609 | 623 | 636 | 649 | 661 | 675 | 688 | 702 | 715 |
| 14 | 729 | 743 | 757 | 772 | 786 | 800 | 815 | 830 | 844 | 859 |
| 15 | 873 | 890 | 905 | 920 | 935 | 951 | 967 | 983 | 998 | ${ }^{1} 15{ }^{*}$ |
| 16 | 1.001031 | 047 | 063 | 080 | 097 | 113 | 130 | 147 | 164 | 182 |
| 17 | 198 | 216 | 233 | 252 | 269 | 287 | 305 | 323 | 341 | 358 |
| 18 | 378 | 396 | 415 | 433 | 452 | 47 I | 490 | 510 | 529 | 548 |
| 19 | 568 | 588 | 606 | 626 | 646 | 667 | 687 | 707 | 728 | 748 |
| 20 | 769 | 790 | 811 | 832 | 853 | 874 |  |  | 938 | $9^{60}$ |
| 21 | 981 | 002* | 024* | 046* | 068* | 091* | 113 * | 135* | I 58* | 181* |
| 22 | 1.002203 | 226 | 249 | 271 | 295 | 319 | 342 | 364 | 389 | 412 |
| 23 | 436 | 459 | 483 | 507 | 532 | 556 | 581 | 605 | 629 | 654 |
| 24 | 679 | 704 | 729 | 754 | 779 | 804 | 829 | 854 | 879 | 905 |
|  | 932 | 958 | . 983 | 010* | 036* | 061* | 088* | $115{ }^{*}$ | 141* | 168* |
| 26 | 1.003195 | 221 | - 248 | 275 | 302 | 330 | 357 | 384 | 412 | 439 |
|  | 467 | 495 | 523 | 550 | 579 | 607 | 635 | 663 | 692 | 720 |
| 28 | 749 | 776 | 806 | 836 | 865 | 893 | 922 | 951 | 98 I | OII* ${ }^{*}$ |
| 29 | 1.00404 1 | 069 | 100 | 129 | 160 | 189 | 220 | 250 | 280 | 310 |
| 30 | 341 | 371 | 403 | 432 | 464 | 494 | 526 | 557 | 588 | 619 |
| 31 | 651 | 682 | 713 | 744* |  | 808 | 840 | 872 |  | ${ }^{936}$ |
| 32 | 968 | 001* ${ }^{*}$ | 033* | 066* | 098* | 132* | 163* | 197* | 229* | 263* |
| 33 | $1.005296$ |  |  | 395 | 427 768 | 461 | 496 | 530 871 | 562 904 | 597 940 |
| 34 | $631$ | 665 | 698 | $73^{2}$ | 768 | 802 | 836 | 87 I | 904 | 940 |
| 35 | 975 | 009* | 044* | 078* | II 5* | 150* | 185* | 219* | 255* | 290* |

Reciprocals of the preceding table.

## Smithsonian tables.

table 106.
DENSITY AND VOLUME OF WATER.
$-10^{\circ} \mathrm{TO}+250^{\circ} \mathrm{C}$.
The mass of one cubic centimeter at $4^{\circ} \mathrm{C}$. is taken as unity.

| Temp. C. | Density. | Volume. | Temp. C. | Density. | Volume. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $-10^{\circ}$ | 0.99815 | 1.00186 | $+35^{\circ}$ | 0.99406 | 1.00598 |
| -9 | - 843 | 157 | 36 | 371 | 633 |
| -8 | - 869 | 131 | 37 | 336 | 669 |
| -7 | 892 | 108 | 38 | 3300 | 706 |
| -6 | 912 | 088 | 39 | 263 | 743 |
| -5 | 0.99930 | 1.00070 | 40 | 0.99225 | 1.00782 |
| -4 | 945 | 055 | 41 | - 187 | 821 |
| -3 | 958 | 042 | 42 | 147 | 861 |
| $-2$ | 970 | 031 | 43 | 107 | 901 |
| -1 | 979 | 021 | 44 | 066 | 943 |
| +0 | 0.99987 | 1.00013 | 45 | 0.99025 | 1.00985 |
| 1 | 993 | 007 | 46 | 0.98982 | 1.01028 |
| 2 | 997 | 003 | 47 | 940 | 072 |
| 3 | 999 | $\infty$ ) | 48 | 896 | 116 |
| 4 | 1.00000 | 1.00000 | 49 | 852 | 162 |
| 5 | 0.99999 | 1.00001 | 50 | 0.98807 | 1.01207 |
| 6 | 997 | 003 | 51 | 762 | 254 |
| 7 | 993 | 007 | 52 | 715 | 301 |
| 8 | 988 | 012 | 53 | 669 | 349 |
| 9 | 981 | $\bigcirc 19$ | 54 | 621 | 398 |
| 10 | 0.99973 | 1.00027 | 55 | 0.98573 | 1.01448 705 |
| 11 | 963 | 037 | 60 | 324 | 705 |
| 12 | 952 | 048 | 65 | $\begin{array}{r}059 \\ \hline\end{array}$ | -979 |
| 13 | 940 | 060 | 70 | 0.97781 | 1.02270 |
| 14 | 927 | 073 | 75 | 489 | 576 |
| 15 | 0.99913 | 1.00087 | 80 | 0.97183 | 1.02899 |
| 16 | 897 | -103 | 85 | 0.96865 | 1.03237 |
| 17 |  | 120 | 90 | 534 | 590 |
| 18 | 862 | 138 | 95 | 192 | 959 |
| 19 | 843 | 157 | 100 | 0.95838 | 1.04343 |
| 20 | 0.99823 | 1.00177 | 110 | 0.9510 | 1.0515 |
| 21 | 802 | 198 | 120 | . 9434 | 1.0601 |
| 22 | 780 | 220 | 130 | . 9352 | 1.0693 |
| 23 | 757 | 244 | 140 | . 9264 | 1.0794 |
| 24 | 733 | 268 | 150 | .9173 | 1.0902 |
| 25 | 0.99708 | 1.00293 | 160 | 0.9075 | 1.1019 |
| 26 | 682 | 320 | 170 | . 8973 | 1.1145 |
| 27 | 655 | 347 | 180 | . 8866 | 1.1279 |
| 28 | 627 | 37.5 | 190 | . 8750 | 1.1429 |
| 29 | 598 | 404 | 200 | . 8628 | 1.1590 |
| 30 | 0.99568 | 1.00434 | 210 | 0.850 |  |
| 31 | 537 | 465 | 220 | . 837 | 1.195 |
| 32 | 506 | 497 | 2.30 | . 823 | 1.215 |
| 33 | 473 | 530 | 240 | . 809 | 1.236 |
| 34 | 440 | 563 | 250 | . 794 | 1.259 |

[^18]DENSITY OF MERCURY
Density or mass in grams per cubic centimeter, and the volume in cubic centimeters of one gram of mercury.

| Temp. C. | Mass in grams per $\mathrm{cu} . \mathrm{cm}$. | Volume of 1 gram in cu. cms. | Temp. C | Massin grams per $\mathrm{cu} . \mathrm{cm}$. | Volume of 1 gram in cu. cms. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $-10^{\circ}$ | 13.6198 | 0.0734225 | $30^{\circ}$ | 13.5213 | 0.0739572 |
|  | 61736148 | 4358 | 31 | $\begin{aligned} & 5189 \\ & 5164 \end{aligned}$ | $\begin{aligned} & 9705 \\ & 9839 \end{aligned}$ |
|  |  | 4492 | 32 |  |  |
|  | 6124 | 4626 | 33 | 5140 | $\begin{aligned} & 9839 \\ & 9973 \end{aligned}$ |
|  | 6099 | 4759 | 34 | 5116 | 40107 |
| -5 | 13.6074 | 0.0734893 | 35 | $13 \cdot 5091$ | 0.0740241 |
| -4 | 6050 | 5026 | 36 | 5066 | 0374 |
| -3 | 6025 | 5160 | 37 | 5042 | 0508 |
| -2 | 6000 | 5293 | 38 | 5018 | 0642 |
| -I | 5976 | 5427 | 39 | 4994 | 0776 |
| -0 | I3.595 1 | 0.0735560 | 40 | 13.4969 | 0.0740910 |
| I | 5926 | 5694 | 50 | 4725 | 2250 |
| 2 | 5901 | 5828 | 60 | 4482 | 3592 |
| 3 | 5877 | 5961 | 70 | 4240 | 4936 |
| 4 | 5852 | 6095 | 80 | 3998 | 6282 |
| 56 | $13 \cdot 5827$ | 0.07362286362 | 90 | 13.3723 | $\begin{array}{r} 0.074763 \mathrm{I} \\ 898 \mathrm{I} \end{array}$ |
|  | 5803 |  | 100110 | $\begin{aligned} & 3515 \\ & 3279 \end{aligned}$ |  |
| 7 | 5778 | 6496 |  |  | $\begin{array}{r} 8981 \\ 50305 \end{array}$ |
| 8 | 5754 | 6629 | 110 120 | $\begin{aligned} & 3279 \\ & 3040 \end{aligned}$ | 1653 |
| 9 | 5729 | 6763 | 130 | 2801 | 3002 |
| 10 | 13.5704 | 0.0736893 | 140 | 13.2563 |  |
| II | 5680 | 7030 | 150 | r 2326 | $\begin{array}{r} 5454 \\ 5708 \end{array}$ |
| 12 | 5655 | 7164 | 160170 | 2090 | 7064 |
| 13 | 5630 | 7298 |  | 1853 | $8422$ |
| 14 | 5606 | 7431 | 170 180 | 1617 | 9784 |
| 15 | 13.5581 | 0.0737565 | 190 | 13.1381 | 0.0761149 |
| 16 | 5557 | 7699 | 200 | I145 | 0.0761149 2516 3886 |
| 17 | 5532 | 7832 | 210 | 0910 | 38865260 |
| 18 | 5507 | 7966 | 220 | 0677 |  |
| 19 | 5483 | 8100 | 230 | 0440 | $6637$ |
| 20 | 13.5458 | 0.0738233 | 240 | 13.0206 | 0.0768017 |
| 21 | 5434 | 8367 | 250 | 12.9972 | $\begin{aligned} & 9402 \\ & 7090 \end{aligned}$ |
| 22 | 5409 | 8501 | 260 | 9738 |  |
| 23 | 5385 | 8635 | 270280 | $\begin{aligned} & 9504 \\ & 9270 \end{aligned}$ | $2182$ |
| 24 | 5360 | 8768 |  |  | 3579 |
| 25 | 13.5336 | 0.0738902 | 290 | $12.9036$ | 0.0774979 |
| 26 | 531 I | 90.36 | 300 | $8803$ |  |
| 27 | 5287 | 9170 | 310 | 8569 | 6385 7795 |
| 28 | 5262 | 9304 | $\begin{aligned} & 320 \\ & 330 \end{aligned}$ | $\begin{aligned} & 8336 \\ & 8 \mathrm{IO} 2 \end{aligned}$ | $9210$ |
| 29 | 5238 | 9437 |  |  | 80630 |
| 30 | 13.5213 | 0.073957 I | 340 350 360 | $\begin{array}{r} 12.7869 \\ 7635 \\ 7402 \end{array}$ | $\begin{array}{r} 0.0782054 \\ 3485 \\ 492 \mathrm{I} \end{array}$ |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

Based upon Thiesen und Scheel, Tätigkeitber. Phys.-Techn. Reichsanstalt, 1897-1898; Chappuis, Trav. Bur. Int. 13, 1903. Thiesen, Scheel, Sell; Wiss. Abh. Phys.-Techn. Reichsanstalt 2, p. 184, 1895, and 1 liter $=1.000027 \mathrm{cu} . \mathrm{dm}$.

The following table gives the density of solutions of various salts in water. The numbers give the weight in grams per cubic centimeter. For brevity the substance is indicated by formula only.

| Substance. | Weight of the dissolved substance in 100 parts by weight of the solution. |  |  |  |  |  |  |  |  |  | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 |  |  |
| $\mathrm{K}_{2} \mathrm{O}$ | 1.047 | 1.098 | 1.153 | 1.214 | 1.284 | 1.354 | 1.503 | 1. 659 | 1.809 | 15. | Schiff. |
| KOH | 1.040 | 1.082 | I.127 | 1.176 | 1.229 | 1.286 | 1.410 | 1.538 | 1.666 | 15. |  |
| $\mathrm{Na}_{2} \mathrm{O}$ | 1.073 | I.144 | 1.218 | 1.284 | 1.354 | 1.421 | 1.557 | 1.689 | 1.829 | 15. | " |
| NaOH | 1.05 S | 1.114 | I.169 | 1.224 | 1.279 | 1.331 | 1.436 | I. 539 | 1.642 | 15. | " |
| $\mathrm{NH}_{8}$. | 0.978 | 0.959 | 0.940 | 0.924 | 0.909 | 0.896 | - |  | - | 16. | Carius. |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 1.015 | 1.030 | 1.044 | 1.058 | 1.072 | - | - | - | - | 15. | Gerlach. |
| KCl . | 1.031 | 1.065 | 1.099 | I.135 | - | - | - | - | - | 15. | " |
| NaCl . | 1.035 | 1.072 | 1.110 | 1.150 | 1.191 | - | - | - | - | 15. | " |
| LiCl . | 1.029 | 1.057 | 1.OS 5 | 1.116 | 1.147 | 1.181 | 1.255 | - | - | 15. | " |
| $\mathrm{CaCl}_{2}$ | $1.04{ }^{1}$ | 1.086 | 1.132 | 1.18I | 1.232 | 1.286 | 1.402 | - | - | 15. | /6 |
| $\mathrm{CaCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1.019 | 1.040 | 1.061 | 1.083 | 1.105 | 1.128 | 1.176 | I. 225 | 1.276 | 18. | Schiff. |
| $\mathrm{AlCl}_{3}$ | 1.030 | 1.072 | 1.111 | 1.153 | 1. 196 | 1.24 I | I. 340 | - | - | 15. | Gerlach. |
| $\mathrm{MgCl}_{2} \cdot{ }^{\circ}$ | 1.041 | I. 085 | 1.130 | 1.177 | 1.226 | 1.278 | - | - | - | 15. | " |
| $\mathrm{MgCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1.014 | 1.032 | 1.049 | 1.067 | 1.085 | 1.103 | 1.141 | 1.183 | 1.222 | 24. | Schiff. |
| $\mathrm{ZnCl}_{2}$ | 1.043 | 1.089 | 1.135 | 1.184 | 1.236 | 1.289 | 1.417 | 1.563 | 1.737 | 19.5 | Kremers. |
| $\mathrm{CdCl}_{2}$ | 1.043 | 1. 087 | 1.138 | 1.193 | 1.254 | 1.319 | 1.469 | 1.653 | 1. 887 | 19.5 | " |
| $\mathrm{SrCl}_{2} \cdot{ }^{\text {- }}$ | 1.044 | I. 092 | 1.143 | 1.198 | 1.257 | 1.321 | - | , | - | 15. | Gerlach. |
| $\mathrm{SrCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1.027 | I. 053 | 1.082 | 1.111 | 1.042 | I. 174 | 1.242 | 1.317 | - | 15. | ، |
| $\mathrm{BaCl}_{2}$ | 1.045 | 1.094 | 1.147 | 1.205 | 1.269 | - | - |  | - | 15. | "' |
| $\mathrm{BaCl}_{2}+2 \mathrm{H}_{2} \mathrm{O}$ | 1.035 | 1.075 | 1.119 | 1.166 | 1.217 | 1.273 | - | - | - | 2 I . | Schiff. |
| $\mathrm{CuCl}_{2}$ | 1.044 | 1.091 | 1.155 | 1.221 | 1.291 | 1.360 | 1.527 | - | - | 17.5 | Franz. |
| $\mathrm{NiCl}_{2}$ | 1.048 | 1.098 | 1.157 | 1.223 | 1.299 | - | , | - | - | 17.5 | " |
| $\mathrm{HgCl}_{2}$ | 1.041 | 1.092 |  | - | - |  |  |  |  | 20. | Mendelejeff. |
| $\mathrm{Fe}_{2} \mathrm{Cl}_{6}$ | 1.041 | 1.086 | 1.130 | 1.179 | 1.232 | 1.290 | 1.413 | 1.545 | 1.668 | 17.5 | Hager. |
| $\mathrm{PtCl}_{4}$. | 1.046 | 1.097 | 1.153 | 1.214 | 1.285 | 1.362 | 1.546 | 1.785 | - |  | Precht. |
| $\mathrm{SnCl}_{2}+2 \mathrm{H}_{2} \mathrm{O}$ | 1.032 | 1.067 | 1.104 | 1.143 | 1.185 | 1.229 | 1.329 | 1.444 | 1.580 | 15. | Gerlach. |
| $\mathrm{SnCl}_{4}+5 \mathrm{H}_{2} \mathrm{O}$ | 1.029 | 1.058 | 1.089 | 1.122 | 1.157 | 1.193 | 1.274 | 1. 365 | 1. 467 | 15. |  |
| Libr | 1.033 | 1.070 | 1.111 | I. 5 5 | 1.202 | 1.252 | 1.366 | I. 498 | - | 19.5 | Kremers. |
| KBr | 1.035 | 1.073 | 1.114 | 1.157 | 1.205 | 1.254 | 1.364 |  | - | 19.5 | " |
| NaBr | 1.038 | 1.078 | 1.123 | 1.172 | 1.224 | 1.279 | I. 40 S | 1.563 | - | 19.5 | " |
| $\mathrm{MgPr}_{2}$ | 1.041 | 1.085 | I. 135 | 1.189 | 1.245 | 1.308 | 1.449 | 1.623 | - | 19.5 | " |
| $\mathrm{ZnBr}_{2}$ | 1.043 | 1.091 | 1.144 | 1.202 | 1.263 | 1. 328 | 1.473 | 1. 648 | 1.873 | 19.5 | " |
| $\mathrm{CdBr}_{2}$ | 1.041 | 1.088 | 1.139 | 1.197 | 1.258 | 1. 324 | 1.479 | 1.678 | 1873 | 19.5 | " |
| $\mathrm{CaBr}_{2}$ | 1.042 | 1.087 | 1.137 | 1.192 | 2.250 | 1.313 | I. 459 | I. 639 | - | 19.5 | " |
| $\mathrm{BaBr}_{2}$ | 1.043 | 1.090 | 1.142 | I. 199 | 1.260 | 1.327 | 1.483 | 1.683 | - | 19.5 | " |
| $\mathrm{SrBr}_{\mathrm{KI}}$ | 1.043 | 1.089 | 1.140 | 1.198 | 1.260 | 1.328 | 1.489 | 1.693 | 1.953 | 19.5 | " |
| KII | 1.036 1.036 | 1.076 | 1.118 | 1.164 | 1.216 | 1.269 | 1.394 | I. 544 | 1.732 | 19.5 | " |
| NaI | 1.036 | 1.077 | 1.122 | 1.170 | 1.222 | 1.278 | 1.412 | 1.573 | 1.775 | 19.5 | " |
| $\mathrm{ZnI}_{2}$ | 1.030 | 1.050 | 1.126 | 1.177 | 1.232 | 1.292 | 1.430 | I. 598 | 1.80 S | 19.5 | " |
| $\mathrm{ZnI}_{2}$ | 1.043 | 1.089 | 1.138 | 1.194 | 1.253 | 1.316 | 1.467 | I. 648 | 1.873 | 19.5 | " |
| $\mathrm{CdI}_{2}$. | 1.042 | 1.086 | 1.136 | 1.192 | 1.251 | 1.317 | 1.474 | 1.678 | - | 19.5 | " |
| $\mathrm{MgI}_{2}$. | 1.041 | 1.086 | 1.137 | 1.192 | 1.252 | 1.318 | 1.472 | 1.666 | 1.913 | 19.5 | " |
| $\mathrm{CaI}_{2}$. | 1.042 | 1.088 | 1.138 | 1.196 | 1.258 | 1.319 | I. 475 | 1.663 | 1.908 | 19.5 | " |
| $\mathrm{SrI}_{2}$ - | 1.043 | 1.089 | 1.140 | 1.198 | 1.260 | 1.328 | 1.489 | 1.693 | 1.953 | 19.5 | " |
| $\mathrm{BaI}_{2}$. | 1.043 | 1.089 | 1.141 | 1.199 | 1.263 | 1.331 | 1.493 | 1.702 | 1.968 | 19.5 | " |
| $\mathrm{NaClO}_{3}$. | 1.035 | 1.068 | 1.106 | 1.145 | 1.188 | 1.233 | 1. 329 | - | - | 19.5 | " |
| $\mathrm{NaHrO}_{3}$. | 1.039 | 1.081 | 1.127 | 1.176 | 1.229 | 1.287 | - | - | - | 19.5 | " |
| $\mathrm{NaNO}_{8}$ - | 1.031 1.031 | 1.064 | 1.099 | 1.135 1.140 | 1.180 | - | - | 1 | - | 15. | Gerlach. |
| $\mathrm{AgNO}_{3}$. . | 1.044 | 1.090 | 1.140 | 1.195 <br> 1.1 | 1.255 | 1.222 1.322 | 1.313 1.479 | 1.416 | 1.918 | 15.2 15. | Kohlrausch. |

DENSITY OF AQUEOUS SOLUTIONS.

| Substance. | Weight of the dissolved substance in 800 parts by weight of the solution. |  |  |  |  |  |  |  |  | $\stackrel{\dot{\Delta}}{\stackrel{\Delta}{E}}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 5 | 10 | 15 | 20 | 25 | 30 | 40 | 50 | 60 |  |  |
| $\mathrm{NH}_{4} \mathrm{NO}$ | 1.020 | 1.041 | 1.063 | 1.085 | 1.107 | 1.131 | 1.178 | 1.229 | 1.282 | 17.5 | Gerlach. |
| $\mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.048 | 1.095 | I. 146 | 1.201 | 1.263 | 1.325 | 1.456 | I. 597 | - | 17.5 | Franz. |
| $\mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | , | 1.054 | - | 1.113 | - | 1.178 | 1.250 | I. 329 | - | 14. | Oudemans. |
| $\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}$ - | 1.037 | 1.075 | I.II8 | 1.162 | I. 211 | 1.260 | 1.367 | 1.482 | 1.604 | 17.5 | Gerlach. |
| $\mathrm{Cu}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.044 | 1.093 | I.I 43 | 1.203 | I. 263 | 1.328 | I. 47 I | - | - | 17.5 | Franz. |
| $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.039 | 1.083 | I. 129 | I. 179 | - | - | - | - | - | 19.5 | Kremers. |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.043 | 1.091 | I.I43 | I. 199 | 1. 262 | 1.332 | - | - | - | 17.5 | Gerlach. |
| $\mathrm{Cd}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.052 | 1.097 | I.I 50 | 1.212 | 1.283 | I. 355 | 1. 536 | 1. 759 | - | 17.5 | Franz. |
| $\mathrm{Co}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.045 | 1.090 | 1.I37 | I.192 | 1.252 | 1.318 | I. 465 |  |  | 17.5 |  |
| $\mathrm{Ni}\left(\mathrm{NO}_{3}\right)_{2}$ | 1.045 | 1.090 | I.I 37 | 1.192 | 1.252 | I. 318 | I. 465 |  | - | 17.5 |  |
| $\mathrm{Fe}_{2}\left(\mathrm{NO}_{3}\right)_{6}$ | 1.039 | 1.076 | 1.117 | 1.160 | 1.210 | I.261 | 1.373 | 1.496 | 1.657 | 17.5 | " ${ }^{\text {c }}$ |
| $\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2}+6 \dot{\mathrm{H}}_{2} \mathrm{O}$ | I. 1.018 | 1.038 | 1.060 | 1.082 | 1.105 | I.I29 | I. 179 | 1.232 | 1.657 | 21 | Schiff. |
| $\mathrm{Mn}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1.025 | 1.052 | 1.079 | I.IOS | 1.138 | 1.169 | I. 235 | 1. 307 | 1.386 | 8 | Oudemans. |
| $\mathrm{K}_{2} \mathrm{CO}_{3} \cdot \cdot \cdot \cdot \cdot$ | 1.044 | 1.092 | 1.141 | 1.192 | 1.245 | I. 300 | I. 417 | I. 543 |  | 15 | Gerlach. |
| $\mathrm{K}_{2} \mathrm{CO}_{3}+2 \mathrm{H}_{2} \mathrm{O}$ | 1.037 | 1.072 | 1.110 | 1.150 | 1.191 | 1.233 | 1. 320 | I.415 | 1.511 | 15. | " |
| $\mathrm{Na}_{2} \mathrm{CO}_{3} \mathrm{IOH}_{2} \mathrm{O}$ | 1.019 | 1.038 | 1.057 | 1.077 | 1.098 | I. 118 | - | - | - | 15. | Schiff |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 1.027 | i. 055 | 1.084 | I.153 | I.142 | I. 170 | 1.226 | 1.287 | - | 19. | Schiff. |
| $\mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 1.045 | 1.096 | I.150 | 1.207 | 1.270 | I. 336 | I. 489 |  |  | 18. | Hager. |
| $\mathrm{FeSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$ | 1.025 | 1.053 | 1.081 | I.III | I.141 | 1.173 | 1.238 | - | - | 17.2 | Schiff. |
| $\mathrm{MgSO}_{4}$ - | 1.051 | 1.104 | 1.161 | 1.221 | 1.284 |  |  |  | - | 15 | Gerlach. |
| $\mathrm{MgSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$. | 1.025 | 1.050 | 1.075 | 1.101 | 1.129 | 1.155 | 1.215 | 1.278 | - | 15. | " |
| $\mathrm{Na}_{2} \mathrm{SO}_{4}+1 \mathrm{IOH}_{2} \mathrm{O}$ | 1.019 | 1.039 | 1.059 | 1.08I | 1.102 | I. 124 |  |  |  | 15. |  |
| $\mathrm{CuSO}_{4}+5 \mathrm{H}_{2} \mathrm{O}$. | 1.03 I | 1.064 | 1.098 | 1.134 | 1.173 | 1.213 | - | - | - | IS'. | Schiff. |
| $\mathrm{MnSO}_{4}+4 \mathrm{H}_{2} \mathrm{O}$. | 1.031 | 1.064 | 1.099 | 1.1 35 | 1.174 | 1.214 | 1.303 | 1. 398 | - | 15. | Gerlach. |
| $\mathrm{ZnSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$. | 1.027 | I. 057 | 1.089 | 1.122 | 1.156 | I.191 | 1.269 | 1.351 | I. 443 | 20.5 | Schiff. |
| $\begin{gathered} \mathrm{Fe}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot \mathrm{~K}_{2} \mathrm{SO}_{4} \\ +24 \mathrm{H}_{2} \mathrm{O} \end{gathered}$ | 1.026 | I. 045 | 1.066 | 1. 088 | I.II2 | 1.141 | - | - | - | 17.5 | ranz. |
| $\begin{gathered} \mathrm{Cr}_{2}\left(\mathrm{SO}_{4}\right)_{3} \cdot \mathrm{~K}_{2} \mathrm{SO}_{4} \\ +24 \mathrm{H}_{2} \mathrm{O} \end{gathered}$ | 1.016 | 1.033 | 1.051 | 1.073 | 1.099 | I. 126 | 1.188 | 1.287 | 1.454 | 17.5 | " |
| $\begin{gathered} \mathrm{MgSO}_{4}+\mathrm{K}_{2} \mathrm{SO}_{4} \\ +6 \mathrm{H}_{2} \mathrm{O} \end{gathered}$ | 1.032 | I. 06 | 1.101 | I. 138 | . | - | - | - | - | 15. | Schiff. |
| $\begin{aligned} & \left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}+ \\ & \mathrm{FeSO}_{4}+6 \mathrm{H}_{2} \mathrm{O} \end{aligned}$ | 1.028 |  | 1.090 | 1.122 | I. 54 | 1.191 | - |  | - | - | ، |
| $\mathrm{K}_{2} \mathrm{CrO}_{4}$ - . . . | 1.039 | 1.082 | 1.127 | I. 174 | I. 225 | 1.279 | 1.397 | - |  | 19.5 | ' |
| $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 1.03 | 1.071 | I.108 | - | - | - | - | - | - | 19.5 | ne |
| $\mathrm{Fe}(\mathrm{Cy})_{6} \mathrm{~K}_{4}$ | 028 | 1.059 | 1.092 | 1.126 | - |  |  |  |  | 15. | chiff |
| $\mathrm{Fe}(\mathrm{Cy})_{6} \mathrm{~K}_{3}$. | 1.025 | 1.053 | 1.070 | I. II 3 | - | - | - | - | - | 13 |  |
| $\mathrm{Pb}\left(\mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}\right)_{2}+$ | 1.031 | 1.06 | I. 100 | I. 137 | 1.177 | 1.220 | I.3I 5 | I. 426 | - | 15. | erlac |
| $\begin{gathered} 2 \mathrm{NaOH}+\mathrm{As}_{2} \mathrm{O}_{5} \\ +24 \mathrm{H}_{2} \mathrm{O} \end{gathered}$ | 1.020 | 1.04 | 1.066 | I.089 | I.II | 1.140 | 1.194 |  | - | 14 | Schiff. |
|  | 5 | 10 | 15 | 20 | 30 | 40 | 60 | 80 | 1 co |  |  |
| $\mathrm{SO}_{3}$ | 1.040 | 1.084 | 1.132 | 1.179 | 1.277 | 1.389 | 1.564 | 1.8.40 | - | I 5. | Brineau. |
| $\mathrm{SO}_{2}$ | I. 013 | 1.028 | 1.045 | 1.063 | - | - |  | I. 506 | - | 4. | Schiff. <br> Kolb |
| $\mathrm{N}_{2} \mathrm{O}_{5}$. | 1.033 | 1.069 | I. 104 | I.I. 41 | 1.217 | 1. 294 | 1.422 | 1.506 | - | 15. |  |
| $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$ | 1.021 | 1.047 | 1.070 | I. 096 | I. 150 | 1.207 |  | - |  | 15. | Gerlach. |
| $\mathrm{C}_{6} \mathrm{H}_{8} \mathrm{O}_{7}$ | 1.018 | 1.038 | 1.058 | 1.079 | 1.123 | 1.170 | 1.273 | - | - | 15. |  |
| Cane suga | 1.019 | 1.039 | 1. 060 | 1.082 | I.129 | 1.178 | 1.289 | - | - | 17.5 | Kolb |
| HCl . | 1.025 | 1.050 | 1.075 | I. IOI | 1.151 | 1. 200 | - | - | - | 15. | Kolb. |
| HBr | 1.035 | 1.073 | 1.114 | I. 158 | 1.257 | I. 376 | - | - | - | 14. | Topso |
| $\mathrm{HI}^{\text {- }}$ | 1.037 | 1.077 | 1.118 | I. 165 | 1.271 | I. 400 |  | - | 1.838 | 13. | Kolb. |
| $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 1.032 | 1.069 | 1.106 | b. 145 | 1.223 | 1.307 | 1.501 | 1.732 | 1.838 | 15. | Kolb. |
| $\mathrm{H}_{2} \mathrm{SiF}_{6}$ | I. 040 | 1.082 | 1.127 | I.174 | 1.273 | 1.38 | 1.676 | - | - | 17.5 |  |
| $\mathrm{P}_{2} \mathrm{O}_{5}+\mathrm{O}_{5}+\mathrm{H}_{2}$ | 1.035 | 1.077 | 1.119 L 108 | I.167 | 1.271 | I. 385 I. 264 | 1.676 1.438 | - | - | 17.5 15. 15. | Hager. Schiff. |
| $\mathrm{P}_{2} \mathrm{O}_{5}+3 \mathrm{H}_{2} \mathrm{O}$. $\mathrm{HNO}_{8}$. | 1.027 1.028 | I. 057 I. 056 | I. 086 I.08S | 1.119 1.119 1.029 | 1.188 I. 184 | 1.264 I. 250 | 1.438 I. 373 | 1.459 | 1. 528 | 15. | Schiff. |
| ${ }_{\text {C2 }} \mathrm{H}_{4} \mathrm{O}_{2}$. ${ }^{\text {- }}$ | 1.028 I.007 | 1.056 I.OI 4 | 1.02 I | 1.028 | I.O4I | 1.052 | I. 068 | ¢. 075 | I. 055 | 15. | Oudemans. |

## DENSITIES OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS

 PER MILLILITER.The densities in this table are numerically the same as specific gravities at the various temperatures in terms of water at $4^{\circ} \mathrm{C}$. as unity. Based upon work done at U. S. Bureau of Standards. See Bulletin Bur. Stds. vol. 9, no. 3; contains extensive bibliography; also Circular r9, 1913.

| Per cent <br> $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}$ by weight | Temperatures. |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $10^{\circ} \mathrm{C}$. | $15^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. | $25^{\circ} \mathrm{C}$. | $30^{\circ} \mathrm{C}$. | $35^{\circ} \mathrm{C}$. | $40^{\circ} \mathrm{C}$. |
| 0 | 0.99973 | 0.99913 | 0.99823 | 0.99708 | 0.99568 | 0.99406 | 0.99225 |
| 1 | 785 | 725 | 636 | 520 | 379 | 217 | 034 |
| 2 | 602 | 542 | 453 | 336 | 194 | 031 | . 98846 |
| 3 | 426 | 365 | 275 | 157 | 014 | . 98849 | 663 |
| 4 | 258 | 195 | 103 | .98984 | . 98839 | 672 | 485 |
| 5 | 098 | 032 | . 98938 | 817 | 670 | 501 | 311 |
| 6 | .98946 | .98877 | 780 | 656 | 507 | 335 | 142 |
| 7 | 801 | 729 | 627 | 500 | 347 | 172 | . 97975 |
| 8 | 660 | 584 | 478 | 346 | 189 | 009 | 808 |
| 9 | 524 | 442 | 331 | 193 | 031 | .97846 | 641 |
| 10 | 393 | 304 | 187 | 043 | . 97875 | 685 | 475 |
| 11 | 267 | 171 | 047 | .97897 | 723 | 527 | 312 |
| 12 | 145 | 041 | . 97910 | 753 | 573 | 371 | 150 |
| 13 | 026 | .97914 | 775 | 611 | 424 | 216 | . 96989 |
| 14 | .97911 | 790 | 643 | 472 | 278 | 063 | 829 |
| 15 | 800 | 669 | 514 | 334 | 133 | .96911 | 670 |
| 16 | 692 | 552 | 387 | 199 | . 96990 | 760 | 512 |
| 17 | 583 | 433 | 259 | 062 | 844 | 607 | 352 |
| 18 | 473 | 313 | 129 | . 96923 | 697 | 452 | - 189 |
| 19 | 363 | 191 | . 96997 | 782 | 547 | 294 | 023 |
| 20 | 252 | 068 | 864 | 639 | 395 | 134 | . 95856 |
| 21 | 139 | .96944 | 729 | 495 | 242 | . 95973 | 687 |
| 22 | 024 | 818 | 592 | 348 | 087 | 809 | 516 |
| 23 | . 96907 | 689 | 453 | 199 | . 95929 | 643 | 343 |
| 24 | 787 | $55^{8}$ | 312 | 048 | 769 | 476 | 168 |
| 25 | 665 | 424 | 168 | . 95895 | 607 | 306 | . 94991 |
| 26 | 539 | 287 | 020 | 738 | 442 | 133 | 810 |
| 27 28 | 406 | 144 | -95867 | 576 | 272 | . 94955 | 625 |
| 28 29 | 268 | . 95996 | 710 | 410 | 098 | 774 | 438 |
| 29 | 125 | 844 | 548 | 241 | . 94922 | 590 | 248 |
| 30 | . 95977 | 686 | 382 | 067 | 741 | 403 | 055 |
| 31 | 823 | 524 | 212 | . 94890 | 557 | 214 | . 93860 |
| 32 | 665 | 357 | 038 | 709 | 370 | 021 | 662 |
| 33 | 502 | 186 | . 94860 | 525 | 180 | .93825 | 461 |
| 34 | 334 | OII | 679 | 337 | . 93986 | 626 | 257 |
| 35 36 | 162 .94986 | .94832 | 494 | 146 | 790 | 425 | ${ }^{051}$ |
| 36 | . 94986 | 650 | 306 | . 93952 | 591 | 221 | . 92843 |
| 37 | 805 | 464 | 114 | 756 | 390 | 016 | 634 |
| 38 39 | 620 | 273 | .93919 | 556 | 186 | . 92808 | 422 |
| 39 | 431 | 079 | 720 | 353 | . 92979 | 597 | 208 |
| 40 | 238 | .93882 | 518 | 148 | 770 | 385 | . 91992 |
| 41 | ${ }^{2} 42$ | 682 | 314 | . 92940 | 558 | 170 | 774 |
| 42 | . 93842 | 478 | $\begin{array}{r}107 \\ \hline 8\end{array}$ | 729 | 344 | . 91952 | 554 |
| 43 | 639 | 271 | .92897 | 516 | 128 | 733 | 332 |
| 44 | 433 | 062 | 685 | 301 | .91910 | 513 | 108 |
| 45 | 226 | .92852 | 472 | 085 | 692 | 291 | . 90884 |
| 46 | $\begin{array}{r}017 \\ \hline 88\end{array}$ | 640 | 257 | .91868 | 472 | 069 | . 660 |
| 47 48 | .92806 593 | 426 211 | 041 .91823 | 649 | 250 | . 90845 | 434 |
| 48 49 | 593 379 | 211 .91995 | .91823 | 429 | 028 | 621 | -207 |
| 49 | 379 | . 91995 | 604 | 208 | .90805 | 396 | . 89979 |
| 50 | 162 | 776 | 384 | .90985 | 580 | 168 | 750 |

DENSITY OF MIXTURES OF ETHYL ALCOHOL AND WATER IN GRAMS
PER MILLILITER.

| Per cent $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}$ by weight | Temperature. |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $10^{\circ} \mathrm{C}$. | $15^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. | $25^{\circ} \mathrm{C}$. | $30^{\circ} \mathrm{C}$. | $35^{\circ} \mathrm{C}$. | $40^{\circ} \mathrm{C}$. |
| 50 | 0.92162 | 0.91776 | 0.91384 | 0.90985 | 0.90580 | 0.90168 | 0.89750 |
| 51 | .91943 | 555 | 160 | 760 | 353 | . 89940 | 519 |
| 52 | 723 | 333 | .90936 | 534 | 125 | 710 | 288 |
| 53 | 502 | 110 | 711 | 307 | . 89896 | 479 | 056 |
| 54 | 279 | . 90885 | 485 | 079 | 667 | 248 | . 88823 |
| 55 | 055 | 659 | 258 | .89850 | 437 | 016 | 589 |
| 56 | .9083 I | 433 | 031 | 621 | 206 | .88784 | 356 |
| 57 | 607 | 207 8 | . 89803 | 392 | . 88975 | 552 | 122 |
| 58 | 381 | . 89980 | 574 | 162 | 744 | 319 | . 87888 |
| 59 | 154 | 752 | 344 | .88931 | 512 | 085 | 653 |
| 60 | . 89927 | 523 | 113 | 699 | 278 | . 87851 | 417 |
| 61 | 698 | 293 | . 88882 | 466 | 044 | 6I5 | 180 |
| 62 | 468 | 062 | 650 | 233 | . 87809 | 379 | . 86943 |
| 63 | 237 | . 88830 | 417 | . 87998 | 574 | 142 | 705 |
| 64 | 006 | 597 | 183 | 763 | 337 | . 86905 | 466 |
| 65 | . 88774 | 364 | . 87948 | 527 | 100 | 667 | 227 |
| 66 | 541 | ${ }^{13} 3$ | 713 | 291 | . 86863 | 429 | . 85987 |
| 67 | 308 | . 87895 | 477 | 054 | 625 | 190 | 747 |
| 68 | 074 | 660 | 241 | .868I7 | 387 | . 85950 | 507 |
| 69 | .87839 | 424 | 004 | 579 | 148 | 710 | 266 |
| 70 | 602 | 187 | . 86766 | 340 | . 85908 | 470 | 025 |
| 71 | 365 | . 86949 | 527 | 100 | 667 | 228 | . 84783 |
| 72 | 127 | 710 | 287 | . 85859 | 426 | . 84986 | 540 |
| 73 | . 86888 | 470 | 047 | 618 | ${ }^{184}$ | 743 | 297 |
| 74 | 648 | 229 | . 85806 | 376 | . 84941 | 500 | 053 |
| 75 | 408 | . 85988 | 564 | ${ }_{8}^{134}$ | 698 | 257 | .83809 |
| 76 | 168 | 747 | 322 | .84891 | 455 | 013 | 564 |
| 77 | . 85927 | 505 | $\bigcirc$ | 647 | ${ }^{211}$ | . 83768 | 319 |
| 78 | 685 | 262 | . 84835 | 403 | . 83966 | 523 | 074 828 |
| 79 | $44^{2}$ | 018 | 590 | 158 | 720 | 277 | . 82827 |
| 80 | 197 | . 84772 | 344 | . 8391 I | 473 | 029 | 578 |
| 81 | . 84950 | 525 | 096 | 664 | 224 | . 82780 | 329 |
| 82 | 702 | 277 | . 83848 | 415 | . 82974 | 530 | 079 8828 |
| 83 | 453 | 028 | 599 | $\begin{array}{r}164 \\ \hline\end{array}$ | 724 | 279 | .81828 |
| 84 | 203 | . 83777 | 348 | . 82913 | 473 | 027 | 576 |
| 85 | 83951 | 525 | ${ }_{8}^{095}$ | 660 | 220 81965 | .81774 | 322 067 |
| 86 | 697 | 271 | . 82840 | 405 | . 81965 | 519 262 | 067 80811 |
| 87 88 | 44 I | OI 4 | 583 | 148 8.888 | 708 | 262 | .80811 |
| 88 | 181 | . 82754 | 323 | .81888 | 448 | ${ }_{8}^{003}$ | 552 |
| 89 | .82919 | 492 | 062 | 626 | 186 | . 80742 | 291 |
| 90 | 654 | 227 | .81797 | 362 | . 80922 | 478 | 028 |
| 91 | 386 | .81959 | 529 | 094 | 655 | 211 | .79761 |
| 92 | 114 | 688 | 257 | . 80823 | 384 | .7994I | 491 |
| 93 | . 81839 | 413 | . 80983 | 549 | 111 | 669 | 220 78947 |
| 94 | 561 | 134 | 705 | 272 | . 79835 | 393 | . 78947 |
|  | 278 | . 80852 | 424 | .79991 | 555 |  | 670 388 |
| 96 | . 80991 | 566 | $\begin{array}{r}138 \\ \hline 89\end{array}$ | 706 | 271 7898 | .78831 | 388 100 |
| 97 98 | 698 | 274 | . 79846 | 415 | .78981 | 542 | 100 .77806 |
| 98 99 | 399 094 | .79975 670 | 547 243 | 117 .78814 | 684 382 | 247 .77946 | 77806 507 |
| 99 | 094 | 670 | 243 | -7884 | 302 | . 7946 |  |
| 100 | . 79784 | 360 | . 78934 | 506 | 075 | 641 | 203 |

Table 110.
DENSITIES OF AQUEOUS MIXTURES OF METHYL ALCOHOL, CANE SUGAR, OR SULPHURIC ACID.

| $\underset{\text { Per cent }}{\text { by weight }} \begin{array}{c}\text { wof } \\ \text { of } \\ \text { substance. }\end{array}$ | Methyl Alcohol. $\text { I } \frac{15^{\circ}}{4^{\circ}} \mathrm{C} .$ | $\begin{gathered} \text { Cane } \\ \text { Sugar. } \\ \text { 20 } \end{gathered}$ | Sulphuric Acid. $\mathrm{D} \frac{20^{\circ}}{4^{\circ}} \mathrm{C}$ | Per cent by weight of | Methyl $\mathrm{D} \frac{15^{\circ}}{4^{\circ}} \mathrm{C}$ | $\begin{gathered} \text { Cane } \\ \substack{\text { Sugar. } \\ 20^{\circ}} \end{gathered}$ | $\begin{aligned} & \text { Sulphuric } \\ & \text { Acid. } \\ & \text { D } \frac{200^{\circ}}{4^{\circ}} \mathrm{C} . \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | 0.99913 | 0.998234 | 0.99823 | 50 | 0.91852 | 1.229567 | I. 39505 |
| 1 | . 99727 | 1.002120 | 1.00506 | 51 | . 91653 | 1.235085 | 1.40487 |
| 2 | . 99543 | 1.006015 | 1.01178 | 52 | . 91451 | 1. 24064 I | I.4148I |
| 3 | . 99370 | 1.009934 | 1.01839 | 53 | . 91248 | 1. 246234 | 1.42487 |
| 4 | . 99198 | 1.013881 | 1.02500 | 54 | .91044 | 1.251866 | I. 43503 |
|  | . 99029 | 1.017854 | 1.03168 | 55 | . 90839 | 1.257535 | 1.44530 |
| 6 | . 98864 | 1.021855 | 1.03843 | 56 | . 90631 | 1. 263243 | 1.45568 |
| 7 | . 98701 | 1.025885 | 1.04527 | 57 | . 90421 | 1. 268989 | 1.46615 |
| 8 | . 98547 | I.029942 | 1.05216 | 58 | . 90210 | 1.274774 | 1.47673 |
| 9 | . 98394 | 1.034029 | 1.05909 | 59 | . 89996 | 1.280595 | 1.48740 |
| 10 | . 98241 | 1.038143 | 1.06609 | 60 | . 89781 | 1.286456 | 1.49818 |
| 11 | . 98093 | 1.042288 | 1. 07314 | 61 | . 89563 | 1.292354 | 1. 50904 |
| 12 | . 97945 | 1.046462 | 1.08026 | 62 | . 89341 | 1.298291 | 1.51999 |
| 13 | . 97802 | 1.050665 | 1.08744 | 63 | . 89117 | 1. 304267 | 1.53102 |
| 14 | . 97660 | 1.054900 | 1. 09468 | 64 | . 88890 | 1.310282 | ${ }^{1.54213}$ |
| 15 | . 97518 | I. 059165 | 1.10199 | 65 | . 88662 | 1.316334 | 1.55333 |
| 16 | . 97377 | 1.063460 | I.10936 | 66 | . 88433 | 1.322425 | 1.56460 |
| 17 | . 97237 | 1.067789 | 1.11679 | 67 | . 88203 | I. 328554 | 1.57595 |
| 18 | . 97006 | 1.072147 | 1.12428 | 68 | . 87971 | 1.334722 | 1.58739 |
| 19 | . 96955 | 1.076537 | 1.13183 | 69 | . 87739 | 1.340928 | 1. 59890 |
| 20 | .96814 | 1.080959 | I.1 3943 | 70 | . 87507 | 1.347174 | 1. 61048 |
| 21 | . 96673 | 1.085414 | I. 14709 | 71 | . 87271 | 1.353456 | 1.62213 |
| 22 | . 96533 | 1.089900 | 1.15480 | 72 | . 87033 | 1. 359778 | 1. 63384 |
| 23 | . 96392 | 1.094420 | 1.16258 | 73 | . 86792 | I. 366139 | 1.64560 |
| 24 | . 96251 | 1.098971 | 1.17041 | 74 | . 86546 | I. 372536 | 1.6573 ${ }^{8}$ |
| 25 | . 96108 | 1.103557 | 1.17830 | 75 | . 86300 | 1.378971 | 1.66917 |
| 26 | . 95963 | I. 108175 | 1.18624 | 76 | . 86051 | I. 385446 | 1.68095 |
|  |  | I.11282S | 1.19423 |  | . 85801 | 1. 391956 | I. 69268 |
| 28 | . 95668 | I.117512 | 1.20227 | 78 | . 85551 | 1. 398505 | 1.70433 |
| 29 | . 95518 | I.122231 | 1.21036 | 79 | . 85300 | 1.405091 | 1.71585 |
| 30 | . 95366 | I. 126984 |  | So | . 85048 | 1.411715 | 1.72717 |
| 31 | .95213 | 1.131773 | I. 22669 | 81 | . 84794 | 1.418374 | 1.73827 |
| $3^{2}$ | . 95056 | I. 136596 | 1.23492 | 82 | . 84536 | 1.425072 | I. 74904 |
| 33 | . 94896 | 1.141453 | 1.24320 | 83 | . 84274 | 1.431807 | I. 75943 |
| 34 | . 94734 | 1.146345 | 1.25154 | 84 | . 84009 | 1.438579 | 1.76932 |
|  | . 94570 | 1.151275 | 1.25992 | 85 | . 83742 | I.445388 | 1.77860 |
| 36 | . 94404 | I.156238 | 1.26836 | 86 | . 83475 | 1.452232 | 1.78721 |
| 37 | . 94237 | 1.161236 | 1.27685 | 87 | . 83207 | 1.459114 | 1.79509 |
| 38 | . 94067 | 1.166269 | 1.28543 | 88 | . 82937 | 1.466032 | 1.80223 |
| 39 | . 93894 | 1.171340 | 1.29407 | 89 | . 82667 | 1.472986 | 1.80864 |
| 40 | . 933720 | I.176447 | 1.30278 | 90 | . 82396 | 1.479976 | 1.81438 |
| 41 | . 93543 | 1.181592 | 1.31157 | 91 | .82124 | 1.487002 | 1.81950 |
| 42 | . 93365 | I.186773 | I. 32043 | 92 | .81849 | 1.494063 | 1.82401 |
| 43 | . 93185 | I.191993 | I. 32938 | 93 | . 81568 | 1. 501158 | 1.82790 |
| 44 | .93001 | 1.197247 | 1.33843 | 94 | .81285 | I. 508289 | 1.83115 |
|  | .92815 | 1.202540 | I. 34759 |  | . 80999 | 1.515455 | 1. 83368 |
| 46 | . 92627 | 1.207870 | 1.35686 | 96 | . 80713 | 1.522656 | I. 83548 |
| 47 | . 92436 | 1.213238 | I. 36625 | 97 | . 80428 | 1.529891 | 1.83637 |
| 48 | . 92242 | 1.218643 | 1.37574 | 98 | .80ı43 | 1.537161 | I. 83605 |
| 49 | . 92048 | 1.224086 | I. 38533 | 99 | . 79859 | 1.544462 |  |
| 50 | . 91852 | 1.229567 | 1.39505 | 100 | . 79577 | 1.551800 |  |

(i) Calculated from the specific gravity determinations of Doroschevski and Rozhdestrenski at $15^{\circ} / 15^{\circ}$ C.; J. Russ., Phys. Chem. Soc., 41, p. 977, 1909.
(2) According to Dr. F. Plato; Wiss. Abh. der K. Normal-Eichungs-Kommission, 2, p. I 53, 1900.
(3) Calculated from Dr. Domke's table; Wiss. Abh. der K. Normal-Eichungs-Kommission, 5, p. I31, 1900.

TABLE 111.
DENSITY OF GASES
The following table gives the density as the weight in grams of a liter (normal liter) of the gas at $0^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ pressure and standard gravity (sea-level, $45^{\circ}$ latitude), the specific gravity referred to dry, carbon-dioxide-free air and to pure oxygen, and the weight in pounds per cubic foot. Dry, carbon-dioxide-free air is of remarkably uniform density; Guye, Kovacs and Wourtzel found maximum variations in the density of only 7 to 8 parts in 10,000. For highest accuracy pure oxygen should be used as the standard gas for specific gravities. Observed densities are closely proportional to the molecular weights.

| Gas. | Formula. | Weight of normal liter in grams. | Specific gravity. |  | Pounds per cubic foot. | Refer. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Air $=1$ | $\mathrm{O}_{2}=\mathrm{I}$ |  |  |
| Air. | - | I. 2930 | 1.0000 | 0.9048 | 0.08072 | I |
| Acetylene. | $\mathrm{C}_{2} \mathrm{H}_{2}$ | I. 1791 | 0.9119 | 0.8251 | 0.07361 | 2 |
| Ammonia. | $\mathrm{NH}_{3}$ | 0.7708 | - 0.596 I | 0.5394 | 0.04812 | 3 |
| Argon. | A | 1.7809 | I. 3773 | I. 2462 | 0.11118 | 3 |
| Bromine | $\mathrm{Br}_{2}$ | 7.14 | 5.52 | 5.00 | 0.446 | 4 |
| Butane. | $\mathrm{C}_{4} \mathrm{H}_{10}$ | 2.594 | 2.006 | I.815 | -.1619 | 4 |
| Carbon dioxide. | $\mathrm{CO}_{2}$ | 1. 9768 | I. 5289 | 1.3833 | 0.12341 | 3 |
| Carbon monoxide | CO | I. 2504 | 0.967 I | 0.8750 | 0.07806 | 3 |
| Chlorine. | $\mathrm{Cl}_{2}$ | 3.22 I | 2.491 | 2.254 | 0.2011 | 3 |
| Coal gas. | - | $\left\{\begin{array}{l}0.41 \text { to } \\ 0.96\end{array}\right.$ | $\left\{\begin{array}{l}0.32 \text { to } \\ 0.74\end{array}\right.$ | $\left\{\begin{array}{l}0.29 \text { to } \\ 0.67\end{array}\right.$ | $\left\{\begin{array}{l}0.026 \text { to } \\ 0.060\end{array}\right.$ | - |
| Cyanogen | $\mathrm{C}_{2} \mathrm{~N}_{2}$ | 2.323 | r. 797 | 1.626 | 0.1450 | 4 |
| Ethane. . | $\mathrm{C}_{2} \mathrm{H}_{6}$ | r. 3562 | r. 0489 | 0.9490 | 0.08467 | 5 |
| Ethylene. | $\mathrm{C}_{2} \mathrm{H}_{4}$ | I. 2609 | 0.9752 | 0.8823 | 0.07872 | 2 |
| Fluorine. | $\mathrm{F}_{2}$ | r. 70 | I. 31 | I. 19 | 0.106 | 6 |
| Helium. | He | -. 1785 | 0.1381 | O. 1249 | 0.OIII5 | 14 |
| Hydrobromic acid. | HBr | 3.616 | 2.797 | 2.530 | 0. 2257 | 4 |
| Hydrochloric acid. | HCl | 1. 6398 | I. 2682 | I. 1475 | 0.10237 | 3 |
| Hydrofluoric acid. | HF | 0.922 | 0.713 | 0.645 | 0.0576 | 8 |
| Hydrogen. | $\mathrm{H}_{2}$ | 0.08987 | 0.06950 | 0.06289 | 0.005610 | 9 |
| Hydrogen sulphide | $\mathrm{H}_{2} \mathrm{~S}$ | 1. 538 | 1.189 | I. 076 | 0.09602 | 3 |
| Krypton...... | $\stackrel{\mathrm{Kr}}{ }$ | 3.708 | 2.868 | 2.595 | 0.2315 | 7 |
| Methane. | $\mathrm{CH}_{4}$ | 0.7168 | -. 5544 | 0.5016 | 0.04475 | 5 |
| Methyl chloride. | $\mathrm{CH}_{3} \mathrm{Cl}$ | 2.304 | 1.782 | 1.612 | -. 1438 | 10 |
| Methyl ether. | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | 2.110 | 1.632 | 1. 477 | -.1317 | 10 |
| Neon.. | Ne | 0.9002 | 0.6962 | 0.6299 | 0.05620 | 7 |
| Nitrogen. | $\mathrm{N}_{2}$ | I. 2507 | 0.9673 | 0.8752 | 0.07808 | 3 |
| Nitric oxide. | NO | 1. 3402 | I. 0365 | 0.9378 | 0.08367 | 3 |
| Nitrous oxide. | $\mathrm{N}_{2} \mathrm{O}$ | r. 9777 | I. 5296 | 1. 3839 | 0.12347 | 3 |
| Oxygen.. | ${ }^{\mathrm{O}_{2}}$ | r. 42905 | I. 1052 | I. 0000 | 0.089214 | 11 |
| Propane. . . . . | $\mathrm{C}_{3} \mathrm{H}_{8}$ | 2.0196 | I. 5620 | 1.4132 | 0.12608 | 12 |
| Steam at $100^{\circ} \mathrm{C}$ | $\mathrm{H}_{2} \mathrm{O}$ | 0.598 | 0.462 | 0.418 | 0.0373 | 13 |
| Sulphur dioxide. | $\underset{\mathrm{X}}{\mathrm{SO}}$ | 2.9266 5.851 | 2.2634 4.525 | 2.0479 | 0.18270 | 3 |
| Xenon.. | X | 5.85I | $4 \cdot 525$ | 4.094 | 0.3653 | 7 |

References: (i) Guye, Kovacs, Wourtzel, Jour. chim. phys., io, p. 332, 1912; (2) Stahrfoss, Arch. Sc. phys. et nat., IV, 28, p. 384, 1909; (3) Guye, Jour. chim. phys., 5, p. 203, 1907 (contains review of best determinations and indicates most probable values); (4) Computed; (5) Baume and Perrot, Jour. chim. phys., 7, p. 369, 1909; (6) Moissan, C. R., I38, 1904; (7) Watson, Jour. Chem. Soc., 97, p. 833, 1910; (8) Thorpe, Hambley, Jour. Chem. Soc., 53, p. 765, 1888; (9) Morley, Smithsonian Contributions to Knowledge, i895; (ıо) Baume, Jour. chim. phys., 6, p. 1, 1908; (iI) Germann, Jour. of Phys. Chem., 19, p. 437, 1915; (12) Timmermans, C. R., 158, p. 789, 1914; (I3) Peabody's Steam Tables, 1909; (I4) Taylor, Phys. Rev., 10, p. 653, 1917.

## Values of $1+.00367 \boldsymbol{t}$.

The quantity $\mathrm{i}+.00367 t$ gives for a gas the volume at $t^{\circ}$ when the pressure is kept constant, or the pressure at $t^{\circ}$ when the volume is kept constant, in terms of the volume or the pressure at $0^{\circ}$.
(a) This part of the table gives the values of $\mathrm{x}+.00367 t$ for values of $t$ between $0^{\circ}$ and $10^{\circ} \mathrm{C}$. by tenths of a degree.
(b) This part gives the values of $1+.00367 t$ for values of $t$ between $-90^{\circ}$ and $+1990^{\circ}$ C. by $10^{\circ}$ steps.

These two parts serve to give any intermediate value to one tenth of a degree by a simple computation as follows:- In the (b) table find the number corresponding to the nearest lower temperature, and to this number add the decimal part of the number in the (a) table which corresponds to the difference between the nearest temperature in the (b) table and the actual temperature. For example, let the temperature be $682^{\circ} .2$ :

We have for 680 in table (b) the number . . . . 3.49560
And for 2.2 in table (a) the decimal . . . . . . .00807
Hence the number for 682.2 is . . . . . . 3.50367
(c) This part gives the logarithms of $1+.00367 t$ for values of $t$ between $-49^{\circ}$ and $+399^{\circ} \mathrm{C}$. by degrees.
(d) This part gives the logarithms of $x+.00367 t$ for values of $t$ between $400^{\circ}$ and $1990^{\circ}$ C. by $10^{\circ}$ steps.
(a) Values of $1+.00367 t$ for Values of $t$ between $0^{\circ}$ and $10^{\circ} \mathrm{C}$. by Tenths of a Degree.

| $t$ | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | 1.00000 | 1.00037 | 1.00073 | 1.00110 | 1.00147 |
| 1 | . 00367 | . 00404 | . 00440 | . 00477 | . 00514 |
| 2 | . 00734 | . 00771 | . 00807 | . 00844 | .0088I |
| 3 | . 01101 | .01138 | . 01174 | . 01211 | . 01248 |
| 4 | -.Or 468 | . 01505 | . 01541 | . 01578 | .OI6I 5 |
| 5 | 1.01835 | 1.01872 | 1.01908 | 1.01945 | 1.01982 |
| 6 | . 02202 | . 02239 | . 02275 | . 02312 | . 02349 |
| 7 | . 02569 | . 02606 | . 02642 | . 02679 | . 02716 |
| 8 | . 02936 | . 02973 | . 03009 | . 03046 | . 03083 |
| 9 | . 03303 | . 03340 | . 03376 | . 03413 | . 03450 |
| $t$ | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| 0 | 1.00184 | 1.00220 | I. 00257 | I. 00294 | 1.00330 |
| 1 | . 00550 | . 00587 | . 00624 | .0066I | . 00697 |
| 2 | . 00918 | . 00954 | . 00991 | . 01028 | . 01064 |
| 3 | . 01284 | . 01321 | . 01358 | . 11395 | .0143I |
| 4 | .01652 | . 01688 | .OI725 | . 01762 | . 01798 |
|  |  | 1.02055 | 1.02092 | 1.02129 | 1.02165 |
| 6 | . 02386 | . 02422 | . 02459 | . 02496 | . 02532 |
| 7 | . 02752 | . 02789 | . 02826 | . 02863 | . 02899 |
| 8 | .03120 | .03156 | . 03193 | . 03290 | . 03266 |
| 9 | . 03486 | . 03523 | . 03560 | . 03597 | . 03633 |

Emithsonian Tables.

Table 112. (continwed).
VOLUME OF GASES.
(b) Values of $1+.00367 t$ for Values of $t$ between $-90^{\circ}$ and $+1990^{\circ} \mathrm{O}$. by $10^{\circ}$ Steps.

| $t$ | 00 | 10 | 20 | 30 | 40 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| -000 | 1.00000 | 0.96330 | 0.92660 | 0.88990 | 0.85320 |
| +000 | 1.00000 | 1.03670 | 1.07340 | 1.11010 | 1.14680 |
| 100 | 1.36700 | 1.40370 | 1.44040 | 1.47710 | 1.51380 |
| 200 | 1.73400 | 1.77070 | 1.80740 | 1.84410 | 1.88080 |
| 300 | 2.10100 | 2.13770 | 2.17440 | 2.21110 | 2.24780 |
| 400 | 2.46800 | 2.50470 | 2.54140 | 2.57810 | 2.61480 |
| 500 | 2.83500 | 2.87170 | 2.90840 | 2.94510 | 2.98180 |
| 600 | 3.20200 | 3.23870 | 3.27540 | $3 \cdot 31210$ | 3.34880 |
| 700 | $3 \cdot 56900$ | 3.60570 | 3.64240 | 3.67910 | 3.71580 |
| 800 | 3.93600 | 3.97270 | 4.00940 | 4.04610 | 4.08280 |
| 900 | $4 \cdot 30300$ | 4.33970 | $4 \cdot 37640$ | 4.41310 | 4.44980 |
| 1000 | 4.67000 | 4.70670 | 4.74340 | 4.78010 | 4.81680 |
| 1100 | 5.03700 | 5.07370 | 5.11040 | 5.14710 | 5.18380 |
| 1200 | 5.40400 | 5.44070 | 5.47740 | 5.51410 | 5.55080 |
| 1300 | 5.77100 | 5.80770 | 5.84440 | 5.88110 | 5.91780 |
| 1400 | 6.13800 | 6.17470 | 6.21140 | 6.24810 | 6.28480 |
| 1500 | 6.50500 | 6.54170 | 6.57840 | 6.61510 | 6.65180 |
| 1600 | 6.87200 | 6.90870 | 6.94540 | 6.98210 | 7.01880 |
| 1700 | 7.23900 | 7.27570 | 7.31240 | 7.34910 | 7.38580 |
| 1800 | 7.60600 | 7.64270 | 7.67940 | 7.71610 | 7.75280 |
| 1900 | 7.97300 | 8.00970 | 8.04640 | 8.08310 | 8.11980 |
| 2000 | 8.34000 | 8.37670 | 8.41340 | 8.45010 | 8.48680 |
| $t$ | 50 | 60 | 70 | 80 | 90 |
| -000 | 0.81650 | 0.77980 | 0.74310 | 0.70640 | 0.66970 |
| +000 | 1.18350 | 1.22020 | 1.25690 | 1.29360 | 1.33030 |
| 100 | 1.55050 | 1.58720 | 1.62390 | 1.66060 | 1.69730 |
| 200 | 1.91750 | 1.95420 | 1.99090 | 2.02760 | 2.06430 |
| 300 | 2.28450 | 2.32120 | 2.35790 | 2.39460 | 2.43130 |
| 400 | 2.65150 | 2.68820 | 2.72490 | 2.76160 | 2.79830 |
| 500 | 3.01850 | 3.05520 - | 3.09190 | 3.12860 | 3.16530 |
| 600 | 3.38550 | 3.42220 | 3.45890 | 3.49560 | 3.53230 |
| 700 | 3.75250 | 3.78920 | 3.82590 | 3.86260 | 3.89930 |
| 800 | 4.11950 | 4.15620 | 4.19290 | 4.22960 | 4.26630 |
| 900 | 4.48650 | 4.52320 | 4.55990 | 4.59660 | 4.63330 |
| 1000 | 4.85350 | 4.89020 | 4.92690 | 4.96360 | 5.00030 |
| 1100 | 5.22050 | 5.25720 | 5.29390 | 5.33060 | 5.36730 |
| 1200 | $5 \cdot 58750$ | 5.62420 | 5.66090 | 5.69760 | 5.73430 |
| 1300 | 5.95450 | 5.99120 | 6.02790 | 6.06460 | 6.10130 |
| 1400 | 6.32150 | 6.35820 | 6.39490 | 6.43160 | 6.46830 |
| 1500 | 6.68850 | 6.72520 | 6.76190 | 6.79860 | 6.83530 |
| 1600 | 7.05550 | 7.09220 | 7.12890 | 7.16560 | 7.20230 |
| 1700 | 7.42250 | 7.45920 | 7.49590 | 7.53260 | 7.56930 |
| 1800 | 7.78950 | 7.82620 | 7.86290 | 7.89960 | 7.93630 |
| 1900 | 8.15650 | 8.19320 | 8.22990 | 8.26660 | 8.30330 |
| 2000 | 8.52350 | 8.56020 | 8.59690 | 8.63360 | 8.67030 |

(c) Logarithms of $1+.00367 \boldsymbol{t}$ for Values

| $t$ | 0 | 1 | 2 | 3 | 4 | Mean diff. per degree. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| -40 | İ.931051 | İ. 929179 | I. 927299 | İ.925410 | I. 923513 | 1884 |
| -30 | . $94934{ }^{\text {I }}$ | . 947546 | . 945744 | . 943934 | . 942117 | 1805 |
| - 20 | . 966892 | . 965169 | . 963438 | . 961701 | . 959957 | 1733 |
| -10 | .983762 | .982104 | . 980440 | . 978769 | . 977092 | 1667 |
| - | 0.000000 | .998403 | .996801 | . 995192 | . 993577 | 1605 |
| + 0 | 0.000000 | 0.001591 | 0.003176 | 0.004755 | 0.006329 | 1582 |
| 10 | . 015653 | . 017188 | . 018717 | . 020241 | . 021760 | 1526 |
| 20 | . 030762 | .032244 | .033721 | .035193 | .036661 | 1474 |
| 30 | . 045362 | . 0.46796 | . 048224 | . 049648 | .051068 | 1426 |
| 40 | .059488 | .06c875 | . 062259 | . 063637 | .065012 | 1381 |
| 50 | 0.073168 | 0.074513 | 0.075853 | 0.077190 | 0.078522 | 1335 |
| 60 | .08643I | . 087735 | .089036 | . 090332 | . 091624 | 1299 |
| 70 | . 099301 | .100567 | .101829 | .103088 | . 104344 | 1259 |
| So | . 111800 | . 113030 | .114257 | .115481 | . 116701 | 1226 |
| 90 | . 123950 | .125146 | .126339 | . 127529 | .128716 | 1191 |
| 100 | 0. 135768 | 0.136933 | 0.138094 | 0.139252 | 0.140408 | 1158 |
| 110 | . 147274 | . 248408 | . 149539 | .150667 | . 151793 | 1129 |
| 120 | . 158483 | . 159588 | . 160691 | . 161790 | .162887 | 1 IOI |
| 130 | .169410 | . 170488 | .171563 | .172635 | .173705 | 1074 |
| 140 | .18006S | .181120 | .182169 | .183216 | . 184260 | 1048 |
| 150 | 0.190472 | -.191498 | 0.192523 | 0.193545 | 0.194564 | 1023 |
| 160 | . 200632 | . 201635 | . 202635 | . 203634 | . 204630 | 1000 |
| 170 | . 210559 | . 211540 | . 212518 | . . 213494 | . 214468 | 976 |
| 180 | . 220265 | . 221224 | . 222 ISo | . 223135 | .224087 | 956 |
| 190 | . 229759 | .230697 | .231633 | .232567 | . 233499 | 935 |
| 200 | 0.239049 | 0.239967 | $0.24088_{4}$ | 0.241798 | 0.242710 | 916 |
| 210 | . 248145 | . 249044 | . 249942 | . 250837 | . 251731 | 897 |
| 220 | .257054 | . 257935 | .258814 | .259692 | . 260567 | 878 |
| 230 | .265734 | . 2666.48 | . 267510 | . 268370 | . 269228 | 861 |
| 240 | . 274343 | .275189 | .276034 | .276877 | . 277719 | 844 |
|  |  |  | 0.284395 | 0.285222 | 0.286048 | 828 |
| $260$ | $\text { . } 290969$ | $.291784$ | . 292597 | . 293409 | . 294219 | 813 |
| 270 | . 299049 | . 299849 | -300648 | . 301445 | . 302240 | 798 |
| 280 | -306982 | - 307768 | . 30855 | -309334 | . 310115 | 784 |
| 290 | -314773 | -315544 | .3163I4 | . 317083 | . 317850 | 769 |
| 300 | 0.322426 | $0.323184$ | 0.323941 |  | 0.325450 | 756 |
| 310 | - 329947 | $.330692$ | . 331435 | . 332178 | . 332919 | 743 |
| 320 | - 337339 | .338072 | . 338803 | . 339533 | . 340262 | $73{ }^{\circ}$ |
| 330 340 | $.344608$ | - 345329 | -346048 | . 346766 | - 347482 | 719 |
| 340 | -351758 | -352466 | . 353174 | -353880 | - 354585 | 707 |
|  | 0.358791 | 0.359488 |  |  |  |  |
| 360 | .365713 | $.366399$ | - 367084 | . 367768 | $.36845 \mathrm{I}$ | 684 |
| 370 380 | .372525 .379233 | . 373201 | . 373875 | . 374549 | . 375221 | 674 |
| 380 390 | . 379233 | -379898 | -380562 | -381225 | $.381887$ | 664 |
| 390 | -385439 | -386494 | . 387148 | .387801 | . 388453 | 654 |

Smithsonian Tables.

GASES.
of $t$ between $-49^{\circ}$ and $+399^{\circ}$ C. by Degrees.

| $t$ | 5 | 6 | 7 | 8 | 9 | Mean diff. per degree. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-40$ | 1. 1.21608 | İ. 919695 | 1. 917773 | IT. 915843 | İ. 913904 | 1926 |
| 30 | . 940292 | . 938460 | . 936619 | . 93477 I | . 932915 | 1845 |
| 20 | .958205 | -956447 | .95468I | . 952909 | .951129 | 1771 |
| 10 | . 975409. | . 973719 | . 972022 | .970319 | . 968609 | 1699 |
| -0 | . 991957 | . 990330 | . 988697 | . 987058 | . 985413 | 1636 |
| + 0 | 0.007897 | 0.009459 | 0.011016 | 0.012567 | 0.014113 | 1554 |
| 10 | . 023273 | . 024781 | . 026284 | . 027782 | . 029274 | 1500 |
| 20 | . 038123 | . 039581 | . 041034 | . 042481 | . 043924 | 1450 |
| 30 | . 052482 | .053893 | . 055298 | . 056699 | .058096 | 1402 |
| 40 | .066382 | .067748 | .069109 | . 070466 | . 071819 | 1359 |
| 50 | 0.079847 | 0.081174 | 0.082495 | $0.083811$ | $0.085123$ | 1315 |
| 60 | . 092914 | . 094198 | . 0954486 | $.096765$ | $.098031$ | 1281 |
| 70 | .105595 | . 106843 | . 108088 | . 109329 | . 110566 | 1243 |
| 80 90 | .117917 .129899 | .119130 .131079 | .120340 .132256 | .121547 .133430 | .122750 .134601 | 1210 1175 |
| 100 | 0.141559 | 0.142708 | 0.143854 | 0.144997 | 0.146137 | 1144 |
| 110 | . 152915 | . 154034 | . 155151 | . 156264 | . 157375 | 1115 |
| 120 | . 163981 | . 164072 | .166161 | . 167246 | . 168330 | 1087 |
| 130 | .174772 | .175836 | . 176898 | -177958 | . 179014 | 1060 |
| 140 | . 185301 | . 186340 | . 187377 | .188411 | . 189443 | 1035 |
| 150 | 0.195581 | 0.196596 | 0.197608 | 0.198619 | 0.199626 | 1011 |
| 160 | . 205624 | . 206615 | . 207605 | . 208592 | . 209577 | 988 |
| 170 | . 215439 | . 216409 | . 217376 | . 218341 | .219304 | 966 |
| 180 | . 225038 | . 225986 | . 226932 | . 227876 | . 228819 | 946 |
| 190 | . 234429 | . 235357 | .236283 | . 237207 | .238129 | 925 |
| 200 | 0.243621 | 0.244529 | 0.245436 | 0.24634 I | 0.247244 | 906 |
| 210 | . 252623 | . 253512 | . 254400 | . 255287 | . 256172 | 887 |
| 220 | .261441 | . 262313 | .263184 | . 264052 | . 264919 | 870 |
| 230 | . 270085 | . 270940 | . 271793 | . 272644 | .273494 | 853 |
| 240 | . 278559 | . 279398 | .280234 | .281070 | .281903 | 836 |
| 250 | 0.286872 | 0.287694 | 0.288515 | 0.289326 | 0.290153 | 820 |
| 260 | . 295028 | . 295835 | . 296640 | . 297445 | . 298248 | 805 |
| 270 | . 303034 | -303827 | -304618 | -305407 | -306196 | 790 |
| 280 | -310895 | -311673 | -312450 | -313226 | -314000 | 776 |
| 290 | . 318616 | -319381 | -320144 | . 320906 | -321667 | 763 |
| 300 | 0.326203 | 0.326954 | 0.327704 | 0.328453 | 0.329201 | 750 |
| 310 | . 333659 | -334397 | . 335135 | . 335871 | . 336606 | 737 |
| 320 | . 340989 | -341715 | -342441 | - 343164 | -343887 | 724 |
| 330 | -348198 | . 348912 | . 349624 | $\cdot 350337$ | -351048 | 713 |
| 340 | . 355289 | -355991 | -356693 | -357394 | -358093 | 701 |
| 350 | 0.362266 | 0.362957 | -. 363648 | 0.364337 |  |  |
| 360 | . 369132 | . 360813 | - 370493 | .371171 .377000 | . .371849 .38567 | 678 668 |
| 370 380 | - 3758582 | - 376562 | $\begin{array}{r}.377232 \\ .383688 \\ \hline\end{array}$ | $.377900$ |  | 668 |
| 380 390 | .382548 .389104 | .383208 .389754 | .383868 .390403 | .384525 .391052 | .385183 .391699 | 658 648 |

Emithsonian Tables.

TABLE 112 (continued).
VOLUME OF GASES.
(d) Logarithms of $1+.00367 t$ for Values of $t$ between $400^{\circ}$ and $1990^{\circ} \mathrm{O}$. by $10^{\circ}$ Steps.

| $t$ | 00 | 10 | 20 | 30 | 40 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 400 | 0.392345 | 0.398756 | 0.405073 | 0.411300 | 0.417439 |
| 500 | 0.452553 | 0.458139 | 0.463654 | 0.469100 | 0.474479 |
| 600 | . 505421 | . 510371 | . 515264 | . 520103 | . 524889 |
| 700 | . 552547 | . 556990 | .56ı388 | . 565742 | .570052 |
| 800 | . 595055 | . 599086 | . 603079 | . 607037 | . 610958 |
| 900 | . 633771 | . 637460 | . 641117 | . 644744 | . 648341 |
| 1000 | 0.669317 | 0.672717 | 0.676090 | 0.679437 | 0.682759 |
| 1100 | . 702172 | .705325 | .708455 | .711563 | .714648 |
| 1200 | . 732715 | . 735655 | .738575 | .741475 | . 744356 |
| 1300 | .761251 | . 764004 | . 766740 | .769459 | . 772160 |
| 1400 | .788027 | .790616 | .793190 | . 795748 | .798292 |
| 1500 | 0.813247 | 0.815691 | 0.818120 | 0.820536 | 0.822939 |
| 1600 | . 837083 | . 839396 | . 841697 | . 843986 | . 846263 |
| 1700 | .859679 | . 861875 | . 864060 | . 866234 | . 868398 |
| 1800 | .881156 | . 883247 | . 885327 | . 887398 | . 889459 |
| 1900 | . 901622 | .903616 | . 905602 | . 907578 | . 909545 |
| $t$ | 50 | 60 | 70 | 80 | 90 |
| 400 | 0.423492 | 0.429462 | 0.435351 | 0.441161 | 0.446894 |
| 500 600 | 0.479791 | 0.4850 .40 | 0.490225 | 0.495350 |  |
| 600 | . 529623 | - 534305 | . 538938 | - 543522 | . 548058 |
| 700 | . 574321 | $\cdot 578548$ | . 582734 | . 586880 | . 590987 |
| 800 | . 614845 | .618696 | . 622515 | . 626299 | . 630051 |
| 900 | .651908 | . 655446 | . 658955 | . 662437 | . 665890 |
| 1000 | 0.686055 | 0.689327 | 0.692574 | 0.695797 | 0.698996 |
| 1100 | . 717712 | . 720755 | . 723776 | . 726776 | .729756 |
| 1200 | . 747218 | .750061 | . 752886 | . 755692 | . 758480 |
| 1300 | . 774845 | . 777514 | .780166 | . 782802 | .785422 |
| 1400 | .800820 | . 803334 | . 805834 | .808319 | .810790 |
| 1500 | 0.825329 | 0.827705 | 0.830069 | 0.832420 | 0.834758 |
| 1600 | . 848528 | . 850781 | . 853023 | . 855253 | . 857471 |
| 1700 | .870550 | . 872692 | . 874824 | . 876945 | . 879056 |
| 1800 | . 891510 | . 893551 | . 895583 | . 897605 | . 899618 |
| 1900 | -911504 | -913454 | . 915395 | .917327 | .919251 |

Smithsonian Tables.

Tables 113-114.

# RELATIVE DENSITY OF MOIST AIR FOR DIFFERENT PRESSURES AND HUMIDITIES. 

TABLE 113.-Values of $\frac{h}{760}$, from $h=1$ to $h=9$, for the Computation of Different Values of the Ratio of Actual to Normal Barometrio Pressure.
This gives the density of moist air at pressure $h$ in terms of the same air at normal atmosphere pressure. When air contains moisture, as is usually the case with the atmosphere, we have the following equation for pressure term: $h=B-0.378 e$, where $e$ is the vapor pressure, and $B$ the corrected barometric pressure. When the necessary psychrometric observations are made the value of $e$ may be taken from Table 189 and then 0.378 e from Table 115, or the dew-point may be found and the value of 0.378 e taken from Table 115.


Examples of Use of the Table.
To find the value of $\frac{h}{760}$ when $h=754 \cdot 3$

To find the value of $\frac{h}{760}$ when $h=5.73$

$$
\begin{aligned}
& h=5 \text { gives .oo65789 }
\end{aligned}
$$

TABLE 114. - Values of the logarithms of $\frac{h}{760}$ for values of $h$ between 80 and 340.
Values from 8 to 80 may be got by subtracting I from the characteristic, and from 0.8 to 8 by subtracting 2 from the characteristic, and so on.

| $\boldsymbol{h}$ | Values of $\log \frac{h}{760}$. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 80 | 1. 02228 | I. 02767 | I. 03300 | İ. 03826 | I. 04347 | I. 0486 I | I. 05368 | I. 0.05871 | I. 06367 | İ.06858 |
| 90 | . 07343 | . 07823 | . 08297 | . 08767 | .09231 | .09691 | . 10146 | . 10596 | . 11041 | . 11482 |
| 100 | I.11919 | I. 12351 | I. 12779 | I. 13202 | I. 13622 | I.I 4038 | I. 14449 | I.14857 | I. 15261 | I. 15661 |
| 110 | . 16058 | . 16451 | . 16840 | . 17226 | .17609 | . 17988 | .18364 | . 18737 | .19107 | . 19473 |
| 120 | . 19837 | . 20197 | . 20555 | . 20909 | . 21261 | .216II | . 21956 | . 22299 | . 22640 | . 22978 |
| 130 | . 23313 | . 23646 | . 23976 | . 24304 | . 24629 | . $2495{ }^{2}$ | . 25273 | . 25591 | .25907 | . 26220 |
| 140 | .26531 | . 26841 | .27147 | . $2745^{2}$ | . 27755 | . 28055 | . 28354 | . 28650 | . 28945 | . 29237 |
| 150 | І. 29528 | I. 29816 | 1.30103 | I. 30388 | I. 3067 I | 1. 30952 | 1.3123I | I. 31509 | - 1.31784 | I. 32058 |
| 160 | . 32331 | -32601 | . 32870 | .33137 | . 33403 | . 33667 | . 33929 | . 34190 | - 34450 | - 34707 |
| 170 | - 34964 | -35218 | -3547 1 | $\cdot 35723$ | -35974 | - 36222 | -36470 | -36716 | -36961 | . 37204 |
| 180 | - 37446 | - 37686 | - 37926 | $\cdot 38164$ | -38400 | . 38636 | . 38870 | -39128 | - 39334 | -39565 |
| 190 | -39794 | . 40022 | . 40249 | . 40474 | . 40699 | . 40922 | .41144 | .41365 | . 41585 | . 418 |
| 200 | I. 42022 | $\overline{\mathrm{I}} .42238$ | I. 42454 | 1. 42668 | I. 42882 | I. 43094 | I. 43305 | I. 43516 | I. 43725 | I. 43933 |
| 210 | . 44141 | . 44347 | . 44552 | . 44757 | . 44960 | . 45162 | . 45364 | . 45565 | . 45764 | . 45963 |
| 220 | .46161 | . 46358 | -46554 | . 46749 | . 46943 | .47137 | -47329 | -47521 | . 47712 | . 47902 |
| 230 | . 48091 | -48280 | . 48467 | . 48654 | . 48840 | . 49025 | . 49210 | - 49393 | . 49576 | . 49758 |
| 240 | . 49940 | . 50120 | . 50300 | . 50479 | -50658 | . 50835 | .51012 | . 51188 | . 51364 | . 51539 |
| 250 | 1.51713 | I. 51886 | I. 52059 | I. 52231 | I. 52402 | 1. 52573 | I. 52743 | 1. 52912 | I. 53081 | $\overline{\mathrm{I}} .53249$ |
| 260 | . 53416 | . 53583 | . 53749 | . 53914 | . 54079 | . 54243 | . 54407 | . 54570 | . 54732 | . 54894 |
| 270 | . 55055 | . 55216 | - 55376 | - 55535 | . 55694 | . 55852 | . 56010 | . 56167 | . 56323 | . 56479 |
| 280 | - 56634 | - 56789 | -56944 | . 578097 | . 57250 | -57403 | . 57555 | - 57707 | - 57858 .59340 | . 58008 |
| 290 | -58158 | -58308 | . 58457 | . 58605 | . 58753 | . 58901 | - 59048 | -59194 | - 59340 | -59486 |
| 300 | I. 59631 | I. 59775 | I. 59919 | - 1.60063 | I. 60206 | - 1.60349 | - 6.60491 | I. 60632 | I. 60774 | - 1.60914 |
| 310 320 | . 61055 | .61195 .62569 | .61334 .62704 | .61473 .62839 | .61611 | .61750 .63107 | . 61887 | . 62025 | .62161 | .62298 .63638 |
| 320 330 | .62434 .63770 | .62569 .63901 | .62704 .64032 | .62839 .64163 | .62973 .64293 | .63107 .64423 | .63240 .64553 | .63373 .64682 | . 63506 | .63638 .64939 |
| 330 340 | . 65067 | . 65194 | . 6532 l | . 65448 | . 6.65574 | . 657421 | . 65826 | . $6595{ }^{2}$ | . 66077 | . 66201 |

TABLE 114 (continued).
DENSITY OF AIR.

Values of logarithms of $\frac{h}{760}$ for values of $h$ between 350 and 800 .

| h | Values of $\log \frac{h}{760}$. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 350 | I. 66325 | $\overline{\mathrm{I}} .66449$ | I. 66573 | İ. 66696 | I. 66819 | İ. 66941 | 1. 67064 | - 1.67185 | $\overline{\mathrm{I}} .67307$ | I. 67428 |
| 360 | . 67549 | . 67669 | . 67790 | . 67909 | . 68029 | .68148 | . 68267 | . 68385 | . 68503 | . 6862 I |
| 370 | . 68739 | . 68856 | . 68973 | . 69090 | . 69206 | .69322 | . 69437 | . 69553 | . 69668 | . 69783 |
| 380 | . 69597 | .70011 | .70125 | . 70239 | . 70352 | .70465 | .70577 | .70690 | . 70802 | .70914 |
| 390 | .71025 | .71136 | . 71247 | .7135S | .71468 | .71578 | .71688 | . 71798 | . 71907 | .72016 |
| 400 | 1.72125 | 1.72233 | 1.7234 | -1.72449 | - 1.72557 | -1.72664 | $\overline{\mathrm{I}} .72771$ | - 1.72878 | - 1.72985 | - 7.73091 |
| 410 | . 73197 | .73303 | . 73408 | .73514 | .73619 | .73723 | .73828 | . 73932 | .74036 | .74140 |
| 420 | .74244 | . $7+347$ | . $74+50$ | . 74553 | .74655 | .74758 | .74860 | . 74961 | .75063 | .75164 |
| 430 | . 75265 | . 75366 | .75467 | . 75567 | . 75668 | . 75768 | . 75867 | . 75967 | . 76066 | .76165 |
| 440 | .76264 | .76362 | .76461 | .76559 | .76657 | .76755 | .76852 | . 76949 | . 77046 | .77143 |
| 450 | 1.77240 | - 1.77336 | 1.77432 | - 7.77528 | - 1.77624 | 1.77720 | - 1.77815 | $\overline{1} .77910$ | İ.78005 | İ.78100 |
| 460 | .7S194 | . 78289 | . 78383 | . 78477 | .7S570 | .78664 | . 78757 | . 78850 | . 78943 | . 79036 |
| 470 | .79128 | .79221 | .79313 | .79405 | . 79496 | . 79588 | . 79679 | . 79770 | .79861 | .79952 |
| 480 | . 50043 | . 80133 | . 80223 | . 80313 | . 80403 | . 80493 | . 80582 | . 80672 | . 80761 | . 80850 |
| 490 | . $5093{ }^{\text {S }}$ | . 81027 | .SIII 5 | .81203 | .81291 | . 81379 | . 81467 | . 81554 | .81642 | .81729 |
| 500 | I. SISI6 | I. 81902 | I. 81989 | İ. 82075 | $\overline{\mathrm{I}} .82162$ | I. 82248 | İ. 82334 | İ. 82419 | İ. 82505 | İ. 82590 |
| 510 | . 82676 | . 82761 | . 82846 | . 82930 | . 83015 | . 83099 | . 83184 | . 83268 | . 83352 | . 83435 |
| 5こ0 | . 83519 | . 83602 | . 83686 | . 83769 | . 83852 | . 83935 | . 84017 | . 84100 | . 84182 | . 84264 |
| 530 | . 84346 | . 54428 | . 84510 | . 84591 | . 84673 | . 84754 | . 84835 | . 84916 | . 84997 | . 85076 |
| 540 | . 85158 | .85238 | . 85319 | . 85399 | . 85479 | . $85555^{8}$ | .85638 | . 85717 | . 85797 | . 85876 |
| 550 | İ. $S_{5955}$ | $\overline{1} .86034$ | İ.86113 | İ.86191 | - 1.86270 | 1. 86348 | 1. 86426 | I. 86504 | İ. 86582 | İ. 86660 |
| 560 | . 86737 | . 86815 | .86892 | . 86969 | . 87047 | . 87123 | . 87200 | . 87277 | . 87353 | . 87430 |
| 570 | . 87506 | . 87582 | . 87658 | . 87734 | . 87810 | . 87885 | . 87961 | . 88036 | . 88111 | . 88186 |
| 580 | .88261 | .88336 | .8841I | . 88486 | . 88560 | . 88634 | . 88708 | . 88782 | . 88856 | . 88930 |
| 590 | . 89004 | . 89077 | . 8915 I | . 89224 | . 89297 | . 89370 | . 89443 | . 89516 | . 89589 | .89661 |
| 600 | İ. 89734 | İ.89806 | I. 89878 | İ. 89950 | I. 90022 | I. 90004 | 1. 90166 | I. 90238 | 1. 90309 | I. 90380 |
| 610 | . 90452 | . 90523 | . 90594 | . 90665 | . 90735 | . 90806 | . 90877 | . 90947 | :91017 | .91088 |
| 620 | -91158 | -91228 | .91298 | .91367 | . 91437 | .91507 | .91576 | . 91645 | .91715 | .91784 |
| 630 | . 91853 | . 91922 | .91990 | . 92059 | .92128 | .92196 | .92264 | . 92333 | . 92401 | . 92469 |
| 640 | .92537 | . 92604 | . 92672 | . 92740 | .92807 | .92875 | . 92942 | . 93009 | . 93076 | .93143 |
| 650 | İ. 93210 | 1. 93277 | I. 9334.3 | I. 93410 | - 2.93476 | İ. 93543 | I. 93609 | 1. 93675 | 1. 93741 | I. 93807 |
| 660 | .93873 | .93939 | -94004 | . 94070 | .94135 | -94201 | . 94266 | -9433I | . 94396 | .94461 |
| 670 | . 94526 | -94591 | . 94656 | -94720 | -94785 | . 94449 | .94913 | . 94978 | . 95042 | .95106 |
| 680 | . 95170 | . 95233 | . 95297 | .95361 | . 95424 | . 95488 | .95551 | .95614 | .95677 | . 95741 |
| 690 | .95804 | .95866 | . 95929 | . 95992 | . 96055 | .9617 7 | .96180 | . 96242 | . 96304 | . 96366 |
| 700 | 1. 96428 | - 1.96490 | 1. $9655^{2}$ | T. 96614 | 1.96676 | 1.96738 | - 1.96799 | 1.96861 | 1. 96922 | 1. 96983 |
| 710 | . 97044 | . 97106 | . 97167 | . 97228 | . 97288 | . 97349 | . 97410 | . 97471 | . 97531 | . 97592 |
| 720 | .97652 | . 97712 | -97772 | . 97832 | .97892 | . 97951 | . 98012 | . 98072 | . 98132 | .98191 |
| 730 | -99251 | .98310 | . 98370 | . 98429 | .98488 | .98547 | . 98606 | . 98665 | . 98724 | . 98783 |
| 740 | -98842 | . 98900 | . 98959 | .99018 | . 99076 | .99134 | -99193 | .9925I | . 99309 | . 99367 |
| 750 | I. 99425 | -1.99483 | I. 199540 | 1. 99598 | 1.99656 | I. 99713 | 1.99771 | I. 99828 | I. 99886 | I. 99942 |
| 760 | 0.00000 | 0.00057 | 0.00114 | 0.00171 | 0.00228 | 0.00285 | 0.00342 | 0.00398 | 0.00455 | 0.00511 |
| 770 780 | . 00568 | .00624 | . 00680 | . 00737 | . 00793 | . 00849 | .00905 | . 00961 | . 01017 | . 01072 |
| 780 | . 01128 | . 01184 | . 01239 | . 01295 | . 01350 | . 01406 | . 01461 | .01516 | . 01571 | . 01626 |
| 790 | . 01685 | . 01736 | .01791 | . 01846 | . 01901 | . 01955 | . 02010 | . 02064 | .02119 | .02173 |

This table gives the humidity term $0.378 e$, which occurs in the equation $\delta=\delta_{0} \frac{h}{760}$ $=\delta_{0} \frac{B-0.378 e}{760}$ for the calculation of the density of air containing aqueous vapor at pressure $e$; $\delta_{0}$ is the density of dry air at normal temperature and barometric pressure, $B$ the observed barometric pressure, and $h=B-0.378 e$, the pressure corrected for humidity. For values of $\frac{760}{h}$, see Table 113. Temperatures are in degrees Centigrade, and pressures in millimeters of mercury.

| Dew point. | Vapor pressure (ice). | $0.378 e$ | Dew point. |  | $0.378 e$ | Dew point. |  | 0. 378 e |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| C | m | mm | $\underset{\mathrm{C}}{\mathrm{C}}$ | mm | mm |  | mm | mm |
| $-50^{\circ}$ | 0.029 | 0.01 | $0^{\circ}$ | 4.58 | 1.73 | $30^{\circ}$ | 31.86 | 12.0 |
| -45 | 0.054 | 0.02 | 1 | $4 \cdot 92$ | I. 86 | 31 | 33.74 | 12.8 |
| -40 | 0.096 | 0.04 | 2 | 5.29 | 2.00 | 32 | 35.70 | 13.5 |
| -35 | -. 169 | 0.06 | 3 | 5.68 | 2.15 | 33 | 37.78 | 14.3 |
| -30 | 0.288 | 0. 11 | 4 | 6.10 | 2.31 | 34 | 39.95 | 15.1 |
| -25 | 0.480 | -. 18 | 5 | 6.54 | 2.47 | 35 | 42.23 | 16.0 |
| 24 | 0. 530 | 0.20 | 6 | 7.01 | 2.66 | 36 | 44.62 | 16.9 |
| 23 | 0.585 | 0.22 | 7 | 7.51 | 2.84 | 37 | 47.13 | 17.8 |
| 22 | 0.646 | 0.24 | 8 | 8.04 | 3.04 | 38 | $49 \cdot 76$ | 18.8 |
| 21 | 0. 712 | 0.27 | 9 | 8.61 | 3.25 | 39 | 52.51 | 19.8 |
| -20 | 0. 783 | 0.30 | 10 | 9.21 | 3.48 | 40 | 55.40 | 20.9 |
| 19 | 0. 862 | 0.33 | II | 9.85 | $3 \cdot 72$ | 41 | 58.42 | 22.I |
| 18 | 0.947 | -0.36 | 12 | 10.52 | 3.98 | 42 | 61.58 | $23 \cdot 3$ |
| 17 | 1.041 | 0.39 | 13 | II 1.24 | 4.25 | 43 | 64.89 | 24.5 |
| 16 | 1.142 | 0.43 | 14 | 11.99 | 4.53 | 44 | 68.35 | 25.8 |
| -15 | I. 252 | 0.47 | 15 | 12.79 | 4.84 | 45 | 71.97 | 27.2 |
| 14 | 1. 373 | 0.52 | 16 | 13.64 | 5.16 | 46 | 75.75 | 28.6 |
| 13 | 1. 503 | 0.57 | 17 | 14.54 | $5 \cdot 50$ | 47 | 79.70 | 30.1 |
| 12 | I. 644 | 0.62 | 18 | 15.49 | 5.85 | 48 | 83.83 | 31.7 |
| 11 | I. 798 | 0.68 | 19 | 16.49 | 6.23 | 49 | 88. 14 | $33 \cdot 3$ |
| -10 | I. 964 | 0. 74 | 20 | 17.55 | 6.63 | 50 | 92.6 | 35.0 |
| 9 | 2.144 | 0.8 I | 21 | 18.66 | 7.06 | 51 | 97.3 | 36.8 |
| 8 | 2.340 | 0.88 | 22 | I9.84 | 7.50 | 52 | 102.2 | 38.6 |
|  | 2.550 | 0.96 | 23 | 21.09 | 7.97 | 53 | 107.3 | 40.6 |
| 6 | 2.778 | 1. 05 | 24 | 22.40 | 8.47 | 54 | II 2.7 | 42.6 |
| -5 | 3.025 | I. 14 | 25 | 23.78 | 8.99 | 55 | 118.2 | 44.7 |
| 4 | 3.291 | I. 24 | 26 | 25.24 | 9.54 | 56 | 124.0 | 46.9 |
| 3 | $3 \cdot 578$ | 1.35 | 27 | 26.77 | 10.12 | 57 | 130.0 | 49.1 |
| 2 | 3.887 | I. 47 | 28 | 28.38 | 10.73 | 58 | 136.3 | 5 F .5 |
| 1 | 4.220 | 1. 60 | 29 | 30.08 | 11.37 | 59 | 142.8 | 54.0 |
| 0 | $4 \cdot 580$ | I. 73 | 30 | 31.86 | 12.04 | 60 | 149.6 | 56.5 |

* Table quoted from Smithsonian Meteorological Tables.

TABLE 116. - Maintenance of Air at Definite Humidities.
Taken from Stevens, Phytopathology, 6, 428, 1916; see also Curtis, Bul. Bur. Standards, 1 I, 359, 1914; Dieterici, Ann. d. Phys. u. Chem., 50, 47, 1893. The relative humidity and vapor pressure of aqueous vapor of moist air in equilibrium conditions above aqueous solutions of sulphuric acid are given below.

| Density of acid sol. | Relative humidity. | Vapor pressure. |  | Density of acid sol. | Relative humidity. | Vapor pressure. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $20^{\circ} \mathrm{C}$ | $30^{\circ} \mathrm{C}$ |  |  | $20^{\circ} \mathrm{C}$ | $30^{\circ} \mathrm{C}$ |
|  |  | mm | mm |  |  | mm | $\begin{gathered} \mathrm{mm} \\ 18.4 \end{gathered}$ |
| 1.00 | 100.0 | 17.4 | 31.6 | I. 30 | $5 \cdot 3$ |  |  |
| 1.05 I. 10 | 97.5 | 17.0 16.3 | 30.7 29.6 | I. 35 | 47.2 | 6.3 | 15.0 |
| I. 10 | 93.9 88.8 | 16.3 15.4 | 29.6 28.0 | 1.40 1.50 | 37.1 18.8 | 6.5 3.3 | 11.9 6.0 |
| 1. 20 | 80.5 | 14.0 | 25.4 | 1.60 | 8.5 | 1. 5 | 2.7 |
| 1. 25 | 70.4 | 12.2 | 22.2 | 1.70 | 3.2 | 0.6 | 1.0 |

## PRESSURE OF COLUMNS OF MERCURY AND WATER.

British and metric measures. Correct at $0^{\circ} \mathrm{C}$. for mercury and at $4^{\circ} \mathrm{C}$. for water.

| Metric Measure. |  |  | British Measure. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{gathered} \text { Cms. of } \\ \mathrm{Hg} . \end{gathered}$ | Pressure in grams per sq. cm. | Pressure in pounds per sq. inch. | $\begin{gathered} \text { Inches of } \\ \text { Hg. } \end{gathered}$ | Pressure in grams per sq. cm. | Pressure in pounds per sq. inch. |
| 1 | 1 3.5956 | 0. 193376 | 1 | 34.533 | 0.491 74 |
| 2 | 27.1912 | 0.386752 | 2 | 69.066 | 0.982348 |
| 3 | 40.7868 | 0.580128 | 3 | 103.598 | 1.473522 |
| 4 | 54.3824 | 0.773504 | 4 | 138.131 | 1.964696 |
| 5 | 67.9780 | 0.966880 | 5 | 172.664 | 2.455870 |
| 6 | 81.5736 | I. 160256 | 6 | 207.197 | 2.947044 |
| 7 | 95.1692 | 1.353632 | 7 | 241.730 | 3.438218 |
| 8 | 108.7648 | 1. 547008 | 8 | 276.262 | 3.929392 |
| 9 | 122.3604 | 1.740384 | 9 | 310.795 | $4 \cdot 420566$ |
| 10 | 135.9560 | 1.933760 | 10 | $345 \cdot 328$ | 4.911740 |
| Cms. of $\mathrm{H}_{2} \mathrm{O}$. | Pressure in grams per sq. cm. | Pressure in pounds per sq. inch. | Inches of $\mathrm{H}_{2} \mathrm{O}$. | Pressure in grams per $\mathrm{sq} . \mathrm{cm}$. | Pressure in pounds per sq. inch. |
| 1 | 1 | 0.0142234 | 1 | 2.54 | 0.036127 |
| 2 | 2 | 0.0284468 | 2 | 5.08 | 0.072255 |
| 3 | 3 | 0.0426702 | 3 | 7.62 | 0.108382 |
| 4 | 4 | 0.0568936 | 4 | 10.16 | 0.144510 |
| 5 | 5 | 0.0711170 | 5 | 12.70 | 0.180637 |
| 6 | 6 | 0.0853404 | 6 | 15.24 | 0.216764 |
| 7 | 7 | 0.0995638 | 7 | 17.78 | 0.252892 |
| 8 | 8 | 0.1137872 | 8 | 20.32 | 0.289019 |
| 9 | 9 | 0.1280106 | 9 | 22.86 | 0.325147 |
| 10 | 10 | 0.1422340 | 10 | 25.40 | 0.361274 |

Smithsonian Tables.

| Corrections for brass scale and English measure. |  | Corrections for brass scale and metric measure. |  | Corrections for glass scale and metric measure. |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Height of barometer in inches. | in inches for temp. F. | Height of barometer in mm. | in mm. for temp. C. | Height of barometer in mm . | in mm. for temp. C. |
| 15.0 | 0.00135 | 400 | 0.0651 | 50 |  |
| 16.0 | . 00145 | 410 | . 0668 | 100 | 0.0086 .0172 |
| 17.0 | . 0151 | 420 | . 0684 | 150 | . 0258 |
| 17.5 | . 0158 | 430 | . 0700 | 200 | . 0345 |
| 18.0 | .00163 | 440 | . 0716 | 250 | .043I |
| 18.5 | .00167 | 450 | .0732 | 300 | . 0517 |
| 19.0 | .00172 | 460 | . 0749 | 350 | . 0603 |
| 19.5 | .00176 | 470 | . 0765 |  |  |
| 20.0 | 0.00181 | 480 | . 0781 | 400 | 0.0689 |
| 20.5 | .00185 | 490 | . 0797 | 450 500 | . 0775 |
| 21.0 | .00190 | 500 | 0.0813 | 520 | . 0895 |
| 21.5 | .00194 | 510 | . 0830 | 540 | . 0930 |
| 22.0 | .00199 | 520 | . 0846 | 560 | . 0965 |
| 22.5 | . 00203 | 530 | . 0862 | 580 | . 0999 |
| 23.0 | . 00208 | 540 | . 0878 |  |  |
| 23.5 | . 00212 | 550 | . 0894 | 600 | 0.1034 |
|  |  | 560 | .0911 | 610 | . 1051 |
| 24.0 | 0.00217 | 570 | . 0927 | 620 | . 1068 |
| 24.5 | . 00221 | 580 | . 0943 | 630 | .1085 |
| 25.0 | . 00226 | 590 | . 0959 | 640 | .1103 |
| 25.5 26.0 | . 00231 |  |  | 650 | . 1120 |
| 26.0 26.5 | . 000236 | 600 610 | 0.0975 .0992 | 660 | . 1137 |
| 27.0 | . 00245 | 620 | . 1008 | 670 | O. 1154 |
| 27.5 | . 00249 | 630 | . 1024 | 680 | .1172 |
|  |  | 640 | . 1040 | 690 | .1189 |
| 28.0 | 0.00254 | 650 | .1056 | 700 | . 1206 |
| 28.5 | . 00258 | 660 | . 1073 | 710 | . 1223 |
| 29.0 | . 00263 | 670 | .1089 | 720 | . 1240 |
| 29.2 | .00265 | 680 | . 1105 | 730 | . $125^{8}$ |
| 29.4 | . 00267 | - 690 | . 112 I |  |  |
| 29.6 | . 00268 |  |  | 740 | 0.1275 |
| 29.8 | . 00270 | 700 | 0.1137 | 750 | .1292 |
| 30.0 | . 00272 | 710 | . 1154 | 760 | . 1309 |
|  |  | 720 | . 1170 | 770 | . 1327 |
| 30.2 | 0.00274 | 730 | .II86 | 780 | . 1344 |
| 30.4 30.6 | . 00276 | 740 | . 1202 | 790 800 | .1361 |
| 30.6 30.8 | . 00277 | 750 | . 1218 | 800 | . 1378 |
| 30.8 31.0 | . 00279 | 760 | .1235 .1251 | 850 |  |
| 31.2 | . 00283 | 780 | . 1267 | 900 | .1564 .1551 |
| 31.4 | . 00285 | 790 | . 1283 | 950 | .1639 |
| 31.6 | . 00287 | 800 | . 1299 | 1000 | .1723 |

[^19]
## REDUCTION OF BAROMETER TO STANDARD GRAVITY.

## Free-air Altitude Term. Correction to be subtracted.

The correction to reduce the barometer to sea-level is $\left(g_{1}-g\right) / g \times B$ where $B$ is the barometer reading and $g$ and $g_{1}$ the value of gravity at sea-level and the place of observation respectively. The following values were computed for free-air values of gravity $g_{1}$ (Table 565). It has been customary to assume for mountain stations that the value of $g_{1}=$ say about $\frac{\pi}{3}$ the free-air value, but a comparison of modern determinations of $g_{1}$ in this country shows that little reliance can be placed on such an assumption. Where $g_{1}$ is known its value should be used in the above correction term. (See Tables 566 and 567 . Similarly for the latitude term, see succeeding tables, the true value of $g$ should be used if known; the succeeding tables are based on the theoretical values, Table 565.)

| Height above sea-level. | $g_{1}-g$ | Observed height of barometer in millimeters. |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 400 | 450 | 500 | 550 | 600 | 650 | 700 | 750 | 800 |  |  |
| meters. |  |  |  |  |  |  |  |  |  |  |  |  |
| 100 | 0.031 | Correction in mm to be subtracted for height above sea-level in first column and barometer reading in the top line. |  |  |  |  |  | . 02 | . 02 | . 02 | - | - |
| 200 | 0.062 |  |  |  |  |  |  | . 04 | . 05 | . 05 | - | - |
| 300 | 0.093 |  |  |  |  |  |  | . 07 | . 07 | . 07 | - | - |
| 400 | -. 123 |  |  |  |  |  | - | . 09 | . 10 | . 10 | - | - |
| 500 | -. 154 | - |  | - |  |  |  | . 11 | . 12 | . 13 | - | - |
| 600 | 0. 185 | - | - |  | - | - | . 12 | . 13 | . 14 | - | - | - |
| 700 | -. 216 | - | - | - | - | - | . 14 | . 15 | . 16 | - | - | - |
| 800 | 0. 247 | - | - | - | - | - | . 16 | . 18 | . 19 | - | - | - |
| 900 | 0. 278 | - | - | 二 | - | - | . 18 | . 20 | . 22 | - | - | - |
| 1000 | 0.309 | - | - |  | . 18 | . 19 | . 20 | . 22 | . 24 | - | - | - |
| 1100 | 0.339 | - | - | - | . 19 | . 21 | . 22 | . 24 | - | - | - | - |
| 1200 | 0.370 | - | - | - | . 21 | . 23 | . 24 | . 26 | - | - | - | - |
| 1300 | 0.401 | - | - | - | . 22 | . 24 | . 26 | . 29 | - | - | - | - |
| 1400 | 0.432 | - | - | - | . 24 | . 26 | . 28 | . 31 | - | - | - | - |
| 1500 | 0.463 | - | - | . 24 | . 26 | . 28 | . 30 | . 33 | - | - | - | - |
| 1600 | 0.494 | - | - | . 25 | . 28 | . 30 | . 32 | - | - | - | - | - |
| 1700 | 0.525 | - | - | . 27 | . 30 | . 32 | - 34 | - | - | - | - | - |
| 1800 | -. 555 | - | - | . 28 | . 31 | . 34 | . 36 | - | - | . 020 | . 0463 | 15000 |
| 1900 | 0. 586 | - | - | . 30 | . 33 | . 36 | . 39 | - | - | . 019 | . 0447 | 14500 |
| 2000 | 0.617 | - | . 28 | . 31 | . 34 | . 38 | . 41 | - | . 021 | . 019 | . 0432 | 14000 |
| 2100 | 0.648 | - | . 30 | . 33 | . 36 | . 40 | - | - | . 021 | . 018 | . 0416 | 13500 |
| 2200 | 0.679 | - | . 31 | . 35 | . 38 | . 41 | - | - | . 020 | . 017 | . 0401 | 13000 |
| 2300 | 0.710 | - | . 32 | . 36 | . 40 | . 43 | - | . 021 | . 019 | . 017 | . 0386 | 12500 |
| 2400 | 0.740 | - | . 34 | . 38 | . 42 | $\begin{aligned} & .45 \\ & .47 \end{aligned}$ | - | . 021 | . 018 | . 016 | . 0370 | 12000 |
| 2500 | 0.771 | . 31 | . 35 | . 39 | . 43 |  | - | . 020 | . 018 | . 015 | . 0355 | 11500 |
| 2600 | 0.802 | . 33 | . 37 | . 41 | - | .47 | . 021 | . 019 | . 017 | . 015 | . 0339 | 11000 |
| 2700 | 0.833 | . 34 | . 38 | . 42 | - | - | . 020 | . 018 | . 016 | . 014 | . 0324 | 10500 |
| 2800 | 0.864 | . 35 | . 40 | . 44 | - |  | . 019 | . 017 | . 015 | . 013 | . 0308 | 10000 |
| 2900 | 0.895 | . 36 | . 41 | . 46 | - |  | . 018 | . 016 | . or 5 | . 013 | . 0293 | 9500 |
| 3000 | 0. 926 | . 38 | . 42 | . 47 | - | $\begin{aligned} & .020 \\ & .019 \end{aligned}$ | . 017 | . 016 | . 014 | . OL 2 | . 0278 | 9000 |
| 3100 | 0.957 | . 39 | . 4.4 | - | - | $\begin{aligned} & .019 \\ & .018 \end{aligned}$ | . 016 | . 015 | . 013 | - | . 0262 | 8500 |
| 3200 | 0. 988 | . 40 | . 46 | - | - | $\begin{aligned} & .018 \\ & .017 \end{aligned}$ | . 015 | . 014 | . 12 | - | . 0247 | 8000 |
| 3300 | 1.019 | . 42 | . 47 | - | . 017 | . 016 | . 014 | . 013 | - | - | . 0231 | 7500 |
| 3400 | I. 049 | . 43 | . 48 | - | . 016 | . 015 | . 013 | . 012 | - | - | . 0216 | 7000 |
| 3500 | 1.080 | . 44 | . 49 | - | . 015 | . 014 | . 012 | . OII | - | - | . 0200 | 6500 |
| 3600 | I.III | . 45 |  | - | . 014 | . 013 | . 011 | - | - | - | . 0185 | 6000 |
| 3700 | 1.142 | . 46 | - | - | . 013 | $\begin{aligned} & .012 \\ & .011 \end{aligned}$ | . OII | - | - | - | . 0170 | 5500 |
| 3800 | I. 173 | . 48 | - | . OI 2 | . OII |  |  | - | - | - | . 0154 | 5000 |
| 3900 | I. 204 | . 49 | - | . 011 | . 010 | . 011 | . 010 | - | - | - | . 0139 | 4500 |
| 4000 | I. 235 | . 50 | - | . 010 | . 009 | . .009 | - |  |  |  | . 0123 | 4000 |
| - | - | - | . 003 | . .08 | . 007 | $.007$$\qquad$ | Corrections in in. to be subtracted for height above sea-level in last column and barometer reading in bottom line. |  |  |  | . 0092 | 3000 |
| - | - | . 006 | . 005 | . 005 | . 004 |  |  |  |  |  | . 0062 | 2000 |
|  |  | . 003 |  |  | - |  |  |  |  |  | . 0031 | 1000 |
|  |  |  |  |  |  |  |  |  |  |  |  | feet. |
|  |  | 30 | 28 | 26 | 24 | 22 | 20 | 18 | 16 | 14 |  |  |
|  |  | Observed height of barometer in inches. |  |  |  |  |  |  |  |  |  | sea-level |

Smithsonian Tables.

REDUCTION OF BAROMETER TO STANDARD GRAVITY.* metric measures.
From Latitude $0^{\circ}$ to $45^{\circ}$, the Correction is to be Subtracted.


## Smithsonian Tables

## REDUCTION OF BAROMETER TO STANDARD GRAVITY.* METRIC MEASURES.

From Latitude $46^{\circ}$ to $90^{\circ}$, the Correction is to be Added.


## REDUCTION OF BAROMETER TO STANDARD GRAVITY.*

 ENGLISH MEASURES.From Latitude $0^{\circ}$ to $45^{\circ}$, the Correction is to be Subtracted.

| Latitude. | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | Inch. | Inch | Inch. | Inch. | nc | nc | Inc | Inch. | Inch. | Inch. | Inch |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| 5 |  |  |  |  |  |  |  |  | . 071 |  |  |  |
| 6 | 0.050 | 0.052 | 0.055 | 0.058 | 0.060 | 0.063 | 0.066 | 0.068 | 0.071 | 0.073 | 0.076 |  |
| 7 | 0.049 | 0.052 | 0.055 | 0.057 | 0.060 | 0.062 | 0.065 | 0.068 | 0.070 | 0.073 | 0.075 | 8 |
| 8 | 0.049 | $0 \cdot 052$ | 0.054 | 0.057 | 0.059 | 0.062 | 0.064 | 0.067 | 0.070 | 0.072 | 0.075 | 0.077 |
| 9 | 0.048 | 0.05 I | 0.054 | 0.056 | 0.059 | 0.061 |  | 0.066 | 0.069 | 0.071 | 0.074 | 0.076 |
| 10 |  |  |  |  |  |  |  |  |  |  |  |  |
| 11 | 0.047 | 0.050 | 0.052 | 0.055 | 0.057 | 0.060 | 0.062 | 0.065 | 0.067 | 0.070 | 0.072 | 0.075 |
| 12 | 0.047 | 0.049 | 0.051 | 0.054 | 0.056 | 0.059 | 0.061 | 0.064 | 0.066 | 0.069 | 0.071 | 0.074 |
| 13 | 0.046 | 0.048 | 0.051 | 0.053 | 0.055 | 0.058 | 0.060 | 0.063 | 0.065 | 0.068 | 0.070 | 0.072 |
| 14 | 0.045 | 0.047 | 0.050 | 0.052 | 0.055 | 0.057 | 0.059 | 0.062 | 0.064 | 0.066 | 0.06 | 0.07 I |
| 15 |  |  |  | 51 |  |  | . | . | . | -0.065 | -0.067 | . 070 |
| 16 | 0.043 | 0.046 | 0.048 | 0.050 | 0.052 | 0.055 | 0.057 | 0.059 | 0.062 | 0.064 | 0.066 | 0.068 |
| 17 | 0.042 | 0.045 | 0.047 | 0.049 | 0.051 | 0.053 | 0.056 | 0.058 | 0.060 | 0.062 | 0.065 | 0.067 |
| 18 | 0.041 | 0.044 | 0.046 | 0.048 | 0.050 | 0.052 | 0.054 | 0.057 | 0.059 | 0.061 | 0.063 | 0.065 |
| 19 | 0.040 | 0.042 | 0.045 | 0.047 | 0.049 | 0.05 I | 0.053 | 0.055 | 0.057 | 0.059 | 0.06 | 0.064 |
| 20 |  | 0.041 | -0.043 | 0.045 |  |  |  |  | 0.056 | 0.058 | 0.060 | 062 |
| 21 | 0.038 | 0.040 | 0.042 | 0.044 | 0.046 | 0.048 | 0.050 | 0.052 | 0.054 | 0.056 | 0.058 | 0.060 |
| 22 | 0.037 | 0.039 | 0.041 | 0.043 | 0.045 | 0.047 | 0.049 | 0.050 | 0.052 | 0.054 | 0.056 | . 058 |
| 23 | 0.036 | 0.038 | 0.039 | 0.041 | 0.043 | 0.045 | 0.047 | 0.049 | 0.051 | 0.053 | 0.054 | 0.056 |
| 24 | 0.034 | 0.036 | 0.038 | 0.040 | 0.0 | 0.043 | 0.045 | 0.047 | 0.049 | 0.051 | 0.052 | 0.054 |
| 25 |  |  |  |  |  |  |  |  |  |  |  |  |
| 26 | 0.032 | 0.033 | 0.035 | 0.037 | 0.038 | 0.040 | 0. | 0.043 | 0.045 | 0.047 | 0.048 | 0.050 |
| 27 | 0.030 | 0.032 | 0.033 | 0.035 | 0.03 | 0.038 | 0.040 | 0.041 | 0.043 | 0.045 | 0.046 | 0.048 |
| 28 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.036 | 0.038 | 0.039 | 0.041 | 0.043 | 0.044 | 0.046 |
| 29 | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.036 | 0.037 | 0.039 | 0.040 | 0.042 |  |
| 30 | 0.026 |  |  |  |  |  |  |  |  |  |  |  |
| 31 | 0.024 | 0.026 | 0.027 | 0.028 | 0.030 | 0.031 | 0.032 | 0.033 | 0.035 | 0.036 | 0.037 | 0.038 |
| 32 | 0.023 | 0.024 | 0.025 | 0.026 | 0.028 | 0.029 | 0.030 | 0.031 | 0.032 | 0034 | 0.035 | 0.036 |
| 33 | 0.021 | 0.022 | 0.023 | 0.025 | 0.026 | 0.027 | 0.028 | 0.029 | 0.030 | 0.031 | 0.032 | 0.034 |
| 34 | 0.020 | 0.021 | 0.022 | 0.023 | 0.024 | 0.025 | 0.026 | 0.027 | 0.028 | 0.029 | 0.030 | 0.031 |
| 35 | -0.018 | . |  |  |  |  |  |  |  |  |  |  |
| 36 | 0.016 | 0.017 | 18 | 0.019 | . 020 | . 02 I | 0.0 | 0.0 | 0.023 | 0.024 | 0.02 | 26 |
| 37 | 0.015 | 0.015 |  | 0.017 | 0.018 | 0.019 | 0.01 | 0.020 | 0.021 | 0.022 | 0.022 | . 023 |
| 38 | 0.013 | 0.014 | 0.014 | 0.015 | 0.016 | 0.016 | 0.017 | 0.018 | 0.018 | 0.019 | 0.020 | 20 |
| 39 | 0.011 | 0.012 | 0.012 | 0.013 | 0.014 | 0.014 | 0.015 | 0.015 | 0.016 | 0.017 | 0.017 |  |
|  | -0.0 | -0.010 | -0.01 1 | 0.011 | 0.012 |  |  | . | 0.014 | O.O1 | 0.01 | 0.015 |
| 40 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | 0.010 | 0.010 | 0.011 | 0.01 I | 0.012 | 0.012 | . 012 |
| 42 | 0.006 | 0.006 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | 0.010 |
| 43 | 0.004 | 0.005 | 0.005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 |  |
| 44 | 0.003 | 0.003 | 3 | 3 | 0.003 | 3 | 3 | 0.004 | 0.004 | 0.004 | 0.004 |  |
|  | 0.00 | 0.00 | . 00 | -0.00I | -0.00 |  | -0.00 | -0.0 | . | 0.00 | O.001 | 0.001 |

## Smithsonian Tables.

## REDUCTION OF BAROMETER TO STANDARD GRAVITY.*

 ENGLISH MEASURES.From Latitude $46^{\circ}$ to $90^{\circ}$ the Correction is to be Added.

| Latitude. | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 45 | In | Inch. | Inch. |  | Inch |  |  |  | Inch | Inch. | Inch. | Inch. |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  | OI | . 001 | 01 | +0.001 | +0.001 | +0.001 | +0.001 | +0.001 | OI |
| 47 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 0.003 | 004 | 0.004 | 0.004 | 0.004 | 0.004 |
| 48 | 0.004 | . 005 | 0.005 | 0.005 | 0.005 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.007 | 0.007 |
| 49 | . 0 | . 006 | 0.007 | 0.007 | 0.007 | 0.008 | 0.008 | 0.008 | 0.009 | 0.009 | 0.009 | 0.010 |
| 50 | 0.008 | 0.008 | 0.000 | 0.009 | 0.010 | o. | 0.010 | 0.01 I | 0.011 | 0.012 | 0.012 | 12 |
| 51 | , | , | 0.011 | -0.011 |  |  |  |  |  |  |  | 5 |
| 52 | 0.011 | 0.012 | 0.012 | 0.013 | 0.014 | 0.014 | 0.015 | 0.015 | 0.016 | 0.016 | 0.017 | 0.018 |
| 53 | 0.013 | 14 | 0.014 | 0.015 | . | 0.016 | 0.017 | 0.018 | . 018 | 0.019 | . | 0 |
| 54 | 0.015 | 0.015 | 0.016 | 0.017 | 0.0 | 0.019 | 0.019 | 0.020 | 0.021 | 0.022 | 0.0 | 0.023 |
|  | 0.016 | 0.017 | 0.018 | 0.019 | 0.020 | 0.021 | 0.02 I | 0.022 | 0.023 | 0.024 | 0.025 | 0.026 |
| 56 | +0.018 | . | 0.020 | 0.023 | . 022 | 0.023 | . | . | 0.020 | 0.026 | 0.027 | 28 |
| 57 | 20 | 0.02 I | 0.022 | 0.023 | 0.024 | 0.025 | 0.026 | 0.027 | 0.028 | 0.029 | 0.030 | 0.031 |
| $58$ | 0.021 | 0.022 | 0.023 | . 025 | 0.02 | 0.027 | 0.028 | 0.029 | 0.030 | 0.03 I | 0.032 | 0.033 |
| $\begin{aligned} & 59 \\ & 60 \end{aligned}$ | 0.023 | 0.024 | 0.025 | 0.026 | 0.028 | 0.029 | 0.030 | 0.031 | 0.032 | 0.033 | 0.035 | 0.036 |
|  | 0.024 | 0.026 | 0.027 | 0.028 | 0.029 | 0.031 | 0.032 | 0.033 | 0.034 | 0.036 | 0.037 | 0.038 |
| 61 | 0.026 | O. | 0.028 | 0.030 | 0.031 | 0.033 | 0.034 | - | 0.037 | 0.038 | +0.039 | 0.041 |
| 62 | 0.027 | 0.029 | 0.030 | 0.032 | 0.033 | 0.034 | 0.036 | 0.037 | 0.039 | 0.040 | 0.042 | 0.043 |
| 63 | 0.029 | 0.030 | 0.032 | 0.033 | 0.035 | 0.036 | 0.038 | 0.039 | 0.041 | 0.042 | 0.044 | 0.045 |
| 64 | 0.030 | 0.032 | 0.033 | 0.035 | 0.036 | 0.038 | 0.040 | 0.04 I | 0.043 | 0.044 | 0.046 | 0.047 |
| 65 | 0.031 | 0.033 | 0.035 |  | 0.038 | 0.040 | 0.041 | $0.043$ | $0.045$ | 0.046 | 0.048 | 0.050 |
| 66 | +0.03 | O.03 | 0.03 |  |  | +0.041 |  |  |  | 0 | +0.050 | 52 |
| 67 | 0.034 | 0.036 | 0.038 | 0.039 | 0.041 | 0.043 | 0.04 | 0.047 | 0.048 | 0.050 | . 052 | . 054 |
| 68 | 0.035 | 0.037 | 0.039 | 0.041 | 0.043 | 0.045 | 0.046 | 0.048 | 0.050 | 0.052 | 0.054 | 0.056 |
| 69 | 0.036 | 0.038 | 0.040 | 0.042 | 0.044 | 0.046 | 0.048 | 0.050 | 0.052 | 0.054 | 0.056 |  |
| 70 | 0.038 | 0.040 |  |  | $0.046$ | 0.048 | $0.050$ | $0.052$ | $0.053$ | $0.055$ | $0.057$ | 0.059 |
| $71$ |  |  |  |  |  |  |  |  |  |  | 0.059 | 0.06 I |
| 72 | 0.040 | 0.042 | 0.044 | 0.046 | 0.048 | 0.050 | 0.052 | 0.054 | 0.057 | 0.059 | 0.06 i | 0.063 |
| 73 | 0.041 | 9.043 | 0.045 | 0.047 | 0.049 | 0.05 | 0.054 | 0.056 | 0.058 | 0.060 | 0.062 | 0.064 |
| 74 | 0.042 | 0.044 | 0.046 | 0.048 | 0.051 | 0.053 | 0.055 | 0.057 | 0.059 | 0.062 | 0.064 | 0.066 |
| 75 | 0.043 | 0.045 | 0.047 | 0.049 | 0.052 | 0.054 | 0.056 | 0.058 | 0.061 | 0.063 |  |  |
| 76 | +0.044 | +0.046 | +0.048 | +0.050 |  |  |  |  |  |  | 0.066 | 0.069 |
| 77 | 0.0 .44 | 0.047 | 0.049 | 0.051 | 0.054 | 0.056 | 0.058 | 0.061 | 0.063 | 0.065 | 0.068 | 0.070 |
| 78 | 0.045 | 0.047 | 0.050 | 0.052 | 0.055 | 0.057 | 0.059 | 0.062 | 0.064 | 0.066 | 0.069 |  |
| $\begin{aligned} & 79 \\ & 80 \end{aligned}$ | 0.046 | 0.048 | 0.05 I | 0.053 | 0.055 | 0.058 | 0.060 | 0.063 | 0.065 |  | 0.070 | 0.072 |
| 80 81 | 0.046 +0.047 | $\begin{array}{r} 0.049 \\ +0.049 \end{array}$ | $0.05 \mathrm{I}$ | $0.054$ | $0.056$ | $0.059$ | $0.061$ | $0.063$ | $0.066$ | $0.068$ | 0.07 I | 0.073 |
| 82 | 0.047 |  |  |  |  |  |  |  |  |  |  |  |
| 83 | 0.048 | 0.050 | 0.053 | 0.056 | 0.058 | 0.061 | 0.06 | 0.066 | 0.068 |  |  | 0.076 |
| 84 | 0.048 | 0.051 | 0.053 | 0.056 | 0.059 | 0.061 | 0.064 | 0.066 | 0.060 | 0.071 | 0.074 | 0.076 |
| 85 | 0.049 | 0.05 I | 0.054 | 0.056 | 0.059 | 0.061 | 0.064 | 0.067 | 0.069 | 0.072 | 0.074 | 0.077 |
|  | . 04 | +0.052 |  | +0.057 | +0.060 | +0.062 |  |  |  | +0.073 |  | -0.078 |

[^20]
## Smithsonian Tables.

Tables 124-125.
TABLE 124.- Correction of the Barometer for Capillarity.*
I. Metric Measure.

| Diameter of tube in mm . | Height of Meniscus in Millimeters. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.4 | 1.6 | 1.8 |
|  | Correction to be added in millimeters. |  |  |  |  |  |  |  |
| 4 | 0.83 | 1.22 | I. 54 | 1.98 | 2.37 | - | - | - |
| 5 | . 47 | 0.65 | 0.86 | 1.19 | 1.45 | 1.80 | - | - |
| 6 | . 27 | . 41 | . 56 | 0.78 | 0.98 | 1.21 | 1.43 | - |
| 7 | . 18 | . 28 | . 40 | . 53 | . 67 | 0.82 | 0.97 | 1.13 |
| 8 | - | . 20 | . 29 | . 38 | . 46 | . 56 | . 65 | 0.77 |
| 9 | - | . 15 | . 21 | . 28 | . 33 | . 40 | .46 | . 52 |
| 10 | - | - | . 15 | . 20 | .25 | . 29 | . 33 | . 37 |
| 11 | - | - | . 10 | . 14 | . 18 | . 21 | .24 | . 27 |
| 12 | - | - | . 07 | . 10 | . 13 | . 15 | . 18 | . 19 |
| 13 | - | - | . 04 | . 07 | . 10 | . 12 | . 13 | . 14 |

2. British Measure.

| Diameter of tube in inches. | Height of Meniscus in Inches. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | . 01 | . 02 | . 03 | . 04 | . 05 | . 06 | - . 07 | . 08 |
|  | Correction to be added in inches. |  |  |  |  |  |  |  |
| . 15 | 0.024 | 0.047 | 0.069 | 0.092 | 0.116 | - | - | - |
| . 20 | . 11 | . 022 | . 033 | . 045 | . 059 | 0.078 | - | - |
| . 25 | . 006 | . 012 | . 019 | . 028 | . 037 | . 047 | 0.059 | - |
| . 30 | . 004 | . 008 | .or 3 | . 018 | . 023 | . 029 | . 035 | 0.042 |
| . 35 | - | . 005 | . 008 | . 012 | .OI 5 | . 018 | . 022 | .026 |
| . 40 | - | . 004 | . 006 | . 008 | . 010 | . 012 | . 014 | . 016 |
| . 45 | - | - | . 003 | . 005 | . 007 | . 008 | . 010 | . 012 |
| . 50 | - | - | . 002 | . 004 | .005 | . 006 | . 006 | . 007 |
| .55 | - | - | . 001 | . 002 | . 003 | . 004 | . 005 | . 005 |

* The first table is from Kohlrausch (Experimental Physics), and is based on the experiments of Mendelejeff and Gutkowski (Jour. de Phys. Chem. Geo. Petersburg, $\mathrm{I}_{77}$, or Wied. Beib. $\mathrm{r}_{77}$ ). The second table has been calculated from the same data by conversion into inches and graphic interpolation.

TABLE 125. - Volume of Mercury Meniscus in Cu. Mm.

| Height of meniscus. | Diameter of tube in mm. |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| mm. I .6 |  | 185 | 214 | 245 | 280 | 318 | 356 | 398 | 444 | 492 | 541 |
| 1.8 | 181 | 211 | 244 | 281 | 320 | 362 | 407 | 455 | 507 | 560 | 616 |
| 2.0 | 206 | 240 | 278 | 319 | 362 | 409 | 460 | 513 | 571 | 631 | 694 |
| 2.2 | 233 | 271 | 313 | $35^{8}$ | 406 | 459 | 515 | 574 | 637 | 70.4 | 776 |
| 2.4 | 262 | 303 | 350 | 400 | 454 | 511 | 573 | 639 | 708 | 781 | 859 |
| 2.6 | 291 | 338 | 388 | 444 | 503 | 565 | 633 | 706 | 782 | 862 | 948 |

## 144

## BAROMETRIC PRESSURES CORRESPONDING TO THE TEMPERATURE OF THE BOILING POINT OF WATER.

Useful when a boiling-point apparatus is used in the determination of heights. Copied from the Smithsonian Meteorological Tables, 4th revised edition.
(A) METRIC UNITS.

| ${ }_{\text {chem- }}^{\text {Terature. }}$ | . 0 | . 1 | . 2 | . 3 | . 4 | . 5 | . 6 | . 7 | . 8 | . 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| C | mm . | mm. | mm. | mm | mm . | mm. | mm . | 65. 58 | mm. | mm. |
| $80^{\circ}$ | 355.40 | 356.84 | 358.28 | 359.73 | 361.19 | 362.65 | 364. 11 | 365.58 | 367.06 | 368.54 |
| 8 8 | 370.03 | 371.52 | 373.01 | 374.51 | 376.02 | 377.53 | 379.05 | 380.57 | 382.09 | 383.62 |
| 82 | 385.16 | 386.70 | 388.25 | 389.80 | 391.36 | 392.92 | 394.49 | 396.06 | 397.64 | 399.22 |
| 83 | 400.8 I | 402.40 | 404.00 | 405.61 | 407.22 | 408.83 | 410.45 | 412.08 | 413.71 | 415.35 |
| 84 | 416.99 | 418.64 | 420.29 | 421.95 | 423.61 | 425.28 | 426.95 | 428.64 | 430.32 | 432.01 |
| 85 | 433.7 I | 435.41 | 437.12 | 438.83 | 440.55 | 442.28 | 444.01 | 445.75 | 447.49 | 449.24 |
| 86 | 450.99 | 452.75 | 454.5I | 456.28 | 458.06 | 459.84 | 461.63 | 463.42 | 465.22 | 467.03 |
| 87 | 468.84 | 470.66 | 472.48 | 474.31 | 476.14 | 477.99 | 479.83 | 481. 68 | 483.54 | 485.41 |
| 88 | 487.28 | 489.16 | 491.04 | 492.93 | 494.82 | 496.72 | 498.63 518.04 | 500.54 520.01 | 502.46 | 504.39 |
| 89 | 506.32 | 508.26 | 510.20 | 512.15 | 514.11 | 516.07 | 518.04 | 520.01 | 52 l . 99 | 523.98 |
| 90 | 525.97 | 527.97 | 529.98 | 531.99 | 534.01 | 536.04 | 538.07 | 540.11 | 542.15 | 544.21 |
| 91 | 546.26 | $5+8.33$ | 550.40 | 552.48 | 554.56 | 556.65 | 558.75 | 560.85 | 562.96 | 565.08 |
| 92 | 567.20 | 569.33 | 571.47 | 573.61 | 575.76 | 577.92 | 580.08 | 582.25 | 584.43 | 586.61 608.82 631 |
| 93 | 588.80 61 I .08 | 591.00 613.35 | 593.20 615.62 | 595.41 617.90 | 597.63 620.19 | 599.86 622.48 | 602.09 624.79 | 604.33 627.09 | 606.57 629.41 | 608.82 631.73 |
| 94 | 611.08 | 613.35 | 615.62 | 617.90 | 620.19 | 622.48 | 624.79 | 627.09 | 629.41 | 63 I .73 |
| 95 | 634.06 | 636.40 | 638.74 | 64 I .09 | 643.45 | 645.82 | 648.19 | 650.57 | 652.96 | 655.35 |
| 96 | 657.75 | 660.16 | 662.58 | 665.00 | 657.43 | 669.87 | 672.32 | 674.77 | 677.23 | 679.70 |
| 97 | 682.18 | 684.66 | 687.15 | 689.65 | 692.15 | 694.67 | 697.19 | 699.71 | 702.25 | 704.79 |
| 98 | 707.35 | 709.90 | 712.47 | 715.04 | 717.63 | 720.22 | 722.81 | 725.42 | 728.03 | 730.65 |
| 99 | 733.28 | 635.92 | 738.56 | 741.21 | 743.87 | 740.54 | 749.22 | 751.90 | 754.59 | 757.29 |
| 100 | 760.00 | 762.72 | 765.44 | 768.17 | 770.91 | 773.66 | 776.42 | 779.18 | 781.95 | 784.73 |

(B) ENGLISH UNITS.

| Tem- | . 0 | . 1 | . 2 | . 3 | . 4 | . 5 | . 6 | . 7 | . 8 | . 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| F. | Inc | Inches. | Inches. | Inches. | Inches. | Inc | Inches. | Inches. | Inches. | Inc |
| $185^{\circ}$ | 17.075 | 17.112 | 17.150 | 17.187 | 17.224 | 17.262 | 17.300 | 17.337 | 17.375 | 17.413 |
| 186 | 17.450 | 17.488 | 17.526 | $17 \cdot 564$ | 17.602 | 17.641 | 17.679 | 17.717 | 17.756 | 17.794 |
| 187 | 17.832 | 17.87 I | 17.910 | 17.948 | 17.987 | 18.026 | 18.065 | 18.104 | 18.143 | 18.182 |
| 188 | 18.221 18.618 | 18.261 18.658 | 18.300 | 18.340 | 18.379 | 18.419 | 18.458 | 18.498 | 18.538 | 18.578 |
| 189 |  |  |  | 18.738 | 18.778 | 18.818 | 18.859 | 18.899 | 18.940 | 18.980 |
| 190 | 19.021 | 19.062 | 19.102 | 19.143 | 19.184 | 19.225 | 19.266 | 19.308 | 19.349 |  |
| 191 | 19.43 I | 19.473 | 19.514 | 19.556 | 19.598 | 19.639 | 19.681 | 19.723 | 19.765 | 19.807 |
| 192 | 19.849 | 19.892 | 19.934 | 19.976 | 20.019 | 20.061 | 20.104 | 20.146 | 20.189 | 20.232 |
| 193 | 20.275 | 20.318 | 20.361 | 20.404 | 20.447 | 20.490 | 20.533 | 20.577 | 20.620 | 20.664 |
| 194 | 20.707 | 20.75 I | 20.795 | 20.839 | 20.883 | 20.927 | 20.97 I | 21.015 | 21.059 | 21.103 |
| 195 | 21.148 | 21.192 | 21. 237 | 21.282 | 21.326 | 21.371 | 21.416 | 21.46r | 21.506 | 21.55I |
| 196 | 21.5971 | 21.642 | 21.687 | 21.733 | 21.778 | 21.824 | 21.870 | 21.915 | 21.961 | 22.007 |
| 197 | 22.053 | 22.099 | 22.145 | 22.192 | 22.238 | 22.284 | 22.331 | 22.377 | 22.424 | 22.47 I |
| 198 | 22.517 | 22.564 | 22.61 I | 22.658 | 22.706 | 22.752 | 22.800 | 22.847 | 22.895 | 22.942 |
| 199 | 22.990 | 23.038 | 23.085 | 23.133 | 23.181 | 23.229 | 23.277 | 23.325 | 23.374 | 23.422 |
| 200 | 23.470 | 23.519 | 23.568 | 23.616 | 23.665 | 23.714 | 23.763 | 23.812 | 23.861 | 23.910 |
| 201 | 23.959 | 24.009 | 24.058 | 24.108 | 24.157 | 24.207 | 24.257 | 24.307 | 24.357 | 24.407 |
| 202 | 24.457 | 24.507 | 24.557 | 2.608 | 24.658 | 24.709 | 24.759 | 24.810 | 24.861 | 24.912 |
| 203 | 24.963 25.478 | 25.014 25.530 | $\left\lvert\, \begin{aligned} & 25.065 \\ & 25.582\end{aligned}\right.$ | 25.116 25.634 | 25.168 25.686 | 25.219 25.738 | 25.271 | 25.322 | 25.374 | 25.426 |
| 04 | 25.478 | 25.530 | $25 \cdot 582$ | 25.634 | 25.686 | 25.738 | 25.791 | 25.843 | 25.896 | 25.948 |
| 205 206 | 26.001 26.534 | 26.054 26.587 | 26.107 <br> 26.641 | 26.160 26.695 | 26.213 | 26.266 | 26.319 | 26.373 | 26.426 | 26.480 |
| 206 | 26.534 27.075 | 26.587 | 27.18 | 26.695 27.239 | 26.749 27.294 | 26.803 | 26.857 | 26.912 | 26.966 | 27.021 |
| 208 | 27.626 | 27.681 | 27.184 27.737 | 27.2 |  | 27.349 27.904 | 27.404 27.060 | 27.460 28.016 | 27.515 | 27.570 |
| 209 | 28.185 | 28.242 | 28.298 | 28.355 | 28.412 | 28.469 | 28.526 | 28.583 | 28.640 | 28.697 |
| 210 | 28.754 | 28.812 | 28.869 | 28.927 | 28.985 | 29.042 | 29.100 | 29.158 | 29.216 |  |
| 211 | 29.333 | 29.391 | 29.450 | 29.508 | 29.567 | 29.626 | 29.685 | 29.744 | 29.803 | 29.862 |
| 212 | 29.92 30.51 | 29.98 I | 30.040 | 30.100 | 30.159 30.761 | 30.219 | 30.279 | 30.339 | 30.399 | 30.459 |

## DETERMINATION OF HEIGHTS BY THE BAROMETER.

> Formula of Babinet : $Z=C \frac{B_{0}-B}{B_{0}+B}$.
> $C$ (in feet) $=52494\left[\mathrm{I}+\frac{t_{0}+t-6_{4}}{900}\right]$ English measures.
> $C$ (in meters) $=16000\left[1+\frac{2\left(t_{0}+t\right)}{1000}\right]$ metric measures.

In which $Z=$ difference of height of two stations in feet or meters.
$B_{0}, B=$ barometric readings at the lower and upper stations respectively, corrected for all sources of instrumental error.
$t_{0}, t=$ air temperatures at the lower and upper stations respectively.
Values of $C$.

| English Measures. |  |  | Metric Measures. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{1}{2}\left(t_{0}+t\right)$. | C | $\log C$ | $\frac{1}{2}\left(t_{0}+t\right)$. | C | $\log C$ |
| Fahr. | Feet. |  | Cent. | Meters. |  |
| $10^{\circ}$ | 49928 | 4.69834 | $-10^{\circ}$ | 15360 | 4.I8639 |
| 15 | 50511 | . 70339 | -8 | I 5488 | . 19000 |
|  |  |  | -6 | I 5616 | . 19357 |
| 20 | 51094 | 4.70837 | -4 | I 5744 | . 19712 |
| 25 | 51677 | . 71330 | -2 | 15872 | . 20063 |
| 30 | 52261 | 4.71818 | 0 | 16000 | 4.20412 |
| 35 | 52844 | . 72300 | +2 | 16128 | . 20758 |
| 40 |  |  | 4 | 16256 16384 | . 211101 |
| 40 45 | 53428 54011 | 4.72777 .73248 | 8 | 16512 | . 21780 |
| 50 | 54595 | 4.737 I 5 | 10 | 16640 | 4.22115 |
| 55 | 55178 | .74177 | 12 | 16768 | . 22448 |
|  |  |  | 14 | 16896 | . 22778 |
| $60$ | 55761 | 4.74633 | 16 | 17024 | .23106 |
| 65 | 56344 | . 75085 | 18 | 17152 | .23431 |
| 70 | 56927 | 4.75532 | 20 | 17280 | 4.23754 |
| 75 | 5751 I | . 75975 | 22 | 17408 | . 2.4075 |
|  |  |  | 24 | 17536 | . 24393 |
| 80 85 | 58094 58677 | 4.76413 .76847 | 26 28 | 17664 17792 | .24709 .25022 |
| 5 | 50677 | -76847 | -8 | 17792 | . 2502 |
| 90 | 59260 | 4.77276 | 30 | 17920 | 4.25334 |
| 95 | 59844 | . 77702 | 32 | 18048 | . 25643 |
|  |  |  | 34 | 18176 | . 25950 |
| 100 | 60427 | 4.78123 | 36 | 18304 | . 26255 |

Values only approximate. Not good for great altitudes. A more accurate formula with corresponding tables may be found in Smithsonian Meteorological Tables.

## Smithsonian Tables.

## VELOCITY OF SOUND IN SOLIDS.

The velocity of sounds in solids varies as $\sqrt{E / \rho}$, where $E$ is Young's Modulus of elasticity and $\rho$ the density. These constants for most of the materials given in this table vary through a somewhat wide range, and hence the numbers can only be taken as rough approximations to the velocity which may be obtained in any particular case. When temperatures are not marked, between $10^{\circ}$ and $20^{\circ}$ is to be understood.

| Substance. | Temp. C. | Velocity in meters per second. | Velocity in feet per second. | Authority. |
| :---: | :---: | :---: | :---: | :---: |
|  | - |  |  | Masson. |
| Brass |  | 3500 | $11480$ | Various. |
| Cadmium . | - | 2307 | 7570 | Masson. <br> " |
| Cobalt . . . | - | 4724 | $\begin{array}{r} 15500 \\ 11670 \end{array}$ |  |
| Copper . . . | 20 | 3560 |  | Wertheim. |
| " | 100 | 3290 | 10800 |  |
| " ${ }^{\text {Gold (saft) }}$. | 200 | 2950 | 9690 |  |
| Gold (soft) . . | 20 | 1743 | $\begin{aligned} & 5717 \\ & 6890 \end{aligned}$ | Various. |
| Iron and soft steel | - | 5000 | 16410 |  |
| Iron . . . | 20 | 5130 | 16820 | Wertheim. |
| " | 100 | 5300 | 17390 |  |
| " . . . . | 200 | 4720 | 15480 | " |
| " cast steel | 20 | 4990 | 16360 | " |
| " " " | 200 | 4790 | 15710 | " |
| Lead. | 20 | 1227 | 4026 | " ${ }^{\text {c }}$ |
| Magnesium | - | 4602 | 15100 | Melde. |
| Nickel | - | 4973 | 16320 | Masson. |
| Palladium . | - | 3150 | 10340 | Various. |
| Platinum | 20 | 2690 | 8815 | Wertheim. |
| * | 100 | 2570 | 8437 |  |
| Silver | 200 20 | 2460 | 8079 | " |
| " | 100 | 2640 | 8553 8658 | " |
| Tin . | - | 2500 | 8200 | Various. |
| Zinc . | - | 3700 | 12140 |  |
| Various: Brick | - | 3652 | 11980 | Chladni. |
| Clay rock | - | 3480 | 11420 | Gray \& Milne. |
| Cork | - | 500 | 1640 | Stefan. |
| Granite Marble | - | 3950 | 12960 | Gray \& Milne. |
| Paraffin . |  | 3810 | 12500 |  |
| Plate | 15 | 1304 | 4280 14800 | Warburg. |
| Tallow . | 16 | 4510 | 14800 1280 | Gray \& Milne. Warburg. |
| Tuff . . . . . | - | 2850 | 9350 | Gray \& Milne. |
| Glass . . from | - | 5000 | 16410 | Various. |
| Ivory $\{$ to | - | 6000 | 19690 |  |
| Ivory ${ }^{\text {Vulcanized }}$ rubber ${ }^{\text {a }}$ | - | 3013 | 9886 | Ciccone \& Campanile. |
| (black) $\}$ | 50 | 54 | 177 | Exner. |
| "، " (red) . | $\bigcirc$ | 69 | 226 | " |
| " " " | 70 | 34 | 111 | " |
| Wax | 17 | 880 | 2890 | Stefan. |
| Woods: " ${ }^{\text {" }}$ - | 28 | 441 | 1450 |  |
| Woods: Ash, along the fibre . | - | 4670 | 15310 | Wertheim. |
| " across the rings | - | 1390 | 4570 | " |
| "* along the rings | - | 1260 | 4140 | " |
| Beech, along the fibre | - | 3340 | 10960 | " |
| " across the rings | - | 1840 | 6030 |  |
| " along the rings | - | 1415 | 4640 | " |
| Elm, along the fibre | - | 4120 | 13516 | " |
| " across the rings | - | 1420 | 4665 | " |
| Fir, along the rings | - | 1013 | 3324 | " |
| Fir, along the fibre . | - | 4640 | 15220 | " |
| Maple "، | - | 4110 | 13470 | " |
| Oak "، | - | 3850 | 12620 | " |
| Pine | - | 3320 | 10900 | " |
| Poplar " | - | 4280 | $14050$ | , |
| Sycamore '، | - | 4460 | 14640 |  |

## VELOCITY OF SOUND IN LIQUIDS AND GASES.

For gases, the velocity of sound $=V_{\gamma} \mathrm{P} / \rho$, where P is the pressure, $\rho$ the density, and $\gamma$ the ratio of specific heat at constant pressure to that at constant volume (see Table 253). For moderate temperature changes $V_{t}=V_{0}(I+a t)$ where $a=0.00367$. The velocity of sound in tubes increases with the diameter up to the free-air value as a limit. The values from ammonia to methane inclusive are for closed tubes.


The pitch relations between two notes may be expressed precisely (i) by the ratio of their vibration frequencies; (2) by the number of equally-tempered semitones between them (E. S.); also, less conveniently, (3) by the common logarithm of the ratio in (1); (4) by the lengths of the two portions of the tense string which will furnish the notes; and (5) in terms of the octave as unity. The ratio in (4) is the reciprocal of that in (1); the number for (5) is $1 / 12$ of that for (2); the number for (2) is nearly 40 times that for (3).

Table 130 gives data for the middle octave, including vibration frequencies for three standards of pitch: $\mathrm{A}_{3}=435$ double vibrations per second, is the international standard, and was adopted by the American Piano Manufacturers' Association. The "just-diatonic scale" of C-major is usually deduced, following Chladni, from the ratios of the three perfect major triads reduced to one octave, thus:


Other equivalent ratios and their values in E. S. are given in Table 131. By transferring $D$ to the left and using the ratio $10: 12: 15$ the scale of A-minor is obtained, which agrees with that of C-major except that $D=262 / 3$. Nearly the same ratios are obtained from a series of harmonics beginning with the eighth; also by taking 12 successive perfect or Pythagorean fifths or fourths and reducing to one octave. Such calculations are most easily made by adding and subtracting intervals expressed in E. S. The notes needed to furnish a just major scale in other keys may be found by successive transpositions by fifths or fourths as shown in Table 131. Disregarding the usually negligible difference of 0.02 E . S., the table gives the 24 notes to the octave required in the simplest enharmonic organ; the notes fall into pairs that differ by a comma, 0.22 E . S. The line " mean tone" is based on Dom Bedos', rule for tuning the organ (1746). The tables have been checked by the data in Ellis' Helmholtz's "Sensations of Tone."

TABLE 130.

| Note. | Interval. |  | Ratios. |  | Logarithms. |  | Number of double Vibrations per second. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Just. | Tem. pered. | Just. | Tem. pered. | Just. | Tempered. | Just. | Just. | Just. | Tem-pered- | Tempered. | Tempered. |
| $\mathrm{C}_{8}$ | E. S. | E. S. | 1.00 | 1.00000 1.05926 | . 0000 | $\begin{aligned} & .00000 \\ & .02509 \end{aligned}$ | 256 | 264 | 258.7 | 258.7 274.0 | 261.6 277.2 | 271.1 287.3 |
| $\mathrm{D}_{3}$ | 2.04 | 2 | 1.125 | 1. 12246 | . 05115 | . 05017 | 288 | 297 | 291.0 | 290.3 | 293.7 | $304 \cdot 3$ |
|  |  | 3 |  | 1.18921 1.25992 |  | .07526 .10034 |  |  |  | 307.6 325.9 | 311.1 329.6 | 322.4 341.6 |
| $\mathrm{F}_{3}$ | 3.86 4.98 | 4 | 1.25 1.33 | 1.25992 1.33484 | .09691 .12494 | .10034 .12543 | 320 341 | 330 352 | 323.4 344.9 | $325 \cdot 9$ $345 \cdot 3$ | 329.6 349.2 | 341.6 361.9 |
|  |  | 6 |  | 1.41421 |  | . 15051 |  |  |  | 365.8 | 370.0 | 383.4 |
| $\mathrm{G}_{8}$ | 7.02 | 7 | 1. 50 | 1.49831 | . 17609 | . 17560 | 384 | 396 | 388 | 387.5 | 392.0 | 406.2 |
|  |  | 8 |  | 1.58740 |  | 20069 |  |  |  | 410.6 | 415.3 | 430.4 |
| $\mathrm{A}_{3}$ | 8.84 | 9 | 1.67 | 1.68179 | .22185 | . 22577 | 426.7 | 440 | 431.1 | 435.0 | 440.0 | 456.0 |
|  |  | 10 |  | 1.78180 1.88775 |  | .25086 .27594 |  |  |  | 460.9 488.3 | 446.2 | 483.1 |
| $\mathrm{C}_{3}$ | 10.88 12.00 | 112 | 1.875 2.00 | 1.88775 2.00000 | .27300 .30103 | . 27594 | 480 512 | 495 528 | 485.0 517.3 | $488 \cdot 3$ $517 \cdot 3$ | 493.9 523.2 | 511.8 542.3 |

TABLE 131.


TABLE 132. - A Fundamental Tone, Its Harmonics (Overtones) and the Nearest Tone of the Equal-tempered Scale.


Note. - Overtones of frequencies not exact multiples of the fundamental are sometimes called inharmonic partials.

## TABLE 133. - Relative Strength of the Partials in Various Musical Instruments.

The values given are for tones of medium loudness. Individual tones vary greatly in quality and, therefore, in loudness.

| Instrument. | Strength of partials in per cent of total tone strength. |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | II | 12 |
| Tuning fork on box.. | 100 | - | - |  | - | - | - | - | - | - | - | - |
| Flute. . . . . . . . . . . | 66 | 24 | 4 | 6 | - | - | - | - | - | - | - | - |
| Violin, A string . . . . | 26 | 25 | 9 | 10 | 27 | I | $\bigcirc$ | 2 | - | - | - | - |
| Oboe. . . . . . . . . . . | 2 | 2 | 4 | 29 | 35 | 14 | 4 | 2 | 3 | 4 | 1 | 0 |
| Clarinet. . . . . . . . . | 12 | - | 10 | 3 | 5 | - | 8 | 18 | 15 | 18 | 5 | 6 |
| Horn. . . . . . . . . . . | 36 | 26 | 17 | 7 | 4 | 3 | 2 | 1 | 1 | 1 | 1 | 1 |
| Trombone......... | 6 | II | 35 | 12 | 8 | II | 6 | 4 | 3 | 2 | 1 | 1 |

## TABLE 134. - Characteristics of the Vowels.

The larynx generates a fundamental tone of a chosen pitch with some 20 partials, usually of low intensity. The particular partial, or partials, most nearly in unison with the mouth cavity is greatly strengthened by resonance. Each vowel, for a given mouth, is characterized by a particular fixed pitch, or pitches, of resonance corresponding to that vowel's definite form of mouth cavity. These pitches may be judged by whispering the vowels. It is difficult to sing vowels true above the corresponding pitches. The greater part of the energy or loudness of a vowel of a chosen pitch is in those partials reinforced by resonance. The vowels may be divided into two classes, - the first having one characteristic resonance region, the second, two. The representative pitches of maximum resonance of a mouth cavity for selected vowels in each group are given in the following table.


## TABLE 135.- Miscellaneous Sound Data.

Koenig's temperature coefficient for the frequency ( $n$ ) of forks is nearly the same for all pitches. $n_{t}=$ $n_{0}\left(\mathrm{I}-0.00011 t^{\circ} \mathrm{C}\right)$, Ann. d. Phys. 9, p. 408 , 1880 .

Vibration frequencies for continuous sound sensations are practically the same as for continuous light sensation, 10 or more per second. Helmholtz' value of 32 per sec. may be taken as the flicker value for the ear. Moving pictures use 16 or more per sec. For light the number varies with the intensity.

Pitch limits of voice: 60 to 1200 vibrations per second.
Piano pitch limits: 27.2 to 4138.4 v . per sec. (over 7 octaves).
Organ pitch limits: 16 ( 32 ft . pipe), sometimes 8 ( 64 ft .) to 4 I 38 ( $\mathrm{r} \frac{1}{2} \mathrm{in}$.) ( 9 octaves).
Ear can detect frequencies of 20,000 to $30,000 \mathrm{v}$. per sec. Koenig, by means of dust figures, measured sounds from steel forks with frequencies up to 00,000 .

The quality of a musical tone depends solely on the number and relative strength of its partials (simple tones) and probably not at all on their phases.

The wave-lengths of sound issuing from a closed pipe of length $L$ are $4 L, 4 L / 3,4 L / 5$, etc., and from an open pipe, $2 L, 2 L / 2,2 L / 3$, etc. The end correction for a pipe with a flange is such that the antinode is $0.82 \times$ radius of pipe beyond the end; with no flange the correction is $0.57 \times$ radius of pipe.

The energy of a pure sine wave is proportional to $n^{2} A^{2}$; the energy per $\mathrm{cm}^{3}$ is on the average $2 \rho \pi^{2} U^{2} A^{2} / \lambda^{2}$; the energy passing per sec. through $\mathrm{I} \mathrm{cm}^{2}$ perpendicular to direction of propagation is $2 \rho \pi^{2} U^{3} A^{2} / \lambda^{2}$; the pressure is $\frac{1}{2}(\gamma+\mathrm{r})$ (average energy per $\mathrm{cm}^{3}$ ); where $n$ is the vibration number per sec., $\lambda$ the wave-length, $A$ the amplitude, $V$ the velocity of sound, $\rho$ the density of the medium, $\gamma$ the specific heat ratio. Altberg (Ann. d. Phys. II, p. 405, 1903) measured sound-wave pressures of the order of 0.24 dynes $/ \mathrm{cm}^{2}=0.00018 \mathrm{~mm} \mathrm{Hg}$.

## Kinetics of Bodies in Resisting Medium.

The differential equation of a body falling in a resisting medium is $d u / d t=g-k u^{2}$. The velocity tends asymptotically to a certain terminal velocity, $V=\sqrt{g / k}$. Integration gives $u=$ $V \cdot \tanh (g t / V), x=\frac{V^{2}}{g} \log \cosh \left(g t / V^{\prime}\right)$ if $u=x=t=0$.
When body is projected upwards, $d u / d t=-g-k u^{2}$, and if $u_{0}$ is velocity of projection, then $\tan ^{-1} u / V=\tan ^{-1}\left(u_{0} / V\right)-g t / V, x=\left(V^{2} / 2 g\right) \log \left(V^{2}+u_{0}^{2}\right)\left(V^{2}+u^{2}\right)$. The particle comes to rest when $t=(V / g) \tan ^{-1}\left(u_{0} / V\right)$ and $x=\left(V^{2} / 2 g\right) \log \left(\mathrm{I}-u_{0}{ }^{2} / V^{2}\right)$.

For small velocities the resistance is more nearly proportional to the velocity.
Stokes' Law for the rate of fall of a spherical drop of radius $a$ under gravity $g$ gives for the velocity, $v$,

$$
v=\frac{2 g a^{2}}{9 \eta}(\sigma-\rho),
$$

where $\sigma$ and $\rho$ are the densities of the drop and the medium, $\eta$ the viscosity of the medium. This depends on five assumptions: (1) that the sphere is large compared to the inhomogeneities of the medium; (2) that it falls as in a medium of unlimited extent; (3) that it is smooth and rigid; (4) that there is no slipping of the medium over its surface; (5) that its velocity is so small that the resistance is all due to the viscosity of the medium and not to the inertia of the latter. Because of 5 , the law does not hold unless the radius of the sphere is small compared with $\eta / v \rho$ (critical radius). Arnold showed that $a$ must be less than 0.6 this radius.

If the medium is contained in a circular cylinder of radius $R$ and length $L$, Ladenburg showed that the following formula is applicable (Ann. d. Phys. 22, 287, 1907, 23, 447, 1908):

$$
V=\frac{2}{9} \frac{g a^{2}(\sigma}{\eta(\mathrm{I}+2 \cdot 4 a / R)} \frac{-\rho)}{(\mathrm{I}+3 \cdot \mathrm{I} a / L)}
$$

As the spheres diminish in size the medium behaves as if inhomogeneous because of its molecular structure, and the velocity becomes a function of $l / a$, where $l$ is the mean free path of the molecules. Stokes' formula should then be modified by the addition of a factor, viz.:

$$
v_{1}=\frac{2}{9} \frac{g a^{2}}{\eta}(\sigma-\rho)\left\{1+\left(0.864+0.29 e^{-1.25(a / l))} \frac{l}{a}\right\}\right.
$$

(See chapter V, Millikan, The Electron, 1917 ; also Physical Review 15, p. 545, 1920.)

## TABLE 137. - Flow of Gases through Tubes.*

When the dimensions of a tube are comparable with the mean free path $(L)$ of the molecules of a gas, Knudsen (Ann. der Phys. 28, 75, 199, 1908) derives the following equation correct to $5 \%$ even when $D / L=0.4: Q$, the quantity of gas in terms of $P V$ which flows in a second through a tube of diameter $D$, length $l$, connecting two vessels at low pressure, difference of pressure $P_{2}-P_{1}$, equals $\left(P_{2}-P_{1}\right) / W \sqrt{\rho}$ where $\rho$ is the density of the gas at one bar ( 1 dyne $/ \mathrm{cm}^{2}$ ) $=(\mathrm{mo}-$ lecular weight $) /\left(83.15 \times 10^{6} 7\right)$ and $W$; which is of the nature of a resistance, $=2.3941 / / D^{3}+$ 3.184/ $D^{2}$. The following table gives the $\mathrm{cm}^{3}$ of air and $H$ at a bar which would flow through different sized tubes, difference of pressure I bar, room temperature.

| $l=1 \mathrm{~cm}$. | $D=1 \mathrm{~cm}$. | $W=5.58$ | $Q, \mathrm{~cm}^{3}$ of air, 5200. | $\mathrm{cm}^{8}$ of $H_{2}, 19700$. |
| :---: | :---: | :---: | :---: | :---: |
| 10 | 1 | 27.1 | 1070. | 4050. |
| 1 | 0.1 | 2710. | 10.7 | 40.5 |
| 10 | 0.1 | 24300. | 1.20 | 3.60 |

Knudsen derives the following equation, equivalent to Poiseuille's at higher, and to the above at lower pressures:
$Q=\left(P_{2}-P_{1}\right)\left\{a P+b\left(1+c_{1} P\right) /\left(1+c_{2} P\right)\right\}$ where $a=\pi D^{4} / \mathbf{1} 28 \eta l$ (Poiseuille's constant) $; b=$ $1 / W \sqrt{\rho} \bar{\rho}$, (coefficient of molecular flow); $c_{1}=\sqrt{\rho} D / \eta ;$ and $c_{2}=1.24 \sqrt{\bar{\rho}} D / \eta ; \eta=$ viscosity coefficient. The following are the volumes in $\mathrm{cm}^{3}$ at i bar, $20^{\circ} \mathrm{C}$, that flow through tube, $D=1 \mathrm{~cm}$, $l=10 \mathrm{~cm}, P_{2}-P_{1}=1$ bar, average pressure of $P$ bars:

$$
\begin{array}{cccccc}
P=10.6 & Q=13,000,000 . & P=5 . & Q=1026 . & P=1 . & Q=1044 . \mathrm{cm}^{8} \\
100 . & 2,227 . & 4 . & 1024 . & 0.1 & 1065 . \\
10 . & 1,058 . & 3 . & 1025 . & 0.01 & 1070 .
\end{array}
$$

When the velocity of flow is below a critical value, $F$ (density, viscosity, diameter of tube), the stream lines are parallel to the axis of the tube. Above this critical velocity, $V_{\mathrm{o}}$, the flow is turbulent. $V_{0}=\mathrm{k} \eta$ pr for small pipes up to about 5 cm diameter, wherc $K$ is a constant, and $r$ the tube radius. When these are in cgs units, $k$ is $10^{3}$ in round numbers. Below $V_{\mathrm{c}}$ the pressure drop along the tube is proportional to the velocity of gas flow; above it to the square of the velocity.

[^21]TAbles 138-139.

## AERODYNAMICS.

TABLE 138. - Air Pressures upon Large Square Normal Planes at Different Speeds through the Air.

The resistance $F$ of a body of fixed shape and presentation moving through a fluid may be written

$$
F=\rho L^{2} V^{2} f(L V / \nu)
$$

in which $\rho$ denotes the fluid density, $\nu$ the kinematic viscosity, $L$ a linear dimension of the body, $V$ the speed of translation. In general $f$ is not constant, even for constant conditions of the fluid, but is practically so for normal impact on a plane of fixed size. In the following, $\rho$ is taken as $1.230 \mathrm{~g} / \mathrm{l}\left(.0768 \mathrm{lbs} . / \mathrm{ft}^{3}\right)$.

The mean pressure on thin square plates of I.I $\mathrm{m}^{2}$ (I2 $\mathrm{ft}^{2}$ ), or over, moving normally through air of standard density at ordinary transportation speeds may be written $P=.0060 v^{2}$ for $P$ in kg per $\mathrm{m}^{2}$ and $v$ in km per hour, or $P=.0032 v^{2}$ for $P$ in lbs. per $\mathrm{ft}^{2}$ and $v$ in miles per hour. The following values are computed from this formula. For smaller areas the correction factors as given in the succeeding table (Table 139) derived from experiments made at the British National Physical Laboratory, may be applied.

Units: the first of each group of three columns gives the velocity; the second, the corresponding pressure in $\mathrm{kg} / \mathrm{m}^{2}$ when the first column is taken as km per hour; the third in $\mathrm{pds} / \mathrm{ft}{ }^{2}$ when in miles per hour.

| Velocity. | Pressure. |  | Velocity. | Pressure. |  | Velocity. | Pressure. |  | Velocity. | Pressure. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Metric. | English. |  | Metric. | English. |  | Metric. | English. |  | Metric. | English. |
| 10 | 0.60 | 0.32 | 40 | 9.60 | 5.12 | 70 | 29.4 | 15.7 | 100 | 60.0 | 32.0 |
| 15 | 0.73 | 0.39 | 4 I | 10.09 | 5.38 | 71 | 30.2 | ${ }^{16.1}$ | IOI | 6 I .2 | 32.6 |
| 12 | 0.86 | 0.46 | 42 | 10.58 | 5.64 | 72 | 31.1 | 16.6 | 102 | 62.4 | 33.3 |
| 13 | 1.01 | -. 54 | 43 | 11.09 | 5.92 | 73 | 32.0 | 17.0 | 103 | 63.7 | 33.9 |
| 14 | 1. 18 | 0.63 | 44 | 11.6 | 6.20 | 74 | 32.8 | 17.5 | 104 | 64.9 | 34.6 |
| 15 | 1.35 | 0.72 | 45 | 12.1 | 6.48 | 75 | 33.7 | 18.0 | 105 | 66.1 | 35.3 |
| 16 | I. 54 | 0.82 | 46 | 12.7 | 6.77 | 76 | 34.7 | 18.5 | 106 | 67.4 | 36.0 |
| 17 | $\underline{1.73}$ | 0.92 | 47 | 13.3 | 7.07 | 77 | 35.6 | 19.0 | 107 | 68.7 | 36.6 |
| 18 | 1.94 | 1.04 | 48 | 13.8 | 7.37 | 78 | 36.5 | 19.5 | 108 | 70.0 | 37.2 |
| 19 | 2.17 | 1.16 | 49 | 14.4 | 7.68 | 79 | 37.4 | 20.0 | 109 | 71.3 | 38.0 |
| 20 | 2.40 | I. 28 | 50 | 15.0 | 8.00 | 80 | 38.4 | 20.5 | 110 | 72.6 | 38.7 |
| 21 | 2.65 | I. 41 | 51 | 15.6 | 8.32 | 8 I | 39.4 | 21.0 | III | 73.9 | 39.4 |
| 22 | 2.90 | I. 55 | 52 | 16.2 | 8.65 | 82 | 40.3 | 21.5 | 112 | 75.3 | 40.1 |
| 23 | 3.17 | 1. 69 | 53 | 16.9 | 8.99 | 83 | $4 \mathrm{4} \cdot 3$ | 22.0 | I13 | 76.6 | 40.9 |
| 24 | 3.46 | 1.84 | 54 | 17.5 | 9.33 | 84 | 42.3 | 22.6 | 114 | 78.0 | 41.6 |
| 25 | 3.75 4.06 | 2.00 | 55 | 18.1 | 9.68 |  | 43.3 | 23.1 | 115 | 79.3 | 42.3 |
| 26 | 4.06 | 2.16 | 56 | 18.8 | 10.04 | 86 | 44.4 | 23.7 | 116 | 80.8 | 43.1 |
| 27 | 4.37 | 2.33 | 57 | 19.5 | 10.40 | 87 | 45.4 | 24.2 | 117 | 82.1 | 43.7 |
| 28 | 4.70 | 2.51 | 58 | 20.2 | 10. 76 | 88 | 46.4 | 24.8 | 118 | 83.5 | 44.6 |
| 29 | 5.05 | 2.69 | 59 | 20.9 | II. 14 | 89 | 47.5 | 25.4 | 119 | 84.9 | 45.3 |
| 30 | 5.40 | 2.88 | 60 | 21.6 | 11.52 | 90 | 48.6 | 25.9 | 120 | 86.4 | 46.1 |
| 31 | 5.77 | 3.08 | 61 | 22.3 | 11.91 | 9 I | 49.7 | 26.5 | 121 | 87.8 | 46.8 |
| 32 | 6.14 | 3.28 | ${ }_{6}^{62}$ | 23.0 | 12.3 | 92 | 50.8 | 27.1 | 122 | 89.3 | 47.6 |
| 33 | 6.54 | 3.48 | 63 | 23.8 | 12.7 | 93 | 51.9 | 27.7 | 123 | 90.8 | 48.4 |
| 34 | 6.93 | 3.70 | 64 | 24.6 | 13.1 | 94 | 53.0 | 28.3 | 124 | 92.2 | 49.2 |
| 35 36 | 7.35 | 3.92 4.15 | 65 | 25.4 26.2 | 13.5 13.9 | 95 96 | 54.2 | 28.9 | 125 | 93.7 | 50.0 50.8 |
| 36 | 7.74 | 4.15 | 66 | 26.2 | 13.9 | 96 | 55.3 | 29.5 | 126 | 95.3 | 50.8 |
| 37 38 | 8.22 8.66 | 4.38 4.62 | 67 68 | 26.9 27.7 | 14.4 <br> 14.8 <br> 1.8 | 97 98 | 56.5 57.6 | 30.7 30.7 3.7 | 127 128 | 96.8 98.4 | 51.6 52.5 |
| 39 | 9.12 | 4.87 | 69 | 28.6 | I5.2 | 99 | 58.8 | 31.7 31.4 | 128 129 | 98.4 98.7 | 52.5 53.2 |

TABLE 139. - Correction Factor for Small Square Normal Planes.
The values of Table 138 are to be multiplied by the following factors when the area of the surface is less than about $1 \mathrm{~m}^{2}$ ( $\mathrm{I} 2 \mathrm{ft}^{2}$ ).

| Metric. |  |  |  | English. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Area. m ${ }^{2}$ | Factor. | Area. m² | Factor. | Area. ft ${ }^{2}$ | Factor. | Area. $\mathrm{ft}^{2}$ | Factor |
| 0.03 | 0.845 | 5.0 | 0.969 | 0.03 | 0.842 | 5.0 | 0. 968 |
| 0.10 | 0.859 | 6.0 | 0.975 | -. 10 | 0.857 | 6.0 | 0.973 |
| 0.50 | 0.884 | 7.0 | 0.979 | 0.50 | 0.884 | 7.0 | 0.977 |
| 0.75 | -. 890 | 8.0 | 0.984 | 0.75 | 0.889 | 8.0 | 0.981 |
| 1. 00 | 0.898 | 9.0 | 0.989 | $1 . \infty$ | 0.896 | 9.0 | 0.986 |
| 2.00 | 0.919 | 10.0 | 0.993 | 2.00 | 0.917 | 10.0 | -. 990 |
| 3.00 | 0.933 | 11.0 | 0.999 | 3.00 | 0.930 | 11.0 | -0.994 |
| $4 . \infty$ | 0.950 | 12.0 | 1.000 | 4.00 | 0.943 | 12.0 | 1.000 |

Smithsonian Tables.

TABLE 140. - Effect of Aspect Ratio upon Normal Plane Pressure (Eiffel).
The mean pressure on a rectangular plane varies with the "aspect ratio," a name introduced by Langley to denote the ratio of the length of the leading edge to the chord length. The effect of aspect ratio on normally moving rectangular plates is given in the following table, derived from Eiffel's experiments.


TABLE 141. - Ratio of Pressures on Inclined and Normal Planes.
The pressure on a slightly inclined plane is proportional to the angle of incidence $a$, and is given by the formula $P_{a}=c \cdot P_{90} \cdot a$. The value of $c$, which is constant for incidences up to about $12^{\circ}$, is given for various aspect ratios. The angle of incidence is taken in degrees.


## TABLE 142. - Skin Friction.

The skin friction on an even rectangular plate moving edgewise through ordinary air is given by Zahm's equation,

$$
\begin{aligned}
& F\left(\mathrm{~kg} / \mathrm{m}^{2}\right)=0.00030\left\{A\left(\mathrm{~m}^{2}\right)\right\}^{0.93}\{V(\mathrm{~km} / \mathrm{hr})\}^{1.86} \mathrm{in} \text { metric units } \\
& F\left(\mathrm{pds} . / \mathrm{ft}{ }^{2}\right)=0.0000082\left\{A\left(\mathrm{ft}{ }^{2}\right)\right\}^{0.93}\{V(\mathrm{ft} . / \mathrm{sec} .)\}^{1.86},
\end{aligned}
$$

where $A$ is the surface area and $V$ the speed of the plane. The following table gives the friction per unit area on one side of a plate.

| Speed. | Skin friction. Kg per sq. m. Plane. |  | Speed. |  | Skin friction. Lbs. per sq. ft. Plane. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{km} / \mathrm{hr}$. | I m long. | 32 m long. | miles/hr. | ft . $/ \mathrm{sec}$. | ff . long. | 32 ft . long. |
| 5 | 0.0059 | 0.0047 | 5 | $7 \cdot 3$ | 0.00033 | 0.00026 |
| 10 | 0.0217 | 0.0171 | 10 | 14.7 | 0.0012 I | 0.00095 |
| 15 | 0.0464 | 0.0364 | 15 | 22.0 | 0.00258 | 0.00202 |
| 20 | 0.079 | 0.062 | 20 | 29.3 | 0.00439 | 0.00345 |
| 25 | O. 122 | 0.095 | 25 | 36.7 | 0.0068 | 0.00530 |
| 30 | -. 169 | -. 133 | 30 | 44.0 | 0.0094 | 0.0074 |
| 40 | -. 288 | 0.225 | 40 | 58.7 | 0.0160 | 0.0125 |
| 50 | 0.439 | 0.346 | 50 | $73 \cdot 3$ | 0.0244 | 0.0192 |
| 60 | 0.616 | 0.482 | 60 | 88.0 | 0.0342 | 0.0268 |
| 70 | 0.82 | 0.64 | 70 | 102.7 | 0.0455 | 0.0357 |
| 80 | I. 06 | 0.83 | 80 | 117.3 | 0.0587 | 0.0461 |
| 90 | 1. 31 | 1.03 | 90 | 132.0 | 0.073 | 0.0572 |
| 100 | I. 58 | I. 24 | 100 | 146.7 | 0.088 | 0.069 |
| 110 | I. 89 | I. 49 | 110 | 161.2 | 0.105 | 0.083 |
| 120 | 2.20 | I. 73 | 120 | 175.8 | 0. 122 | 0.096 |
| 125 | 2.39 | 1.87 | 125 | 183.4 | -. 133 | -. 104 |
| 130 | 2.56 | 2.01 | 130 | 190.5 | -. 142 | O. 112 |
| 135 | 2.68 | 2.10 | 135 | 197.8 | -. 149 | -. 117 |
| 140 | 2.94 | 2.31 | 140 | 205.4 | -. 164 | -. 128 |
| 145 | 3.15 | 2.47 | 145 | 212.5 | -. 175 | -. 137 |
| 150 | $3 \cdot 37$ | 2.65 | 150 | 220.0 | -. 188 | -. 147 |

## Tables 143-145.

 AERODYNAMICS.The following tables, based on Eiffel, show the variation of the resistance coefficient $K$, with the angle of impact $i$, the aspect (ratio of leading edge to chord length), shape and velocity $V$ in the formula

$$
R\left(\mathrm{~kg} / \mathrm{m}^{2}\right)=K S\left(\mathrm{~m}^{2}\right)\{V(\mathrm{~m} / \mathrm{sec} .)\}^{2}
$$

The value of $K$ for $\mathrm{km} /$ hour would be 0.77 times greater.
TABLE 143. - Variation of Air Resistance with Aspect and Angle.

| Size of plane. | Aspect. | Values of $i$. |  |  |  |  |  |  |  | Max. ratio. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $6^{\circ}$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $45^{\circ}$ | $60^{\circ}$ | $75^{\circ}$ | Value. | $i$. |
|  |  | Values of $K i / K_{90}$. |  |  |  |  |  |  |  |  |  |
| $15 \times 90 \mathrm{~cm}$. | $\frac{1}{6}$ | . 07 | . 13 | . 40 | 0.67 | 0.92 | 1.08 | 1.07 | 1. 03 | 1.07 | 60 |
| $15 \times 45 \mathrm{~cm}$. | $\frac{1}{3}$ | . II | . 21 | . 51 | -. 89 | 1. 20 | 1.22 | 1.06 | 1.02 | 1.22 | 45 |
| $25 \times 25 \mathrm{~cm}$.. | 1 | . 20 | . 36 | . 80 | I. 24 | I. 17 | 1.08 | 1.03 | 1.02 | 1. 46 | 38 |
| $30 \times 15 \mathrm{~cm}$. | 2 | . 26 | . 43 | . 91 | 0.72 | 0.79 | 0.82 | 0.90 | 0.97 | 0.91 | 20 |
| $45 \times 15 \mathrm{~cm}$.. | 3 | . 31 | . 50 | . 77 | 0.77 | 0.84 | 0.88 | 0.94 | 0.99 | 0.77 | 20 |
| $90 \times 15 \mathrm{~cm}$. | 6 | . 37 | . 58 | . 70 | 0.78 | 0.84 | 0.88 | 0.93 | 0.98 | 0.69 | 15 |
| $90 \times 10 \mathrm{~cm}$. | 9 | . 45 | . 62 | . 73 | 0.80 | 0.85 | 0.88 | 0.94 | 0.99 |  | - |

TABLE 144. - Variation of Air Resistance with Shape and Size.

Cylinder, base $\perp$ to wind:
Diameter of base, 30 cm
Diameter of base, 15 cm

| Length. | 0 cm | $1 R^{*}$ | $2 R^{*}$ | $4 R^{*}$ | $6 R^{*}$ | $8 R^{*}$ | $14 R^{*}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $K=$ | .0675 | .068 | .055 | .050 | - | - | - |
| $K=$ | .066 | .066 | .055 | .051 | .051 | .0515 | .059 |

Cylinder, base || to wind: diameter base, 15 cm , length, $60 \mathrm{~cm} \mathrm{~K}=.040^{\circ}$ Cylinder, base |l to wind: diameter base, 3 cm , length, $100 \mathrm{~cm} K=.060$ Cone, angle $60^{\circ}$, diam. base, 40 cm , point to wind, solid
$K=.032$ Cone, angle $30^{\circ}$, diam. base, 40 cm , point to wind, solid
$K=.021$ Sphere, 25 cm diam.
Hemisphere, same diam., convex to wind
Hemisphere, same diam., concave to wind
$K=.011$

Sphero-conic body, diam, 20 cm , cone $20^{\circ}$ point forward Sphero-conic body, diam., 20 cm , cone $20^{\circ}$, point to rear Cylinder, 120 cm long, spherical ends to wind
$K=.021$

The wind velocity for the values of this table was $10 \mathrm{~m} / \mathrm{sec}$.
Tables I43 and I44 were taken from "The Resistance of the Air and Aviation," Eiffel, translated by Hunsaker, igrz.

* In the case of these cylinders the percentages due to skin friction are $2,3,6,8$, ri and 16 per cent respectively, excluding the disk.


## TABLE 145. - Variation of Air Resistance with Shape, Size and Speed.

This table shows the peculiar drop in air resistance for speeds greater than 4 to 12 meters per second. Another change occurs when the velocity approaches that of sound.

| Shape. |  | Values of $K$. |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Shape. | Speed, m/sec. | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 20 | 32 |
| Sphere, 16.2 cm diameter |  | 33 | 030 | . 028 | . 027 | . 02 | . 009 | 0095 | 010 | OII |
| Sphere, 24.4 cm diameter |  | . 025 | . 025 | . 021 | . 013 | . 010 | . 10 | . 010 | . 010 | . 010 |
| Sphere, 33 cm diameter . . |  | . 023 | . 017 | . 012 | . 010 | . 010 | . 010 | . OII | . 012 | . 012 |
| Concave cup, 25 cm dia |  | . 090 | . 090 | . 089 | . 087 | . 087 | . 088 | . 089 | . 095 | . 100 |
| Convex cup, 25 cm diam |  | . 027 | . 022 | . 021 | . 022 | . 022 | . 021 | . 020 | . 019 | . 018 |
| Disk, 25 cm diameter ........... |  | .071 | . 070 | . 070 | . 070 | . 070 | . 070 | . 070 | . 070 | . 068 |
| Cylinderelementto wind, $d=15 \mathrm{~cm}, l=15.0$ |  | . 043 | . 042 | . 037 | . 030 | . 025 | . 022 | 02 | . 022 | . 022 |
| element $\frac{1}{\text { to wind, }} 30$ l 30.0 |  | . $0+45$ | . 032 | . 027 | . 023 | . 024 | . 025 | . 025 | . 025 | . 023 |
| element $\perp$ to wind, $\quad 15$ |  | . 035 | . 034 | . 032 | . 031 | . 031 | . 031 | . 030 | .030 | . 030 |
| element $\perp$ to wind, 15 I 52.0 |  | . 038 | . 037 | . 036 | . 032 | . 030 | . 028 | . 027 | . 025 | . 025 |
| element $\perp$ to wind, element \|| to wind, | 522.5 | . 042 | . 041 | . 038 | . 034 | . 031 | . 028 | . 025 | . 022 | . 020 |
|  | 105.0 | . 069 | . 061 | . 057 | . 055 | . 053 | .052 | .051 | .051 | . 050 |
| Spherical ends, | 20.0 | . 024 | . 022 | . 019 | . 018 | . 018 | . 018 | . 017 | . 016 | . 015 |

Taken from "Nouvelles Recherches sur la résistance de l'air et l'aviation," Eiffel, 1914.
Smithsonian Tables.

The required force $F$ necessary to just move an object along a horizontal plane $=f N$ where $N$ is the normal pressure on the plane and $f$ the "coefficient of friction." The angle of repose $\Phi(\tan \Phi=F / N)$ is the angle at which the plane must be tilted before the object will move from its own weight. The following table of coefficients was compiled by Rankine from the results of General Morin and other authorities and is sufficient for ordinary purposes.

| Material. |  |  |  |  |  | $f$ | $1 / f$ | $\phi$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | .25-.50 | 4.00-2.00 | 14.0-26.5 |
|  |  |  |  |  |  | .20 $.50-.60$ | $\stackrel{5.00}{2.00-1.67}$ | 11.5 $26.5-31.0$ |
|  |  |  |  |  |  | .24-. 26 | 4.17-3.85 | $13.5-14$ |
|  |  |  |  |  |  | . 20 | 5.00 | II. 5 |
|  |  |  |  |  |  | .20-. 25 | 5.00-4.00 | I 1.5-14.0 |
|  |  |  |  |  |  | . 53 | 1. 89 | 28.0 |
|  |  |  |  |  |  | . 33 | 3.00 | 18.5 |
|  |  |  |  |  |  | .27-.38 | 3.70-2.86 | 1 5.0-19.5 |
|  |  |  |  |  |  | . 56 | $\begin{array}{r}1.79 \\ \hline 2.78\end{array}$ | 29.5 |
|  |  |  |  |  |  | - 36 | 2.78 | 20.0 |
|  |  |  |  |  |  | .23 | $4 \cdot 35$ | 13.0 |
|  |  |  |  |  |  | . 15 | 6.67 | 8.5 |
|  |  |  |  |  |  | .15-.20 | $6.67-5.00$ 3.33 | 8.5-11.5 |
|  |  |  |  |  |  | $\stackrel{.3}{.0} 7^{-.08}$ | $3 \cdot 33$ $14.3-12.50$ | 16.5 $4.0-4.5$ |
|  |  |  |  |  |  | . 05 | $14.3-12.50$ 20.00 | $4.0-4.5$ 3.0 |
|  |  |  |  |  |  | .03-.036 | 33.3-27.6 | 1.75-2.0 |
|  |  |  |  |  |  | . 20 | 5.00 | 11.5 |
|  |  |  |  |  |  | . 107 | 9.35 | 6.1 |
|  |  |  |  |  |  | .30-.70 | 3.33-1.43 | 16.7-35.0 |
|  |  |  |  |  |  | About 40 | 2.50 | 22.0 |
|  |  |  |  |  |  | $.60-.70$ .74 | 1. $67-1.43$ 1.35 | 33.0-35.0 |
|  |  |  |  |  |  | . 51 | 1.35 1.96 | 36.5 27.0 |
|  |  |  |  |  |  | .33 | 3.00 | 18.25 |
|  |  |  |  |  |  | .25-1.00 | 4.00-1.00 | 14.0-45.0 |
|  |  |  |  |  |  | . $3^{8-.} 75$ | 2.63-1. 33 | 21.0-37.0 |
|  |  |  |  |  |  | 1.00 | 1.00 | 45.0 |
|  |  |  |  |  |  | . 31 | 3.23 | 17.0 |
|  |  |  |  |  |  | .81-I.11 | 1.23-0.9 | $39.0-48.0$ |

[^22]
## TABLE 147. - Lubricants.

The best lubricants are in general the following: Low temperatures, light mineral lubricating oils. Very great pressures, slow speeds, graphite, soapstone and other solid lubricants. Heavy pressures, slow speeds, ditto and lard, tallow and other greases. Heavy pressures and high speeds, sperm oil, castor oil, heavy mineral oils. Light pressures, high speeds, sperm, refined petroleum olive, rape, cottonseed. Ordinary machinery, lard oil, tallow oil, heavy mineral oils and the heavier vegetable oils. Steam cylinders, heavy mineral oils, lard, tallow. Watches and delicate mechanisms, clarified sperm, neat's-foot, porpoise, olive and light mineral lubricating oils.

TABLE 148. - Lubricants For Cutting Tools.

| Material. | Turning. | Chucking. | Drilling. | Tapping Milling | Reaming. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Tool Steel, Soft Steel, Wrought iron Cast iron, brass Copper Glass | dry or oil <br> dry or soda water <br> dry or soda water <br> dry <br> dry <br> turpentine or kerosene | oil or s. w. soda water soda water dry dry | oil <br> oil or s. w. <br> oil or s. w. <br> dry <br> dry | $\begin{aligned} & \text { oil } \\ & \text { oil } \\ & \text { oil } \\ & \text { dry } \\ & \text { dry } \end{aligned}$ | lard oil lard oil lard oil dry mixture |

Mixture $=1 / 3$ crude petroleum, $2 / 3$ lard oil. $\quad$ Oil $=$ sperm or lard.
Tables 147 and 148 quoted from "Friction and Lost Work in Machinery and Mill Work," Thurston, Wiley and Sons.
Smithsonian Tables.

## TABLE 149. - Viscosity of Fluids and Solids.

The coefficient of viscosity of a substance is the tangential force required to move a unit area of a plane surface with unit speed relative to another parallel plane surface from which it is separated by a layer a unit thick of the substance. Viscosity measures the temporary rigidity it gives to the substance. The viscosity of fluids is generally measured by the rate of flow of the fluid through a capillary tube the length of which is great in comparison with its diameter. The equation generally used is

$$
\mu, \text { the viscosity, }=\frac{\gamma \pi g d^{4} t}{I 28 Q(l+\lambda)}\left(h-\frac{m v^{2}}{g}\right),
$$

where $\gamma$ is the density $\left(\mathrm{g} / \mathrm{cm}^{3}\right), d$ and $l$ are the diameter and length in cm of the tube, $Q$ the volume in $\mathrm{cm}^{3}$ discharged in $t$ sec., $\lambda$ the Couette correction which corrects the measured to the effective length of the tube, $h$ the average head in $\mathrm{cm}, m$ the coefficient of kinetic energy correction, $m v^{2} / g$, necessary for the loss of energy due to turbulent in distinction from viscous flow, $g$ being the acceleration of gravity ( $\mathrm{cm} / \mathrm{sec} / \mathrm{sec}$ ), $v$ the mean velocity in cm per sec. (See Technologic Paper of the Bureau of Standards, 100 and 112, Herschel, 1917-1918, for discussion of this correction and $\lambda$.)

The fluidity is the reciprocal of the absolute viscosity. The kinetic viscosity is the absolute viscosity divided by the density. Specific viscosity is the viscosity relative to that of some standard substance, generally water, at some definite temperature. The dimensions of viscosity are $M L^{-1} T^{-1}$. It is generally expressed in cgs units as dyne-seconds per $\mathrm{cm}^{2}$ or poises.

The viscosity of solids may be measured in relative terms by the damping of the oscillations of suspended wires (see Table 78). Ladenburg (Igo6) gives the viscosity of Venice turpentine at $18.3^{\circ}$ as 1300 poises; Trouton and Andrews (1904) of pitch at $0^{\circ}, 51 \times 10^{10}$, at $15^{\circ}, 1.3 \times 10^{10}$; of shoemakers' wax at $8^{\circ}, 4.7 \times 10^{6}$; of soda glass at $575^{\circ}$, II $\times \mathrm{IO}^{12}$; Deeley ( IgO 8 ) of glacier ice as $12 \times \mathrm{IO}^{13}$.

TABLE 150. - Viscosity of Water in Centipoises. Temperature Variation.
Bingham and Jackson, Bulletin Bureau of Standards, 14, 75, 1917.

| ${ }^{\circ} \mathrm{C}$. | Viscosity. cp | ${ }^{\circ} \mathrm{C}$. | Vis- cosity. cp | ${ }^{\circ} \mathrm{C}$. | Viscosity. cp | ${ }^{\circ} \mathrm{C}$. | Viscosity. cp | ${ }^{\circ} \mathrm{C}$. | $\begin{aligned} & \text { Vis- } \\ & \text { cosity. } \\ & \text { cp } \end{aligned}$ | ${ }^{\circ} \mathrm{C}$. | $\begin{aligned} & \text { Vis- } \\ & \text { cosity. } \\ & \text { cp } \end{aligned}$ | ${ }^{\circ} \mathrm{C}$. | Viscosity. cp |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\bigcirc$ | 1.7921 | 10 | 1. 3077 | 20 | 1.0050 | 30 | 0.8007 | 40 | 0.6560 | 50 | 0.5494 | 60 | 0.4688 |
| I | 1.7313 | 11 | 1.2713 | 21 | 0.9810 | 31 | 0.7840 | 41 | 0.6439 | 51 | 0.5404 | 65 | 0.4355 |
| 2 | 1. 6728 | 12 | I. 2363 | 22 | 0.9579 | 32 | 0.7679 | 42 | 0.632 I | 52 | -. 5315 | 70 | 0.4061 |
| 3 | x.619x | 13 | I. 2028 | 23 | 0.9358 | 33 | 0.7523 | 43 | 0.6207 | 53 | 0. 5229 | 75 | $0.3799^{\circ}$ |
| 4 | 1.5674 | 14 | 1.1709 | 24 | 0.9142 | 34 | 0.737I | 44 | 0.6097 | 54 | -. 5146 | 80 | 0.3565 |
| 5 | 1. 5188 | 15 | r. 1404 | 25 | 0.8937 | 35 | 0.7225 | 45 | 0. 5988 | 55 | 0. 5064 | 85 | 0.3355 |
| 6 | I. 4728 | 16 | I. 1111 | 26 | 0.8737 | 36 | 0.7085 | 46 | 0.5883 | 56 | 0.4985 | 90 | 0.3165 |
| 7 | I. 4284 | 17 | I. 0828 | 27 | 0.8545 | 37 | 0.6947 | 47 | O. 5782 | 57 | 0.4907 | 95 |  |
| 8 | 1.3860 | 18 | I. 0559 | 28 | 0.8360 | 38 | 0.6814 | 48 | -0.5683 | 58 | 0.4832 | 100 | -. 28388 |
| 9 | 1.3462 | 19 | 1.0299 | 29 | 0.8180 | 39 | 0.6685 | 49 | 0. 5588 | 59 | 0.4759 | 153. | 0.181 * |

TABLE 151. - Viscosity of Alcohol-water Mixtures in Centipoises. Temperature Variation.

| ${ }^{\circ} \mathrm{C}$. | Percentage by weight of ethyl alcohol. |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\bigcirc$ | IO | 20 | 30 | 39 | 40 | 45 | 50 | 60 | 70 | 80 | 90 | 100 |
| $\bigcirc$ | I. 792 | 3.311 | 5.319 | 6.94 | 7.25 | 7.14 | 6.94 | 6.58 | 5.75 | 4.762 | 3.690 | 2.732 | 1.773 |
| 5 | T. 519 | 2.577 | 4.065 | 5.29 | 5.62 | 5.59 | 5.50 | 5.26 | 4.63 | 3.906 | 3.125 | 2.309 | I. 623 |
| 10 | 1. 308 | 2.179 | 3.165 | 4.05 | 4.39 | 4.39 | 4.35 | 4.18 | 3.77 | 3.268 | 2.710 | 2.101 | 1. 466 |
| 15 | I. 140 | 1.792 | 2.618 | 3.26 | 3.52 | 3.53 | 3.51 | 3.44 | 3.14 | 2.770 | 2.309 | 1.802 | 1.332 |
| 20 | 1.005 | 1. 538 | 2.183 | 2.71 | 2.88 | 2.91 | 2.88 | 2.87 | 2.67 | 2.370 | 2.008 | 1.610 | I. 200 |
| 25 | 0.894 | I. 323 | x.815 | 2.18 | 2.35 | 2.35 | 2.39 | 2.40 | 2.24 | 2.037 | 1.748 | 1.424 | 1.096 |
| 30 | 0.801 | I. 160 | $\underline{1.553}$ | 1.87 | 2.00 | 2.02 | 2.02 | 2.02 | 1.93 | 1.767 | I. 531 | I. 279 | 1.003 |
| 35 | 0.722 | 1.006 | I. 332 | 1. 58 | 1.71 | 1.72 | 1.73 | 1.72 | 1. 66 | 1. 529 | I. 355 | I. 147 | 0.914 |
| 40 | 0.656 | 0.907 | I. 160 | 1. 368 | 1.473 | 1.482 | I. 495 | 1. 499 | I. 447 | 1.344 | I. 203 | 1. 035 | -. 834 |
| 45 | 0.599 | 0.812 | 1.015 | I. 189 | I. 284 | I. 289 | 1.307 | 1.294 | 1.271 | r.189 | 1.081 | 0.939 | 0.764 |
| 50 | 0.549 | 0.734 | 0.907 | 1.050 | 1.124 | 1.132 | 1. 148 | I. 155 | 1.127 | 1.062 | 0.968 | 0.848 | 0.702 |
| 60 | 0.469 | 0.609 | 0.736 | 0.834 | 0.885 | 0.893 | 0.907 | 0.913 | 0.902 | 0.856 | 0.789 | 0.704 | 0. 592 |
| 70 | 0.406 | 0.514 | 0.608 | 0.683 | 0.725 | 0.727 | 0.740 | 0.740 | 0.729 | 0.695 | 0.650 | 0.589 | 0.504 |
| 80 | 0.356 | 0.430 | 0.505 | 0.567 | 0.598 | 0.601 | 0.609 | 0.612 | 0.604 |  |  |  |  |

TABLE 152．－Viscosity and Density of Sucrose in Aqueous Solution．
See Scientific Paper 298，Bingham and Jackson，Bureau of Standards，1917，and Technologic Paper 100，Herschel，Bureau of Standards， 1917.

| Tempera－ ture． | Viscosity in centipoises． |  |  |  | Density $d_{4}{ }^{t}$ ． |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Per cent sucrose by weight． |  |  |  | Per cent sucrose by weight． |  |  |  |
|  | － | 20 | 40 | 60 | $\bigcirc$ | 20 | 40 | 60 |
| $0^{\circ} \mathrm{C}$ | 1.7921 | 3．804 | 14.77 | 238. | 0.99987 | 1． 08546 | 1． 18349 | I． 29560 |
| 5 | 1．5188 | 3.154 | 11.56 | 156. | －． 99999 | I． 08460 | 1．18192 | I． 29341 |
| 10 | 1．3077 | 2.652 | 9.794 | 109.8 | 0.99973 | 1． 08353 | 1． 18020 | I． 29117 |
| 15 | I． 1404 | 2.267 | 7.468 | 74.6 | －．99913 | 1．08233 | 1． 17837 | I． 28884 |
| 20 | 1.0050 | I． 960 | 6.200 | 56.5 | 0.99823 | 1.08094 | 1． 17648 | I． 28644 |
| 30 | 0． 8007 | 1． 504 | $4 \cdot 382$ | 33.78 | 0.99568 | 1.07767 | 1． 17214 | 1． 28144 |
| 40 | 0.6560 | I． 193 | 3.249 | 21.28 | 0.99225 | 1.07366 | 1． 16759 | 1． 27615 |
| 50 | 0． 5494 | 0.970 | 2.497 | 14.01 | 0.98807 | I． 06898 | I． 16248 | 1． 27058 |
| 60 | 0． 4688 | 0.808 | I． 982 | 9.83 | 0.98330 | 1．06358 | I． 15693 | I． 26468 |
| $\begin{aligned} & 70 \\ & 80 \end{aligned}$ | 0． 4061 | 0.685 | I． 608 | 7.15 |  |  |  |  |
|  | 0.3565 | 0.590 | 1.334 | 5.40 | Densities due to Plato． |  |  |  |

TABLE 153．－Viscosity and Density of Glycerol in Aqueous Solution（ $20^{\circ} \mathrm{C}$ ）．

| Glycerol． | Den－ sity． $\mathrm{g} / \mathrm{cm}^{3}$ | Viscos－ ity in centi－ poises． | $100 \times$ <br> Kine－ <br> matic <br> viscos－ <br> ity． | $\stackrel{\%}{\%}$ erol. | $\begin{gathered} \text { Den- } \\ \text { sity. } \\ \mathrm{g} / \mathrm{cm}^{3} \end{gathered}$ | Viscos－ ity in centi－ poises． | $\begin{array}{\|c\|} \hline \text { 1oo } X \\ \text { Kine- } \\ \text { matic } \\ \text { viscos- } \\ \text { ity. } \end{array}$ | $\begin{aligned} & \% \\ & \text { Glyc- } \\ & \text { erol. } \end{aligned}$ | Den－ sity． $\mathrm{g} / \mathrm{cm}^{3}$ | Viscos－ ity in centi－ poises． | $100 \times$ Kine－ matic viscos－ ity． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | 1． 00098 | 1． 181 | 1.170 | 35 | 1． 0855 | 3．115 | 2.870 | 65 | I． 1662 | 14.51 | 12.44 |
| 10 | 1．0217 | 1． 364 | 1．335 | 40 | 1.0989 | 3.791 | 3.450 | 70 | I． 1797 | 21.49 | 18.22 |
| 15 | 1． 0337 | I． 580 | I． 529 | 45 | I． 1124 | 4.692 | 4．218 | 75 | I． 1932 | 33.71 | 28.25 |
| 20 | I． 0461 | 1．846 | 1．765 | 50 | 1． 1258 | 5.908 | 5．248 | 80 | I． 2066 | $55 \cdot 34$ | 45.86 |
| 25 | 1． 0590 | 2.176 | 2.055 | 55 | I． 1393 | 7.664 | 6.727 | 85 | I． 2201 | 102.5 | 84.01 |
| 30 | I． 0720 | 2.585 | 2.411 | 60 | I． 1528 | 10.31 | 8.943 | 90 | I． 2335 | 207.6 | 168.3 |

The kinematic viscosity is the ordinary viscosity in cgs units（poises）divided by the density．
TABLE 154．－Viscosity and Density of Castor Oil（Temperature Variation）．

| ${ }^{\circ} \mathrm{C}$ | N |  |  | ${ }^{\circ} \mathrm{C}$ | 苞范范 |  | 管言 | ${ }^{\circ} \mathrm{C}$ |  |  |  | ${ }^{\circ} \mathrm{C}$ |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | ． 9707 | 37.6 | 38.7 | 14 | ． 9645 | 16.61 | 17.22 | 23 | ． 9583 | 7.67 | 8.00 | 32 | ． 9520 | 3.94 | 4.14 |
| 6 | ． 9700 | 34.5 | 35.5 | 15 | ． 9638 | 15.14 | 15.71 | 24 | ． 9576 | 7.06 | 7.37 | 33 | ． 9513 | 3.65 | 3.84 |
| 7 | ． 9693 | 31.6 | 32.6 | I6 | ． 9631 | 13.80 | 14.33 | 25 | ． 9569 | 6.51 | 6.80 | 34 | ． 9506 | 3.40 | $3 \cdot{ }^{8}$ |
| 8 | ． 9686 | 28.9 | 29.8 | 17 | ． 9624 | 12.65 | 13．14 | 26 | ． 9562 | 6.04 | 6.32 | 35 | ． 9499 | 3.16 | $3 \cdot 33$ |
| 9 | ． 9679 | 26.4 | 27.3 | 18 | ． 9617 | 11.62 | 12.09 | 27 | ． 9555 | 5.61 | 5.87 | 36 | ． 9492 | 2.94 | 3.10 |
| 10 | ． 9672 | 24.2 | 25.0 | 19 | ． 9610 | 10.71 | II．I5 | 28 | ． 9548 | 5.21 | 5.46 | 37 | ． 9485 | 2.74 | 2.89 |
| 11 | ． 9665 |  | 22.8 | 20 | ． 9603 | 9.86 | 10.27 | 29 | ． 9541 | 4.85 | 5.08 | 38 | ． 9478 | 2.58 | 2.72 |
| 12 | .9659 | 20． 1 | 20.8 | 21 | ． 9596 | 9.06 |  | 30 | ． 9534 | $4 \cdot 51$ | 4.73 | 39 | ． 9471 | 2.44 | 2.58 |
| 13 | ．96．52 | 18.2 | 18.9 | 22 | ． 9589 | 8.34 | 8.70 | 31 | ． 9527 | 4.21 | 4.42 | 40 | ． 9464 | 2.31 | 2.44 |

Tables 153 and 154，taken from Technologic Paper 112，Bureau of Standards，1918．Glycerol data due to Archbutt，Deeley and Gerlach；Castor Oil to Kahlbaum and Räber．See preceding table for definition of kinematic viscosity．Archbutt and Deeley give for the density and viscosity of castor oil at $65.6^{\circ} \mathrm{C}, 0.9284$ and 0.605 ，respectively；at $100^{\circ} \mathrm{C}, 0.9050$ and 0.169 ．
SMITHSONIAN TABLES．

VISCOSITY OF LIQUIDS.
Viscosities are given in cgs units, dyne-seconds per $\mathrm{cm}^{2}$, or poises.

| Liquid. | ${ }^{\circ} \mathrm{C}$ | Viscosity. | Reference. | Liquid. | ${ }^{\circ} \mathrm{C}$ | Viscosity. | Reference |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetaldehyde. . . . . . . . . | 0. | 0.00275 | 1 | * Dark cylinder | 37.8 | 7.324 | 10 |
| , | 10. | 0.00252 0.00231 | I | *"Extra L. L. ${ }^{\text {\% }}$. | 100.8 37.8 | 0.341 11.156 | 10 |
| Air | -192.3 | 0.00172 | 2 |  | 37.8 100.0 | 11.156 0.451 | 10 |
| Anilin | 20. | 0.04467 | 3 | Linseed . $925 \ddagger$ | 30. | 0.331 | 9 |
|  | 60. | 0.0156 | 3 | " . $922 .$. | 50. | 0.176 | 9 |
| Bismuth | 285. | 0.0161 | 4 | " ${ }^{\text {ar }}$ | 90. | 0.071 | 9 |
|  | 365. | 0. 0146 | 4 | Olive .9195 | 10. | 1. 38 | 1 |
| Copal lac Glycerine | ${ }_{22}^{22.8}$ | 4.80 42.2 | 5 |  | 15. | 1.075 | 11 |
| Glycerine | 2.8 14.3 | 42.2 13.87 | 6 | " ${ }^{\text {، }} 919065$ | 20. 30. | 0.840 0.540 | 11 |
| " ${ }^{\text {a }}$, | 20.3 | 8.30 | 6 | "، . 9000 | 40. | -. 363 | II |
| 80.31 H | 26.5 | 4.94 | 6 | "، . 8935 | 50. | -. 258 | 11 |
| "، $80.3 \mathrm{I} \% \mathrm{H}_{2} \mathrm{O} .$. | 8.5 | 1.021 | 6 | . 8800 | 70. | -. 124 | 11 |
| " $64.05 \% \mathrm{H}_{2} \mathrm{O} .$. | 8.5 | 0.222 | 6 | $\dagger$ Rape. | 15.6 | 1.118 | 10 |
| " ${ }^{\text {\% }}$, $49.79 \% \mathrm{H}_{2} \mathrm{O} .$. | 8.5 | 0.092 | 6 |  | 37.8 | 0.422 | 10 |
| Hydrogen, liquid ...... | - | 0.00011 | 2 |  | 100.0 | -0.080 | 10 |
| Menthol, solid. | 14.9 34.9 | $2 \times 10^{12}$ 0.069 | 7 | " ${ }^{\text {a }}$ (another) | 15.6 100.0 | 1.176 0.085 | 10 |
| Mercury . . . . . | - 20. | 0.018 | 8 | Soya bean . $919 \pm$ | 100.0 30.0 | 0.085 0.406 | 10 |
|  | -. | 0.01661 | 4 | "، " . 915. | 50.0 | -. 206 | 9 |
| , | 20. | 0.01547 | 4 | " " . 906 | 90.0 | 0.078 | 9 |
|  | 34. | 0.01476 | 4 | † Sperm. | 15.6 | 0.420 | 10 |
| " | 98. | 0.01263 | 4 |  | 37.8 | 0. 185 | 10 |
| " | 193. | 0.01079 | 4 |  | 100.0 | 0.046 | 10 |
| Oils: | 299. | 0.00975 | 4 | Paraffins: Pentane. | 21.0 | 0.0026 | 12 |
| Dogfish-liver ${ }_{6} .923 \ddagger \ldots$ | 30. | 0.414 | 9 | Hexane. | 23.7 | 0.0033 | 12 |
| "، " . 918. | 50. | 0. 211 | 9 | Heptane | 24.0 | 0.0045 | 12 |
| " " . 908 | 90. | 0.080 | 9 | Octane. | 22.2 | 0.0053 | 12 |
| Linseed . 925. | 30. | -0.331 | 9 | Nonane | 22.3 | 0.0062 | 12 |
| " 922 | 50. | 0.176 | 9 | Decane. | 22.3 | 0.0077 | 12 |
|  |  | 0.071 |  | Undecane. | 22.7 | 0.0095 | 12 |
| * Spindle oil ${ }_{\text {c/ }} 885$ | 15.6 | 0.453 | 10 | Dodecane | 23.3 | 0.0126 | 12 |
|  | 37.8 | 0.162 | 10 | Tridecane. | 23.3 | 0.0155 | 12 |
|  | 100.0 | 0.033 | 10 | Tetradecane | 21.9 | 0.0213 | 12 |
| * Light machinery |  |  |  | Pentadecane | 22.0 | 0.0281 | 12 |
|  | 15.6 | 1. 138 | 10 | Hexadecane | 22.2 | -. 0359 | 12 |
| * Light marhinery.... | 37.8 | -. 342 | 10 | Phenol. | 18.3 | 0. 1274 | 13 |
| * "Solar red" engine.. | 100.0 15.6 | 0.049 1.915 | 10 | Sulphur | 90.0 170. | 0.0126 320.0 | 13 |
|  | 37.8 | 0.496 | 10 |  | 180. | 550.0 | 14 |
|  | 100.0 | -0.058 | 10 | , | 187. | 560.0 | 14 |
| * " Bayonne" engine.. | 15.6 | 2.172 | 10 | " | 200. | 500.0 | 14 |
|  | 37.8 | 0.572 | 10 | " | 250. | 104.0 | 14 |
| * | 100.0 | 0.063 | 10 | " | 300. | 24.0 | 14 |
| *" Queen's red" engine | 15.6 | 2.995 | 10 | " | 340. | 6.2 | 14 |
|  | 37.8 | 0.711 | 10 | , | 380. | 2.5 | 14 |
|  | 100.0 | 0.070 | 10 | , | 420. | 1.13 | 14 |
| * " Galena" axle oil .. | 15.6 | 4.366 | 10 |  | 448. | 0.80 | 14 |
|  | 37.8 | - 0.909 | 10 | $\dagger$ Tallow | 66. | 0.176 | 10 |
| * Heavy machinery ... | 15.6 | 6.606 | 10 |  | 100. | 0.078 | 10 |
|  | 37.8 | 1. 274 2.406 | 10 | Zinc. | 280. | 0.0168 | 4 |
| * Filtered cylinder.... | 37.8 100.0 | 2.406 0.187 | 10 | . | 357. 389. | 0.0142 0.0131 |  |
| * Dark cylinder...... | 37.8 | 4.224 | 10 |  |  |  |  |
|  | 100.0 | 0. 240 | 10 |  |  |  |  |

* American mineral oils; based on water as . 01028 at $20^{\circ} \mathrm{C}$. $\dagger$ Based on water as per ist footnote. $\ddagger$ Densities.

References: (1) Thorpe and Rodger, 1894-7; (2) Verschaffelt, Sc. Ab. 1917; (3) Wijkander, 1879; (4) Plüss. Z. An. Ch. 93, 1915; (5) Metz, C. R. 1903; (6) Schöttner, Wien. Ber. 77, 1878, 79, 1879; (7) Heydweiller, W. Ann. 63, 1897; (8) Koch, W. Ann. 14, 1881; (9) White, Bul. Bur. Fish. 32, 1912; (10) Archbutt-Deeley, Lubrication and Lubricants, 1912; (II) Higgins, Nat. Phys. Lab. II, 1914; (12) Bartolli, Stracciati, 1885-6; (13) Scarpa, 1903-4; (I4) Rotinganz, Z. Ph. Ch. 62, Igo8.

## VISCOSITY OF LIQUIDS.

Compiled from Landolt and Börnstein, 1912. Based principally on work of Thorpe and Rogers, 1894-97. Viscosity given in centipoises. One centipoise $=0.01$ dyne-second per $\mathrm{cm}^{2}$.

| Liquid. | Viscosity in centipoises. |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Formula. | $0^{\circ} \mathrm{C}$ | $10^{\circ} \mathrm{C}$ | $20^{\circ} \mathrm{C}$ | $30^{\circ} \mathrm{C}$ | $40^{\circ} \mathrm{C}$ | $50^{\circ} \mathrm{C}$ | $70^{\circ} \mathrm{C}$ | $100^{\circ} \mathrm{C}$ |
| Acids: Formic | $\mathrm{CH}_{2} \mathrm{O}_{2}$ | solid | 2.247 | 1. 784 | I. 460 | I. 219 | 1.036 | . 780 | . 549 |
| Acetic. | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}_{2}$ | solid | solid | I. 222 | I. 040 | 0.905 | -. 796 | . 631 | . 465 |
| Propioni | $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}_{2}$ | 1.52 I | I. 289 | I. 102 | 0.960 | -. 845 | -. 752 | . 607 | . 459 |
| Butyric | $\mathrm{C}_{4} \mathrm{H}_{8} \mathrm{O}_{2}$ | 2.286 | I. 85 I | I. 540 | I. 304 | I . 120 | 0.975 | . 760 | -55I |
| i-Butyric | $\mathrm{C}_{4} \mathrm{H}_{8} \mathrm{O}_{2}$ | 1.887 | I. 568 | 1.318 | I. I 29 | 0.980 | 0.862 | . 683 | 501 |
| Alcohols: Methy | $\mathrm{CH}_{4} \mathrm{O}$ | -.817 | 0.690 | -. 596 | 0. 520 | 0.456 | 0.403 | - | - |
| Ethyl * | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | 1.772 | I . 466 | I. 200 | I. 003 | -. 834 | 0. 702 | . 510 | - |
| Allyl | $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}$ | 2.145 | I. 705 | 1. 363 | I. 168 | 0.914 | -. 763 | - 553 | - |
| Propy | $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}$ | 3.883 | 2.918 | 2.256 | I. 779 | I. 405 | I. 130 | . 760 | - |
| i-Propy | $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}$ | 4.565 | 3.246 | 2.370 | I. 757 | I. 33 I | 1.029 | . 646 | - |
| Butyric | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | 5.186 | 3.873 | 2.948 | 2.267 | 1. 782 | I. 411 | . 930 | 540 |
| i-Butyri | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | 8.038 | $5 \cdot 548$ | 3.907 | 2.864 | 2.122 | 1.611 | - | . 527 |
| Amyl, op. a | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 11.129 | 7.425 | 5.092 | $3 \cdot 594$ | 2.607 | 1.937 | - | . 610 |
| Amyl, op. inac | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 8.532 | 6.000 | 4.342 | 3.207 | 2.415 | I. 851 | - | . 632 |
| Aromatics: Benz | $\mathrm{C}_{6} \mathrm{H}_{6}$ | 0.906 | 0. 763 | -. 654 | -. 567 | -. 498 | 0. 444 | . 359 | - |
| Toluene | $\mathrm{C}_{7} \mathrm{H}_{8}$ | 0.772 | 0.671 | -. 590 | -. 525 | 0.471 | 0.426 | . 354 | . 278 |
| Ethylbenzo | $\mathrm{C}_{8} \mathrm{H}_{10}$ | 0.877 | 0. 761 | 0.669 | -. 594 | -. 53 I | 0.479 | . 397 | . 310 |
| Orthoxylene | $\mathrm{C}_{8} \mathrm{H}_{10}$ | I. 105 | -. 937 | 0.810 | -. 709 | 0.627 | -. 560 | . $45^{8}$ | . 352 |
| Metaxylen | $\mathrm{C}_{8} \mathrm{H}_{10}$ | 0.806 | 0.702 | 0.620 | -. 552 | 0.497 | 0.451 | - 375 | . 296 |
| Paraxylene | $\mathrm{C}_{8} \mathrm{H}_{10}$ | solid | 0.738 | 0.648 | -. 574 | 0.513 | 0.463 | - 383 | - 300 |
| Bromides: Ethyl | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br}$ | 0.487 | 0.44 I | 0.402 | 0. 368 | - | - | - | - |
| Propy | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Br}$ | 0.651 | -. 582 | -. 524 | 0.475 | 0.433 | 0.397 | . 338 | - |
| i-Propy | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Br}$ | 0.6 II | -. 545 | -. 489 | 0.443 | 0.403 | -. 368 | - | - |
| Allyl. | $\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{Br}$ | 0.626 | 0. 560 | -. 504 | -. 458 | 0.419 | -. 384 | . 328 | - |
| Ethylen | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{Br}$ | 2.438 | 2.039 | I. 721 | I. 475 | I. 286 | 1. 131 | . 903 | 678 |
| Bromine. | ${ }^{\mathrm{Br}}$ | 1. 267 | I . 120 | I. 005 | 0.911 | 0.830 | -. 761 | - | - |
| Chlorides: Prop | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{Cl}$ | 0.442 | -. 396 | -. 359 | -. 326 | 0. 299 | - | - | - |
| Allyl. | $\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{Cl}$ | 0.413 | -. 372 | -. 337 | 0. 307 | 0. 282 | - | - | - |
| Ethylen | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{Cl}$ | I. I32 | 0.966 | -. 838 | -. 736 | 0.652 | 0. 584 | 479 | - |
| Chlorof | $\mathrm{CHCl}_{3}$ | 0.706 | -. 633 | -. 571 | -. 519 | 0.474 | 0.435 | - | - |
| Carbon-tetra | $\mathrm{CCl}_{4}$ | I. 35 I | I. 138 | 0.975 | -. 848 | 0. 746 | 0.662 | . 534 | - |
| Ethers: Diethyl | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | -. 294 | 0. 268 | -. 245 | 0. 223 | - | - | - | - |
| Methyl-propyl | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | -.314 | -. 285 | 0. 260 | -. 237 | 1 | - | - | - |
| Ethyl-prop | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 0.402 | 0. 360 | -. 324 | -. 294 | 0. 268 | 0. 245 | - | - |
| Dipropyl | $\mathrm{C}_{6} \mathrm{H}_{14} \mathrm{O}$ | -. 544 | -. 479 | -. 425 | -.381 | -. 344 | 0.311 | - | - |
| Esters: Methylformate | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}_{2}$ | 0.436 | -. 391 | -. 355 | -. 325 |  |  | - | - |
| Ethylformate | $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}$ | 0.510 | -. 454 | -. 408 | -. 369 | 0.336 | 0.308 | - | - |
| Methylacet | $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}_{2}$ | 0.484 | -. 431 | -. 388 | -. $35^{2}$ | -. 320 | 0. 293 | - | - |
| Ethylaceta | $\mathrm{C}_{4} \mathrm{H}_{8} \mathrm{O}_{2}$ | 0. $5^{82}$ | - 512 | 0. 455 | -. 407 | -. 367 | -. 333 | . 279 | - |
| Iodides: Methy | $\mathrm{CH}_{3} \mathrm{I}$ | 0.606 | -. 548 | 0. 500 | 0. 460 | 0.424 | - | - | - |
| Ethy | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | 0.727 | 0.654 | -. 592 | - . 540 | O. 495 | 0. 456 | . 391 | - |
| Propy | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{I}$ | 0.944 | 0.833 | -. 744 | 0. 669 | -. 607 | -. 552 | . 466 | - 371 |
| Paraffines: Pentane | $\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{I}$ | 0.936 | 0.826 | -. 734 | 0.660 | -. 597 | -. 544 | . 458 | 365 |
| i-Pentane. | $\mathrm{C}_{5} \mathrm{H}_{12}$ | 0.289 0.284 | 0. 262 | 0. 240 | 0. 220 | - |  |  |  |
| Hexan | $\mathrm{C}_{6} \mathrm{H}_{14}$ | 0.401 | 0.360 | -. 326 | 0. 296 | 0.271 | 0.248 |  |  |
| i-He | $\mathrm{C}_{6} \mathrm{H}_{14}$ | 0.376 | -. 338 | -. 306 | -. 279 | -. 254 | 0.233 | - | - |
| Heptan | $\mathrm{C}_{7} \mathrm{H}_{16}$ | 0.524 | 0.465 | -. 416 | -. 375 | -. 341 | -. 310 | . 262 | - |
| i-Hepta | $\mathrm{C}_{7} \mathrm{H}_{16}$ | 0.48 I | 0. 428 | -. 384 | -. 347 | -. 315 | -. 288 | . 243 | - |
| Sulphide | $\mathrm{C}_{8} \mathrm{H}_{18}$ | 0.706 | 0.616 | -. 542 | 0.483 | -. 433 - | -.391 | . 324 | .252 |
| Sulphides: <br> Ethyl. | $\mathrm{CS}_{2}$ | 0.438 | 0. 405 | 0. 376 | 0. 352 | 0. 330 |  |  | - |
| Turpentine $\dagger$ | ${ }_{4}$ | 0.563 2.248 | O. 501 | 0.450 | 0.407 | -. 309 | -. 338 | 287 |  |
|  |  |  |  |  | 1.27 | 1.071 | -. 92 | . 7 |  |

[^23]Smithsonian Tables.

VISCOSITY OF SOLUTIONS.

This table is intended to show the effect of change of concentration and change of temperature on the viscosity of solutions of salts in water. The specific viscosity $\times 100$ is given for two or more densities and for several temperatures in the case of each solution. $\mu$ stands for specific viscosity, and $t$ for temperature Centigrade.

| Salt. | Percentage by weight of salt in solution. | Density | $\mu$ | $t$ | $\mu$ | $t$ | $\mu$ | $t$ | $\mu$ | $t$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\underset{"}{\mathrm{BaCl}_{2}}$ | 7.60 | - | 77.9 | 10 | 44.0 | 30 | 35.2 | 50 | - | - | Sprung. |
|  | 15.40 | - | 86.4 | " | 56.0 | ${ }^{6}$ | 39.6 | \% | - | _ | "، |
|  | 24.34 | - | 100.7 | " | 66.2 | " | 47.7 | " | - | - | ' |
| $\underset{\sim}{\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}}$ | 2.98 | 1.027 | 62.0 | 15 | 51.1 | 25 | 42.4 | 35 | 34.S | 45 | Wagner. |
|  | 5.24 | 1.051 | 68.1 |  | 54.2 |  | 44.1 |  | 36.9 |  |  |
| $\begin{gathered} \mathrm{CaCl}_{2} \\ " 6 \\ " 6 \end{gathered}$ | 15.17 | - | 110.9 | 10 | 71.3 | 30 | 50.3 | 50 | - | - | Sprung. |
|  | 31.60 | - | 272.5 | " | 177.0 |  | 124.0 |  | - | - |  |
|  | 39.75 | - | 670.0 | " | 379.0 | " | 245.5 | " | - | - | " |
|  | 44.09 | - | - | - | 593.1 | " | 363.2 | ، | - | - | " |
| $\underset{"}{\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}}$ | $17 \cdot 55$ | 1.171 | 93.8 | 15 | 74.6 | 25 | 60.0 | 35 | 49.9 | 45 | Wagner. |
|  | 30.10 | 1.274 | 144.1 |  | I 12.7 | ، | 90.7 | " | 75.1 | " |  |
|  | 40.13 | 1.386 | 242.6 | " | 217.1 | " | I 56.5 | " | 128.1 | " | " |
| $\underset{6}{\mathrm{CdCl}_{2}}$ | 11.09 | 1.109 | 77.5 | 15 | 60.5 | 25 | 49.1 | 35 | 40.7 | 45 | " |
|  | 16.30 | 1.18I | 88.9 | ، | 70.5 |  | 57.5 | " | 47.2 | ، | ، |
|  | 24.79 | 1. 320 | 104.0 | " | 80.4 | " | 64.6 | " | 53.6 | " | " |
| $\underset{"}{\mathrm{Cd}(\underset{\mathrm{NO}}{3}})_{2}$ | 7.81 | 1.074 | 61.9 | 15 | 50.1 | 25 | 4 I .1 | 35 | 34.0 | 45 | " |
|  | 15.71 | I. 159 | 71.8 | ، | 58.7 |  | 48.8 | 6 | 41.3 |  | " |
|  | 22.36 | 1.241 | 85.1 | " | 69.0 | " | 57.3 | ، | 47.5 | " | \% |
| $\mathrm{CdSO}_{4}$" | 7.14 | 1.068 | 78.9 | I5 | 6ı. 8 | 25 | $49 \cdot 9$ | 35 | 41.3 | 45 | " |
|  | 14.66 | 1.159 | 96.2 | ، | 72.4 | ، | 58.1 | ${ }_{6}$ | 48.8 | ، | " |
|  | 22.01 | 1.268 | 120.8 | " | 9 I .8 | " | 73.5 | " | 60.1 | " | " |
| $\mathrm{CoCl}_{2}$ | 7.97 | 1.081 | 83.0 | 15 | 65.1 | 25 | 53.6 | 35 | 44.9 | 45 | " |
|  | 14.86 | 1.161 | III. 6 | ، | 85.1 | ، | 73.7 | ، | 58.8 | . 6 | " |
|  | 22.27 | 1.264 | 161.6 | " | 126.6 | " | 101.6 | " | 85.6 | " | ' |
| $\underset{" ،}{\mathrm{Co}\left(\mathrm{NO}_{3}\right)_{2}}$ | 8.28 | 1.073 | $74 \cdot 7$ | I 5 | 57.9 | 25 | 48.7 | 35 | 39.8 | 45 | " |
|  | 15.96 | 1.144 | 87.0 | ، 6 | 69.2 | ، | 55.4 | " | 44.9 |  | " |
|  | 24.53 | 1.229 | 110.4 | " | 88.0 | " | 71.5 | " | 59.1 | " | " |
| $\underset{\text { " }}{\mathrm{CoSO}_{4}}$ | 7.24 | 1.086 | 86.7 | I5 | 68.7 | 25 | 55.0 | 35 | 45.I | 45 | " |
|  | 14.16 | I.I 59 | 117.8 | " | 95.5 | ، | 76.0 |  | 61.7 | \% | ، |
|  | 21.17 | 1.240 | 193.6 | " | 146.2 | " | 113.0 | " | 89.9 | " | " |
| $\underset{\text { CuCl }}{2}$ | 12.01 | I. 104 | 87.2 | I 5 | 67.8 | 25 | 55.1 | 35 | 45.6 | 45 | " |
|  | 21.35 | I. 215 | 121.5 | ، | 95.8 | ، | 77.0 | . | 63.2 |  | " |
|  | 33.03 | 1.331 | 178.4 | * | 137.2 | " | 107.6 | " | 87.1 | ، | " |
| $\underset{،}{\mathrm{Cu}\left(\mathrm{NO}_{3}\right)_{2}}$ | 18.99 | 1.177 | 97.3 | 15 | 76.0 | 25 | 61.5 | 35 | 51.3 | 45 | " |
|  | 26.68 | I. 264 | 126.2 | ${ }^{6}$ | 98.8 | " | 80.9 | 3.6 | 68.6 | " | " |
|  | 46.71 | 1. 536 | 382.9 | " | 283.8 | " | $215 \cdot 3$ | " | 172.2 | " | " |
| $\mathrm{CuSO}_{4}$ | 6.79 | I. 055 | 79.6 | 15 | 61.8 | 25 | 49.8 | 35 | 4 I .4 | 45 | " |
|  | 12.57 | 1.115 | 98.2 | ، | 74.0 | ، | 59.7 | ." | 52.0 | " | " |
|  | 17.49 | 1.163 | 124.5 | " | 96.8 | " | 75.9 | " | 61.8 |  | " |
| $\mathrm{HCl}$ | 8.14 | 1.037 | 71.0 | 15 | 57.9 | 25 | $48 \cdot 3$ | 35 | 40. I | 45 | " |
|  | 16.12 | 1.084 | 80.0 | ، | 66.5 | ، | 56.4 | 3. | 48.1 | ، | " |
|  | 23.04 | I. 114 | 9 I .8 | " | 79.9 | " | 65.9 | " | 56.4 | " | " |
| $\mathrm{HgCl}_{2}$ | 0.23 | 1.002 | - | - | 58.5 | 20 | 46.8 | 30 | 38.3 | 40 | " |
|  | $3 \cdot 55$ | 1.033 | 76.75 | 10 | 59.2 | " | 46.6 | " | 38.3 | " | ، |

VISCOSITY OF SOLUTIONS.

| Salt. | Percentage by weight of salt in solution. | Density. | $\mu$ | $t$ | $\mu$ | $t$ | $\mu$ | $t$ | $\mu$ | $t$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{HNO}_{3}$ | 8.37 | ı. 067 | 66.4 | 15 | 54.8 | 25 | 45.4 | 35 | 37.6 | 45 | Wagner. |
|  | 12.20 | 1.116 | 69.5 | ، | 57.3 | " | 47.9 | 3 | 40.7 | 4 | Wagner. |
|  | 28.31 | 1.178 | So. 3 | " | 65.5 | " | 54.9 | " | 46.2 | " | " |
|  | 7.87 | 1.065 | 77.8 | 15 | 61.0 | 25 | 50.0 | 35 | 41.7 | 45 | " |
|  | 15.50 | 1.130 | 95.1 |  | 75.0 | " | 60.5 | \% | 49.8 | " | " |
|  | 23.43 | 1.200 | 122.7 | " | 95.5 | " | $77 \cdot 5$ | ، | $64 \cdot 3$ | ، | " |
| $\mathrm{KCi}$ | 10.23 | - | 70.0 | 10 | 46.1 | 30 | 33.1 | 50 | - | - | Sprung. |
|  | 22.21 | - | 70.0 | " | 48.6 | " | 36.4 | " | - | - | " |
| $\begin{gathered} \mathrm{KBr} \\ " \\ \hline \end{gathered}$ | 14.02 | - | 67.6 | 10 | 44.8 | 30. | 32.1 | 50 | - | - | " |
|  | 23.16 | - | 66.2 | " | 44.7 |  | 33.2 | " | - | - | " |
|  | 34.64 | - | 66.6 | " | 47.0 | " | 35.7 | " | - | - | " |
| $\underset{، ~}{\mathrm{KI}}$ | 8.42 | - | 69.5 | 10 | 44.0 | 30 | 31.3 | 50 | - | - | " |
|  | 17.01 | - | 65.3 | " | 42.9 |  | 3 I .4 |  | - | - | " |
| " | 33.03 | - | 61.8 | " | 42.9 | " | 32.4 | " | - | - | " |
|  | 45.98 | - | 63.0 | " | 45.2 | " | $35 \cdot 3$ | " | - | - | " |
| " | 54.00 | - | 68.8 | " | 48.5 | " | 37.6 | " | - | - | " |
| $\mathrm{KClO}_{3}$ | $3 \cdot 51$ | - | 71.7 | 10 | 44.7 | 30 | 31.5 | 50 | - | - | " |
|  | 5.69 | - |  | " | 45.0 | " | 3 I .4 | " | - | - | " |
| $\underset{\text { " }}{\mathrm{KNO}_{3}}$ | 6.32 | - | 70.8 | 10 | 44.6 | 30 | 3 I .8 | 50 |  | - | " |
|  | 12.19 | - | 68.7 | " | 44.8 | " | 32.3 | " | - | - | " |
|  | 17.60 | - | 68.8 | " | 46.0 | " | 33.4 | " | - | - | " |
| $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 5.17 | - | 77.4 | 10 | 48.6 | 30 | $34 \cdot 3$ | 50 | - | - | * |
|  | 9.77 | - | 81.0 | " | 52.0 |  | 36.9 | ، | - | - | " |
| $\mathrm{K}_{2} \mathrm{CrO}_{4}$ | 11.93 | - | 75.8 | 10 | 62.5 | 30 | 41.0 | 40 | - | - | " |
|  | 19.61 | - | 85.3 | ، | 68.7 | ، | 47.9 | " | - | - | " |
|  | 24.26 | 1.233 | 97.8 | " | 74.5 | " | 54.5 | " | - | - |  |
|  | 32.78 | - | 109.5 | " | 88.9 | " | 62.6 | " | - | - | Sprung. |
| $\underset{4}{\mathrm{~K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}}$ |  | $1.032$ |  | 10 |  | 20 |  | 30 |  |  |  |
|  | 6.97 | $\text { I. } 049$ | 73.1 | " | 56.4 | " | $45 \cdot 5$ | " | $37 \cdot 7$ | \% | 66 |
| LiCl" | 7.76 | - | 96.1 | 10 | 59.7 | 30 | 41.2 |  | - |  |  |
|  | 13.91 | - | 121.3 | " | 75.9 | ، | 52.6 | " | - | - | ${ }_{\text {Sprung }}$ |
|  | 26.93 | - | 229.4 | " | 142.1 | " | 98.0 | " | - | - | " |
| $\underset{\text { "، }}{\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2}}$ | 18.62 | 1.102 | 99.8 | 15 | 8 I .3 | 25 | 66.5 | 35 | 56.2 | 45 | Wagner. |
|  | 34.19 | 1.200 | 213.3 | ، | 164.4 | ، | 132.4 | \% | 109.9 | " | " |
|  | 39.77 | 1.430 | 317.0 | " | 250.0 | " | 191.4 | " | 158.1 | " | " |
| $\underset{\text { "، }}{\mathrm{MgSO}_{4}}$ |  | - |  | 10 | 59.0 | 30 | 40.9 | 50 | - | - |  |
|  | 9.50 | - | 130.9 | " | 77.7 | " | 53.0 | " | - | - | ${ }_{\text {Sprang }}$ |
|  | 19.32 | - | 302.2 | " | 166.4 | " | 106.0 | " | - | - |  |
| $\underset{\text { " }}{\mathrm{MgCrO}_{4}}$ | 12.31 | 1.089 | 111.3 | 10 | 84.8 | 20 | 67.4 | 30 | 55.0 | 40 | Slotte. |
|  | 21.86 | 1.164 | 167.1 | " | 125.3 | " | 99.0 | " | 79.4 | " | S ${ }^{\text {cte }}$ |
|  | 27.71 | 1.217 | 232.2 | " | I7 2.6 | " | 133.9 | " | 106.6 | " | " |
| $\underset{\text { ¢ }}{\mathrm{MnCl}_{2}}$ |  | 1.096 | 92.8 | 15 |  |  |  | 35 |  |  |  |
|  | 15.65 | 1.196 | 130.9 | " | 104.2 | " | 84.0 | ، | 68.7 | ، |  |
|  | 30.33 | $1.337$ | 256.3 | " | $193.2$ | " | 155.0 | " |  | " | " |
|  | 40.13 | I. 453 | $537 \cdot 3$ | ، | 393.4 | " | 300.4 | " | $246.5$ | " |  |

Smithsonian Tables.

VISCOSITY OF SOLUTIONS.

| Salt. | Percentage by weight solution. shun. | Density. | ${ }^{\mu}$ | $t$ | ${ }^{\mu}$ | $t$ | ${ }^{\mu}$ | $t$ | ${ }^{\mu}$ | $t$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Mn}\left(\underset{\text { ( }}{ } \mathrm{NO}_{3}\right)_{2}$ | 18.31 | I. 148 | 96.0 |  |  |  |  |  |  | 45 | Wagner. |
| " | 29.60 49.31 | $\begin{aligned} & 1.323 \\ & 1.506 \end{aligned}$ | $\begin{aligned} & 167.5 \\ & 396.8 \end{aligned}$ | "، | $\begin{aligned} & 126.0 \\ & 301.1 \end{aligned}$ | $\ddot{ }$ | $\begin{aligned} & 104.6 \\ & 221.0 \end{aligned}$ | " | 88.6 188.8 | ، |  |
| $\mathrm{MnSO}_{4}$ | 11.45 | I.147 | 129.4 | ${ }_{1}^{15}$ | 98.6 | 25 | 78.3 | 35 | 63.4 | 45 | " |
| " | 18.80 22.08 | 1.251 I. 306 | 228.6 66 r .8 | " | 172.2 474.3 | " | 1 37.1 347.9 | " | 107.4 266.8 | "' | " |
| NaCl | 7.95 | - | 82.4 | Io | 52.0 | 30 | 31.8 | 50 | - | - | Sprung. |
| " | 14.3 I | - | 94.8 | " | 60.1 | " | 36.9 | " | - | - | "، |
| " | 23.22 | - | ¢ 28.3 | " | 79.4 | " |  | " | - | - | " |
| $\mathrm{NaBr}^{\text {a }}$ |  | - |  | ${ }^{10}$ | 48.7 | 30 |  |  |  | - | " |
|  | 18.58 | - | 82.6 |  | 53.5 | " | 38.2 | " | - | - | " |
|  |  | - |  | " |  | " |  |  | - | - | " |
| NaI | 8.83 | - | 73.1 | 10 | 46.0 | 30 | 32.4 |  |  | - | " |
| " | 17.15 | - | 73.8 | " | 47.4 | " | 33.7 | " | - | - | " |
| " | 35.69 55.47 | - | 86.0 157.2 | " | 55.7 96.4 | " | 40.6 66.9 | " | - | - | "، |
|  | $55 \cdot 47$ | - | 157.2 |  |  |  | 66.9 |  | - | - | " |
| $\mathrm{NaClO}_{3}$ | 11.50 | - | 78.7 | 10 |  | 30 |  | 50 | - | - | " |
| " | 20.59 33.54 | - | 88.9 121.0 | " | 56.8 75.7 | " | 40.4 53.0 |  | - | - | " |
| $\mathrm{NaNO}_{3}$ | 7.25 | - | 75.6 | 10 | 47.9 | 30 | 33.8 | 50 | - | - | " |
| " | 12.35 | - | 81.2 | " | 51.0 | 3 | 36.1 | " | - | - | " |
| " | 18.20 | - | 87.0 | " | 55.9 | " | 39.3 | " | - | - | " |
| " | 31.55 | - | 121.2 | " | 76.2 | " | 53.4 | " | - | - | " |
| $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 4.98 | - | 96.2 | 10 | 59.0 | 30 | 40.9 | 50 | - | - | " |
| " | 9.50 | - | 130.9 | " | 77.7 |  | 53.0 | " | - | - | " |
|  | 14.03 19.32 | - | $\begin{aligned} & 187.9 \\ & 302.2 \end{aligned}$ | " | 107.4 166.4 | " | 71.1 106.0 | " | - | - | " |
| $\mathrm{Na}_{2} \mathrm{CrO}_{4}$ | 5.76 | 1.058 | 85.8 | 10 | 66.6 | 20 |  | 30 | 43.8 | 40 | Slotte. |
|  | 10.62 | 1.112 | 103.3 | " | 79.3 | " | 63.5 |  | 52.3 |  |  |
| " | 14.81 | 1.164 | 127.5 | " | 97.I | " | $77 \cdot 3$ | " | 63.0 | " | " |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 3.67 | - | 71.5 | 10 | 45.0 | 30 | 31.9 | 50 | - | - | Sprung. |
| " | 8.67 | - | 69.1 | " | 45.3 |  | 32.6 |  | - | - | " |
| " | 15.68 | - | 67.3 | " | 46.2 | " | 34.0 | "، | - | - | " |
| " | 23.37 | - | 67.4 | " | 47.7 | " | 36.1 | " | - | - | " |
| ${ }_{\text {NH4 }}{ }_{4} \mathrm{Br}$ | 15.97 | - | 65.2 | 10 | 43.2 | 30 | 31.5 | 50 | - | - | " |
|  | 25.33 36.88 | - | 62.6 | " | 43.3 | " | 32.2 | " | - | - | " |
| " | 36.88 | - | 62.4 | " | 44.6 | " | $34 \cdot 3$ | " | - | - | " |
| $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | 5.97 | - | 69.6 | ${ }^{10}$ | $44 \cdot 3$ | 30 | 3 3 .6 | 50 | - | - | " |
|  | 12.19 | - | 66.8 | " | $44 \cdot 3$ |  | 31.9 |  | - | - | " |
| " | 27.08 37.22 | - | 67.0 | " | 47.7 | " | 34.9 38.8 | " | - | - | " |
| ". | $\begin{aligned} & 37.22 \\ & 49.83 \end{aligned}$ | - | 71.7 81.1 | " | 51.2 63.3 | " | 38.8 48.9 | " | - | - | " |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 8.10 | - | 107.9 | 10 | 52.3 | 30 | 37.0 | 50 | - | - | " |
|  | 15.94 25.51 | - | $\begin{aligned} & 120.2 \\ & 148.4 \end{aligned}$ | " | 60.4 74.8 | " | 43.2 54.1 | " | - | - | " |

Smithsonian Tables.

| Salt. | Percentage by weight of salt in solution. | Density. | ${ }^{\mu}$ | $t$ | $\mu$ | $t$ | ${ }^{\mu}$ | $t$ | ${ }^{\mu}$ | $t$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\underset{\text { ( } \left.\mathrm{NH}_{4}\right)_{2} \mathrm{CrO}_{4}}{\text { "، }}$ | 10.52 | 1.063 | 79.3 | 10 | 62.4 | 20 |  | - | 42.4 | 40 | Slotte. |
|  | 19.75 28.04 | I.120 I.173 | 88.2 101.1 | " | 70.0 80.7 | " | 57.8 60.8 | $3{ }^{\circ}$ | $\begin{aligned} & 48.4 \\ & 56.4 \end{aligned}$ | - | " |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$" | 6.85 | 1.039 | 72.5 | 10 | 56.3 | 20 | 45.8 | 30 | 38.0 | 40 | " |
|  | 13.00 | 1.078 | 72.6 | " | 57.2 | " | 46.8 | " | 39.1 |  | " |
|  | 19.93 | I. 126 | 77.6 | " | 58.8 | " | 48.7 | " | 40.9 | " | " |
| $\begin{gathered} \mathrm{NiCl}_{2} \\ " \end{gathered}$ | 11.45 | I. 109 | 90.4 | 15 |  | 25 |  | 35 | 48.2 | 45 | Wagner. |
|  | 22.69 30.40 | 1.226 I. 337 | 140.2 229.5 | ، | $\begin{aligned} & 109.7 \\ & 171.8 \end{aligned}$ | " | 87.8 139.2 | " | 72.7 111.9 | " | " |
| $\underset{"}{\mathrm{Ni}\left(\mathrm{NO}_{3}\right)_{2}}$ | 16.49 | 1.136 | 90.7 | 15 | 70.1 | 25 | 57.4 | 35 | 48.9 | 45 | " |
|  | 30.01 | I. 278 | ${ }_{1} 135.6$ |  | 105.9 |  | 85.5 |  | 70.7 152 |  | " |
|  | 40.95 | I. 388 | 222.6 | " | 169.7 | " |  |  | 152.4 | " |  |
| $\mathrm{NiSO}_{4}$ | 10.62 | 1.092 | 94.6 | 15 | 73.5 | 25 | 60.1 | 35 | 49.8 | 4.5 | " |
|  | 18.19 25.35 | 1.198 1.314 | 154.9 298.5 | ، | 119.9 <br> 224.9 | " | 99.5 173.0 | " | 75.7 152.4 | " | " |
|  |  |  |  |  |  |  |  |  |  |  |  |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$ | 17.93 | 1.179 | 74.0 | ${ }_{1}^{15}$ | $59 \cdot 1$ | ${ }^{25}$ | $48.5$ | 35 | $40 \cdot 3$ | 45 | " |
|  | 32.22 | 1.362 | 91.8 |  | $72.5$ |  | $59.6$ |  | $50.6$ |  | " |
| $\underset{\text { "، }}{\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}}$ | 10.29 | 1.088 | 69.3 | ${ }^{1} 5$ |  | ${ }^{25}$ |  | 335 |  | 45 |  |
|  | 21.19 32.61 | I.124 I. 307 | 87.3 116.9 |  | $\begin{aligned} & 69.2 \\ & 93 \cdot 3 \end{aligned}$ | " | 57.8 76.7 | " | 48.1 62.3 |  | " |
| $\mathrm{ZnCl}_{2}$ | 15.33 | 1.146 | 93.6 | 15 | 72.7 | 25 | 57.8 | 35 | 48.2 | 45 | " |
|  | 23.49 | 1.229 | 111.5 |  | 86.6 |  | 69.8 | ، | 57.5 |  | " |
|  | 33.78 | 1.343 | 151.7 | " | 117.9 | " | 90.0 | " | 72.6 | " | " |
| $\begin{gathered} \mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2} \\ \text { "، } \end{gathered}$ | 15.95 | I.115 | 80.7 | ${ }_{1} 15$ |  |  |  | 35 |  | 45 |  |
|  | 30.23 44.50 | I.229 I.437 | 104.7 167.9 | " | 85.7 130.6 | "" | 69.5 105.4 | " | 57.7 87.9 | " | " |
| $\begin{gathered} \mathrm{ZnSO}_{4} \\ \text { "، } \end{gathered}$ | 7.12 | I. 106 | 97.1 | ${ }^{1} 5$ | 79.3 | 25 | 62.7 | 35 | 51.5 | 45 | " |
|  | 16.64 | 1.195 | 156.0 | " | 118.6 |  | 94.2 |  | 73.5 | " | " |
|  | 23.09 | 1.281 | 232.8 | " | 177.4 | " | 135.2 | " | 108.1 | " | " |

Smithsonian Tables.

Table 158.
SPECIFIC VISCOSITY.*.

| Dissolved salt. | Normal solution. |  | $\frac{1}{2}$ normal. |  | 4 normal. |  | $\frac{1}{8}$ normal. |  | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 產 |  | 芴 ¢ ¢ |  |  |  |  |  |  |
| Acids : $\mathrm{Cl}_{2} \mathrm{O}_{3}$ | 1.0562 | 1.012 | 1.0283 | 1.003 | I. 0143 | 1.000 | 1.0074 | 0.999 | Reyher. |
| HCl | 1.0177 | 1.067 | 1.0092 | 1.034 | 1.0045 | 1.017 | 1.0025 | 1.009 |  |
| $\mathrm{HClO}_{3}$ | 1.0485 | 1.052 | I. 0244 | 1.025 | 1.0126 | 1.014 | I. 0064 | 1.006 |  |
| $\mathrm{HNO}_{3}$ | 1.0332 | 1.027 | 1.0168 | I.OII | 1.0086 | 1.005 | 1.0044 | 1.003 | " ${ }^{\text {c }}$ |
| $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 1.0303 | 1.090 | I. 1254 | 1.043 | 1.0074 | 1.022 | 1.0035 | 1.008 | Wagner. |
| Aluminium sulphate | 1.0550 | 1.406 | 1.0278 | 1.178 | 1.0138 | 1.082 | I. 0068 | 1.038 | " |
| Barium chloride . . | 1.0884 | 1.123 | 1.0441 | 1.057 | 1.0226 | 1.026 | I.OI 14 | 1.013 | " |
| " nitrate ${ }^{\text {. }}$ |  |  | 1.0518 | 1.044 | 1.0259 | 1.021 | 1.0130 | 1.008 | " |
| Calcium chloride | 1.0446 | I.I 56 | 1.0218 | 1.076 | I. 0105 | 1.036 | 1.0050 | 1.017 |  |
| nitrate | 1.0596 | 1.117 | 1.0300 | 1.053 | I.OI 51 | 1.022 | 1.0076 | 1.008 | " |
| Cadmium chloride | 1.0779 | 1.I34 | I. 0394 | 1.063 | 1.0197 | 1.031 | 1.0098 | 1.020 | " |
| " nitrate | 1.0954 | 1.165 | 1.0479 | 1.074 | I. 0249 | 1.038 | I.OII9 | 1.018 | " |
| " sulphate. | 1.0973 | 1.348 | 1.0487 | 1.157 | 1.0244 | 1.078 | 1.0120 | 1.033 | " |
| Cobalt chloride . | 1.0571 | 1.204 | 1.0286 | 1.097 | I. 0144 | 1.048 | 1.0058 | 1.023 | ' |
| " nitrate | 1.0728 | 1.166 | 1.0369 | 1.075 | I. 1.184 | 1.032 | 1.0094 | I. 1.18 | " |
| " sulphate | 1.0750 | 1. 354 | 1.0383 | 1.160 | I.OI93 | 1.077 | 1.0110 | 1. 040 | * |
| Copper chloride | 1.0624 | 1.205 | 1.0313 | 1.098 | 1.01 $5^{8}$ | 1.047 | 1.0077 | 1.027 | " |
| "، nitrate | 1.0755 | 1.179 | 1.0372 | 1.080 | 1.0185 | 1.040 | 1.0092 | 1.018 | " |
| " sulphate | 1.0790 | 1.358 | 1.0402 | 1.160 | 1.0205 | 1.080 | I. 0103 | 1.038 | " |
| Lead nitrate . | 1.1380 | I.IOI | 0.0699 | 1.042 | 1.0351 | 1.017 | I. 0175 | 1.007 | " |
|  | 1.0243 | 1.142 | 1.0129 | 1.066 | 1.0062 | $1.031$ | $1.0030$ |  |  |
| " sulphate | I. 0453 | 1.290 | 1.0234 | 1.137 | I.OII 5 | 1.065 | $1.0057$ | 1.032 | " |
| Magnesium chloride | 1.1375 | 1.201 | I. 1.188 | 1.094 | 1.0091 | I. 044 | 1.0043 | 1.021 | " |
| " nitrate. | 1.0512 | 1.171 | 1.0259 | 1.082 | 1.01 30 | 1.040 | 1.0066 | 1.020 | " |
| " sulphate | 1.0584 | 1.367 | 1.0297 | 1.164 | I. 0152 | 1.078 | 1.0076 | 1.032 |  |
| Manganese chloride | 1.0513 | 1. 209 | I. 0259 | 1.098 | I.OI 25 | 1.048 | 1.0063 | 1.023 | " |
| " nitrate . | 1.0690 | I.183 | 1.0349 | 1.087 | 1.0174 | 1.043 | 1.0093 | 1.023 | " |
| " sulphate | 1.0728 | I. 364 | 1.0365 | 1.169 | 1.0179 | 1.076 | 1.0087 | 1.037 |  |
| Nickel chloride | 1.0591 | 1.205 | 1.0308 | 1.097 | I.OI 44 | 1.044 | 1.0067 | 1.021 |  |
| ": nitrate. | 1.0755 | 1.180 | 1.0381 | I. 084 | 1.0192 | 1.042 | 1.0096 | I.OI9 | " |
| " sulphate. . | 1.0773 | 1.361 | 1.0391 | 1.16I | 1.0198 | 1.075 | 1.0017 | 1.032 | " |
| Potassium chloride . | 1.0466 | 0.987 | 1.0235 | 0.987 | 1.0117 | 0.990 | I. 0059 | 0.993 | " |
| " chromate | 1.0935 | 1.113 | 1.0475 | I. 053 | I.024I | 1.022 | 1.0121 | 1.012 | " |
| " nitrate | 1.0605 | 0.975 | 1.0305 | 0.982 | I.0161 | 0.987 | 1.0075 | 0.992 | " |
| " sulphate | 1.0664 | I.IO5 | 1.0338 | 1.049 | 1.0170 | 1.021 | 1.0084 | 1.008 |  |
| Sodium chloride. | 1.0401 | 1.097 | 1.0208 | 1.047 | 1.0107 | 1.024 | 1.0056 | I. 123 | Reyher. |
| " ${ }^{\text {a }}$ bromide. | 1.0786 | 1.064 | 1.0396 | 1.030 | 1.0190 | 1.015 | 1.0100 | 1.008 |  |
| " chlorate | 1.0710 | 1.090 | 1.0359 | 1.042 | I.OI80 | 1.022 <br> 1.012 <br> 1.026 | 1.0092 1.0071 | 1.012 1.007 | " |
| "، nitrate | 1.0554 1.1386 | 1.065 | 1.0281 1.0692 | 1.026 | I.OI 41 <br> I.O34 | 1.012 | 1.0071 1.0173 | 1.007 1.000 | Wagner. |
| Strontium chloride | 1.0676 | I.I4I | 1.0336 | 1.067 | 1.0171 | 1.034 | 1.0084 | 1.014 | " |
| " nitrate | 1.0822 | I.II 5 | 1.0419 | 1.049 | 1.0208 | 1.024 | 1.0104 | I.OII |  |
| Zinc chloride | 1.0590 | 1.189 | 1.0302 | 1.096 | 1.0152 | 1.053 | 1.0077 | 1.024 | " |
| " nitrate. | I. 0758 | 1.164 | 1.0404 | 1.086 | I.0191 | 1.039 | 1.0096 | $1.019$ |  |
| " sulphate. . | 1.0792 | 1.367 | 1.0402 | 1.173 | I.OI98 | 1.082 | 1.0094 | 1.036 | " |

[^24]The values of $\mu$ given in the table are $10^{6}$ times the coefficients of viscosity in C. G. S. units.

| Substance. | $\xrightarrow{\text { Temp }}$ | $\mu$ | Reference. | Substance. | ${ }_{\text {comp }}^{\text {Temp }}$ |  | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetone. | 18.0 | 78. | 1 | Ether | 16.1 | 73.2 | I |
| Air* | -21.4 | 163.9 | 2 |  | 36.5 | 79.3 | 1 |
|  | 0.0 | 173.3 | 2 | Ethyl chloride. | -. | 93.5 | 4 |
| * | 15.0 | 180.7 | 2 | Ethyl iodide. | 72.3 | 216.0 | 3 |
| * | 99.1 | 220.3 | 2 | Ethylene. | 0.0 | 96.1 | 2 |
| . | 182.4 | 255.9 | 2 | Helium. | 0.0 | 189.1 | 5 |
| ' . . . . . . . . | 302.0 | 299.3 | 2 |  | 15.3 | 196.9 | 5 |
| Alcohol, Methyl | 66.8 | 135. | 3 | ، | 66.6 | 234.8 | 5 |
| Alcohol, Ethyl. . | 78.4 | 142 . | 3 | " .... | 184.6 | 269.9 | 5 |
| Alcohol, Propyl, |  |  |  | Hydrogen. | -20.6 | 8 8 .9 | 2 |
| norm............ | 97.4 | 142. | 3 |  | 0.0 | 86.7 | 10 |
| Alcohol, Isopropyl. . | 82.8 | 162. | 3 | " | 15. | 88.9 | 2 |
| Alcohol, Butyl,norm. | 116.9 | 143. | 3 | " | 99.2 | 105.9 | 2 |
| Alcohol, Isobutyl. . | 108.4 | 144. | 3 | " 6 | 182.4 | 121.5 | 2 |
| Alcohol, Tert. butyl. | 82.9 | 160. | 3 | '6 | 302.0 | 139.2 | 2 |
| Ammonia.... | 0.0 | 96. | 4 | Krypton. | 15.0 | 246. | II |
|  | 20.0 | 108. | 4 | Mercury. | 270.0 | $489 . \dagger$ | 8 |
| Argon | 0.0 | 210.4 | 5 |  | 300.0 | $532 . \dagger$ | 8 |
|  | 14.7 | 220.8 | 5 | "6 | 330.0 | $582 . \dagger$ | 8 |
| ، | 17.9 | 224. I | 5 | "6 | 360.0 | $627 . \dagger$ | 8 |
| , | 99.7 | 273.3 | 5 | " . | 390.0 | $671 . \dagger$ | 8 |
| " ... | 183.7 | 322.1 | 5 | Methane. | 20.0 | 120.1 | 4 |
| Benzene | -. | 70. | ro | Methyl chloride | 0.0 | 98.8 | 2 |
|  | 19.0 | 79. | 6 |  | 15.0 | 105.2 | 2 |
|  | 100.0 | 118. | 6 | " ${ }^{6}$ | 302.0 | 213.9 | 2 |
| Carbon bisulphide | 16.9 | 92.4 | I | Methyl iodide. | 44.0 | 232. | 3 |
| Carbon dioxide. . | -20.7 | 129.4 | 2 | Nitrogen. | -2I. 5 | 156.3 | 7 |
|  | 0. | 142. | 10 |  | $\bigcirc$. | 166. | 10 |
| " ${ }^{4}$ | 15.0 | 145.7 | 2 | " | 10.9 | 170.7 | 7 |
| " ${ }^{\text {" }}$ | 99.1 | 186. I | 2 | " | 53.5 | 189.4 | 7 |
| " ${ }^{\text {a }}$ | 182.4 | 222.1 | 2 | Nitric oxide. | $\bigcirc$. | 179. | 10 |
| "6 " ... | 302.0 | 268.2 | 2 | Nitrous oxide. | 0. | 138. | 10 |
| Carbon monoxide. | 0.0 | 163.0 | 10 | Oxygen. | - | 189. | 10 |
|  | 20.0 | 184.0 | 4 |  | 15.4 | 195.7 | 7 |
| Chlorine. | 0.0 | 128.7 | 4 | Water Vap | $53 \cdot 5$ | 215.9 | 7 |
|  | 20.0 | 147.0 | 4 | Water Vapor | 0.0 | 90.4 | 1 |
| Chloroform | 0.0 | 95.9 | I |  | 16.7 | 96.7 | 1 |
|  | 17.4 | 102.9 | 1 |  | 100.0 | 132.0 | 9 |
| ، ....... | 61.2 | 189.0 | 3 | Xenon. | 15. | 222. | II |
| Ether. | 0.0 | 68.9 | I |  |  |  |  |



8 Koch, Wierl. Ann. 14, 1881, 19, 1883.
I Puluj, Wien. Ber. 69 (2), 1874.
2 Breitenbach, Ann. Phys. 5, 1901.
3 Steudel, Wied. Ann. 16, 1882
4 Graham, Philos. Trans. Lond. 1846, III.
5 Schultze, Ann. Phys. (4), 5, 6, 1901.
6 Schumann, Wied. Ann. 23, 1884.

9 Meyer-Schumann, Wied. Ann. 13, 188ı. io Jeans, assumed mean, 1916.
II Rankine, 1910.
12 Vogel (Eucken, Phys. Z. 14, 1913). For summaries see: Fisher, Phys. Rev. 24, 1904; Chapman, Phil. Tr. A. 211 , ıgıI; Gilchrist, Phys. Rev. I, 1913. Schmidt, Ann. d. Phys. 30, 1909.

* Gilchrist's value of the viscosity of air may be taken as the most accurate at present available. His value at $20.2^{\circ} \mathrm{C}$ is $\mathrm{I} .812 \times 10^{-4}$. The temperature variation given by Holman (Phil. Mag. 1886) gives $\mu=1715.50 \times 10^{-7}\left(1+.00275 t-.000000344^{2}\right)$. See Phys. Rev. I, 1913. Millikan (Ann. Phys. 4I, 759, 1913) gives for the most accurate value $\mu_{t}=0.00018240$ -$0.000000493(23-t)$ when $(23>1>12)$ whence $\mu_{20}=0.0001809 \pm 0.1 \%$. For $\mu_{0}$ he gives 0.0001711.
$\dagger$ The values here given were calculated from Koch's table (Wied. Ann. 19, p. 869, 1883) by the formula $\mu=489[1+746(t-270)]$.
Smithsonian tables.

VISCOSITY OF GASES.

## Variation of Viscosity with Pressure and Temperature.

According to the kinetic theory of gases the coefficient of viscosity $\mu=\frac{1}{c}(\rho \bar{c} l), \rho$ being the density, $\bar{c}$ the average velocity of the molecules, $l$ the average path. Since $l$ varies inversely as the number of molecules per unit volume, $\rho l$ is a constant and $\mu$ should be independent of the density and pressure of a gas (Maxwell's law). This has been found true for ordinary pressures; below $\frac{1}{60}$ atmosphere it may fail, and for certain gases it has been proved untrue for high pressures, e.g., $\mathrm{CO}_{2}$ at $33^{\circ}$ and above 50 atm . See Jeans, "Dynamical Theory of Gases."
$\bar{c}$ depends only on the temperature and the molecular weight; viscosity should, therefore, increase with the pressures for gases. $\bar{c}$ varies as the $\sqrt{T}$, but $\mu$ has been found to increase much more rapidly. Meyer's formula, $\mu_{i}=\mu_{0}(\mathrm{x}+a t)$, where $a$ is a constant and $\mu_{0}$ the viscosity at $0^{\circ} \mathrm{C}$, is a convenient approximate relation. Sutherland's formula (Phil. Mag. 3I, 1893).

$$
\mu_{t}=\mu_{o} \frac{273+C}{T+C}\left(\frac{T}{273}\right)^{\frac{3}{2}},
$$

is the most accurate formula in use, taking in account the effect of molecular forces. It holds for temperatures above the critical and for pressures following approximately Boyle's law. It may be thrown into the form $T=K T^{\frac{3}{2}} / \mu-C$ which is linear in terms of $T$ and $T^{\frac{3}{2}} / \mu$, with a slope equal to $K$ and the ordinate intercept equal to $-C$. See Fisher, Phys. Rev. 24, 1907, from which most of the following table is taken. Onnes (see Jeans) shows that this formula does not represent Helium at low temperatures with anything like the accuracy of the simpler formula $\mu=\mu_{0}(T / 273 \cdot \mathrm{I})^{n}$.

The following table contains the constants for the above three formulae, $T$ being always the absolute temperature, Centigrade scale.

| Gas. | C | $\times{ }^{K}{ }_{10}{ }^{7}$ | $a$ | $n *$ | Gas. | C | $\times{ }^{K}{ }_{10^{7}}$ | a | $n^{*}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Air. | 124 | 150 | - | . 754 | Hydrogen. | 72 | 66 | - | . 69 |
| Argon | 172 | 206 | - | .819 | Krypton. | 188 | - | - | - |
| Carbon mo- |  |  |  |  | Neon. | 252 | - | - | - |
| noxide. | 102 | 135 | . 00269 | . 74 | Nitrogen. | I IO | 143 | . 00269 | . 74 |
| Carbon dioxide | 240 | 158 | . 00348 | . 98 | Nitrous oxide, |  |  |  |  |
| Chloroform | 454 | 159 | - | - | $\mathrm{N}_{2} \mathrm{O}$. | 313 | 172 | . $00345^{\circ}$ | . 93 |
| Ethylene. | 226 | 106 | . 00350 | - | Oxygen. | 131 | 176 | - | . 79 |
| Helium. | 80 | 148 | - | . 683 | Xenon. | 252 | - | - | - |
| Helium. | - | - | - | . 647 |  |  |  |  |  |

*The authorities for $n$ are: Air, Rayleigh; Ar, Mean, Rayleigh, Schultze; $\mathrm{CO}, \mathrm{CO}_{2}, \mathrm{~N}_{2}$, $\mathrm{N}_{2} \mathrm{O}$, von Obermayer; Helium, Mean, Rayleigh, Schultze; 2 d value, low temperature work of Onnes; $\mathrm{H}_{2}, \mathrm{O}_{2}$, Mean, Rayleigh, von Obermayer.

Smithsonian Tables.

DIFFUSION OF AN AQUEOUS SOLUTION INTO PURE WATER.
If $k$ is the coefficient of diffusion, $d S$ the amount of the substance which passes in the time $d t_{\text {, }}$ at the place $x$, through $q$ sq. cm . of a diffusion cylinder under the influence of a drop of concentration $d c / d x$, then

$$
d S=-k q \frac{d c}{d x} d t
$$

$k$ depends on the temperature and the concentration. c gives the gram-molecules per liter. The unit of time is a day.

| Substance. | c | $t^{\circ}$ | $k$ | 密 | Substance. | c | $t^{\circ}$ | $k$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bromine . | 0.1 | 12. | 0.8 | 1 | Calcium chloride | 0.864 | 8.5 | 0.70 | 4 |
| Chlorine. |  | 12. | 1.22 |  |  | 1.22 | 9. | 0.72 |  |
| Copper sulphate | " | 17. | $0.39$ | 2 | "، "، | 0.060 | 9. | 0.64 | " |
| Glycerine |  | 10.14 | 0.357 | 3 | Copper sulphate | 0.047 | 9. | 0.68 | " |
| Hydrochloric acid Iodine | " | 12. | 2.21 $(0.5)$ | 2 | Copper sulphate | 1.95 0.95 | 17. | 0.23 0.26 | $\stackrel{2}{ }$ |
| Iodine ${ }^{\text {I }}$ Nitric acid |  | 12. 19.5 | $(0.5)$ 2.07 | 1 |  | 0.95 0.30 | 17. | 0.26 0.33 | " |
| Potassium chloride | " | 17.5 | 1.38 | 2 | " ${ }^{\text {a }}$. | 0.005 | 17. | 0.47 | " |
| " hydroxide |  | 13.5 | 1.72 | 2 | Glycerine | $2 / 8$ | 10.14 | 0.354 | 3 |
| Silver nitrate |  | 12. | 0.985 | 2 |  | 6/8 | 10.14 | 0.345 | " |
| Sodium chloride |  | 15.0 | 0.94 | 2 |  | 10/8 | 10.14 | 0.329 | " |
| Urea |  | 14.8 | 0.97 | 3 |  | 14/8 | 10.14 | 0.300 | " |
| Acetic acid | 0.2 | 13.5 | 0.77 | 4 | Hydrochloric acid | 4.52 | 11.5 | 2.93 | $\stackrel{4}{4}$ |
| Barium chloride Glycerine | " | $8 .$ | 0.66 3.55 | 4 |  | 3.16 0.945 | II. II. | 2.67 2.12 | "، |
| Sodium actetate | " | 12. | 0.67 | 5 | " " | 0.945 0.387 | II. | 2.02 | " |
| " chloride |  | 15.0 | 0.94 | 2 | ". " . | 0.250 | 11. | 1.84 | " |
| Urea |  | 14.8 | 0.969 | 3 | Magnesium sulphate | 2.18 | 5.5 | 0.28 | 4 |
| Acetic acid | 1.0 | 12. | 0.74 | 6 |  | 0.541 | 5.5 | 0.32 |  |
| Ammonia |  | 15.23 | I. 54 | 7 |  | 3.23 | 10. | 0.27 | " |
| Formic acid | " | 12. | 0.97 |  | Potassium hydroxide | 0.402 | 10. | 0. 34 | " |
| Glycerine |  | 10.14 | 0.339 | 3 | Potassium hydroxide | 0.75 | 12. | 1.72 | 6 |
| Hydrochloric acid . | " | 12. | 2.09 | 6 |  | 0.49 | 12. | 1.70 |  |
| Magnesium sulphate Potassium bromide. |  | 7. | 0.30 | 4 | " nitrate | 0.375 | 12. | 1.70 | " |
| "" hydroxide | " | 12. | 1.13 1.72 | 6 | tra | 3.9 1.4 | 17.6 17.6 | 0.89 1.10 | " |
| Sodium chloride | " | 15.0 | 0.94 | 2 | " " . | 0.3 | 17.6 | I. 26 | " |
| " |  | 14.3 | 0.964 | 3 | " " . | 0.02 | 17.6 | 1.28 | " |
| "، hydroxide |  | 12. | 1.11 | $\stackrel{2}{2}$ | sulphate | 0.95 | 19.6 | 0.79 | " |
| Su"ar. iodide |  | 10. | 0.80 | 8 | " " . | 0.28 | 19.6 | 0.86 | " |
| Sugar ${ }^{\text {S }}$. ${ }^{\text {a }}$, |  | 12. | 0.254 | 6 | " " | 0.05 | 19.6 | 0.97 | " |
| Sulphuric acid |  | 12. | 1.12 | 6 | Silver nitrate | 0.02 | 19.6 | 1.01 | " |
| Zinc sulphate . <br> Acetic acid |  | 14.8 12. | 0.236 0.69 | 9 | Silver nitrate | 3.9 0.9 | 12. | 0.535 0.88 | " |
| Calcium chloride | ".0 | 10. | 0.68 | 8 | " ، . | 0.9 0.02 | 12. | 1.035 |  |
| Cadmium sulphate | " | 19.04 | 0.246 | 9 | Sodium chloride | 2/8 | 14.33 | I. 013 | 3 |
| Hydrochloric acid | " | 12. | 2.21 |  | " ${ }^{\text {c }}$. | 4/8 | 14.33 | 0.996 | " |
| Sodium iodide | " | Io. | 0.90 | 8 | " " | $6 / 8$ | 14.33 | 0.980 | 2 |
| Sulphuric acid |  | 12. | 1.16 | 6 | " " . | 10/8 | 14.33 | 0.948 | " |
| Zinc acetate |  | 18.05 | 0.210 | 9 | Sulphuric acid | $14 / 8$ | 14.33 | 0.917 2 | " |
| Acetic acid |  | ${ }_{12 .}^{0.04}$ | 0.120 0.68 0 | $\underline{9}$ | Sulphuric acid ${ }_{\text {"، }}$ | 9.85 4.85 |  | 2.36 1.90 | $\stackrel{2}{\prime}$ |
| Potassium carbonate | 3 ، | 10. | 0.60 | - | " ، | 2.85 | 18. | 1.90 1.60 | " |
| " hydroxid |  | 12. | 1.89 | 6 | " " | 0.85 | 18. | 1.34 | " |
| Acetic acid ${ }^{\text {a }}$ | 4.0 | 12. | 0.66 |  | " " | 0.35 | 18. | 1.32 | " |
| Potassium chloride .- |  | 10. | 1.27 | 8 | " ". . | 0.005 | 18. | I. 30 | " |
| ${ }^{1}$ Euler, Wied. Ann. |  | 1897. |  |  | awalki, | n. 5 | 894 |  |  |
| 2 Thovert, C. R. 133, 1901; 134, 1902. |  |  |  |  |  |  |  |  |  |
| 3 Heimbrodt, Diss. Leipzig, 1903. 7 Abegg, Zeitschr. Phys. Chem. II, 1893. |  |  |  |  |  |  |  |  |  |
| 4 Scheffer, Chem. Ber. 15, 1882; 16, 1883; |  |  |  |  | ; 8 Schuhmeister, W | . Be | 79 (2) | , 1879. |  |

## DIFFUSION OF VAPORS.

Coefficients of diffusion of vapors in C. G. S. units. The coefficients are for the temperatures given in the table and a pressure of 76 centimeters of mercury.*


[^25]Smithsonian Tables.

TABLE 163. - Coefficients of Diffusion for Various Gases and Vapors.*

| Gas or Vapor diffusing. | Gas or V'apor diffused into. | $\begin{aligned} & \text { Temp. } \\ & \circ \mathrm{C} . \end{aligned}$ | Coefficient of Diffusion. | Authority: |
| :---: | :---: | :---: | :---: | :---: |
| Air | Hydrogen . . | $\bigcirc$ | 0.661 | Schulze. |
| * | Oxygen . . . . . | $\bigcirc$ | 0.1775 | Obermayer. |
| Carbon dioxide | Air . . . . . . | $\bigcirc$ | 0.1423 | Loschmidt. <br> Waitz |
| "، "، | Carbon monoxide | $\bigcirc$ | 0.1360 0.1405 | Waitz. Loschmidt. |
| " ${ }^{\text {a }}$ | "، " | $\bigcirc$ | 0.1314 | Obermayer. |
| " " . . | Hydrogen . | $\bigcirc$ | 0.5437 |  |
| " " . . . | Methane . . | $\bigcirc$ | 0.1465 | " |
| " ${ }^{\text {c }}$ | Nitrous oxide . . . | $\bigcirc$ | 0.0983 | Loschınidt. |
| " " . | Oxygen . . . . . | $\bigcirc$ | 0.1802 |  |
| Carbon disulphide | Air. . | 0 | 0.0995 | Stefan. |
| Carbon monoxide | Carbon dioxide . . | $\bigcirc$ | 0.1314 | Obermayer. |
| " ${ }^{\text {" }}$ | Ethylene . . . . . . | $\bigcirc$ | 0.101 |  |
| " "\% . . . | Hydrogen . . . . . | $\bigcirc$ | 0.6422 | Loschmidt. |
| "، "، | Oxygen . . . . . . | $\bigcirc$ | 0.1802 0.1872 | Obermayer. |
| Ether . | Air . | - | 0.0827 | Stefan. |
| " | Hydrogen . . . | $\bigcirc$ | 0.3054 |  |
| Hydrogen . | Air . . . . . | $\bigcirc$ | 0.6340 | Obermayer. |
| " | Carbon dioxide ${ }^{\text {a }}$ | $\bigcirc$ | 0.5384 |  |
| * | Ethane monoxide | $\bigcirc$ | 0.6483 | " |
| " . . . . . | Ethylene . . . . . . | $\bigcirc$ | 0.4593 0.4863 | " |
| " . . . . . | Methane . . . . | $\bigcirc$ | 0.6254 | " |
| " . . . . . . | Nitrous oxide . . | $\bigcirc$ | 0.5347 | " |
| " . . . . | Oxygen . . . | - | 0.6788 | " |
| Nitrogen . . | " . . . | $\bigcirc$ | 0.1787 | " |
| Oxygen . . . . . | Carbon dioxide . . . | - | 0.1357 |  |
| " | Hydrogen . . . . . | $\bigcirc$ | $\begin{aligned} & 0.7217 \\ & 0.1710 \end{aligned}$ | Loschmidt. Obermayer. |
| Sulphur dioxide . | Nitrogen . . . . - | - | 0.1710 0.4828 | Loschmidt. |
| Water | Air . . | 8 | 0.2390 | Guglilemo. |
| " | " ${ }^{\text {c }}$ - . . . . | I8 | $\begin{aligned} & 0.2475 \\ & 0.8710 \end{aligned}$ |  |

* Compiled for the most part from a similar table in Landolt \& Börnstein's Phys. Chem. Tab.


## TABLE 164:- Diffusion of Metals into Metals.

$\frac{d v}{d t}=k \frac{d^{2} v}{d x}$; where $x$ is the distance in direction of diffusion; $v$, the degree of concentration of the diffusing metal ; $t$, the time ; $k$, the diffusion constant $=$ the quantity of metal in grams diffusing through a sq. cm. in a day when unit difference of concentration (gr. per $\mathrm{cl} . \mathrm{cm}$.) is maintained between two sides of a layer one cm . thick.

| Diffusing Metal. | Dissolving Metal | Temperature ${ }^{\circ} \mathrm{C}$. | $k$. | Diffusing Metal. | Dissolving Metal. | Temperature ${ }^{\circ} \mathrm{C}$. | $k$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Gold . | Lead | 555 | 3.19 | Platinum . | Lead | 492 | 1. 69 |
| " . | " | 492 | 3.00 | Lead . | Tin. | 555 | 3.18 |
| " . | " 6 | 251 | 0.03 | Rhodium. | Lead . | 550 | 3.04 |
| " | " | 200 | 0.008 | Tin . | Mercury | I5 | 1.22* |
| " | " | 165 | 0.004 | Lead . | " | 15 | 1.0* |
| " | Bismuth | 100 | 0.00002 | Zinc - | " | 15 | 1.0* |
| " | Bismuth | 555 | 4.52 | Sodium . |  | 15 | 0.45* |
|  | Tin . | 555 | 4.65 | Potassium | " | 15 | 0.40* |
| Silver . | " | 555 | 4.14 | Gold | " | 15 | 0.72* |

From Roberts-Austen, Philosophical Transactions, 187A, p. 383, 1896.
*These values are from Guthrie.

Table 165.

## SOLUBILITY OF INORGANIC SALTS IN WATER; VARIATION WITH THE TEMPERATURE.

The numbers give the number of grams of the anhydrous salt soluble in 1000 grams of water at the given temperatures.

| Salt. | Temperature Centigrade. |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\bigcirc$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ | $90^{\circ}$ | $100^{\circ}$ |
| $\mathrm{AgNO}_{3}$ | 1150 | 1600 | 2150 | 2700 | 3350 | 4000 | 4700 | 5500 | 6500 | 7600 | 2100 |
| $\mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 313 | 335 | 362 | 404 | 457 | 521 | 591 | 662 | 731 | 808 | 891 |
| $\mathrm{Al}_{2} \mathrm{~K}_{2}\left(\mathrm{SO}_{4}\right)_{4}{ }^{\text {a }}$ | 30 |  |  | 84 |  |  | 248 | - |  | - | 1540 |
| $\mathrm{Al}_{2}\left(\mathrm{NH}_{4}\right)_{2}\left(\mathrm{SO}_{4}\right)_{4}$ | 26 | 45 | 66 | 91 | 124 | I 59 | 211 | 270 | 352 | - |  |
| $\mathrm{B}_{2} \mathrm{O}_{3}$. | 11 | 15 | 22 |  | 40 |  | 62 |  | 95 |  | 157 |
| $\mathrm{BaCl}_{2}$ | 316 | 333 | 357 | 382 | 408 | 436 | 464 | 494 | 524 | 556 | 588 |
| $\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}$ | 50 | 70 | 92 | 116 | 142 | 171 | 203 | 236 | 270 | 306 | 342 |
| $\mathrm{CaCl}_{2}$ | 595 | 650 | 745 | 1010 | 1153 |  | 1368 | 1417 | 1470 | 1527 | 1590 |
| $\mathrm{CoCl}_{2}$ | 405 | 450 | 500 | 565 | 650 | 935 | 940 | 950 | 960 |  | 1030 |
| $\mathrm{CsCl}^{\text {. }}$ | 1614 | 1747 | 1865 | 1973 | 2080 | 2185 | 2290 | 2395 | 2500 | 2601 | 2705 |
| $\mathrm{CsNO}_{3}$ | 93 | I49 | 230 | 339 | 472 | 644 | 838 | 1070 | 1340 | 1630 | 1970 |
| $\mathrm{Cs}_{2} \mathrm{SO}_{4}$ | 1671 | 1731 | 1787 | 1841 | 1899 | 1949 | 1999 | 2050 | 2103 | 2149 | 2203 |
| $\mathrm{Cu}\left(\mathrm{NO}_{3}\right)_{2}$ | 818 |  | 1250 |  | 1598 |  | 1791 |  | 2078 |  | - |
| $\mathrm{CuSO}_{4}$ | 149 | - |  | 255 | 295 | 336 | 390 | 457 | 535 | 627 | 735 |
| $\mathrm{FeCl}_{2}$. | - | - | 685 |  | - | 820 |  |  | 1040 | 1050 | 1060 |
| $\mathrm{Fe}_{2} \mathrm{Cl}_{6}$ | 744 | 819 | 918 | - | - | 3151 | - | - | 5258 | - | 5357 |
| $\mathrm{FeSO}_{4}$ | 156 | 208 | 264 | 330 | 402 | 486 | 550 | 560 | 506 | 430 |  |
| $\mathrm{HgCl}_{2}$ | 43 | 66 | 74 | 8 | +96 | ${ }_{-13}$ | 139 860 1 | 173 | 243 | 371 | 540 1050 |
| $\mathrm{K}^{\mathrm{Br}}$. | 540 | - | 650 |  | 760 | - | 860 | - | 955 |  | 1050 |
| $\mathrm{K}_{2} \mathrm{CO}_{3}$ | 1050 |  |  | II 40 | 1170 | 121 | 1270 | 1330 | 1400 | 1470 | 1560 |
| ${ }^{\mathrm{KCl}}$ - | 285 | 312 | 343 | 373 | 401 | 429 | 455 | 483 | 510 | 538 | 566 |
| $\mathrm{KClO}_{3}$ | 33 | 50 | 71 | 101 | 145 | 197 | 260 | 325 | 396 | 475 | 560 |
| $\mathrm{K}_{2} \mathrm{CrO}_{4}$. | 589 | 609 | 629 | 650 | 670 | 690 | 710 | 730 | 751 | 77 I | 791 |
| $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 50 | 85 | 131 |  | 292 |  | 505 |  | 730 | - | 1020 |
| $\mathrm{KHCO}_{3}$. | 225 | 277 | 332 | 390 | 453 1600 | 522 1680 | 600 |  |  | 10 | O |
| $\mathrm{KNO}_{3}{ }^{\text {a }}$ | 1279 133 | + 209 | + 416 | $\begin{array}{r} \\ 458 \\ \hline\end{array}$ | $\begin{array}{r} \\ 6 \\ \hline\end{array}$ | 855 | 1099 | 1380 | 1690 | 2040 | 2460 |
| $\mathrm{KOH}^{\text {, }}$ | 970 | 1030 | II20 | 1260 | 1360 | 1400 | 1460 | 1510 | I 590 | 1650 | 1780 |
| $\mathrm{K}_{2} \mathrm{PtCl}_{6}$. | 7 | 9 | 11 | 14 | 18 | 22 | 26 | 32 | 38 | 45 | 52 |
| $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 74 | 92 | 111 | 130 | 148 | 165 | $1 \mathrm{~S}_{2}$ | 198 | 214 | 228 | 241 |
| LiOH | 127 | 127 | 128 | 129 | 130 | 133 | ${ }^{1} 38$ | 144 | 153 | - | 175 |
| $\mathrm{MgCl}_{2}$ | 528 | 535 | 545 | - | 575 | - | 610 |  | 660 | - | 730 |
| $\mathrm{MgSO}_{4} \cdot$ - (7aq) | 260 | 309 | 356 | 409 | 456 |  | - | - | 612 |  |  |
| ${ }^{\text {" }}$ - $\cdot$ (6aq) | 408 | 422 | 439 | 453 |  | 504 | 550 | 596 | 642 | 689 | 738 |
| $\mathrm{NH}_{4} \mathrm{Cl}{ }_{-} \cdot$ | 297 | 333 | 372 | 414 | $45^{8}$ | 504 | $55^{2}$ | ${ }^{6} 2$ | ${ }^{656}$ | ${ }^{71}$ | 773 |
| NH4 ${ }^{\text {NHCO}}$ | 119 1183 | 159 | 210 | 270 2418 | 2970 | - ${ }^{-} 40$ ? | 4300? | 5130? | 5800 | 7400 | 8710 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$. | 706 | 730 | 754 | 780 | 810 | ¢ 84 | 880 | 916 | 953 | 992 | 1033 |
| NaBr . | 795 | 845 | 903 |  | 1058 | 1160 | 1170 | - | 1185 |  | 1205 |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7}$ | - | 16 | - | 39 |  | 105 | 200 | 244 | 314 | 408 | 523 |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ - . (roaq) | 71 | 126 | 214 | 409 |  |  |  |  |  |  |  |
| " . . ${ }^{\text {(7aq) }}$ | 204 | 263 | 335 | 435 | (raq) | 475 | 464 | 458 | 452 | 452 | 452 |
| $\stackrel{\mathrm{NaCl}}{ }$ | 356 | 357 | 358 | 360 | ${ }^{363}$ | 367 | 371 | 375 | 380 | 385 | $\begin{array}{r}391 \\ 2040 \\ \hline 180\end{array}$ |
| $\mathrm{NaClO}_{3}$. | 820 | 890 | 990 | - | 1235 | - | 1470 |  | 1750 |  | 2040 |
| $\mathrm{Na}_{2} \mathrm{CrO}_{4}$ | 317 | 502 | 900 |  | 960 | 1050 | 1150 |  | 1240 3860 |  |  |
| $\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ NaHCO | 1630 69 | 1700 82 | 1800 96 | 1970 III | 2200 127 | 2480 145 | 2830 164 | ${ }^{32} 30$ |  |  |  |
| $\mathrm{Na}_{2} \mathrm{HPO}_{4}$ | 25 | 39 | 93 | 241 | 639 |  | - | 949 | - | - | 988 |
| NaI . | 1590 | 1690 | 1790 | 1900 | 2050 | 2280 | 2570 | - | 2950 | - | 3020 |
| $\mathrm{NaNO}_{3}$ | 730 | 805 | 880 | 962 | 1049 | II40 | 1246 | 1360 | 1480 | 1610 | 1755 |

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.
Smithsonian Tables.

TABLE 165 (concluded) - Solnbility of Inorganic Salts in Water; Variation with the Temperature.
The numbers give the number of grams of the anhydrous salt soluble in 1000 grams of water at the given temperatures.

| Salt. | Temperature Centigrade. |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\circ^{\circ}$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ | $90^{\circ}$ | $10{ }^{\circ}$ |
| NaOH | 420 | 515 | 1090 | 1190 | 1290 | 1450 | 1740 | - | 3130 | - |  |
| $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$. | 32 | 39 | 62 | 99 | 135 | 174 | 220 | 255 | 300 |  |  |
| $\mathrm{Na}_{2} \mathrm{SO}_{3} \cdot . . .$. | 141 | - | 287 | - | 495 |  | - |  |  | - | 330 |
| ${ }^{\mathrm{Na}_{2} \mathrm{SO}_{4}}$. . (roaq) | 50 196 | $\begin{array}{r} 90 \\ 305 \end{array}$ | $194$ | 400 | $\} 482$ | 468 | 455 | 445 | 437 | 429 | 427 |
| $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$. . . | 525 | 610 | 700 | 847 | 1026 | 1697 | 2067 | - | 2488 | 2542 | 2660 |
| $\mathrm{NiCl}_{2}$. |  | 600 | 640 | 680 | 720 | 760 | 810 | - |  |  |  |
| $\mathrm{NiSO}_{4}$ | 272 | - 6 | - 8 | 425 | - | 502 | 548 | 594 | 632 | 688 | 776 |
| ${ }_{\mathrm{PbBr}}^{2} \mathrm{O} \mathrm{NO}_{3}$ | 5 | 6 | 8 | 12 | ${ }^{1} 5$ | 20 | 24 | 28 | 33 | - | 48 |
| $\mathrm{RbCl}^{\mathrm{Pb}\left(\mathrm{NO}_{3}\right.}$ | 365 770 | 444 844 | 523 | 607 | 694 1035 | 787 1093 | 880 1155 | ${ }_{1214}^{977}$ | 1272 | 1174 | 1270 1389 |
| $\mathrm{RbNO}_{3}$ | 195 | 330 | 533 | 813 | 1167 | 1556 | 2000 | 2510 | 3090 | 3750 | 4520 |
| $\mathrm{Rb}_{2} \mathrm{SO}_{4}$ | 364 | 426 | 482 | 535 | 585 | 631 | 674 | 714 | 750 | 787 | 818 |
| $\mathrm{SrCl}_{2}$. | 442 | 483 | 539 | 600 | 667 | 744 | 831 | 896 | 924 | 962 | 1019 |
| $\mathrm{SnI}_{2}$ |  |  | 10 | 12 | 14 | 17 | 21 | 25 | 30 | 34 | 40 |
| $\underset{\mathrm{Sr}}{\left(\mathrm{NO}_{3}\right)_{2}} \cdot \cdots \cdot$ | 395 | 549 | 708 | 876 | 913 | 926 | 940 | 956 | $97^{2}$ | 990 | 1011 |
| $\mathrm{Th}\left(\mathrm{SO}_{4}\right)_{2}$. . ${ }^{(9 \mathrm{aq})}$ | 7 | 10 | 14 | 20 | $3{ }^{30}$ | 51 25 | 16 | - |  | - |  |
| TlCl . . . . 4 aq$)$ | - 2 | 2 | 3 | 5 | 40 | 8 | 10 | 13 | 16 | 20 | - |
| $\mathrm{TlNO}_{3}$ | 39 | 62 | 96 | 143 | 209 | 304 | 462 | 695 | 1110 | 2000 | 4140 |
| $\mathrm{Tl}_{2} \mathrm{SO}_{4}$. | 27 | 37 | 49 | 62 | 76 | 92 | 109 | 127 | 146 | 165 |  |
| $\mathrm{Yb}_{2}\left(\mathrm{SO}_{4}\right)_{3}$ | 442 |  | - | - | 06 | - | ${ }^{104}$ | 72 | 69 | 58 | 47 |
| $\mathrm{ZnSO}_{3}^{\mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2}}$ | 948 | - | - | - | 2069 | -68 | - | - | - 86 | 020 | $\overline{-8}$ |

TABLE 166. - Solubility of a Few Organic Salts in Water; Variation with the Temperature.

| Salt. | $\circ^{\circ}$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ | $90^{\circ}$ | $100^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{H}_{2}\left(\mathrm{CO}_{2}\right)_{2}$ | 36 | 53 | 102 | 159 | 228 | 321 | 445 | 635 | 978 | 1200 | - |
| $\mathrm{H}_{2}\left(\mathrm{CH}_{2} . \mathrm{CO}_{2}\right)_{2}$ | 28 | 45 | 69 | 106 | 162 | 244 | 358 | 511 | 708 | - | 1209 |
| Tartaric acid | 1150 | 1260 | 1390 | 1560 | 1760 | 1950 | 2180 | 2440 | 2730 | 3070 | 3430 |
| Racemic " | 92 | 140 | 206 | 291 | 433 | 595 | 783 | 999 | 1250 | 1530 | 1850 |
| $\underset{\mathrm{KH}\left(\mathrm{HCO}_{2}\right)}{ } \mathrm{C}_{4} \mathrm{H}^{\text {a }}$ | 2900 | - | 3350 | - | 3810 |  | 4550 | 32 | 5750 |  | 7900 69 |
| $\mathrm{KH}\left(\mathrm{C}_{4} \mathrm{H}_{4} \mathrm{O}_{6}\right)$ | 3 | 4 |  | 9 | 13 | 18 | 24 | 32 | 45 | 57 | 69 |

TABLE 167.-Solubility of Gases in Water; Variation with the Temperature.
The table gives the weight in grams of the gas which will be absorbed in 1000 grams of water when the partial pressure of the gas plus the vapor pressure of the liquid at the given temperature equals 760 mm .

| Gas. | $\bigcirc$ | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{O}_{2}$ | . 0705 | .0551 | . 0443 | . 0368 | .03II | . 0263 | . 022 I | . 0181 | . 0135 |
| $\mathrm{H}_{2}$ | . 0192 | . 0174 | . 0160 | .00147 | .00138 | .00129 | . 0118 | . 00102 | . 00079 |
| $\mathrm{N}_{2}$ | . 0293 | . 0230 | . 0189 | .016I | .or 39 | . 0121 | . 0105 | . 0089 | . 0069 |
| $\mathrm{Br}_{2}$ | 431. | 248. | 148. | 94. | 62. | 40. | 28. | 18. | 11. |
| $\mathrm{Cl}_{2}$ | - | 9.97 | 7.29 | 5.72 | 4.59 | 3.93 | 3.30 | 2.79 | 2.23 |
| $\mathrm{CO}_{2}$ | 3.35 | 2.32 | 1.69 | I. 26 | 0.97 | 0.76 | 0.58 |  | - |
| $\mathrm{H}_{2} \mathrm{~S}$ | 7.10 | $5 \cdot 30$ | 3.98 | - | - | , | - | - | - |
| $\mathrm{NH}_{3}$ | 987. | 689. | 535. | 422. | - | - | - | - | - |
| $\mathrm{SO}_{2}$ | 228. | 162. | 113. | 78. | 54. | - | - | - | - |

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.
Smithsonian Tables.

## CHANGE OF SOLUBILITY PRODUCED BY UNIFORM PRESSURE.*

|  | $\mathrm{CdSO}_{4} 8 / 3 \mathrm{H}_{2} \mathrm{O}$ at $25^{\circ}$ |  | $\mathrm{ZnSO}_{4.7} \mathrm{H}_{2} \mathrm{O}$ at $25^{\circ}$ |  | Mannite at $24.05^{\circ}$ |  | NaCl at ${ }_{24 .} .00^{\circ}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |
| 1 | 76.80 | - | 57.95 | - | 20.66 | - | $35 \cdot 90$ | - |
| 500 | 78.01 | $+1.57$ | 57.87 | $-0.14$ | 21.14 | +2.32 | 36.55 | +1.81 |
| 1000 | 78.84 | $+2.68$ | 57.65 | $-0.52$ | 21.40 | $+3.57$ | 37.02 | +3.12 |
| 1500 | - | - | - | - | 21.64 | +4.72 | 37.36 | $+4.07$ |

* E. Cohen and L. R. Sinnige, Z. physik. Chem. 67, p. 432, 1909; 69, p. 102, r909. E. Cohen, K. Inouye and C. Euwen, ibid. 75, p. 257, 1911. These authors give a critical résumé of earlier work along this line.

Smithsonian Tables.

## ABSORPTION OF GASES BY LIQUIDS.*

| Temperature Centigrade. <br> $t$ | Absorption Cobfficients, $a_{t}$, for Gases in Water. |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Carbon dioxide. $\mathrm{CO}_{2}$ |  | Carbon monoxide. CO | $\underset{\mathrm{H}}{\text { Hydrogen. }}$ | $\underset{\mathrm{N}}{\text { Nitrogen. }}$ |  |  | Nitrous oxide. $\mathrm{N}_{2} \mathrm{O}$ | Oxygen. |
| 0 5 10 15 20 25 30 40 50 100 | 1.7 1.4 1.18 1.00 0.9 0.7 0.5 0.2 |  | $\begin{array}{r} 0.0354 \\ .0315 \\ .0282 \\ .0254 \\ .0232 \\ .0214 \\ .0200 \\ .0177 \\ .0161 \\ .0141 \end{array}$ | $\begin{array}{r} 0.02110 \\ .02022 \\ .01944 \\ .01875 \\ .01809 \\ .01745 \\ .01690 \\ .01644 \\ .01608 \\ .01600 \end{array}$ | $\begin{array}{r} 0.02399 \\ .02134 \\ .01918 \\ .01742 \\ .01599 \\ .01481 \\ .01370 \\ .01195 \\ .01074 \\ .01011 \end{array}$ | 0.07 <br> .06 <br> .05 <br> .05 <br> .04 <br> .04 <br> .04 <br> .03 <br> .03 <br> .02 |  | 1.048 <br> 0.8778 <br> 0.7377 <br> 0.6294 <br> 0.5443 <br> $-$ <br> - | 0.04925 <br> .04335 <br> .03456 <br> .03137 <br> .02874 <br> .02646 <br> .02316 <br> . 02080 <br> .01690 |
| Temperature Centigrade. $t$ | Air. |  | $\underset{\mathrm{NH}_{3}}{\underset{\text { Ammonia }}{ }}$ | $\underset{\mathrm{Cl}}{\text { Chlorine. }}$ | $\begin{gathered} \text { Ethylene. } \\ \mathrm{C}_{3} \mathrm{H}_{4} \end{gathered}$ | Methane. $\mathrm{CH}_{4}$ | Hydrogen $\underset{\mathrm{H}_{2} \mathrm{~S}}{\substack{\text { sulphide }}}$ |  | Sulphur dioxide. $\mathrm{SO}_{2}$ |
| 0 5 10 15 20 25 | 0.02 .02 .019 .01 .01 |  | 1174.6 971.5 840.2 756.0 683.1 610.8 | $\begin{aligned} & 3.036 \\ & 2.808 \\ & 2.585 \\ & 2.388 \\ & 2.156 \\ & \text { 1.950 } \end{aligned}$ | $\begin{array}{r} 0.2563 \\ .2153 \\ .1837 \\ .1615 \\ .1488 \end{array}$ | 0.05 .04 .04 .039 .03 .02 |  | 4.371 3.965 3.586 3.233 2.905 2.604 | $\begin{aligned} & 79.79 \\ & 67.48 \\ & 56.65 \\ & 47.28 \\ & 39.37 \\ & 32.79 \end{aligned}$ |
| orption Coefficients, $\alpha_{t}$, for Gases in Alcohol, $\mathrm{C}_{2} \mathrm{H}_{5}$ |  |  |  |  |  |  |  |  |  |
| Centigrade. <br> $t$ | Carbon dioxide. $\mathrm{CO}_{3}$ | Ethylene. $\mathrm{C}_{2} \mathrm{H}_{4}$ | e. Methane. $\mathrm{CH}_{4}$ | $\underset{\mathrm{H}}{\text { Hydrogen. }}$ | $\underset{\mathrm{N}}{\mathrm{Nitrogen}}$ | Nitric oxide. NO | $\begin{aligned} & \text { Nitrous } \\ & \text { oxide. } \\ & \mathrm{N}_{2} \mathrm{O} \end{aligned}$ | Hydrogen sulphide. $\mathrm{H}_{2} \mathrm{~S}$ | Sulphur dioxide. $\mathrm{SO}_{2}$ |
| $\bigcirc$ | 4.329 | $3 \cdot 595$ | 0.5226 | 0.0692 | 0.1263 | 0.3161 | 4.190 | 17.89 | 328.6 |
| 5 | 3.8913.514 | 3.323 | . 5086 | . 0685 | .1241 | . 2998 | 3.838 | -14.78 | 251.7 |
| 10 |  | 3.086 | . 4953 | . 0679 | . 1228 | . 2861 | 3.525 | 511.99 | 190.3 |
| 15 | $\begin{aligned} & 3 \cdot 514 \\ & 3 \cdot 199 \end{aligned}$ | 2.882 | . 4828 | . 0673 | .1214 | . 2748 | 3.215 | $5 \quad 9.54$ | 144.5 |
| 20 | $\begin{aligned} & 3.199 \\ & 2.946 \end{aligned}$ | $\begin{aligned} & 2.713 \\ & 2.578 \end{aligned}$ | . 4710 | . 0667 | . 1204 | . 2659 | 3.015 | $5 \quad 7.41$ | 114.5 |
| 25 | 2.946 2.756 |  | $\cdot 4598$ | . 0662 | .1196 | . 2595 | 2.819 | -5.62 | 99.8 |

*This table contains the volumes of different gases, supposed measured at $0^{\circ} \mathrm{C}$. and 76 centimeters' pressure, which unit volume of the liquid named will absorb at atmospheric pressure and the temperature stated in the first column. The numbers tabulated are commonly called the absorption coefficients for the gases in water, or in alcohol, at the temperature $t$ and under one atmosphere of pressure. The table has been compiled from data published by Bohr \& Bock, Bunsen, Carius, Dittmar, Hamberg, Henrick, Pagliano \& Emo, Raoult, Schönfeld, Setschenow, and Winkler. The numbers are in many cases averages from several of these authorities.

Note. - The effect of increase of pressure is generally to increase the absorption coefficient. The following is approximately the magnitude of the effect in the case of ammonia in alcohol at a temperature of $23^{\circ} \mathrm{C}$. :

$$
\left\{\begin{array}{lllll}
P=45 \mathrm{cms} . & 50 \text { cms. } & 55 \mathrm{cms} . & 60 \mathrm{cms} . & 65 \mathrm{cms} \\
a_{23}=69 & 74 & 79 & 84 & 88
\end{array}\right.
$$

According to Setschenow the effect of varying the pressure from 45 to 85 centimeters in the case of carbonic acid in water is very small.

## 8 mithsonian Tables.

TABLE 170. - Water and Alcohol in Contact with Air.

| Temp. | Surface tension in dynes per centimeter. |  | Temp. C. | Surface tension in dynes per centimeter. |  | $\begin{gathered} \text { Temp. } \\ \text { C. } \end{gathered}$ | Surface tension in dynes per centimeter. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Water. | Ethyl alcohol. |  | Water. | Ethyl alcohol. |  | Water. |
| $0^{\circ}$ | 75.6 | $23 \cdot 5$ | $40^{\circ}$ | 70.0 | 20.0 | $80^{\circ}$ | 64.3 |
| 5 | 74.9 | 23.1 | 45 | 69.3 | 19.5 | 85 | 63.6 |
| 10 | 74.2 | 22.6 | 50 | 68.6 | 19.1 | 90 | 62.9 |
| 15 | 73.5 | 22.2 | 55 | 67.8 | 18.6 | 95 | 62.2 |
| 20 | 72.8 | 21.7 | 60 | 67.1 | 18.2 | 100 | 61.5 |
| 25 | 72.1 | 21.3 | 65 | 66.4 | 17.8 | - | - |
| 30 | 71.4 | 20.8 | 70 | 65.7 | 17.3 | - | - |
| 35 | 70.7 | 20.4 | 75 | 65.0 | 16.9 | - | - |

TABLE 171. - Miscellaneous Liquids in Contact with Air.

| Liquid. | $\begin{gathered} \text { Temp. } \\ \text { C.O. } \end{gathered}$ | Surface tension in dynes per centimeter. | Authority. |
| :---: | :---: | :---: | :---: |
| Aceton | 16.8 | $23 \cdot 3$ | Ramsay-Shields. |
| Acetic acid. | 17.0 | 30.2 | Average of various. |
| Amyl alcohol . . | 15.0 | 24.8 |  |
| Benzole . . . | 15.0 | 28.8 | ' |
| Butyric acid . | 15.0 | 28.7 | Q " |
| Carbon disulphide | 20.0 | 30.5 | Quincke. |
| Chloroform | 20.0 | 28.3 | Average of various. |
| Ether . . | 20.0 | 18.4 |  |
| Glycerine . . | 17.0 | 63.14 | Hall. |
| $\underset{\text { Hexane . . . }}{ }$ | 0.0 68.0 | 2 I .21 | Schiff. |
| Mercury | 18.0 | 520.0 | Average of various. |
| Methyl alcohol | 15.0 | 24.7 | " |
| Olive oil . | 20.0 | 34.7 |  |
| Petroleum . | 20.0 | 25.9 | Magie. |
| Propyl alcohol | 5.8 97.1 | 25.9 18.0 | Schiff. |
| Toluol . | 97.1 15.0 | 18.0 | ، |
| " | 109.8 | 18.9 | " |
| Turpentine . | 21.0 | 28.5 | A verage of various. |

TABLE 172. -Solutions of Salts in Water. $\dagger$

| Salt in solution. | Density. | $\begin{gathered} \text { Temp. } \\ \mathbf{C} .{ }^{\circ} . \end{gathered}$ | Tension in dynes per cm . |
| :---: | :---: | :---: | :---: |
| $\mathrm{BaCl}_{2}$ | 1.2820 | 15-16 | 81. 8 |
|  | 1.0497 | $15-16$ | 77.5 |
| $\mathrm{CaCl}_{2}$ | 1.3511 | 19 | 95.0 |
|  | 1.2773 | 19 | 90.2 |
| HCl | 1.1190 | 20 | 73.6 |
| " | 1.0887 | 20 | 74.5 |
| K | 1.0242 | 20 | 75.3 |
| KCl | 1.1699 | $15-16$ | 82.8 |
| " | I.101I | $15-16$ | 80.1 |
| " | 1.0463 | $15-16$ | 78.2 |
| $\mathrm{MgCl}_{2}$ | 1.2338 | 15-16 | 90.1 |
|  | 1.1694 | $15-16$ | 85.2 |
| " | 1.0362 | 15-16 | 78.0 |
| NaCl | I.1932 | 20 | S5.8 |
| " | 1.1074 | 20 | 80.5 |
| " | 1.0360 | 20 | 77.6 |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 1.0758 | 16 | 84.3 |
| " | 1.0535 | 16 | 81.7 |
| " | 1.0281 | 16 | 78.8 |
| $\mathrm{SrCl}_{2}$ | 1.3114 | $15^{-16}$ | 85.6 |
|  | 1.1204 | 15-16 | 79.4 |
| K ${ }^{\text {cos }}$ | 1.0567 | $15-16$ | 77.8 |
| $\mathrm{K}_{2} \mathrm{CO}_{3}$ | 1.3575 | $15^{-16}$ | 90.9 |
| " | 1.1576 | $15-16$ | 8 I .8 |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 1.0400 | $15-16$ | 77.5 |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 1.1329 | $14^{-15}$ | 79.3 |
|  | 1.0605 | $14^{-15}$ | 77.8 |
| $\mathrm{KNO}_{3}$ | 1.0283 1.1263 | $14-15$ 14 | 77.2 78.9 |
| " | 1.0466 | 14 | 77.6 |
| $\mathrm{NaNO}_{3}$ | 1.3022 | 12 | 83.5 |
|  | I.I3II | 12 | 80.0 |
| $\mathrm{CuSO}_{4}$ | 1.1775 | $15-16$ | 78.6 |
| ${ }^{6}{ }^{\text {CO}}$ | 1. 0276 | $15-16$ | 77.0 |
| $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 1. 8278 | 15 | 63.0? |
| " | I. 4453 | 15 | 79.7 |
| $\mathrm{K}_{5} \mathrm{SO}_{4}$ | 1.2636 | ${ }^{1} 5$ | 79.7 |
| $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 1.0744 | $15-16$ | 78.0 |
| ${ }^{\text {\% }} \mathrm{SO}_{4}$ | 1.0360 | 15-16 | 77.4 |
| $\mathrm{MgSO}_{4}$ | 1.2744 | ${ }^{1} 5-16$ | 83.2 |
|  | 1.0680 | $15-16$ | 77.8 |
| $\mathrm{Mn}_{2} \mathrm{SO}_{4}$ | 1.1119 | ${ }^{1} 5-16$ | 79.1 |
|  | 1.0329 | 15-16 | $77 \cdot 3$ |
| $\underset{\text { '60 }}{ } \mathrm{ZnSO}_{4}$ | 1.3981 | $15-16$ |  |
| " | $\begin{aligned} & 1.2830 \\ & 1.1030 \end{aligned}$ | $\begin{aligned} & 15-16 \\ & 15-16 \end{aligned}$ | So. 7 <br> 77.8 |

[^26]| Liquid. |  |  |  |  | Specific gravity. | Surface tension in dynes per centimeter of liquid in contact with - |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | Air. | Water. | Mercury. |
| Water |  |  |  |  | 1.0 | 75.0 | 0.0 | (392) |
| Mercury |  | . |  |  | 13.543 | 513.0 | 392.0 |  |
| Bisulphide of carbon |  |  |  | . | 1.2687 | 30.5 | 41.7 | (387) |
| Chloroform . . |  |  |  | - | 1.4878 | (31.8) | 26.8 | (415) |
| Ethyl alcohol |  |  |  |  | 0.7906 | (24.1) | 8.6 | 364 |
| Olive oil . |  | - | - |  | 0.9136 | 34.6 | 18.6 | 317 |
| Turpentine . . |  |  | . | . | 0.8867 | 28.8 | 11.5 | 241 |
| Petroleum . . |  |  |  | . | . 7977 | 29.7 | (28.9) | 271 |
| Hydrochloric acid . . |  | . | - | . | 1.10 | (72.9) | - | (392) |
| Hyposulphite of soda solution | . | . | - | . | 1.1248 | 69.9 | - | 429 |

TABLE 174. - Surface Tension of Liquids at Solidifying Point. $\dagger$

| Substance. |  |  | Temperature of solidification. Cent. ${ }^{\circ}$ | Surface tension in dynes per centimeter | Substance. |  |  | Temperature of solidification. Cent. ${ }^{\circ}$ | Surface tension in dynes per centimeter. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Platinum | - |  | 2000 | 1691 | Antimony |  | - | 432 | 249 |
| Gold | . |  | 1200 | 1003 | 3orax . |  | . | 1000 | 216 |
| Zinc | . |  | 360 | 877 | Carbonate of | soda | - | 1000 | 210 |
| Tin | . |  | 230 | 599 | Chloride of | sodium | - | - | 116 |
| Mercury | . |  | -40 | 588 | Vater . | . . | . | 0 | $87.9 \ddagger$ |
| Lead | . |  | 330 | 457 | Selenium | - . | - | 217 | 71.8 |
| Silver | . | . | 1000 | 427 | Sulphur |  |  | 111 | 42.1 |
| Bismuth | - |  | 265 | I 390 | Posphorus |  | . | 43 | 42.0 |
| Potassium Sodium | . | . | 58 90 | 371 258 | Wax | . . |  | 68 | 34.1 |

TABLE 175. - Tension of Soap Films.
Elaborate measurements of the thickness of soap films have been made by Reinold and Rucker.\| They find that a film of oleate of soda solution containing I of soap to 70 of water, and having 3 per cent of $\mathrm{KNO}_{3}$ added to increase electrical conductivity, breaks at a thickness varying between 7.2 and 14.5 micro-millimeters, the average being 12.1 micromillimeters. The film becomes black and apparently of nearly uniform thickness round the point where fracture begins. Outside the black patch there is the usual display of colors, and the thickness at these parts may be estimated from the colors of thin plates and the refractive index of the solution.

When the percentage of $\mathrm{KNO}_{3}$ is diminished, the thickness of the black patch increases. For example, $\quad \mathrm{KNO}_{3}=3 \quad 1 \quad 0.5 \quad 0.0$ Thickness $=12.413 .514 .5 \quad 22.1$ micro-mm.
A similar variation was found in the other soaps.
It was also found that diminishing the proportion of soap in the solution, there being no $\mathrm{KNO}_{3}$ dissolved, increased the thickness of the film.

I part soap to 30 of water gave thickness 21.6 micro-mm.
I part soap to 40 of water gave thickness 22.1 micro- mm .
I part soap to 60 of water gave thickness 27.7 micro-mm.
I part soap to 80 of water gave thickness 29.3 micro-mm.

* This table of tensions at the surface separating the liquid named in the first column and air, water or mercury as stated at the head of the last three columns, is from Quincke's experiments (Pogg. Ann. vol. 139, and Phil. Mag. 1871). The numbers given are the equivalent in dynes per centimeter of those obtained by Worthington from Quincke's results (Phil. Mag. vol. 20, 1885) with the exception of those in brackets, which were not corrected by Worthington ; they are probably somewhat too high, for the reason stated by Worthington. The temperature was about $20^{\circ} \mathrm{C}$.
$\dagger$ Quincke, " Pogg. Ann." vol. 135, p. 663.
$\ddagger$ It will be observed that the value here given on the authority of Quincke is much higher than his subsequent measurements, as quoted above, give.
" "Proc. Koy. Soc." 1877, and "Phil. Trans. Koy. Soc." 1881, 1883, and 1893.
Note. - Quincke points out that substances may be divided into groups in each of which the ratio of the surface tension to the density is nearly constant. Thus, if this ratio for mercury be taken as unit, the ratio for the bromides and iodides is about a half: that of the nitrates, chlorides, sugars, and fats, as well as the metals, lead, bismuth, and antimony, about i; that of water, the carbnnates, sulphates, and probably phosphates, and the metals platinum, gold, silver, cadmium, tin, and copper, 2 ; that of zinc, iron, and palladium, 3 ; and that of sodium, 6 .

TABLE 176. - Vapor Pressure of Elements.


TABLE 177. - Vapor Pressure and Rate of Evaporization.

| ${ }^{\circ} \mathrm{K}$ | $\underset{\text { mm }}{\text { Mo }}$ | $\underset{\mathrm{mm}}{\mathrm{W}}$ | $\underset{\substack{\text { Evaporation rate. } \\ \mathrm{g} / \mathrm{cm}^{2} / \mathrm{sec} .}}{ }$ |  | Platinum. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Mo | w | ${ }^{\text {K }}$ | mm | $\mathrm{g} / \mathrm{cm}^{2} / \mathrm{sec}$. |
| 180020002200240026002800300032003500 | 0.08643 <br> 0.06789 0.04396 <br> $0 . \mathrm{O}_{2} \mathrm{IO} 27$ <br> 0.0160 <br> $\left.\begin{array}{c}3800^{3} \\ 760 \mathrm{~mm}\end{array}\right\}$ |  | -. $\mathrm{O}_{10} 863$ <br> 0.07100 <br> 0. 06480 <br> 0. $\mathrm{O}_{3} \mathrm{I} 79$ <br> 0. $\mathrm{O}_{2} \mathrm{I} 8 \mathrm{I}$ |  | 1000 | 0.017324 | -. 019832 |
|  |  |  |  |  | 1200 | 0.012111 | 0.014260 |
|  |  |  |  |  | 1400 | -0.09188 | - 0.01401 |
|  |  |  |  |  | 1600 | 0.07484 | - 0.9966 |
|  |  |  |  |  | 1800 | -. 0.350 | -0.07667 |
|  |  |  |  |  | 2000 | $0^{0.0 .03107}$ | -. 0.5195 |
|  |  |  |  |  | 4180 | 760 mm |  |
|  |  |  |  |  |  |  | ay, Phys. |
|  |  |  |  |  |  | 1913; 4, |  |

$p=K . T^{-\frac{1}{2}} e^{-\lambda_{0} / R T}$ dynes $/ \mathrm{cm}^{2}$. Egerton, Phil. Mag. 33, p. 33, 1917.
$\mathrm{Zn}, \lambda_{0}=3.28 \times \mathrm{IO}^{4} ; K=1.17 \times \mathrm{IO}^{14} \mathrm{Cd}, \lambda_{0}=2.77 \times \mathrm{IO}^{4} ; K=5.27 \times \mathrm{IO}^{13}$ $\mathrm{Hg}, \lambda_{0}=1.60 \times 10^{4} ; \quad=3.72 \times 10^{13}$ (Knudsen)

## VAPOR PRESSURES.

The vapor pressures here tabulated have been taken, with one exception, from Regnault's results The vapor pressure of Pictet's fluid is given on his own authority. The pressures are in centimeters of mercury.

| Tem-perature Cent. | $\begin{gathered} \text { Acetone. } \\ \mathrm{C}_{5} \mathrm{H}_{6} \mathrm{O} \end{gathered}$ | $\begin{gathered} \text { Benzol. } \\ \mathrm{C}_{6} \mathrm{H}_{6} \end{gathered}$ | Carbon bisul${ }^{\text {phide. }}$ | Carbon tetra$\mathrm{CCl}_{4}$ | Chloro${ }_{\mathrm{CHCl}}^{3}$ CH: | $\begin{gathered} \text { Ethyl } \\ \text { alcchol. } \\ \mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O} \end{gathered}$ | $\begin{gathered} \text { Ethyl } \\ \begin{array}{c} \text { Ether. } \\ { }_{4}{ }_{4} \mathrm{H}_{10} \mathrm{O} \end{array} \end{gathered}$ | $\begin{gathered} \text { Ethyl } \\ \begin{array}{c} \text { bromide. } \\ \mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br} \end{array} \\ \hline \end{gathered}$ | Methyl alcohol. $\mathrm{CH}_{4} \mathrm{O}$ | Turpentine. $\mathrm{C}_{10} \mathrm{H}_{6}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-25^{\circ}$ | - | - | - | - | - | - |  | 4.41 | 41 | - |
| -20 | - | . 58 | 4.73 | . 98 | - | .33 | 6.89 | 5.92 | . 63 |  |
| -15 | - | . 88 | 6.16 | 1.35 |  | . 51 | 8.93 | 7.81 | . 93 |  |
| 10 |  | 1.29 | 7.94 | 1.85 |  | . 65 | 11.47 | 10.15 | 1.35 |  |
| -5 | - | 1.83 | 10.13 | 2.48 |  | .91 | 14.61 | 13.06 | 1.92 |  |
| 0 | - | 2.53 | 12.79 | 3.29 | 5.97 | 1.27 | 18.44 | 16.56 | 2.68 | . 21 |
| 5 | - | 3.42 | 16.00 | 4.32 |  | 1.76 | 23.09 | 20.72 | 3.69 |  |
| 10 | - | 4.52 | 19.85 | 5.60 | 10.05 | 2.42 | 28.68 | 25.74 | 5.01 | . 29 |
| 15 |  | 5.89 | 24.41 | 7.17 |  | $3 \cdot 30$ | $35 \cdot 36$ | 31.69 | 6.71 8.87 |  |
| 20 | 17.96 | 7.56 | 29.80 | 9.10 | 16.05 | 4.45 | 43.28 | 38.70 | 8.87 | . 44 |
| 25 | 22.63 | 9.59 | 36.11 | 11.43 | 20.02 | 5.94 | 52.59 | 46.91 | 11.60 |  |
| 30 | 28.10 | 12.02 | 43.46 | 14.23 | 24.75 | 7.85 | 63.48 | 56.45 | 15.00 | . 69 |
| 35 | 34.52 | 14.93 | 51.97 | 17.55 | 30.35 | 10.29 | 76.12 | 67.49 | 19.20 |  |
| 40 | 42.01 | 18.36 | 61.75 | 21.48 | 36.93 | 13.37 | 90.70 | 80.19 | 24.35 | 1.08 |
| 45 | 50.75 | 22.41 | 72.95 | 26.08 | 44.60 | 17.22 | 107.42 | 94.73 | 30.61 |  |
| 50 | 62.29 | 27.14 | 85.71 | 31.44 | 53.50 | 21.99 | 126.48 | 111.28 | 38.17 | 1.70 |
| 55 | 72.59 | 32.64 | 100.16 | 37.63 | 63.77 | 27.86 | 148.11 | 130.03 | 47.22 |  |
| 60 | 86.05 | 39.01 | 116.45 | 44.74 | 75.54 | 35.02 | 172.50 | 151.19 | 57.99 | 2.65 |
| 65 | 101.43 | 46.34 | 134.75 | 52.87 | 88.97 | 43.69 | 199.89 | 174.95 | 70.73 8 |  |
| 70 | 118.94 | 54.74 | ${ }^{1} 55.2 \mathrm{I}$ | 62.11 | 104.21 | 54.11 | 230.49 | 201.51 | 85.71 | 4.06 |
| 75 | 138.76 16.10 | 64.32 | 177.99 203.25 | 72.57 84.33 | 121.42 140.76 | 66.55 81.29 | 264.54 302.28 | 231.07 263.86 | 103.21 123.85 | 6.13 |
| 8 | 161.10 186.18 | 75.19 87.46 | 203.25 231.17 | 84.33 97.51 | 140.76 162.41 | 86.59 98.64 | 343.95 | 300.06 | 147.09 |  |
| 90 | 214.17 | 101.27 | 261.91 | 112.23 | 186.52 | 118.93 | 389.83 | 339.89 | 174.17 | 9.06 |
| 95 | 245.28 | 116.75 | 296.63 | 128.69 | 213.28 | 142.51 | 440.18 | 383.55 | 205.17 |  |
| 100 | 279.73 | 134.01 | 332.51 | 146.71 | 242.85 | 169.75 | 495.33 | 431.23 | 240.51 | 13.11 |
| 105 | 317.70 | 153.18 | 372.72 | 166.72 | 275.40 | 201.04 | 555.62 | 483.12 | 280.63 |  |
| 110 | 359.40 | 174.44 | 416.41 | 188.74 | 311.10 | 236.76 | 621.46 | 539.40 |  | 18.60 |
| 115 | 405.00 | 197.82 | 463.74 | 212.91 | 350.10 | 277.34 | 693.33 | 600.24 66.80 | 376.98 | 25.70 |
| 120 | 454.69 | 223.54 | 514.88 | 239.37 | 392.57 | 323.17 | 771.92 | 665.80 | 434.18 | 25.70 |
| 125 | 508.62 | 251.71 | 569.97 | 268.24 | 438.66 | 374.69 | - | 736.22 | 498.05 | - |
| 130 | 566.97 | 282.43 | 629.16 | 299.69 | 488.51 | 432.30 | - | 811.65 | 569.13 | 34.90 |
| 135 | 629.87 | 315.85 | 692.59 | 333.86 | 542.25 | 496.42 | - | 892.19 | 647.93 | - |
| 140 | 697.44 | 352.07 | 760.40 | 370.90 | 600.02 | 567.46 | - | 977.96 | 733.71 830.89 | 46.40 |
| 145 | - | 391.21 | 832.69 | 411.00 | 661.92 | 645.80 | - | - | 830.89 |  |
| 150 | - | $433 \cdot 37$ | 909.59 | 454.31 | 728.06 | 731.84 | - | - | 936.13 | 60.50 |
| 155 | - | 478.65 | - | 501.02 | 798.53 | 825.92 | - | - | - | 68.60 |
| 160 | - | 527.14 | - | $551.3{ }^{\text {I }}$ | 873.42 | - | - | - | - | 77.50 |
| 165 | - | 568.30 | - | ${ }_{6}^{605.38}$ | 952.78 | - | - | - | - | - |
| 170 | - | 634.07 | - | 663.44 | - | - | - | - | - | - |

Bmithsonian Tables.

## VAPOR PRESSURES.

| Tem-perature, Centigrade. | $\underset{\mathrm{NH}_{3}}{\text { Ammonia. }}$ | Carbon dioxide. $\mathrm{CO}_{2}$ | Ethyl chloride. $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}$ | Ethyl iodide. $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | Methyl chloride. $\mathrm{CH}_{3} \mathrm{Cl}$ | Methylic ether. $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | Nitrous oxide. $\mathrm{N}_{2} \mathrm{O}$ | Pictet's fluid. $64 \mathrm{SO}_{2}+$ $44 \mathrm{CO}_{2}$ by weight | Sulphur dioxide. $\mathrm{SO}_{2}$ | Hydrogen $\underset{\mathrm{H}_{2} \mathrm{~S}}{\substack{\text { sulphide. } \\ \hline}}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-30^{\circ}$ | 86.6I | - | 11.02 | - | 57.90 | 57.65 | - | 58.52 | 28.75 | - |
| -25 | 110.43 | 1300.70 | 14.50 | - | 71.78 | 71.61 | 1569.49 | 67.64 | $37 \cdot 38$ | 374.93 |
| -20 | 139.21 | 1514.24 | 18.75 | - | 88.32 | 88.20 | 1758.66 | 74.48 | 47.95 | 443.85 |
| -I5 | 173.65 | 1758.25 | 23.96 | - | 107.92 | 107.77 | 1968.43 | 89.68 | 60.79 | 519.65 |
| -10 | 214.46 | 2034.02 | 30.21 | - | 130.96 | 130.66 | 2200.80 | 101. 84 | 76.25 | 608.46 |
| -5 | 264.42 | 2344.13 | 37.67 | - | I 57.87 | ${ }^{1} 57.25$ | 2457.92 | 121.60 | 94.69 | 706.60 |
| 0 | 318.33 | 2690.66 | 46.52 | 4.19 | 189.10 | 187.90 | 2742.10 | 139.08 | 116.51 | 820.63 |
| 5 | 383.03 | 3075.38 | 56.93 | 5.41 | 225.11 | 222.90 | 3055.86 | 167.20 | 142.11 | 949.08 |
| 10 | 457.40 | 3499.86 | 69.11 | 6.92 | 266.38 | 262.90 | 3401.91 | 193.80 | 171.95 | 1089.63 |
| 15 | 543.34 | 3964.69 | 83.26 | 8.76 | 313.41 | 307.98 | 3783.17 | 226.48 | 206.49 | 1244.79 |
| 20 | 638.78 | 4471.66 | 99.62 | 11.00 | 366.69 | 358.60 | 4202.79 | 258.40 | 246.20 | 1415.15 |
| 25 | 747.70 | 5020.73 | 118.42 | 13.69 | 426.74 | 415.10 | 4664.14 | 297.92 | 291.60 | 1601.24 |
| 30 | 870.10 | 5611.90 | 139.90 | 16.91 | 494.05 | 477.80 | 5170.85 | 338.20 | 343.18 | 1803.53 |
| 35 | 1007.02 | 6244.73 | 164.32 | 20.71 | 569.1 I | - | 6335.98 | 383.80 | 401.48 | 2002.43 |
| 40 | 1159.53 | 6918.44 | 191.96 | 25.17 | - | - | - | 434.72 | 467.02 | 2258.25 |
| 45 | 1328.73 | 7631.46 | 223.07 | 30.38 | - | - | - | 478.80 | 540.35 | 2495.43 |
| 50 | 1515.83 | - | 257.94 | 36.40 | - | - | - | 521.36 | 622.00 | 2781.48 |
| 55 | 1721.98 | - | 266.84 | 43.32 | - | - | - | 5 | 712.50 | 3069.07 |
| 60 | 1948.21 | - | 340.05 | 51.22 | - | - | - | - | 812.38 | 3374.02 |
| 65 | 2196.51 | - | 387.85 | - | - | - | - | - | 922.14 | 3696.15 |
| 70 | $2467 \cdot 55$ | - | 440.50 | - | - | - | - | - | - | $4035 \cdot 3^{2}$ |
| 75 | 2763.00 | - | 498.27 | - | - | - | - | - | - | - |
| 80 | 3084.3I | - | 561.41 | - | - | - | - | - | - | - |
| 85 | 3433.09 | - | 630.16 | - | - | - | - | - | - | - |
| 90 | 3810.92 | - | 704.75 | - | - | - | - | - | - | - |
| 95 | 4219.57 | - | 785.39 | - | - | - | - | - | - | - |
| 100 | 4660.82 | - | 872.28 | - | - | - | - | - | - | - |

Smithsonian Tables.

TABLE 179, - Vapor Pressure of Ethyl Alcohol.*

|  | $0{ }^{\circ}$ | $1{ }^{\circ}$ | $2^{\circ}$ | $3{ }^{\circ}$ | 4 | $5{ }^{\circ}$ | $6^{\circ}$ | $7{ }^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Vapor pressure in millimeters of mercury at $\mathrm{o}^{\circ} \mathrm{C}$. |  |  |  |  |  |  |  |  |  |
| $0^{\circ}$ | 12.24 | 13.18 | 14.15 | 15.16 | 16.21 | 17.31 | 18.46 | 19.68 | 20.98 | 22.34 |
| 10 | 23.78 | 25.31 | 27.94 | 28.67 | 30.50 | 32.44 | 34.49 | 36.67 | 38.97 | 41.40 |
| 20 | 44.00 | ${ }^{+6.66}$ | 49.47 | 52.44 | 55.56 | 58.86 | 62.33 | 65.97 | 69.80 | 73.83 |
| 30 | 78.06 | 82.50 | 87.17 | 92.07 | 97.21 | 102.60 | 108.24 | 114.15 | 120.35 | 126.86 |
| 40 | 133.70 | 140.75 | 148.10 | 155.80 | 163.80 | 172.20 | 181.00 | 190.10 | 199.65 | 209.60 |
| 50 | 220.00 | 230.80 | 242.50 | 253.80 | 265.90 | 278.60 | 291.85 | 305.65 | 319.95 | 334.85 |
| 60 | 350.30 | 366.40 | $3{ }^{3} 3.10$ | 400.40 | 418.35 | 437.00 | 456.35 | 476.45 | 497.25 | 518.85 |
| 70 | 541.20 | ${ }_{564} 65$ | 588.35 | 613.20 | 638.95 | 665.55 | 693.10 | 721.55 | 751.00 | 781.45 |

From the formula $\log p=a+b \alpha^{t}+c \boldsymbol{\beta}^{t}$ Ramsay and Young obtain the following numbers. $\dagger$


TABLE 180.- Vapor Pressure of Methyl Alcohol. $\ddagger$

|  | $0^{\circ}$ | $1{ }^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Vapor pressure in millimeters of mercury at $\mathrm{o}^{\circ} \mathrm{C}$. |  |  |  |  |  |  |  |  |  |
| $0{ }^{\circ}$ | 29.97 | 31.6 | 33.6 | 35.6 | 37.8 | 40.2 | 42.6 | 45.2 | 47.9 | 50.8 |
| 10 | 53.8 | 57.0 | 60.3 | 63.8 | 67.5 | 71.4 | $75 \cdot 5$ | 79.8 | 84.3 | 89.0 |
| 20 | 94.0 | 99.2 | 104.7 | 110.4 | I 16.5 | 122.7 | I 29.3 | 136.2 | 143.4 | 151.0 |
| 30 | 158.9 | 167.1 | 175.7 | 184.7 | 194.I | 203.9 | 214.1 | 224.7 | 235.8 | $247 \cdot 4$ |
| 40 | 259.4 | 271.9 | 285.0 | 298.5 | 312.6 | 327.3 | 342.5 | 358.3 | 374.7 | 391.7 |
| 50 | 409.4 | 427.7 | 446.6 | 466.3 | 486.6 | 507.7 | 529.5 | 552.0 | $575 \cdot 3$ | 599.4 |
| 60 | $624 \cdot 3$ | 650.0 | 676.5 | 703.8 | 732.0 | 761.1 | $791 . \mathrm{I}$ | 822.0 | 5 S | 5 |

[^27]VAPOR PRESSURE.*
Carbon Disulphide, Chlorobenzene, Bromobenzene, and Aniline.

| Temp. | $0{ }^{\circ}$ | $1{ }^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5{ }^{\circ}$ | $6^{\circ}$ | $7{ }^{\circ}$ | $8^{\circ}$ | $9{ }^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (a) Carbon Disulphide. |  |  |  |  |  |  |  |  |  |  |
| $0{ }^{\circ}$ | 127.90 | 133.85 | 140.05 | 146.45 | 153.10 | 160.00 | 167.15 | 174.60 | 182.25 | 190.20 |
| 10 | 198.45 | 207.00 | 215.80 | 224.95 | 234.40 | 244.15 | 254.25 | 264.65 | 275.40 | 286.55 |
| 20 | 298.05 | 309.90 | 322.10 | 334.70 | 347.70 | 361.10 | 374.95 | 389.20 | 403.90 | 419.00 |
| 30 | 434.60 | 450.65 | 467.15 | 484.15 | 501.65 | 519.65 | 538.15 | 557.15 | 576.75 | 596.85 |
| 40 | 617.50 | 638.70 | 660.50 | 682.90 | 705.90 | 729.50 | 753.75 | 778.60 | 804.10 | 830.25 |
| (b) Chlorobenzene. |  |  |  |  |  |  |  |  |  |  |
| $20^{\circ}$ | 8.65 | 9.14 | 9.66 | 10.21 | 10.79 | 11.40 | 12.04 |  |  | 14.17 |
| 30 | 14.95 | 15.77 | 16.63 | 17.53 | 18.47 | 19.45 | 20.48 | 21.56 | 22.69 | 23.87 |
| 40 | 25.10 | 26.38 | 27.72 | 29.12 | 30.58 | 32.10 | 33.69 | $35 \cdot 35$ | 37.08 | 38.88 |
| 50 | 40.75 | 42.69 | 44.72 | 46.84 | 49.05 | 51.35 | 53.74 | 56.22 | 58.79 | 61.45 |
| 60 | 64.20 | 67.06 | 70.03 |  | 76.30 | 79.60 | 83.02 | 86.56 | 90.22 | 94.00 |
| 70 | 97.90 | 101.95 | 106.10 | 110.41 | 114.85 | 119.45 | 124.20 | 129.10 | 134.15 | 139.40 |
| 80 | 144.80 | 150.30 | 156.05 | 161.95 | 168.00 | 174.25 | 181.70 | 187.30 | 194.10 | 201.15 |
| 90 | 208.35 | 215.80 | 223.45 | 231.30 | 239.35 | 247.70 | 256.20 | 265.00 | 274.00 | 283.25 |
| 100 | 292.75 | 302.50 | 312.50 | 322.80 | 333.35 |  | 355.25 | 366.65 | 378.30 | 390.25 |
| 110 | 402.55 | 415.10 | 427.95 | 441.15 | 454.65 | 468.50 | 482.65 | 497.20 | 512.05 | 527.25 |
| 120 | 542.80 718.95 | 558.70 738.65 | $\begin{aligned} & 575.05 \\ & 758.80 \end{aligned}$ | 591.70 | 608.75 | $\underset{-}{626.15}$ | $643 \cdot 95$ | 662.15 | 680.75 | 699.65 |
| (c) Bromobenzene. |  |  |  |  |  |  |  |  |  |  |
| $40^{\circ}$ | - | - | - | - | - | 12.40 | ${ }^{1} 3.06$ | ${ }^{1} 3.75$ | 14.47 | 15.22 |
| 50 | 16.00 | 16.82 | 17.68 | 18.58 | 19.52 | 20.50 | 21.52 | 22.59 | 23.71 | 24.88 |
| 60 | 26.10 | 27.36 | 28.68 | 30.06 | 31.50 | 33.00 | 34.56 | 36.18 | 37.86 | 39.60 |
| 70 | 41.40 | 43.28 | 45.24 | 47.28 | 49.40 | 51.60 | 53.88 | 56.25 | 58.71 | 61.26 |
| 80 | 63.90 | 6.64 | 69.48 | 7242 10788 | 75.46 | 78.60 | 81.84 | 85.20 | 88.68 | 92.28 |
| 90 | 96.00 | 99.84 | 103.80 | 107.88 | 112.08 | 116.40 | 120.86 | 125.46 | 130.20 | 135.08 |
| 100 | 140.10 | 145.26 |  |  |  | 167.40 |  |  |  |  |
| 10 | 198.70 | 205.48 | 212.44 | 219.58 | 226.90 | 234.40 | 242.10 | 250.00 | $255.10$ | 266.40 |
| 120 | 274.90 | 283.65 | 292.60 | 301.75 | 311.15 | 320.80 | 330.70 | 340.80 | 351.15 | 361.80 |
| 130 | 372.65 | 383.75 | 395.10 | 406.70 | 418.60 | 430.75 | 443.20 | 455.90 | 468.90 | 482.20 |
| 140 | 495.80 | 509.70 | 523.90 | 538.40 | 553.20 | 568.35 | 583.85 | 599.65 | 615.75 | 632.25 |
| 150 | 649.05 | 666.25 | 683.80 | 701.65 | 719.95 | 738.55 | 757.55 | 776.95 | 796.70 | 816.90 |
| (d) Aniline. |  |  |  |  |  |  |  |  |  |  |
| $80^{\circ}$ | 18.80 | 19.78 | 20.79 | 21.83 | 22.90 | 24.00 | 25.14 | 26.32 | 27.54 | 28.80 |
| 90 | 30.10 | 31.44 | 32.83 | 34.27 | 35.76 | 37.30 | 38.90 | 40.56 | 42.28 | 44.06 |
| 100 | 45.90 | 47.80 | 49.78 | 51.84 | 53.98 | 56.20 | 58.50 | 60.88 | 63.34 | 65.88 |
| 110 | 68.50 | 71.22 | 74.04 | 76.96 | 79.98 | 83.10 | 86.32 | 89.66 | 93.12 | 96.70 |
| 120 | 100.40 | 104.22 | 108.17 | 112.25 | 116.46 | 120.80 | 125.28 | 129.91 | ${ }_{1} 134.69$ | 1 39.62 |
| 130 | 144.70 | 149.94 | 155.34 | 160.90 | 166.62 | 172.50 | 178.56 | 184.80 | 191.22 | 197.82 |
| 140 | 204.60 | 211.58 | 218.76 | 226.14 | 233.72 | 241.50 | 249.50 | 257.72 | 266.16 | 274.82 |
| 150 | 283.70 | 292.80 |  | 311.75 | 321.60 | 331.70 |  |  |  | 374.60 |
| 160 | 386.00 | 397.65 | 409.60 | 421.80 | 434.30 | 447.10 | 460.20 | 473.60 | 487.25 | 501.25 |
| 170 | 515.60 | 530.20 | 545.20 | 560.45 | 576.10 | 592.05 | 608.35 | 625.05 | 642.05 | 659.45 |
| 180 | 677.15 | 695.30 | 713.75 | 732.65 | 751.90 | 771.50 | - |  | - | - |

* These tables of vapor pressures are quoted from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47). The tables are intended to give a series suitable for hot-jacket purposes.
Smithsonian Tables.

Methyl Salicylate, Bromonaphthalene, and Mercury.

| Temp. C. | $0^{\circ}$ | $1{ }^{\circ}$ | $2{ }^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $6^{\circ}$ | $6^{\circ}$ | $7{ }^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (e) Methyl Salicylate. |  |  |  |  |  |  |  |  |  |  |
| $70^{\circ}$ | 2.40 | 2.58 | 2.77 | 2.97 | 3.18 | 3.40 | 3.62 | 3.85 | 4.09 | $4 \cdot 34$ |
| So | 4.60 | 4.87 | 5.15 | 5.44 | 5.74 | 6.05 | 6.37 | 6.70 | 7.05 | $7 \cdot 42$ |
|  | 7.80 |  |  | 9.06 | $9 \cdot 52$ | 9.95 | 10.44 | 10.95 | $11.4{ }^{5}$ | 12.03 |
| 100 | 12.60 | 13.20 | 13.82 | 14.47 | 15.15 | 15.85 | 16.58 | 17.34 | 18.13 | 18.95 |
| 110 | 19.80 | 20.68 | 21.60 | 22.55 | 23.53 | 24.55 | 25.61 | 26.71 | 27.85 | 29.03 |
| 120 | 30.25 | 31.52 | 32.84 | 34.21 | 35.63 | 37.10 | 38.67 | 40.24 | 41.84 | $43 \cdot 54$ |
| 130 | $45 \cdot 30$ | 47.12 | 49.01 | 50.96 | 52.97 | 55.05 | 57.20 | 59.43 | 61.73 | 64.10 |
| 140 | 66.55 | 69.08 | 71.69 | 74.38 | 77.15 | 80.00 | 82.94 | 85.97 | 89.09 | 92.30 |
| 150 | 95.60 | 99.00 | 102.50 | 106.10 | 109.80 | 113.60 | 117.51 | 121.53 | 125.66 | 129.90 |
| 160 | 134.25 | ${ }_{1} 38.72$ | 143.31 | 148.03 | 152.88 | ${ }^{1} 57.85$ | 162.95 | 168.19 | 173.56 | 179.06 |
| 170 | I 84.70 | 190.48 | 196.41 | 202.49 | 208.72 | 215.10 | 221.65 | 228.30 | 235.15 | 242.15 |
| 180 | 249.35 | 256.70 | 264.20 | 271.90 | 279.75 | 287.80 | 296.00 | 304.48 | 313.05 | 32 I .85 |
| 190 | 330.85 | 340.05 | 349.45 | 359.05 | 368.85 | 378.90 | 389.15 | 399.60 | 410.30 | 421.20 |
| 200 | 432.35 | 443.75 | $455 \cdot 35$ | 467.25 | 479.35 | 491.70 | 504.35 | 517.25 | 530.40 | 543.80 |
| 210 | 557.50 | 571.45 | 585.70 | 600.25 | 615.05 | 630.15 | $645 \cdot 55$ | 661.25 | 677.25 | 693.60 |
| 220 | 710.10 | 727.05 | $744 \cdot 35$ | 761.90 | 779.85 | 798.10 |  |  |  |  |
| (f) Bromonaphthalene. |  |  |  |  |  |  |  |  |  |  |
| $110^{\circ}$ | 3.60 | 3.74 | 3.89 | 4.05 | 4.22 | 4.40 | $4 \cdot 59$ | 4.79 | 5.00 | 5.22 |
| 120 | 5.45 | 5.70 | 5.96 | 6.23 | 6.51 | 6.80 | 7.10 | 7.42 | 7.76 | 8.12 |
| 130 | 8.50 | 8.89 | 9.29 | 9.71 | 10.15 | 10.60 | 11.07 | 11.56 | 12.07 | 12.60 |
| 140 | 13.15 | 13.72 | 14.31 | 14.92 | 15.55 | 16.20 | 16.87 | 17.56 | 18.28 | 19.03 |
| 150 | 19.80 | 20.59 | 21.41 | 22.25 | 23.11 | 24.00 | 24.92 | 25.86 | 26.83 | 27.83 |
| 160 | 28.85 | 29.90 | 30.98 | 32.09 | 33.23 | 34.40 | 35.60 | 36.83 | 38.10 | 39.41 I |
| 170 | . 40.75 | 42.12 | $43 \cdot 53$ | 44.99 | 46.50 | 48.05 | 49.64 | 51.28 | 52.96 | 54.68 |
| 180 | 56.45 | 58.27 | 60.14 | 62.04 | 64.06 | 66.10 | 68.19 | 70.34 | 72.55 | 74.82 |
| 190 | 77.15 | 79.54 | 81.99 | 84.51 | 87.10 | 89.75 | 92.47 | 95.26 | 98.12 | 101.05 |
| 200 | 104.05 | 107.12 | 110.27 | 113.50 | 116.81 | I 20.20 | 123.67 | 127.22 | 130.86 | 134.59 |
| 210 | 138.40 | 142.30 | 146.29 | 150.38 | I 54.57 | I 58.85 | 163.25 | 167.70 | 172.30 | 176.95 |
| 220 | 181.75 | 186.65 | 191.65 | 196.75 | 202.00 | 207.35 | 212.80 | 218.40 | 224.15 | 230.00 |
| 230 | 235.95 | 242.05 | 248.30 | 254.65 | 261.20 | 267.85 | 274.65 | 281.60 | 288.70 | 295.95 |
| 240 | 303.35 | 310.90 | 318.65 | 326.50 | 334.55 | 342.75 | 351.10 | 359.65 | 368.40 | $377 \cdot 30$ |
|  | 386.35 | 395.60 | 405.05 | 414.65 | 424.45 | 434.45 | 444.65 | 455.00 | 465.60 | 476.35 |
| $260$ | 487.35 | 498.55 | 509.90 | 521.50 | 533.35 | $545 \cdot 35$ | 557.60 | 570.05 | 582.70 | 595.60 |
| 270 | 608.75 | 622.10 | 635.70 | 649.50 | 663.55 | 677.85 | 692.40 | 707.15 | 722.15 | 737.45 |
| (g) Mercury. |  |  |  |  |  |  |  |  |  |  |
|  | 123.92 | 126.97 |  | 133.26 | 136.50 | 139.81 | 143.18 | 146.61 | 150.12 | 153.70 |
| 280 | 157.35 | 161.07 | 164.86 | 168.73 | 172.67 | 176.79 | 180.88 | 185.05 | 189.30 | 193.63 |
| 290 | 198.04 | 202.53 | 207.10 | 211.76 | 216.50 | 221.33 | 226.25 | 23 r .25 | 236.34 | 24 I. 53 |
| 300 | 246.81 | 252.18 | 257.65 | 263.21 | 268.87 | 274.63 | 280.48 | 286.43 | 292.49 | 298.66 |
| 310 | 304.93 | 311.30 | 317.78 | 324.37 | 331.08 | 337.89 | 344.81 | 351.85 | 359.00 | 366.28 |
| 320 | 373.67 | 381.18 | 388.81 | 396. 56 | 404.43 | 412.44 | 420.58 | 428.83 | 437.22 | 445.75 |
| 330 340 | 454.41 548.64 | 463.20 558.87 | 472.12 569.25 | 481.19 | 490.40 | 499.74 | 509.22 | 518.85 | 528.63 | 538.56 |
| 340 | 548.64 | 558.87 | 569.25 | 579.78 | 590.48 | 601.33 | 612.34 | 623.51 | 634.85 | 646.36 |
| $\begin{array}{r} 350 \\ 360 \end{array}$ | $\begin{aligned} & 658.03 \\ & 784.3 \mathrm{I} \end{aligned}$ | 669.86 | 68ı. 86 | 694.04 | 706.40 | 718.94 | 731.65 | $744 \cdot 54$ | 757.61 | 770.87 |

Table 182.
VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER.*
The first column gives the chemical formula of the salt. The headings of the other columns give the number of gram-molecules of the salt in a liter of water. The numbers in these columns give the lowering of the vapor pressure produced by the salt at the temperature of boiling water under 76 centimeters barometric pressure.


[^28] Phys." ch. 2, 42, 1886.

VAPOR PRESSURE OF SOLUTIONS OF SALTS IN WATER.

| Substance. |  | 0.5 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 8.0 | 10.0 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{MgSO}_{4}$ | - | 6.5 | 12.0 | 24.5 | $47 \cdot 5$ |  |  |  |  |  |
| $\mathrm{MgCl}_{2}$. | . | 16.8 | 39.0 | 100.5 | 183.3 | 277.0 | 377.0 |  |  |  |
| $\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2}$ | - . | 17.6 | 42.0 | 101.0 | 174.8 |  |  |  |  |  |
| $\mathrm{MgBr}{ }_{2}$ | - | 17.9 | 44.0 | I 15.8 | 205.3 | 298.5 |  |  |  |  |
| $\mathrm{MgH}_{2}\left(\mathrm{SO}_{4}\right)_{2}$ | - | 18.3 | 46.0 | 116.0 |  |  |  |  |  |  |
| $\mathrm{MnSO}_{4}$ | - . | 6.0 | 10.5 | 21.0 |  |  |  |  |  |  |
| $\mathrm{MnCl}_{2}$. | - . | 15.0 | 34.0 | 76.0 | 122.3 | 167.0 | 209.0 |  |  |  |
| $\mathrm{NaH}_{2} \mathrm{PO}_{4}$ | . | 10.5 | 20.0 | 36.5 | 51.7 | 66.8 | 82.0 | 96.5 | 126.7 | 157.1 |
| $\mathrm{NaHSO}_{4}$ | . . | 10.9 | 22.1 | $47 \cdot 3$ | 75.0 | 100.2 | 126.1 | 148.5 | 189.7 | 231.4 |
| $\mathrm{NaNO}_{3}$ | . . | 10.6 | 22.5 | 46.2 | 68.1 | 90.3 | 111.5 | 131.7 | 167.8 | 198.8 |
| $\mathrm{NaClO}_{3}$ | - . | 10.5 | 23.0 | 48.4 | 73.5 | 98.5 | 123.3 | $147 \cdot 5$ | 196.5 | 223.5 |
| $\left(\mathrm{NaPO}_{3}\right)_{6}$ | - . | 1 I .6 |  |  |  |  |  |  |  |  |
| NaOH | . . | 11.8 | 22.8 | 48.2 | $77 \cdot 3$ | 107.5 | 139.1 | 172.5 | 243.3 | 314.0 |
| $\mathrm{NaNO}_{2}$ | - - | I 1.6 | 24.4 | 50.0 | 75.0 | 98.2 | 122.5 | 146.5 | I89.0 | 226.2 |
| $\mathrm{Na}_{2} \mathrm{HPO}_{4}$ | - | 12.1 | 23.5 | 43.0 | 60.0 | 78.7 | 99.8 | 122.I |  |  |
| $\mathrm{NaHCO}_{3}$ | - . | 12.9 | 24.1 | 48.2 | 77.6 | 102.2 | 127.8 | 152.0 | 198.0 | 239.4 |
| $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | - . | 12.6 | 25.0 | 48.9 | 74.2 |  |  |  |  |  |
| NaCl . | - . | 12.3 | 25.2 | 52.1 | 80.0 | 111.0 | 143.0 | 176.5 |  |  |
| $\mathrm{NaBrO}_{3}$ | . . | 12.1 | 25.0 | 54.I | SI. 3 | 108.8 | 136.0 |  |  |  |
| NaBr | . . | 12.6 | 25.9 | 57.0 | 89.2 | 124.2 | 159.5 | 197.5 | 268.0 |  |
| NaI | - . | 12.1 | 25.6 | 60.2 | 99.5 | I 36.7 | $177 \cdot 5$ | 221.0 | 301.5 | 370.0 |
| $\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7}$ | $\cdots$ | 13.2 | 22.0 |  |  |  |  |  |  |  |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | . . | 14.3 | 27.3 | 53.5 | 80.2 | 111.0 |  |  |  |  |
| $\mathrm{Na}_{2} \mathrm{C}_{2} \mathrm{O}_{4}$ | - • | 14.5 | 30.0 | 65.8 | 105.8 | 146.0 |  |  |  |  |
| $\mathrm{Na}_{2} \mathrm{WO}_{4}$ | - . | 14.8 | 33.6 | 7 I .6 | I 15.7 | 162.6 |  |  |  |  |
| $\left.\mathrm{Na}_{3} \mathrm{PO}\right)_{4}$ | - $\cdot$ | 16.5 | 30.0 | 52.5 |  |  |  |  |  |  |
| $\left(\mathrm{NaPO}_{3}\right)_{3}$ $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | $\cdot$. | 17.1 12.8 18 | 36.5 22.0 | 42.1 | 62.7 | 82.9 | 103.8 | 121.0 | 152.2 | 180.0 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SiFl}_{6}$ | . . | 11.5 | 25.0 | 44.5 |  |  |  |  |  |  |
| $\mathrm{NH}_{4} \mathrm{Cl}$ - | - . | 12.0 | 23.7 | 45.1 | 69.3 | 94.2 | 118.5 | I 38.2 | 179.0 | 213.8 |
| $\mathrm{NH}_{4} \mathrm{HSO}_{4}$. | - . | I I. 5 | 22.0 | 46.8 | 71.0 | $94 \cdot 5$ | 118. | 139.0 | 181.2 | 218.0 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$. | . . | 11.0 | 24.0 | 46.5 | 69.5 | 93.0 | 117.0 | 141.8 |  |  |
| $\mathrm{NH}_{4} \mathrm{Br}$ | - . | 11.9 | 23.9 | 48.8 | 74.1 | 99.4 | 121.5 | 145.5 | 190.2 | 228.5 |
| $\mathrm{NH}_{4} \mathrm{I}$. | - . | 12.9 | 25.1 | 49.8 | 78.5 | 104.5 | 132.3 | I 56.0 | 200.0 | $243 \cdot 5$ |
| $\mathrm{NiSO}_{4}$ | - . | 5.0 | 10.2 | 21.5 |  |  |  |  |  |  |
| $\mathrm{NiCl}_{2}$. | . . | 16. 1 | 37.0 | 86.7 | 147.0 | 212.8 |  |  |  |  |
| $\mathrm{Ni}\left(\mathrm{NO}_{3}\right)_{2}$ | - - | 16.1 | $37 \cdot 3$ | 9 I .3 | 156.2 | 235.0 |  |  |  |  |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$ | . . | 12.3 | 23.5 | 45.0 | 63.0 |  |  |  |  |  |
| $\mathrm{Sr}_{\mathrm{Sr}}\left(\mathrm{SO}_{3}\right)_{2}$ | - $\cdot$ | 7.2 | 20.3 | 47.0 |  |  |  |  |  |  |
| $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | - . | 15.8 | 31.0 | 64.0 | 97.4 | I 31.4 |  |  |  |  |
| $\mathrm{SrCl}_{2}$. | - . | 16.8 | 38.8 | 91.4 | I 56.8 | 223.3 | 281.5 |  |  |  |
| $\mathrm{SrHr}_{2}$. | . . | 17.8 | 42.0 | IOI.I | 179.0 | 267.0 |  |  |  |  |
| $\mathrm{ZnSO}_{4}$ | - . | 4.9 | 10.4 | 21.5 | 42.1 | 66.2 |  |  |  |  |
| $\mathrm{ZnCl}_{2}{ }^{\text {a }}$ | - . | 9.2 | 18.7 | 46.2 | 75.0 | 107.0 | 153.0 | 195.0 |  |  |
| $\mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2}$. | - . | 16.6 | 39.0 | 93.5 | I 57.5 | 223.8 |  |  |  |  |

Smithsonian Tables.

TABLES 183-185.
PRESSURE OF SATURATED AQUEOUS VAPOR.
The following tables for the pressure of saturated aqueous vapor are taken principally from the Fourth Revised Edition (1918) of the Smithsonian Meteorological Tables.

TABLE 183. - At Low Temperatures, $-69^{\circ}$ to $0^{\circ} \mathrm{C}$ over Ice.

| Temp. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| -60 | 0.008 | 0.007 | 0.006 | 0.005 | 0.004 | 0.004 | 0.003 | 0.003 | 0.003 | 0.002 |
| -50 | 0.020 | 0.026 | 0.023 | 0.020 | 0.017 | 0.015 | 0.013 | 0.012 | 0.010 | 0.009 |
| -40 | 0.096 | 0.086 | 0.076 | 0.068 | 0.060 | 0.054 | 0.048 | 0.042 | 0.037 | 0.033 |
| -30 | 0.288 | 0.259 | 0.233 | 0.209 | 0.188 | 0.169 | 0.15 I | 0.135 | 0.12 I | 0.108 |
| -20 | 0.783 | 0.712 | 0.646 | 0.585 | 0.530 | 0.480 | 0.434 | 0.392 | 0.354 | 0.319 |
| -10 | 1.964 | 1.798 | 1.644 | 1.503 | 1.373 | 1.252 | 1.142 | 1.04 I | 0.947 | 0.86 I |
| -0 | 4.580 | 4.220 | 3.887 | 3.578 | 3.29 I | 3.025 | 2.778 | 2.550 | 2.340 | 2.144 |

TABLE 184.-At Low Temperatures, $-16^{\circ}$ to $0^{\circ} \mathrm{C}$ over Water.

| Temp. | 0 | I | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| $-10^{\circ}$ | 2.144 | 1.979 | 1.826 | 1.684 | 1.55 I | 1.429 | 1.315 | - | - | - |
| $-0^{\circ}$ | 4.579 | 4.255 | $3.95^{2}$ | 3.669 | 3.404 | 3.158 | 2.928 | 2.712 | 2.509 | 2.32 I |

TABLE 185. - For Temperatures $0^{\circ}$ to $374^{\circ} \mathrm{C}$ over Water.

| Temp. | . 0 | . 1 | . 2 | . 3 | . 4 | . 5 | . 6 | . 7 | . 8 | -9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| $0^{\circ}$ | 4.580 | 4.614 | 4.647 | 4.68 I | 4.715 | 4.750 | 4. 784 | 4.819 | 4.854 | 4.889 |
| 1 | 4.924 | 4.960 | 4.996 | 5.032 | 5.068 | 5.105 | 5.142 | 5.179 | 5.216 | 5.254 |
| 2 | 5.291 | $5 \cdot 329$ | $5 \cdot 368$ | 5.406 | 5.445 | 5.484 | $5 \cdot 523$ | 5.562 | 5.602 | 5.642 |
| 3 | 5.682 | 5.723 | 5.763 | 5.804 | 5.846 | 5.887 | 5.929 | 5.971 | 6.013 | 6.056 |
| 4 | 6.098 | 6.14 I | 6.185 | 6.228 | 6.272 | 6.316 | 6.361 | 6.406 | 6.450 | 6.496 |
| 5 | 6.541 | 6.587 | 6.633 | 6.680 | 6.726 | 6.773 | 6.820 | 6.868 | 6.916 | 6.964 |
| 6 | 7.012 | 7.061 | 7.110 | 7.159 | 7.209 | 7.259 | 7.309 | 7.360 | 7.410 | $7 \cdot 462$ |
| 7 | 7.513 | $7 \cdot 565$ | 7.617 | 7.669 | 7.722 | 7.775 | 7.828 | 7.882 | 7.936 | 7.991 |
| 8 | 8.045 | 8.100 | 8.156 | 8.211 | 8.267 | 8.324 | 8.380 | 8.437 | 8.494 | 8.552 |
| 9 | 8.610 | 8.669 | 8.727 | 8.786 | 8.846 | 8.906 | 8.966 | 9.026 | 9.087 | 9.148 |
| 10 | 9.21 | 9.27 | 9.33 | 9.40 | 9.46 | 9.52 | 9.59 | 9.65 | 9.72 | 9.78 |
| 11 | 9.85 | 9.91 | 9.98 | 10.04 | 10. 11 | 10. 18 | 10. 25 | 10.31 | 10.38 | 10. 45 |
| 12 | 10.52 | 10.59 | 10.66 | 10.73 | 10.80 | 10.87 | 10.94 | II. 02 | 11.09 | II. I6 |
| 13 | II 124 | 11.31 | 11. 38 | II. 46 | II 1.53 | II. 61 | I 1.68 | I 1 . 76 | II . 84 | II. 92 |
| 14 | II. 99 | 12.07 | 12. 15 | 12.23 | 12.31 | 12.39 | 12.47 | 12.55 | 12.63 | 12.71 |
| 15 | 12.79 | 12.88 | 12.96 | 13.04 | 13.13 | I3. 21 | 13.30 | 13.38 | 13.47 | $13 \cdot 56$ |
| 16 | 13.64 | 13.73 | 13.82 | 13.91 | 14.00 | 14.08 | 14.17 | 14.26 | 14.36 | 14.45 |
| 17 | 14.54 | 14.63 | 14.73 | 14.82 | 14.91 | 15.01 | 15.10 | 15.20 | 15.29 | 15.39 |
| 18 | 15.49 | 15.58 | 15.68 | 15.78 | 15.88 | 15.98 | 16.08 | 16.18 | 16.28 | 16.39 |
| 19 | 16.49 | 16.59 | 16.70 | 16.80 | 16.91 | 17.01 | 17.12 | 17.22 | 17.33 | 17.44 |
| 20 | 17.55 | 17.66 | 17.77 | 17.88 | 17.99 | 18. 10 | 18.21 | 18.32 | I8. 44 | 18. 55 |
| 21 | 18.66 | 18.78 | 18.90 | 19.01 | 19.13 | 19.25 | 19.36 | 19.48 | 19.60 | 19. 72 |
| 22 | 19.84 | 19.96 | 20.09 | 20.21 | 20.33 | 20.46 | 20.58 | 20.71 | 20.83 | 20.96 |
| 23 | 21.09 | 21.22 | 21.34 | 21.47 | 21.60 | 21.73 | 21.87 | 22.00 | 22.13 | 22.26 |
| 24 | 22.40 | 22.53 | 22.67 | 22.80 | 22.94 | 23.08 | 23.22 | $23 \cdot 36$ | 23.50 | 23.64 |
| 25 | 23.78 | 23.92 | 24.06 | 24.21 | $24 \cdot 35$ | 24.50 | 24.64 | 24.79 | 24.94 | 25.09 |

TABLE 185. - For Temperatures $0^{\circ}$ to $374^{\circ} \mathrm{C}$ over Water.

| Temperature. | . 0 | . I | . 2 | . 3 | . 4 | . 5 | 6 | . 7 | . 8 | - 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| $25^{\circ}$ | 23.78 | 23.92 | 24.06 | 24.21 | 24.35 | 24.50 | 24.64 | 24.79 | 24.94 26.46 | 25.09 26.61 |
| 26 | 25.24 | 25.38 | 25.54 | 25.69 | 25.84 | 25.99 27.56 | 26.14 27.72 | 26.30 27.80 | 26.46 28.05 | 26.61 28.22 |
| 27 | 26.77 | 26.92 | 27.08 | 27.24 | 27.40 | 27.56 | 27.72 29.39 | 27.89 29.56 | 28.05 | 28.22 |
| 28 | 28.38 | 28.55 | 28.71 | 28.88 | 29.05 | 29.22 | 29.39 | 29.56 | 29.73 | 29.90 |
| 29 | 30.08 | 30.25 | 30.43 | 30.60 | 30.78 | 30.96 | 31.14 | 31.32 | 31.50 | 31.68 |
| 30 | 31.86 | 32.04 | 32.23 | 32.41 | 32.60 | 32.79 | 32.97 | 33.16 | 33.35 | 33.54 |
| 31 | 33.74 | 33.93 | 34.12 | $34 \cdot 32$ | 34.51 | 34.71 | 34.91 | 35.10 | 35.30 | 35.50 |
| 32 | 35.70 | 35.91 | 36.11 | 36.32 | 36.52 | 36.73 | 36.94 | 37.14 | 37.35 | 37.56 |
| 33 | 37.78 | 37.99 | 38.20 | 38.42 | 38.63 | 38.85 | 39.06 | 39.28 | 39.50 | 39.72 |
| 34 | 39.95 | 40.17 | 40.39 | 40.62 | 40.85 | 41.07 | 41.30 | 41.53 | 41.76 | 41.99 |
| 35 | 42.23 | 42.46 | 42.70 | 42.93 | 43.17 | 43.418 | 43.65 | 43.89 | 44.13 | $44 \cdot 37$ |
| 36 | 44.62 | 44.86 | 45.11 | 45.36 | 45.61 | 45.86 | 46.11 | 46.36 | 46.62 | 46.87 |
| 37 | 47.13 | 47.38 | 47.64 | 47.90 | 48.16 | 48.43 | 48.69 | 48.95 | 49.22 | 49.49 |
| 38 | 49.76 | 50.02 | 50.30 | 50.57 | 50.8 .4 | 51.12 | 51.39 | 51.67 | 51.95 | 52.23 |
| 39 | 52.51 | 52.79 | 53.08 | 53.36 | 53.65 | 53.94 | 54.23 | 54.52 | 54.81 | 55.10 |
| 40 | 55.40 | 55.69 | 55.99 | 56.29 | 56.59 | 56.89 | 57.19 | 57.50 | 57.80 | 58.11 |
| 4 I | 58.42 | 58.73 | 59.04 | 59.35 | 59.66 | 59.98 | 60.30 | 60.62 | 60.94 | 6 I .26 |
| 42 | 61.58 | 61.90 | 62.23 | 62.56 | 62.89 | 63.22 | 63.55 | 63.88 | 64.22 | 64.55 |
| 43 | 64.89 | 65.23 | 65.57 | 65.91 | 66.26 | 66.60 | 66.95 | 67.30 | 67.64 | 68.00 |
| 44 | 68.35 | 68.70 | 69.06 | 69.42 | 69.78 | 70.14 | 70.50 | 70.87 | 71.23 | 71.60 |
| 45 | 71.97 | 72.34 | 72.71 | 73.09 | 73.46 | 73.84 | 74.22 | 74.60 | 74.98 | 75.36 |
| 46 | 75.75 | 76.14 | 76.53 | 76.92 | 77.31 | 77.70 | 78.10 | 78.50 | 78.90 | 79.30 |
| 47 | 79.70 | 80.11 | 80.51 | 80.92 | 81.33 | 81.74 | 82.16 | 82.57 | 82.99 | 83.41 |
| 48 | 83.83 | 84.25 | 84.68 | 85.10 | 85.53 | 85.96 | 86.39 | 86.83 | 87.26 | 87.70 |
| 49 | 88.14 | 88.58 | 89.02 | 89.47 | 89.92 | 90.36 | 90.82 | 91.27 | 91.72 | 92.18 |
|  | 0. | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. |
| 50 | 92.6 | 97.3 | 102.2 | 107.3 | 112.7 | 118.2 | 124.0 | 130.0 | 136.3 | 142.8 |
| 60 | 149.6 | 156.6 | 16.4 .0 | 171.6 | 179.5 | 187.8 | 196.3 | 205.2 | 214.4 | 224.0 |
| 70 | 233.9 | 244.2 | 254.9 | 266.0 | 277.4 | 289.3 | 301.6 | 314.4 | 327.6 | 341.2 |
| 80 | 355.4 | 370.0 | 385.2 | 400.8 | 417.0 | 433.7 | 451.0 | 468.8 | 487.3 | 506.3 |
| 90 | 526.0 | 5.46 .3 | 567.2 | 588.8 | 611.1 | 634.1 | 657.8 | 682.2 | 707.4 | 733.3 |
| 100 | 760.0 | 787.5 | 815.9 | 845.0 | 875.1 | 906.0 | 937.8 | 970.5 | 1004.2 | 1038.8 |
| 110 | 1074 | 1111 | 1149 | 1187 | 1227 | 1268 | 1310 | 1353 | 1397 | 1442 |
| 120 | 1489 | 1536 | 1585 | 1636 | 1687 | 1740 | 1794 | 1850 | 1907 | 1965 |
| 130 | 2025 | 2086 | 2149 | 2214 | 2280 | 2347 | 2416 | 2487 | 2559 | 2633 |
| 1.40 | 2709 | 2786 | 2866 | 2947 | 3030 | 3115 | 3201 | 3290 | 3381 | 3473 |
| 150 | 3568 | 3665 | 3763 | 3864 | 3967 | 4072 | 4180 | 4290 | 4402 | 4516 |
| 160 | 4632 | 4751 | 4873 | 4997 | 5123 | 5252 | 5383 | 5518 | 5654 | 5794 |
| 170 | 5936 | 6080 | 6228 | 6378 | 6532 | 6688 | 6847 | 7009 | 7174 | 7342 |
| 180 | 7513 | 7688 | 7865 | 80.46 | 8230 | 8417 | 8608 | 8802 | 8999 | 9200 |
| 190 | 9.404 | 9612 | 9823 | 10040 | 10260 | 10480 | 10700 | 10940 | 11170 | 11410 |
| 200 | 11650 | 11890 | 12140 | 12400 | 12650 | 12920 | 13180 | 13450 | 13730 | 14010 |
| 210 | 14290 | 14580 | 14870 | 15160 | 15470 | 15770 | 16080 | 16400 | 16720 | 17040 |
| 220 | 17370 | 17710 | 18050 | 18390 | 18740 | 19100 | 19450 | 19820 | 20190 | 20560 |
| 230 | 20950 | 21.330 | 21720 | 22120 | 22520 | 22930 | 23350 | 23770 | 24190 | 24620 |
| 240 | 25060 | 25500 | 25950 | 26410 | 26870 | 27340 | 27810 | 28290 | 28780 | 29270 |
| 250 | 29770 | 30280 | 30790 | 31310 | 31830 | 32360 | 32900 | 33450 | 34000 | 34560 |
| 260 | 35130 | 35700 | 36280 | 36870 | 37470 | 38070 | 38680 | 39300 | 39920 | 40560 |
| 270 | 41200 | 41840 | 42500 | 43160 | 4.38 .40 | $4+520$ | 45200 | 45900 | 46600 | 47320 |
| 280 | 480.40 | 48760 | 49500 | 50250 | 51000 | 51770 | 52540 | 53.320 | 54110 | 54910 |
| 290 | 55710 | 56530 | 57360 | 58190 | 59040 | 59890 | 60750 | 61620 | 62510 | 63400 |
| 300 | 64.300 | 65210 | 66130 | 67060 | 68000 | 68960 | 69920 | 70890 | 71870 | 72860 |
| 310 | 73870 | 74880 | 75910 | 769.40 | 77990 | 79050 | 80120 | 81200 | 82290 | 83390 |
| 320 | 8.4500 | 856.30 | 86760 | 87910 | 89070 | 90250 | 91430 | 92630 | 938.40 | 95060 |
| 330 | 96290 | 97530 | 98790 | 100060 | 101350 | 102640 | 103950 | 105280 | 106600 | 108000 |
| 340 | 109300 | 110700 | 112100 | 113500 | I 14900 | 116300 | 117800 | 119200 | I 20700 | 122200 |
| 350 | 123700 | 125200 | 126800 | 128300 | 129900 | 131400 | 133000 | 134600 | 136300 | 137900 |
| 360 | 139600 | 141200 | 142900 | 14.4600 | 1.46300 | 148100 | 149800 | 151600 | 153400 | 155200 |
| 370 | 157000 | 158800 | 160700 | 102600 | 164400 | - | - | - | - | - |

TABLES 186-188.
TABLE 186. - Weight in Grams of a Cubic Meter of Saturated Aqueous Vapor.

| Temp. | $0^{\circ}$ | $\mathbf{I}^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-20^{\circ}$ | 0.894 | 0.816 | 0.743 | 0.677 | 0.615 | 0. 559 | 0.508 | 0. 461 | 0.418 | 0.378 |
| $-10$ | 2. 158 | 1.983 | 1.820 | 1.671 | 1. 531 | 1.403 | 1. 284 | I. 174 | 1.073 | 0.980 |
| - | 4.847 | 4.482 | 4.144 | 3.828 | 3.534 | 3.261 | 3.006 | 2.770 | 2.551 | 2.347 |
| $+0^{\circ}$ | 4.847 | 5.192 | 5.559 | 5.947 | 6.36 c | 6.797 | 7.261 | 7.751 | 8.271 | 8.821 |
| +10 | 9.401 | 10.015 | 10.664 | 11.348 | 12.070 | 12.832 | 13.635 | 14.482 | 15.373 | 16.311 |
| +20 | 17.300 | 18.338 | 19.430 | 20.578 | 21.783 | 23.049 | 24.378 | 25.771 | 27.234 | 28.765 |
| $+30$ | 30.371 | 32.052 | 33.812 | 35.656 | 37.583 | 39.599 | 41.706 | 43.908 | 46.208 | 48.609 |

For higher temperatures, see Table 259.

TABLE 187. - Weight in Grains of a Cubic Foot of Saturated Aqueous Vapor.

| Temp. | $0^{\circ}$ | $\mathrm{I}^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-20^{\circ}$ | 0.167 | 0. 158 | 0. 150 | 0.141 | 0. 134 | 0. 126 | 0.119 | 0.112 | -. 106 | 0. 100 |
| $-10$ | 0. 286 | 0.272 | 0.258 | -. 244 | 0. 232 | 0. 220 | 0. 208 | -. 197 | 0. 187 | 0.176 |
| - 0 | 0. 479 | 0.455 | 0.433 | 0.41 I | - 0.391 | 0.371 | 0.353 | 0.335 | 0. 318 | 0.302 |
| $+0^{\circ}$ | 0.479 | 0.503 | 0.529 | 0. 556 | -. 584 | 0.613 | 0.644 | 0.676 | 0.709 | 0.744 |
| $+10$ | 0.780 | 0.818 | 0.858 | 0. 900 | O. 943 | 0.988 | 1. 035 | 1. 084 | 1.135 | 1. 189 |
| $+20$ | I. 244 | 1.301 | 1.362 | 1.425 | 1.490 | I. 558 | 1.629 | 1.703 | 1. 779 | r. 859 |
| $+30$ | 1.942 | 2.028 | 2.118 | 2. 200 | 2. 286 | 2.375 | 2.466 | 2.560 | 2.658 | 2.759 |
| +40 | 2.863 | 2.970 | 3.082 | 3. 196 | 3.315 | 3.436 | 3.563 | 3.693 | 3.828 | 3.965 |
| +50 | 4. 108 | 4.255 | 4.407 | 4. 564 | 4.725 | 4.891 | 5.062 | 5.238 | 5.420 | 5.607 |
| +60 | 5.800 8.066 | 5.999 8.329 | 6.203 8.600 | 6.413 8.870 | 6.630 0.165 | 6.852 | 7.082 | 7.317 10.072 | 7.560 10 | 7.809 |
| +70 +80 | 8.066 II 1.056 | 8.329 11.401 | 8.600 11.756 | 8.879 12.121 | $\begin{array}{r}9.165 \\ 12.494 \\ \hline\end{array}$ | 9.460 12.878 | 9.761 13.272 | 10.072 13.676 | 10.392 14.000 | 10.720 14.515 |
| +90 | 14.951 | 15.400 | 15.858 | 16.328 | 16.810 | 17.305 | 17.812 | 18.330 | 18.863 | 19.407 |
| $10{ }^{\circ}$ | 19.966 | 20.538 | 21.123 | 21.723 | 22.337 | 22.966 | 23.611 | 24.271 | 24.946 | 25.636 |
| 110 | 26.343 | 27.066 | 27.807 | 28.563 | 29.338 | 30. 130 | 30.940 | 31.768 | 32.616 | 33.482 |

Tables are abridged from Smithsonian Meteorological Tables, fourth revised edition.

## TABLE 188. - Pressure of Aqueous Vapor in the Atmosphere.

## For various altitudes (barometric readings).

The first column gives the depression of the wet-bulb temperature $t_{1}$ below the air temperature $t$. The value corresponding to the barometric height at the altitude of observation is to be subtracted from the vapor pressure corresponding to the wet-bulb temperature taken from Table 185. The temperature corresponding to this vapor pressure taken from Table 185 is the dew point. The wet bulb should be ventilated about 3 meters per second. For sea-level use Table 189. Example: $t=35^{\circ}, t_{1}=30^{\circ}$, barometer 74 cm . Then $3 \mathrm{I} .83-2.46=29.37 \mathrm{~mm}=$ aqueous vapor pressure; the dew point is $28.6^{\circ} \mathrm{C}$.

Abridged from Smithsonian Meteorological Tables, 1907.

| $t^{\circ}-t_{1}$ | Barometric pressure in centimeters. |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 74 | 72 | 70 | 68 | 66 | 64 | 62 | 60 | 58 | 56 | 54 | 52 | 50 | 48 |
|  | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm | mm |
| $\mathrm{I}^{\circ}$ | 0.50 | 0.48 | 0.47 | 0.46 | 0.44 | 0. 43 | 0.42 | 0.40 | 0.39 | 0.38 | 0.36 | 0.35 | 0.34 | 0.32 |
| 2 | 0.98 | 0.96 | 0.93 | 0.90 | 0.88 | 0.85 | 0.82 | -. 80 | 0. 77 | 0.75 | 0.72 | 0.69 | 0.67 | 0.64 |
| 3 | 1. 47 | 1.43 | I. 39 | 1.35 | 1.32 | I. 28 | I. 24 | 1. 20 | I. 15 | 1.12 | 1. 08 | I. 04 | I. 00 | 0.96 |
| 4 | 1.97 | 1.91 | 1. 86 | I. 8 I | 1.75 | I. 70 | I. 65 | I. 60 | 1. 54 | I. 49 | 1. 44 | I. 38 | I. 33 | I. 28 |
| 5 | 2.46 | 2.39 | 2.32 | 2.26 | 2. 19 | 2.13 | 2.06 | 1. 99 | 1.93 | 1.86 | 1.80 | 1.73 | I. 66 | 1.60 |
| 6 | 2.95 | 2.87 | 2.79 | 2.71 | 2.6 .3 | 2.55 | 2.47 | 2.39 | 2.32 | 2.24 | 2. 16 | 2.08 | 2.00 | 1.92 |
| 7 | 3.45 | 3.36 | 3.26 | 3.17 | 3.08 | 2.99 | 2.89 | 2.80 | 2.71 | 2.61 | 2.52 | 2.43 | 2.33 | 2.24 |
| 8 | 3.95 | 3.84 | 3.73 | 3.63 | 3.53 | 3.42 | 3.31 | 3.20 | 3.10 | 2.99 | 2.88 | 2.78 | 2.67 | 2.56 |
| 9 | 4.44 | 4.32 | 4.21 | 4.09 | 3.97 | 3.85 | 3.73 | 3.61 | $3 \cdot 49$ | $3 \cdot 37$ | 3.25 | 3.13 | 3.00 | 2.88 |
| 10 | 4.94 | 4.81 | 4.68 | 4.54 | 4.41 | 4.28 | 4.14 | 4 . OI | 3.88 | 3.74 | 3.61 | 3.48 | 3.34 | 3.21 |
| II | 5.44 | $5 \cdot 30$ | 5.15 | 5.00 | 4.86 | 4.71 | 4.56 | 4.42 | 4.27 | 4.12 | 3.97 | 3.83 | 3.68 | 3.53 |
| 12 | 5.94 | 5.78 | 5.62 | 5.46 | 5.30 | 5.14 | 4.98 | 4.82 | 4.66 | 4.50 | $4 \cdot 34$ | 4.18 | 4.02 | 3.85 |
| 13 | 6.45 | 6.27 | 6.10 | 5.92 | 5.75 | 5.57 | 5.40 | 5.23 | 5.05 | 4.88 | 4.70 | 4.53 | 4.36 | 4.18 |
| 14 | 6.95 | 6.76 | 6.58 | 6.39 | 6.20 | 6.01 | 5.83 | 5.64 | 5.45 | 5.26 | 5.07 | 4.88 | 4.70 | 4.51 |
| 15 | 7.46 | 7.26 | 7.06 | 6.85 | 6.65 | 6.45 | 6.25 | 6.05 | 5.85 | 5.64 | 5.44 | 5.24 | 5.04 | 4.84 |
| 16 | 7.96 | 7.75 | 7.54 | $7 \cdot 32$ | 7.11 | 6.89 | 6.68 | 6.46 | 6.24 | 6.03 | 5.81 | 5.60 | $5 \cdot 38$ | 5.17 |
| 17 | 8.47 | 8.24 | 8.02 | $7 \cdot 79$ | 7.56 | 7.33 | 7.10 | 6.87 | 6.64 | 6.41 | 6.18 | 5.95 | 5.72 | 5.50 |

This table gives the vapor pressure corresponding to various values of the difference $t-t_{1}$ between the readings of dry and wet bulb thermometers and the temperature $t_{1}$ of the wet bulb thermometer．The difference $t-t_{1}$ is given by two－degree steps in the top line，and $t 1$ by degrees in the first column．Temperatures in Centigrade degrees，vapor pressures in millimeters of mercury are used throughout the table．The table was calculated for barometric pressure $B$ equal to 76 centimeters．A correction is given for each centimeter at the top of the columns．Ventilating velocity of wet thermometer about 3 meters per second．

| $t_{1}$ | $\begin{aligned} & t-t_{1} \\ &=0\end{aligned}$ | $2^{\circ}$ | $4^{\circ}$ | $6^{\circ}$ | $8^{\circ}$ | $10^{\circ}$ | $12^{\circ}$ | $14^{\circ}$ | $16^{\circ}$ | $18^{\circ}$ | $20^{\circ}$ | Differ－ ence for |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Corrections for $B$ per cm |  | ． 013 | ． 026 | ． 040 | ． 053 | ． 066 | ． 079 | ． 092 | ． 106 | ． 119 | ． 132 | $\underset{i-i_{1}}{0.18}$ |
| －10 | 1.96 | 0.97 |  | － | － | Example． |  |  |  |  |  | 0.050 |
| －9 | 2.14 | I． 15 | 0.16 |  |  | $t=17.2 ; t_{1}=10.0 ; B=74.5 \mathrm{~cm}$ |  |  |  |  |  | 0.050 |
| －8 | 2.34 | I． 35 | 0.35 | － | － |  |  |  |  |  |  | 0.050 |
| $=7$ -6 | 2．55 | 1． 56 | 0.66 |  |  | $t-t_{1}=7.20 .0, B=74.5 \mathrm{~cm}$ |  |  |  |  |  | 0.050 |
| － 6 | 2.78 | 1.78 | 0.79 |  |  | From table： $6.17-12 \times 0.050=5.57$ <br> For $B$ ，I． $5 \times .048=107$ |  |  |  |  |  | 0.050 |
| 5 | 3.02 | 2.03 | 1.03 | 0.03 | － | Hence $p \times .05$ |  |  |  |  |  | 0.050 |
| －4 | 3.29 | 2.29 | 1． 29 | 0.29 |  |  |  |  |  | $=5.64$ |  | 0.050 |
| － 3 | 3.58 | 2.58 | 1． 58 | －． 58 | 二 |  |  |  |  |  |  | 0.050 |
| 1 -1 | 3.89 4.22 | 2.89 3.22 | 1.89 2.22 | 0.88 1．21 | 0.21 |  |  | － | － | － | 二 | 0.050 |
| $\bigcirc$ | 4． 58 | 3.58 | 2.57 | 1． 57 | 0． 57 | 二 | － | 二 | 二 | 二 | 二 | 0.0500.050 |
| 1 | 4.92 | 3.92 | 2.92 | I． 91 | －．91 |  |  |  |  |  |  |  |
| 2 | 5.29 | 4.29 | 3.28 | 2.27 2.66 | 1.27 | 0.26 | － | 二 | 二． | － | － | $\begin{aligned} & 0.050 \\ & 0.050 \end{aligned}$ |
| 3 4 | 5.68 6.10 | 4.68 5.09 | 3.67 4.08 | 2.66 3.07 | 1.66 2.07 | 0.65 I． 06 | －0．05 | 二 | － | 二 | 二 |  |
| 5 | 6.54 | 5.53 | 4.52 | 3.5 I | 2.51 | 1． 50 | 0.49 | － | 二 | 二 | 二 | 0.0500.050 |
| 6 | 7.01 | 6.00 | 4.99 | 3.98 | 2.97 | I． 96 | 0.95 |  | － |  |  |  |
| 7 | 7.51 8.04 8.61 | 6.50 7.03 | 5.49 6.02 | 4.48 5 | 3.47 4.00 | 2.46 | I． 45 | 0.43 |  | － |  | $0.050$ |
| 8 | 8.04 8.61 | 7.03 7.60 | 6.02 6.58 | 5.01 5.57 | 4.00 4.56 | $\begin{aligned} & 2.98 \\ & 3.54 \end{aligned}$ | $\begin{aligned} & 1.97 \\ & 2.53 \end{aligned}$ | 1． 52 <br> 1 | 0.50 | 二 | － |  |
| 10 | 9.21 | 8.20 | 7.18 | 6.17 | 5.15 | 4.14 | 3.12 | 2.11 | 1.09 | 0.08 | 二 | 0.050 |
| 11 | 9.85 | 8.83 | 7.81 | 6.80 | 5.78 | 4.77 | 3.12 3.75 | 2.73 | 1.72 | 0．78 |  | 0.051 |
| 12 | 10.52 | 9.50 | 8.49 | 7.47 | 6.45 | 5.446.146.14 | $\begin{aligned} & 4.42 \\ & 5.13 \end{aligned}$ | $\begin{aligned} & 3.40 \\ & 4.1 I \end{aligned}$ | $\begin{aligned} & 2.38 \\ & 3.09 \end{aligned}$ | $\underline{1} 37$ | $\begin{aligned} & 0.35 \\ & 1.05 \end{aligned}$ | 0.051 |
| 13 | II． 24 | 10． 22 | 9.20 | 8． 18 | 7.16 |  |  |  |  | 2.072.82 |  | $\begin{aligned} & 0.051 \\ & 0.051 \end{aligned}$ |
| 14 | 11.99 | 10.97 | 9.95 | 8.93 | 7.91 | 6.90 | 5.88 | 4.86 | $\begin{aligned} & 3.09 \\ & 3.84 \end{aligned}$ |  | $\begin{aligned} & 1.05 \\ & 1.80 \end{aligned}$ |  |
| 15 | 12.79 | 11.77 | 10.75 | 9．73 | 8.71 | 7.69 | 6.67 | 5.656.49 | 4.63 | 3.61 | 2.59 | 0.051 |
| 16 | 13.64 | 12.62 | 11.60 | 10.58 | 9.96 | $\begin{array}{r} 8.53 \\ 9.42 \end{array}$ |  |  | 5.66.476.36 | 4.655.335 | $\begin{array}{r} 3.43 \\ 4.31 \\ \hline \end{array}$ | 0.051 |
| 17 | 14.54 | 13.52 | 12.49 | 11.47 | 10.45 |  |  | 6．497.388.32 |  |  |  |  |
| 18 | 15.49 | 14.46 | 13.44 | 12.42 | 11.39 | I0． 37II． 36 | $\begin{array}{r} 9.34 \\ 10.34 \end{array}$ |  | 7.308.29 | 6.277.26 | 5.256.24 | $\begin{aligned} & 0.05 \mathrm{I} \\ & 0.05 \mathrm{I} \end{aligned}$ |
| 19 | 16.49 | 15.46 | 14.44 | 13.41 | 12.39 |  |  | $\begin{aligned} & 8.32 \\ & 9.3 \mathrm{I} \end{aligned}$ |  |  |  |  |
| 20 | 17.55 | 16.52 | 15.50 | 14.47 | 13.44 | 12.42 | 11.39 | 10． 36 | 9.34 | 8.31 | 7.29 | 0.051 |
| 21 | 18.66 | 17.64 | 16．6r | 15.58 | 14.56 | $\begin{aligned} & 13.53 \\ & 14.70 \end{aligned}$ | $\begin{aligned} & 12.50 \\ & 13.67 \end{aligned}$ | $\begin{aligned} & 11.47 \\ & 12.64 \end{aligned}$ | $\begin{aligned} & 10.45 \\ & 1.62 \end{aligned}$ | 9.4210.59 | $\begin{array}{r} 8.39 \\ 10.57 \end{array}$ | $\begin{aligned} & 0.051 \\ & 0.051 \end{aligned}$ |
| 22 | 19.84 | 18.82 | 17.79 | 16.76 | 15.73 |  |  |  |  |  |  |  |
| 23 | 21.09 | 20.06 | 19.03 | 18.00 | 16.97 | $\begin{aligned} & 15.94 \\ & 17.24 \end{aligned}$ | 14.9116.21 | $\begin{aligned} & 13.88 \\ & 15.18 \end{aligned}$ | $\begin{aligned} & 12.85 \\ & 14.15 \end{aligned}$ | $\begin{aligned} & 11.82 \\ & 13.12 \end{aligned}$ | $\begin{aligned} & 10.79 \\ & 12.09 \end{aligned}$ | $\begin{aligned} & 0.051 \\ & 0.05 \mathrm{I} \end{aligned}$ |
| 24 | 22.40 | 21.37 | 20.34 | 19．31 | 18.27 |  |  |  |  |  |  |  |
| 25 | 23.78 | 22.75 | 21.71 | 20.68 | 19.65 | 18.62 | 17.59 | 16.56 | 15.52 | 14.49 | I3．46 | 0.052 |
| 26 | 25.24 | 24.20 | 23.17 | 22.14 | 21.10 | $\begin{aligned} & 20.07 \\ & 21.60 \\ & 23.20 \end{aligned}$ | $\begin{aligned} & 19.04 \\ & 20.56 \\ & 22.17 \end{aligned}$ | $\begin{aligned} & 18.00 \\ & 19.53 \\ & 21.13 \end{aligned}$ | $\begin{aligned} & 16.97 \\ & 18.49 \\ & 20.10 \end{aligned}$ | $\begin{aligned} & 15.94 \\ & 17.46 \end{aligned}$ | 14.90 | $\begin{aligned} & 0.052 \\ & 0.052 \end{aligned}$ |
| 27 28 | 26.77 | 25.73 | 24.70 | 23.66 | 22.63 |  |  |  |  |  | 16.42 |  |
| 28 | 28.38 | 27.34 | 26.31 | 25.27 | 24.24 |  |  |  |  | $\begin{aligned} & 19.06 \\ & 20.75 \end{aligned}$ | $\begin{aligned} & 18.02 \\ & 19.71 \end{aligned}$ | $\begin{aligned} & 0.052 \\ & 0.052 \end{aligned}$ |
| 29 | 30.08 | ． 29.04 | 28.00 | 26.97 | 25.93 | $\begin{aligned} & 23.20 \\ & 24.89 \end{aligned}$ | $23.86$ | $\begin{aligned} & 21.13 \\ & 22.82 \end{aligned}$ | $\begin{aligned} & 20.10 \\ & 21.78 \end{aligned}$ |  |  |  |
| 30 | 31.86 | 30.82 | 29.78 | 28.75 | 27.71 | 26.67 | 25.63 | 24.60 | 23.56 | 22.52 | 21.48 | 0.052 |
| 31 | 33.74 | 32.70 | 31.66 | 30.62 | 29.58 | $\begin{aligned} & 28.54 \\ & 30.50 \\ & 32.57 \end{aligned}$ | $\begin{aligned} & 27.50 \\ & 29.46 \\ & 31.53 \end{aligned}$ | $\begin{aligned} & 26.46 \\ & 28.42 \\ & 30.49 \end{aligned}$ | $\begin{aligned} & 25.42 \\ & 27 \cdot 38 \end{aligned}$ | 24.38 | 23.34 | $\begin{aligned} & 0.052 \\ & 0.052 \end{aligned}$ |
| 32 | 35.70 |  |  | 32.58 | 31.54 |  |  |  |  | 26.34 | 25.30 |  |
| 33 34 | 37.78 39.95 | 36.73 38.90 | 35.69 37.86 | 34.65 36.82 | 33.61 35.78 |  |  |  | $\begin{aligned} & 29.44 \\ & 3 \mathrm{I} .6 \mathrm{I} \end{aligned}$ | $\begin{aligned} & 28.40 \\ & 30.57 \end{aligned}$ | 27.36 | $\begin{aligned} & 0.052 \\ & 0.052 \end{aligned}$ |
| 34 | 39.95 | 38.90 | 37.86 | 36.82 | 35.78 | $\begin{aligned} & 32.57 \\ & 34.73 \end{aligned}$ | 31.53 33.69 | $\begin{aligned} & 30.49 \\ & 32.65 \end{aligned}$ |  |  | 29.52 |  |
| 35 | 42.23 | 41． 18 | 40.14 | 39．10 | 38.05 | 37.01 | 35.97 | 34.92 | 33.88 | 32.83 | 31.79 | 0.052 |
| 36 37 | 44.62 47.13 | 43.57 46.08 | 42.53 | 41.43 | 40.44 | 39.40 | 38.35 | 37.31 | 36． 26 | 35.22 | 34.17 | 0.052 |
| 37 38 | 47.13 49.76 | 46.08 48.71 | 45.04 47.66 | 43.99 | 42.94 | 41.90 | 40.85 | 39.81 | 38.76 | 37.71 | 36.67 | 0.052 |
| 39 | 49.76 52.51 | 48.71 51.46 | 47.60 50.41 | 46.61 49.37 | 45.57 48.32 | 44.52 47.27 | 43.47 46.22 | 42.43 45.17 | 44．38 | 40.33 43.08 | 39.29 42.03 | 0.052 0.052 |
| 40 | 55.40 | 54.35 | 53.30 | 52.25 | 51.20 | 50.15 | 49． 10 | 48.05 | 47.00 | 45.95 | 44.00 | 0.052 |

Emithsonian Tables．

Table 190.
RELATIVE HUMIDITY.
Vertical argument is the observed vapor pressure which may be computed from the wet and drybulb readings through Table 188 or 189 . The horizontal argument is the observed air temperature (dry-bulb reading). Based upon Table 43, p. 142, Smithsonian Meteorological Tables, 3 d Revised Edition, 1907.


Smithsonian Tables.

|  | Air Temperatures, dry bulb, ${ }^{\circ}$ Cenigrade. |
| :---: | :---: |
|  | ${ }^{20} 210$ |
| 1 2 2 | cccccccccccccccccccccccccc |
| $\begin{array}{r} 5 \\ 6 \\ 7 \\ 7 \\ \hline 9 \end{array}$ |  |
| $\begin{aligned} & 10 \\ & 11 \\ & 12 \\ & 13 \\ & 14 \end{aligned}$ |  |
| $\begin{aligned} & 15 \\ & 16 \\ & 17 \\ & 18 \end{aligned}$ |  <br>  |
| $\begin{aligned} & 20 \\ & 21 \\ & 20 \\ & 23 \\ & 20 \end{aligned}$ |  |
| $\begin{aligned} & 25 \\ & 26 \\ & 26 \\ & 28 \\ & 29 \end{aligned}$ |  |
| $\begin{aligned} & 30 \\ & 31 \\ & 32 \\ & 33 \\ & 33 \\ & 34 \end{aligned}$ |  |
|  | - - - - - 999489 |
| 36 <br> 37 |  |
| ${ }_{39}^{38}$ |  |
| ${ }_{41}^{40}$ | -969086 |
| 41 42 43 |  |
| ${ }_{44}^{4}$ | -999489 |
| 45 | - 9698 |
| ${ }_{48}^{47}$ |  |
|  |  |
| 50 52 51 5 | $\begin{aligned} & 93 \\ & 995 \end{aligned}$ |
| 54 | こ こ - - - - - - - -99 |
| 55 | - - - - |

MITHSONIAN TABLES.

Tables 190 (concluded), 191.
TABLE 190 (concluded).-Relative Humidity.
(Data from $20^{\circ}$ to $60^{\circ} \mathrm{C}$. based upon Table 185).

| Vapor <br> Pressure mm. | Air Temperatures, dry bulb, ${ }^{\circ}$ Centigrade. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $40^{\circ}$ | $41^{\circ}$ | 42 | $43^{\circ}$ | $44^{\circ}$ | $45^{\circ}$ | $46^{\circ}$ | 47 | $48^{\circ}$ | $49^{\circ}$ | 50 | $51^{\circ}$ | $52^{\circ}$ | 53. | 54. | 55 |  |  | 58. | 590 | 600 |
| 5 | 9 |  |  | 8 | 7 | 7 |  | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 4 | 4 |  |  | 4 | 4 | 3 |
| 10 | 18 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 8 |  |  | 7 | 7 | 7 |
| 15 | 27 | 26 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 |  | 11 | 10 | 10 |
| 20 | 36 | 34 | 33 | 31 | 29 | 28 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 15 | 14 | 13 |
| 25 | 45 | 43 | 41 | 39 | 37 | 35 | 33 | 31 | 30 | 28 | 27 | 26 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 |
| 30 | 54 | 51 | 49 | 46 | 44 | 42 | 40 | 38 | 36 | 34 | 32 | 3 I | 29 | 28 | 27 | 25 | 24 | 23 | 22 | 21 | 20 |
| 35 | 63 |  | 57 | 54 | 51 | 49 | 46 | 44 | 42 | 40 | 38 | 36 | 34 | 33 | 31 | 30 | 28 |  | 26 | 25 | 23 |
| 40 |  |  | 65 | 62 | 59 | 56 | 53 | 50 | 48 | 45 | 43 | 41 | 39 | 37 | 36 | 34 | 32 | 31 | 29 | 28 | 27 |
| 45 50 |  | 77 | 73 81 | 69 | 66 | 63 | 59 | 57 | 54 | 5 I | 49 | 46 | 44 | 42 | 40 | 38 | 36 |  | 33 | 32 | 30 |
| 50 |  | 86 | 81 | 77 | 73 | 70 | 66 | 63 | 60 | 57 | 54 | 51 | 49 | 47 | 44 | 42 | 40 |  | 37 | 35 | 33 |
| 55 | 99 | 94 | 89 | 85 | 81 | 76 | 73 | 69 | 66 | 62 | 59 |  | 54 | 51 | 49 | 46 | 44 |  | 40 | 39 | 37 |
| 60 | - |  | 98 | 93 | 88 | 83 | 79 | 75 | 72 | 68 | 65 | 62 | 60 | 56 | 53 | 51 | 48 |  | 44 | 42 | 40 |
| 65 | - |  |  |  | 95 | 90 | 86 | 82 | 78 |  | 70 | 67 | 64 | 61 | 58 | 55 | 52 |  |  | 46 | 43 |
| 70 | - |  |  |  |  | 97 | 92 | 88 | 84 |  | 76 |  | 68 | 65 | 62 | 59 | 56 |  | 51 | 49 | 47 |
| 75 |  |  |  |  |  |  | 99 | 94 | 90 |  | 81 | 77 | 74 | 70 | 67 | 64 | 60 |  | 55 | 53 | 50 |
| 80 | - | - | - | - | - | - |  | 100 | 96 | 91 | 86 | 82 | 78 | 75 | 71 | 68 | 64 |  | 59 | 56 | 54 |
| 85 90 | - | - | - | - | - | - | - |  |  | 97 | 92 | 87 | 84 | 79 | 75 | 72 | 69 |  | 62 | 60 | 57 |
| $\begin{aligned} & 90 \\ & 95 \end{aligned}$ |  |  | mm. | $57^{\circ}$ | 58 | 59 |  | - | - |  | 97 | 93 | 88 | 84 |  | 76 | 73 |  | 66 | 63 | 60 |
| 100 | - |  | 125 | 96 | 92 | 88 | 84 |  |  |  | - | 9 | 98 | 93 | 89 | . 85 | ${ }_{81}$ | 73 | 73 | 70 | 67 |
| 105 | - |  | 130 | 100 | 95 | 91 | 87 | - | - | - | - |  |  | 98 | 93 |  | 85 |  |  | 74 | 70 |
| 110 | - |  | 135 | - | 99 | 95 | 90 | - | - | - | - | - | - |  |  | 93 | 89 |  | 81 | 77 | 74 |
| 115 | - |  | 140 | - |  | 98 | 94 |  |  | - | - | - |  |  |  | 97 |  |  | 84 | 81 | 77 |
| 120 | - |  | 145 | - | - | - | 97 |  |  | - | - | - | - |  |  |  |  |  |  | 84 | 80 |
| 125 | - |  | 150 | - | - |  | 100 | - | - | - | - | - | - | - | - | - | - | 96 | 92 | 88 | 84 |

## TABLE 191, - Relative Humldity.

This table gives the relative humidity direct from the difference between the reading of the dry ( $t{ }^{\circ} \mathrm{C}$.) and the wet ( $t_{1}{ }^{\circ}$ C.) thermometer. It is computed for a barometer reading of $\overline{\xi 6 \mathrm{~cm} \text {. The wet thermometer should be ventilated }}$ about 3 meters per second. From manuscript tables computed at the U.S. Weather Bureau.

| $\mathrm{t}^{\circ}$ | Depression of wet-bulb thermometer, $\mathrm{t}^{0}-\mathrm{t}_{1}{ }^{\circ}$. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $0.2{ }^{\circ}$ | $0.4{ }^{\circ}$ | $0.6{ }^{\circ}$ | $0.8{ }^{\circ}$ | $1.0^{\circ}$ | $1.2{ }^{\circ}$ | $1.4{ }^{\circ}$ | $1.6{ }^{\circ}$ | $1.8{ }^{\circ}$ | $2.0{ }^{\circ}$ | 2.50 | $3.0{ }^{\circ}$ | $3.5{ }^{\circ}$ | $4.0{ }^{\circ}$ | $4.5{ }^{\circ}$ | $5.0{ }^{\circ}$ | 5.50 |
| -15 | 90 | 91 | 72 | 62 | 53 | 44 | 35 | 25 | 16 | 7 | - | - | - | - | - | - | - |
|  | 92 | 85 | 77 | 69 | 62 | 54 | 47 | 39 | 32 | 25 | 7 | - | - | - | - | - | - |
| -9 | 94 | 88 | 81 85 | 75 | 70 | 62 | 56 | 50 | 44 | 39 | 23 | 25 | - | $\overline{2}$ | - | - | - |
| -6 -3 | 95 96 | 89 91 | 85 87 | 80 82 | 74 78 | 69 74 | 64 69 | 69 | 54 64 | 49 59 | 36 46 | 25 36 | 13 26 | 17 | 7 | - | - |
| 0 | 96 | 92 | 89 | 85 | 81 | 78 | 74 | 71 | 67 | 64 | 55 | 46 | 38 | 29 | 21 | 13 | 6 |
| +3 | 97 | 94 | $9{ }^{1}$ | 87 | 84 | 81 | 78 | 75 | 72 | 69 | 62 | 54 | 46 | 40 | 32 | 25 | 18 |
|  | $0.5^{\circ}$ | $1.0^{\circ}$ | $1.5^{\circ}$ | $2.0{ }^{\circ}$ | $2.5{ }^{\circ}$ | $3.0{ }^{\circ}$ | $3.5{ }^{\circ}$ | $4.0{ }^{\circ}$ | $4.5{ }^{\circ}$ | $5.0^{\circ}$ | $6.0^{\circ}$ | $7.0^{\circ}$ | $8.0{ }^{\circ}$ | $9.0{ }^{\circ}$ | 10.0 | 11.0 | 12.0 |
| +3 | 92 | 84 | 76 | 69 | 62 | 54 | 46 | 40 | 32 | 25 | 12 | - | - | - | - | - | - |
| +6 | 94 | 87 | 80 | 73 | 66 | 60 | 54 | 47 | 41 | 35 | 23 | 11 | 12 | $\bar{\square}$ | - | - | - |
| +9 +12 | 94 | 88 | 82 | 76 | 70 | 65 | 59 | 53 | 48 | 42 | 32 | 22 | 12 | 3 | - | - | - |
| +12 | 94 | 89 | 84 | 78 | 73 | 68 | 63 | 58 | 53 | 48 | 38 | 30 | 21 | 12 | 4 | - | - |
| $+15$ | 95 | 90 | 85 | 80 | 76 | 71 | 66 | 62 | 58 | 53 | 44 | 36 | 28 | 20 | 13 | 4 | - |
| +18 | 95 | 90 | 86 | 82 | 78 | 73 | 69 | 65 | 61 | 57 | 49 | 42 | 35 | 27 | 20 | 13 | 3 |
| +21 | 96 | 91 | 87 | 83 | 79 | 75 | 71 | 67 | 64 | 60 | 5.3 | 46 | 39 | 32 | 26 | 19 | 13 |
| $+24$ | 96 | 92 | 88 | 85 | 81 | 77 | 74 | 70 | 66 | 63 | 56 | 49 | 43 | 37 | 31 | 26 | 21 |
| +27 | 96 | 93 | 90 | 86 | 82 | 79 | 76 | 72 | 68 | 65 | 59 | 53 | 47 | 41 | 36 | 31 | 26 |
| +30 | 96 | 93 | 90 | 86 | 82 | 79 | 76 | 73 | 70 | 67 | 61 | 55 | 50 | 44 | 39 | 35 | 30 |
| $+33$ | 96 | 93 | 90 | 86 | 83 | 80 | 77 | 74 | 71 | 68 | 63 | 57 | 52 | 47 | 42 | 37 | 33 |
| +36 +39 | 97 | 93 | 90 | 87 88 | 84 8 | 81 82 | 78 | 75 | 72 | 70 | $6_{4}$ | 57 | 54 | 50 | 45 | 41 | 36 |
| +39 | 97 | 94 | 91 | 88 | 85 | 82 | 79 | 76 | 74 | 71 | 66 | 61 | 56 | 52 | 47 | 43 | 39 |

## THERMOMETER THREAD.

When the temperature of a portion of a thermometer stem with its mercury thread differs much from that of the bulb, a correction is necessary to the observed temperature unless the instrument has been calibrated for the experimental conditions. This stem correction is proportional to $n \beta(T-t)$, where $n$ is the number of degrees in the exposed stem, $\beta$ the apparent coefficient of expansion of mercury in the glass, $T$ the measured temperature, and $t$ the mean temperature of the exposed stem. For temperatures up to $100^{\circ} \mathrm{C}$, the value of $\beta$ is for Jena ${ }^{16} 6^{\mathrm{III}}$ or Greiner and Friedrich resistance glass, $0.0001_{59}$, for Jena $59^{\mathrm{II}}, 0.000164$, and when of unknown composition it is best to use a value of about 0.000155 . The formula requires a knowledge of the temperature of the emergent stem. This may be approximated in one of three ways: (r) by a "fadenthermometer" (see Buckingham, Bulletin Bureau of Standards, 8, p. 239, 1912); (2) by exploring the temperature distribution of the stem and calculating its mean temperature; and (3) by suspending along the side of, or attaching to the stem, a single thermometer. Table 192 is taken from the Smithsonian Meteorological Tables, Tables 193-195 from Rimbach, Z. f. Instrumentenkunde, 10, p. 153,1890 , and apply to thermometers of Jena or resistance glass.

TABLE 192. - Stem Correction for Centigrade Thermometers.
Values of $0.000155 n(T-t)$.

| $n$ | ( $T-t$ ). |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ |
| $10^{\circ} \mathrm{C}$ | 0.02 | 0.03 | 0.05 | 0.06 | 0.08 | 0.09 | 0.11 | 0.12 |
| 20 | 0.03 | 0.06 | 0.09 | 0. 12 | -. 16 | -. 19 | 0.22 | 0.25 |
| 30 | 0.05 | 0.09 | -. 14 | -. 19. | 0.23 | 0. 28 | 0. 33 | 0.37 |
| 40 | 0.06 | 0. 12 | -.19 | 0. 25 | 0. 31 | 0.37 | 0.43 | 0.50 |
| 50 | 0.08 | 0.16 | 0.23 | 0.31 | -. 39 | 0.46 | 0. 54 | 0.62 |
| 60 | 0.09 | O. 19 | 0. 28 | 0.37 | 0.46 | 0.56 | 0.65 | 0.74 |
|  | O. 11 | 0. 22 | 0.33 | 0.43 | -. 54 | 0.65 | 0.76 | 0.87 |
| 80 | 0.12 | 0.25 | 0.37 | 0. 50 | 0.62 | 0.74 | 0.87 | 0.99 |
| 90 | 0. 14 | 0. 28 | 0.42 | 0. 56 | 0. 70 | 0.84 | 0.98 | I. 12 |
| 100 | -. 16 | 0.31 | 0.46 | 0.62 | 0.78 | 0.93 | 1.08 | I. 24 |

TABLE 193. - Stem Correction for Thermometer of Jena Glass ( $0^{\circ}$ to $\mathbf{3 6 0}{ }^{\circ}$ C).
Degree length 0.9 to 1.1 mm; $t=$ the observed temperature; $t^{\prime}=$ that of the surrounding air 1 dm . away; $n=$ the length of the exposed thread.


CORRECTION FOR TEMPERATURE OF MERCURY IN THERMOMETER STEM (continued).

TABLE 194. - Stem Correction for Thermometer of Jena Glass ( $\mathbf{0}^{\circ}-\mathbf{3 6 0}{ }^{\circ}$ C).
Degree length I to 1.6 mm ; $t=$ the observed temperature ; $t^{\prime}=$ that of the surrounding air one dm. away; $u=$ the length of the exposed thread.

| $\boldsymbol{n}$ | Correction to be added to Thermometer Rbading.* |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $t$ - $t^{\prime}$ |  |  |  |  |  |  |  |  |  | $n$ |
|  | $70^{\circ}$ | $80^{\circ}$ | $90^{\circ}$ | $100^{\circ}$ | $120^{\circ}$ | $140^{\circ}$ | $160^{\circ}$ | $180^{\circ}$ | $200^{\circ}$ | $220^{\circ}$ |  |
| $10^{\circ}$ | 0.02 | 0.03 | 0.05 | 0.07 | 0.11 | 0.17 | 0.21 | 0.27 | 0.33 | 0.38 | $10^{\circ}$ |
| 20 | 0.13 | 0.15 | 0.18 | 0.22 | 0.29 | 0.38 | 0.46 | 0.53 | 0.61 | 0.67 | 20 |
| 30 | 0.24 | 0.28 | 0.33 | 0.39 | 0.48 | 0.59 | 0.70 | 0.78 | 0.88 | 0.97 | 30 |
| 40 | 0.35 | 0.41 | 0.48 | 0.56 | 0.68 | 0.82 | 0.94 | I. 04 | I.16 | 1.28 | 40 |
| 50 | 0.47 | 0.53 | 0.62 | 0.72 | 0.88 | 1.03 | 1.17 | I. 31 | I. 44 | 1.59 | 50 |
| 60 | 0.57 | 0.66 | 0.77 | 0.89 | 1.09 | 1.25 | 1.42 | I. 58 | 1.74 | 1.90 | 60 |
| 70 | 0.69 | 0.79 | 0.92 | 1.06 | 1.30 | I. 47 | 1.67 | I. 86 | 2.04 | 2.23 | 70 |
| 80 | 0.80 | 0.91 | 1.05 | 1.21 | 1.52 | I. 71 | I. 94 | 2.15 | 2.33 | 2.55 | 80 |
| 90 | 0.91 | 1.04 | 1.19 | 1.38 | 1.73 | 1.96 | 2.20 | 2.42 | 2.64 | 2.89 | 90 |
| 100 | 1.02 | 1.18 | I. 35 | 1.56 | I. 97 | 2.18 | 2.45 | 2.70 | 2.94 | 3.23 | 100 |
| 110 | - | - | - | 1. 78 | 2.19 | 2.43 | 2.70 | 2.98 | 3.26 | $3 \cdot 57$ | 110 |
| 120 | - | - | - | 1.98 | 2.43 | 2.69 | 2.95 | 3.26 | $3 \cdot 58$ | 3.92 | 120 |
| 130 | - | - | - | - | 2.68 | 2.94 | 3.20 | 3.56 | 3.89 | 4.28 | 130 |
| 140 | - | - | - | - | 2.92 | 3.22 | 3.47 | 3.86 | 4.22 | 4.64 | 140 |
| 150 | - | - | - | - | - | - | 3.74 | 4.15 | 4.56 | 5.01 | 150 |
| 160 | - | - | - | - | - | - | 4.00 | 4.46 | 4.90 | $5 \cdot 39$ | 160 |
| 170 | - | - | - | - | - | - | 4.27 | 4.76 | 5.24 | 5.77 | 170 |
| 180 | - | - | - | - | - | - | 4.54 | 5.07 | $5 \cdot 59$ | 6.15 | 180 |
| 190 | - | - | - | - | - | - |  | $5 \cdot 38$ | 5.95 | 6.54 | 190 |
| 200 | - | - | - | - | - | - | - | $5 \cdot 70$ | 6.30 | 6.94 | 200 |
| 210 | - | - | - | - | - | - | - | - | 6.68 | $7 \cdot 35$ | 210 |
| 220 | - | - | - | - | - | - | - | - | 7.04 | 7.75 | 220 |

* See Hovestadt's "Jena Glass" (translated by J. D. and A. Everett) for data on changes of thermometer zeros.

TABLE 195. - Stem Correction for a so-called Normal Thermometer of Jena Glass ( $0^{\circ}-100^{\circ} \mathbf{C}$ ).
Divided into tenth degrees; degree length about 4 mm .

| Correction to be added to the Reading $t$. |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $n$ | $t-t^{\prime}$ |  |  |  |  |  |  |  |  |  |  |  |
|  | $30^{\circ}$ | $35^{\circ}$ | $40^{\circ}$ | $45^{\circ}$ | $50^{\circ}$ | $55^{\circ}$ | $60^{\circ}$ | $65^{\circ}$ | $70^{\circ}$ | $75^{\circ}$ | $80^{\circ}$ | $85^{\circ}$ |
| 10 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.06 | 0.06 | 0.07 | 0.08 | 0.09 | 0.10 | 0.10 |
| 20 | 0.12 | 0.12 | 0.13 | 0.14 | 0.15 | 0.16 | 0.17 | O.I 8 | 0.19 | 0.20 | 0.22 | 0.23 |
| 30 | 0.21 | 0.22 | 0.23 | 0.24 | 0.25 | 0.25 | 0.27 | 0.29 | 0.31 | 0.33 | 0.35 | 0.37 |
| 40 | 0.28 | 0.29 | 0.31 | 0.33 | 0.35 | 0.37 | 0.39 | 0.41 | 0.43 | 0.45 | 0.48 | 0.51 |
| 50 | 0.36 | 0.38 | 0.40 | 0.42 | 0.44 | 0.46 | 0.48 | 0.50 | 0.53 | 0.57 | 0.61 | 0.65 |
| 60 | 0.45 | 0.48 | 0.51 | 0.53 | - 0.55 | 0.57 | 0.60 | 0.63 | 0.66 | 0.69 | 0.73 | 0.78 |
|  | 5 | - | , | . | - | 0.66 | 0.69 | 0.71 | 0.75 | 0.81 | 0.87 | 0.92 |
| 80 | - | - | - | - | - | - | 0.76 | 0.81 | 0.87 | 0.93 | 1.00 | I. 06 |
| 90 | - | - | - | - | - | - | - | 0.92 | 0.99 | 1.06 | 1.13 | 1.20 |
| 100 | - | - | - | - | - | - | - | - | 1.10 | I.18 | 1.26 | 1.34 |

Smithsonian Tables.

## THERMOMETERS.

TABLE 196. - Gas and Mercury Thermometers.

- If $t_{\mathrm{H}}, t_{\mathrm{N}}, t_{\mathrm{CO} 2}, t_{16}, i_{69}, t_{\mathrm{T}}$, are temperatures measured with the hydrogen, nitrogen, carbonic acid, 16 III, $59{ }^{\text {III }}$, and "verre dur " (Tonnelot), respectively, then

$$
\begin{aligned}
& t_{\mathrm{H}}-t_{\mathrm{T}}=\frac{(\mathrm{I} 00-t) t}{100^{2}}\left[-0.61859+0.004735 \mathrm{I} . t-0.00001 \mathrm{I} 577 . t^{2}\right]^{*} \\
& t_{\mathrm{N}}-t_{\mathrm{T}}=\frac{(100-t) t}{100^{2}}\left[-0.5554 \mathrm{I}+0.0048240 . t-0.000024807 . t^{2}\right]^{*} \\
& t_{\mathrm{C} 02}-t_{\mathrm{T}}=\frac{(100-t) t}{100^{2}}\left[-0.33386+0.0039910 . t-0.000016678 . t^{2}\right]^{*} \\
& t_{\mathrm{H}}-t_{16}=\frac{(100-t) t}{100^{2}}\left[-0.67039+0.004735 \mathrm{I} . t-0.00001 \mathrm{I} 577 . t^{2}\right] \dagger \\
& t_{\mathrm{H}}-t_{59}=\frac{(100-t) t}{100^{2}}\left[-0.31089+0.0047351 . t-0.00001 \mathrm{I} 577 . t^{2}\right]^{2} \dagger
\end{aligned}
$$

* Chappuis ; Trav. et Mém. du Bur. internat. des Poids et Mes. 6, 1888.
$\dagger$ Thiesen, Scheel, Sell; Wiss. Abh. d. Phys. Techn. Reichanstalt, 2, 1895 ; Scheel; Wied. Ann. 58, 1896; D. Mech. Ztg. 1897.

TABLE 197. $t_{H}-t_{16}$ (Hydrogen $\left.-16^{\text {III }}\right)$.

|  | $\bigcirc$ | $1{ }^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0^{\circ}$ | . $000{ }^{\circ}$ | -. $007^{\circ}$ | -. $013^{\circ}$ | $-.019^{\circ}$ | $-.025^{\circ}$ | -.031 ${ }^{\circ}$ | -. $036^{\circ}$ | -. $042^{\circ}$ | -. $047^{\circ}$ | $-.051^{\circ}$ |
| 10 | -. 056 | -.06I | -. 065 | -. 069 | -. 073 | -. 077 | -. 080 | -. 084 | -. 087 | -. 090 |
| 20 | -. 093 | -. 096 | -. 098 | -. 101 | -. 103 | -. 105 | -. 107 | -. 109 | -. 110 | -. 112 |
| 30 | -. 113 | -.114 | -.115 | -. 116 | -.117 | -.118 | -.119 | -.119 | 一.119 | -. 120 |
| 40 | -. 120 | -.120 | -.120 | -.120 | -. 119 | -.119 | -. 118 | -. 118 | -.117 | -. 116 |
| 50 | -.116 | 一.115 | -.114 | -.II3 | -. 111 | -.110 | -. 109 | -. 107 | -. 106 | -.104 |
| 60 | -. 103 | -.101 | -. 099 | -. 097 | -. 096 | -. 094 | -. 092 | -. 090 | -. 087 | -. 085 |
| 70 | -. 083 | -.08I | -. 078 | -. 076 | -. 074 | -. 071 | -. 069 | -. 066 | -. 064 | -.06I |
| 80 | -. 0.08 | -. 0.086 | -. 053 | -. 050 | -. 048 | -. 045 | -. 042 | -. 039 | -. 036 | -. 033 |
| 90 | -. 030 | -. 027 | -. 024 | -.021 | -. 018 | -. 015 | -. 012 | -. 009 | -. 0.06 | -. 003 |
| 100 | . 000 |  |  |  |  |  |  |  |  |  |

TABLE 198. $t_{H}-t_{59}$ (Hydrogen $-59{ }^{I I I}$ ).

|  | $\bigcirc^{\circ}$ | $1^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0^{\circ}$ | . $000{ }^{\circ}$ | $-.003^{\circ}$ | -. $006^{\circ}$ | $-.009^{\circ}$ | -. $011^{\circ}$ | $-.014^{\circ}$ | -. $016^{\circ}$ | -. $018^{\circ}$ | -. $020{ }^{\circ}$ | -.022 ${ }^{\circ}$ |
| 10 | -. 024 | -. 025 | -. 027 | -. 028 | -. 030 | -.031 | -. 032 | -. 033 | -. 034 | -. 035 |
| 20 | -. 035 | -.036 | -. 036 | -. 037 | -. 037 | $-.037$ | -. 038 | -. 038 | -. 038 | $-.038$ |
| 30 | -. 038 | -. 037 | -. 037 | $-.037$ | $-.037$ | -. 036 | -. 036 | -. 035 | -. 035 | -. 034 |
| 40 | -. 034 | -. 033 | -. 032 | -. 032 | -.031 | -. 030 | -. 029 | -. 028 | -. 028 | -. 027 |
| 50 | -. 026 | -. 025 | -. 024 | -.023 | -. 022 | -.021 | -. 020 | -.019 | -. 018 | -. 017 |
| 60 | -.016 | -. 015 | -. 015 | -.014 | -. 013 | -. 012 | -. 011 | -. 010 | -.009 | -. 008 |
| 70 | -. 008 | -. 007 | -.006 | -.005 | -. 005 | -. 004 | -.003 | -.003 | -.002 | -.001 |
| 80 | -.001 | -. 001 | . 000 | . 000 | +.001 | +.001 | +.001 | +.002 | +.002 | +.002 |
| 90 100 | +.002 | +.002 | +.002 | +.002 | $+.002$ | $+.002$ | +.001 | +.001 | +.001 | . 000 |
| 100 | . 000 |  |  |  |  |  |  |  |  |  |

TABLE 199. (Hydrogen - 16 ${ }^{\text {III }}$ ), (Hydrogen - $69^{\text {III }}$ ).

|  | $-5^{\circ}$ | $-10^{\circ}$ | $-15^{\circ}$ | $-20^{\circ}$ | $-25^{\circ}$ | $-30^{\circ}$ | $-35^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $t_{1}-t_{16}$ <br> $t_{\mathrm{H}}-\mathrm{t}_{59}$ | $+0.04^{\circ}$ <br> $+0.02^{\circ}$ | $+0.08^{\circ}$ <br> $+0.04^{\circ}$ | $+0.13^{\circ}$ <br> $+0.07^{\circ}$ | $+0.19^{\circ}$ <br> $+0.10^{\circ}$ | $+0.25^{\circ}$ <br> $+0.14^{\circ}$ | $+0.32^{\circ}$ <br> $+0.18^{\circ}$ | $+0.40^{\circ}$ <br> $+0.23^{\circ}$ |

All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.
Smithsonian Tables.

## AIR AND MERCURY THERMOMETERS．

TABLE 200．$t_{A I R}-t_{16}$ ．（AIr $\left.-16{ }^{I I I}.\right)$

| ${ }^{\circ} \mathrm{C}$ ． | $\bigcirc{ }^{\circ}$ | $\mathrm{r}^{\circ}$ | $2^{\circ}$ | $3^{\circ}$ | $4{ }^{\circ}$ | $5{ }^{\circ}$ | $6^{\circ}$ | $7{ }^{\circ}$ | 80 | $9{ }^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\bigcirc$ | ． 000 | －． 006 | －． 012 | －． 017 | －． 02 | －． 027 | －． 032 | －． 037 | －．041 | －． 045 |
| 10 | －． 049 | －． 053 | －． 057 | －． 061 | －． 065 | －． 068 | －． 071 | －． 074 | －． 077 | －． 080 |
| 20 | －． 083 | －． 086 | －． 089 | －． 091 | －． 093 | －． 095 | －． 097 | －． 099 | －．ior | 02 |
| 30 | －． 103 | －． 104 | －． 105 | －． 106 | －． 107 | －． 108 | －． 109 | －． 1110 | －． 110 | 10 |
| 40 | －．110 | 二．110 | 二．111 | 二．111 | －．110 | 二．110 | －．110 | －． 109 | － 109 | 8 |
| 60 | 二．107 | －． 107 | －．106 | －． 1092 | －．104 | －． 0.088 | －．102 | 二．101 | －．100 | -.098 -.080 |
| 70 | －． 078 | －． 076 | －． 074 | －． 072 | －． 070 | －． 067 | －． 065 | －． 062 | －． 060 | －． 057 |
| 80 | －． 054 | －． 052 | －． 049 | －． 047 | －． 044 | －．04I | －． 039 | －． 036 | －． 034 | －． 031 |
| 90 | －． 028 | －． 025 | －． 023 | ． 020 | －． 017 | －． 010 | －． 011 | －． 009 | －． 006 | －． 003 |
| $\bigcirc$ | ． 000 | ＋． 003 | ＋．006 | ＋． 008 | ＋．ori | $+.014$ | ＋．017 | ＋．019 | ＋． 022 | ＋． 025 |
| 110 | ＋． 028 | ＋．030 | ＋．033 | ＋． 035 | ＋．038 | ＋．041 | ＋． 043 | ＋．046 | ＋． 048 | ＋．050 |
| 120 | ＋－053 | ＋．055 | ＋．057 | ＋．060 | ＋．062 | ＋．064 | ＋．066 | ＋． 068 | ＋．070 | ＋．072 |
| 130 | ＋． 074 | ＋． 076 | ＋．078 | ＋． 080 | ＋．08I | ＋．083 | ＋． 084 | ＋． 086 | ＋．087 | ＋．089 |
| 140 | ＋． 090 | ＋．091 | ＋．092 | ＋． 093 | ＋．094 | ＋．095 | ＋． 096 | ＋． 096 | ＋．097 | ＋． 097 |
| 150 | ＋． 098 | ＋．098 | ＋． 098 | ＋． 099 | ＋．099 | ＋． 099 | ＋．098 | ＋．098 | ＋．098 | ＋． 097 |
| 160 | ＋． 097 | ＋．096 | ＋． 095 | ＋． 094 | ＋．093 | $+.092$ | ＋．090 | ＋．089 | ＋． 088 | ＋． 086 |
| 170 | ＋． 084 | ＋．082 | ＋． 080 | ＋． 078 | ＋．076 | ＋． 073 | ＋．07I | ＋． 068 | ＋．065 | ＋．062 |
| 180 | ＋． 059 | ＋．055 | ＋．052 | ＋． 048 | ＋． 045 | ＋．041 | ＋．037 | ＋．033 | ＋． 028 | ＋．023 |
| 190 | ＋．019 | ＋．o14 | ＋．009 | ＋．004 | －． 001 | －． 007 | －． 013 | －． 019 | －． 025 | －．031 |
| 200 | －． 038 | －． 045 | －．05I | －． 058 | －． 066 | －． 073 | －． 080 | －． 088 | －． 096 | －． 105 |
| 210 | －．113 | －． 122 | －． 130 | －． 139 | －． 148 | －． 158 | ． 168 | －． 177 | －． 187 | －． 198 |
| 220 | －． 208 | －． 219 | －． 230 | －． 241 | －． 252 | －． 264 | －． 275 | －． 287 | －． 300 | －．312 |
| 230 | －． 325 | －． 338 | －351 | －． 365 | －． 378 | －． 392 | －． 407 | －． 421 | －． 436 | －． 450 |
| 240 | －． 466 | －． 481 | －． 497 | －． 513 | －． 529 | －． 546 | －． 562 | －． 579 | －． 597 | －．614 |
| 250 | －． 032 | －． 650 | －． 668 | －． 687 | －． 706 | －． 725 | －． 745 | －． 765 | －． 785 | －． 805 |
| 260 270 | －． 825 | －． 846 | －． 867 | －． 889 | －．911 | －． 933 | －． 955 | －．978 | －1．001 | －1．025 |
| 280 | －I．301 | －1．328 | －1．356 | － 1.384 | －1．412 | －I．440 | －1．469 | －1．498 | －1．528 | －1．558 |
| 290 | －1．588 | －1．618 | －1．649 | －r．680 | －1．711 | －1．743 | －1．776 | －1．808 | －I．841 | －r．874 |
| 300 | －1．908 |  |  |  |  |  |  |  |  |  |

Note：See Circular 8，Bureau of Standards relative to use of thermometers and the various precautions and corrections．

TABLE 201．$t_{\text {AIR }}-t_{59}$ ．（AII -59 III．$)$

| ${ }^{\circ} \mathrm{C}$ ． | $0^{\circ}$ | $\mathrm{I}^{\circ}$ | $2{ }^{\circ}$ | $3^{\circ}$ | $4^{\circ}$ | $5^{\circ}$ | $6^{\circ}$ | $7{ }^{\circ}$ | $8^{\circ}$ | $9^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 100 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 | ． 000 |
| 110 | ． 000 | ． 000 | ． 000 | －． 0001 | －．001 | －．001 | －．001 | －．001 | －． 002 | －． 002 |
| 120 | －． 002 | －． 002 | －． 002 | －． 002 | －． 002 | －． 003 | －．003 | －． 003 | －． 004 | －． 004 |
| 130 | －． 004 | －． 004 | －． 005 | －． 005 | －． 006 | －． 006 | －． 006 | －． 007 | －． 007 | －． 008 |
| 140 | －． 008 | －． 008 | －．009 | －． 009 | －． 010 | －． 010 | －． 011 | －． 011 | －． 012 | －．012 |
| 150 | －． 013 | －． 013 | －． 014 | －． 015 | －．016 | －．016 | －． 016 | －． 017 | －． 018 | －．019 |
| 160 | －．019 | －． 020 | 21 | －．02I | －． 022 | －． 023 | －． 024 | －． 025 | －． 026 | －． 027 |
| 170 | －． 028 | －． 029 | $-.030$ | －．031 | －． 032 | －． 033 | －． 034 | －． 035 | －． 037 | －．038 |
| 180 | －． 039 | －． 040 | －．041 | －． 043 | －． 044 | －． 045 | $-.046$ | －． 048 | $-.049$ | －．051 |
| 190 200 | -.052 -.067 | －． 053 | －． 055 | －．056 | －． 057 | －． 059 | －． 060 | －． 062 | －． 064 | －． 066 |

## Smithsonian Tables．

GAS, MERCURY, ALCOHOL, TOLUOL, PETROLETHER, PENTANE, THERMOMETERS.

TABLE 202. - $t^{\text {H}} t_{\text {M }}$ (Hydrogen-Mercury).

| Temperature, C. | Thuringer Glass. | Verre dur. <br> Tonnelot. $\dagger$ | Resistance Glass.* | English Crystal Glass. | Choisy-leRoi.* | $122^{\text {III.** }}$ | Nitrogen Thermometer. $\mathrm{T}_{\mathrm{H}}-\mathrm{T}_{\mathrm{x}} . \dagger$ | $\begin{aligned} & \mathrm{CO}_{2} \text { Ther- } \\ & \text { mometer- } \\ & \mathrm{T}_{\mathrm{H}}-\mathrm{T}_{\mathrm{CO}_{2}} \cdot \dagger \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | - | $\bigcirc$ | $\bigcirc$ |
| $\bigcirc$ | . 000 | . 000 | . 000 | . 000 | . 000 | . 000 | . 000 | . . 000 |
| 10 | -. 075 | -.052 | -. 066 | -. 008 | -. 007 | -. 005 | -. 006 | -. 025 |
| 20 | -. 125 | -.035 | -.108 | -.001 | -. 004 | -. 006 | -. 010 | -. 043 |
| 30 | -. $5^{66}$ | -. 102 | -.131 | +.017 | +.004 | -. 002 | -. 011 | -. 054 |
| 40 | -. 168 | -. 107 | -. 140 | $+.037$ | $+.014$ | +.001 | -. 011 | -. 059 |
| 50 | -. 166 | -. 103 | -. 135 | $+.057$ | $+.025$ | +.004 | -. 009 | -. 059 |
| 60 | -. 150 | -. 090 | -.119 | $+.073$ | $+.033$ | $+.008$ | -. 005 | -. 053 |
| 70 | -. 124 | -. 072 | -. 095 | $+.079$ | +.037 | $+.009$ | -.001 | -. 044 |
| 80 | -. 088 | -. 050 | -. 068 | $+.070$ | $+.032$ | $+.007$ | $+.002$ | -. 031 |
| 90 | -. 0.47 | $-.026$ | -. 034 | +.046 | +.022 | +.006 | $+.003$ | -.016 |
| 100 | . 000 | . 000 | . 000 | . 000 | . 000 | . 000 | . 000 | . 000 |

* Schlösser, Zt. Instrkde. 21, 1901.
$\dagger$ Chappuis, Trav. et mém. du Bur. Intern. des Poids et Mes. 6, 1888.

TABLE 203. - Comparison of Air and High Temperature Mercury Thermometers.
Comparison of the air thermometer with the high temperature mercury thermometer, filled under pressure and made of $59^{\text {III }}$ glass.

| Air. | $59^{\mathrm{III}}$. | Air. | $59^{\mathrm{III} .}$ |
| :---: | :---: | :---: | :---: |
| 0 | 0 | 0 | 0 |
| 0 | 0. | 375 | 385.4 |
| 100 | 100. | 400 | 412.3 |
| 200 | 200.4 | 425 | 440.7 |
| 300 | $304 . \mathrm{I}$ | 450 | 469.1 |
| 325 | 330.9 | 475 | 498.0 |
| 350 | $358 . \mathrm{I}$ | 500 | 527.8 |

Mahlke, Wied. Ann. 1894.

TABLE 204. - Comparisoil of Hydrogen and Other Thermometers.
Comparison of the hydrogen thermometer with the toluol, alcohol, petrolether, and pentane thermometers (verre dur).

| Hydrogen. | Toluol.* | Alcohol I.* | Alcohol II.* | Petrolether.t | Pentane. $\ddagger$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0.00 | 0.00 | 0.00 | - | 0.00 |
| -10 | -8.54 | -9.31 | -9.44 | - | -9.03 |
| -20 | -16.90 | -18.45 | -18.71 | - | -17.87 |
| -30 | -25.10 | -27.44 | -27.84 | - | -26.55 |
| -40 | -33.15 | -36.30 | -36.84 | -35.04 |  |
| -50 | -41.08 | -45.05 | -45.74 | -42.6 | -4.3 .36 |
| -60 | -480 | -53.71 | -54.55 | - | -51.50 |
| -70 | -56.63 | - | - | - | -51 |
| -100 | - | - | - | -80.2 | -82.46 |
| -150 | - | - | -113.0 | -116.87 |  |
| -200 | - | -140.7 | -146.84 |  |  |

* Chappuis, Arch. sc. phys. (3) 18, 1892.
$\dagger$ Holborn, Ann. d. Phys. (4) 6, 1901.
$\ddagger$ Rothe, unpublished.
All compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.
Smithsonian Tables.

Tables 205-207.

Callendar has shown that if we define the platinum temperature, pt, by pt $=100\left\{\left(\mathrm{R}-\mathrm{R}_{0}\right)\right.$ $\left./\left(\mathrm{R}_{100}-\mathrm{R}_{0}\right)\right\}$, where R is the observed resistance at $\mathrm{t}^{\circ} \mathrm{C}$., $\mathrm{R}_{0}$ that at $\mathrm{O}^{\circ}, \mathrm{R}_{100}$ at $100^{\circ}$, then the relation between the platinum temperature and the temperature $t$ on the scale of the gas thermometer is represented by $\mathrm{t}-\mathrm{pt}=\delta\{\mathrm{t} / \mathrm{I} 00-\mathrm{I}\} \mathrm{t} / \mathrm{I} 00$ where $\delta$ is a constant for any given sample of platinum and about 1.50 for pure platinum (impure platinum having higher values). This holds good between - $23^{\circ}$ and $450^{\circ}$ when $\delta$ has been determined by the boiling point of sulphur ( $445^{\circ}$.)
See Waidner and Burgess, Bul. Bureau Standards, 6, p. 149, 1909. Also Bureau reprints 224, 143 and 149.

TABLE 206.-Thermodynamic Temperature of the Ice Point, and Reduction to Thermodynamic Scale.

$$
\text { Mean }=273.13^{\circ} \mathrm{C} . \text { (ice point) } .
$$

For a discussion of the various values and for the corrections of the various gas thermometers to the thermodynamic scale see Buckingham, Bull. Bureau Standards, 3, p. 237, 1907.

Scale Corrections for Gas Thermometers.

| Temp. $\mathrm{C}^{\circ}$. | Constant pressure $=100 \mathrm{~cm}$. |  |  | Constant vol., $\mathrm{p}_{0}=100 \mathrm{~cm}, \mathrm{t}_{0}=\mathrm{O}^{\circ} \mathrm{C}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | He | H | N | He | H | N |
| $-240^{\circ}$ | - | +1.0 | - | $+0.02$ | +0.18 | - |
| - 200 | +0.13 | + . 26 | - | +. OI | + .06 | - |
| - 100 | $+.04$ | $+.03$ | +0.40 | . 000 | + .010 | +0.06 |
| - 50 | $+.012$ | $+.02$ | +.12 | . 000 | +.004 | + . 02 |
| + 25 | -. 003 | -. 003 | -. 020 | . 000 | . 000 | -. 006 |
| $+50$ | -. 003 | -. 003 | -. 025 | . 000 | . 000 | -. 006 |
| + 75 | -. 003 | -. 003 | -. 017 | . 000 | . 000 | -. 004 |
| +150 | $+.007$ | $+.01$ | $+.04$ | +.000 | $+.001$ | +.01 |
| $+200$ | + . OI | $+.02$ | +.11 | . 000 | +.002 | $+.04$ |
| $+450$ | $+.1$ | +0.04 | $+.5$ | 0.00 | +0.01 | $+.2$ |
| $+1000$ | +0.3 | - | +1.7 | - | - | +.7 |
| +1500 | - | - | +3. | - | - | +1.3 |

See also Appendix, p. 438.

TABLE 207.—Standard Points for the Calibration of Thermometers.

| Substance. | Point. | Atmosphere. | Crucible. | Temperatures. |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Nitrogen Scale. | Thermodynamic. |
| Water | boiling, 760 mm . | air | - | $\begin{gathered} { }^{\circ} \mathrm{C} . \\ 100.00 \end{gathered}$ | $\begin{gathered} \circ \\ 100.00 \end{gathered}$ |
| Naphthalene | ${ }_{\text {boiling, }} 760 \mathrm{~m}$ ، | " | - | 218.0 | 218.0 |
| Benzophenone | " " " | - | - | $305.85 \pm 0.1$ | 305.9 |
| Cadmium | melting or solidify. | air | graphite | $320.8 \pm 0.2$ | 320.9 |
| Zinc | " ${ }^{\text {a }}$ | " |  | $419.3 \pm 0.3$ | 419.4 |
| Sulphur | boiling, 760 mm . | - | - | $444.45 \pm 0.1$ | 444.55 |
| Antimony | melting or solidify. | $\mathrm{CO}_{6}$ | graphite | $629.8=0.5$ | 630.0 658.7 |
| Aluminum | solidification | " |  | $658.5=0.6$ | 658.7 |
| Silver | melting or solidify. | " | " | 960.0 1062.4 |  |
| Copper | " " | " | '6 | $1082.6=0.8$ |  |
| $\mathrm{Li}_{2} \mathrm{SiO}_{8}$ | melting | air | platinum | 1201.0 于 1.0 |  |
| Diopside, pure | " | " |  | ${ }_{1} 391.2 \pm 1.5$ |  |
| Nickel | melting or solidify. | H and N | magnesia and Mg. aluminate | $1452.3 \pm 2.0$ |  |
| Cobalt | " " " | " | magnesia | $1489.8 \pm 2.0$ |  |
| Palladium | " " | air |  | ${ }^{1} 549.2=2.0$ |  |
| Anorthite, pure | melting | " | platinum |  |  |
| Platinum |  |  |  | $\begin{array}{ll} 1752 . & \pm 5 . * \\ 1755 . & \pm 5 . t \end{array}$ |  |

*Thermoelectric extrapolation. †Optical extrapolation.
(Day and Sosman, Journal de Physique, 1912. Mesure des témperatures élevées.) A few additional points are: H, boils - $252.6^{\circ}$; O, boils - $182.7^{\circ}$; $\mathrm{CO}_{2}$, sublimes - $78.5^{\circ}$; Hg . freezes - $38.87^{\circ}$; Alumina melts $2000^{\circ}$; Tungsten melts $3400^{\circ}$.

TABLE 208. - Standard Calibration Curve for Pt. - Pt. Rh. (10\% Rh.) Thermo-Element.
Giving the temperature for every 100 microvolts. For use in conjunction with a deviation curve determined by calibration of the particular element at some of the following fixed points:

| Water | boiling-pt. | 100.0217.95 | 643 mv . |  | melting-pt. |  | 960.2 | $\underset{\substack{911 \text { Imv. } \\ \text { 10296 }}}{ }$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Naphthalene |  |  | 1585 | Gold |  |  | 1062.6 |  |
| Tin | melting-pt. | 231.9 | 1706 | Copper | " | " | 1082.8 | 10534 |
| Benzophenone | boiling-pt. | 305.9 | 2365 | $\mathrm{Li}_{2} \mathrm{SiO}_{3}$ | " | " | 1201. | 11941 |
| Cadmium | melting-pt. | 320.9 | 2503 | Diopside | " | " | 1391.5 | 14230 |
| Zinc | " " | 419.4 | 3430 | Nickel | " | " | 1452.6 | 14973 |
| Sulphur | boiling-pt. | 444.55 | 3672 |  |  |  |  |  |
| Antimony | melting-pt. | 630.0 | 5530 | Palladium | " |  | 1549.5 | 18144 |
| Aluminum | " ${ }^{\text {" }}$ | 658.7 | 5827 | Platinum |  | " | 1755. |  |



TABLE 209. - Standard Calibration Curve for Copper - Constantan Thermo-Element.
For use in conjunction with a deviation curve determined by the calibration of the particular element at some of the following fixed points:

Water, boiling-point, $100^{\circ}, 4276$ microvolts; Naphthalene, boiling-point, $217.95,10248 \mathrm{mv}$.; Tin, melting-point, 231.9, 11009 mv .; Benzophenone, boiling-point, 305.9 , 15203 mv .; Cadmlum, melting-point, 320.9 , 16083 mv .


Tables 210-213.
MECHANICAL EQUIVALENT OF HEAT.
TABLE 210.—Summary of Older Work.
Taken from J. S. Ames, L'équivalent mécanique de la chaleur, Rapports présentés au congrès international du physique, Paris, $\mathbf{I} 900$.
Reduced to Gram-calorie at $20^{\circ} \mathrm{C}$. (Nitrogen thermometer).

| JouleRowlandGriffithsSchuster-GannonCallendar-Barnes | $4.169 \times 10^{7}$ ergs. |  | * |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $4.169 \times 10^{7}$ ergs. |  |  |
|  | 4.181 | " ، | 4.181 | " |  |
|  | 4.192 | " | 4.184 | " | ، |
|  | 4.189 | " " | 4.18 I | " | " |
|  | 4.186 | " " | 4.178 | " | " |

* Admitting an error of 1 part per 1000 in the electrical scale. The mean of the last four then gives
1 gram ( $20^{\circ} \mathrm{C}$ ) oalorie $=4.181 \times 10^{7}$ ergs. See next table.
1 gram ( $15^{\circ} \mathrm{C}$.) calorie $=4.185 \times 10^{7}$ ergs assuming sp. ht. of water at $20^{\circ}=0.9990$.


## TABLE 211.-(1915.) Best Value, Electrical and Mechanical Equivalents of Heat.

Since the preparation of Dr. Ames' Paris report, considerable work has been done on the mechanical equivalent of heat, including recomputations from the older measurements using better walues for some of the electrical relations, etc. Taking all the available material into account the U.S. Bureau of Standards has adopted, provisionally, the relation

## 1 ( $\mathbf{2 0}{ }^{\circ} \mathrm{C}$.) gram-calorie $=4.183$ international electric joules.

No exact comparison between the results of electrical equivalent and mechanical equivalent of heat measurements can be made without exact knowledge of the relations between the international and absolute electrical units. A recent absolute measurement of absolute resistance by F . E. Smith of the National Physical Laboratory of England indicates a difference of one part in 2000 between the international and absolute ohms. Pending the general acceptance of some definite figure for this relation it is useless to fix upon a single value to use for " J " better than about one part in a thousand. The value

### 4.183 international joules = probably 4.184 mechanical joules.

This value is made the basis of the following table.
TABLE 212.-Conversion Factors for Units of Work.

|  | Joules. | Foot-pounds. | Kilogrammeters. | $\begin{gathered} 20^{\circ} \\ \text { Calories. } \end{gathered}$ | British thermal units. | Kilowatt-hours. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 Joule . | 1 | $0.7376 \dagger$ | $0.1020 \dagger$ | 0.2390 | 0.0009476 | $0.2778 \times 10^{-6}$ |
| 1 Foot-pound . $=$ | 1.356* | I | 0.1383 | $0.3240^{*}$ | $0.001285 *$ | $0.3766 \times 10^{-6 *}$ |
| I Kilogram-meter $=$ | 9.807* | 7.233 |  | 2.344* | 0.009293* | $2.724 \times 10^{-6 *}$ |
| I $20^{\circ} \mathrm{Calorie}$. $=$ | 4.184 | $3.086 \dagger$ | $0.4267 \dagger$ | I | 0.003965 | $1.162 \times 10^{-6}$ |
| unit <br> I Kilowatt-hour . | 1055. | $778.3 \dagger$ 2655000 |  | 252.2 860300. | $\stackrel{\text { I }}{341 \mathrm{I}}$. | $\underset{\mathrm{I}}{0.0002931}$ |

The value used for $g$ is the standard value, 980.665 cm . per sec. per sec. $=32.174$ feet per sec. per sec.
*The values thus marked vary directly with "g.",
$\dagger$ The values thus marked vary inversely with "g." For values of " g " see Tables 565-56\%.
TABLE 213.-Value of the English and American Horsepower (746 watts) in Local Foot-pounds and Kilogram-meters per Second at Various Altitudes and Latitudes.

| Altitude, | Kilogram-meters per second. |  |  |  |  | Foot-pounds per second. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Latitude. |  |  |  |  | Latitude. |  |  |  |  |
|  | $0^{\circ}$ | $30^{\circ}$ | $45^{\circ}$ | $60^{\circ}$ | $90^{\circ}$ | $0^{\circ}$ | $30^{\circ}$ | $45^{\circ}$ | $60^{\circ}$ | $90^{\circ}$ |
| 0 km . | 76.275 | 76.175 | 76.074 | 75.973 | 75.873 |  |  | 550.24 |  | 548.79 |
| 1. 5 * | 76.297 | 76.197 | 76.095 | 75.995 | 75.895 | 551.86 | 551.13 | 550.41 | 549.68 | 548.95 |
| $3.0{ }^{\circ}$ | 76.320 | 76.220 | 76.119 | 76.018 | 75.918 | 552.03 | 551.30 | 550.57 | 549.85 | 549.12 |

## Smithsonian Tables.

The metals in heavier type are often used as standards.
The melting points are reduced as far as possible to a common (thermodynamic) temperature scale. This scale is defined in terms of Wien's law, with $\mathrm{C}_{2}$ taken as 14,350 , and on which the melting point of platinum is $1755^{\circ} \mathrm{C}$ (Nernst and Wartenburg, 1751 ; Waidner and Burgess, 1753; Day and Sosman, 1755; Holborn and Valentiner, 1770; see C. R. 148, p. 1177, 1909). Above $1100^{\circ} \mathrm{C}$, the temperatures are expressed to the nearest $5^{\circ} \mathrm{C}$. Temperatures above the platinum point may be uncertain by over $50^{\circ} \mathrm{C}$.

| Element. | Melting point. ${ }^{\circ} \mathrm{C}$ | Remarks. | Element. | Melting point. $0^{\circ} \mathrm{C}$ | Remarks. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum. | 658.7 | Most samples | Manganese. . | - 87 | Burgess-Waltenberg. |
|  |  | give 657 or less (Burgess). | Mercury . . . Molybdenum | -38.87 2535 | ne |
| Antimony | 630.0 | Ranısay-Travers | Neodymium. <br> Neon <br> Nickel | 2535 840 ? | (Muthmann-Weiss.) |
|  |  |  |  | -253? |  |
| Argon. | -188 |  |  | 1452 | Day, Sosman, Bur- |
| Arsenic | 850 |  |  |  | gess, Waltenberg. |
| Barium | 850 | (Guntz.) | Niobium | 1700 ? |  |
| Beryllium.. | 1280 |  | Nitrogen | -2II | (Fischer-Alt.) |
| Bismuth. . . | 271 | Adjusted. | Osmium | About 2700 | (Waidner-Burgess, unpublished.) |
| Boron | 2200-2500? | $\begin{array}{ll} \text { Range: } \quad 320.7- \\ 320.9 \end{array}$ | Oxygen | -218 |  |
| Bromine | -7.3 |  | Palladium. . | $1549 \pm 5$ | (Waidner-Burgess, Nernst-Wartenburg, Day and Sosman.) |
| Cadmium.. | 320.9 |  |  |  |  |
| Cæsium.... | 26 | Range: $26.37^{-}$ | Phosphorus.. Platinum. | $44 \cdot 2$ |  |
| Calcium | 810 | Adjusted. |  |  | See Note. |
| Carbon | ( $>3500$ ) | Sublimes. | Potassium. | 62.3 |  |
| Cerium. . . | 640 |  | Praseodymium. | 940 | Muthmann-Weiss.) |
| Chlorine. . . <br> Chromium | -101. 5 | (Olszewski.) | Radium..... | 700 |  |
|  |  |  | Rhodium. . | 1950 | (Mendenhall-Inger- |
| Chromium. |  | Burgess-Waltenberg. | Rubidium... | 38 |  |
| Cobalt. . . | 1480 | Burgess-Waltenberg. | Ruthenium. Samarium. | 2450? | Muthman |
|  |  |  | Scandium. | ? |  |
| Copper.... | $1083 \pm 3$ | Mean, Holborn-Day, Day-Clement. | Selenium. | 217-220 |  |
|  |  |  | Silicon | 1420 | Adjusted. |
|  |  |  | Silver | 960.5 | Adjusted. |
| Erbium.... <br> Fluorine. |  |  | Sodium. | $97 \cdot 5$ |  |
|  | $-223$ | (Moissan-Dewar.) | Strontium. | $\left(\begin{array}{ll}S_{i} & 112.8\end{array}\right.$ |  |
|  |  |  | Sulphur..... | $\left\{\begin{array}{llll} S_{i i} & 1 & 19.2 \\ S_{i i i} & 106.8 \end{array}\right.$ | Various Forms. See Landolt-Börnstein. |
| Gallium. . | 30. I |  |  |  |  |
| Germanium | 958 | Adjusted. | Tantalum... | 2900 | Adjusted from Waid-ner-Burgess $=2910$. |
| Gold. . | 1063.0 |  |  |  |  |
| Helium. | $<-271$ |  |  |  |  |
| Hydrogen. | -259 |  | Tellurium | 452 | Adjusted. |
| Iodine. . . . . | ${ }^{155}$ | (Thiel.) | Thallium... | 302 |  |
|  | 113.5 | Range: 112-115. | Thorium.... | $\begin{aligned} & >1700 \\ & <\text { Mo } \end{aligned}$ | v. Wartenburg. |
| Iridium. . . | 2350? |  | Tin | $23 \mathrm{I} .9 \pm .2$ |  |
|  |  |  | Titanium. . | 1795 | Burgess-Waltenberg. |
| Iron . . . . . | 1530 | Burgess-Waltenberg. | Tungsten... | 3400 | Adjusted. |
| Krypton... | -169 |  |  |  |  |
| Lanthanum | 810? | (MuthmannWeiss.) | Uranium.... | $<1850$ |  |
| Lead | $327 \pm 0.5$ | Weiss.) | Vanadium... | 1720 | Burgess-Waltenberg. Ramsay. |
|  |  |  | Ytterbium. . |  |  |
|  |  |  | Yttrium | 1490 |  |
| Lithium... | 186 | (Kahlbaum.) | Zinc. . . . . . . | $419.4$ |  |
| Magnesium | 651 | (Grube) in clay crucibles, 635 . | Zirconium... | 1700? | Troost. |

BOILING-POINTS OF THE CHEMICAL ELEMENTS.

| Element. | Range. | Boiling. ${ }^{\text {point }}{ }^{\circ} \mathrm{C}$ | Observer; Remarks. |
| :---: | :---: | :---: | :---: |
|  | - | - |  |
| Aluminum | - | 1800. | Greenwood, Ch. News, 100, 1909. |
| Antimony | - | 1440. |  |
| Argon | - | -186. 1 | Ramsay-Travers, Z. Phys. Ch. 38, 1901. |
| Arsenic | 449-450 |  | Gray, sublimes, Conechy. ${ }^{\text {Black, sublimes, Engel, C. R }}$ |
| * | 280-310 | $>360$. | (ellow, sublimes. |
| Barium | - | - | Borls in vacuo, Guntz, 1903. |
| Bismuth | 1420-1435 | 1430. | Barus, 1894; Greenwood, 1. c. |
| Boron |  |  | Volatilizes without melting in electric arc. |
| Bromine | 59-63 | 61.1 | Thorpe, 1880; van der Plaats, 1886. |
| Cadmium | - | 778. | Berthelot, 1902. |
| Cæsium | - | 670. | Ruff-Johannsen. |
| Carbon | - | 3600. | Conputed, Violle, C. R. 120, 1895. <br> Volatilizes without melting in electric oven. Moisson. |
| Chlorine | - | -33.6 | Regnault, 1863 : |
| Chromium | - | 2200. | Greenwood, Ch. News, 100, 1909. |
| Copper | 2100-2310 | 2310. | " 1.c. |
| Fluorine | - | -187. | Moisson-Dewar, C. R. 136, 1903. |
| Helium Hydrogen | 252.5-252.8 | -267. | Computed, Tracers Ch. News, 86, 1902. Mean |
| Iodine |  | $>200$. |  |
| Iron | - | 2450. | Greenwood, 1. c. |
| Krypton | - | -151.7 | Ramsay, Ch. News, 87, 1903. |
| Lead | - | 1525. | Greenwood, 1. c. |
| Lithium | - | 1400. | Ruff-Johannsen, Ch. Ber. 38, 1905. |
| Magnesium | - | 1120. | Greenwood, 1 c. |
| Manganese | - | 1900. |  |
| Mercury | - | 357. | Crafts; Regnault. |
| Molybdenum | - | 3620. | Langmuir, Mackay, Phys. Rev. 1914. |
| Nieon | - | -239. | Dewar, 1901. |
| Nitrogen | -195.7-194.4 | -195. | Mean. |
| Oxygen | ${ }^{-182.5-182.9}$ | -182.7 | Troost C. R 126, 1898. |
| Phosphorus | 287-290 | $\begin{array}{r} -119 . \\ 288 . \end{array}$ | Troost. C. R. 126, 1898. |
| Platinum | - | 3910. | Langmuir, Mackay, Phys. Rev. 1914. |
| Potassium | 667-757 | 712. | Perman; Ruff-Johannsen. |
| Rubidium |  | 696. | Ruff-Johannsen. |
| Selenium | 664-694 | 690. |  |
| Silver | - | 1955. | Greenwood, 1. c. |
| Sodium | 742-757 | 750. | Perman; Ruff-Johannsen. |
| Sulphur | 444.7-445 | 444.7 | Mean. |
| Tellurium | - | 1390. | Deville-Troost, C. R. 91, 1880. |
| Thallium | - | 1280. | v. Wartenberg, 25 Anorg. Ch. 56, 1908 |
| Tin | - | 2270. | Greenwood, 1.c. |
| Tungsten | - | 5830. | Langmuir. Phys. Rev. 1913. |
| Xenon | - | -109.1 | Ramsay, Z. Phys, Ch. 44. 1903. |
| Zinc | 916-9+2 | 930. |  |

## Smithsonian Tables.

| Substance. | Melting point at $1 \mathrm{~kg} / \mathrm{sq} . \mathrm{cm}$ | Highest experimental pressure: kg/sq. cm | $\begin{gathered} d t / d p \\ \text { at } \mathrm{I} \mathrm{~kg} / \mathrm{sq} . \mathrm{cm} . \end{gathered}$ | $\begin{gathered} \Delta t \text { (observed) } \\ \text { for } \\ 1000 \mathrm{~kg} / \mathrm{sq} . \mathrm{cm} \end{gathered}$ | Reference |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Hg . | $-38.85$ | 12,000 | 0.00511 | 5.1 ${ }^{*}$ | 1 |
| K. | 59.7 | 2,800 | 0.0136 | 13.8 | 2 |
| Na . | 97.62 | 12,000 | 0.00860 | +12.3 $\dagger$ | 4 |
| Bi. | 271.0 | 12,000 | -0.00342 | $-3 \cdot 5 \dagger$. | 4 |
| Sn | 231.9 | 2,000 | 0.00317 | 3.17 | 3 |
| Bi. | 270.9 | 2,000 | -0.00344 | -3.44 | 3 |
| Cd. | 320.9 | 2,000 | 0.00609 | 6.09 | 3 |
| Pb . | 327.4 | 2,000 | 0.00777 | 7.77 | 3 |

* $\Delta t$ (observed) for $10,000 \mathrm{~kg} / \mathrm{sq} . \mathrm{cm}$ is $50.8^{\circ}$.
$\dagger \mathrm{Na}$ melts at $177.5^{\circ}$ at $12,000 \mathrm{~kg} / \mathrm{cm}^{2}$; K at $179.6^{\circ}$; Bi at $218.3^{\circ}$; Pb at $644^{\circ}$. Luckey obtains melting point for tungsten as follows: 1 atme, $3623^{\circ} \mathrm{K} ; 8,3594 ; 18,3572 ; 28,3564$. Phys. Rev. 1917.
References: (1) P. W. Bridgman, Proc. Am. Acad. 47, pp. 391-96, 416-19, 1911; (2) G. Tammann, Kristallisieren und Schmelzen, Leipzig, 1903, pp. 98-99; (3) J. Johnston and L. H. Adams, Am. J. Sci. 31, p. 516, 1911; (4) P. W. Bridgman, Phys. Rev. 6, I, 1915.

A large number of organic substances, selected on account of their low melting points, have also been investigated: by Tammann, loc. cit.; G. A. Hulett, Z. physik. Chem. 28, p. 629, 1899; F. Körber, ibid., 82, p. 45, 1913; E. A. Block, ibid., 82, p. 403, 1913; Bridgman, Phys. Rev. 3, 126, 1914; Pr. Am. Acad. 51, 55, 1915; 51, 581, 1916; 52, 57, 1916; 52, 91, 1916. The results for water are given in the following table.

TABLE 217. - Effect of Pressure on the Freezing Point of Water (Bridgman ${ }^{*}$ ).

| Pressure: $\dagger$ | Frezzing point. | Phases in Equilibrium. |
| :---: | :---: | :---: |
| 1 | 0.0 | Ice I - liquid. |
| 1,000 | -8.8 | Ice I - liquid. |
| 2,000 | -20.15 | Ice I - liquid. |
| 2,115 | $-22.0$ | Ice I - ice III - liquid (triple point). |
| 3,000 | - 18.40 | Ice III - liquid. liquid (triple point) |
| 3,530 | $-17.0$ | Ice III- ice V - liquid (triple point). |
| 4,000 | -13.7 $-\quad 1.6$ | Ice $V$ - liquid. |
| 6,380 | + 0.16 | Ice V-ice VI - liquid (triple point). |
| 8,000 | 12.8 | Ice VI - liquid. |
| 12,000 | 37.9 | Ice VI - liquid. |
| 16,000 | 57.2 | Ice VI- liquid. |
| 20,000 | 73.6 | Ice VI - liquid. |

* P. W. Bridgman, Proc. Am. Acad. 47, pp. 441-558, 1912.
$\dagger$ I atm. $=1.033 \mathrm{~kg} / \mathrm{sq} . \mathrm{cm}$.
TABLE 218. - Effect of Pressure on Boiling Point.*

| Metal. | Pressure. | ${ }^{\circ} \mathrm{C}$ | Metal. | Pressure. | ${ }^{\circ} \mathrm{C}$ | Metal. | Pressure. | ${ }^{\circ} \mathrm{C}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bi | 10.2 cm Hg . | I 200 | Ag | 26.3 cm Hg . | 1780 | Pb | 20.6 cm Hg . | 1410 |
| Bi | 25.7 cm Hg . | 1310 | Cu | 10.0 cm Hg . | 1980 | Pb | 6.3 atme. | 1870 |
| Bi | 6.3 atme. | 1740 | Cu | 25.7 cm Hg . | 2180 | Pb | 11.7 atme. | 2100 |
| Bi | 11.7 atme. | 1950 | Sn | 10. 1 cm Hg . | 1970 | Zn | 11.7 atme. | 1230 |
| Bi | 16.5 atme. | 2060 | Sn | 26.2 cm Hg . | 2100 | Zn | 21. 5 atme. | 1280 |
| Ag | 10.3 cm Hg . | 1660 | Pb | 10.5 cm Hg . | 1315 | Zn | 53.0 atme. | 1510 |

[^29]Table 219.
DENSITIES AND MELTING AND BOILING POINTS OF INORGANIC COMPOUNDS.

| Substance. | Chemical formula. | Density about $20^{\circ} \mathrm{C}$ | Melting point C |  | Boiling point C | Pressure mm | 完 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum chloride. | $\mathrm{AlCl}_{3}$ | - | 190. | 1 | $183 .{ }^{\circ}$ | 752 | I |
| "، nitrate | $\mathrm{Al}\left(\mathrm{NO}_{3}\right)_{3}+9 \mathrm{H}_{2} \mathrm{O}$ | - | 72.8 | 2 | 134. * | 75 | - |
| oxide. | $\mathrm{Al}_{2} \mathrm{O}_{3}$ | 4.00 | 2050. | 28 | - | - | - |
| Ammonia. . | $\mathrm{NH}_{3}$ | - | -75. | 3 | -33.5 | 760 | 7 |
| Ammonium nitrate | $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | 1. 72 | 165. | - | 210.* | 7 | 7 |
| " sulphate... | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 1.77 | 140. | 4 |  | - | - |
| " phosphite.. | $\mathrm{NH}_{4} \mathrm{H}_{2} \mathrm{PO}_{3}$ | 1.77 | 123. | 5 | I50.* | - | - |
| Antimony trichloride... | $\mathrm{SbCl}_{3}$ | 3.06 | 73. | - | 223. | 760 | - |
| " pentachloride | $\mathrm{SbCl}_{5}$ | 2.35 | 3. | II | 102. | 68 | 14 |
| Arsenic trichloride . . . . | $\mathrm{AsCl}_{3}$ | 2.20 | $-18$. | 8 | I30. 2 | 760 | 23 |
| Arsenic hydride | $\mathrm{AsH}_{3}$ | - | -113.5 | 6 | $-54.8$ | 760 | 6 |
| Barium chloride | $\mathrm{BaCl}_{2}$ | 3.86 | 960. | II | - | , | - |
| " nitrate | $\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}$ | 3.24 | 575. | 24 | - | - | - |
| " perchlorate | $\mathrm{Ba}\left(\mathrm{ClO}_{4}\right)_{2}$ | - | 505. | 10 | - | - |  |
| Bismuth trichloride | $\mathrm{BiCl}_{3}$ | 4.56 | 232.5 | - | 440. | 760 | - |
| Boric acid. | $\mathrm{H}_{3} \mathrm{BO}_{3}$ | I. 46 | 185. | - | - | - | - |
| " anhydride | $\mathrm{B}_{2} \mathrm{O}_{3}$ | 1.79 | 577. | - | - | - | - |
| Borax (sodium borate).. | $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7}$ | 2.36 | 741. | 27 | - | - | - |
| Cadmium chloride . . . . | $\mathrm{CdCl}_{2}$ | 4.05 | 560. | 25 | $900 \pm$ | - | 9 |
| "6 nitrate. | $\mathrm{Cd}\left(\mathrm{NO}_{3}\right)_{2}+4 \mathrm{H}_{2} \mathrm{O}$ | 2.45 | 59.5 | 2 | 132. | 760 | 4 |
| Calcium chloride | $\mathrm{CaCl}_{2}$ | 2.26 | 774.0 | - | - | - | - |
| " chloride | $\mathrm{CaCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | I. 68 | 29.6 | - | - | - | - |
| " nitrate | $\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}$ | 2.36 | 499. | 24 | -* | - | - |
| " nitrate | $\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}+4 \mathrm{H}_{2} \mathrm{O}$ | I. 82 | 42.3 | 26 | 132.* | - | - |
| oxide | CaO | $3 \cdot 3$ | 2570. | 28 |  | - | - |
| Carbon tetrachlori | $\mathrm{CCl}_{4}$ | I. 59 | $-24$. | 22 | 76.7 | 760 | 23 |
| " trichloride | $\mathrm{C}_{2} \mathrm{Cl}_{6}$ | 1.63 | 184. | - | - | - |  |
| " monoxide | CO | - | -207. | 6 | -190. | 760 | 6 |
| " dioxide. | $\mathrm{CO}_{2}$ | I. 56 | -57. | 3 | -80. | subl. | - |
| " disulphide | $\mathrm{CS}_{2}$ | I. 26 | -110. | I 3 | 46.2 | 760 | - |
| Chloric (per) acid | $\mathrm{HClO}_{4}+\mathrm{H}_{2} \mathrm{O}$ | I. 8 I | 50. | 15 | - | - | - |
| Chlorine dioxide | $\mathrm{ClO}_{2}$ | - | -76 . | 3 | $9 \cdot 9$ | 731 | 21 |
| Chrome alum. | $\mathrm{KCr}\left(\mathrm{SO}_{4}\right)_{2}+\mathrm{I}_{2} \mathrm{H}_{2} \mathrm{O}$ | I. 83 | 89. | 16 | - | - | - |
| " nitrate. | $\mathrm{Cr}_{2}\left(\mathrm{NO}_{3}\right)_{6}+18 \mathrm{H}_{2} \mathrm{O}$ |  | 37. | 2 | 170. | 760 | 2 |
| Chromium oxide | $\mathrm{Cr}_{2} \mathrm{O}_{3}$ | 5.04 | 1990. | 28 | - * | - | - |
| Cobalt sulphate | $\mathrm{CoSO}_{4}$ | 3.53 | 97. | 16 | 880.* | - | - |
| Cupric chloride. . | $\mathrm{CuCl}_{2}$ | 3.05 | 498. | 9 |  | - | - |
| Cuprous chloride | $\mathrm{Cu}_{2} \mathrm{Cl}_{2}$ | 3.7 | 42 I . | - | 1000 * | 760 | 9 |
| Cupric nitrate. | $\mathrm{Cu}\left(\mathrm{NO}_{3}\right)_{2}+3 \mathrm{H}_{2} \mathrm{O}$ | 2.05 | 114.5 | 2 | 170.* | 760 | 2 |
| Hydrobromic acid | HBr |  | -86.7 | 3 | $-68.7$ | 760 | - |
| Hydrochloric acid | HCl | - | -III. 3 | 17 | -83. 1 | 755 | 17 |
| Hydrofluoric acid | HFl | 0.99 | -92.3 | 6 | $-36.7$ | 755 | 17 |
| Hydriodic acid | HI |  | $-51.3$ | 17 | -35.7 | 760 |  |
| Hydrogen peroxid | $\mathrm{H}_{2} \mathrm{O}_{2}$ | 1.5 | -2. |  | 80.2 | 47 | 20 |
| "6 phosphid | $\mathrm{PH}_{3}$ | - | -132.5 | 6 | - | - | - |
| " sulphide | $\mathrm{H}_{2} \mathrm{~S}$ | - | -86. | 3 | -62. |  | - |
| Iron chloride | $\mathrm{FeCl}_{3}$ | 2.80 | 301. | - | - | - | - |
| " nitrate | $\mathrm{Fe}\left(\mathrm{NO}_{3}\right)_{3}+9 \mathrm{H}_{2} \mathrm{O}$ | 1. 68 | 47.2 | 2 | -- | - | - |
| * sulphate. | $\mathrm{FeSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$ | 1.90 | 64. | 16 | - | - | - |
| Lead chloride | $\mathrm{PbCl}_{2}$ | 5.8 | 500. | 9 | $900 \pm$ | 760 | - |
| " metaphosphate | $\mathrm{Pb}\left(\mathrm{PO}_{3}\right)_{2}$ | - | 800. | 9 | - | - | - |
| Magnesium chloride | $\mathrm{MgCl}_{2}$ | 2.18 | 708. | 9 | - | - | - |
| " oxide. | MgO | 3.4 | 2800. | 28 | - | - | - |
| " nitrate | $\mathrm{Mg}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | I. 46 | 90. | 2 | 143. | 760 | 2 |
| " sulphate | $\mathrm{MgSO}_{4}+5 \mathrm{H}_{2} \mathrm{O}$ | 1. 68 | 150. | 16 | - | - | - |
| Manganese chloride. | $\mathrm{MnCl}_{2}+4 \mathrm{H}_{2} \mathrm{O}$ | 2.01 | 87.5 | I9 | 106. | $760$ | 19 |
| " nitrate. | $\mathrm{Mn}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1.82 | 26. | 2 | 129. | 760 | 2 |
| " sulphate | $\mathrm{MnSO}_{4}+5 \mathrm{H}_{2} \mathrm{O}$ | 2.09 | 54. | 16 | - | - | - |
| Mercurous chloride. | $\mathrm{Hg}_{2} \mathrm{Cl}_{2}$ | 7.10 | 450 * | - | - | - | - |
| Mercuric chloride. | $\mathrm{HgCl}_{2}$ | 5.42 | 282. | - | 305. | - | - |

(1) Friedel and Crafts; (2) Ordway; (3) Faraday; (4) Marchand; (5) Amat; (6) Olszweski; (7) Gibbs; (8) Baskerville; (9) Carnelly; (ro) Carnelly and O'Shea; (11) Ruff; (13) Wroblewski and Olszewski; (14) Anschütz; (15) Roscoe; (16) Tilden; (17) Ladenburg; (18) Staedel; (19) Clarke, Const. of Nature; (20) Bruhl; (2I) Schacherl; (22) Tammann; (23) Thorpe; (24) Ramsay; (25) Lorenz; (26) Morgan; (27) Day; (28) Kanolt.

| Substance． | Chemical formula． | $\begin{aligned} & \text { Density, } \\ & \text { about } \\ & 20^{\circ} \mathrm{C} \end{aligned}$ | $\underset{\substack{\text { Melting } \\ \text { ( }}}{\text { Moint }}$ | $\begin{aligned} & \text { 言 } \\ & \text { 薄 } \end{aligned}$ | $\begin{gathered} \text { Boiling } \\ \text { point } \\ \text { C } \end{gathered}$ | $\begin{aligned} & \text { Pres- } \\ & \text { sure } \\ & \mathrm{mm} \end{aligned}$ | 宮 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Nickel car | $\mathrm{C}_{4} \mathrm{O}_{4}$ | 1.32 | －25． | 1 | $43 .{ }^{\circ}$ | 760 | － |
| nitr | $\mathrm{Ni}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 2.05 | 56.7 | 2 | 136.7 | 760 | 2 |
| ＂oxide | $\stackrel{\mathrm{NiO}}{\mathrm{NiSO}_{4}}$ | 6.69 | － | － | － | - | － |
| ＂\％sulph | $\mathrm{NiSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$ $\mathrm{HNO}_{3}$ | 1.98 1.52 | －42． | 3 | ． | \％ | 16 |
| Nitric acid．．． | $\mathrm{N}_{2} \mathrm{O}_{5}$ | 1.52 1.64 | -42 30 | $\begin{aligned} & 4 \\ & 5 \end{aligned}$ | 48. | $760$ | 16 9 |
| ＂${ }^{\text {a }}$＊ | NO | 1.27 | －167． | － | － 153. | 760 | 6 |
| peroxid | $\mathrm{N}_{2} \mathrm{O}_{4}$ | I． 49 | －9．6 | 8 | 21.6 | 760 | － |
| Nitrous anhyd | $\mathrm{N}_{2} \mathrm{O}_{3}$ | 1． 45 | －III． | 7 | 3.5 | 760 | － |
| ＂oxide | $\mathrm{N}_{2} \mathrm{O}$ |  | －102．4 | 8 | －89．8 | 760 | 8 |
| Phosphoric acid（ortho）． | $\mathrm{H}_{3} \mathrm{PO}_{4}$ | 1.88 | $40 \pm$ |  |  |  | － |
| Phosphorous acid．．．．． | $\mathrm{H}_{3} \mathrm{PO}_{3}$ | 1． 65 | 72. | － | － |  |  |
| Phosphorus trichloride．． | $\mathrm{PCl}_{3}$ | 1．61 | －111．8 | 10 | 76. | 760 | 19 |
| ＂oxychloride ．${ }^{\text {disulphide．}}$ | $\mathrm{POCl}_{3}$ | 1.68 | ＋1．3 |  | 108. | 760. |  |
| ＂pentasulphide | $\mathrm{P}_{2} \mathrm{P}_{5}$ | － | 297. |  |  | 760 |  |
| ＂sesquisulphide | $\mathrm{P}_{4} \mathrm{~S}_{3}$ | 2.00 | 16 | 13 | 40 | 760 | － |
| ＂trisulphide | $\mathrm{P}_{2} \mathrm{~S}_{3}$ | － | ＝ | 14 | 490. | 760 | 25 |
| Potassium carbonate | $\mathrm{K}_{2} \mathrm{CO}_{3}$ | 2.29 | ． | － | 49 | 0 | 25 |
| ＂chlorate | $\mathrm{KClO}_{3}$ | 2.34 | 3 | 15 |  |  |  |
| ＂chroma | $\mathrm{K}_{2} \mathrm{CrO}_{4}$ | 2.72 | 975. | 17 | － |  |  |
| ＂، cyanide | KCN | 1． 52 | red h＇t | － | － | － |  |
| ＂perchlora | $\mathrm{KClO}_{4}$ | 2.52 | 610. | 15 | $410 . \dagger$ | 760 |  |
| ＂chlorid | KCl | 1． 99 | 772. |  | 1500. | 760 | － |
| ＂، nitrate ．．．．．．． | $\mathrm{KNO}_{3}$ | 2.10 | 341. | － | $400 . \dagger$ |  | － |
| ＂، acid phosphate | $\mathrm{KH}_{2} \mathrm{PO}_{4}$ | 2.34 | 96. | 3 |  |  |  |
| Silver chloride．．．．．．．．． | AgCl | $5 \cdot 56$ | 205. |  |  |  |  |
| nitrate | $\mathrm{AgNO}_{3}$ | 4. | 218 | － |  |  |  |
| perchlorat | $\mathrm{AgClO}_{4}$ | － | 486 | 18 |  |  |  |
| ＂phosphate | $\mathrm{Ag}_{3} \mathrm{PO}_{4}$ | 6.37 | 849 | 15 | － |  |  |
| ＂metaphosp | $\mathrm{AgPO}_{3}$ | － | 482. | 15 | － |  | － |
| ＂sulphate | $\mathrm{Ag}_{2} \mathrm{SO}_{4}$ | 5.45 | $655 \pm$ | － | $1085 . \dagger$ | $\square$ | － |
| Sodium chloride | NaCl | 2.17 | 800. | 11 | 1490. | 760 | － |
| ＂hydroxide | NaOH | 2．I | 318. | 27 | － | － |  |
| ＂nit | $\mathrm{NaNO}_{3}$ | 2． 26 | 315. |  | $380 . \dagger$ |  |  |
| ＂chlor | $\mathrm{NaClO}_{3}$ | 2.48 | 248. | 28 | $\dagger$ |  |  |
| ＂${ }^{\text {carbona }}$ | $\mathrm{NaClO}_{4}$ | － | 482. | 18 |  |  |  |
| carbonat | $\mathrm{Na}_{2} \mathrm{CO}_{3}+10$ | 2.48 | 852. | － | $\dagger$ |  |  |
| ＂phosphate | $\mathrm{Na}_{2} \mathrm{HPO}_{4}+\mathrm{I}_{2} \mathrm{H}_{2} \mathrm{O}$ | I． 54 | 34 | － |  |  |  |
| ＂metaphosphate． | $\mathrm{NaPO}_{3}$ | 2．48 | 617. | 15 |  |  |  |
| pyrophosphate | ${ }^{\mathrm{Na}_{4} \mathrm{P}_{2} \mathrm{O}_{7}}$ | 2.45 | 970 | 30 |  |  |  |
| ＂، phosphite | $\left(\mathrm{H}_{2} \mathrm{NaPO}_{3}\right)_{2}+5 \mathrm{H}_{2} \mathrm{O}$ | － | 42 | 20 |  |  |  |
| ＂${ }^{\text {chulphate }}$ | $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 2.67 | 884. | II | － |  |  |
| ＂Sulphate． | $\mathrm{Na}_{2} \mathrm{SO}_{4}+10 \mathrm{H}_{2} \mathrm{O}$ | I． 46 | 32.38 | 17 | $\dagger$ |  |  |
| Sulphur hyposulphite | $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}+{ }_{5} \mathrm{H}_{2} \mathrm{O}$ | 1． 73 | 48.16 | － |  | － |  |
| Sulphur dioxide | $\mathrm{SO}_{2}$ | － | -76 ． | － | －10． | 760 | － |
| Sulphuric acid | ${ }_{\text {2 }} \mathrm{H}_{2} \mathrm{SO}_{4}$ | 1． 83 | 10.4 | 21 | 338. | 760 | 22 |
| acid | $\mathrm{I}_{2} \mathrm{H}_{2} \mathrm{SO}_{4}+\mathrm{H}_{2} \mathrm{O}$ $\mathrm{H}_{2} \mathrm{SO}_{4}+\mathrm{H}_{2} \mathrm{O}$ | － | －0． 5 | 22 | － |  | － |
| ＂acid（py | $\mathrm{H}_{2} \mathrm{~S}_{2} \mathrm{O}_{7}$ |  |  |  |  |  |  |
| Sulphur trioxide． | $\mathrm{SO}_{3}$ | 1.91 | 16.8 | 22 |  |  |  |
| Tin，stannic chloride． | $\mathrm{SnCl}_{4}$ | 2.28 | －33． |  | 114. |  |  |
| ＂stannous chloride | $\mathrm{SnCl}_{2}$ |  | 250. | 24 | 605. | 760 | $\underline{1}$ |
| Zinc chlorid | 7 nCl | 2.91 | 365. | 29 | 710. | 760 | － |
| ＂chlor | $\mathrm{ZnCl}_{2}+3 \mathrm{H}_{2} \mathrm{O}$ |  | 6.5 | 26 | － | － | － |
| ＂، nitrate | $\mathrm{Zn}\left(\mathrm{NO}_{3}\right)_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 2.06 | 36.4 | 3 | 13 I ． | 760 | 2 |
| sulpha | $\mathrm{ZnSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$ | 2.02 | 50. | 3 |  |  | － |

[^30]
## DENSITIES, MELTING-POINTS, AND BOILING-POINTS OF SOME ORGANIC COMPOUNDS.

N.B. - The data in this table refer only to normal compounds.

| Substance. | Formula | Temp. | Den- sity. | Melting point | Boiling-point. | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (a) Paraffin Series: $\mathrm{C}_{n} \mathrm{H}_{2 n+2}$. |  |  |  |  |  |  |
| Methane* | $\mathrm{CH}_{4}$ | -164. | 0.415 | -184. | -165. | Olszewski, Young. |
| Ethanet . | $\mathrm{C}_{2} \mathrm{H}_{6}$ | , | . 446 | -171.4 | $-93$. | Ladenburg, " |
| Propane . . . | $\mathrm{C}_{3} \mathrm{H}_{8}$ | - | . 536 | -195. | -45. | Young, Hainlen. |
| Butane . | $\mathrm{C}_{4} \mathrm{H}_{10}$ | $\bigcirc$ | . 60 | $-135$. | 1. | Butlerow, Young. |
| Pentane. | $\mathrm{C}_{5} \mathrm{H}_{12}$ | $\bigcirc$ | . 647 | -131. | 36.3 | Thorpe, Young. |
| Hexane - | $\mathrm{C}_{6} \mathrm{H}_{14}$ | 17. | . 663 | -94. | 69. | Schorlemmer. |
| Heptane. | $\mathrm{C}_{7} \mathrm{H}_{16}$ | - | . 701 | -97. | 98.4 | Thorpe, Young. |
| Octane - | $\mathrm{C}_{8} \mathrm{H}_{18}$ | - | . 719 | -56.6 | 125.5 |  |
| Nonane . | $\mathrm{C}_{9} \mathrm{H}_{20}$ | $\bigcirc$ | .733 | -51. | 150. | Krafft. |
| Decane - | ${ }_{\substack{\mathrm{C}_{11} \mathrm{H}_{22} \\ \mathrm{H}_{24} \\ \\ \text { d }}}$ | - | . 745 | - 31. | 173. | "، |
| Undecane - | ${ }_{\substack{\text { C }}}^{\mathrm{C}_{12} \mathrm{H}_{24} \mathrm{H}_{26}}$ | $\bigcirc$ | .756 .765 | -26. | 195. | " |
| Tridecane | $\mathrm{C}_{13} \mathrm{H}_{28}$ | - | . 77 I | -6. | 234. | " |
| Tetradecane | $\mathrm{C}_{14} \mathrm{H}_{30}$ | 4. | . 775 | 5. | 25. | " |
| Pentadecane | $\mathrm{C}_{15} \mathrm{H}_{32}$ | 10. | . 776 | 10. | 270. | " |
| Hexadecane | $\mathrm{C}_{16} \mathrm{H}_{34}$ | 18. | . 775 | 18. | 287. | " |
| Heptadecane | $\mathrm{C}_{17} \mathrm{H}_{36}$ | 22. | . 777 | 22. | 303. | " |
| Octadecane | $\mathrm{C}_{18} \mathrm{H}_{38}$ | 28. | . 777 | 28. | 317. | " |
| Nonadecane | $\mathrm{C}_{19} \mathrm{H}_{40}$ | 32. | . 777 | 32. | 330. | " |
| Eicosane. - | $\mathrm{C}_{20} \mathrm{H}_{42}$ | 37. | . 778 | 37. | 121.8 | " |
| Heneicosane Docosane. | ${ }_{\text {C }} \mathrm{C}_{21} \mathrm{H}_{44}$ | 40. | .778 .778 | 44. | 129.8 | " |
| Tricosane - | $\mathrm{C}_{22} \mathrm{C}_{23} \mathrm{H}_{48}$ | 44. | .778 <br> .779 | 44. | 136.58 | " |
| Tetracosane | $\mathrm{C}_{24} \mathrm{H}_{50}$ | 51. | . 779 | 5 I. | 243.7 | " |
| Heptacosane . | $\mathrm{C}_{27} \mathrm{H}_{56}$ | 60. | . 780 | 60. | 172.8 | " |
| Pentriacontane | $\mathrm{C}_{31} \mathrm{H}_{64}$ | 68. | . 781 | 68 | 199.8 | " |
| Dicetyl . . . | $\mathrm{C}_{32} \mathrm{H}_{66}$ | 70. | . 781 | 70. | 205.8 | " |
| Penta-tria-contane | $\mathrm{C}_{35} \mathrm{H}_{72}$ | 75. | . 782 | 75. | $331 . \ddagger$ | " |
| - (b) Olefines, or the Ethylene Series : $\mathrm{C}_{n} \mathrm{H}_{2 n}$. |  |  |  |  |  |  |
| Ethylene | $\mathrm{C}_{2} \mathrm{H}_{4}$ | - | 0.610 | - 169. | $-103$. |  |
| Propylene . . Butylene. | $\mathrm{C}_{\mathrm{C}_{3} \mathrm{H}_{6}}^{\mathrm{C}_{4} \mathrm{H}_{8}}$ | -13.5 | . 635 | -180. | -50.2 | Ladenburg, Krïgel. Sieben. |
| Amylene | $\mathrm{C}_{5} \mathrm{H}_{10}$ | - | . | - | 36. | Wagner or Saytzeff. |
| Hexylene | $\mathrm{C}_{6} \mathrm{H}_{12}$ | $\bigcirc$ | . 76 | - | 69. | W reden or Znatowicz. |
| Heptylene | $\mathrm{C}_{7} \mathrm{H}_{14}$ | 19.5 | . 703 | - | 96.-99. | Morgan or Schorlemmer. |
| Octylene. . | $\mathrm{C}_{8} \mathrm{H}_{16}$ | 17. | . 722 | - | 122.-123. | Möslinger. |
| Nonylene | $\mathrm{C}_{9} \mathrm{H}_{18}$ | 20. | . 767 | - | 140.-142. | Beilstein, " Org. Chem." |
| Decylene . | ${ }^{\mathrm{C}} \mathrm{C}_{10} \mathrm{H}_{20}$ | - | - | - | 175. | " " " |
| Undecylene | $\mathrm{C}_{11} \mathrm{H}_{22}$ | 20. | .773 | - | $196 .-197$ |  |
| Dodecylene . | $\mathrm{C}_{12} \mathrm{C}_{13} \mathrm{H}_{24}$ | -31. | . 795 | -31. | 212.-214. |  |
| Tridecylene ${ }^{\text {Tetradecylene. }}$ | ${ }^{\mathrm{C}_{13} \mathrm{H}_{26}}$ | 15. | .774 .794 | - | 233. $127 . \ddagger$ | Bernthsen. Krafft. |
| Pentadecylene. | $\mathrm{C}_{15} \mathrm{H}_{30}$ | - | . 814 | - | 247. | Bernthsen. |
| Hexadecylene . | $\mathrm{C}_{16} \mathrm{H}_{32}$ | 4. | . 792 | 4. | $155 . \ddagger$ | Krafft, Mendelejeff, etc. |
| Octadecylene . | $\mathrm{C}_{18} \mathrm{H}_{36}$ | 18. | . 791 | 18. | 179. $\ddagger$ | Krafft. |
| Eicosylene . . | ${ }_{\text {C }}^{20} \mathrm{C}_{27} \mathrm{H}_{40}$ | $\bigcirc$ | ${ }^{.871}$ | 58. | 390.-400. | Reilstein, "Org. Chem." Bernthsen. |
| Melene . | $\mathrm{C}_{30} \mathrm{H}_{60}$ | - | - | 62. | - |  |

[^31] ORGANIC COMPOUNDS.

(e) Alcoholic ethers: $\mathrm{C}_{n} \mathrm{H}_{2 n+2} \mathrm{O}$.

| Dimethyl ether | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | - | - | - | $-23.6$ | Erlenmeyer, Kreichbaumer. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Diethyl ether . | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | 4. | 0.731 | - II7 | $+34.6$ | Regnault, Olszewski. |
| I ipropyl ether | $\mathrm{C}_{6} \mathrm{H}_{14} \mathrm{O}$ | $\bigcirc$. | . 763 | - | +90.7 | Zander and others. |
| Di-iso-propyl ether. | $\mathrm{C}_{6} \mathrm{H}_{14} \mathrm{O}$ | 0. | . 743 | - | 69. | " |
| Di-n-butyl ether . . . | $\mathrm{C}_{8} \mathrm{H}_{18} \mathrm{O}$ | O. | .784 | - | 141. | Lieben, Rossi, and others. |
| Di-sec-butyl ether | $\mathrm{C}_{8} \mathrm{H}_{18} \mathrm{O}$ | 21. | . 756 | - | 121 | Kessel. |
| Di-iso-butyl " | $\mathrm{C}_{8} \mathrm{H}_{18} \mathrm{O}$ | 15. | . 762 | - | 122. | Reboul. |
| Ii-iso-amyl " | $\mathrm{C}_{10} \mathrm{H}_{22} \mathrm{O}$ | -. | . 799 | - | 170.-175. | Wurtz. |
| Di-sec-hexyl " . | $\mathrm{C}_{12} \mathrm{H}_{26} \mathrm{O}$ | - | - | - | 203.-208. | Erlenmeyer and Wanklyn. |
| Di-norm-octyl". | $\mathrm{C}_{16} \mathrm{H}_{34} \mathrm{O}$ | 17. | . 805 | - | 280.-282. | Moslinger. |

(f) Ethyl ethers: $\mathrm{C}_{n} \mathrm{H}_{2 n+2}$ ().

| Ethyl-methyl ether | $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}$ | O. | 0.725 | - | 11. | Wurtz, Williamson. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| " propyl " | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 20. | 0.739 | - | 63.-64. | Chancel, Brühl. |
| "، iso-propyl ether | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 0. | . 745 | - | 54. | Markownikow. |
| " norm-butyl ether | $\mathrm{C}_{6} \mathrm{H}_{14} \mathrm{O}$ | -. | . 769 | - | 92. | Lieben, Rossi. |
| " iso-butyl ether | $\mathrm{C}_{6} \mathrm{II}_{14} \mathrm{O}$ | - | . 751 | - | 78.-80. | Wurtz. |
| " iso-amyl ether | $\mathrm{C}_{7} \mathrm{H}_{16} \mathrm{O}$ | 18. | . 764 | - | I12. | Williamson and others. |
| " norm-hexyl ether | $\mathrm{C}_{8} \mathrm{H}_{18} \mathrm{O}$ | - | - | - | I $34 .{ }^{-1} 37$. | Lieben, Janeczek. |
| " norm-heptyl ether | $\mathrm{C}_{9} \mathrm{H}_{26} \mathrm{O}$ | 16. | -790 | - | 165. | Cross. |
| " norm-octyl ether | $\mathrm{C}_{10} \mathrm{H}_{22} \mathrm{O}$ | 17. | . 794 | - | 182.-184. | Moslinger. |

[^32](g) Miscellaneous.

| Substance | Chemical formula. | Density tempera | and ture. | Melting point C | Boiling point C | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetic acid | $\mathrm{CH}_{3} \mathrm{COOH}$ | 1. 115 | $0^{\circ}$ | 16.7 | 118.5 | Young, 'o9 |
| Acetone. | $\mathrm{CH}_{3} \mathrm{COCH}_{3}$ | 0.812 | $\bigcirc$ | -94.6 | 56.1 |  |
| Aldehyde. . . . . . . | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}$ | 0.806 | $\bigcirc$ | -120. | +20.8 |  |
| Aniline. . . . . . . . | $\mathrm{C}_{6} \mathrm{H}_{5} \mathrm{NH}_{2}$ | 1.038 | 0 | -8. | 183.9 |  |
| Beeswax. |  | $0.96 \pm$ |  | 62. |  |  |
| Benzoic acid. | $\mathrm{C}_{7} \mathrm{H}_{6} \mathrm{O}_{2}$ | I. 293 | 4 | 12 I . | 249. |  |
| Benzene . . . | $\mathrm{C}_{6} \mathrm{H}_{6}$ | 0.879 | 20 | 5.48 | 80.2 | Richards |
| Benzophenone | $\left(\mathrm{C}_{6} \mathrm{H}_{5}\right)_{2} \mathrm{CO}$ | 1.090 | 50 | 48. | 305.9 | HolbornHenning |
| Butter.. |  | 0.86-7 |  | $30 \pm$ |  |  |
| Camphor. | $\mathrm{C}_{10} \mathrm{H}_{16} \mathrm{O}$ | 0.99 | 10 | 176. | 209. |  |
| Carbolic acid.... | $\mathrm{C}_{6} \mathrm{H}_{5} \mathrm{OH}$ | 1.060 | 21 | 43. | 182. |  |
| Carbon bisulphide " tetrachlor- | $\mathrm{CS}_{2}$ | I. 292 | $\bigcirc$ | -110. | 46.2 |  |
| ide....... | $\mathrm{CCl}_{4}$ | 1. 582 | 21 | -30. | 76.7 | Young |
| Chlorbenzene | $\mathrm{C}_{6} \mathrm{H}_{5} \mathrm{Cl}$ | I. III | 15 | -40. | 132. |  |
| Chloroform. | $\mathrm{CHCl}_{3}$ | 1. 257 | $\bigcirc$ | -65. | 61.2 |  |
| Cyanogen . | $\mathrm{C}_{2} \mathrm{~N}_{2}$ |  |  | -35. | -21. |  |
| Ethyl bromide | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br}$ | 1.45 | 15 | -117. | 38.4 |  |
| " chloride | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}$ | 0.918 | 8 | -141.6 | 14. |  |
| " ether. | $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | -. 736 | $\bigcirc$ | - II8. | 34.6 |  |
| " iodide | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | 1.944 | 14 | - | 72. |  |
| Formic acid. | HCOOH | I. 242 | $\bigcirc$ | 8.6 | 100.8 |  |
| Gasolene . |  | $0.68 \pm$ |  | - | 70-90 |  |
| Glucose . | $\mathrm{CHO}(\mathrm{HCOH})_{4} \mathrm{CH}_{2} \mathrm{OH}$ | 1. 56 |  | 146. | - |  |
| Glycerine . . . . . . | $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}_{3}$ | I. 269 | - | 20. | 290. |  |
| Iodoform. | $\mathrm{CHI}_{3}$ | 4.01 | 25 | 119. | - |  |
| Lard. . . . . . . . . |  |  |  | $29 \pm$ | - |  |
| Methyl chloride.. | $\mathrm{CH}_{3} \mathrm{Cl}$ | 0.992 | -24 | -103.6 | -24. 1 |  |
| Methyl iodide.... | $\mathrm{CH}_{3} \mathrm{I}$ | 2. 285 | 15 | -64. | $42 \cdot 3$ |  |
| Naphthalene . . . | $\mathrm{C}_{6} \mathrm{H}_{4} \cdot \mathrm{C}_{4} \mathrm{H}_{4}$ | I. 152 | 15 | 80. | 218. | HolbornHenning |
| Nitrobenzene. | $\mathrm{C}_{6} \mathrm{H}_{5} \mathrm{O}_{2} \mathrm{~N}$ | 1. 212 | $7 \cdot 5$ | 5. | 211. |  |
| Nitroglycerine . . . | $\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{~N}_{3} \mathrm{O}_{9}$ | 1.60 |  | - | - |  |
| Olive oil......... |  | 0.92 |  | $20 \pm$ | $300 \pm$ |  |
| Paraffin wax, soft. | ${ }_{2} \mathrm{H}_{2} \mathrm{O}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ | 1. 68 |  | $\begin{gathered} 190 . \\ 38-52 \end{gathered}$ | 350-390 |  |
| " " hard |  | - |  | 52-56 | 390-430 |  |
| Pyrogallol. . . . . . | $\mathrm{C}_{6} \mathrm{H}_{3}(\mathrm{OH})_{3}$ | 1. 46 | 40 | 133. | 293. |  |
| Spermaceti. . . . . |  | 0.95 | 15 | $45 \pm$ | - |  |
| Starch . | $\mathrm{C}_{6} \mathrm{H}_{10} \mathrm{O}_{5}$ | 1. 56 |  | none | - |  |
| Sugar, cane..... . | $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11}$ | 1. 588 | 20 | 160. | - |  |
| Stearine........ | $\left(\mathrm{C}_{18} \mathrm{H}_{35} \mathrm{O}_{2}\right)_{3} \mathrm{C}_{3} \mathrm{H}_{5}$ | 0.925 | 65 | 71. | - |  |
| Tallow, beef . . . |  | 0.94 | 15 | 27-38 | - |  |
| " mutton.. |  | 0.94 | 15 | 32-4I | - |  |
| Tartaric acid. | $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$ | I. 754 |  | 170. | - |  |
| 'Toluene. | $\mathrm{C}_{6} \mathrm{H}_{5} \mathrm{CH}_{3}$ | 0.882 | $\infty$ | -92. | 110.31 | Richards |
| Xylene (o) | $\mathrm{C}_{6} \mathrm{H}_{4}\left(\mathrm{CH}_{3}\right)_{2}$ | 0.863 | 20 | -28. | 142. |  |
| " ${ }^{\prime}$ (m)..... | $\mathrm{C}_{6} \mathrm{H}_{4}\left(\mathrm{CH}_{3}\right)_{2}$ | 0.864 | 20 | 54. | 140. |  |
| " (p)..... | $\mathrm{C}_{6} \mathrm{H}_{4}\left(\mathrm{CH}_{3}\right)_{2}$ | 0.86I | 20 | 15. | 138. |  |


| Metals. | Melting-points, $\mathrm{C}^{\text {O }}$. |  |  |  |  |  |  |  |  |  |  | ¢ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Percentage of metal in second column. |  |  |  |  |  |  |  |  |  |  |  |
|  | \% \% | 10\% | 20\% | $30 \%$ | 40\% | 50\% | 60\% | 70\% | 80\% | 90\% | 100\% |  |
| Pb . Sn . | 326 | 295 | 276 | 262 | 240 | 220 | 190 |  | 200 | 215 |  | 7 |
| B1. | 322 | 290 |  |  | 179 | 145 | 126 600 | 168 480 | 205 | 4 | 268 | 7 8 |
| Te. | 322 328 | 710 460 | 790 | 880 | 917 620 | 760 650 | 600 705 | 480 775 | -410 840 | 425 | 446 | 8 |
| Ag. | 328 | 460 360 | 545 420 | 590 400 | 620 370 | 650 330 | 705 290 | 775 250 | 840 200 | 905 130 | 959 | 9 13 |
| Cu . | 326 | 870 | 920 | 925 | 945 | 950 | 955 | 985 | 1005 | 1020 | 1084 | 2 |
| Sb. | 326 | 250 | 275 | 330 | 395 | 440 | 490 | 525 | 560 | 600 | 632 | 16 |
| Al. Sb . | 650 | 750 | 840 | 925 | 945 | 950 | 970 | 1000 | 1040 | 1010 | ${ }_{632}$ | 17 |
| Cu . | 650 | 630 | 600 | 560 | 540 | 580 | 610 | 755 | 930 | 1055 | 1084 | 18 |
| Au. | 655 650 | 675 625 | 740 615 | 800 600 | 855 590 | 915 580 | ${ }_{5}^{975}$ | 1025 570 | 1055 650 | 675 750 | 1062 | 10 |
| Ag Zn. | 650 654 | 625 640 | 615 620 | 600 600 | 590 580 | 580 560 | 5575 | 570 510 | 650 475 | 750 425 | 954 419 | 17 |
| Fe . | 653 | 860 | 1015 | 1110 | 1145 | 1145 | 1220 | 1315 | 1425 | 1500 | 1515 | 3 |
| Sn . | 650 | 645 | -635 | 625 | 620 | 605 | 590 | 570 | 560 | 540 | 232 | 17 |
| Sb . Bi . | 632 | 610 | 590 | 575 | 555 | $54^{\circ}$ | 520 | 470 | 405 | 330 | 268 | 16 |
| Ag. | ${ }^{3} 3^{\circ}$ | 595 | 570 | 545 | 520 | 500 | 505 | 545 | 680 | 850 | 959 | 9 |
| Sn . | 622 | 600 | 570 | 525 | 4 So | 430 | 395 | 350 | 310 | 255 | 232 | 19 |
| Zn . | 632 | 555 | 510 | 540 | 570 | 565 | 540 | 525 | 510 | 470 | 419 | 17 |
| Ni. Sn. |  | 1380 | 1290 | 1200 | 1235 |  | 1305 | 1230 | 1060 | 800 | 232 | 17 |
| Na . Bi . | 96 | 425 | 520 | 590 | 645 | 690 | 720 | 730 | 715 | 570 | 268 | ${ }^{2} 3$ |
| Cd. | 96 | 125 | 185 | 245 | 285 | 325 | 330 | 340 | 360 | 390 | 322 | 13 |
| Cd. Ag. | 322 | 420 | 520 | 610 | 700 | 760 | 805 | 850 | 895 | 940 | 954 | 17 |
| T1. | 32 I | 300 | 285 | 270 | 262 | 258 | 245 | 230 | 210 | 235 | 302 | 14 |
| Zn . | 322 | 280 | 270 | 295 | 313 | 327 | 340 | 355 | 370 | 390 | 419 | 18 |
| $\mathrm{Au} . \mathrm{Cu}$. | 1063 | 910 | 890 | 895 | 905 | 925 | 975 | 1000 | 1025 | 1060 | 1084 | 4 |
| Ag. | 1064 | 1062 | 106r | 1058 | 1054 | 1049 | 1039 | 1025 | 1006 | 982 | 963 | 5 |
| $\stackrel{\mathrm{Pr}}{ }$ | 1075 | 1125 | 1190 | 1250 | 1320 | 1380 | 1455 | 1530 | 1610 | 1685 | 1775 | 20 |
| K. Na. | 62 | 17.5 | -10 | -3.5 | 5 | 11 | 26 | 41 | 58 |  | 97.5 | 15 |
| H. | - |  | - | - | - | 90 | 110 | 135 | 162 | 265 |  | 13 |
| Tl. | 62.5 | 133 | 165 | 188 | 205 | 215 | 220 | 240 | 280 | 305 | 301 | 14 |
| Cu . Ni. | 1080 | 1180 | 1240 | 1290 | 1320 | 1335 | 1380 | 1410 | ${ }^{1430}$ | 1440 | 1455 | 17 |
| Ag. | 1082 | 1035 | 990 | 945 | 910 | 870 680 | 830 | 788 | 814 | 875 | 960 | 9 |
| Sn . | 1084 | 1005 | 890 | 755 | 725 | 680 880 | 630 820 | 580 | 530 | 440 580 | 232 | 12 |
| Ag. ${ }_{\mathrm{Zn}}^{\mathrm{Zn}}$. | 1084 | 1040 850 8 | 995 | 930 | 900 | 880 | 820 630 | 780 610 | 700 | 580 | 419 | 6 |
| ${ }^{\text {Sn }}$. | 959 | 870 |  | 705 630 |  | 495 | 450 | 420 | 375 | 300 | ${ }_{232}$ | 9 |
| Na . Hg . | 96.5 | 90 | 80 | 70 | 60 | 45 | 22 | 55 | 95 | 215 | - | 13 |

: Means, Landolt-Börnstein-Roth Tabellen.
2 Friedrich-Leroux, Metal. 4, 1907.
3 Gwyer, Zs. Anorg. Ch. 57, 1908.
4 Means, L.-B.-R. Tabellen.
Roberts-Austen Chem. News, 87, 2, 1903 .
Shepherd J. ph. ch. 8, 1904.
Kapp, Diss., Königsberg, ıgor.
Fay and Gilson, Trans. Am. Inst. Min. Eng. Nov. 1901.

Heycock and Neville, Phil. 'Trans. 189 A, 1897. 194 A, $201,1900$.

11 Heycock and Neville, J. Chem. Soc. 71, 1897.
12 " " Phil. Trans. 202A, 1, 1903.
${ }_{13}$ Kurnakow, Z. Anorg. Chem. 23, 439, 1900.
14 " "، "، "، 30, 86, 1902.
16 Roland-Gosselin, Bul. Soc. d'Encour. (5) 1, 1896.
17 Gautier, "" "، "" (5) $\mathbf{1}$,
18 Le Chatelier, " " " (4) 10, 573, 1895.

19 Reinders, Z. A norg. Chem. 25, 113, 1896.
20 Erhard and Schertel, Jahrb. Berg-u. Hüttenw. Sachsen. 1879, 17.

TABLE 222. - Alloy of Lead, Tin, and Bismuth.

|  | Per cent. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Lead. . . | 32.0 | 25.8 | 25.0 | 43.0 | 33.3 | 10.7 | 50.0 | 35.8 | 20.0 | 70.9 |
| Tin Bismuth. . . | 15.5 52.5 | 19.8 | 15.0 60.0 | 14.0 | 33.3 | 23.1 | 3.3 .0 | 52.1 | 60.0 | 9.1 |
| Bismuth . . . | 52.5 | 54.4 | 60.0 | 43.0 | 33.3 | 66.2 | 17.0 | 12.1 | 20.0 | 20.0 |
| Solidification at | $96^{\circ}$ | 1010 | $125^{\circ}$ | $128^{\circ}$ | $145^{\circ}$ | $148^{\circ}$ | $161^{\circ}$ | $181^{\circ}$ | $182^{\circ}$ | $234^{\circ}$ |

Charpy, Soc. d'Encours, Paris, 1 gox.
TABLE 223. - Low Melting-point Alloy.

|  | Per cent. |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Cadmium . . | 10.8 | 10.2 | 14.8 | 13.1 | 6.2 | 7.1 | 6.7 |
| ${ }_{\text {Tin }}^{\text {Lead }}$. . . . | 14.2 24.9 | 14.3 | 7.0 | 13.8 | 9.4 | - | - |
| Bismuth . . . | 24.9 <br> 50.1 | 25.1 <br> 50.4 | 26.0 52.2 | 24.3 <br> 48.8 | $\begin{aligned} & 34.4 \\ & 50.0 \end{aligned}$ | $\begin{aligned} & 39 \cdot 7 \\ & 53 \cdot 2 \end{aligned}$ | $\begin{aligned} & 43 \cdot 4 \\ & 49 \cdot 9 \end{aligned}$ |
| Solidification at | $65.5^{\circ}$ | $67.5^{\circ}$ | $68.5^{\circ}$ | $68.5^{\circ}$ | $76.5{ }^{\circ}$ | $89.5{ }^{\circ}$ | $95^{\circ}$ |

Drewitz, Diss. Rostock, 1902.
All conipiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

Table 224.
TRANSFORMATION AND MELTING TEMPERATURES OF LIME-ALUMINASILICA COMPOUNDS AND EUTECTIC MIXTURES.
The majority of these determinations are by G. A. Rankin. (Part unpublished.)


The accuracy of the melting-points is 5 to ro units. Geophysical Laboratory. See also Day and Sosman, Am. J. of Sc. xxxi, p. 34I, 19 II.

## LOWERING OF FREEZING-POINTS BY SALTS IN SOLUTION.

In the first column is given the number of gram-molecules (anhydrous) dissolved in 1000 grams of water; the second contains the molecular lowering of the freezing-point ; the freezing-point is therefore the product of these two columns. After the chemical formula is given the molecular. weight, then a reference number.

|  |  |  |  |
| :---: | :---: | :---: | :---: |
| $\mathrm{Pb}\left(\mathrm{NO}_{3}\right)_{2}$, 331.0: 1, 2.0 | $0.0500 \quad 3.47^{\circ}$ | $0.4978 \quad 2.02^{\circ}$ | $\mathrm{MgCl}_{2}, 95.26: 6,14 .$ |
| $0.0003625 .5{ }^{\circ}$ | .10003 .42 | 81122.01 | $0.0100 \quad 5.1^{\circ}$ |
| .001204 5.30 | . 2000 3.32 | 1.5233 2.28 | $.0500 \quad 4.98$ |
| . 002805 5.17 | . 500 3.26 | $\mathrm{BaCl}_{2}, 208.3$ : 3, 6, 13. | $.1500 \quad 4.96$ |
| . $005570 \quad 4.97$ | $1.000 \quad 3.14$ | $0.00200 \quad 5.5^{\circ}$ | . 3000 5.186 |
| . 017374.69 | $\mathrm{LiNO}_{3}, 69.07$ : 9. | . 004985.2 | . 60995.69 |
| . $5015 \quad 2.99$ | 0.0398 3.4 ${ }^{\circ}$ | .01005 .0 | KCl, 74.60: 9, 17-19. |
| $\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}, 26 \mathrm{r} .5$ : 1. | .16713 .35 | $.0200 \quad 4.95$ | $0.02910 \quad 3.54^{\circ}$ |
| $0.0003835 .6{ }^{\circ}$ | .4728 3.35 | .048054 .80 | . $05845 \quad 3.46$ |
| .001259 5.28 | $1.0164 \quad 3.49$ | $.100 \quad 4.69$ | .112 3.43 |
| .002681 5.23 | $\mathrm{Al}_{2}\left(\mathrm{SO}_{4}\right)_{3}, 342.4$ : 10. | $.200 \quad 4.66$ | . $3139 \quad 3.41$ |
| . 0054225.13 | 0.0131 | . 500 4.82 | .476 3.37 |
| . 0083525.04 | . 0261 4.9 | $.586 \quad 5.03$ | $1.000 \quad 3.286$ |
| $\mathrm{Cd}\left(\mathrm{NO}_{3}\right)_{2},{ }^{236.5}$ : 3. | .0543 4.5 | . 750 5.2 | $1.989 \quad 3.25$ |
| 0.00298 5.4 | .1086 | $\mathrm{CdCl}_{2}, 183 \cdot 3: 3,14 .$ | 3.2693 .25 |
| . 006895.25 | . 217 3 383 | $0.00299 \quad 5.0^{\circ}$ | $\mathrm{NaCl}, 58.50$ : $3,20,12,16$. |
| . 01997 5.18 | $\mathrm{CdSO}_{4}, 208.5$ : $1,1 \mathrm{I}$. | . 006904.8 | - $0.003993 .7^{\circ}$ |
| . $04873 \quad 5.15$ | $0.000704 \quad 3.35^{\circ}$ | . $0200 \quad 4.64$ | . $01000 \quad 3.67$ |
| $\mathrm{AgNO}_{3}, 167.0: 4,5$ | . 0026853.05 | .054I 4.1I | . 02213.55 |
| 0.1506 $3.32^{\circ}$ | OII5I 2.69 <br> 03120 2.42 | . 0818 3.93 | . 04949 3.51 |
| .5001 2.96 | .03120 2.42 | $\begin{array}{ll}.214 & 3.39\end{array}$ | . 10815 |
| . $8645 \quad 2.87$ | .1473 2.13 | .4293 .03 | $.2325 \quad 3.42$ |
| 1.749 2.27 | .4129 1.80 | . 858 2.71 | . 4293 3.37 |
| 2.953 I. 85 | . $7501 \quad 1.76$ | $\begin{array}{ll}1.072 & 2.75\end{array}$ | $\begin{array}{ll}.700 & 3.43\end{array}$ |
| $\begin{array}{ll}3.856 & 1.64 \\ 0.0560 & 3.82\end{array}$ |  |  | $\mathrm{NH}_{4} \mathrm{Cl}, 53.52$ : 6, 15. |
| $\begin{array}{rr}0.0560 & 3.82 \\ .1401 & 3.58\end{array}$ | $\begin{array}{cc}\mathrm{K}_{2} \mathrm{SO}_{4}, 174.4: 3,5,6,10,12 . \\ 0.00200 & 5.4\end{array}$ | $\begin{array}{ll} 1,1,035 \cdot 3 \cdot 9 \\ 0.0350 \end{array} \quad 4.9^{\circ}$ | $\begin{array}{cc} \mathrm{NH}_{4} C, 53.52: 0 \\ 0.0100 \end{array}$ |
| $\begin{array}{ll}.1401 & 3.58 \\ .3490 & 3.28\end{array}$ | $\begin{array}{rr}0.00200 & 5.4 \\ .00398 & 5.3\end{array}$ | . 33374 | . 02003.56 |
|  | $\begin{array}{ll}.00398 & 5 \cdot 3 \\ .00865 & 4.9\end{array}$ | . 3380 ( 4.92 | $.0350 \quad 3.50$ |
| KN3, 0.0100 | .0200 4.9 <br> .00  | .7149 5.32 | .1000  <br> .2000 3.43 |
| . 0200 3.5 | . 0500 4.60 | $\mathrm{CoCl}_{2}$, 129.9: 9. | $\begin{array}{ll}0000 & 3.396 \\ 000 & 3.393\end{array}$ |
| . 0500 3.41 | .1000 4.32 | 0.0276 | $\begin{array}{ll}.4000 & 3.393 \\ .7000 & 3.41\end{array}$ |
| .100 3.31 | 4.07 | .10944 .9 |  |
| . 200 3.19 | . 454 3.87 | $\begin{array}{ll}.2369 & 5.03 \\ .4399 & 5.30\end{array}$ |  |
| $\begin{array}{ll}.250 & 3.08 \\ .500 & 2.04\end{array}$ | $\mathrm{CuSO}_{4}, 159.7 \mathrm{l}^{\text {a }}$ : $1,4,11$. 0.00286 | $\begin{array}{ll}.4399 & 5.30 \\ .538 & 5.5\end{array}$ | 0.00992 $3.7^{\circ}$ <br> .0455 3.5 |
| $\begin{array}{ll}.500 & 2.94 \\ .750 & 2.81\end{array}$ | $\begin{array}{rr}0.000286 & 3.3 \\ .000843 & 3.15\end{array}$ |  | $\begin{array}{ll}.0455 & 3 \cdot 5 \\ .09952 & 3.53\end{array}$ |
| 1.0002 .66 | .002279 3.03 |  | .2474 3.50 |
| NaNO ${ }_{3}, 85.09: 2,6,7$ | . 0066702.79 | . $05028 \quad 4.85$ | . 5012 3.61 |
| $0.0100 \quad 3.6{ }^{\circ}$ | . $01463 \quad 2.59$ | . 10064.79 | . $7939 \quad 3.71$ |
| . 0250 3.46 | .1051 2.28 | . 5077 5.33 | $\mathrm{BaBr}_{2}, 297.3$ : 14. |
| . 505003.44 | . 20741.95 | .946 5.3 | $0.100 \quad 5.1^{\circ}$ |
| . 2000 3.345 | . 4043 l I. 84 | $2.432 \quad 8.2$ | .150 |
| .500 3.24 | . 8898 1.76 | 3.46911 .5 | . 200 5.00 |
| .5015 $5 \cdot 30$ | $\mathrm{MgSO}_{4}, 120.4: 1,4,11$. | $3.829 \quad 14.4$ | . 500 5.18 |
| $1.000 \quad 3.15$ | 0.000675 | 0.0478 - 5.2 | $\mathrm{Br}_{3}, 267.0: 9$. |
| $1.0030 \quad 3.03$ | . 002381 3.10 | . 533 4.91 | 0.0078 1.4 ${ }^{0}$ |
| NH4 $\mathrm{NO}_{3}, 80.1 \mathrm{II}: 6,8$. | . 01263 2.72 | .331 5.15 | . 0559 I.2 |
| $0.01003 .6{ }^{\circ}$ | . 0580 | . $612 \quad 5.47$ | .1971 .07 |
| . 0250 3.50 | .2104 2.23 | .998 | .4355 $\quad 1.07$ |

1 Hausrath, Ann. Phys. 9, 1902.
2 Leblanc-Noyes, Z. Phys. Ch. 6, 1890.
3 Jones, Z. Phys. Ch. 11, $1893 \cdot$
${ }_{4}$ Raoult, Z. Plys. Ch. 2, 1888.
5 Arrhenius, Z. Phys. Ch. 2, 1888.
6 Loomis. Wied. Ann. 57, 1896.
7 Jones, Am. Chem. J. 27, 1902.
8 Jones-Caldwell, Am. Chem. J. 25, 1901.
9 Biltz, Z. Phys. Ch. 40, 1902.
Jones-Mackay, Am. Chem. J. 19, 1897.
Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.

LOWERING OF FREEZING-POINTS BY SALTS IN SOLUTION (continued).

|  |  |  |  |
| :---: | :---: | :---: | :---: |
| $\mathrm{CdBr}_{2}, 272.3: 3,14$. | KOH, 56.16: $1,15,23$. | $\mathrm{Na}_{2} \mathrm{SiO}_{3}, \mathbf{1 2 2 . 5}$ : 15. | $0.472 .20{ }^{\circ}$ |
| $0.003245 .1^{\circ}$ | $0.003523 .60^{\circ}$ | $0.01052 \quad 6.4^{\circ}$ | . 944 2.27 |
| . 007184.6 | . 007703.59 | . 052395.86 | 1.6202 .60 |
| $\begin{array}{ll}.03627 & 3.84\end{array}$ | . 020023.44 | .1048 5.28 | $(\mathrm{COOH})_{2}, 90.02: 4,15$. |
| .0719 3.39 | .050063 .43 | .20994 .66 | 0.01002 |
| .1122 3.18 | . 10013 | . 5233 3.99 | . 02005 3.19 |
| $.220 \quad 2.96$ | .20033 .424 | $\mathrm{HCl}, 36.46$ : | .050193 .03 |
| $\begin{array}{ll}.440 & 2.76\end{array}$ | $\begin{array}{ll}230 & 3.50\end{array}$ | $1-3,6,13,18,22 .$ | . $1006 \quad 2.83$ |
| . $800 \quad 2.59$ | ${ }_{4} .465 \quad 3.57$ | $0.003053 .68^{\circ}$ | . 20222.64 |
|  | $\mathrm{CH}_{3} \mathrm{OH}, 32.03: 24,25$. 0.0100 \% 1.8 | $\begin{array}{ll}.00695 & 3.66 \\ .0100 & 3.6\end{array}$ | $.366 \quad 2.56$ |
| $\begin{array}{cl}0.0242 & 5.1^{\circ} \\ .0817 & 5.1\end{array}$ | $\begin{array}{rr}0.0100 & 1.80 \\ .0301 & 1.82\end{array}$ | $\begin{array}{ll}.0100 & 3.6 \\ .01703 & 3.59\end{array}$ |  |
| . $2255 \quad 5.27$ | . 2018 I.8II | $.0500 \quad 3.59$ | $\mathrm{C}_{3} \mathrm{H}_{5}(\mathrm{OH})_{3}, 92.06: 24,25$. |
| . 60035.89 | 1.046 | .1025 3.56 | $\begin{array}{rl}0.0200 & 1.86 \\ .1008 & 1.86\end{array}$ |
| $\mathrm{CaBr}_{2}, 200.0$ : 14. | 3.41 | $\begin{array}{ll}.2000 & 3.57 \\ .3000 & 3612\end{array}$ | .2031 1.85 |
| 0.0871 | $6.200 \quad 1.944$ | $\begin{array}{ll}.3000 & 3.612 \\ .464 & 3.68\end{array}$ | . 535 I.91 |
| .1742 5.18 | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}, 46.04$ : | $\begin{array}{ll}.464 & 3.6 \\ .516 & 3.79\end{array}$ | $2.40 \quad 1.98$ |
| $\begin{array}{ll}.3484 & 5.30 \\ .5226 & 5.64\end{array}$ |  | .5103 | $5.24 \quad 2.13$ |
|  | . 004993 I. 67 | 1.0324 .10 | $\left(\mathrm{C}_{2} \mathrm{H}_{5}\right)_{2} \mathrm{O}, 74.08$ : 24 |
|  | . 0100 ll | 1.500 4.42 | $0.01001 .6{ }^{\circ}$ |
| $\begin{array}{ll}0.0517 & 5.4 \\ .103\end{array}$ | . 028921.707 | $2.000 \quad 4.97$ | $.0201 \quad 1.67$ |
| $\begin{array}{ll}.103 & 5.16 \\ .207 & 5.26\end{array}$ | . 0705 I.85 | 2.11504 .52 | $.1011 \quad 1.72$ |
| $\begin{array}{ll}.207 & 5.26 \\ .517 & 5.85\end{array}$ | . 2922 1.829 | 3.0006 | $.2038 \quad 1.702$ |
| -517 5.85 | . 2024 I.832 | $3.053 \quad 4.90$ | Dextrose, 180.1 : 24, 30. |
| $\mathrm{KBr}, 119.1 \mathrm{I}$ : 9, 21. | . 52521.834 | 4.065 | $0.0198 \quad 1.84^{\circ}$ |
| $0.03053 .61{ }^{\circ}$ | $1.0891 \quad 1.826$ | $4657 \quad 6.19$ | $.0470 \quad 1.85$ |
| $\begin{array}{ll}.1850 \\ .680 r & 3.49\end{array}$ | $1.760 \quad 1.83$ | $\mathrm{HNO}_{3}, 63.05: 3,13,15$. | .1326 1.87 |
| $\begin{array}{ll}.680 r & 3.30 \\ .200\end{array}$ | 3.901 | $0.02004 \quad 3.55^{\circ}$ | .4076 - 1.894 |
| $\begin{array}{ll}.250 & 3.78 \\ .500 & 3.56\end{array}$ | 7.91 - 2.02 | . 050153 | 1.1021 .921 |
| -500 3. | 11.1I 2.12 | .0510 3.71 | Levulose, 180.1: $24,25$. |
| $\mathrm{CdI}_{2}, 366.1 \mathrm{I}$ : 3, 5, 22. | 18.76 I.8ı | . 10043.48 | $0.0201 \quad 1.87^{\circ}$ |
| $0.00210 \quad 4.5^{\circ}$ | 0.0173 I.80 | $.1059 \quad 3.53$ | $.2050 \quad 1.871$ |
| . 006264.0 | . 0778 1.79 | . 2015 3.45 | . 554 2.01 |
| . $02062 \quad 3.52$ | $\mathrm{K}_{2} \mathrm{CO}_{3}, 138.30$ : 6 | $.250 \quad 3.50$ | 1.384 |
| . 04857 2.70 | $0.01005 .1{ }^{\circ}$ | . 500 3.62 | 2.77 3.04 |
| . $1360 \quad 2.35$ | . $0200 \quad 4.93$ | 1.0003 .80 | $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11}, 342.2 \mathrm{I}$ I, 24, 26. |
| . 33312.13 | . 0500 4.71 | 2.000 4.17 | $0.000332 \quad 1.90^{\circ}$ |
| $\begin{array}{ll}.684 & 2.23 \\ .888 & 2.51\end{array}$ | .100 4.54 | $3.000 \quad 4.64$ | .001410 1.87 |
| . 888 2.51 | . 200 4.39 | $\mathrm{H}_{3} \mathrm{PO}_{2}$, 66.0: 29. | . $009978 \quad 1.86$ |
| $\mathrm{KI}, 166.0$ : 9, 2.3 | $\mathrm{Na}_{2} \mathrm{CO}_{3}, 106.10: 6$. | $0.1260 \quad 2.90^{\circ}$ | . 0201 1.88 |
| $0.0651 \quad 3.5^{\circ}$ | $0.01005 .11^{\circ}$ | . 2542 2.75 | .1305 I.SS |
| $\begin{array}{ll}.2782 & 3.50 \\ .6030 & 3.42\end{array}$ | . 0200 4.93 | $\begin{array}{ll}.5171 & 2.59 \\ 1.071 & 2.45\end{array}$ | $\mathrm{H}_{2} \mathrm{SO}_{4}, 98.08 \text { : }$ |
| $\begin{array}{ll}.6030 & 3.42 \\ 1.003 & 3.37\end{array}$ | $\begin{array}{ll}.0500 & 4.64 \\ .1000 & 4.42\end{array}$ |  | $0.00+6 \mathrm{I}^{13,20,31-33 .} 4.8^{\circ}$ |
| $\mathrm{SrI}_{2}, 34 \mathrm{I} .3$ : 22. | . 2000 4.17 | $0.0745 \quad 3.0^{\circ}$ | $\begin{array}{ll}.0100 & 4.49\end{array}$ |
| $0.0545 .1^{\circ}$ | $\mathrm{Na}_{2} \mathrm{SO}_{3}, 126.2$ : 28. | . 12412.8 | . 0200 4.32 |
| . 108 5.2 | 0.1044 $4.51^{\circ}$ | .2482 2.6 | .0461 4.10 |
| . 216 5.35 | . $3397 \quad 3.74$ | $1.00 \quad 2.39$ | .1003 .96 |
| . 327 5.52 | .7080 $\quad 3.38$ | $\mathrm{H}_{3} \mathrm{PO}_{4}$, 98.0: 6, 22. | .2003 .85 |
| $\mathrm{NaOH}, 40.06$ : 15. | $\mathrm{Na}_{2} \mathrm{HPO}_{4}$, 142.1: $22,29$. | $0.0100 \quad 2.8^{\circ}$ | . 400 3.9S |
| $0.020023 .45^{\circ}$ | 0.010015 | . 02002.68 | $1.000 \quad 4.19$ |
| . $05005 \quad 3.45$ | .020034 .84 | . $0500 \quad 2.49$ | $1.500 \quad 4.96$ |
| .1001 3.41 | .050084 .60 | .1000 2.36 | $2.000 \quad 5.65$ |
| . 20003.407 | . 10024.34 | . 20002.25 | $2.500 \quad 6.53$ |

1-20 See page 217 .
21 Sherrill, Z. Phys. Ch. 43, 1903.
22 Chambers-Frazer, Am. Ch. J. 23, 1900.
23 Noyes-Whitney, Z. Phys. Ch. 15, $1894^{\circ}$
24 Loomis, Z. Phys. Ch. 32, 1900.
25 Abegg, Z. Phys. Ch. 15, 1894.
26 Nernst-Abegg, Z. Phys. Ch. $15,1894$.

27 Pictet-Altschul, Z. Phys. Ch. 16, 1895.
28 Barth, Z. Phys. Ch. 9, iSg2.
29 Petersen, Z. Phys. Ch. II, 1893.
30 Roth, Z. Phys. Ch. 43, 1903.
31 Wildermann, Z. Phys, Ch. 15, 1894.
32 Jones-Carroll, Am. Ch. J. 28, 1902.
33 Jones-Murray, Am. Ch. J. 30, 1903.

## RISE OF BOILING-POINT PRODUCED BY SALTS DISSOLVED IN WATER.*

This table gives the number of grams of the salt which, when dissolved in 100 grams of water, will raise the boil-ing-point by the amount stated in the headings of the different columns. The pressure is supposed to be 76 centimeters.

| Salt. |  | $1^{\circ} \mathrm{C}$. | $2^{\circ}$ | 3 | $4^{\circ}$ | 5 | $7^{\circ}$ | $10^{\circ}$ | $15^{\circ}$ | $20^{\circ}$ | $25{ }^{3}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{aligned} & \mathrm{BaCl}_{2}+2 \mathrm{H}_{2} \mathrm{O} . \\ & \mathrm{CaCl} \\ & \mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}+2 \mathrm{H}_{2} \mathrm{O} \\ & \mathrm{KOH} \\ & \mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2} . \end{aligned}$ |  | 15.0 | 3 I .1 | $47 \cdot 3$ | 63.5 | (71.6 gives $4^{0} .5$ rise of temp.) |  |  |  |  |  |
|  |  | 6.0 | I 1.5 | 16.5 | 21.0 | 25.0 | 32.0 | $4 \mathrm{I} \cdot 5$ | 55.5 | 69.0 | 84.5 |
|  |  | 12.0 | 25.5 | 39.5 | 53.5 | 68.5 | 101.0 | 152.5 | 240.0 | 331.5 | $443 \cdot 5$ |
|  |  | 4.7 | $9 \cdot 3$ | 13.6 | $17 \cdot 4$ | 20.5 | 26.4 | 34.5 | 47.0 | 57.5 | 67.3 |
|  |  | 6.0 | 12.0 | 18.0 | 24.5 | 31.0 | 44.0 | 63.5 | 98.0 | 134.0 | 171.5 |
| KCl |  | 9.2 | 16.7 | 23.4 | 29.9 | 36.2 | 48.4 | ( 57.4 g | ves a ris | ise of 8 |  |
| $\mathrm{K}_{2} \mathrm{CO}_{3}$ |  | II. 5 | 22.5 | 32.0 | 40.0 | 47.5 | 60.5 | 78.5 | 103.5 | 127.5 | 152.5 |
| $\mathrm{KClO}_{3}$ |  | 13.2 | 27.8 | 44.6 | 62.2 |  |  |  |  |  |  |
| KI |  | 15.0 | 30.0 | 45.0 | 60.0 | 74.0 | 99.5 | I 34. | 185.0 ( | 220 give | es $18^{\circ} \cdot 5$ ) |
| $\mathrm{KNO}_{3}$ |  | 15.2 | 31.0 | 47.5 | 64.5 | 82.0 | 120.5 | 188.5 | $33^{8.5}$ |  |  |
| $\mathrm{K}_{2} \mathrm{C}_{4} \mathrm{H}_{4} \mathrm{O}_{6}+\frac{1}{2} \mathrm{H}_{2} \mathrm{O}$ |  | 18.0 | 36.0 | 54.0 | 72.0 | 90.0 | 126.5 | 182.0 | 284.0 |  |  |
| $\mathrm{KNaC}_{4} \mathrm{H}_{4} \mathrm{O}_{6}+\dot{+}$ |  | 17.3 | 34.5 | 51.3 | 68.1 | 84.8 | 119.0 | 171.0 | 272.5 | 390.0 | 510.0 |
| $\mathrm{KNaC}_{4} \mathrm{H}_{4} \mathrm{O}_{6}+4 \mathrm{H}_{2} \mathrm{O}$ |  | 25.0 | 53.5 | 84.0 | I 18.0 | 157.0 | 266.0 | 554.0 | 5510.0 |  |  |
| LiCl |  | 3.5 | 7.0 | 10.0 | 12.5 | I 5.0 | 20.0 | 26.0 | 35.0 | 42.5 | 50.0 |
| $\mathrm{LiCl}+2 \mathrm{H}_{2} \mathrm{O}$ |  | 6.5 | 13.0 | 19.5 | 26.0 | 32.0 | 44.0 | 62.0 | 92.0 | 123.0 | 160.5 |
| $\mathrm{MgCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ |  | I 1.0 | 22.0 | 33.0 | 44.0 | 55.0 | 77.0 | I 10.0 | 170.0 | 241.0 | $334 \cdot 5$ |
| $\mathrm{MgSO}_{4}+7 \mathrm{H}_{2} \mathrm{O}$ |  | 41.5 | 87.5 | 138.0 | 196.0 | 262.0 |  |  |  |  |  |
| $\underset{\mathrm{NaOH}}{\mathrm{NaCl}}$. |  | $4 \cdot 3$ | 8.0 | 11.3 | 14.3 | 17.0 | 22.4 | 30.0 | 41.0 | 5 I .0 | 60.1 |
|  |  | 6.6 | 12.4 | 17.2 | 21.5 | 25.5 | 33.5 | (40.7 gi | ives 80.8 | 8 rise) |  |
| $\mathrm{NaNO}_{3}$ |  | 9.0 | 18.5 | 28.0 | 38.0 | 48.0 | 68.0 | 99.5 | I 56.0 | 222.0 |  |
| $\mathrm{NaC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}+3 \mathrm{H}_{2} \mathrm{O}$ |  | 14.9 | 30.0 | 46.1 | 62.5 | 79.7 | I 18.1 | 194.0 | 480.06 | 6250.0 |  |
|  |  | 14.0 | 27.0 | 39.0 | 49.5 | 59.0 | 77.0 | 104.0 | 152.0 | 214.5 | 311.0 |
|  |  | 17.2 | 34.4 44.4 | 51.4 68.2 | 68.4 | 85.3 121.3 |  |  |  |  |  |
| $\mathrm{Na}_{2} \mathrm{C}_{4} \mathrm{H}_{4} \mathrm{O}_{6}+2 \mathrm{H}_{2} \mathrm{O}$. |  | 21.4 | 44.4 | 68.2 | 93.9 | 121.3 | 183.0 | $(237 \cdot 3 \mathrm{~g}$ | gives $8^{\circ}$. | . 4 rise) |  |
| $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}+5 \mathrm{H}_{2} \mathrm{O}$. |  | 23.8 | 50.0 | 78.6 | 108. 1 | 139.3 | 216.0 | 400.0 | 1765.0 |  |  |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}+10 \mathrm{H}_{2} \mathrm{O}$ |  | 34. 1 | 86.7 | 177.6 | 369.4 | 1052.9 |  |  |  |  |  |
| $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7}+10 \mathrm{H}_{2} \mathrm{O}$. 3 |  | 39. | 93.2 | 254.2 | 898.5 | (5555.5 | gives | 0.5 rise |  |  |  |
| $\begin{aligned} & \mathrm{NH}_{4} \mathrm{Cl} \\ & \mathrm{NH}_{4} \mathrm{NO}_{3} \end{aligned}$ |  | 6.5 | 12.8 | 19.0 | 24.7 | 29.7 | 39.6 | 56.2 | 88.5 |  |  |
|  |  | 10.0 | 20.0 | 30.0 | 41.0 | 52.0 | 74.0 | 108.0 | 172.0 | 248.0 | 337.0 |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | I | I 5.4 | 30.1 | 44.2 | 58.0 | 71.8 | 99.1 | ( 115 | gives 10 | 08.2) |  |
| $\mathrm{SrCl}_{2}+6 \mathrm{H}_{2}$ | 2 | 20.0 | 40.0 | 60.0 | 8 I .0 | 103.0 | 150.0 | 234.0 | 524.0 |  |  |
| $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | 2 | 24.0 | 45.0 | 63.6 | 8 I .4 | 97.6 |  |  | 524 |  |  |
| $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$, ${ }^{\text {d }}$ | 1 | 17.0 | 34.4 | 52.0 | 70.0 | 87.0 | 123.0 | 177.0 | 272.0 | 374.0 | 484.0 |
| $\mathrm{C}_{6} \mathrm{H}_{8} \mathrm{O}_{7}+\mathrm{H}_{2} \mathrm{O}$ | I | 19.0 | 40.0 | 62.0 | 86.0 | 112.0 | 169.0 | 262.0 | 540.0 I | I316.0 | 50000.0 |
|  |  | 29.0 | 58.0 | 87.0 | 116.0 | 145.0 | 208.0 | 320.0 | 553.0 | 952.0 |  |
| Salt. | $40^{\circ}$ |  | $0^{\circ}$ | $80^{\circ}$ | $100^{2}$ | $120^{\circ}$ | $140^{\circ}$ | $160^{\circ}$ | $180^{\circ}$ | $200^{\circ}$ | $240^{\circ}$ |
| $\mathrm{CaCl}_{2}$ | 137.5 |  | 2.0 | 314.0 |  |  |  |  |  |  |  |
| KOH | 92.5 |  | 1.7 | ${ }^{1} 52.6$ | 185.0 | 219.8 | 263.1 | 312.5 | 375.0 | - 444.4 | 623.0 |
| NaOH | 93.5 |  | 0.8 | 230.0 | 345.0 | 526.3 | 800.0 | 1333.0 | 2353.0 | 6452.0 |  |
| $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | 682.0 | 137 | 0.0 | 2400.0 | 4099.0 | 8547.0 | $\infty$ |  |  |  |  |
| $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$ | 980.0 | 377 | 4.0 | (infinit | gives | 170) |  |  |  |  |  |

[^33]Smithsonian Tables.

## FREEZING MIXTURES.*

Column 1 gives the name of the principal refrigerating substance, $A$ the proportion of that substance, $B$ the proportion of a second substance named in the column, $C$ the proportion of a third substance, $D$ the temperature of the substances before mixture, $E$ the temperature of the mixture, $F$ the lowering of temperature, $G$ the temperature when all snow is melted, when snow is used, and $H$ the amount of heat absorbed in heat units (small calories when $A$ is granis). Temperatures are in Centigrade degrees.

| Substance. | A | $B$ | C | $D$ | $E$ | F | G | H |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{NaC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ (cryst.) | 85 | $\mathrm{H}_{2} \mathrm{O}-\mathrm{I} 00$ | - | 10.7 | -4.7 | I 5.4 | - | - |
| $\mathrm{NH}_{4} \mathrm{Cl}$. | 30 |  | - | 13.3 | -5.1 | 18.4 | - | - |
| $\mathrm{NaNO}_{3}$. - . | 75 | " | - | 13.2 | $-5.3$ | 18.5 | - | - |
| $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ (cryst.) . | 110 | " | - | 10.7 | -8.0 | 18.7 | .- | - |
| KI. - | 140 | " | - | 10.8 | - 11.7 | 22.5 | - | - |
| $\mathrm{CaCl}_{2}$ (cryst.) | 250 | " | - | 10.8 | $-12.4$ | 23.2 | - | - |
| $\mathrm{NH}_{4} \mathrm{NO}_{3}$. | 60 | " | - | I 3.6 | - 13.6 | 27.2 | - | - |
| $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ - . | 25 | " 50 | $\mathrm{NH}_{4} \mathrm{NO}_{3}-25$ | - | - | 26.0 | - | - |
| $\mathrm{NH}_{4} \mathrm{Cl}$. . . | 25 | " " | " ، | - | - | 22.0 | - | - |
| $\mathrm{CaCl}_{2}$. . | 25 | " | " | - | - | 20.0 | - | - |
| $\mathrm{KNO}_{3}$ - | 25 | " | $\mathrm{NH}_{4} \mathrm{Cl}-25$ | - | - | 20.0 | - | - |
| $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 25 | " " |  | - | - | 19.0 | - | - |
| $\mathrm{NaNO}_{3}$. | 25 | " | " " | - | - | 17.0 | - | - |
| $\mathrm{K}_{2} \mathrm{SO}_{4}$. . | 10 | Snow 100 | - | - I | - I. 9 | 0.9 | - |  |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ (cryst.) | 20 | " " | - | I | -2.0 | 1.0 | - | - |
| $\mathrm{KNO}_{3}$. . | 13 | " | - | - I | $-2.85$ | 1.85 | - | - |
| $\mathrm{CaCl}_{2}$ - . | 30 | " " | - | - I | - 10.9 | 9.9 | - | - |
| $\mathrm{NH}_{4} \mathrm{Cl}$. - | 25 | " | - | - I | - 15.4 | 14.4 | - | - |
| $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | 45 | " | - | - I | -16.75 | 15.75 | - | - |
| $\mathrm{NaNO}_{3}$. | 50 | " | - | - I | -17.75 | 16.75 | - | - |
| NaCl . | 33 | " | - | - I | - 21.3 | 20.3 | - | - |
|  | 1 | " 1.097 | - | - I | - 37.0 | 36.0 | - 37.0 | 0.0 |
|  | 1 | " 1.26 | - | - I | - 36.0 | 35.0 | - 30.2 | 17.0 |
| $\begin{aligned} & \mathrm{H}_{2} \mathrm{SO}_{4}+\mathrm{H}_{2} \mathrm{O} \\ & \left(66.1 \% \mathrm{H}_{2} \mathrm{SO}_{4}\right) \end{aligned}$ | I |   <br>  1.38 | - | - I | - 35.0 | 34.0 | $-25.0$ | 27.0 |
|  | 1 | " 2.52 | - | - I | - 30.0 | 29.0 | - 12.4 | 133.0 |
|  | I | " $4 \cdot 32$ | - | - I | - 25.0 | 24.0 | -7.0 | 273.0 |
|  | 1 | " 7.92 | - | - I | - 20.0 | 19.0 | -3.1 | 553.0 |
|  | I | ${ }^{6} 13.08$ | - | - I | $-16.0$ | I 5.0 | $-2.1$ | 967.0 |
|  | 1 | " 0.35 | - | $\bigcirc$ | - | - | 0.0 | 52.1 |
|  | I | " . 49 | - | $\bigcirc$ | - | - | - 19.7 | 49.5 |
|  | 1 | " .61 | - | 0 | - | - | - 39.0 | 40.3 |
| $\mathrm{CaCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 1 | 6 .70 | - | 0 | - | - | - $54.9{ }^{\dagger}$ | 30.0 |
|  | I | " 61 | - | $\bigcirc$ | - | - | -40.3 | 46.8 |
|  | 1 | " 1.23 | - | $\bigcirc$ | - | - | - 21.5 | 88.5 |
|  | 1 | " 2.46 | - | $\bigcirc$ | - | - | -9.0 | 192.3 |
|  | 1 | " 4.92 | - | $\bigcirc$ | - | -. | $-4.0$ | 392.3 |
| Alcohol at $4^{\circ}$ | 77 | " 73 | - | 0 | - 30.0 | - | - | - |
| Alcohol at 4 \{ |  | $\mathrm{CO}_{2}$ solid | - | - | - 72.0 | - | - | - |
| Chloroform . . | - | " " | - | - | - 77.0 | - | - | - |
| Ether ${ }^{\text {c }}$ | - | "، ${ }^{\prime}$ | - | - | $-77.0$ | - | - | - |
| Liquid $\mathrm{SO}_{2}$. | - | " " | - | - | -82.0 | - | - | - |
| N $\mathrm{NH}_{4} \mathrm{NO}_{3} \quad . \quad\{$ | 1 | $\mathrm{H}_{2} \mathrm{O}-.75$ | - | 20 | 5.0 | - | - | 33.0 |
|  | 1 | " 94 | - | 20 | -4.0 | - | - | 21.0 |
|  | 1 | " ${ }^{\text {c }}$ | - | 10 | -4.0 | - | - | 34.0 |
|  | 1 | " | - | 5 | -4.0 | - | - | 40.5 |
|  | 1 | Snow " | - | $\bigcirc$ | -4.0 | - | - | 122.2 |
|  | I | $\mathrm{H}_{2} \mathrm{O}-1.20$ | - | 10 | - 14.0 | - | - | 17.9 |
|  | I | Snow " | - | $\bigcirc$ | - 14.0 | - | - | 129.5 |
|  | 1 | $\mathrm{H}_{2} \mathrm{O}-\mathrm{I} .3 \mathrm{I}$ | - | 10 | $-17.5 \dagger$ | - | - | 10.6 |
|  | I | Snow " | - | $\bigcirc$ | $-17.5 \dagger$ | - | - | 131.9 |
|  | 1 | $\mathrm{H}_{2} \mathrm{O}-3.61$ | - | 10 | -8.0 | - | - | 0.4 |
|  | 1 | Snow " | - | $\bigcirc$ | -8.0 | - | - | 327.0 |

[^34] Tollinger.
$\dagger$ Lowest temperature obtained.

## Smithsonian Tables.

$\boldsymbol{\theta}=$ Critical temperature.
$P=$ Critical pressure in atmospheres.
$\phi=$ Critical volume referred to volume at $0^{\circ}$ and 76 centimeters pressure.
$d=$ Critical density in grams per cubic centimeter.
$a, b$, Van der Waals constants in $\left(p+\frac{a}{v^{2}}\right)(v-b)=r+a t$.

| Substance. | $\theta$ | $P$ | $\phi$ | $d$ | $\mathrm{a} \times{ }_{10}{ }^{5}$ | $\mathrm{b} \times 10^{6}$ | Observer |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Air | -140.0 | 39.0 | - | - | 257 | 1560 | 1 |
| Alcohol ( $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ ) . | 243.6 | 62.76 | 0.00713 | 0.288 | 2407 | 3769 | 2 |
| " ( $\mathrm{CH}_{4} \mathrm{O}$ ) . | 239.95 | 78.5 | - | - | 1898 | 2992 | 3 |
| Ammonia . . | 130.0 | 115.0 | - | - | 798 | 1606 | 4 |
| Argon | -117.4 | 52.9 | - | - | 259 | 1348 | 5 |
| Benzene | 288.5 | 47.9 | - | 0.305 | 3726 | 5370 | 3 |
| Bromine . | 302.2 |  | 0.00605 | 1.18 | 1434 | 2020 | 6 |
| Carbon dioxide . | 31.2 | 73. | 0.0044 | 0.46 | 717 | 1908 | - |
| " monoxide. | -141.1 | 35.9 | - | - | 275 | 1683 | 7 |
| " disulphide | 273. | 72.9 | 0.0090 | - | 2316 | 3430 | 8 |
| Chloroform . . | 260.0 | 54.9 | . | - | 2930 | 4450 | 9 |
| Chlorine . | 141.0 | 83.9 | - | - | 1157 | 2259 | 4 |
| " . | 146.0 | 93.5 | - | - | 1063 | 2050 | 10 |
| Ether | 197.0 | 35.77 | 0.01584 | 0.208 | 3496 | 6016 | 11 |
| " | 194.4 | 35.61 | 0.01344 | 0.262 | 3464 | 6002 | 3 |
| Ethane - | 32.1 | 49.0 | - | - | 1074 | 2848 | 12 |
| Ethylene . . | - 9.9 | 51.1 | - | - | 886 | 2533 | - |
| Helium . . | <-268.0 | 2.3 | - | - | 5 | 700 | 13 |
| Hydrogen . | -240.8 | 14. | - | - | 42 | 880 | 14 |
| "، chloride. | 51.25 | 86.0 | - | 01 | 692 | 1726 | 15 |
| " sulphide | 52.3 | 86.0 | - | 0.61 | 697 888 | 1731 | 4 |
| " sulphide. | 100.0 -62.5 | 88.7 | - | - | 888 | 1926 | 1 |
| Krypton Methane | -62.5 | 54.3 54.9 | - | - | 462 376 | 1776 | 5 |
| Methane | -81.8 -95.5 | 54.9 50.0 | - | - | 376 357 | 1557 1625 | 1 |
| Neon : | <-205.0 | 29. | - | - | 3 | - | 5,13 |
| Nitric oxide (NO) . | -93.5 | 71.2 | - | - | 257 | 1160 | 1 |
| Nitrogen <br> " monoxide | -146.0 | 35.0 | - | 0.44 | 259 | 1650 | I |
| $\left(\mathrm{N}_{2} \mathrm{O}\right)$ |  | 75.0 | 0.0048 | 0.41 | 720 | 1888 | 4,17 |
| Oxygen - | -118.0 | 50.0 | 0.0058 | 0.6044 | 273 | 1420 |  |
| Sulphur dioxide | ${ }^{1} 55.4$ | 78.9 | 0.00587 | 0.49 | 1316 | 2486 |  |
| Water . . | 358.1 374. | 217.5 | 0.001874 | 0.429 - | 1089 | ${ }_{1} \overline{3}^{-}$ | $\begin{array}{r} 6 \\ 16 \end{array}$ |

(1) Olszewski, C. R. 98, 1884; 99, 1884; 100, 1885; Beibl. 14, 1890; Z. Phys. Ch. 16, 1893.
(2) Ramsay-Young, Tr. Roy. Soc. $177,1886$.
(3) Young, Phil. Mag. 1900.
(4) Dewar, Phil. Mag. 18, 1884 ; Ch. News, 84, 1901.
(5) Ramsay, Travers, Phil. Trans. 16, 17, 1901.
(6) Nadejdine, Beibl.9, 1885.
(7) Wroblewski, Wied. Ann. 20, 1883 ; Stz. Wien. Ak. 9I, 1885.
(9) Sajotschewsky, Beibl. 3, 1879.
(10) Knietsch, Lieb. Ann. 259, 1890.
(iI) Batelli, Mem. Torino (2), 41, 1890.
(12) Cardozo, Arch. sc. phys. 30, 1910.
(13) Kamerlingh-Onnes, Comno. Phys. tab. Leiden, 1908, 1909, Proc. Amst. II, 1908, C. R. 147, 1908.
(14) Olszewski, Ann. Phys. 17, 1905.
(15) Ansdell, Chem. News, 41, 1880.
(16) Holborn, Baumann Ann. Phys. 31, 1910
(17) Cailletet, C. R. 102, 1886; 104, 1887.
(8) Batelli, 1890.

[^35]
## Smithsonian Tables.

CONDUCTIVITY FOR HEAT, METALS AND ALLOYS.
The coefficient $k$ is the quantity of heat in small calories which is transmitted per second through a plate one centimeter thick per square centimeter of its surface when the difference of temperature between the two faces of the plate is one degree Centigrade. The coefficient $k$ is found to vary with the absolute temperature of the plate, and is expressed approximately by the equation $k_{t}=k_{0}\left[\mathrm{I}+a\left(t-t_{0}\right)\right] . \quad k_{0}$ is the conductivity at $t_{0}$, the lower temperature of the bracketed pairs in the table, $k_{t}$ that at temperature $t$, and $a$ is a constant. $k_{t}$ in $g$-cal. per degree C per sec. across cm cube $=0.239 \times k_{t}$ in watts per degree C per sec. across cm cube.

| Substance | $t^{\circ} \mathrm{C}$ | $k_{t}$ | $a$ |  | Substance. | $t^{\circ} \mathrm{C}$ | $k_{t}$ | $a$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{rr\|} \text { Aluminum. }_{6} & -. . \\ - \end{array}$ | $\begin{array}{r} -160 \\ 18 \\ 100 \end{array}$ | -. 514 <br> 0.480 <br> 0.492 | $+.$ | I | Mercury . . . |  | $\left.\begin{array}{l}0.0148 \\ 0.0189\end{array}\right\}$ | $+.0055$ |  |
|  |  |  |  | 2 |  |  |  |  | 6 |
|  |  |  |  |  | Molybdenum Nickel. . . . . |  |  | - | 1 |
|  | 400 |  | $+.0020$ | 3 | Nickel. . . . . ¢ | -160 18 | O. 1420 | - | 2 |
|  |  | 0.885 | $+.0014$ | 3 |  | (r 18 | -.1380 | $-.00032$ | 3 |
|  | 600 | $\left.\begin{array}{l} 1.01 \\ .0442 \\ 0.0396 \end{array}\right\}$ |  |  |  |  |  |  |  |
| Antim |  |  | $-.00104$ | 4 |  | 200 | -.1325 | $-.00095$ |  |
| Bism | 100 | $\left\{\begin{array}{l} 0.025 \\ 0.0194 \\ 0.0167 \end{array}\right\}$ |  |  | " |  | 0.064 |  | 3 |
|  |  |  |  | 5 |  | 1000 |  | -. 00047 |  |
|  |  |  | -.0021 |  | Palladium.. ${ }_{\text {". }}$ | $\begin{array}{\|r\|} \hline 1200 \\ 18 \end{array}$ | $\left.\begin{array}{l} 0.058 \\ 0.1683 \end{array}\right\}$ | +.0010 |  |
| Brass | -16 | $\begin{aligned} & 0.181 \\ & 0.260 \end{aligned}$ |  | I |  | $\begin{array}{r}100 \\ 18 \\ \hline 18\end{array}$ | 0.182 |  |  |
|  |  |  |  |  | Platinum. |  | o. 1664 |  |  |
| , |  | O. 204 | $+.0024$ | 4 |  |  | -.173.3 |  | 2 |
|  |  | -. 246 | +.0015 | 4 | $\mathrm{Pt} 10 \% \mathrm{Ir} .$. |  | 0.074 | +.0002 | 6 |
| Cadmium,pure <br> 66 | $\left\lvert\, \begin{array}{r} -160 \\ 18 \\ 100 \end{array}\right.$ | $0.239$$0.222\}$ |  | I |  |  | $\begin{aligned} & 0.072 \\ & 0.060 \end{aligned}$ | $+.0002$ |  |
|  |  |  |  |  |  |  |  |  | 1 |
|  |  | $\left.\begin{array}{l} 0.215 \\ 0.0540 \\ 0.0640 \end{array}\right\}$ | $\left\|\begin{array}{l} -.00038 \\ +.00227 \end{array}\right\|$ | 2 | Platinoid.. Potassium.$\qquad$ | $\begin{array}{r\|r} 18 & 0 \\ 5.0 & 0 \end{array}$ | $\left.\begin{array}{r} 232 \\ .216 \end{array}\right\}$ | -.0013 |  |
| Constantan | 18 |  |  |  |  | 57.40 | 0.216 |  |  |
| (60 Cu+40 Ni) |  |  | $\sim$ | 2 |  | $\begin{array}{r} 17 \\ -160 \\ -10 \end{array}$ | 0.210 | -.0010 | 6 |
| Copper,* pure. | -160 18 | $\left\{\begin{array}{l} 1.079 \\ 0.918 \\ 0.908 \end{array}\right\}$ |  | 1 |  |  | $\left.\begin{array}{l}\text { 0. } 998 \\ \text { r. } 006 \\ 0.992\end{array}\right\}$ | $-$ |  |
| " |  |  | $\left\lvert\, \begin{aligned} & -.00013 \\ & +.0027 \end{aligned}\right.$ | 2 |  | $\begin{array}{r\|r} 18 & 1 \\ 100 & 1 \end{array}$ |  |  | I |
| German sil |  | $0.070$ |  | 6 | Sodium. . . . . | $\begin{array}{r\|r} 5.7 & 0 \\ 88.10 \end{array}$ | $\left.\begin{array}{\|}0.321 \\ 0.288\end{array}\right\}$ |  | 2 |
| Gold. |  |  | $\left\lvert\, \begin{aligned} & -.00007 \\ & +.0003 \end{aligned}\right.$ |  |  |  |  | -.0012 |  |
| Graphi |  | $\begin{aligned} & 0.705 \\ & 0.037 \end{aligned}$ |  | 6 | Tantalum... | 17 | -. 130 | -.0001 |  |
| Iridium | $\begin{array}{r\|r} 17 & 0 . \\ 18 & 0 . \\ 100 & 0 . \end{array}$ | $\left\{\begin{array}{l} 0.141 \\ 0.161 \\ 0.15 I \end{array}\right\}$ | $\begin{aligned} & +.0003 \\ & -.0005 \end{aligned}$ | 8 |  | $\begin{aligned} & 1700 \\ & 1900 \\ & 2100 \end{aligned}$ | $\left.\begin{array}{l}\text { o. } 174 \\ \text { o. } 186 \\ \text {-. } 198\end{array}\right\}$ | $+.00032$ |  |
| Iron, $\dagger$ pur |  |  | $\left\lvert\, \begin{aligned} & -.0005 \\ & -.0008 \end{aligned}\right.$ |  | " |  |  |  |  |
| Iron, wrought |  |  |  | 2 |  |  |  |  | 9 |
| Iron, wrought | $\left.\begin{array}{r\|r\|r}-160 & 0.152 \\ 18 & 0.144 \\ 100 & 0.143 \\ 18 & 0.108 \\ 100 & 0.107\end{array}\right\}$ |  |  |  | Tin. pure. | $\begin{array}{r} 0 \\ 100 \\ -160 \end{array}$ | $\left.\begin{array}{l}\text { o. I55 } \\ \text { o. } 145 \\ \text { o. 192 }\end{array}\right\}$ | -. 00069 |  |
| " ." . |  |  |  |  |  |  |  |  |  |
| " ${ }^{\text {" }}$ steel, $\mathrm{I} \%$ |  |  |  |  |  |  |  |  |  |
|  |  |  | -.0001 | 2 | Tungsten.... | 17 | 0.476 | -.0001 |  |
| Lead | $\left\{\begin{array}{r} -160 \\ 10 \\ 108 \\ 0 \text { to } \\ 100 \\ -160 \\ 18 \\ 100 \end{array}\right.$ | $\left\{\begin{array}{l\|l} 0.092 \\ 8 & 0.083 \\ 0.081 \end{array}\right\}$ |  | $\begin{gathered} - \\ -.0001 \\ - \\ -.0026 \end{gathered}$ |  | Tungsten. | $\begin{aligned} & 1600 \\ & 2000 \end{aligned}$ |  |  | $+.00023$ |
|  |  |  |  |  |  |  |  |  | 10 |  |
|  |  |  | $\left.\begin{array}{l}0.272 \\ 0.294 \\ 0.313\end{array}\right\}$ |  |  |  |  |  |  |  |
| Magnesium... |  |  |  |  |  | " ... | 24002800 | +.00016 | 0 |  |
|  |  |  |  |  |  |  |  | +.00016 | $\begin{aligned} & 7 \\ & 1 \\ & \hline \end{aligned}$ |  |
| Manga |  |  | 1 |  | Wood's allo | 6 | -. 319 |  |  |  |
|  |  |  | 2 |  | Zinc, pure. | -160 | 0. 278 |  |  |  |
|  |  |  |  |  | " ، . | 18 100 | $\left.\begin{array}{l}0.2653 \\ 0.2619\end{array}\right\}$ | -. 00016 | 2 |  |

References: (1) Lees, Phil. Trans. 1908; (2) Jaeger and Diesselhorst, Wiss. Abh. Phys. Tech. Reich. 3, 1900; (3) Angell, Phys. Rev. 19II; (4) Lorenz; (5) Macchia, 1907; (6) Barratt, Pr. Phys. Soc. 1914; (7) H. F. Weber, 1879; (8) Hornbeck, Phys. Rev. 1913; (9) Worthing, Phys. Rev. 1914; (io) Worthing, Phys. Rev. 1917.

[^36]TABLE 230. - Thermal Conductivity at High Temperatures.
(See also Table 229 for metals; $k$ in gram-calories per degree centigrade per second across a centimeter cube.)

| Material. | Temperature, ${ }^{\circ} \mathrm{C}$ | $k$ | 皆 | Material. | Tempera$\stackrel{\text { ture, }}{\circ} \mathrm{C}$ | $k$ | ¢ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Amorphous carbon... | 37-163 | .028-.003 | I | Brick: Carborundum | 150-1200 | . $0032-.027$ | 3 |
|  | 170-330 | .027-.004 | I | Building | 15-1100 | . 0018 -.0038 | 3 |
|  | ${ }^{240-523}$ | .020-.003 | I | Terra-cotta | 125-1220 | . $0032-.0054$ | 3 |
|  | 283-597 $100-360$ | $.011-.004$ .089 | 1 | Fire-clay.... | $125-1220$ $100-1125$ | . $003{ }^{2-.0054}$ | 3 3 3 |
|  | 100-751 | . 124 | 2 | Graphite... | 300-700 | . 024 | 3 |
|  | 100-842 | - 129 | 2 | Magnesia.... | 50-1130 | . $0027-.0072$ | 3 |
| Graphite (artificial)... | 100-390 | . 338 | 2 |  | 100-1000 | . 002 -. 0033 | 3 |
|  | 100-546 | .324 .306 | 2 | Granite. . | 100 | . $0045-0050$ | 4 |
|  | 100-720 | - 306 | $\stackrel{2}{2}$ |  | 200 | . $0043-.0097$ | 4 |
|  | $100-914$ $30-2830$ | .291 .162 | 2 | Limestone. | 50 40 | . 004046 -. 0057 | 4 4 |
|  | 2800-3200 | . 002 | I |  | 100 | .0039-.0049 | 4 |
|  | ${ }^{90-110}$ | . $55-.45$ | $\underline{1}$ |  | ${ }^{350}$ | . $00322-.0035$ | 4 |
|  | 180-120 | . $44^{-.} 34$ | ${ }^{1}$ | Porcelain (Sèvres)... | 165-1055 | .0039-.0047 | 3 |
|  | 500-700 | .3I-. 22 | 1 | Stoneware mixtures. | 70-1000 | . $0029^{-.} .0053$ | 3 |

References: (i) Hansen, Tr. Am. Electrochem. Soc. 16, 329, 1909; (2) Hering, Tr. Am. Inst. Elect. Eng. 1910; (3) Bul. Soc. Encouragement, 111, 879, 1909; Electroch. and Met. Ind. 7, 383, 433, 1909; (4) Poole, Phil. Mag. 24, 45, 1912; see also Clement, Egy, Eng. Exp. Univers. Ill. Bull. 36, 1909; Dewey, Progressive Age, 27, 772, 1909; Woolson, Eng. News, 58, 166, 1907, heat transmission by concretes; Richards, Met. and Chem. Eng. 11, 575, 1913. The ranges in values under 1 do not depend on variability in material but on possible errors in method; reduced from values expressed in other units.

TABLE 231. - Thermal Conductivity of Various Substances.

| Substance, temperature. | $k_{t}$ | Reference. | Substance, temperature. | $k_{t}$ | Refer ence. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Aniline BP $183{ }^{\circ} \mathrm{C} .,-160$. | .000112 | 1 | Naphthalene MP $79{ }^{\circ} \mathrm{C} .,-160 . .$. | . 0013 | 1 |
| Carbon, gas.............. | . 010 | - | Naphthalene M P $79^{\circ} \mathrm{C}$., o........ | . 00081 | 1 |
| Carbon, graphite | . 012 | - | Naphthol- $\beta$, MP $122^{\circ} \mathrm{C} .,-160$. | . 00068 | 1 |
| Carborundum. | . 00050 | 2 | Naphthol, $\circ$................... | . 00062 | 1 |
| Concrete, cinder | . 00081 | - | Nitrophenol, MP $114{ }^{\circ} \mathrm{C}$., -160.. | . 00106 | 1 |
| stone. | . 0022 | 3 | Nitrophenol, 0.0 .1 .......... | . 00065 | 1 |
| Diatomaceous ea | . 00013 | 4 | Paraffin MP $54{ }^{\circ} \mathrm{C}$., - 16 | . 00062 | 1 |
| Earth's crust | . 004 | $-$ | Paraffin, o.... | . 00059 | 1 |
| Fire-brick. | . 00028 | 4 | Porcelain.. | . 0025 |  |
| Fluorite, - 190 | . 093 | 5 | Quartz $\perp$ to axis, -190 | . 0586 | 5 |
| Fluorite, o. | . 025 | 5 |  | . 0173 | 5 |
| Glass: window | . 0025 |  |  | . 0133 | 5 |
| crown, O35\%2, | . 0118 | 5 | Quartz \|| to axis, | . 0325 | 5 |
| crown, 03572, o . | . 00280 | 5 | Rock salt, o.. | . 0167 | 5 |
| crown, 03572,10 | . 00324 | 5 | Rock salt, $30 . . . .$. | . 0150 | 5 |
| h'vy fint 0165 , | . 00081 | 5 | Rubber, vulcanized, | . 00033 | 5 |
| h'vy fint $0165,0$. | . 00170 | 5 | Rubber, O . | .00037 | 5 |
| Glycerine, -160........ | . 00077 | ${ }_{5}$ | Sand, white, dry | .00045 | 6 |
| Granite.. | . 0053 | 6 | Sandstone, dry | . 0055 | 6 |
| Ice, -160 | . 0066 | 1 | Sawdust... | .00012 | - |
| Ice, 0. | . 050 | 1 | Slate $\perp$ to cleavage | . 0034 | 6 |
| Iceland spar, -19 | . 038 | 5 | Slate \|| to cleavage. | . 0060 | 6 |
| Iceland spar, o | . 0103 | 5 | Snow, fresh, dens. $=0.1 \mathrm{rr}$ | . 00026 | 7 |
| Lime. | . 00029 | 4 | Snow, old. | . 0012 | 7 |
| Limestones, calcite | . 0047 to | 6 | Soil, average, sl't | . 0037 |  |
| Marbles, dolomite | . .056 | $\stackrel{6}{-}$ | Soil, very dry... | . 0037 | 5 |
| Mica.............. | . 0018 | $\stackrel{7}{6}$ | Sulphur, rhombic | .00070 .00022 | 5 8 |
| Micaceous \\| to cleavage | . 0044 | 6 | Vulcanite. | . 00087 | 9 |

References: (1) Lees, Tr. R. S. 1905; (2) Lorenz; (3) Norton; (4) Hutton, Blard; (5) Eucken, Ann. d. Phys., 191I; (6) Herschel, Lebour, Dunn, B. A. Committee, 1879; (7) Jansson, 1904; (8) Melmer, I9II; (9) Stefan.

THERMAL CONDUCTIVITIES OF INSULATING MATERIALS.
Conductivity in g -cal. flowing in I sec . through plate Icm thick per $\mathrm{cm}^{2}$ for $\mathrm{I}^{\circ} \mathrm{C}$ difference of temperature.

| Material. | Conduc tivity. | Density. <br> $\mathrm{g} / \mathrm{cm}^{3}$ | Remarks. |
| :---: | :---: | :---: | :---: |
| Air. | 0.00006 | - | Horizontal layer, heated from above. |
| Calorox | 0.000076 | 0.064 | Fluffy, finely divided mineral matter. |
| Hair felt | 0.000085 | 0.27 |  |
| Keystone hair | 0.000093 | 0. 30 | Felt between layers of bldg. paper. |
| Pure wrool. | 0.000084 | -. 107 | Firmly packed. |
| " " | 0.000084 | 0.102 |  |
| " " | 0.000090 | 0.061 | Loosely packed. |
|  | 0.000101 | 0.039 | Very loosely packed. |
| Cotton wool | 0.00010 |  | Firmly packed. |
| Insulite Linofelt | 0.000102 | I. 9 | Pressed wood-pulp - rigid, fairly strong. |
| Linofelt......... | 0.000103 | 0.18 | Vegetable fibers between layers of paper soft and flexible. |
| Corkboard (pure) | 0.000106 | 0.18 |  |
| Eel grass. | 0.00011 | 0.25 | Inclosed in burlap. |
| Flaxlinum. | 0.000113 | -. 18 | Vegetable fibers - firm and flexible. |
| Fibrofelt. | 0.000113 | -. 18 |  |
| Rock cork. | 0.000119 | 0.33 | Rock wool pressed with binder, rigid. |
| Balsa wood | 0.00012 | 0. 12 | Very light and soft. |
| Waterproof lith | 0.00014 | 0.27 | Rock wool, vegetable fiber and binder, not flexible. |
| Pulp board. | 0.00015 | - | Stiff pasteboard. |
| Air cell $\frac{1}{2}$ in. thick | 0.000154 | 0.14 | Corr. asbestos paper with air space. |
| Air cell I in. thick | 0.000165 | 0.14 |  |
| Asbestos paper. | 0.00017 | -. 50 | Fairly firm, but easily broken. |
| Infusorial earth, block.. | 0.00020 | 0.69 |  |
| Fire-felt, sheet......... | 0.000205 | 0.42 | Asbestos sheet coated with cement, rigid. |
| Fire-felt, roll | 0.00022 | 0.68 | Soft, flexible asbestos. |
| Three-ply regal roofing. | 0.00024 | 0.88 | Flexible tar roofing. |
| Asbestos mill board.... | 0.00029 | 0.97 | Pressed asbestos, firm, easily broken. |
| Woods, kiln dried: Cypress...... |  |  |  |
| Cypress... | 0.00023 | 0.46 |  |
| White pine | 0.00027 | 0.50 |  |
| Mahogany. | 0.00031 | 0. 55 |  |
| Oak..... | 0.00035 | 0.61 |  |
| Hard maple | 0.00038 | 0.71 |  |
| Asbestos wood, sanded.. | 0.00093 | 1.97 | Asbestos and cement, very hard, rigid. |

Dickinson and van Dusen, Am. Soc. Refrigerating Eng. J. 3, Sept. 1916.

## Smithsonian tables.

## TABLE 233. - Various Substances.

$\mathrm{k}_{\mathrm{t}}$ is the heat in gram-calories flowing in I sec. through a plate I cm . thick per $\mathrm{sq} . \mathrm{cm}$. for $\mathrm{I}^{\circ} \mathrm{C}$ drop in temperature.

| Substance. | Density. | ${ }^{\circ} \mathrm{C}$. | $\mathrm{k}_{\text {t }}$ | Substance. | $\mathrm{k}_{6}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Asbestos fiber | 0.201 | 500 | .00019 | Asbestos paper | 0.00043 | ) Lees-Chorl- |
| 85\% magnesia asbestos. | . 216 | $\left\{\begin{array}{l}100 \\ 500\end{array}\right.$ | .00016 | Blotting paper Portland cement |  | $\}$ ton. |
| Cotton . . . . . . . | . 021 | 500 100 | .00017 | Cork, $\mathrm{t}, \mathrm{o}^{\circ} \mathrm{C}$ | .0007? | Forbes. |
| " | . 101 | " | .000071 | Chalk. ${ }^{\text {F }}{ }^{\circ}$ | . 0020 | $\} \begin{aligned} & \text { H, L, D, } \\ & \text { see p. } 205 .\end{aligned}$ |
| Eiderdown | $.0021$ | 150 | .00015 | $\underset{\text { Glass, mean }}{\text { Ebonite, }{ }^{\text {a }} \text { ( } 9^{\circ} \text {. . . }}$ | .ooo37 |  |
|  |  | f 100 | .000074 | Ice. . | . 0057 | Neumann. |
| Lampblack, Cabot number 5 | .193 | $\{500$ | . 000107 | Leather, cow-hide | .00042 |  |
| Quartz, mesh 200 | 1.05 | [ $\begin{array}{r}500 \\ 200\end{array}$ |  | Linen . chamois. . | .00015 | $\} \begin{aligned} & \text { Lees-Chorl- } \\ & \text { ton. }\end{aligned}$ |
| Poplox, popped $\mathrm{Na}_{2} \mathrm{SiO}_{3}$ | 0.093 | $\left\{\begin{array}{l}200 \\ 500\end{array}\right.$ | .000091 | Silk . . . . . . | .000095 |  |
| Wool fibers . | . 015 | 100 3 | .000118 .000085 | Caen stone, limestone Free stone, sandstone | . 0043 | \} H, L, D. |
| " " | .192 |  | . 000054 |  |  |  |

Left-hand half of table from Randolph, Tr. Am. Electroch. Soc. XXI ., p. 550, 1912; $\mathrm{k}_{\mathrm{t}}$ (Randolph's values) is mean conductivity between given temperature and about $10^{\circ} \mathrm{C}$. Note effect of compression (density). The following are from Barratt Proc. Phys. Soc., London, 27, 81, 1914.

| Substance. | Density. | $\mathrm{k}_{\mathrm{t}}$ |  | Substance. | Density. | $\mathrm{k}_{\mathrm{t}}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | at $20^{\circ} \mathrm{C}$. | at $100^{\circ} \mathrm{C}$. |  |  | at $20^{\circ} \mathrm{C}$. | at $100^{\circ} \mathrm{C}$. |
|  |  |  | . 00109 | Boxwood . |  | . 00036 | .00041 |
| Carbon, gas | 1.42 | .0085 | . 0095 | Greenheart . | 1.08 | . 00112 | . 00110 |
| Ebonite . | 1.19 | . 00014 | .00013 | Lignumvitæ. | 1.16 | .00060 | .00072 |
| Fiber, red - | 1.29 | .00112 | .00119 | Mahogany . |  |  |  |
| Glass, soda - | 2.59 | . 00172 |  | Oak. . ${ }^{\text {W }}$ | 0.65 | .00058 | . 00061 |
| Silica, fused. | 2.17 | 00237 | . 00255 | Whitewood . | 0.58 | . 00041 | . 00045 |

The following values are from unpublished data furnished by C. E. Skinner of the Westinghouse Co., Pittsburgh, Penn. They give the mean conductivity in gram-calories per sec. per cm . cube per ${ }^{\circ} \mathrm{C}$. when the mean temperature of the cube is that stated in the table. Resistance in thermal ohms (watts $/ \mathrm{inch} 2 / \mathrm{inch} /{ }^{\circ} \mathrm{C}$.) $=\frac{1}{10.6}$ conductivity.

| Substance. | Grans. per $\mathrm{cm}^{3}$. | Conductivity. |  |  |  |  | Safe temp. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $10{ }^{\circ} \mathrm{C}$. | $200^{\circ} \mathrm{C}$. | $300^{\circ} \mathrm{C}$. | $400^{\circ} \mathrm{C}$. | $50{ }^{\circ} \mathrm{C}$. |  |
| Air-cell asbestos . | 0.232 | 0.00034 | 0.00043 | 0.00050 | - | - | 320 |
| Cork, ground . . . . . . | . 168 | .00015 | .00019 | - | - | , | 180 |
| Diatomit - . . . |  |  | .00032 | .00037 | 0.00042 | 0.00046 | 600 |
|  | - 506 | . 00034 | .00032 | .00040 | - | - |  |
| " " h'd pressed blocks | . 328 | .00030 | .00029 | .00033 | .00036 | 二 | 400 |
| $\underset{\text { Magnesium carbonate . . . }}{\text { Vitribestos }}$ | . 450 | .00023 | .00025 | .00025 | - | -00102 | 300 600 |
| Vitribestos . . . . . . | . 362 | .00049 | .00066 | . 00079 | .00090 | .00102 | 600 |

TABLE 234.- Water and Salt Solutions.

| Substance. | ${ }^{\circ} \mathrm{C}$. | $\mathrm{k}_{\mathrm{t}}$ | Authority. | Solution in water. | Density. | ${ }^{\circ} \mathrm{C}$. | $\mathrm{k}_{\mathrm{t}}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Water | $\begin{array}{r} \circ \\ 11 \\ 25 \\ 20 \end{array}$ | 0.00150 .00147 .00136.0143 0143 |  | $\mathrm{CuSO}_{4}$ | 1.160 | 4.4 | 0.00118 | H. F. Weber. |
|  |  |  |  | $\underset{\mathrm{NaCl}}{\mathrm{KCl}}$ |  | 13. <br> 4.4 | .00116 .0015 | Graetz. |
|  |  |  |  | ${ }^{\text {NaCl }}$ | ${ }^{1.178}$ | 4.4 26.3 | . 0.0115 | H. F. Weber. |
|  |  |  |  | $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 1.054 | 20.5 | .00126 | Chree. |
|  |  |  |  |  | 1.180 | 21. | .00130 |  |
|  |  |  |  | $\underset{4}{ } \mathrm{ZnSO}_{4}$ | 1.134 1.136 | 4.5 4.5 | .00118 .0015 | \} H. F. Weber. |
|  |  |  |  |  | 1.136 | 4.5 | . 00115 |  |

TABLE 235．－Thermal Conductivity of Organic Liquids．

| Substance． | ${ }^{\circ} \mathrm{C}$ | $k t$ | 宮 | Substance． | ${ }^{\circ} \mathrm{C}$ | $k_{t}$ | 亗 | Substance． | ${ }^{\circ} \mathrm{C}$ | $k_{t}$ | 荙 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetic acid．．．．． | （ $\begin{gathered}9-15 \\ 11 \\ 11\end{gathered}$ | ． 03472 | 1 | Carbon disulphide． | － | ． 03387 | 3 | Oils：olive．． | － | ． 03395 | 4 |
|  |  | ．0352 | 2 | Chloroform．．．．．． |  | ． 03288 | 1 |  |  | ． 03425 | 4 |
| ＂، ethyl． |  | ．0346 | 2 | Ether．．．．．．．．．．． | 9－15 | ． 03303 | I | Toluene．．． | O | ． 03349 | 32 |
| Aniline | － | ． 03345 | 3 |  | 25 13 | ．0368 | 5 | Xylene．．． | 25 | ． 03343 |  |
| Benzene | 9－15 | ． 03333 | 1 | ＂turpentine．． | 13 | ．03325 | 5 |  |  |  |  |

References：（1）H．F．Weber；（2）Lees；（3）Goldschmidt；（4）Wachsmuth；（5）Graetz．

TABLE 236．－Thermal Conductivity of Gases．

The conductivity of gases，$k_{t}=\frac{1}{2}(9 \gamma-5) \mu C_{v}$ ，where $\gamma$ is the ratio of the specific heats，$C_{p} / C_{v}$ ，and $\mu$ is the viscosity coefficient（Jeans，Dynamical Theory of Gases，19r6）．Theoretically $k_{t}$ should be independent of the density and has been found to be so by Kundt and Warburg and others within a wide range of pressure below one atm．It increases with the temperature．

| Gas． | $t^{\circ} \mathrm{C}$ | $k_{t}$ | Ref． | Gas． | $t^{\circ} \mathrm{C}$ | $k t$ | Ref． | Gas． | $t^{\circ} \mathrm{C}$ | $k_{t}$ | Ref． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Air＊．．． | －191 | 0.0000180 | 1 | $\mathrm{CO}_{2}$ | 100 | 0.0000496 | 1 | Hg | 203 | －． 0000185 | 3 |
|  |  | 0.0000566 | 1 | $\mathrm{C}_{2} \mathrm{H}_{4}$ | $\bigcirc$ | 0.0000395 | 2 | $\mathrm{N}_{4}$ | －191 | 0.0000183 | 1 |
|  | 100 | 0.0000719 | $\underline{1}$ | ${ }_{6}$ | －193 | 0.000146 | 1 | ＂ | $\bigcirc$ | 0.0000568 | I |
| ${ }_{6}{ }_{6}$ | －183 | 0.0000142 | 1 | ＂ | $\bigcirc$ | 0.000344 | 4 | $\mathrm{O}_{2}$ | 100 | 0.0000718 | I |
| ＂ | 100 | 0．0000388 | I | $\mathrm{H}_{2}$ | 100 -102 | 0．000398 | I |  | －191 | 0.0000172 | $\underline{1}$ |
| CO | 100 | 0.000509 | 1 | \％ | －192 | 0．000416 | 4 | ＂ | 100 | 0．0000570 | 1 |
| $\mathrm{CO}_{2}$ | －78 | 0.0000219 | I | ＂ | 100 | 0.000499 | 1 | NO | 8 | 0.000046 | 2 |
|  | － | 0.0000332 | I | $\mathrm{CH}_{4}$ | － | 0.0000720 | 4 | $\mathrm{N}_{2} \mathrm{O}$ | － | 0.0000353 | 4 |

References：（1）Eucken，Phys．Z．12，1911；（2）Winkelmann，1875；（3）Schwarze，1903；（4）Weber， 1917.
${ }^{*}$ Air： $\mathrm{k}_{0}=5.22\left(\mathrm{ro}^{-5}\right)$ cal． $\mathrm{cm}^{-1} \mathrm{sec}^{-1}$ deg． $\mathrm{C}^{-1} ; 5.74$ at $22^{0}$ ；temp．coef．$=.0029$ ；Hercus－Laby，Pr．R．Soc．A95， 190，1919．

## TABLE 237．－Diffusivities．

The diffusivity of a substance $=h^{2}=k / c \rho$ ，where $k$ is the conductivity for heat，$c$ the specific heat and $\rho$ the density （Kelvin）．The values are mostly for room temperatures，about $18^{\circ} \mathrm{C}$ ．

| Material． | Diffusivity． | Material． | Diffusivity． |
| :---: | :---: | :---: | :---: |
| Aluminum | 0.826 | Coal． | 0.002 |
| Antimony | －． 139 | Concrete（cinder） | 0.0032 |
| Bismuth． | 0．0678 | Concrete（stone） | 0．0058 |
| Brass（yellow） Cadmium．．． | 0.339 0.467 | Concrete（light slag） | 0.006 0.0017 |
| Copper． | I． 133 | Ebonite．．．．．． | 0.0010 |
| Gold． | 1．182 | Glass（ordinary） | 0.0057 |
| Iron（wrought，also mild | －． 173 | Granite． | 0.0155 |
| Iron（cast，also $1 \%$ carbo | －．12I | Ice． | 0.0112 |
| Lead． | 0.237 | Limestone． | 0.0092 |
| Magnesium | 0.883 | Marble（white） | 0.0090 |
| Mercury | 0．0327 | Paraffin． | 0.00098 |
| Nickel． | 0．152 | Rock material（earth aver | 0.0118 |
| Palladium | －． 240 | Rock material（crustal roc | －． 0064 |
| Platinum | 0． 243 | Sandstone． | －． 0133 |
| Silver． | 1.737 | Snow（fresh）． | 0.0033 |
| Tin． | －0．407 | Soil（clay or sand，slightly | 0.005 |
| Zinc | 0． 402 | Soil（very dry） | 0．0031 |
| Air．． | 0．179 | Water． | 0．0014 |
| Asbestos（loose）．．．］ Brick（average fire） | 0.0035 0.0074 | Wood（pine，cross grain）． | 0.00068 0.0023 |
| Brick（average building） | 0.0050 |  |  |

Taken from An Introduction to the Mathematical Theory of Heat Conduction，Ingersoll and Zobel， 1913.

## LINEAR EXPANSION OF THE ELEMENTS.

In the heading of the columns $t$ is the temperature or range of temperature; $C$ is the coefficient of linear expansion; $A_{1}$ is the authority for $C ; M$ is the mean coefficient of expansion between $\circ^{\circ}$ and $100^{\circ} \mathrm{C}$; $\boldsymbol{a}$ and $\beta$ are the coefficients in the equation $l_{t}=l_{0}\left(\mathrm{I}+a_{t}+\beta_{t^{2}}\right)$, where $l_{0}$ is the length at $\circ^{\circ} \mathrm{C}$ and $l_{t}$ the length at $t^{\circ} \mathrm{C} ; A_{2}$ is the authority for $a, \beta$, and $M$. See footnote for Molybdenum and Tungsten.


References: (1) Fizeau; (2) Calvert, Johnson and Lowe; (3) Chatelier; (4) Henning; (5) Dittenberger; (6) Matthiessen; (7) Andrews; (8) Holborn-Day; (9) Benoit; (io) Pisati and De Franchis; (11) Hagen; (I2) Spring; (13) Day and Sosman; (14) Griffiths; (I5) Dorsey; (16) Grüneisen.

Tungsten: $\left(L-L_{0}\right) / L_{0}=4.44 \times 10^{-6}(T-300)+45 \times{ }^{10} 0^{-11}(T-300)^{2}+2.20 \times 10^{-13}(T-300)^{3} . L_{0}=$ length at $300^{\circ} \mathrm{K}$. Coefficient at $300^{\circ} \mathrm{K}=4.44 \times 10^{-6} ; 1300^{\circ} \mathrm{K}, 5.19 \times 10^{-6} ; 2300^{\circ} \mathrm{K}, 7.26 \times 10^{-6}$. Worthing, Phys. Rev. 1917.

Molybdenum: $L_{t}=L_{0}\left(\mathrm{I}+5.15 t \times 10^{-6}+0.00570 t^{2} \times 10^{-6}\right)$, for $19^{\circ}$ to $-\mathrm{r}_{42^{\circ}} \mathrm{C} ; \quad=L_{0}\left(\mathrm{r}+5.01 t \times 10^{-6}+\right.$ $0.001386^{2} \times 10^{-6}$ ), for $19^{\circ}$ to $+305^{\circ} \mathrm{C}$; Schad and Hidnert, Phys. Rev. $190^{\circ} 9$.
The Holborn-Day and Sosman data are for temperatures from $20^{\circ}$ to $1000^{\circ} \mathrm{C}$. The Dittenberger, $0^{\circ}$ to $600^{\circ} \mathrm{C}$.

## Smithsonian Tables

## LINEAR EXPANSION OF MISCELLANEOUS SUBSTANCES.

The coefficient of cubical expansion may be taken as three times the linear coefficient. $t$ is the temperature or range of temperature, $C$ the coefficient of expansion, and A. the authority

| Substance. | $t$ | $C \times 1{ }^{4}$ | A. | Substance. | $t$ | $C \times 104$ | A. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Brass: |  |  |  |  |  |  |  |
| Cast. | 0-100 | -. 1875 | 1 | Platinum -silver: |  |  |  |
| Wire. |  | -. 1930 | 1 | ${ }^{1} \mathrm{Pt}+{ }_{2} \mathrm{Ag}$. | 0-100 | 0.1523 |  |
| . $\mathrm{Cu}+27.7 \mathrm{Zn}+$ |  | .1783-. 193 | 2 | Porcelain ....... | 20-790 | 0.0413 | 19 20 |
| $\begin{aligned} & 71.5 \mathrm{Cu}+27.7 \mathrm{Zn}+ \\ & 0.3 \mathrm{Sn}+0.5 \mathrm{~Pb} . . \end{aligned}$ | 40 | 0. 1859 | 3 | Quartz: Bayeux.. | 1000-1400 | 0.0553 |  |
| ${ }^{71} \mathrm{Cu}+29 \mathrm{Zn} . \ldots$. | $0-100$ | 0. 1906 | 4 | Parallel to axis... | --80 | 0.0797 | 6 |
| Bronze: |  |  |  |  | -190 to + 16 | 0.0521 | 21 |
| ${ }_{3} \mathrm{Cu}+\mathrm{ISn}$. | 16.6-100 | 0. 1844 | 5 | Perpend. to axis... | --80 | -.1337 | 6 |
|  |  |  |  | Quartz glass . . . . ${ }_{\text {a }}$ | -190 to +16 16 to 500 | -0.0026 | 13 26 26 |
| " " " | 16.6-350 | 0.2116 | 5 | " " $\quad . . . . .$. . | 16-1000 | 0.0057 0.0058 | 26 26 |
|  |  |  |  | Rock salt. . . . . . . . . | 40 | 0.4040 | 3 |
|  |  |  |  | Rubber, hard...... | $\bigcirc^{\circ}$ | 0.691 | 27 |
| $86.3 \mathrm{Cu}+9.7 \mathrm{Sn}+$ | 16.6-957 | 0. 1737 | 5 | Speculum metal. | -160 | 0.300 0.1933 | 27 |
| $4 \mathrm{Zn} \mathrm{C}_{\mathrm{u}}+\ldots \ldots \ldots$. | 40 | 0.1782 | 3 | Topaz: | -100 | 0.1933 |  |
| $\underset{2.2}{97.6} \mathrm{Cu}+\mathrm{Sn}+$ hard | $0-80$ | 0.1713 | 6 | Parallel to lesser |  |  |  |
| ${ }_{0.2}^{2.2} \mathrm{P}$ |  | 0.1708 | 6 | horizontal axis... | " | 0.083 | 8 |
| Caoutchouc.. | - ${ }^{-}$ | 0.657-0.686 | 2 | horizontal axis... | ، | 0.0836 | 8 |
| Constantan. | 16.7-25.3 | 0.770 | 7 | Parallel to vertical | " |  | 8 |
| Ebonite. . | 25.3-35.4 | - 0.1523 |  | Tourmaline: |  | 0.0472 | 8 |
| Fluor spar: $\mathrm{CaF}_{2}$ | -100 | -. 1950 | 8 | Parallel to longi- |  |  |  |
| German silver....... |  | 0. 1836 | 8 | tudinal axis... | " | 0.0937 | 8 |
| Gold-platinum: | " | 0. 1523 | 4 | Parallel to horizon- | " | 0.0773 | 8 |
| Gold-copper: |  | 0.1523 | 4 | Type metal. | 16.6-254 | 0. 0.1952 | 8 |
| ${ }_{2} \mathrm{Au}+{ }_{\mathrm{r}} \mathrm{Cu}$ | " | 0.1552 | 4 | Vulcanite. | O-18 | 0.6360 | 22 |
| Glass: |  |  |  | Wedgwood ware. . | --100 | 0.0890 | 5 |
| Tube | "، | 0.0833 | 1 | Wood: |  |  |  |
|  | " | 0.0828 | 9 | Parallel to fiber: |  |  |  |
| Plate. | " | 0.0891 | 10 | Ash.... | " | 0.0951 | 23 |
| Crown (mean) | 50-60 | 0.0897 | 10 | Beech.. | 2:34 | 0.0257 | 24 |
|  | 50-60 | 0.0954 | 1 I | Chestnut |  | 0.0649 | 24 |
| Flint |  | 0.0788 | II | Elm. | " | 0.0565 | 24 |
|  | --100 | 0.08 r | 12 | Mahogany | ، | 0.0361 0.0638 | 24 24 24 |
| mometer ${ }_{\text {a }}$ |  |  |  | Oak.... | " | 0.03492 | 24 24 |
| $1^{\prime \prime} 59^{\text {III }} \ldots$ | " | 0.058 | 12 | Pine | " | 0.0541 | 24 |
| " | - rer to + 16 | 0.424 | 13 | Walnut. | " | 0.0658 | 24 |
| Gutta percha. | 20 | 1.983 | 14 | Across the fiber: |  |  |  |
| Ice. . . | - 20 to - 1 | -. 51 | 15 | Beech. | " | 0.614 | 24 |
| Iceland spar: |  |  |  | Chestnut | " | -. 325 | 24 |
| Parallel to axis..... | --80 | $0.263 \mathrm{I}^{\circ}$ | 6 | Elm. | " | 0.443 | 24 |
| Perpendicular to axis |  | 0.0544 | 6 | Mahogany |  | 0.404 | 24 |
| Lead-tin (solder) |  |  |  | Maple. | " | -0.484 | 24 |
| ${ }_{2} \mathrm{~Pb}+1 \mathrm{Sn}$.. | --100 | 0. 2508 | 1 | Oak. | " | - 544 | 24 |
| Magnalium. | 12-39 | 0. 238 | 16 | Pine.. |  | - 3.341 | 24 |
| Manganin. . . . . . . . . | - | -. 18 r | - | Walnut | " | -0.484 | 24 |
| Marble............. | 15-100 | 0.117 | 17 | Wax: White | 10-26 | 2.300 | 25 |
| Paraffin. |  | 1. 0662 I. 3030 |  | "، "، | 26-31 | 3.120 4.860 | 25 25 |
|  | $16-38$ $38-49$ | I. 3030 4.7707 | 18 18 |  | $\begin{aligned} & 31-43 \\ & 43-57 \end{aligned}$ | 4.860 15.227 | 25 25 |
| Platinum-iridium $10 \mathrm{Pt}+\mathrm{IIr} . \ldots \ldots .$ | 40 | 0.0884 | 3 |  |  |  |  |

## References:

(1) Smeaton.
(2) Various.
(3) Fizeau.
(4) Matthiessen
(5) Daniell.
(6) Benoit.
(7) Kohlrausch.
(8) Pfaff.
(9) Deluc.
(ı) Lavoisier and Laplace
(xi) Pulfrich.
(12) Schott.
(13) Henning.
(I4) Russner.
15) Mean
(ı6) Stadthagen.
(17) Fröhlich.
(ı8) Rodwell.
(19) Braun.
(20) Deville and Troost.
(2I) Scheel.
(22) Mayer.
(23) Glatzel.
(24) Villari.
(25) Kopp.
(26) Randall
(27) Dorsey.

## CUBICAL EXPANSION OF SOLIDS.

If $v_{2}$ and $v_{1}$ are the volumes at $t_{2}$ and $t_{1}$ respectively, then $v_{2}=v_{1}(1+C \Delta t), C$ being the coefficient of cubical expansion and $\Delta t$ the temperature interval. Where only a single temperature is stated $C$ represents the true coefficient of cubical expansion at that temperature.*

| Substance | $t$ or $\Delta t$ | $C \times 1{ }^{4}$ | Authority. |
| :---: | :---: | :---: | :---: |
| Antimony . . | 0-100 | 0.3167 | Matthiessen |
| Beryl . . . . . . . | $0-100$ | 0.0105 | Pfaff |
| Bismuth . . . . . | 0-100 | 0.3948 | Matthiessen |
| Copper . . . . . . | 0-100 | $0.499^{8}$ |  |
| Diamond . . . . | 40 | 0.0354 | Fizeau |
| Emerald . . . . . | 40 | 0.0168 |  |
| Galena . . . . . | $0-100$ | 0.558 | Pfaff |
| Glass, common tube . . | 0-100 | 0.276 | Regnault |
| " hard . Jena, borosilicate | $0-100$ | 0.214 |  |
| 59 IlI . . . | 20-100 | 0.156 | Scheel |
| " pure silica . . | 0-80 | 0.0129 | Chappuis |
| Gold . . . . . . | 0-100 | 0.4411 | Matthiessen |
| Ice . . . . . . | -20-1 | 1.1250 | Brunner |
| Iron . . . . . . | 0-100 | 0.3550 | Dulong and Petit |
| Lead . . . . . | 0-100 | 0.8399 | Matthiessen |
| Paraffin . . . . | 20 | 5.88 | Russner |
| Platinum . . . | 0-100 | 0.265 | Dulong and Petit |
| Porcelain, Berlin . . | 20 | 0.0814 | Chappuis and Harker |
| Potassium chloride . | $0-100$ | 1. 094 | Playfair and Joule |
| " nitrate . | 0-100 | 1.967 |  |
| " sulphate . | 20 | 1.0754 | Tutton |
| Quartz . . . . . | 0-100 | 0.3840 | Pfaff |
| Rock salt . . | 50-60 | 1.2120 | Pulfrich |
| Rubber . . . . . | 20 | 4.87 | Russner |
| Silver . . . . . . | 0-100 | 0.5831 | Matthiessen |
| Sodium - . . . | 20 | 2.1364 | E. Hazen |
| Stearic acid. . | $33.8-45 \cdot 5$ | 8.1 | Kopp |
| Sulphur, native . . | $13.2-50.3$ | 2.23 | " ${ }^{\text {a }}$ |
| Tin . . . . . | 0-100 | 0.6889 | Matthiessen |
| Zinc . . | $0-100$ | 0.8928 | , |

* For tables of cubical expansion complete to $\mathbf{1 8 7 6}$, see Clark's Constants of Nature, Smithsonian Collections, 289.

CUBICAL EXPANSION OF LIQUIDS.
If $V_{o}$ is the volume at $0^{\circ}$ then at $t^{\circ}$ the expansion formula is $V_{t}=V_{o}\left(\mathrm{I}+\alpha t+\boldsymbol{\beta} t^{2}+\boldsymbol{\gamma}^{3}\right)$. The table gives values of $\alpha, \beta$ and $\boldsymbol{\gamma}$ and of $C$, the true coefficient of cubical expansion, at $20^{\circ}$ for some liquids and solutions. $\Delta t$ is the temperature range of the observation and $A$ the authority.

| Liquid. | $\Delta t$ | $a 10^{3}$ | $\beta{ }^{10}{ }^{6}$ | $\gamma 10^{8}$ | $\begin{gathered} C 1^{3} \\ \text { at } 20^{\circ} \end{gathered}$ | A |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetic acid | 16-107 | 1.0630 | 0.12636 | 1.0876 | 1.07 I | 3 |
| Acetone | --54 | 1. 3240 | 3.8090 | $-0.87983$ | 1.487 | 3 |
| Alcohol : |  |  |  |  |  |  |
| Amyl | -15-80 | 0.9001 | 0.6573 | $1.1845^{8}$ | 0.902 | $4^{\text {a }}$ |
| Ethyl, 30\% by vol. . . | 18-39 | 0.2928 | 10.790 | -1. 1.87 | - | 6 |
| " $50 \%$ "، . | --39 | 0.7450 | 1.85 | 0.730 | - | 6 |
| " $99.3 \%$ " . | 27-46 | 1.012 | 2.20 | - | 1.12 | 6 |
| " 500 atmo. press. . | 0-40 | 0.866 | - | - |  | 1 |
| " 3000 " " Methyl | 0-40 | 0.524 | 1.3635 | - | - | 1 |
| Methyl . . . . . . | 0-61 | 1.1342 | 1.3635 | 0.8741 | 1. 199 | 5 5 |
| Benzene . | I I-8i | 1.17626 | 1.27776 | 0.80648 | 1.237 | 5 a |
| Calcium chloride : $5.8 \% \text { solution . . }$ | 18-25 | 0.07878 | 4.2742 | - | 0.250 | 7 |
| 40.9\% " . . | $17-24$ | 0.42383 | 0.8571 | - | 0.458 | 7 |
| Carbon disulphide . . | -34-60 | I. 13980 | 1.37065 | 1.91225 | 1. 218 | 4 a |
| 500 atmos. pressure | --50 | 0.940 | - | - | - | 1 |
| 3000 " " | --50 | 0.581 | - | - | - | 1 |
| Carbon tetrachloride | $0-76$ | 1.18384 | 0.89881 | 1.35135 | 1.236 | 4 b |
| Chloroform | --63 | 1.10715 | 4.66473 | -1.74328 | 1.273 | 4 b |
| Ether . . . . | -15-38 | 1.51324 | 2.35918 | 4.00512 | 1. 656 | 4a |
| Glycerine . . . . . | - | 0.4853 | 0.4895 | - | 0. 505 | - 8 |
| Hydrochloric acid: <br> $33.2 \%$ solution |  | 0.4460 |  |  |  |  |
| Mercury . . . . | $0-33$ $0-100$ | 0.4460 0.18182 | 0.215 0.0078 | - | 0.455 0.18186 | 9 13 |
| Olive oil . . | - | 0.6821 | I.1405 | -0.539 | 0.721 | 10 |
| Pentane. | --33 | 1.4646 | 3.09319 | 1.6084 | 1.608 | 14 |
| Potassium chloride : <br> $24.3 \%$ solution | 16-25 | 0.2695 | 2.080 | - | 0.353 | 7 |
| Phenol . . . . . . | 36-1.57 | 0.8340 | 0.10732 | 0.4446 | I. 090 | II |
| Petroleum : Density $0.8467 . .$. | 24-120 | 0.8994 | 1. 396 | - | 0.955 | 12 |
| Sodium chloride : <br> $20.6 \%$ solution | 0-29 | 0.3640 | 1. 237 | - | 0.414 | 9 |
| Sodium sulphate: $24 \%$ solution | 11-40 | 0.3599 | 1.258 | - | 0.410 | 9 |
| Sulphuric acid: $10.9 \%$ solution. | O-30 | 0.2835 | 2.580 | - | 0.387 | 9 |
| 100.0\% . . | $0-30$ | 0.5758 | -0.432 | - | 0.558 | 9 |
| Turpentine . | -9-106 | 0.9003 | 1.9595 | -0.44998 | 0.973 | 5b |
| Water . | --33 | -0.06427 | 8.5053 | -6.7900 | 0.207 | 13 |

## Authorities.

1. Amagat: C. R. 105, p. 1120 ; 1887.
2. Thorpe : Proc. Roy. Soc. 24, p. 283; 1876.
3. Zander: Lieb. Ann. 225, p. 109; 1884
4. Pierre: a. Lieb. Ann. 56, p. 139; 1845.
b. Lieb. Ann. 80, p. 125 ; 1851 .
5. Kopp : a. Lieb. Ann. 94, p. 257 ; 1855.
b. Lieb. Ann. 93, p. $129 ; 1855$.
6. Recknagel : Sitzber. bayr. Ak. p. 327, 2 Abt.; 1866.
7. Irecker: Wied. Ann. 34, p. 952; i888.
8. Emo: Ber. Chem. Ges. 16, 1857 ; 1883 .
9. Marignac: Lieb. Ann., Supp. VIII, p. 335 ; 1872.
10. Spring: Bull. Brux. (3) 3, p. $33^{1}$; 1882.
11. Pinette: Lieb. Ann. 243, p. 32 ; 1888.
12. Frankenheim: Pogg. Ann. 72, p. 422; 1847.
13. Scheel: Wiss. Abh. Reichsanstalt, 4, p. i; 1903.
14. Thorpe and Jones: J. Chem. Soc. 63, p. 273; 1893.

Coefficients of Expansion of Gases.
Pressures are given in centimeters of mercury.

| Coefficient at Constant Volume. |  |  |  | Coefficient at Constant Pressure. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Substance. | Pressure cm. | $\begin{gathered} \text { Coeffi- } \\ \substack{\text { cient } \\ \times \\ \text { too. }} \end{gathered}$ | \% | Substance. | Pressure cin. | $\begin{gathered} \text { Coeffi- } \\ \text { ceint } \\ \times \\ 100 . \end{gathered}$ |  |
| Air | . 6 | -3 |  | Air | 76. |  |  |
|  | 1.3 | . 3717 | " |  | 257. | . 3603 | 3 |
| " | 10.0 | . 3663 | " | " $0^{\circ}-100^{\circ}$ | 100.1 | . 36728 | 2 |
|  | 25.4 | . 36580 | " | Hydrogen $0^{\circ}-100^{\circ}$ | 100.0 | . 36600 | " |
|  | 75.2 | - 36660 | " |  | 200 Atm. | . 332 | $\stackrel{9}{4}$ |
| $0^{\circ}-100^{\circ}$ | 100.1 | . 36744 | 2 |  | 400 " | . 295 | " |
|  | 76.0 | - 3665 | 3 |  | 600 | . 261 | " |
|  | 200.0 2000 | - 3690 |  | Carbon dioxide | ${ }^{800}$ | . 242 | \% |
| " | 10000. |  | " | Carbon dioxide | ${ }_{51}^{76.8}$ | -3710 | 3 |
| Argon | 51.7 | . 3668 | 4 | " $0^{\circ}-40^{\circ}$ | 51.8 | . 371 |  |
| Carbon dioxide | 76.0 | . 3685 | 3 | " $0^{\circ}-100$ | 51.8 | -37073 |  |
| " " . | 1.8 | . 36753 | 1 | " $0^{\circ}-20$ | 99.8 | . 37602 | " |
| " " | 5.6 | . 36641 | " | " " $0^{\circ}-100^{\circ}$ | 99.8 | . 37410 | " |
| " "، ${ }^{\circ}$ | 74.9 | . 37264 | " | " $\bigcirc^{\circ}-20^{\circ}$ | 137.7 | . 37972 | " |
| " " $0^{\circ}-20^{\circ}$ | 51.8 | . 36985 | $\stackrel{2}{1}$ | " " ${ }^{\circ} 0^{\circ}-100^{\circ}$ | 137.7 | . 37703 | " |
| " " " $0^{\circ}-40^{\circ}$ | 51.8 | - 36972 | " | " " ${ }^{\circ}{ }^{\circ}-7.5^{\circ}$ | 2621. | .1097 | 6 |
| "، "، $0^{\circ}-100^{\circ}$ | 51.8 | $.36981$ | " | " " $64^{\circ}-100^{\circ}$ | 2621. | . 6574 |  |
| "، "، $0^{\circ}-20^{\circ}$ | 99.8 | . 37335 | " | Carbon monoxide. | 76. | . 3669 | 3 |
| "، " ${ }^{\circ} 0^{\circ}-100^{\circ}$ | 99.8 | . 37262 | " | Nitrous oxide | 76. | -3719 |  |
| " " | 100.0 | - 37248 | 5 | Sulphur dioxide | 76. | - 3903 |  |
| Carbon monoxide Helium . | 76. 56.7 |  | 3 |  | 98. | -3980 |  |
| Hydrogen $16^{\circ}-132^{\circ}$ | 56.7 .0077 | - 30328 | 6 | $0^{\circ}$ | 76. 76. | .4187 .4189 | ${ }_{10}$ |
| "، $15^{\circ}-132^{\circ}$ | . 025 | . 3623 | " | Water- ${ }^{\text {vapor }}$, $0^{\circ}-162^{\circ}$ | 76. | . 4071 | " |
| ${ }^{12^{\circ}-185^{\circ}}$ | . 47 | - 3656 |  | apor $0^{\circ}-200^{\circ}$ | 76. | . 3938 | " |
| " . | ${ }_{\text {II. }} .93$ |  | I | $10^{\circ}-247^{\circ}$ | 76. | . 3799 |  |
|  | 76.4 |  |  |  |  |  |  |
| " $0^{\circ}-100^{\circ}$ | 100.0 | . 36626 |  | Thomson has given, Encyc. Brit. "Heat," the following for the calculation of the expansion, E, between $0^{\circ}$ and $100^{\circ} \mathrm{C}$. Expansion is to be taken as the change of volume under constant pressure: $\begin{array}{ll} \text { Hydrogen, } & E=.3662(1-.00049 \mathrm{~V} / \tau), \\ \text { Air, } & E=.3662(\mathrm{I}=.0026 \mathrm{~V} / v) \text {, } \\ \text { Oxygen, } & \mathrm{F}=.3662(\mathrm{I}=.0032 \mathrm{~V} / v) \text {, } \\ \text { Nitrogen, } & E=.3662=.03 \mathrm{~V} / \mathrm{V} / v) \text {, } \\ \mathrm{CO}_{2} & E=.3662(1-.0164 \mathrm{~V} / v) . \end{array}$ <br> $V / v$ is the ratio of the actual density of the gas at $0^{\circ} \mathrm{C}$ to what it would have at $0^{\circ} \mathrm{C}$ and ${ }_{1}$ Atm. pressure. |  |  |  |
| Nitrogen $13^{\circ}{ }^{\circ}{ }^{1} 32^{\circ}$ | . 06 | . 3021 | 6 |  |  |  |  |
| "، $9^{\circ}-133^{\circ}$ | . 53 | . 3290 |  |  |  |  |  |
| $0^{\circ}-20$ $0^{\circ}-100$ | 100.2 |  | $\stackrel{2}{6}$ |  |  |  |  |
|  |  |  | 6 |  |  |  |  |
|  |  | . 36082 <br> .4161 |  |  |  |  |  |
|  | $\begin{aligned} & .25 \\ & .51 \end{aligned}$ | . 3984 |  |  |  |  |  |
|  |  | .3831 | " |  |  |  |  |
|  | 1.9 .3668 .3 |  |  |  |  |  |  |
|  | 18.5 | . 36681 |  |  |  |  |  |
|  | $\begin{aligned} & 76 . \\ & 76 . \\ & 76 . \end{aligned}$ |  |  |  |  |  |  |  |
|  |  | $\begin{aligned} & .3676 \\ & .3845 \end{aligned}$ |  |  |  |  |  |
|  |  |  |  |  |  |  |  |
| I Meleander, Wied. Beibl. 14, 1890; Wied. Ann. 47, 1892. <br> 2 Chappuis, Trav. Mem. Bur. Intern. Wts. Meas. $13,1903$. <br> 3 Regnault, Ann. chim. phys. (3) 5, 1842. <br> 4 Keunen-Randall, Proc. R. Soc. 59, 1896. <br> 5 Chappuis, Arch. sc. phys. (3), 18, 1892. <br> 6 Baly-Ramsay, Phil. Mag. (5), 38, 1894 - <br> 7 Andrews, Proc. Roy. Soc. 24, iS76. <br> 8 Meleander, Acta Soc. Fenn. 19, 1891. <br> 9 Amagat. C. R. iri, iSgo. <br> ı Hirn, Théorie méc. chaleur, 1862. |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

SPECIFIC HEAT OF THE CHEMICAL ELEMENTS.

| Element. | Range* of temperature, ${ }^{\circ} \mathrm{C}$ | Specific heat. | Refer ence. | Element. | $\underset{{ }_{\mathrm{C}}}{\text { Range }} \text { tof of }$ | Specific heat. | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum. | -240.6* | . 0092 | 45 | Cobalt. | 500 | . 1452 | 18 |
|  | -190.0 | . 0889 | 45 |  | 1000 | . 204 | 18 |
| " ${ }^{\prime}$........ | -73.0 | . 190 | 46 | "، | -182 to +15 | . 0822 | 19 |
| " $\quad . . .$. .... | -190 to -82 | - 1466 | 47 | Copper $\dagger$. . . . . . . | $15-100$ -249.5 | 1030 .0035 | 19 |
| " | -76 to -1 +16 to | .1962 .2122 | 47 48 | Copper $\dagger$......... | -249.5 -223 | . 0035 | 45 |
| " | +16 to +304 | . 2250 | 48 | " | -185 | . 0532 | 45 |
| " | -250 | . 1428 | 1 | " | -63 | . 0865 | 46 |
| " | $\bigcirc$ | . 2089 | 1 | "، $\quad$.......... | +25 | . 0917 | 44 |
| " | 100 | . 2226 | 1 | ، ${ }^{\text {a }}$, | 76 84 | . 0937 | $5 \mathrm{5I}$ |
| " | 500 | .2382 .2739 | 1 | " | 100 | . 09342 | 51 2 |
| Ant | 16-100 | . 2122 | 43 | " ${ }^{\prime}$ | 362 | . 0997 | 51 |
| Antimony | 15 | . 0489 | 2 | "، | 900 | . 1259 | 20 |
| " | 100 | . 0503 | 2 | " | [15-238 | . 0951 | 43 |
| Arsenic, gray | -200 | . 0520 | 2 3 | " $\quad .$. ...... | -181 to 13 $23-100$ | . 0868 | 21 21 |
| Arsenic, black | -100 | .0861 | 3 | Gallium, liquid. | 12 to 113 | . 080 | 22 |
| Barium... | -185 to +20 | . 068 | 4 | " ${ }^{\text {colid. }}$ | 12-23 | . 079 | 22 |
| Bismuth. | -186 | . 0284 | 5 6 | Germanium....... | \%-100 | . 0737 | 23 |
| " | ${ }_{75}$ | .0301 .0300 | 6 | Gold.............. | $\underset{\substack{185 \\ \text {-10 } \\ 0-100}}{ }$ | .033 | 24 |
| " | 20-100 | . 0302 | 7 | Indium. | --100 | . 0570 | 13 |
| " fluid | 280-380 | . 0363 | 8 | Iodine. | -90 to +17 | . 0485 | 49 |
| Boron. | - 100 | . 307 | 9 |  | -rig to -80 | . 0454 | 49 |
| " $\quad .$. | -19 r to -78 <br> -76 to <br> 0 | . 0707 | 47 | Iridium | -186 to ${ }^{-98}$ | .0541 | 25 26 |
| Bromine, solid | -78 to -20 | . 0843 | 10 | " | 18-100 | . 0323 | 26 |
| " solid | -192 to -80 | . 0702 | 49 | Iron | -223 | . 0176 | 46 |
| " fluid | 13-45 | . 107 | 19 |  | -163 | . 0622 | 46 |
| Cadmium. | -223 | . 0308 | 46 |  | -63 | .096r | 46 |
| " | -173 | . 0478 | 46 | " cast | +37 | . 1092 | 46 |
| " ${ }^{\text {a }}$, | -75 | . 05333 | 46 2 | " wrought. | $20-100$ $15-100$ | .1189 | 27 28 |
| "' | 100 | . 0570 | 2 | " wrought. | 1000-1200 | . 1989 | 28 |
| " | 200 | . 0594 | 2 | " wrought. | 500 | .176 | 28 |
| Ca' | 300 | .0617 | 2 | " hard-drawn.. | O-18 | . 0986 | 29 |
| Casium. | $\stackrel{\text { O-26 }}{-185}$ | . 0482 | 12 | " hard-drawn. | 20-100 | . 1146 | 29 |
| Calcium. | -185 to ${ }_{0-18 \mathrm{I}}+20$ | . 157 | 4 | " ،............ | -185 to +20 | . 0958 | 4 |
| Carbon, graphite | $\stackrel{0-181}{-191}$ to -79 | .170 .0573 | 13 47 |  | 0 to +200 0 to +300 | $\begin{array}{r}1175 \\ .1233 \\ \hline\end{array}$ | 53 53 |
| " ${ }^{\text {" }}$ | -76 to -o | . 1255 | 47 | " | - to +400 | . 1282 | 53 |
| " " | -50 | . 114 | 14 | , | - to +500 | . 1338 | 53 |
| " "، | +11 | . 160 | 14 |  | - to +600 | . 1396 | 53 |
| " "، | 977 | . 467 | 14 |  | - to +700 | . 1487 | 53 |
|  | $\left\{\begin{array}{l}1730 \\ -244\end{array}\right.$ | .50 .005 | 52 50 | ، ............ | $\circ$ to +800 0 to +900 | 1597 .1544 .154 | 53 |
| Acheson | $\left\{\begin{array}{l}-244 \\ -186\end{array}\right.$ | . .027 | 50 | " | - to +1000 | - 1644 .1557 . | 53 53 |
| Carbon, diamond.. | -50 | . 0635 | 47 | " ${ }^{\text {a }}$. | - to +iroo | . 1534 | 53 |
|  | +11 | . 113 | 47 | Lanthanum | -100 | . 0448 | 15 |
| " " | 985 | . 459 | 47 | Lead. | -250 | . 0143 | 46 |
| Cerium....... | - 100 | . 0448 | 15 |  | - 236 | . 0217 | 46 |
| Chlorine, liquid. | --24 | . 2262 | 16 | " | -193 | . 0276 | 46 |
| Chromium... | -200 | . 0666 | 17 |  | -73 | . 0295 | 46 |
| ، | 0 | . 1039 | 17 |  | 15 | . 0299 | 2 |
| * | 100 | .1121 .1872 | 17 17 |  | 100 300 | .0311 | 2 |
|  | -185 to +20 | . 086 | 4 | " fluid. | 310 | . 0356 | 30 |

* When one temperature is given, the "true" specific heat is indicated, otherwise the "mean" specific heat.
$\dagger 0.3834+0.00020(t-25)$ intern. j per g degree $=0.0917+0.000048(t-25)$ cal20 per g degree. ${ }^{(G)}{ }^{(G r i f f i t h} \mathrm{t}_{\mathrm{t}}$ 1913.)

Smithsonian Tables.

*When one temperature is given, the "true" specific heat is indicated, otherwise the "mean" specific heat. See page 226 for references.

Smithsonian tables.

## HEAT CAPACITIES. TRUE AND•MEAN SPECIFIC HEATS. AND

## LATENT HEATS AT FUSION.

The following data are taken from a research and discussion entitled "Die TemperaturWärmeinhaltskurven der technisch wichtigen Metalle," Wüst, Meuthen und Durrer, Forschungsarbeiten herausgegeben vom Verein Deutscher Ingenieure, Springer, Heft 204, I918.
(a) There follow the constants of the equation for the heat capacity: $W=a+b t+c t^{2}$; for the mean specific heat: $s=a t^{-1}+b+c t$; and for the true specific heat: $s^{\prime}=b+2 c t$; also the latent heats at fusion. (See also Table 243, pp. 223-224.)

| Element. | $\begin{aligned} & \text { Tempera- } \\ & \text { ture } \\ & \text { range. } \\ & \text { of } \end{aligned}$ | $a$ | $b$ | $c \times 10^{6}$ | $\left.\begin{gathered} \text { La- } \\ \text { tent } \\ \text { heat. } \\ \text { cal./g } \end{gathered} \right\rvert\,$ | Element. | $\begin{gathered} \text { Tempera- } \\ \text { ture } \\ \text { range. } \\ \circ \end{gathered}$ | $a$ | $b$ | $c \times 10^{6}$ | Latent heat cal./g |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{aligned} & \mathrm{Cr} \\ & \mathrm{Mo} \\ & \mathrm{~W} \\ & \mathrm{Pt} \\ & \mathrm{Sn} \end{aligned}$ | 0-1500 | - | 0. 10233 | 33.47 | - | Ag | --961 | - | 0.05725 | 5.48 | 26.0 |
|  | $0-1500$ | - | 0.06162 | 10.99 | - |  | 961-r300 | 53.17 | 0.00710 | 28.30 | - |
|  | $0-1500$ | - | 0.03325 | 1.07 | - | Au | --1064 | - | 0.03171 | I. 30 | 15.9 |
|  | --1500 | - | 0.03121 | 3.54 | - |  | 1064-1300 | 26.35 | 0.01420 | 8.52 | - |
|  | 0-232 |  | 0.06829 | - | 13.8 | Cu | -0-1084 | - | -. 10079 | 3.05 | 41.0 |
|  | 232-1000 | 14.33 | 0.07020 | -18.30 | - |  | 1084-1300 | 130.74 | -. 04150 | 65.6 |  |
| Bi | 0-270 | - | 0.03141 | 5.22 | 10.2 | Mn | -0-1070 | . | -. 12037 | 25.41 | 36.6 |
|  | 270-1000 | 10.31 | 0.03107 | 5.41 | - |  | 1130-1210 | $-7.41$ | O. 17700 | - | 24.14* |
| Cd | c-321 | 6.30 | 0.05550 | 6.28 6.37 | 10.8 | Ni | $1230-1250$ $0-320$ | 3.83 | O. 19800 | 52.40 | 56.1 |
| Pb | $321-1000$ <br> $0-327$ | - 6. | 0.03591 | -11.47 | $5 \cdot 47$ |  | 330-1451 | 0.4 I | -. 1293 I | - | 1.33* |
|  | 327-1000 | 6.07 | 0.02920 | 3.30 | 5 |  | 1451-1520 | 50.21 | -.13380 | - | - |
| Zn | --419 |  | 0.08777 | 43.48 | 23.0 | Co | 0-950 | 50. | -.09119 | 40.77 | 58.2 |
|  | 419-1000 | 14.34 | 0.13340 | -16.10 |  |  | 1100-1478 | 22.00 | -. 11043 | 14.57 | 14.70* |
| Sb | 0-630 |  | 0.05179 | 3.00 | 38.9 |  | 1478-1600 | 57.72 | -. 14720 |  |  |
|  | 630-1000 | 39.42 | 0.05090 | 2.96 |  | Fe | 0-725 |  | -. 10545 | 56.84 |  |
| Al | -0-657 |  | 0. 22200 | 38.57 | 94.0 |  | 785-919 | $-1.63$ | -. 1592 | - |  |
|  | 657-1000 | 102.39 | 0.21870 | 24.00 |  |  | 919-1404 | 18.31 | o. 14472 | 0.05 | $6.67^{*}$ |
|  |  |  |  |  |  |  | 1405-1528 | -77.18 | -. 21416 | - | 1.94* |
|  |  |  |  |  |  |  | $1528-1600$ | 70.03 | -. 15012 | - | - |

* Allotropic heat of transformation: $\mathrm{Mn}, 1070-1130^{\circ}$; Ni, $320-330^{\circ}$; $\mathrm{Co}, 950-1100^{\circ}$; Fe , $725-785^{\circ} ; 919^{\circ} \pm \mathrm{I} ; 1404.5^{\circ} \pm 0.5$.
(b) True Specific Heats.

| ${ }^{\circ} \mathrm{C}$ | Pb | Zn | Al | Ag | Au | Cu | Ni | Fe | Co | Quartz. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0^{\circ} \mathrm{C}$ | 0.0359 | 0.0878 | O. 2220 | 0.0573 | 0.0317 | O. 1008 | O. 1095 | O. 1055 | 0.0912 | - |
| 100 | 0.0336 | -. 0965 | -. 2297 | -. 0583 | 0.0320 | O. 1014 | 0. 1200 | - . 1168 | 0.0993 | 0. 2372 |
| 200 | 0.0313 | -. 1052 | -. 2374 | -. 0594 | 0.0322 | O. 1020 | O. 1305 | -. 1282 | - . 1073 | -. 2416 |
| 300 | 0.0290 | -. 1139 | -. 2451 | 0.0605 | 0.0325 | O. 1026 | O. 1409 | -. 1396 | - I I 54 | 0. 2460 |
| 400 | 0.0266 | -. 1226 | -. 2529 | 0.0616 | -. 0328 | O. 1032 | O. I 294 | -. 1509 | O. I 235 | 0. 2504 |
| 500 | 0.0259 | -. 1173 | -. 2606 | 0.0627 | -. 0330 | -. 1038 | -. 1294 | -. 1623 | -. I316 | -. 2548 |
| 600 | 0.0252 | O. II4 1 | -. 2683 | -. 0638 | -. 0333 | O. 1045 | O. 1294 | -. 1737 | - I 396 | 0. 2592 |
| 700 | 0.0246 | -. 1109 | -. 2523 | 0.0649 | -. 0335 | -. 1051 | -. 1295 | O. 1850 | -. $1477{ }^{\circ}$ | -. 2636 |
| 800 | 0.0239 | -. 1076 | -. 2571 | 0.0660 | -. 0338 | -. 1057 | -. 1295 | -. 1592 | -. 1558 | -. 2680 |
| 900 | 0.0233 | -. 1044 | -. 2619 | 0.0671 | 0.0341 | -. 1063 | O. 1295 | -. I592 | - I639 | 0. 2724 |
| 1000 | 0.0226 | O. 1012 | 0. 2667 | 0.0637 | -. 0343 | -. 1069 | -. 1295 | -. 1448 | - | -. 2768 |
| 1100 | - | - | - | 0.0694 | 0.0329 | -. 1028 | O. 1296 | - I 4488 | O. 1424 | 0. 2812 |
| I 200 | - | - | - | 0.0750 | 0.0346 | -. 1159 | -. 1296 | - 1448 | -. 1454 | -. 2856 |
| 1300 | - | - | - | 0.0807 | 0.0364 | -. 129 I | -. 1296 | - I 449 | -. 1483 | O. 2900 |
| 1400 | - | - | - | - | - | - | O. 1296 | - I 1449 | -. 1512 | -. 2944 |
| 1500 | - | - | - | - | - | - | -. 1338 | O. 2142 | -. 1472 | -. 2988 |
| 1600 | - | - | - | - | - |  |  | -. 15010 | 0.1472 |  |

For more elaborate tables and for all the elements in upper table, see original reference.

The atomic and specific heats are due to Dewar, Pr. Roy. Soc. 89A, 168, 1913.

| $\begin{gathered} \text { Ele- } \\ \text { ment. } \end{gathered}$ | $\begin{gathered} \text { Specific } \\ \text { heat } \\ -223^{\circ} \mathrm{C} . \end{gathered}$ | $\left\lvert\, \begin{gathered} \text { Atomic } \\ \text { heat } \\ -223{ }^{\circ} \mathrm{C} . \end{gathered}\right.$ | Atomic volume. | Ele- | $\begin{gathered} \text { Specific } \\ \text { heat } \\ -223^{\circ} \mathrm{C} . \end{gathered}$ | $\left\|\begin{array}{c} \text { Atomic } \\ \text { heat } \\ -223^{\circ} \mathrm{C} . \end{array}\right\|$ | Atomic volume. | Ele- ment. | $\begin{array}{\|c\|} \text { Specific } \\ \text { heat } \\ -223^{\circ} \mathrm{C} . \end{array}$ | $\left\lvert\, \begin{gathered} \text { Atomic } \\ \text { heat } \\ -223^{\circ} \mathrm{C} . \end{gathered}\right.$ | Atomic volume |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Li | 0. 1924 | 1.35 | 13.0 | Cr | 0.0142 | 0.70 | 7.6 | Sn | 0.0286 | 3.41 | 20.3 |
| G1 | 0.0137 | 0.125 | 4.9 | Mn | 0.0229 | 1.26 | 7.4 | Sb | 0.0240 | 2.89 | 18.2 |
| B | 12 | 0.24 | 4.5 | Fe | 0.0175 | 0.98 | 7. | I | 0.0361 | 4.59 | 25.7 |
| C* | 0.0137 | 0.16 | 5 | Ni | 0.0208 | 1.22 | 6.7 | Te | 0.0288 | 3.68 | 21.2 |
| C $\dagger$ | 0.0028 | 0.03 | 3.4 | Co | 0.0207 | 1.22 | 6.8 | Cs | 0.0513 | 6.82 | 71.0 |
| Na | 0.1519 | 3.50 | 23.6 | Cu | 0.0245 | I. 56 | 7.1 | Baq | 0.0350 | 4.80 | 36.6 |
| Mg | 0.0713 | 1. 74 | 14.1 | Zn | 0.0384 | 2.52 | 9.2 | La | 0.0322 | 4.60 | 22.6 |
| $\mathrm{Al}^{\text {a }}$ | 0.0413 | 1.12 | 10.0 | As | 0.0258 | 1.94 | 15.9 | Ce | 0.0330 | 4.64 | 20.3 |
| Si $\ddagger$ | 0.0303 | 0.86 | 14.2 | Se | 0.0361 | 2.86 | 18.5 | W | 0.0095 | 1.75 | 9.8 |
| Si § | 0.0303 | 0.77 | 11.4 | $\stackrel{\mathrm{Br}}{ }$ | 0.0453 | 3.62 | 24.9 | Os | 0.0078 | I. 49 | 8.5 |
| P |  |  |  | $\mathrm{Rb}^{\mathrm{Rb}}$ | 0.0711 | 6.05 | 55.8 | $\mathrm{Ir}_{\text {Pt }}$ | 0.0099 | 1.92 | 8.6 |
| yel | 0.0774 | 2.40 | 17.0 | $\mathrm{Sr} \mathrm{Sr}^{\text {Zr }}$ | 0.0550 | 4.82 2.38 | 34.5 24 | $\stackrel{\mathrm{Pt}}{\mathrm{Au}}$ | 0.0135 | 2.63 | 9.2 |
| red | 0.0431 | I. 34 |  | Mo | 0.0241 | 2.88 I. 36 | 34.8 0.3 | ${ }^{\mathrm{Hg}}$ | 0.0160 | 3.16 | 10.2 |
| S | 0.0546 | 1.75 | 16. | Ru | 0.0109 | 1.11 1.15 | 9.0 | Ti | 0.0232 0.0235 | 4.65 4.80 | 14.8 17.2 |
| $\mathrm{Cl}^{\mathrm{Cl}}$ | 0.0967 | 3.43 | 24.6 | Rh | -. 0134 | 1.38 | 8.5 | Pb | 0.0240 | 4.96 | 18.3 |
| K | 0. 1280 | 5.01 | 44.7 | Pd | 0.0190 | 2.03 | 9. | Bi | 0.0218 | 4.54 | 21.3 |
| Ca | 0.0714 | 2.86 | 25.9 | ${ }^{\mathrm{Ag}}$ | 0.0242 | 2.62 | 10.2 | Th | 0.0197 | 4.58 | 21.1 |
| Ti | 0.0205 | 0.99 | 10.7 | Cd | 0.0308 | 3.46 | 13.0 | U | 0.0138 | $3 \cdot 30$ | 12.8 |

* Graphite. $\dagger$ Diamond. $\ddagger$ Fused. § Crystallized. II Impure.

References to Table 243:
(r) Bontschew.
(2) Naccari, Atti Torino, 23, 1887-88.
(3) Wigand, Ann. d. Phys. (4) 22, 1907.
(4) Nordmeyer-Bernouli, Verh. d. phys. Ges. 9, 1907; 10, 1908.
(5) Giebe, Verh. d. phys. Ges. 5, 1903.
(6) Lorenz, Wied. Ann. 13, 188 I.
(7) Stücker, Wien. Ber. 114, 1905.
(8) Person, C. R. 23, 1846; Ann. d. chim. (3) 21,$1847 ; 24,1848$.
(9) Moisson-Gautier, Ann. chim. phys. (7) 17, 1896.
(10) Regnault, Ann. d. chim. (3) 26, 1849; $63,1861$.
(ii) Andrews, Pog. Ann. 75, 1848.
(12) Eckardt-Graefe, Z. Anorg. Ch. 23, 1900.
(13) Bunsen, Pogg. Ann. 141, 1870; Wied. Ann. 31, 1887.
(14) Weber, Phil. Mag. (4) $49,1875$.
(15) Hillebrand, Pog. Ann. 158, 1876.
(16) Knietsch.
(17) Adler, Beibl. 27, 1903.
(18) Pionchon, C. R. 102-103, 1886.
(19) Tilden, Phil. Trans. (A) 201, 1903.
(20) Richards, Ch. News, 68, 1893.
(21) Trowbridge, Science, 8, 1898.
(22) Berthelot, Ann. d. chim. (5) 15, 1878.
(23) Pettersson-Hedellius, J. Pract. Ch. 24, 1881.
(24) Violle, C. R. 85,$1877 ; 87,1878$.
(25) Regnault, Ann. d. chim (2) 73, 1840; (3) 63,1861 .
(26) Behn, Wied. Ann. 66, 1898; Ann. d. Phys. (4) I, 1900.
(27) Schmitz, Pr. Roy. Soc. 72, 1903.
(28) Nichol, Phil. Mag. (5) 12, 1881.
(29) Hill, Verh. d. phys. Ges. 3, 1901.
(30) Spring, Bull. de Belg. (3) 11, 1886; 29, 1895.
(31) Laemmel, Ann. d. Phys. (4) 16, 1905.
(32) Barnes-Cooke, Phys. Rev. 16, 1903.
(33) Wiegand, Fort. d. Phys. 1906.
(34) Tilden, Pr. Roy. Soc. 66, 1900; 71, 1903; Phil. Trans. (A) 194, 1900; 20I, 1903.
(35) White, Phys. Rev. 12, 436, 1918.
(36) Dewar, Ch. News, 92, 1905.
(37) Kopp, Phil. Trans. London, 155, 1865.
(38) Nilson, C. R. 96, 1883.
(39) Nilson-Pettersson, Zt. phys. Ch. 1, 1887.
(40) Mache, Wien, Ber. 106, 1897.
(41) Blümcke, Wied. Ann. 24, 1885.
(42) Mixter-Dana, Lieb Ann. 169, 1873.
(43) Magnus, Ann. d. Phys. 31, 1910.
(44) Harper, Bull. Bureau of Stds. in, p. 259, 1914.
(45) Nernst, Lindemann, i910, igif.
(46) Nernst, Dewar.
(47) Kosef, Ann. d. Phys. 36, 191 .
(48) Magnus, Ann. d. Phys. 31, 1910.
(49) Estreicher, Straniewski, 1912.
(50) Nernst, Ann. d. Phys. 36, 395, 1911.
(51) King, Phys. Rev. 11, 1918.
(52) Worthing, Phys. Rev. 12, 1918.
(53) Harker, Pr. Phys. Soc. London, 19, 703, 1905; Fe .01; C .02; Si .03; S .04; P, Mn trace.

TABLE 246.-Specific Heat of Various Solids.

| Solic. | Temperature ${ }^{\circ} \mathrm{C}$. | Specific heat. | Authority. |
| :---: | :---: | :---: | :---: |
| Alloys: |  |  |  |
| Bell metal. | 15-98 | 0.0858 | R |
| Brass, red. | 0 | . 08991 | L |
| " yellow | 0 | . 08831 |  |
| $80 \mathrm{Cu}+20 \mathrm{Sn}$. | 14-98 | . 0862 | R |
| $88.7 \mathrm{Cu}+11.3 \mathrm{Al}$ | 20-100 | . 10432 | Ln |
|  | 0-100 | . 09464 | T |
| Lipowitz alloy: $24.97 \mathrm{~Pb}+10.13 \mathrm{Cd}+50.66 \mathrm{Bi}$ |  |  | M |
| 14.24 Sn | 100-150 | . 0426 | $\stackrel{1}{6}$ |
| Rose's alloy : $27.5 \mathrm{~Pb}+48.9 \mathrm{Bi}+23.6 \mathrm{Sn}$ | -77-20 | .0356 | S |
| Wood's "lloy : $2_{25.85} . \dot{\mathrm{Pb}}+6.99 \mathrm{C} \mathrm{C}+{ }_{52.43 \mathrm{Bi}}$ | 20-89 | . 0552 |  |
| , +14.73 Sn . . . | 5-50 | . 0352 | M |
| " " (fluid) | 100-150 | . 0.426 |  |
| Miscellaneous alloys: |  |  |  |
| $17.5 \mathrm{Sb}+29.9 \mathrm{Bi}+18.7 \mathrm{Zn}+33.9 \mathrm{Sn}$ | 20-99 | .05657 | R |
| $37.15 \mathrm{Sb}+62.9 \mathrm{~Pb}$ | 10-98 | . 03880 |  |
| 39.9 Pb $+60.1{ }_{6} \mathrm{Bi}$ | 16-99 | . 03165 | P |
| " ${ }^{\text {، }}$ (fluid) | 144-358 | . 03500 |  |
| $63.7 \mathrm{~Pb}+36.3 \mathrm{Sn}$ | 12-99 | . 04073 | R |
| $46.7 \mathrm{~Pb}+53.3 \mathrm{Sn}$ | 10-99 | . 04507 |  |
| $63.8 \mathrm{Bi}+36.2 \mathrm{Sn}$ | 20-99 | . 04001 | " |
| $46.9 \mathrm{Bi}+53.1 \mathrm{Sn}$ | 20-99 | . 04504 |  |
| Gas coal . . . | 20-1040 | .3145 |  |
| Glass, normal thermometer \% $^{\prime \prime}$ | 19-100 | . 1988 |  |
| " French hard thermometer |  | . 1869 | Z |
| "، crown . | 10-50 | . 161 | H M |
| Ice . ${ }^{\text {" }}$. | $\xrightarrow{10-50}$ | .117 .146 | D |
| Ic | -78--188 | . 285 |  |
|  | -18--78 | .463 | " T |
| India rubber (Para) | ?-100 | . 48 I | G T |
| Mica . . . | 20 | . 10 |  |
| Paraffin | $-20-+3$ | . 3768 | R W |
| "، . . . . . . . . | $-19-+20$ | . 5251 |  |
| " . . . . . . . . . . | 0-20 | . 6939 |  |
| " ${ }^{\text {a }}$ | 35-40 | . 622 | B |
| Vulcanite fluid | 60-63 | . 712 |  |
| Vulcanite . . . . . | $\xrightarrow{20-100}$ | . 3327 | AM |

TABLE 247.-Specific Heat of Water and of Mercury.

| Specific Heat of Water. |  |  |  |  |  |  | Specific Heat of Mercury. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Temperature, ${ }^{\circ} \mathrm{C}$. | Barnes. | Rowland. | BarnesRegnault. | Temperature, ${ }^{\circ} \mathrm{C}$. | Barnes | BarnesRegnault. | Temperature, ${ }^{\circ} \mathrm{C}$. | Specific Heat. | Temperature, ${ }^{\circ} \mathrm{C}$. | Specific Heat. |
| -5 | 1.0155 | - | - | 60 | 0.9988 | 0.9994 | 0 | 0.03346 | 90 | 0.03277 |
| 0 | 1.0091 | 1.0070 | 1.0094 | 65 | . 9994 | 1.0004 | 5 | . 03340 | 100 | . 03269 |
| $+5$ | 1.0050 | 1.0039 | 1.0053 | 70 | 1.0001 | 1.0015 | 10 | . 03335 | 110 | . 03262 |
| 10 | 1.0020 | 1.0016 | 1.0023 | 80 | 1.0014 | 1.0042 | 15 | . 03330 | 120 | . 03255 |
| 15 | 1.0000 | 1.0000 | 1.0003 | 90 | 1.0028 | 1.0070 | 20 | . 03325 | 130 | . 03248 |
| 20 | 0.9987 | .9991 | 0.9990 | 100 | 1.0043 | 1.0ior | 25 | . 03320 | 140 | . 03241 |
| 25 | . 9978 | . 9989 | . 998 r | 120 | - | 1.0162 | 30 | . 03316 | 150 | . 0324 |
| 30 | . 9973 | . 9990 | . 9976 | 140 | - | 1.0223 | 35 | . 03312 | 170 | . 0322 |
| 35 | . 9971 | . 9997 | . 9974 | 160 | - | 1.0285 | 40 | . 03308 | 190 | . 0320 |
| 40 | . 9971 | 1.0006 | . 9974 | 180 | - | 1.0348 | 50 | . 03300 | 210 | . 0319 |
| 45 | . 9973 | 1.0018 | . 9976 | 200 | - | 1.0410 | 60 | . 03294 | - | - |
| 50 | . 9977 | 1.0035 | . 9980 | 220 | - | 1.0476 | 70 | . 03289 | - | - |
| 55 | .9982 | 1.0045 | .9985 | - | - | - | 80 | .03284 | - | - |

Barnes's results: Phil. Trans. (A) 199, 1902 ; Phys. Rev. 15, 1902; 16, 1903. (H thermometer.)
Bousfield, Phil. Trans. A 21s, p. 199, 1911. Barnes-Regnault's as revised by Peabody ; Steam Tables.
The mercury data from $0^{\circ}$ C to 80 , Barnes-Cooke ( H thermometer); from $90^{\circ}$ to 140 , mean of Winklemann, Naccari and Milthaler (air thermometer); above $14^{\circ}$, mean of Narcari and Milthaler.

TABLE 248. - Specific Heat of Various Liquids.

| Liquid. | $\begin{aligned} & \text { Temp. } \\ & \hline \text { C. } \end{aligned}$ | Spec. heat. |  | Liquid. | $\stackrel{\text { Temp. }}{\text { Comp. }}$ | Spec. heat. | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Alcohol, ethy | -20 |  | R | Ethyl ether | $\bigcirc$ | -. 529 | R |
|  | - | 0. 548 |  | Glycerine. . . . . . . . . . $\therefore$ | 15-50 | -. 576 | E |
| " ${ }^{6}$. | 40 | $\bigcirc .648$ | " | $\mathrm{KOH}+30 \mathrm{H}_{2} \mathrm{O} \ldots \ldots$. | 18 | -. 876 | TH |
| Alcohol, methyl | 5-10 | 0. 590 | " | " $+100{ }^{\circ}$ | 18 | -. 975 |  |
| "6, ، | I $5-20$ | 0.601 | " | $\mathrm{NaOH}+50 \mathrm{H}_{2} \mathrm{O}$ | 18 | -. 942 | " |
| Anilin | 15 | 0.514 | G | " + 100 | 18 | 0.983 | " |
|  | 30 | 0.520 |  | $\cdot \mathrm{NaCl}+10 \mathrm{H}_{2} \mathrm{O}$ | 18 | -. 791 | " |
|  | 50 | 0.529 | I-D | " $+200{ }^{\prime \prime}$ | 18 | 0.978 | " |
| Benzole, $\mathrm{C}_{6} \mathrm{H}$ | 10 | 0. 340 | $\mathrm{H}-\mathrm{D}$ | Naphthalene, $\mathrm{C}_{10} \mathrm{H}_{8}$ | 80-85 | -. 396 | B |
|  | 40 | $0: 423$ |  |  | 90-95 | 0.409 |  |
| $\mathrm{CaCl}_{2}$, sp. gr. $\mathrm{C}_{6} \mathrm{H}_{6}$. | 65 -15 | 0.482 0.764 | DMG | Nitrobenzole | 14 | 0.350 0.362 | A |
| $\mathrm{CaCl}_{2}, \mathrm{Sp}_{6} \mathrm{~g} . \mathrm{gr}_{6} \mathrm{I} .1$ | - I5 | 0.764 0.775 | DMG | Oils: castor | 28 |  | W |
| " "6 " | +20 | 0.787 | " | citron | 5.4 | 0.438 | HW |
| " '6 "، r. 20 | -20 | 0.695 | " | olive | 6.6 | 0.47 I |  |
| " " " ${ }^{\text {" }}$ | $\bigcirc$ | 0.712 | " | sesame | - | 0.387 | W |
| " ، | +20 | 0.725 | " | turpenti | $\bigcirc$ | 0.411 | R |
| " " "6 I.26 | -20 | 0.65 I | " | Petroleum. . . . . . . . . . . | 21-58 | 0.511 | $\mathrm{Pa}_{6}$ |
|  | $\bigcirc$ | 0.663 | " |  | 17.5 | 0.980 |  |
| " " ${ }^{6}$ | +20 | 0.676 | Pa |  | 17.5 | 0.938 | ، |
| $\mathrm{CuSo}_{66}+50 \mathrm{H}_{2} \mathrm{O}$ | $12-\mathrm{I} 5$ | 0. 848 | Pa | " " ${ }^{\text {a }}$, " 1.0463 . | 17.5 | 0.903 | " |
| $" \mathrm{c}$ + 200 " | 12-14 | 0.951 |  | Toluol, $\mathrm{C}_{6} \mathrm{H}_{8}$ | 10 | 0. 364 | H-D |
| " ${ }^{\prime}+400$ " | $13-17$ | 0.975 | ، |  | 65 | 0.490 | ، |
| Diphenylamine, $\mathrm{C}_{12} \mathrm{H}_{11} \mathrm{~N} .$ |  |  | B | $\mathrm{ZnSO}_{4}+50 \mathrm{H}$ | 85 $20-52$ | 0. 534 | Ma |
| $\mathrm{Cl}_{2}$ | 65 | 0.482 | ${ }_{6}$ | ${ }^{6}+200{ }^{\prime \prime}$ | 20-52 | 0.952 | Ma |

References: (A) Abbot; (B) Batelli; (E) Emo; (G) Griffiths; (DMG) Dickinson, Mueller, and George; (H-D) de Heen and Deruyts; (Ma) Marignac; (Pa) Pagliani; (R) Regnault; (Th) Thomsen; (W) Wachsmuth; (Z) Zouloff; (HW) H. F. Weber.

TABLE 249. - Specific Heat of Liquid Ammonia under Saturation Conditions.
Expressed in Calories ${ }_{20}$ per Gram per Degree C. Osborne and van Dusen, Bul. Bureau of Standards, igi8.

| Temp. | - | I | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| -40 | 1.062 | 1.061 | 1.060 | 1.059 | I. 058 | 1. 058 | 1. 057 | I. 056 | 1.055 | 1.055 |
| -30 | 1.070 | 1. 069 | 1.068 | I. 067 | 1. 066 | I. 065 | 1. 064 | 1.064 | 1.063 | 1.062 |
| -20 | 1.078 | 1.077 | 1.076 | 1.075 | I. 074 | I. 074 | 1.073 | 1.072 | 1.071 | 1.070 |
| -10 | 1.088 | 1.087 | 1.086 | 1.085 | 1.084 | 1.083 | 1.082 | I.08I | 1.080 | 1.079 |
| - 0 | 1.099 | 1.098 | 1.097 | 1. 096 | I. 094 | I. 093 | I. 092 | 1.091 | 1.090 | 1.089 |
| + 0 | 1.099 | I. 100 | 1. IOI | 1. 103 | I. 104 | I. 105 | 1. 106 | 1. 108 | 1. 109 | 1.110 |
| +10 | I. II 2 | I. II 3 | I. II4 | I. II6 | I. 117 | I. II8 | I. 120 | 1.122 | 1.123 | 1.125 |
| +20 | I. 126 | I. 128 | I. 129 | I. 131 | I. 132 | I. I34 | I. I36 | I. 137 | I. I39 | 1.141 |
| $+30$ | I. 142 | I. 144 | I. 146 | I. 148 | I. 150 | I. 152 | I. I54 | I. 156 | I. 158 | I. 160 |
| +40 | 1. 162 | I. 164 | I. 166 | I. 169 | I. 171 | I. 173 | I. 176 | 1. 178 | I. 18 I | 1.183 |

TABLE 250. - Heat Content of Saturated Liquid Ammonia,
Heat content $=H=\epsilon+p v$, where $\epsilon$ is the internal or intrinsic energy. Osborne and van Dusen, Bul. Bureau of Standards, 1918.

$$
\begin{array}{l|l|c|c|c|c|c|c|c|c|c|c}
\text { Temperature } \ldots & -50^{\circ} & -40^{\circ} & -30^{\circ} & -20^{\circ} & -10^{\circ} & 0^{\circ} & +10^{\circ} & +20^{\circ} & +30^{\circ} & +40^{\circ} & +50^{\circ} \\
H=\epsilon+p v \ldots . & -53.8 & -43.3 & -32.6 & -21.8 & -11.0 & 0.0 & +11.1 & +22.4 & -33.9 & -45.5 & -57.4
\end{array}
$$

SPECIFIC HEATS OF MINERALS AND ROCKS.
TABLE 251.-Specific Heat of Minerals and Rocks.

| Substance; | Temperature ${ }^{\circ} \mathrm{C}$. | Specific Heat. | Refer ence. | Substance. | Temperature ${ }^{\circ} \mathrm{C}$. | Specific Heat. | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Andalusite | 0-100 | 0.1684 | 1 | Rock-salt | 13-45 | 0.219 | 6 |
| Anhydrite, $\mathrm{CaSO}_{4}$ | 0-100 | . 1753 | 1 | Serpentine - | 16-98 | . 2586 | 2 |
| Apatite . . | $15-99$ | . 1903 | 2 | Siderite | 9-98 | . 1934 | 4 |
| Asbestos | 20-98 | . 195 | 3 | Spinel . | $15-47$ | . 194 | 6 |
| Augite | 20-98 | .1931 | 3 | Talc | 20-98 | . 2092 | 3 |
| Barite, $\mathrm{BaSO}_{4}$ | 10-98 | . 1128 | 4 | Topaz . ${ }^{\text {a }}$ | 0-100 | . 2097 | 1 |
| Beryl . | 1 5-99 | . 1979 | 2 | Wollastonite ${ }^{\text {- }}$ | 19-51 | .178 | 6 |
| Borax, $\mathrm{Na}_{2} \mathrm{~B}_{4} \mathrm{O}_{7}$ fused | 16-98 | . 2382 | 4 | Zinc blende, ZnS . | 0-100 | .I 146 | 1 |
| Calcite, $\mathrm{CaCO}_{3}$. | 0-50 | . 1877 | I | Zircon . | 21-51 | .132 | 6 |
| " ${ }^{\prime}$ | --100 | . 2005 | I | Rocks: |  |  |  |
| " " | --300 | . 2204 | 1 | Basalt, fine, black | 12-100 | . 1996 | 6 |
| Cassiterite $\mathrm{SnO}_{2}$ | 16-98 | . 0933 | 4 | " | 20-470 | . 199 | 9 |
| Chalcopyrite | 1 5-99 | . 1291 | 2 | " "، " | 470-750 | . 243 | 9 |
| Corundum | 9-98 | . 1976 | 4 | " " " | 750-880 | . 626 | 9 |
| Cryolite, $\mathrm{Al}_{2} \mathrm{~F}_{6} .6 \mathrm{NaF}$ | 16-99 | . 2522 | 2 | " " " | 880-1190 | $\cdot 323$ | 9 |
| Fluorite, $\mathrm{CaF}_{2}$ | $15-99$ | . 2154 | 4 | Dolomite | 20-98 | . 222 | 3 |
| Galena, PbS . | 0-100 | . 0466 | 5 | Gneiss | 17-99 | .196 | 10 |
| Garnet . | 16-100 | . 1758 | 2 | " . | 17-213 | . 214 | 10 |
| Hematite, $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | I 5-99 | . 1645 | 2 | Granite | 12-100 | . 192 | 7 |
| Hornblende . | 20-98 | . 1952 | 3 | Kaolin . | 20-98 | . 224 | 3 |
| Hypersthene | 20-98 | . 1914 | 3 | Lava, Aetna | 23-100 | . 201 | II |
| Labradorite | 20-98 | . 1949 | 3 | " " | 31-776 | . 259 | II |
| Magnetite | 18-45 | . 156 | 6 | Kilauea | 25-100 | . 197 | II |
| Malachite, $\mathrm{Cu}_{2} \mathrm{CO}_{4} \mathrm{H}_{2} \mathrm{O}$ | 1 5-99 | . 1763 | 2 | Limestone | $15-100$ | .216 | 12 |
| Mica (Mg) | 20-98 | .206I | 3 | Marble | 0-100 | . 21 | - |
| " (K) | 20-98 | . 2080 | 3 | Quartz sand | 20-98 | .191 | 3 |
| Oligoclase | 20-98 | . 2048 | 3 | Sandstone . |  | . 22 | - |
| Orthoclase | $15-99$ | . 1877 | 2 |  |  |  |  |
| Pyrolusite, $\mathrm{MnO}_{2}$ - | 17-48 | . 159 | 6 | 1 Lindner. 6 | p. | Barto |  |
| Quartz, $\mathrm{SiO}_{6}{ }_{6}$. | 12-100 | .188 | 7 | 2 Oeberg. 7 | y. | Mora |  |
| * ${ }^{\text {a }}$ | 350 | $\begin{array}{r} .1737 \\ .2786 \end{array}$ | 8 | 3 Ulrich. 8 | nchon. |  |  |
|  | $\stackrel{300-1200}{ }$ | . 305 | 8 | 4 Regnault. 9 R | berts-A u Weber. | en, Rüc | ker. |

Compiled from Landolt-Börnstein-Meyerhoffer's Physikalisch-chemische Tabellen.
TABLE 252.-Specific Heats of Silicates.

| Silicate. | Mean specific heats. $\mathrm{o}^{\circ} \mathrm{C}$ to |  |  |  | True specific heats. at |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $100^{\circ}$ | $500^{\circ}$ | $900^{\circ}$ | $1400^{\circ}$ | $0^{\circ} \mathrm{C}$ | $100^{\circ}$ | $500^{\circ}$ | $1000^{\circ}$ | ${ }^{1300}$ |
| Albite | . 1948 | . 2363 | . 2561 | - | . 178 | . 211 | . 263 | . 294 | - |
| "" glass . ${ }^{\text {a }}$. | . 1977 | .2410 | . 2640 | 731 |  | - | - |  | - |
| Amphibole, Mg. silicate | . 2033 | .2461 | . 2661 | .2731* | . 185 | . 219 | . 279 | . 304 | - |
| Andesine <br> glass | . 2040 | .2474 .2330 | . 2525 |  |  | - | 265 | - | - |
| Andesine glass | . 1925 | ${ }^{2} 330$ | . 2525 | - | - | - | . 265 | - |  |
| Anorthite . | . 1901 | . 2296 | 02481 | . 2674 | . 174 | . 205 | . 260 | . 286 | . 318 |
| " ${ }_{\text {Cristas }}$ | . 1883 | . 2305 |  | - |  |  |  |  |  |
| Cristobalite | . 1883 | . 2426 | . 2568 | . 2680 |  |  |  | 8 |  |
| Diopside . ${ }^{\text {c }}$ | . 1924 | . 2314 | . 2500 | . $2604{ }^{\dagger}$ | . 176 | . 207 | . 262 | .284 |  |
| Microcline ${ }^{\text {chass }}$ | .1939 .1871 | .2332 .2262 |  | - |  |  | . 258 | - 279 |  |
| " glass | -1919 | . 2321 | . 24514 | -2598* | . 171 | . 201 | . 258 | . 279 | - |
| Pyroxene | . 2039 | . 2484 | , | - | - | - | - |  | - |
| Quartz . | . 1868 | . 2379 | . 2596 | .2640* | . 168 | . 204 | . 294 | . 285 | - |
| Silica glass | . 1845 | . 2302 | . 2512 | - | . 166 | . 202 | . 266 | . 29 |  |
| Wollastonite . |  | - | . 2344 | - | - | - | - | - | - |
| " $\quad \begin{aligned} & \text { glass } \\ & \text { pseudo }\end{aligned}$ | .1852 .1844 | . 22206 | . 2324 | ${ }^{-2448}$ | . 171 | . 197 | . 243 | . 262 | - $\mathrm{B}^{272}$ |


| Substance. | Range of temp. | $\begin{gathered} \text { Sp. ht. } \\ \text { constant } \\ \text { pres- } \\ \text { sure. } \end{gathered}$ | Authority. | $\begin{gathered} \text { Range } \\ \text { of } \\ \text { temp. } \end{gathered}$ | $\begin{array}{\|l\|} \text { Mean } \\ \text { ratio of } \\ \text { specific } \\ \text { heats. } \\ C_{p} / C_{v} . \\ \hline \end{array}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Acetone, $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}$ | 26-110 | 0.3468 | Wiedemann. |  |  |  |
| Air | $-30-10$ | -. 2377 | Regnault. | -70 | I. 4011 | Moody. |
|  | 20-440 | 0.2375 0.2366 |  | -79.3 | I. 405 | Koch, 1907. |
| " | $\begin{aligned} & 20-440 \\ & 20-630 \end{aligned}$ | $\left\|\begin{array}{l} 0.2366 \\ 0.2429 \end{array}\right\|$ | Holborn and Austin. | -79.3 0 | 2.333 I. 828 | " ${ }^{200}$ atm |
|  | 20-800 | 0. 2430 |  | 500 | I. 399 | Fürstenau. |
| Alcohol, $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | 108-220 | 0.4534 | Regnault. | 53 | I. 133 | Jaeger. |
|  | - | - |  | 100 | I. 134 | Stevens. |
| $\mathrm{CH}_{3} \mathrm{OH}$ | 101-223 | 0.4580 | Regnault. | 100 | I. 256 |  |
| Ammonia | $23-100$ $27-200$ | 0.5202 0.5356 | Wiedemann. | $\stackrel{-}{100}$ | I. 3172 I. 2770 | Wüllner. |
| Argon. | $27-200$ $20-90$ | 0.5350 0.1233 | Dittenberger. | 100 | 1.2770 I .667 | Niemeyer. |
| Benzene, $\mathrm{C}_{6} \mathrm{H}$ | 34-115 | -. 2990 | Wiedemann. | 20 | I. 403 | Pagliani. |
|  | 35-180 | 0.3325 |  | 60 | 1.403 |  |
| " ${ }^{\text {B }}$ | 116-218 | 0. 3754 | Regnault. | 99.7 | I. 105 | Stevens. |
| Bromine | 83-228 | 0.0555 |  | 20-388 | 1. 293 | Strecker. |
| Carbon dioxide, ${ }_{\text {" }} \mathrm{CO}_{2}$ | -28-+7 $15-100$ | $\begin{aligned} & 0.1843 \\ & 0.2025 \end{aligned}$ | " | 4-II | 1. 2995 | Lummer and Pringsheim. |
| " | 11-214 | 0.2169 | W." | $\bigcirc$ | 1.3003 | Moody, 1912. |
| "، monoxide, CO.. | 23-99 | -. 2425 | Wiedemann. | $\bigcirc$ | 1.403 | Wüllner. |
| " disulphide, $\mathrm{CS}_{2}$. . | $26-198$ $86-190$ | 0.2426 0.1596 | Regnault. | 100 | I. 395 <br> I. 205 | Beyme. |
| Chlorine........ | 16-343 | -.1125 | Strecker. | 3-67 | 1.336 1. 236 | Martini. |
| Chloroform, $\mathrm{CHCl}_{3}$ | 27-118 | o.1441 | Wiedemann. | 22-78 | I. 102 | Beyme. |
|  | 28-189 | -.1489 |  | 99.8 | I. 150 | Stevens. |
| Ether, | 69-224 | 0.4797 | Regnault. | 42-45 | I. 029 | Müller. |
|  | 25-111 | 0.4280 | Wiedemann. | 12-20 | 1.024 | Low, 1894. |
| Helium....... |  | - | - | $\bigcirc$ | I. 64 | Mean, Jeans. |
| Hydrochloric acid, ${ }_{\text {c }}$ " | $13-100$ $22-214$ | O. 1940 O. 1867 | Strecker. Regnault. | 20 100 | I. 389 | Strecker. |
| Hydrog | -28-+ | 3.3996 |  | 4-16 | 1.400 | Lummer and |
|  | 12-198 | $3 \cdot 4090$ | W." |  |  | Pringsheim. |
| " sulphide, | $21-100$ $20-206$ | 3.4100 | Wiedemann. |  | I. 419 | Hartmann. |
| Krypton........... | 20-20 | $0.245^{\text {I }}$ | Regnault. | 9 | I. 324 I. 666 | apstick., |
| Mercury. | - | - | - | 310 | I. 666 | Kundt and Warburg |
| Methane, C | 18-208 | -. 5929 | Regnault. | II-30 | 1.316 | Müller. |
| Neon. | - | - |  | 19 | 1. 642 | Ramsay, '12 |
| Nitrogen | --200 | O. 2438 | Regnault. | - | 1.41 | Cazin. |
|  | 20-440 | O. 2419 | Holborn and | - | I. 405 | Masson. |
| " | 20-630 | 0. 2464 | Austin. |  |  |  |
| Nitric oxide, | 20-80 13 | 0.2497 0.2317 1.625 | Regnault. |  |  | ' |
| Nitrogen tetroxide, $\mathrm{NO}_{6}{ }^{\text {2 }}$ | 27-67 | 1. 625 | Berthelot and | - | 1. 1.35 | Natanson |
| "، " | 27-150 | I. 115 | Olger. |  |  |  |
| Nitrous oxide, $\mathrm{N}_{2}$ | $27-280$ $16-207$ | 0.05 0.2262 | Regnaul |  |  |  |
|  | 26-103 | 0. 2126 | Wiedemann. | 100 | 1. 272 |  |
|  | 27-206 | -0.2241 |  |  | I. 324 | Leduc, '98. |
| Oxy | $13-207$ | 0. 2175 | Regnault. | 5-14 | I. 3977 | Lummer and |
|  | 20-440 | O. 2240 | Holborn and |  |  | Pringsheim. |
| Sulphur dioxide, $\mathrm{SO}^{\text {a }}$ | 16-202 | 0.2300 0.1544 | Regnault. |  | I. 256 | Müller. |
| Water vapor, $\mathrm{H}_{4} \mathrm{O}$ | $\bigcirc$ | -0. 4655 | Thiesen. | 78 | I. 274 | Beyme. |
|  | 100 | 0.42 I |  | 94 | I. 33 | Jaeger. |
|  | 180 | 0. 51 |  | 100 | 1. 305 | Makower. |
| Xenon. | - |  | - | 19 | 1. 666 | Ramsay,' 12. |

LATENT HEAT OF VAPORIZATION.
The temperature of vaporization in degrees Centigrade is indicated by $t$, the latent heat in large calories per kilogram or in small calories or therms per gram by $r$; the total heat from $\circ^{\circ}$ C , in the same units by $H$. The pressure is that due to the vapor at the temperature $t$.

| Substance. | Formula. | $t^{\circ} \mathrm{C}$ | $r$ | ${ }^{H}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Acetic acid. | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}_{2}$ | $118{ }^{\circ}$ | 84.9 | - | Ogier. |
| Air | - | - | 50.97 | - | Fenner-Richtmyer. |
| Alcohol: Amyl | $\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ | 131 | 120 | - | Schall. |
| Ethyl | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | 78. I | 205 | 255 | Wirtz. |
|  | ، | - | 236 | 236 | Regnault. |
| " | /6 | 50 | - | 264 |  |
| " | , | 100 | - | 267 | /6 |
|  |  | 150 | - | 285 |  |
| Methyl. | $\mathrm{CH}_{4} \mathrm{O}$ | 64.5 | 267 | 307 | Wirtz. |
| , | ، | $\bigcirc$ | 289 | 289 | Ramsay and Young. |
| " | " | 50 | - | 274 | "6 "6 |
| " | " | 100 | - | 246 | "، ، ، |
| " | ، | 15 | - | 152 | " ${ }^{6}$ " |
| '، | " | 238.5 | - | +44.2 | " 6 " |
| Aniline. | $\mathrm{C}_{6} \mathrm{H}_{7} \mathrm{~N}$ | r84 | 110 | 4 | Mean. |
| Benzene. | $\mathrm{C}_{6} \mathrm{H}_{6}$ | 80.1 | 92.9 | 127.9 | Wirtz. |
| Bromine. | Br | 61 | 45.6 | - | Andrews. |
| Carbon dioxide, solid. | $\mathrm{CO}_{2}$ | - | - | 138.7 | Favre. |
| "6 ${ }^{6}$ 6 ${ }^{\text {6 }}$ 6، | '6 | -25 | 72.23 | - | Cailletet and Mathias. |
| " ${ }^{\text {6 }}$ | " | 0 | 57.48 | - | Mathias |
| " 6 " | " | 12.35 | 44.97 | - | ${ }^{\text {Mathas. }}$ |
| "6 " | " | 29.85 | 14.4 | - | " |
| " " " | " | 30.82 | 3.72 | - | " |
| " disulphide. | $\mathrm{CS}_{2}$ | 46.1 | 83.8 | 94.8 | Wirtz. |
|  |  | $\bigcirc$ | 90 | 90 | Regnault. |
| " 6 | " | 100 | - | 100.5 |  |
| " | ${ }^{6}$ | 140 | - | 102.4 | " |
| Chloroform . | $\mathrm{CHCl}_{3}$ | 60.9 | 58.5 | 72.8 | Wirtz. |
| Ether. | $\mathrm{C}_{4} \mathrm{H}_{610} \mathrm{O}$ | $34 \cdot 5$ | 88.4 | 107 |  |
| / |  | 34.9 | 90.5 | - | Andrews. |
| 6 | " | - | 94 | 94 | Regnault. |
| " | '6 | 50 | - | II5.1 |  |
|  |  | 120 | - | 140 |  |
| Ethyl bromide | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br}$ | 38.2 | 60.4 | - | Wirtz. |
| " chloride | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}$ | 12.5 | - | 98 | Regnault. |
| " iodide | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | 71 | 47 | - | Mean. |
| Heptane. | $\mathrm{C}_{7} \mathrm{H}_{16}$ | 90 | 77.8 | - | Young. |
| Hexane. | $\mathrm{C}_{6} \mathrm{H}_{14}$ | 70 | 79.2 | - |  |
| Iodine | I | - | 23.95 | - | Favre and Silbermann. |
| Mercury | Hg | 357. | 65 | - | Mean. |
| Nitrogen | $\mathrm{N}_{2}$ | -195.6 | 47.65 | - | Alt. |
| Octane. | $\mathrm{C}_{8} \mathrm{H}_{18}$ | 1 JO | 70.0 | - | Young. |
| Oxygen | $\mathrm{O}_{2}$ | -182.9 | 50.97 | - | Alt. |
| Pentane. | $\mathrm{C}_{5} \mathrm{H}_{12}$ | 30 | 85.8 | - | Young. |
| Sulphur | S | 316 | 362.0 | - | Person. |
| Sulphur dioxide | $\mathrm{SO}_{6}$ | 0 30 | 91.2 80.5 | - | Cailletet and Mathias. |
| " ${ }^{\text {a }}$ | " | 65 | 68.4 | - | ، |
| Toluene | $\mathrm{C}_{7} \mathrm{H}_{8}$ | III | 86.0 | - | Mean. |
| Turpentine | $\mathrm{C}_{10} \mathrm{H}_{10}$ | 159.3 | 74.04 | - | Brix. |

## LATENT HEAT OF VAPORIZATION.

TABLE 255. - Formulae for Latent and Total Heats of Vapors.
$r=$ latent heat of vaporization at $t^{\circ} \mathrm{C} ; B=$ total heat from fluid at $\circ^{\circ}$ to vapor at $t^{\circ} \mathrm{C}$. $T^{\circ}$ refers to K elvin scale. Same units as preceding table.

| Acetone, $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O} . . . . . . . . .$. | $H=140.5+0.36644 t-0.000516 t^{2}$ | $-3^{\circ}$ to $147^{\circ}$ | R |
| :---: | :---: | :---: | :---: |
|  | $\begin{aligned} R & =140.5+0.33356 t+0.00055358 t^{2} \\ & =139.9+0.2381\end{aligned}$ | -3 147 | W. |
|  | $r=139.9-0.27287 t+0.000157 \mathrm{I}^{2}$ | -3 147 | W |
| Benzene $\mathrm{C}_{6} \mathrm{H}_{6}$ | $H=109.0+0.24429 t-0.00013152^{2}$ | $7{ }^{7} \quad 215$ | R |
| Carbon dioxide | $r^{2}=118.485(3 \mathrm{I}-t)-0.4707(3 \mathrm{1}-t)^{2}$ | $\begin{array}{rr}-25 & 31 \\ -6 & 143\end{array}$ | C |
| Carbon bisulphide, $\mathrm{CS}_{2} \ldots$ | $H=90.0+0.14601 t-0.0004123 t^{2}$ | $\begin{array}{ll}-6 & 143 \\ -6 & \text { I }\end{array}$ | R |
|  | $H=89.5+0.16993 t-0.0010161 r^{2}+0.05342 t^{3}$ | $\begin{array}{ll}-6 & 143 \\ -6 & 143\end{array}$ | W |
| Carbon tetrachloride, $\mathrm{CCl}_{4}$. | $r=89.5-0.06530 t-0.0010976 t^{2}+0.03342 t^{3}$ $H=52.0+0.14625 t-0.000172 t^{2}$ | $\begin{array}{rr}-6 & 143 \\ 8 & 163\end{array}$ | W |
|  | ${ }_{H}=52.9+0.17867 t-0.0009599 t^{2}+0.053733 t^{3}$ | $8 \quad 163$ | W |
|  | $r=51.9-0.01931 t-0.0010505 t^{2}+0.053733 t^{3}$ | $8 \quad 163$ | W |
| Chloroform, $\mathrm{CHCl}_{\text {che...... }}$ | $H=67.0+0.1375 t$ | $5 \quad 159$ | R |
|  | $H=67.0+0.147 \mathrm{r} 6 t-0.0000937 t^{2}$ | $\begin{array}{ll}-5 & 159 \\ -59\end{array}$ | W |
|  | $r=67.0-0.08519 t-0.0001444 t^{2}$ | -5 159 | W |
| Ether, $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ | $H=94.0+0.45000 t-0.0005556 t^{2}$ | 4121 | R |
|  | $r=94.0-0.07900 t-0.0008514 l^{2}$ | -4 121 | R |
| Molybdenum | $r=177000-2.5 T(\mathrm{cal} / \mathrm{g}$-atom) | - | A |
| Nitrogen, $\mathrm{N}_{2} \ldots$ | $r=68.85-0.2736 T+0.928(36.4-t)^{2}$ |  | ${ }_{\text {A }}$ |
| Nitrous oxide, N | $r=69.67-0.2080 T$ | - | A |
| Platinum. | $r=128000-2.5 T$ ( $\mathrm{cal} / \mathrm{g}$-atom) |  | L |
| Sulphur dioxide | $r=91.87-0.3842 t-0.000340 t^{2}$ |  | M |
| Tungsten | $r=217800-1.8 T\left(\mathrm{cal} / \mathrm{g}\right.$-atom) ${ }^{\text {a }}$ |  | L |
| Water, $\mathrm{H}_{2}$ | $H=638.9+0.3745(t-100)-0.00099(t-100)^{2}$ <br> $r=94.210(365-t)^{0.31249} \quad$ (See Table 259) | - 100 | H |

TABLE 256.-Latent Heat of Vaporization of Ammonia.
CALORIES PER GRAM.

| ${ }^{\circ} \mathrm{C}$ | $\bigcirc$ | I | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| -40 | 331.7 | 332.3 | 333.0 | 333.6 | 334.3 | 334.9 | 335.5 | 336.2 | 336.8 | 337.5 |
| -30 | 324.8 | 325.5 | 326.2 | 326.9 | 327.6 | 328.3 | 329.0 | 329.7 | 330.3 | 331.0 |
| -20 | 317.6 | 318.3 | 319.1 | 319.8 | 320.6 | 32 I .3 | 322.0 | 322.7 | 323.4 | 324.1 |
| 10 | 309.9 | 310.7 | 311.5 | 312.2 | 313.0 | 313.8 | 314.6 | 315.3 | 316.1 | 316.8 |
| - 0 | 301.8 | 302.6 | 303.4 | 304.3 | 305.1 | 305.9 | 306.7 | 307.5 | 308.3 | 309.1 |
| +o | 301.8 | 300.9 | 300.1 | 299.2 | 298.4 | 297.5 | 296.6 | 295.7 | 294.9 | 294.0 |
| +10 | 293.1 | 292.2 | 291.3 | 290.4 | 289.5 | 288.6 | 287.6 | 286.7 | 285.7 | 284.8 |
| $+20$ | 283.8 | 282.8 | 281.8 | 280.9 | 279.9 | 278.9 | 277.9 | 276.9 | 275.9 | 274.9 |
| $+30$ | 273.9 | 272.8 | 271.8 | 270.7 | 269.7 | 268.6 | 267.5 | 266.4 | 265.3 | 264.2 |
| +40 | 263.1 | 262.0 | 260.8 | 259.7 | 258.5 | 257.4 | 256.2 | 255.0 | 253.8 | 252.6 |

Osborne and van Dusen, Bul. Bureau Standards, 14, p. 439, 1918.

## TABLE 257. - "Latent Heat of Pressure Variation" of Liquid Ammonia.

When a fluid undergoes a change of pressure, there occurs a transformation of energy into heat or vice versa, which results in a change of temperatura of the substance unless a like amount of heat is abstracted or added. This change expressed as the heat so transformed per unit change of pressure is the "latent heat of pressure variation." It is expressed below as Joules per gram per $\mathrm{kg} / \mathrm{cm}^{2}$. Osborne and van Dusen, loc. cit., p. 433, 19 r 8 .


## LATENT AND TOTAL HEATS OF VAPORIZATION OF THE ELEMENTS.

The following table of theoretical values is taken from J. W. Richards, Tr. Amer. Electrcch. Soc. 13, p. 447, 1908. They are computed as follows: $8 T_{m}(8=$ mean value atomic specific heat, Dulong-Petit constant, $0^{\circ}$ to $T^{\circ} \mathrm{K}, T_{m}=$ melting point, Kelvin scale) plus $2 T_{m}$ (latent heat of fusion is approximately $2 T_{m}$, J. Franklin Inst. 1897) plus $10\left(T_{b}-T_{m}\right)$ (specific heat of liquid metals is nearly constant and equal to that of the solid at $T_{m}, T_{b}=$ boiling point, Kelvin scale) plus ${ }_{23} T_{b} \quad(23=$ Trouton constant; latent heat of vaporization of molecular weight in grams is approximately 23 times $\left.T_{b}\right)=33 T_{b}$. Total heat of vapor when raised from $273^{\circ} \mathrm{K}$ $\left(0^{\circ} \mathrm{C}\right.$ ) equals $33 T_{b}-1700$ (mean value of Dulong-Petit constant between $0^{\circ}$ and $273^{\circ} \mathrm{K}$ is 1700). Heats given in small calories per gram.

| Element. | ${ }^{\circ}{ }^{T b}$ | ${ }_{23} \mathrm{~Tb}$ | Latent heat of vapori zation. | $\begin{gathered} 33 T_{b}- \\ 1700 \end{gathered}$ | Total heat vapor $\underset{273^{\circ} \mathrm{K}}{\substack{\text { from } \\ \hline}}$ $273^{\circ} \mathrm{K}$ | Element. | ${ }^{\text {o }}$ Tb | ${ }_{23} \mathrm{~Tb}_{6}$ | Latent heat of vaporization. | $\begin{gathered} 33 T_{b}- \\ 1700 \end{gathered}$ | Total heat of vapor from $273^{\circ} \mathrm{K}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Hg | 630 | 14,500 | 72 | 19,100 | 96 | Rh | 2773 | 63,800 | 620 | 90,000 | 870 |
| K | 993 | 22,800 | 590 | 31,100 | 800 | Ru | 2790 | 64,100 | 630 | 90,000 | 880 |
| Cd | 1050 | 24,200 | 230 | 33,000 | 310 | Au | 2800 | 64,500 | 330 | 91,000 | 460 |
| Na | 1170 | 27,000 | 1170 | 37,000 | 1610 | Pd | 2810 | 64,600 | 610 | 91,000 | 850 |
| Zn | 1200 | 27,700 | 430 | 38,000 | 580 | Ir | 2820 | 64,800 | 340 | 91,300 | 470 |
| In | 1270 | 29,300 | - | 40,300 | - | Os | 2870 | 66,000 | 350 | 93,000 | 490 |
| Mg | 1370 | 31,600 | 1320 | 43,600 | 1820 | U | 3170 | 73,000 | 305 | 103,000 | 430 |
| Te | 1660 | 38,200 | 300 | 54,900 | 430 | Mo | 3470 | 80,000 | 830 | II3,000 | 1180 |
| Bi | 1710 | 39,300 | 190 | 56,400 | 270 | W | 3970 | 91,400 | 500 | 129,000 | 700 |
| Sb | 1870 | 43,100 | 360 | 60,000 | 510 | $\mathrm{H}_{2}$ | 20 | 460 | 230 | - | - |
| Tl | 1970 | 45,400 | 220 | 63,400 | 310 | $\mathrm{N}_{2}$ | 77 | 1,770 | 63 | - | - |
| Pb | 2070 | 47,700 | 230 | 66,700 | 320 | $\mathrm{O}_{2}$ | 85 | 1,960 | 61 | - | - |
| Ag | 2310 | 53,000 | 490 | 74,600 | 690 | $\mathrm{Cl}_{2}$ | 251 | 5,780 | 8 I | - | - |
| Cu | 2370 | 54,500 | 860 | 76,600 | 1210 | $\mathrm{Br}_{2}$ | 33 I | 7,600 | 48 | - | - |
| Sn | 2440 | 56,100 | 480 | 78,800 | 670 | $\mathrm{I}_{3}$ | 447 | 10,300 | 27 | - |  |
| Mn | 2470 | 56,500 | 1030 | 79,500 | 1440 | $\mathrm{P}_{3}$ | 560 | 13,000 | 138 | - | - |
| Ni | 2690 | 59,800 | 1010 | 84,000 | 1420 | $\mathrm{As}_{3}$ | 723 | 16,600 | 74 | - | - |
| Cr | 2640 | 60,700 | 1170 | 85,400 | 1640 | $\mathrm{Se}_{3}$ | 963 | 22,100 | 94 | - | - |
| Fe | 2690 | 62,000 | IIIO | 87,200 | 1560 | $\mathrm{B}_{2}$ | 3970 | 91,000 | 4200 | - | - |
| Pt | 2720 | 62,600 | 320 | 88,000 | 450 | $\mathrm{C}_{2}$ | 3970 | 91,000 | 3800 | - |  |
| Ti | 2750 | 63,200 | 1320 | 89,000 | I850 |  |  |  |  |  |  |

Smithsonian Tables.

## Metrio and Common Units.

Reprinted by permission of the author and publishers from "Tables of the Properties of Steam," Cecil H. Peabody, Sth edition, rewritten in 1909. Calorie used is heat required to raise i Kg . water from $15^{\circ}$ to $16^{\circ} \mathrm{C}$. B. T. U. is heat required to raise 1 pd. water from $62^{\circ}$ to $63^{\circ} \mathrm{F}$. Mechanical Equiv. of heat used, $77^{8} \mathrm{ft}$. pds. or $427 \mathrm{~m} . \mathrm{Kg}$. Specific heats, see Barnes-Kegnault-Peabody results, p. 227. Heat of Liquid, q. heat required to raise i Kg. (i lb.) to corresponding temperature from on C . Heat of vaporization, r . heat required to vaporize $\mathrm{I}_{\mathrm{Kg}} \mathrm{Kg}$. I lb .) at corresponding temperature to dry saturated vapor against corresponding pressure; see Henning, Ann. der Phys., 21, p. 849, 1906. Total Heat, H=r+q, see Davis, T'r. Am. Soc. Mech. Eng., 1908.

|  | Pressure. |  |  | Heat of the Liquid. |  | Heat of Vaporization. |  | Heat Equivalent of Internal Work. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Mm. of Mercury. p. | $\begin{gathered} \text { Kg. } \\ \underset{\text { per sq. }}{\text { p. }} \text { p. } \\ \text { p. } \end{gathered}$ | $\begin{aligned} & \text { Pds. } \\ & \text { per sq. in. } \\ & \text { p. } \end{aligned}$ | Calories. <br> q. | $\begin{gathered} \text { B. T } \\ \text { q. } \end{gathered}$ | Calories. <br> r. | $\begin{gathered} \text { B. T. U. } \\ \mathrm{r} . \end{gathered}$ | Calories. $\rho$. | $\begin{aligned} & \text { B. T. U. } \\ & \quad \rho . \end{aligned}$ |  |
| 0 | 4.579 | 0.00623 | 0.0886 | 0.00 | 0.0 | 595.4 | 1071.7 | 565.3 | 1017.5 | 32.0 |
| 5 | 6.541 | .00859 | . 1265 | 5.04 | 9.1 | 592.8 | 1067.1 | 562.2 | 1011.9 | 41.0 |
| 10 | 9.205 | . 01252 | .1780 | 10.06 | 18.1 | 590.2 | 1062.3 | 559.0 | 1006.2 | 50.0 |
| 15 | 12.779 | . 01737 | . 2471 | 15.06 | 27.1 | 587.6 | 1057.6 | 555.9 | 1000.5 | 59.0 |
| 20 | 17.51 | . 0238 SI | $\cdot 3386$ | 20.06 | 36.1 | 584.9 | 1052.8 | 552.7 | 994.8 | 68.0 |
| 25 | 23.69 | . 03221 | .4581 | 25.05 | 45. I | 582.3 | 1048.1 | $549 \cdot 5$ | 989.1 | 77.0 |
| 30 | 31.71 | . 0431 I | $\bigcirc 132$ | 30.04 | 54.1 | 579.6 | 1043.3 | 546.3 | 983.4 | 86.0 |
| 35 | 42.02 | . 05713 | .8126 | 35.03 | 63.1 | 576.9 | 1038.5 | 543.1 | 977.6 | 95.0 |
| 40 | 55.13 | . 07495 | 1.0661 | 40.02 | 72.0 | 574.2 | 1033.5 | 539.9 | 971.7 | 104.0 |
| 45 | 71.66 | . 09743 | $1.385^{8}$ | 45.00 | 81.0 | 571.3 | 1028.4 | 536.5 | 965.7 | 113.0 |
| 50 | 92.30 | . 12549 | 1.7849 | 49.99 | 90.0 | 568.4 | 1023.2 | 533.0 | 959.6 | 122.0 |
| 55 | 117.85 | . 16023 | 2.279 | 54.98 | 99.0 | 565.6 | 1018.1 | 539.7 | 953.5 | 131.0 |
| 60 | 149.19 | . 20284 | 2.885 | 59.97 | 108.0 | 562.8 | 1013.1 | 526.4 | $947 \cdot 5$ | 140.0 |
| 65 | 187.36 | . 2547 | 3.623 | 64.98 | 117.0 | 559.9 | 1007.8 | 523.0 | 941.3 | 149.0 |
| 70 | $233 \cdot 53$ | . 3175 | $4 \cdot 516$ | 69.98 | 126.0 | 556.9 | 1002.5 | 519.5 | 935.0 | 158.0 |
| 75 | 289.0 | -3929 | $5 \cdot 589$ | 74.99 | ${ }^{1} 35.0$ | 554.0 | 997.3 | 516.0 | 928.8 | 167.0 |
| 80 | 355.1 | . 4828 | 6.867 | 80.01 | 144.0 | 55 I .1 | 991.9 | 512.6 | 922.6 | 176.0 |
| 85 | 433.5 | .5894 | 8.383 | 85.04 | 153.1 | 54.1 | 986.5 | 509.1 | 916.3 | 185.0 |
| 90 | 525.8 | .7149 | 10.167 | 90.07 | 162.1 | 544.9 | 980.9 | 505.4 | 909.9 | 194.0 |
| 91 | 546.1 | .7425 | 10.560 | 91.08 | 163.9 | 544.3 | 979.8 | 504.7 | 908.5 | 195.8 |
| 92 | 567.1 | . 7710 | 10.966 | 92.08 | 165.7 | 543.7 | 978.7 | 504.0 | 907.2 | 197.6 |
| 93 | 588.7 | . 8004 | 11.384 | 93.09 | 167.5 | 543.1 | 977.6 | $503 \cdot 3$ | 906.0 | 199.4 |
| 94 | 611.0 | . 8307 | II.8I 5 | 94.10 | 169.3 | 542.5 | 976.5 | 502.6 | 904.7 | 201.2 |
| 95 | 634.0 | . 8620 | 12.260 | 95.11 | 171.2 | 541.9 | 975.4 | 501.9 | 903.4 | 203.0 |
| 96 | 657.7 | . 8942 | 12.718 | 96.12 | 173.0 | 541.2 | 974.2 | 501.1 | 902.1 | 204.8 |
| 97 | 682.1 | . 9274 | 13.190 | 97.12 | 174.8 | 540.6 | 973.1 | 500.4 | 900.8 | 206.6 |
| 98 | $707 \cdot 3$ | . 9616 | 13.678 | 98.13 | 176.6 | 539.9 | 971.9 | 499.6 | 899.4 | 208.4 |
| 99 | $733 \cdot 3$ | . 9970 | 14.180 | 99.14 | 178.5 | 539.3 | 970.8 | 498.9 | 898.2 | 210.2 |
| 100 | 760.0 | 1.0333 | 14.697 | 100.2 | 180.3 | 538.7 | 969.7 | 498.2 | 896.9 | 212.0 |
| 101 | 787.5 | 1.0707 | 15.229 | 101.2 | 182.1 | 538.1 | 968.5 | $497 \cdot 5$ | 895.5 | 213.8 |
| 102 | 815.9 | 1.1093 | 15.778 | 102.2 | 183.9 | 537.4 | $967 \cdot 3$ | 496.8 | 894.1 | 215.6 |
| 103 | 845.1 | I. 1490 | 16.342 | 103.2 | 185.7 | 536.8 | 966.2 | 496.1 | 892.9 | 217.4 |
| 104 | 875.1 | 1.1898 | 16.923 | 104.2 | 187.6 | 536.2 | 965. I | $495 \cdot 4$ | 891.6 | 219.2 |
| 105 | 906.1 | 1.2319 | 17.522 | 105.2 | 189.4 | 535.6 | 964.0 | 494.7 | 890.3 | 221.0 |
| 106 | 937.9 | 1.2752 | 18.137 | 106.2 | 191.2 | 534.9 | 962.8 | 493.9 | 889.0 | 222.8 |
| 107 | 970.6 | 1.3196 | 18.769 | 107.2 | 193.0 | 534.2 | 96 I .6 | 493.1 | 887.6 | 224.6 |
| 108 | 1004.3 | 1.3653 | 19.420 | 108.2 | 194.8 | 533.6 | 960.5 | 492.4 | 886.3 | 226.4 |
| 109 | 1038.8 | 1.4123 | 20.089 | 109.3 | 196.7 | 5.32 .9 | 959.3 | 49 I .6 | 885.0 | 228.2 |
| 110 | $1074 \cdot 5$ | 1.4608 | 20.777 | 110.3 | 198.5 | 532.3 | 958.1 | 490.9 | 883.6 | 230.0 |
| 1112 | 1111.1 | 1.5106 | 21.486 | 111.3 | 200.3 | 531.6 | 956.9 | 490.2 | 882.3 | 231.8 |
| 112 | 1148.7 | 1.5617 | 22.214 | 112.3 | 202.1 | 530.9 | 955.7 | 489.4 | 880.9 | 233.6 |
| 113 | 1187.4 | 1.614 .4 1.6654 | 22.962 | 113.3 | 203.9 | 530.3 | $954 \cdot 5$ | 488.7 | 879.5 | 235.4 |
| 114 | 1227.1 | 1.6654 | 23.729 | 114.3 | 205.8 | 529.6 | 953.3 | 487.9 | 878.2 | 237.2 |
| 115 | 1267.9 | 1.7238 | 24.518 | 115.3 | 207.6 | 528.9 | 952.1 | 487.1 | 876.8 | 239.0 |
| 116 | 1309.8 | 1.7808 | 25.328 | 116.4 | 209.4 | 528.2 | 950.8 | 486.3 | 875.4 | 240.8 |
| 117 118 | 1332.8 1397.0 | 1.8393 I .8993 | 26.150 | 117.4 | 211.2 | 527.5 | $949 \cdot 5$ | 485.5 | 873.9 | 242.6 |
| 118 | 1397.0 | 1.8993 | 27.015 | 118.4 | 213.0 | 526.9 | 948.4 | 484.8 | 872.6 | 24.4 .4 |
| 119 | 1442.4 | I.961 1 | 27.893 | 119.4 | 214.9 | 526.2 | $947 \cdot 2$ | 484.0 | 871.3 | 246.2 |

Table 259 (continued).
PROPERTIES OF SATURATED STEAM.

## Metric and Common Units.

If a is the reciprocal of the Mechanical Equivalent of Heat, p the pressure, $s$ and $\sigma$ the specific volumes of the liquid and the saturated vapor, $s-. \sigma$, the change of volume, then the heat equivalent of the external work is Apu $=$ $\mathrm{Ap}(\mathrm{s}-\sigma)$. Heat equivalent of internal work, $\rho=\mathrm{r}-\mathrm{Apu}$. For experimental sp. vols. see k noblauch, linde and Klebe, Mitt. über Forschungarbeiten, 21, p. 33, 1905. Entropy $=\mathrm{SdQ} / \mathrm{T}$, where $\mathrm{dQ}=$ amount of heat added at absolute temperature T. For pressures of saturated steam see Holborn and Henning, Ann. der Plyys. 26, p. 833, 1908; for temperatures above $205^{\circ} \mathrm{C}$. corrected from Regnault.

|  | Heat Equivalent of External W ork. |  | Entropy of the Liquid. | Entropy of Evaporation. | Specific Volume. |  | Density. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Calories. | B.T.U. |  |  | Cubic Meters per Kilogram. | Cubic Feet per Pound. | Kilograms per Cubic Meter. | Pounds per Cubic Foot. |  |
| t | Apu. | Apu. | $\theta$ | $\stackrel{\mathrm{r}}{\mathrm{T}}$ | s | s | 1 s | $\begin{aligned} & 1 \\ & 8 \end{aligned}$ |  |
| $\bigcirc$ | 30.1 | 54.2 | 0.0000 | 2.1504 | 206.3 | 3304. | 0.00485 | 0.000303 | 32.0 |
| 5 | 30.6 | 55.2 | . 0183 | 2.1320 | I 47. I | 2356. | .00680 | . 000424 | 41.0 |
| 10 | 31.2 | 56.1 | .0361 | 2.0850 | 106.3 | 1703. | . 00941 | . 000587 | 50.0 |
| 15 | 31.7 | 57.1 | . 0537 | 2.0396 | 77.9 | 1248. | . 01283 | .000801 | 59.0 |
| 20 | 32.2 | 58.0 | . 0709 | I. 9959 | 57.8 | 926. | . 01730 | . 001080 | 68.0 |
| 25 | 32.8 | 59.0 | . 0878 | 1.9536 | 43.40 | 695. | . 02304 | . 001439 | 77.0 |
| 30 | $33 \cdot 3$ | 59.9 | . 1044 | 1.9126 | 32.95 | 528. | . 03035 | . 001894 | 86.0 |
| 35 | 33.8 | 60.9 | . 1207 | 1. 8728 | 25.25 | 404.7 | . 03960 | . 002471 | 95.0 |
| 40 | 34.3 | 61.8 | . 1368 | I. 834 I | 19.57 | 313.5 | .0511 | .003190 | 104.0 |
| 45 | 34.8 | 62.7 | .1526 | 1.7963 | I 5.25 | 244.4 | .0656 | .004092 | 113.0 |
| 50 | 35.4 | 63.6 | . 1682 | 1.7597 | 12.02 | 192.6 | .0832 | . 00519 | 122.0 |
| 55 | 35.9 | 64.6 | .1835 | 1.7242 | 9.56 | 153.2 | . 1046 | . 00653 | 131.0 |
| 60 | 36.4 | 65.6 | . 1986 | 1. 6899 | 7.66 | 122.8 | . 1305 | . 00814 | 140.0 |
| 65 | 36.9 | 66.5 | .2135 | 1. 6563 | 6.19 | 99.2 | .1615 | . 01008 | 149.0 |
| 70 | 37.4 | 67.4 | . 2282 | 1.6235 | 5.04 | 80.7 | . 1984 | . 01239 | 158.0 |
| 75 | 38.0 | 68.5 | . 2427 | I. 5918 | 4.130 | 66.2 | .2421 | . 01510 | 167.0 |
| So | 38.5 | 69.3 | . 2570 | 1. 5609 | 3.404 | 54.5 | . 2938 | . 01835 | 176.0 |
| 85 | 39.0 | 70.2 | . 2711 | 1. 5307 | 2.824 | 45.23 | . 3541 | . 02211 | 185.0 |
| 90 | 39.5 | 71.0 | . 2851 | 1.5010 | 2.358 | 37.77 | . 424 I | . 02648 | 194.0 |
| 91 | 39.6 | 71.3 | . 2879 | $1.495^{2}$ | 2.275 | 36.45 | . 4395 | . 02743 | 195.8 |
| 92 | 39.7 | 71.5 | . 2906 | 1.4894 | 2.197 | 35.19 | . 4552 | . 02842 | 197.6 |
| 93 | 39.8 | 71.6 | . 2934 | 1. 4836 | 2.122 | 34.00 | . 47 I 3 | . 02941 | 199.4 |
| 94 | 39.9 | 71.8 | . 2961 | 1.4779 | 2.050 | 32.86 | .4878 | . 03043 | 201.2 |
| 95 | 40.0 | 72.0 | .2989 | 1.4723 | I. 980 | 31.75 | . 505 | .03149 | 203.0 |
| 96 | 40.1 | 72.1 | . 3016 | I. 4666 | 1.913 | 30.67 | . 523 | . 03260 | 204.8 |
| 97 | 40.2 | 72.3 | - 3043 | 1.4609 | 1.849 | 29.63 | . 541 | . 03375 | 206.6 |
| 98 | 40.3 | 72.5 | . 3070 | 1.4552 | 1.787 | 28.64 | . 560 | . 03492 | 208.4 |
| 99 | 40.4 | 72.6 | . 3097 | I. 4496 | 1.728 | 27.69 | . 579 | .03611 | 210.2 |
| 100 | 40.5 | 72.8 | -3125 | I. 4441 | 1.671 | 26.78 | . 598 | . 03734 | 212.0 |
| 101 | 40.6 | 73.0 | -3152 | 1.4386 | 1.617 | 25.90 | . 618 | . 03861 | 213.8 |
| 102 | 40.6 | 73.2 | . 3179 | I. 4330 | 1. 564 | 25.06 | .639 | . 03990 | 215.6 |
| 103 | 40.7 | $73 \cdot 3$ | . 3205 | I. 4275 | 1.514 | 24.25 | .661 | W. 04124 | 217.4 |
| 10.4 | 40.8 | 73.5 | . 3232 | I. 4220 | 1.465 | 23.47 | . 683 | . 04261 | 219.2 |
| 105 | 40.9 | 73.7 | . 3259 | 1.4165 | 1.419 | 22.73 | .705 | . 04400 | 221.0 |
| 106 | 41.0 | 73.8 | - 3286 | 1.4111 | 1. 374 | 22.01 | .728 | . 04543 | 222.8 |
| 107 | 41.1 | 74.0 | - 3312 | 1.4057 | 1.33 I | 21.31 | . 751 | . 04692 | 224.6 |
| 108 | 41.2 | 74.2 | . 3339 | 1.4003 | I. 289 | 20.64 | . 776 | . 04845 | 226.4 |
| 109 | 41.3 | 74.3 | . 3365 | I. 3949 | 1.248 | 19.99 | . 801 | . 0500 | 228.2 |
| 110 | 41.4 | 74.5 | -3392 | I. 3895 | 1.209 | 19.37 | . 827 | . 0516 | 230.0 |
| 111 | 41.4 | 74.6 | . 3418 | 1.3842 | 1.172 | 18.77 | . 853 | . 0533 | 231.8 |
| 112 | 41.5 | 74.8 | . 3445 | 1.3789 | I. 136 | 18.20 | . 880 | . 0550 | 233.6 |
| 113 | 41.6 | 75.0 | -347 1 | I. 3736 | I.IOI | 17.64 | . 908 | . 0567 | 235.4 |
| 114 | 41.7 | 75.1 | - 3498 | I. 3683 | 1.068 | 17.10 | .936 | . 0585 | 237.2 |
| 115 | 41.8 | $75 \cdot 3$ | . 3524 | 1.3631 | 1.036 | 16.59 | . 965 | . 0603 | 239.0 |
| 116 | 41.9 | 75.4 | . 3550 | 1.3579 | 1.005 | 16.09 | . 995 | .0622 | 240.8 |
| 117 | 42.0 | 75.6 | - 3576 | 1.3527 | 0.9746 | 15.61 | 1. 026 | . 0641 | 242.6 |
| 118 | 42.1 | 75.8 | . 3602 | I. 3475 | 0.9460 | 15.16 | 1.057 | . 0659 | 244.4 |
| 119 | 42.2 | 75.9 | . 3628 | 1.3423 | 0.9183 | 14.72 | 1.089 | . 0679 | 246.2 |

Metric and Common Units.

|  | Pressure |  |  | Heat of the Liquid. |  | $\begin{gathered} \text { Heat of } \\ \text { Vaporization. } \end{gathered}$ |  | Heat Equivalent of Internal Work. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Kg. per sq. cm. p. | Pds. per sq. in. p. | Calories. | B. T. U. <br> q | Calories. | B. T. U. | Calories | B. T. U. |  |
| 120 | 1489 | 2.024 | 28.79 | 120.4 | 216.7 | 525.6 | 946.0 | 483.4 | 870.0 | 248.0 |
| 121 | 1537 | 2.089 | 29.72 | 121.4 | 218.5 | 524.9 | 944.8 | 482.6 | 868.6 | 24.8 |
| 122 | ${ }_{1} 586$ | 2.156 | 30.66 | 122.5 123.5 | 220.4 222.2 | 524.2 523.5 | $943 \cdot 5$ 942.3 | 481.0 | 865.8 | 251.6 253.4 |
| 123 | 1636 1685 | 2.224 2.29 .4 | 31.64 32.64 | 123.5 124.5 | 222.2 224.1 | 523.5 522.8 | 942.3 941.0 | 481.0 480.2 | 86.1 864.3 | 253.4 255.2 |
| 125 | 1740 | 2.366 | 33.66 | 125.5 | 225.9 | 522.1 | 939.9 | 479.4 | 863.0 | 257.0 |
| 126 | 1795 | 2.440 | 334.71 | 126.5 | 227.7 | 521.4 | 938.6 | 478.6 | 861.6 | 258.8 |
| 127 | 1850 | 2.516 | 35.78 | 127.5 | 229.5 | 520.7 | 937.3 | 477.8 | 860.2 | 260.6 |
| 128 | 1907 | 2.593 | 36.88 | 128.6 | 231.4 | 520.0 | 936.1 | 477.0 | 858.8 | 262.4 |
| 129 | 1966 | 2.673 | 38.01 | 129.6 | $233 \cdot 3$ | 519.3 | 934.8 | 476.3 | 857.4 | 264.2 |
| 130 | 2026 | 2.754 | 39.17 | I 30.6 | 235.1 | 518.6 | 933.6 | 475.5 | 856.0 | 266.0 |
| ${ }_{13}{ }^{1}$ | 2087 | 2.837 | 40.36 | 131.6 | 236.9 | 517.9 | 932.3 | 474.7 | 854.6 | 267.8 |
| 132 | 2150 | 2.923 | 41.57 | 132.6 | 238.7 20.6 | 517.3 516.6 | $93 \mathrm{Pr.1}$ | 474.0 | 853.2 851.8 | 269.6 |
| 133 | 2214 | 3.010 | 42.81 44.09 | 133.7 134.7 | 2.40 .6 242.4 | 516.6 515.9 | 929.8 928.5 | 473.3 472.5 | 851.8 850.4 | 271.4 273.2 |
| 134 | 2280 | 3.100 | 44.09 | 134.7 | 242.4 | 515.9 | 928.5 | 472.5 |  | 273.2 |
|  | 2348 | 3.192 | 45.39 | 135.7 | 244.2 | 515.1 | 927.2 | 471.6 | 848.9 | 275.0 |
| 136 | 2416 | 3.285 | 46.73 | 136.7 | 246.0 | 514.4 | 925.9 | 470.8 | 847.5 | 276.8 |
| 137 | 2487 | $3 \cdot 3^{82}$ | 48.10 | 137.7 | 247.9 | 513.7 | 924.6 | 470.1 | 846.1 | 278.6 |
| 138 | 2560 | $3 \cdot 480$ | 49.50 | 138.8 | 249.7 | 513.0 | 923.3 | 469.3 | 844.6 | 280.4 |
| ${ }^{1} 39$ | 2634 | 3.581 | 50.93 | 139.8 | 251.6 | 512.3 | 922.1 | 468.5 | $843 \cdot 3$ | 282.2 |
| 140 | 2710 | 3.684 | 52.39 | 140.8 | 253.4 | 511.5 | 920.7 | 467.6 | 841.8 | 284.0 |
| 141 | 2787 | 3.789 | 53.89 | 141.8 | 255.3 | 510.7 | 919.3 | 466.8 | 840.2 | 285.8 |
| 142 | 2866 | 3.897 | 55.43 | 142.8 | 257. I | 510.1 | 918.1 | 466.1 | 838.9 | 287.6 |
| 143 | 2948 | 4.008 | 57.00 | 143.9 | 259.0 | 509.3 | 916.7 | $465 \cdot 3$ | 837.4 | 289.4 |
| 144 | 3030 | 4.121 | 58.60 | 144.9 | 260.8 | 508.6 | 915.4 | 464.4 | 835.9 | 291.2 |
| 145 | 3115 | 4.236 | 60.24 | 145.9 | 262.7 | 507.8 | 914.1 | 463.6 | 834.5 | 293.0 |
| 146 | 3202 | 4.354 | 61.92 | 146.9 | 264.5 | 507.1 | 912.8 | 462.8 | 833.1 | 294.8 |
| 147 | 3291 | 4.474 | 63.64 | 148.0 | 266.4 | 506.4 | 911.5 | 462.0 | 831.6 | 296.6 |
| 148 | 3381 | 4.597 4.723 | 65.39 67.18 | 149.0 | 268.2 270.1 | 505.6 504.9 | 910.1 908.8 | 46 r .2 460.4 |  | 298.4 300.2 |
| 149 | 3474 | 4.723 | 67.18 | 150.0 | 270.1 | 504.9 | 908.8 | 460.4 | 828.7 | 300.2 |
| 150 | 3569 | 4.852 | 69.01 | 151.0 | 271.9 | 504.1 | 907.4 | 459.5 | 827.2 | 302.0 |
| 151 | 3665 | 4.984 | 70.88 | 152.1 | 273.8 | 503.4 | 906.1 | 458.7 | 825.7 | 303.8 |
| ${ }_{1}{ }^{5}$ | 3764 | 5.118 | 72.79 | 153.1 | 275.6 | 502.6 | 904.7 | 457.9 | 824.2 | 305.6 |
| 153 | 3865 | 5.255 | 74.74 | 154.1 | $277 \cdot 4$ | 501.9 | 903.3 | 457.I | 82.7 | 307.4 |
| ${ }^{1} 54$ | 3968 | $5 \cdot 395$ | 76.73 | ${ }^{1} 55.1$ | 279.2 | 501.1 | 901.9 | 456.3 | 821.2 | 309.2 |
|  | 4073 | 5.538 | 78.76 | 156.2 | $28 \mathrm{I} . \mathrm{I}$ | 500.3 | 900.5 |  | 819.6 |  |
| 156 | 4181 | 5.684 | 80.84 | 157.2 | 283.0 | 499.6 | 899.2 | 454.6 | 818.2 | 312.8 |
| 157 | 4290 | 5.833 | 82.96 | 158.2 | 284.8 | 498.8 | 897.8 | 453.8 | 816.7 | 314.6 |
| ${ }_{158}^{15}$ | 4402 | 5.985 | 85.12 | 159.3 | 286.7 | 498.1 | 896.5 | 453.0 | 815.3 | 316.4 |
| ${ }^{1} 59$ | 4517 | 6.141 | 87.33 | 160.3 | 288.5 | $497 \cdot 3$ | 895.1 | $45^{2.1}$ | 813.7 | 318.2 |
| 160 | 4633 | 6.300 | 89.59 | 16 I .3 | 290.4 | 496.5 | 893.7 | 451.2 | 812.2 | 320.0 |
| 161 | 4752 | 6.462 | 91.89 | 162.3 | 292.2 | 495.7 | 892.3 | 450.4 | 810.7 | 321.8 |
| 162 | 4874 | 6.628 | 94.25 | 163.4 | 294.1 | 494.9 | 890.9 | 449.5 | 809.2 | 323.6 |
| 163 | 4998 | 6.796 | 96.65 | 164.4 | 295.9 | 494.2 | 889.5 | 448.7 | 807.7 | 325.4 |
| 164 | 5124 | 6.967 | 99.09 | 165.4 | 297.7 | $493 \cdot 4$ | 888.1 | 447.9 | 806.2 | 327.2 |
| 165 | 5253 | 7.142 | 101. 6 | 166.5 | 299.6 | 492.6 | 886.7 | 447.0 | 804.7 | 329.0 |
| 165 | 5384 | 7.320 | 104.1 | 167.5 | 301.5 | 491.9 | 885.4 | 446.3 | 803.3 | 330.8 |
| 167 168 | 5518 5655 | 7.502 7.688 | 106.7 109.4 | 168.5 | 303.3 305.1 | 491.1 | 883.9 882.5 | 445.4 444.6 | 801.7 800.1 | 332.6 334.4 |
| 169 | 5794 | 7.877 | 112.0 | 170.6 | 307.0 | 498.3 489.5 | 881.0 | 444.6 | 800.1 798.5 | 334.4 336.2 |

PROPERTIES OF SATURATED STEAM.
Matric and Common Units.

|  | Heat Equivalent of External Work. |  | Entropy of the Liquid. <br> $\theta$. | Entropy of Evaporation.$\frac{\mathrm{r}}{\mathbf{T}}$ | Specific Volume. |  | Density. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Calories. | B. T. U. |  |  | Cubic Meters per Kilogram. | Cubic <br> Feet per Pound. | Kilograms per Cubic Meter. | Pounds per Cubic Foot. |  |
|  | Apu. | Apu. |  |  | s. | s. | ${ }_{8}^{1 .}$ | ${ }_{8}^{1 .}$ |  |
| 120 | 42.2 | 76.0 | 0.3654 | 1. 3372 | 0.8914 | 14.28 | 1.122 | 0.0700 | 248.0 |
| 121 | 42.3 | 76.2 | . 3680 | I.3321 | . 8653 | 13.86 | I. 156 | . 0721 | 249.8 |
| 122 | 42.4 | 76.4 | . 3705 | 1. 3269 | . 8401 | 13.46 | 1.190 | . 0743 | 251.6 |
| 123 | 42.5 | 76.5 | . 3731 | I. 3218 | .8I 58 | 13.07 | I. 226 | . 0765 | 253.4 |
| 124 | 42.6 | 76.7 | . 3756 | 1.3167 | . 7924 | 12.69 | 1.262 | . 0788 | 255.2 |
| 125 | 42.7 | 76.8 | . 3782 | 1.3117 | .7698 | 12.33 | 1.299 | . 0811 | 257.0 |
| 126 | 42.8 | 77.0 | . 3807 | 1.3067 | . 7479 | 11.98 | 1.337 | . 0835 | 258.8 |
| 127 | 42.9 | 77.1 | -3833 | 1.3017 | . 7267 | 11.64 | 1. 376 | . 0859 | 260.6 |
| 128 | 43.0 | 77.3 | . 3858 | 1.2967 | . 7063 | 11.32 | 1. 416 | . 0883 | 262.4 |
| 129 | 43.0 | $77 \cdot 4$ | -3884 | 1.2917 | . 6867 | 11.00 | 1. 456 | .0909 | 264.2 |
| 130 | 43.1 | 77.6 | - 3909 | 1. 2868 | . 6677 | 10.70 | 1. 498 | . 0935 | 266.0 |
| 131 | 43.2 | 77.7 | - 3934 | 1.2818 | . 6493 | 10.40 | 1.540 | .0961 | 267.8 |
| 132 | $43 \cdot 3$ | 77.9 | - 3959 | 1.2769 | .6315 | 10.12 | I. 583 | . 0988 | 269.6 |
| 133 | $43 \cdot 3$ | 78.0 | - 3985 | 1.2720 | . 6142 | 9.839 | 1. 628 | . 1016 | 271.4 |
| 134 | $43 \cdot 4$ | 78.1 | . 4010 | 1.2672 | . 5974 | 9.569 | I. 674 | .1045 | 273.2 |
| 135 | $43 \cdot 5$ | 78.3 | . 4035 | 1.2623 | . 5812 | 9.309 | 1.721 | . 1074 | 275.0 |
| 136 | 43.6 | 78.4 | . 4060 | I. 2574 | .5656 | 9.060 | 1.768 | . 1104 | 276.8 |
| 137 | 43.6 | 78.5 | . 4085 | 1.2526 | . 5506 | 8.820 | ı. 816 | . I 34 | 278.6 |
| 138 | 43.7 | 78.7 | .4110 | 1.2479 | . 5361 | 8.587 | 1.865 | . 1165 | 280.4 |
| 139 | 43.8 | 78.8 | .4135 | 1.2431 | . 5219 | 8.360 | 1.916 | . 1196 | 282.2 |
| 140 | $43 \cdot 9$ | 78.9 | .4160 | 1.2383 | .5081 | 8.140 | 1.968 | . 1229 | 284.0 |
| 141 | 43.9 | 79.1 | .4185 | I. 2335 | . 4948 | 7.926 | 2.021 | .1262 | 285.8 |
| 142 | 44.0 | 79.2 | . 4209 | I. 3288 | . 4819 | 7.719 | 2.075 | . 1296 | 287.6 |
| 143 | 44.0 | 79.3 | . 4234 | 1.2241 | . 4694 | $7 \cdot 519$ | 2.130 | .1330 | 289.4 |
| 144 | 44.2 | 79.5 | . 4259 | 1.2194 | . 4574 | $7 \cdot 326$ | 2.186 | .1365 | 291.2 |
| 145 | 44.2 | 79.6 | .4283 | I. 2147 | . 4457 | 7.139 | 2.244 | . 1401 | 293.0 |
| 146 | 44.3 | 79.7 | . 4307 | 1.2100 | -4343 | 6.957 | 2.303 | . 1437 | 294.8 |
| 147 | 44.4 | 79.9 | . 4332 | 1.2054 | .4232 | 6.780 | 2.363 | . 1475 | 296.6 |
| 148 | 44.4 | 80.0 | . 4356 | 1.2008 | .4125 | 6.609 | 2.424 | .1513 | 298.4 |
| 149 | 44.5 | 80.1 | . 4380 | 1.1962 | . 4022 | 6.443 | 2.486 | . $155{ }^{2}$ | 300.2 |
| 150 | 44.6 | 80.2 | . 4405 | 1.1916 | -392I | 6.282 | 2.550 | . 1592 | 302.0 |
| 151 | 44.6 | 80.4 | . 4429 | 1.1870 | . 3824 | 6.126 | 2.615 | .1632 | 303.8 |
| 152 | 44.7 | So. 5 | . 4453 | 1.1824 | . 3729 | 5.974 | 2.682 | .1674 | 305.6 |
| 153 | 44.8 | 80.6 | . 4477 | 1.1778 | .3637 | 5.826 | 2.750 | .1716 | 307.4 |
| 154 | 44.8 | 80.7 | . 4501 | 1.1733 | . 3548 | 5.683 | 2.818 | .1759 | 309.2 |
| 155 | 44.9 | 80.9 | -4525 | 1.1688 | . 3463 | $5 \cdot 546$ | 2.888 | .1803 | 311.0 |
| 156 | 45.0 | 81.0 | -4549 | I. 1644 | . 3380 | 5.413 | 2.959 | .1847 | 312.8 |
| 157 | 45.0 | 8 I .1 | . 4573 | I. 1599 | -3298 | $5 \cdot 282$ | 3.032 | . 1893 | 314.6 |
| 158 | 45.1 | 81.2 | . 4596 | 1.1554 | -3218 | 5.154 | $3 \cdot 108$ | . 1940 | 316.4 |
| 159 | 45.2 | 81.4 | . 4620 | 1.1509 | -3140 | 5.029 | 3.185 | . 1988 | 318.2 |
| 160 | $45 \cdot 3$ | 8 I .5 | .4644 | I.1465 | . 3063 | 4.906 | 3.265 | . 2038 | 320.0 |
| 161 | $45 \cdot 3$ | Si. 6 | . 4668 | 1.142 I | . 2989 | 4.789 | $3 \cdot 345$ | . 2088 | 321.8 |
| 162 | 45.4 | 8 I .7 | .4692 | 1.1377 | . 2920 | 4.677 | $3 \cdot 425$ | . 2138 | 323.6 |
| 163 | 45.5 | 8 8 .8 | .4715 | 1.1333 | .2855 | 4.571 | $3 \cdot 503$ | . 2188 | 325.4 |
| 164 | 45.5 | 8 I .9 | . 4739 | 1.1289 | .2792 | 4.469 | $3 \cdot 582$ | .2238 | 327.2 |
| 165 | 45.6 | 82.0 | .4763 | 1.1245 | .2729 | $4 \cdot 368$ | 3.664 | .2289 | 329.0 |
| 166 | 45.6 | 82.1 | . 4786 | 1.1202 | .2666 | 4.268 | 3.751 | . 2343 | 330.8 |
| 167 | 45.7 | 82.2 | . 4810 | 1.1159 | .2603 | 4.168 | 3.842 | . 2399 | 332.6 |
| 168 : | 45.7 | 82.4 | .4833 | I. 1115 | . 2540 | 4.070 | 3.937 | . 2457 | $334 \cdot 4$ |
| 169 | 45.8 | 82.5 | .4857 | 1.1072 | .248o | 3.975 | 4.032 | .2516 | 336.2 |

Metric and Common Units.

|  | Pressure. |  |  | Heat of the Liquid. |  | Heat of Vaporization. |  | Heat Equivalent of Internal Work. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Mm. of Mercury. p. | Kg. per sq. cm. p. | Pds. per sq. in. p. | Calories. <br> q. | B. T. U. q. | Calories. | B. T. U. | Calories. | B. T. U. p. |  |
| 170 | 5937 | 8.071 | 11.4 .8 | 171.6 | 308.9 | 488.7 | 879.6 | $442 . \mathrm{S}$ | 797.0 | 338.0 |
| 171 | 6081 | 8.268 | 117.6 | 172.6 | 310.7 | 487.9 | 878.3 | 441.9 | 795.6 | 339.8 |
| 172 | 6229 | 8.469 | 120.4 | 173.7 | 312.6 | 487.1 | 876.9 | 441.1 | 794. 1 | 341.6 |
| 173 | 6379 | 8.673 | 123.4 | 174.7 | 314.5 | 486.3 | 875.4 | 440.2 | 792.5 | 3.33 .4 |
| 174 | 6533 | 8.852 | 126.3 | 175.7 | $3^{16.3}$ | 485.5 | 873.9 | 439.4 | 790.9 | 345.2 |
| 175 | 6689 | 9.094 | 129.4 | 176.8 | 318.2 | 484.7 | 872.4 | 438.5 | 789.3 | 347.0 |
| 176 | 68.48 | 9.310 | 132.4 | 177.8 | 320.0 | 483.9 | 871.0 | 437.7 | 787.8 | 348.8 |
| 177 | 7010 | 9.53 .1 | 135.6 | 178.8 | 321.8 | 483.1 | 869.5 | 436.8 | 786.2 | 350.6 |
| 178 | 7175 | 9.755 | 138.8 | 179.9 | 323.7 | 482.3 | 868.1 | 436.0 435.0 | 784.7 783.1 | 352.4 354.2 |
| 179 | 7343 | 9.983 | 142.0 | I 80.9 | 325.6 | 48 I .4 | 866.6 | 435.0 | 783.1 | 354.2 |
| 1 So | 7514 | 10.216 | 1.45 .3 | 181.9 | 327.5 | 480.6 | 865.1 | 434.2 | 781.5 | 356.0 |
| $1 \mathrm{~S}_{1}$ | 7688 | 10.453 | 148.7 | 183.0 | 329.3 | 479.8 | 863.6 | $433 \cdot 3$ | 779.9 | 357.8 |
| 182 | 7866 | 10.695 | 152.1 | 184.0 | 331.2 | 479.0 | 862.2 | 432.5 | 778.4 | 3.59 .6 |
| 183 | 8046 | 10.940 | 155.6 | 185.0 | 333.0 | 478.2 | S00.7 | 43 I .6 | 776.9 | 361.4 |
| $1 \mathrm{~S}_{4}$ | S230 | II.IS9 | 159.2 | 186.1 | 334.9 | 477.4 | 859.2 | 430.8 | $775 \cdot 3$ | 363.2 |
| 185 | 8417 | 11.44 | 162.8 | 187.1 | 336.8 | 476.6 | 857.7 | 429.9 | 773.7 | 365.0 |
| 186 | 8603 | 11.70 | 166.5 | 188.1 | 338.6 | 475.7 | 856.3 | 429.0 | 772.2 | 366.8 |
| 187 | 8 SO 2 | 1 I .97 | 170.2 | 189.2 | 3.40 .5 | 474.8 | 854.7 | 428.0 | 770.5 | 368.6 |
| 188 | 8999 | 12.24 | 174.0 | 190.2 | 342.4 | 474.0 | 853.2 | 427.2 | 768.9 | 370.4 |
| 189 | 9200 | 12.51 | 177.9 | 191.2 | 344.2 | 473.2 | 851.7 | 426.3 | 767.4 | 372.2 |
| 190 | 9.404 | 12.79 | 18ı. 8 | 192.3 | 346.1 | 472.3 | 850.2 | 425.4 | 765.8 | 374.0 |
| 191 | 9612 | 13.07 | 185.9 | 193.3 | 347.9 | 471.5 | 848.7 | 424.5 | 764.2 | 375.8 |
| 192 | 9823 | 13.36 | 190.0 | 194.4 | 349.8 | 470.6 | S47.1 | 423.6 | 762.5 | 377.6 |
| 193 | 10038 | 13.65 | 194.1 | 195.4 | 351.7 | 469.8 | 845.6 | 422.8 | 761.0 | 379.4 |
| 194 | 10256 | ${ }^{1} 3.94$ | 198.3 | 196.4 | 353.5 | 468.9 | 844.1 | 421.9 | 759.4 | 381.2 |
| 195 | 10.480 | 14.25 | 202.6 | 197.5 | 355.4 | 468.1 | 842.5 | 421.0 | 757.7 | 383.0 |
| 196 | 10700 | 14.55 | 207.0 | 198.5 | $357 \cdot 3$ | 467.2 | 841.0 | 420.1 | 756.1 | 384.8 |
| 197 | 10930 | 14.87 | 211.4 | 199.5 | 359.2 | 466.4 | 839.5 | 419.2 | 754.6 | 386.6 |
| 198 | 11170 | 15.18 | 216.0 | 200.6 | 361.1 | 465.6 | 838.0 | 418.4 | 753.0 | 388.4 |
| 199 | 11410 | 15.51 | 220.6 | 201.6 | 362.9 | $46+7$ | 836.4 | 417.4 | 751.3 | 390.2 |
| 200 | 11650 | 15.84 | 225.2 | 202.7 | 364.8 | 463.8 | 834.8 | 416.5 | 749.7 | 392.0 |
| 201 | 11890 | 16.17 | 223.0 | 203.7 | 366.7 | 462.9 | 833.3 | 415.6 | 748.1 | 393.8 |
| 202 | 12140 | 16.51 | 234.8 | 204.7 | 368.5 | 462.1 | 831.8 | 414.8 | 746.6 | 395.6 |
| 203 | 12400 | 16.85 | 239.7 | 205.8 | 370.4 | 461.2 | 830.2 | 413.8 | 744.9 | 397.4 |
| 204 | 12650 | 17.20 | 244.7 | 206.8 | 372.3 | 460.3 | S28.6 | 412.9 | $743 \cdot 3$ | 399.2 |
| 205 | 12920 | 17.56 | 249.8 | 207.9 | 374.1 | 459.4 | 827.0 | 412.0 | 741.6 | 401.0 |
| 206 | 13180 | 17.92 | 254.9 | 208.9 | 376.0 | $45^{8.6}$ | 825.4 | 411.1 | 740.0 | 402.8 |
| 207 | 13450 | 18.29 | 260.1 | 210.0 | 377.9 | 457.7 | 823.8 | 410.2 | 738.3 | 404.6 |
| 208 | 13730 | 18.66 | 265.4 | 211.0 | 379.8 | 456.8 | 822.2 | 409.3 | 736.7 | 406.4 |
| 209 | 14010 | 19.04 | 270.8 | 212.0 | 331.6 | 455.9 | 820.6 | 408.4 | 735.I | 408.2 |
| 210 | 14290 | 19.43 | 276.3 | 213.1 | 383.5 | 455.0 | 819.1 | 407.5 | 733.6 | 410.0 |
| 211 | 14580 | 19.82 | 281.9 | 214.1 | 385.4 | 454.1 | 817.4 | 406.6 | 731.9 | 411.8 |
| 212 | 1.4870 | 20.22 | 287.6 | 215.2 | 387.3 | 453.2 | 815.8 | 405.7 | 730.2 | 413.6 |
| 213 | 15170 | 20.62 | 293.3 | 216.2 | 389.2 | 452.4 | 814.3 | 404.9 | 728.7 | 415.4 |
| 214 | 15470 | 21.03 | 299.2 | 217.3 | 391.1 | 451.5 | 812.7 | 404.0 | 727.1 | 417.2 |
| 215 | 15780 | 21.45 | 305.1 | 218.3 | 392.9 | 450.6 | SII.O | 403. 1 | 725.4 | 419.0 |
| 216 | 16090 | 21.88 | 311.1 | 219.3 | 394.8 | 449.6 | 809.3 | 402.1 | 723.7 | 420.8 |
| 217 | 16410 | 22.31 | 317.3 | 220.4 | 396.7 | 448.7 | 807.7 | 401.2 | 722.1 | 422.6 |
| 218 | 16730 | 22.74 | 323.5 | 221.4 | 398.5 | 447.8 | 806.1 | 400.3 | 720.5 | 424.4 |
| 219 | 17060 | 23.19 | 329.8 | 222.5 | 400.4 | 446.9 | 804.5 | 399.4 | 718.9 | 4262 |
| 220 | 17390 | 23.64 | 336.2 | 223.5 | 402.3 | 446.0 | 802.9 | 398.5 | 717.3 | 428.0 |

Table 253 (continued).
PROPERTIES OF SATURATED STEAM.
Metric and Common Units.

|  | Heat Equivalent of External Work. |  | Entropy of the Liquid. <br> $\theta$. | Entropy of Evaporation.$\frac{\mathrm{r}}{\mathrm{~T}}$ | Specific Volume. |  | Density. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Calories. | B. T. U. |  |  | Cubic Meters per Kilogram. | Cubic <br> Feet per <br> Pound. | Kilograms per Cubic Meter. | Pounds per Cubic Foot. |  |
|  | Apu. | Apu. |  |  | s. | s. | $\frac{1}{8}$ | $\frac{1}{8} \cdot$ |  |
| 170 | $45 \cdot 9$ | 82.6 | 0.4880 | I. 1029 | 0.2423 | 3.883 | 4.127 | 0.2575 | . 338.0 |
| 171 | 46.0 | 82.7 | . 4903 | 1.0987 | . 2368 | 3.794 | 4.223 | . 2636 | 339.8 |
| 172 | 46.0 | 82.8 | . 4926 | 1.0944 | . 2314 | 3.709 | 4.322 | . 2696 | 341.6 |
| 173 | 46. 1 | 82.9 | . 4949 | 1.0901 | . 2262 | 3.626 | 4.42 I | . 2758 | 343.4 |
| 174 | 46.1 | 83.0 | . 4972 | 1.0859 | . 2212 | $3 \cdot 545$ | 4.52 I | . 2821 | 345.2 |
| 175 | 46.2 | 83.1 | . 4995 | 1.0817 | . 2164 | 3.467 | 4.621 | . 2884 | 347.0 |
| 176 | 46.2 | 83.2 | . 5018 | 1.0775 | . 2117 | $3 \cdot 391$ | 4.724 | . 2949 | 348.8 |
| 177 | 46.3 | $83 \cdot 3$ | . 5041 | 1.0733 | . 2072 | $3 \cdot 318$ | 4.826 | .3014 | 350.6 |
| 178 | 46.3 | 83.4 | . 5064 | 1.0691 | . 2027 | 3.247 | 4.933 | -3080 | 352.4 |
| 179 | 46.4 | 83.5 | . 5087 | 1. 0649 | .1983 | 3.177 | 5.04 | . 3148 | 354.2 |
| 180 | 46.4 | 83.6 | . 5110 | 1.0608 | .194 I | 3.109 | 5.15 | . 3217 | 356.0 |
| 181 | 46.5 | 83.7 | . 5133 | 1.0567 | .1899 | 3.041 | 5.27 | . 3288 | 357.8 |
| 182 | 46.5 | 83.8 | . 5156 | 1.0525 | .1857 | 2.974 | $5 \cdot 38$ | . 3362 | 359.6 |
| 183 184 | 46.6 46.6 | 83.8 | . 5178 | 1.0484 | .1817 | 2.911 | 5.50 | - 3435 | 361.4 |
| 184 | 46.6 | 83.9 | . 5201 | 1.0443 | .1778 | 2.849 | 5.62 | . 3510 | 363.2 |
| 185 | 46.7 | $8_{4.0}$ | . 5224 | 1.0403 | . 1740 | 2.787 | 5.75 | . 3588 | 365.0 |
| 186 | 46.7 | 84.1 | . 5246 | 1.0362 | . 1702 | 2.727 | 5.88 | - 3667 | 366.8 |
| 187 | 46.8 | 84.2 | . 5269 | 1.0321 | . 1666 | 2.669 | 6.00 | . 3746 | 368.6 |
| 188 | 46.8 | 84.3 | .5291 | 1.0280 | .1632 | 2.614 | 6.13 | . 3826 | 370.4 |
| 189 | 46.9 | $84 \cdot 3$ | . 5314 | 1.0240 | . 1598 | 2.560 | 6.26 | . 3906 | 372.2 |
| 190 | 46.9 | 84.4 | . 5336 | 1.0200 | . 1565 | 2.507 | 6.39 | . 3989 | 3740 |
| 191 | 47.0 | 84.5 | . 5358 | 1.0160 | . 1533 | 2.456 | 6. 52 | . 4072 | 375.8 |
| 192 | 47.0 | 84.6 | . 5381 | 1.0120 | .1501 | 2.405 | 6.66 | . 4158 | 377.6 |
| 193 | 47.0 | 84.6 | . 5403 | 1.0080 | .1470 | 2.355 | 6.80 | .4246 | 379.4 |
| 194 | 47.0 | 84.7 | . 5426 | 1.0040 | . 1440 | 2.306 | 6.94 | .4336 | 381.2 |
| 195 | 47.1 | 84.8 | . 5448 | 1.0000 | . 1411 | 2.259 | 7.09 | . 4426 | 383.0 |
| 196 | 47.1 | 84.9 | . 5470 | 0.9961 | . 1382 | 2.214 | 7.23 | . 4516 | 384.8 |
| 197 | 47.2 | 84.9 | . 5492 | . 9982 | . 1354 | 2.169 | $7 \cdot 38$ | . 4610 | 386.6 |
| 198 | 47.2 | 85.0 | . 5514 | . 9882 | . 1327 | 2.126 | 7.53 | . 4704 | 388.4 |
| 199 | $47 \cdot 3$ | 85.1 | . 5536 | . 9843 | . 1300 | 2.083 | 7.69 | . 4 SOI | 390.2 |
| 200 | $47 \cdot 3$ | 85.1 | . $555{ }^{8}$ | . 9804 | . 1274 | 2.04 I | 7.84 | . 4900 | 392.0 |
| 201 | $47 \cdot 3$ | 85.2 | . 5580 | . 9765 | . 1249 | 2.001 | 8.00 | . 4998 | 393.8 |
| 202 | $47 \cdot 3$ | 85.2 | . 5602 | . 9727 | . 1225 | 1.962 | 8.16 | . 510 | 395.6 |
| 203 | $47 \cdot 4$ | 85.3 | . 5624 | . 9688 | . 1201 | 1.923 | 8.33 | . 520 | 397.4 |
| 204 | $47 \cdot 4$ | 85.3 | . 5646 | . 9650 | . 1177 | 1.885 | 8.50 | .531 | 399.2 |
| 205 | 47.4 | 85.4 | . 5668 | .9611 | . 1153 | I. 847 | 8.67 | -541 | 401.0 |
| 206 | 47.5 | 85.4 | . 5690 | . 9572 | . 1130 | 1.810 | 8.85 | -552 | 402.8 |
| 207 | 47.5 | 85.5 | . 5712 | . 9534 | . 1108 | 1.774 | 9.03 | . 564 | 404.6 |
| 208 | $47 \cdot 5$ | 85.5 | . 5733 | . 9496 | .1086 | 1.739 | 9.21 | . 575 | 406.4 |
| 209 | $47 \cdot 5$ | 85.5 | . 5755 | . 9458 | .1065 | 1.705 | 9.39 | . 587 | 408.2 |
| 210 | 47.5 | 85.5 | - 5777 | . 9420 | . 1044 | 1.673 | 9.58 | . 598 | 410.0 |
| 211 | 47.5 | 85.5 | . 5799 | . 9382 | .1024 | 1. 640 | 9.77 | . 610 | 411.8 |
| 212 | $47 \cdot 5$ | 85.6 | . 5820 | . 9344 | .1004 | 1. 608 | 9.96 | . 622 | 413.6 |
| 213 | $47 \cdot 5$ | 85.6 | .5842 | . 9307 | . 0984 | 1.577 | 10.16 | . 634 | 415.4 |
| 214 | $47 \cdot 5$ | 85.6 | .5863 | .9269 | . 0965 | I. 546 | 10.36 | . 647 | 417.2 |
| 215 | 47.5 | 85.6 | . 5885 | . 9232 | . 0947 | 1.516 | 10.56 | . 660 | 419.0 |
| 216 | $47 \cdot 5$ | 85.6 | . 5906 | . 9195 | .0928 | I. 486 | 10.78 | . 673 | 420.8 |
| 217 218 | 47.5 | 85.6 | . 5927 | .9157 | .0910 | 1.458 | 10.99 | . 686 | 422.6 |
| 218 219 | $47 \cdot 5$ 47.5 | 85.6 85.6 | . 5948 | .9120 | .0893 | 1.430 | 11.20 | . 699 | 424.4 |
| 219 | $47 \cdot 5$ | 85.6 | -5969 | . 9084 | . 0876 | 1.403 | 11.41 | .713 | 426.2 |
| 220 | $47 \cdot 5$ | 85.6 | . 5991 | . 9047 | . 0860 | 1.376 | 11.62 | . 727 | 428.0 |

## LATENT HEAT OF FUSION.

This table contains the latent heat of fusion of a number of solid substances in large calories per kilogram or small calories or therms per gram. It has been compiled principally from Landolt and Börnstein's tables. $C$ indicates the composition, $T$ the temperature Centigrade, and $H$ the latent heat.

| Substance. | c | $T$ | H | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Alloys: $30.5 \mathrm{~Pb}+69.5 \mathrm{Sn}$ | $\mathrm{PbSn}_{4}$ | 183 | 17. | Spring. |
| $36.9 \mathrm{~Pb}+63.15 \mathrm{Sn}$ | $\mathrm{PbSn}_{3}$ | 179 | 15.5 |  |
| $\begin{aligned} & \text { 63.7Pb+ } \\ & 77.8 \mathrm{~Pb}\end{aligned}+22.2 \mathrm{Sn}$. | $\mathrm{PbS}_{2} \mathrm{Pn}$ | 177.5 176.5 | 11.6 | , |
| Britannia metal, ${ }^{77.8 \mathrm{Sn}+\mathrm{IPb}}$ | $\mathrm{Pb}_{2} \mathrm{Sn}$ | 176.5 236 | 28.54 | Ledebur. |
| Rose's alloy, $24 \mathrm{~Pb}+27.3 \mathrm{Sn}+48.7 \mathrm{Bi}$ | - | 98.8 | 6.85 | Mazzotto. |
| Wood's alloy $\left\{\begin{array}{l}25.8 \mathrm{~Pb}+14.7 \mathrm{Sn} \\ +52.4 \mathrm{Bi}+7 \mathrm{Cd}\end{array}\right\}$ | - | 75.5 | 8.40 | " |
| Aluminum . . . . | Al | 658. | 76.8 | Glaser. |
| Ammonia . . . . | $\mathrm{NH}_{3}$ | -75. | 108. | Massol. |
| Benzene . | $\mathrm{C}_{6} \mathrm{H}_{6}$ | 5.4 | 30.6 | Mean. |
| Bromine . . . . | Br | -7.3 | 16.2 | Regnault. |
| Bismuth . | Bi | 268 | 12.64 | Person. |
| Cadmium | ${ }^{\mathrm{Cd}}$ | 320.7 | 13.66 | " |
| Calcium chloride . . | $\mathrm{CaCl}_{2}+6 \mathrm{H}_{2} \mathrm{O}$ | 28.5 | 40.7 | Mean |
| Copper . . | $\mathrm{Cu}^{\text {c }}$ | 1083 | 42. | Mean. |
| Iron, Gray cast . . . | - | - | 23. | Gruner. |
| " Shite" . . | - | - | 33. | " |
| Iodine . . . . | I | - | 11.71 | Favre and Silbermann. |
| Ice | $\mathrm{H}_{2} \mathrm{O}$ | - | 79.63 | \{ Dickinson, Harper, Osborne. $\dagger$ |
| " . . . . . . | " | $\bigcirc$ | 79.59 | Smith. $\ddagger$ |
| " (from sea-water). | $\left\{\begin{array}{c}\mathrm{H}_{2} \mathrm{O}+3.535 \\ \text { of solids }\end{array}\right\}$ | -8.7 | 54.0 | Petterson. |
| Lead . | Pb | 327 | 5.36 | Mean. |
| Mercury . . . . | Hg | -39 | 2.82 | Person. |
| Naphthalene . . . | $\mathrm{C}_{10} \mathrm{H}_{8}$ | 79.87 | 35.62 | Pickering. |
| Nickel - | Ni | 1435 | 4.64 | Pionchon. |
| Palladium . | Pd | 1545 | 36.3 | Violle. |
| Phosphorus | P | 44.2 | 4.97 | Petterson. |
| Platinum | Pt | 1755 | 27.2 | Violle. |
| Potassium . . | K | 62 | 15.7 | Joannis. |
| Potassium nitrate | $\mathrm{KNO}_{3}$ | 333.5 | 48.9 | Person. |
| Phenol | $\mathrm{C}_{6} \mathrm{H}_{6} \mathrm{O}$ | 25.37 | 24.93 | Petterson. |
| Paraffin | - | 52.40 | 35.10 | Batelli. |
| Silver | Ag | 961 | 21.07 | Person. |
| ${ }_{\text {Sodium }}{ }_{\text {nitrate }}$. | $\underset{\substack{\mathrm{Na} \\ \mathrm{NaNO}_{3}}}{ }$ | 97 305.8 | 31.7 64.87 | Joannis. |
| " phosphate | $\left\{\begin{array}{c}\mathrm{NaNO}_{3} \mathrm{Na}_{2} \mathrm{HPO}_{4} \\ +{ }_{2} \mathrm{H}_{2}\end{array}\right\}$ | 305.8 36.1 | 64.87 66.8 | ، |
| Spermaceti . | $\left\{\underset{-}{+12 \mathrm{H}_{2} \mathrm{O}}\right\}$ | 43.9 | 36.98 | Batelli. |
| Sulphur . | S | 115 | 36.97 9.37 | Person. |
| $\mathrm{Tin}^{\text {d }}$ | Sn | 232 | 14.0 | Mean. |
| Wax (bees) | - | 61.8 | 42.3 | " |
| Zinc | Zn | 419 | 28.13 | " |

[^37]Smithsonian tables.

TABLE 261. - Heat of Combustion of Some Carbon Compounds.

\begin{tabular}{|c|c|c|c|c|c|c|c|}
\hline Compound. \& Formula. \& Kg. cal. per g mol. \& Kg. cal. per $g$ \& Compound. \& Formula. \& Kg. cal. per g- \& Kg. cal per $g$ <br>
\hline Paraffins: \& \& \& \& Alcohols: \& \& \& <br>
\hline Methane, g \& $\mathrm{CH}_{4}$ \& $214 p$ \& 13.30 \& Methyl, 1 \& $\mathrm{CH}_{4} \mathrm{O}$ \& 170p \& 5.31p <br>
\hline Ethane, g \& $\mathrm{C}_{2} \mathrm{H}_{6}$ \& $371 p$ \& 12.40 \& Ethyl, 1 \& $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ \& $327 p$ \& 7.10p <br>
\hline Propane, \& $\mathrm{C}_{3} \mathrm{H}_{8}$ \& $528 p$ \& $12.0 p$ \& n-propyl, \& $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}$ \& 483 p \& $8.00 p$ <br>
\hline i-Butane, g - ${ }^{\text {dexane, }}$, \& $\mathrm{C}_{4} \mathrm{C}_{6} \mathrm{H}_{14}$ \& $687 p$
$995 p$ \& $11.8 p$
$11.6 v$ \& n-buty \& $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$
$\mathrm{C}_{5} \mathrm{H}_{12} \mathrm{O}$ \& $644 p$ \& 8.680 <br>
\hline n -Heptane, \& $\mathrm{C}_{7} \mathrm{H}_{16}$ \& 11390 \& $11.4 p$ \& Ethers: \& \& $788 p$ \& 8.96p <br>
\hline n-Octane, \& $\mathrm{C}_{8} \mathrm{H}_{18}$ \& 1315 p \& 11.50 \& Dimethyl, g \& $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ \& 346p \& 7.60 p <br>
\hline Dekane, 1 \& $\mathrm{C}_{10} \mathrm{H}_{22}$ \& 1626p \& 11.40 \& Diethyl, v \& $\mathrm{C}_{4} \mathrm{H}_{10} \mathrm{O}$ \& 6600 \& $8.92 p$ <br>
\hline Olefines: \& \& \& \& Ethyl-methyl, \& $\mathrm{C}_{3} \mathrm{H}_{5} \mathrm{O}$ \& $506 p$ \& 8.43p <br>
\hline Ethylene, g \& $\mathrm{C}_{2} \mathrm{H}_{4}$ \& $343 p$ \& $12.2 p$ \& Acids: \& \& \& <br>
\hline Propylene, i \& $\mathrm{C}_{3} \mathrm{H}_{6}$ \& 496p \& II. 80
II $6 p$ \& Formic, \& $\mathrm{CH}_{2} \mathrm{O}_{2}$ \& 62p \& 1.3570 <br>
\hline i-Butylene, \& $\mathrm{C}_{4} \mathrm{H}_{8}$
$\mathrm{C}_{5} \mathrm{H}_{10}$ \& $651 p$
$804 p$ \& $11.6 p$
$11.5 p$ \& Asetic, 1. \& $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}_{2}$
$\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}_{2}$ \& 210p \& 3.490 <br>
\hline Ampxylene, 1 \& ${ }^{\mathrm{C}_{6} \mathrm{CH}_{12}{ }^{\text {c }}}$ \& $804 p$
$962 p$ \& $11.5 p$
II. 40 \& Propionic, \& $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}_{2}$
$\mathrm{C}_{4} \mathrm{O}_{2}$ \& $368 p$
$525 p$ \& 4.960
5.950 <br>
\hline Acetylene, g. \& $\mathrm{C}_{2} \mathrm{H}_{2}$ \& $313 p$ \& $12.0 p$ \& Lactic, 1 \& $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}_{8}$ \& 3300 \& 5.960
3.660 <br>
\hline Trimethylene, g \& $\mathrm{C}_{3} \mathrm{H}_{6}$ \& $503 p$ \& II.9p \& \& \& \& <br>
\hline Benzene, 1. \& $\mathrm{C}_{6} \mathrm{H}_{6}$ \& $78 \mathrm{I} p$ \& 10.0p \& Cellulose, s \& $\mathrm{C}_{6} \mathrm{H}_{10} \mathrm{O}_{5}$ \& 680 \& 4. 580 <br>
\hline Benzene, g \& $\mathrm{C}_{6} \mathrm{H}_{6}$ \& 788p \& $10.1 p$ \& Dextrine, \& $\mathrm{C}_{12} \mathrm{H}_{20} \mathrm{O}_{10}$ \& 414 \& - <br>
\hline Naphthalene, \& $\mathrm{C}_{10} \mathrm{H}_{8}$ \& $1235 p$ \& $9.6 v$ \& Glycerine, \& $\mathrm{C}_{3} \mathrm{H}_{8} \mathrm{O}_{3}$ \& 397 \& 4.32 <br>
\hline Toluene, 1.. \& $\mathrm{C}_{7} \mathrm{CH}_{8}$ \& 937p \& 10.20 \& Phenol, 1. \& \& 735 \& 7.8 x <br>
\hline  \& $\mathrm{CHCl}_{3}$ \& 70
$253 p$ \& 3.280 \& Sugar, cane \& $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11}$
$\mathrm{C}_{6} \mathrm{H}_{10} \mathrm{O}_{5}$ \& 1353

685 \& 3.950 <br>
\hline Carbon disulphide
Methyl-chloride, 8 \& ${ }_{\mathrm{CH}}^{\mathrm{CH}}{ }_{3} \mathrm{Cl}$ \& 253p
$169 p$ \& $3.28 v$
$3.26 p$ \& Starch, \& ${ }_{\text {C6 }}^{\mathrm{C}_{6} \mathrm{H}_{10} \mathrm{CO}_{5}}$ \& 685
1353 \& 4.23
$9.02 p$ <br>

\hline Ethyl-chloride, v \& $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}$ \& $332 p$ \& 5.10p \& Urea, 1. \& $\mathrm{CO}\left(\mathrm{NH}_{2}\right)_{2}$ \& ${ }_{152}$ \& | 2.53 |
| :--- |
| $2.02 p$ | <br>

\hline
\end{tabular}

$0, p$, following the heats of combustion, signify at constant volume and pressure respectively. When referred to constant pressure, the values are 0.58 Kg -cal. greater (at about $18^{\circ} \mathrm{C}$ ) for each condensed gaseous molecule. The values are means from various observers. The combustion products are gaseous $\mathrm{CO}_{2}$, liquid water, etc.

TABLE 262. - Heat of Combustion- Miscellaneous.

| Substance. | Small calories per $g$ substance. | 递 | Substance. | Small calories per $g$ substance. | 華 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Asphalt. | 9530 | 1 | Oils: petroleum: |  |  |
| Butter. | 9200 | - | crude. | 11500 | 2 |
| Carbon: amorphous | 8080 | 2 | light. | 10000 | 2 |
| charcoal. | 8100 7860 | 2 | heav | 10200 | ${ }^{2}$ |
| graphite. |  | 3 | rape.. | 9500 10000 |  |
| Copper (to CuO ). | 590 | 5 | Paraffin (to $\mathrm{CO}_{2}, \mathrm{H}_{2} \mathrm{O} \mathrm{i}$ ) | 11140 | 6 |
| Dynamite, 75\%. | 1290 | 4 | Parafin (to $\mathrm{CO}_{2}, \mathrm{H}_{2} \mathrm{O} \mathrm{g}$ ). | 10340 | 6 |
| Egg, white of. | 5700 | $-$ | Pitch. | 8400 | - |
| Egg, yolk of. | 8100 | - | Sulphur, rhombic | 2200 | 2 |
| Fats, animal | 9500 | 2 | Sulphur, monoclinic | 22.40 | 5 |
| Hemoglobin | 5900 | $\overline{-}$ | Tallow. .......... | 9500 | 8 |
| $\xrightarrow{\text { Hydrogen }}$ (to $\mathrm{Fe}_{2} \mathrm{O}_{3}$ ) | 33900 1582 | $\stackrel{2}{-}$ |  | 4170 4210 | 8 |
| Magnesium (to MgO) | 15080 | - | oak, $13 \% \mathrm{H}_{2} \mathrm{O}$.. | 3990 | 8 |
| Oils: cotton-seed. | 9500 9300 | - | pine, $\mathbf{1} 2 \% \mathrm{H}_{2} \mathrm{O}$ | 4420 | 8 |
|  | 9300 9400 | 2 |  |  |  |

References: (1) Slossen, Colburn; (2) Mean; (3) Berthellot; (4) Roux, Sarran; (5) Thomsen; (6) Stohmann; (7) Gibson; (8) Gottlieb.


* $\mathrm{C}_{2} \mathrm{H}_{\mathrm{f}}$. Data from the Geological Survey, Poole's The Calorific Power of Fuels, and for natural gas from Snelling (Van Nostrand's Chemical Annual).


# CHEMICAL AND PHYSICAL PROPERTIES OF FIVE DIFFERENT CLASSES OF EXPLOSIVES． 

| Explosive． |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 为宫兑 | E゙ | 免 ${ }^{\text {a }}$ |  | $\begin{aligned} & \dot{\mathscr{E}} \\ & \stackrel{y}{E} \\ & \stackrel{y}{\mid c} \end{aligned}$ | 告 |  | 先 |
| （A）Forty－per－cent nitro－ glycerin dynamite | 1.22 | 1221.4 | 8235 | 227＊ | 4688 | ． 358 | 24.63 | 12 | $\begin{aligned} & 88.4 \\ & 79.7 \\ & 14.5 \end{aligned}$ | 25 |
| （B）FFF black blasting powder | 1.25 | 789.4 | 4817 | $\begin{aligned} & 374^{\dagger} \\ & 458^{*} \end{aligned}$ | $469.4!$ | 925. | 54.32 | － | $\begin{array}{r} 154.4 \\ 126.9 \\ 4.1 \end{array}$ | 25 |
| （C）Permissible explo－ sive；nitroglycerin class | 1.10 | 760.5 | 5912 | 301＊ | 3008 | ． 47 I | 27.79 | 4 | $\begin{array}{r} 103.9 \\ 65.1 \\ 15.4 \end{array}$ | 1000 |
| （D）Permissible explo－ sive；ammonium nitrate class | 0.97 | 992.8 | 7300 | 279＊ | 3438 § | .483 | 25.68 | I | $\begin{aligned} & 89.8 \\ & 27.5 \\ & 75 \cdot 5 \end{aligned}$ | 800 |
| （E）Permissible explo－ sive；hydrated class | 1． 54 | 6ı0．6 | 6597 | 434＊ | 2479 | .338 | 17.49 | 3 | $\begin{aligned} & 86.1 \\ & 56.0 \\ & 33.0 \end{aligned}$ | $\begin{gathered} \text { Over } \\ 1000 \end{gathered}$ |
| Chemical Analyses． |  |  |  |  |  |  |  |  |  |  |
| （A）Moisture M . . . . . 0.91 <br> Nitroglycerin ． . . . . . . . |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

TABLE 265. - Additional Data on Explosives.

| Explosive. <br> (Ref. Young, Nature, 102, 216, 1918.) | Vol. gas per $g$ in $\mathrm{cc}=\boldsymbol{V}$ | Calories $\stackrel{\text { per }}{=} Q$ | $\begin{gathered} \text { Coefficient } \\ =Q V \\ \div 1000 \end{gathered}$ | Coefficient $G P=1$ | Calculated Temperature Q/C C, sp. ht. gases $=0.24$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | cc |  |  |  |  |
| Gunpowder..................... . . . . . . . . . . | 280 | 738 | 207 | 1 | $2240^{\circ} \mathrm{C}$ |
| Nitroglycerine . . . . . . . . . . . . . . . . . . . . . . | 741 | 1652 | 1224 | 6 | 6880 |
| Nitrocellulose, $13 \% \mathrm{~N}_{2} \ldots \ldots \ldots \ldots$ | 923 | 931 | 859 | $4 \cdot 3$ | 3876 |
| Cordite, Mk. I. (NG, 57 ; NC, 38 ; Vaseline, 5 ) | 871 | 1242 | 1082 | 5.2 | 5175 |
| Cordite, MD (NG, 30; NC, 65; Vaseline, 5)... | 888 | 1031 | 915 | $4 \cdot 4$ | 4225 |
| Ballistite (NG, 50; NC, 50; Stabilizer, 5) .... | 817 877 | 1349 810 | 1102 | $5 \cdot 3$ | 5621 |
| Picric acid (Lyddite) . . . . . . . . . . . . . . . . . . . | 877 | 810 | 710 | 3.4 | 3375 |

Shattering power of explosive $=$ vol. gas per $\mathrm{g} \times$ cals. $/ \mathrm{g} \times V_{d} \times$ density where $V_{d}$ is the velocity of detonation.
Trinitrotoluene: $V_{d}=7000 \mathrm{~m} / \mathrm{sec}$. Shattering effect $=.87$ picric acid.
Amatol (Ammonium nitrate + trinitrotoluene, TNT): $V_{d}=4500 \mathrm{~m} / \mathrm{sec}$.
Ammonal (Ammonium nitrate, TNT, Al): $1578 \mathrm{cal} / \mathrm{g} ; 682 \mathrm{cc}$ gas; $V_{d}=4000 \mathrm{~m} / \mathrm{sec}$.
Sabulite (Ammonium nitrate, 78, TNT 8, Ca silicide 14): about same as ammonal.
TABLE 266. - Ignition Temperatures Gaseous Mixtures.
Ignition temperature taken as temperature necessary for hot body immersed in gas to cause ignition; slow combination may take place at lower temperatures. McDavid, J. Ch. Soc. Trans. 111, 1003, 1917. Gases were mixed with air. Practically same temperatures as with $\mathrm{O}_{2}$ (Dixon, Conrad, loc. cit. 95, 1909).

| Benzene and air | $1062^{\circ} \mathrm{C}$ | Ether and air. | $1033{ }^{\circ} \mathrm{C}$ |
| :---: | :---: | :---: | :---: |
| Coal gas and air | 878 | Ethylene and air. | 1000 |
| CO and air... | 931 | Hydrogen and air | 747 |

TABLE 267. - Time of Heating for Explosive Decomposition.

| Temperature ${ }^{\circ} \mathrm{C}$. | 170 | ${ }^{180}$ | 190 | 200 | 220 | Ignition temperature. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Time. | sec. | ec. | sec. | sec. | sec. | ${ }^{\circ} \mathrm{C} \dagger$ | ${ }^{\circ} \mathrm{C} \ddagger$ |
| ck powder |  |  |  |  |  | 440 |  |
| Smokeess powder A | coich | $\substack{195 \\ 130}_{\substack{\text { a }}}$ | ${ }^{130}$ | 45 | ${ }_{25}^{23}$ | \{300 | 二 |
| Cellulid Pyroxylin.: | ${ }_{870}^{170}$ | ${ }_{165}^{60}$ | ${ }_{6} 7$ | 21 <br> 56 | $\stackrel{9}{8}$ | 300 | 二 |
| Cellulid **...... | ${ }_{n}^{160}$ | 150 <br> 340 <br> 10 | 60 240 | 5is | 30 | 590 | 450 |
| Parlor matches Cotton wool... | n | $\stackrel{n}{n}$ | $\stackrel{n}{n}$ | 590 | 480 | $\bigcirc$ |  |

$n$, failure to explode in twenty minutes. * The decomposition of nitrocellulose in celluloid commences at about $100^{\circ} \mathrm{C}$; above that the heat of decomposition may raise the mass to the ignition point if loss of heat is prevented. Above $170^{\circ}$, decomposition occurs with explosive violence as with nitrocellulose. Rate of combustion is 5 to 10 times that of poplar, pine, or paper of the same size and conditions.
$\dagger$ Measured by contact with porcelain tube of given temperature. Average.
$\ddagger$ Measured by contact with molten lead. Average.
Taken from Technologic Paper of Bureau of Standards, No. 98, 1917.
TABLE 268. - Flame Temperatures.
Measures made with optical pyrometer by Féry, J. de Phys. (4) 6, 1907.

| Alcohol, with NaCl . | $1705^{\circ} \mathrm{C}$ | Hydrogen flame. | $1900^{\circ} \mathrm{C}$ |
| :---: | :---: | :---: | :---: |
| Bunsen flame, no air | 1712 | Hydrogen-oxygen |  |
| Bunsen flame, $\frac{1}{2}$ air. | 1812 | Acetylene burner. | 2458 |
| Bunsen flame, full air............. | 1871 | Acetylene-oxygen. | 3000 |
| Illuminating gas-oxygen. . . . . . . . . | 2200 | Cooper-Hewlit Hg | 3500 |

## THERMO-CHEMISTRY. CHEMICAL ENERGY DATA.

The total heat generated in a chemical reaction is independent of the steps from initial to final state. Heats of formation may therefore be calculated from steps chemically impracticable. Chemical symbols now represent the chemical energy in a gram-molecule or mol(e); treat reaction equations like algebraic equations: $\mathrm{CO}+\mathrm{O}=\mathrm{CO}_{2}+68 \mathrm{Kg}$-cal; subtract $\mathrm{C}+2 \mathrm{O}=\mathrm{CO}_{2}$ +97 Kg -cal, then $\mathrm{C}+\mathrm{O}=\mathrm{CO}+29 \mathrm{Kg}$-cal. We may substitute the negative values of the formation heats in an energy equation and solve $\mathrm{MgCl}_{2}+2 \mathrm{Na}=2 \mathrm{NaCl}+\mathrm{Mg}+\mathrm{x} \mathrm{Kg}$-cal; $-15 \mathrm{I}=-196+\mathrm{x} ; \mathrm{x}=45 \mathrm{Kg}$-cal. Heats of formation of organic compounds can be found from the heats of combustion since burned to $\mathrm{H}_{2} \mathrm{O}$ and $\mathrm{CO}_{2}$. When changes are at constant volume, energy of external work is negligible; also generally for solid or liquid changes in volume. When a gas forms a solid or liquid at constant pressure, or vice versa, it must be allowed for. For N mols of gas formed (disappearing) at $\mathrm{T}_{\mathrm{K}}{ }^{\circ}$ the energy of the substance is decreased (increased) by $0.002 \cdot \mathrm{~N} \cdot \mathrm{~T}_{\mathrm{K}} \mathrm{Kg}$-cal. $\mathrm{H}_{2}+\mathrm{O}=\mathrm{H}_{2} \mathrm{O}+67.5 \mathrm{Kg}$-cal. at $18^{\circ} \mathrm{C}$. at constant volume ; $\frac{1}{2}\left(2 \mathrm{H}_{2}+\mathrm{O}_{2}-2 \mathrm{H}_{2} \mathrm{O}=135.0+0.002 \times 3 \times 29 \mathrm{I}=136.7\right)=68.4 \mathrm{Kg}$-cal.

The heat of solution is the heat, + or 一, liberated by the solution of 1 mol of substance in so much water that the addition of more water will produce no additional heat effects. Aq. signifies this amount of water; $\mathrm{H}_{2} \mathrm{O}$, one mol. ; $\mathrm{NH}_{3}+\mathrm{Aq}=\mathrm{NH}_{4} \mathrm{OH} \cdot \mathrm{Aq} .+8 \mathrm{Kg}$-cal.

TABLE 269. (a). Heats of Formation from Elements in Kilogram Calories. At ordinary temperatures.

| Compound. | Heat of Formation. | Compound. | Heat of Formation. | Compound. | Heat of Formation. | Compound. | Heat o Forma tion. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Al}_{2} \mathrm{O}_{3}$ | 380. | HgO | 21.4 | KCl | 105.7 | $\mathrm{Li}_{2} \mathrm{SO}_{4}$ | 334.2 |
| $\mathrm{Ag}_{2} \mathrm{O}$ | 6.5 | $\mathrm{Na}_{2} \mathrm{O}$ | 100. | LiCl | 93.8 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 283. |
| BaO | 126. | $\mathrm{Nd}_{2} \mathrm{O}_{3}$ | 435. | $\mathrm{MgCl}_{2}$ | 151.0 | $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 328.3 |
| $\mathrm{BaO}_{2}$ | 142. | ${ }_{\mathrm{PiO}}{ }^{\text {N }}$ | 57.9 | $\mathrm{MnCl}_{2}$ | 112.3 | $\mathrm{MgSO}_{4}$ | 301.6 |
| $\mathrm{Bi}_{2} \mathrm{O}_{3}$ | ${ }^{1} 38$. | $\mathrm{P}_{2} \mathrm{O}_{5} \mathrm{sgs}$ | 370. | $\stackrel{\mathrm{NaCl}}{ }{ }^{\text {a }}$ | 97.8 | $\mathrm{PbSO}_{4}$ | 216.2 |
| CO am | 29.0 | PbO | 50.3 | $\mathrm{NdCl}_{3}$ | 250. | $\mathrm{Tl}_{2} \mathrm{SO}_{4}$ | 221.0 |
| $\mathrm{CO}^{\text {di }}$ | 26.1 | $\mathrm{PbO}_{2}$ | 62.4 | $\mathrm{NH}_{4} \mathrm{Cl}$ | 76.3 | $\mathrm{ZnSO}_{4}$ | 229.6 |
| $\mathrm{CO}_{2} \mathrm{am}$ | 97.0 | $\mathrm{Pr}_{2} \mathrm{O}_{3}$ | 412. | $\mathrm{NiCl}_{2}$ | 74.5 | $\mathrm{CaCO}_{3}$ | 270. |
| $\mathrm{CO}_{2} \mathrm{CO} \mathrm{Cr}_{2} \mathrm{dr}$ | 94.8 94.3 | ${ }^{\mathrm{Rb}_{2} \mathrm{O}} \mathrm{SO}_{2} \mathrm{rh}$ sgg | 89.2 70. | $\mathrm{PbCl}_{2}$ | 83.4 | $\mathrm{CuCO}_{3}$ | 143. |
| $\mathrm{CO}_{2} \mathrm{Ci}$ | 94.3 152. | ${ }_{\text {S }} \mathrm{SO}_{2}$ rh sgg | 70. 191.0 | ${ }_{\mathrm{PtCl}}^{4}$ | 40.5 60.4 | $\mathrm{FeCO}_{3} \mathrm{FeCO}_{3}$ | 179. <br> 280. |
| $\mathrm{CeO}_{2}$ | 225. | SnO | 66.9 | $\mathrm{SnCl}_{2}$ | 80.8 | $\mathrm{MgCO}_{3}$ | 267. |
| $\mathrm{Cl}_{2} \mathrm{O} \mathrm{g}$ | -16.5 | $\mathrm{SnO}_{2}$ cr | 137.5 | $\mathrm{SnCl}_{4}$ | 128. | $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 272. |
| CoO am | 50.5 | $\mathrm{SrO}_{2}$ | 135. | $\mathrm{SrCl}_{2}$ | 185. | $\mathrm{ZnCO}_{3}$ | 194. |
| CoO cr | 57.5 | $\mathrm{ThO}_{2}$ | 326. | ThCl ${ }_{6}$ | 300. | $\mathrm{AgNO}_{3}$ | 28.7 |
| $\mathrm{Co}_{3} \mathrm{O}_{4}$ | 193.4 | $\mathrm{TiO}_{2} \mathrm{am}$ | 215.6 | TICl | 48.6 | $\mathrm{Ca}\left(\mathrm{NO}_{3}\right)_{2}$ | 209. |
| $\mathrm{CrO}_{3}$ | 140. | $\mathrm{TiO}_{2}$ cr | 218.4 | RbCl | 105.9 | $\mathrm{Cu}\left(\mathrm{NO}_{3}\right)_{2} 6 \mathrm{H}_{2} \mathrm{O}$ | 92.9 |
| $\mathrm{Cs}_{2} \mathrm{O}$ | 91.3 | $\mathrm{TlO}_{2}$ | 42.2 | $\mathrm{ZnCl}_{2}$ | 97.3 | $\mathrm{HNO}_{3} \mathrm{gggl}$ | 41.6 |
| $\mathrm{Cu}_{2} \mathrm{O}$ | 42.3 | $\mathrm{WO}_{2}$ | 131. | $\mathrm{HBrglg}^{\text {r }}$ | 8.6 | $\mathrm{KNO}_{3}$ | 119.2 |
| CuO | 37.2 | $\mathrm{WO}_{3}$ | 194. | $\mathrm{NH}_{4} \mathrm{Br}$ | 66. | $\mathrm{LiNO}_{3}$ | 112. |
| FeO | 65.7 | ZnO | 85.2 | HI gsg | -6.2 | $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | 88.3 |
| $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | 196.5 | AgCl | 29.2 | HF ggg | 38. | $\mathrm{NaNO}_{3}$ | 111.0 |
| $\mathrm{Fe}_{3} \mathrm{O}_{4}$ | 270.8 | $\mathrm{Ag}_{2} \mathrm{Cl}$ | 29.5 | $\mathrm{Ag}_{2} \mathrm{~S}$ | 3.3 | $\mathrm{TlNO}_{3}$ | 58.2 |
| $\mathrm{H}_{2} \mathrm{O} \mathrm{ggl}$ | 68.4 | $\mathrm{AlCl}_{3}$ | 161.4 | ${ }^{\mathrm{CS}_{2} \mathrm{sgg}}$ | -26.0 | $\mathrm{CH}_{4} \mathrm{sgg}$ | 20. |
| $\mathrm{H}_{2} \mathrm{O}_{2} \mathrm{ggl}$ | 46.8 | $\mathrm{AuCl}_{\mathrm{y}}$ | 5.81 | $\mathrm{CaS}^{\text {a }}$ | 90.8 | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{Hgg}$ | 25. |
| $\xrightarrow{\mathrm{HgO}}$ | 22.2 21.4 | $\mathrm{AuCl}_{3 \mathrm{y}}^{\mathrm{A}}{ }^{\text {y }}$ | ${ }^{22.8}$ | ${ }_{\left(\mathrm{Cu}_{2} \mathrm{~S}\right.} \mathrm{NH}_{2} \mathrm{~S}$ | 66.2 18.3 | $\mathrm{C}_{2} \mathrm{H}_{2} \mathrm{sgg}$ HCN digsgg | -53. |
| $\mathrm{K}_{2} \mathrm{O}$ | 9 r. | $\mathrm{BiCl}_{3}$ | 90.6 | $\mathrm{CuS}^{\text {Cus }}$ | 18.3 I 4.6 | $\mathrm{NH}_{3} \mathrm{ggg}{ }^{\text {reg }}$ | - 12.5 |
| $\mathrm{La}_{2} \mathrm{O}_{3}$ | 447. | $\mathrm{CCl}_{4} \mathrm{am}$ | 21.0 | $\mathrm{H}_{2} \mathrm{~S}$ gsg | 2.73 | $\mathrm{Ca}(\mathrm{OH})_{2}$ | 23 . |
| $\mathrm{LiO}_{2}$ | 141.6 | $\mathrm{CaCl}_{2}$ | 187. | $\mathrm{K}_{2} \mathrm{~S}$ | 103.4 | $\mathrm{NH}_{4} \mathrm{OH}$ | 88.8 |
| MgO | 143.6 | $\mathrm{CdCl}_{2}$ | 93.2 | MgS | 79.4 | NaOH | 102. |
| MnO | 90.8 | $\mathrm{CoCl}_{2}$ | 76.5 | $\mathrm{Na}_{2} \mathrm{~S}$ | 89.3 | $\mathrm{Na} \cdot \mathrm{H}_{2} \mathrm{O} \cdot \mathrm{Aq}-\mathrm{H}$ | 44.** |
| $\mathrm{MnO}_{2}$ | 123. | $\mathrm{CuCl}_{2}$ | 51.5 | $\stackrel{\mathrm{PbS}}{ }$ | 19.3 | $\frac{1}{2}\left(2 \mathrm{Na} \cdot \mathrm{O} \cdot \mathrm{H}_{2} \mathrm{O}\right)$ | 68.* |
| $\mathrm{Mn}_{3} \mathrm{O}_{4}$ | 325. | $\mathrm{CuCl}^{\text {a }}$ | 34.1 | $\mathrm{CaSO}_{4}$ | 262. | $\frac{1}{2}\left(\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{H}_{2} \mathrm{O} \cdot \mathrm{Aq}\right)$ | 30.* |
| $\mathrm{MoO}_{2}$ | 143. | $\mathrm{FeCl}_{2}$ | 82.1 | $\mathrm{CuSO}_{4}$ | 111.5 |  | 103.5 |
| ${ }^{\mathrm{MoO}_{3}} \mathrm{~N}_{2} \mathrm{O}$ ggg | 174. -18.2 | $\underset{\mathrm{GlCl}}{3}$ | ${ }^{96.0}$ |  | ${ }_{\text {1293 }}^{19}$ | $\mathrm{K} \cdot \mathrm{H}_{2} \mathrm{O} \cdot \mathrm{Aq}-\mathrm{H}$ | 45.** |
| $\stackrel{N}{1}_{\mathrm{N}_{2} \mathrm{O} \mathrm{Oggg}}^{\mathrm{NO} \mathrm{ggg}}$ | -18.2 | $\mathrm{ClCl}_{2}{ }_{\mathrm{HCl}}{ }^{\text {gl }}$ | 155. 22. | $-\mathrm{SO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | $\stackrel{21.3}{175 .}$ |  | 69.** |
| $\mathrm{NO}_{2}$ | -8.1 | $\mathrm{HgCl}^{\text {b }}$ | $3 \mathrm{I} \cdot 3$ | $\mathrm{HgSO}_{4}$ | 165. |  | $35 \cdot 5$ |
| $\mathrm{Na}_{2} \mathrm{O}_{4}$ | - 2 | $\mathrm{HgCl}_{2}$ | $53 \cdot 3$ | $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 344.3 |  |  |

$\mathrm{am}=$ amorphous ; di = diamond; $\mathrm{gr}=$ graphite $; \mathrm{cr}=$ crystal ; $\mathrm{g}=$ gas ; $\mathrm{l}=$ liquid; $\mathrm{s}=$ solid; $\mathrm{y}=$ yellow (gold);

## HEATS OF FORMATION OF IONS IN KILOGRAM-CALORIES.

+ and - signs indicate signs of ions and the number of these signs the valency. For the ionisation of each gram-molecule of an element divide the numbers in the table by the valency, e. g., $9.03 \mathrm{gr} . \mathrm{Al}=9.03 \mathrm{gr} . \mathrm{Al}++40.3 \mathrm{Kg} . \mathrm{cal}$. When a solution is of such dilution that further dilution does not increase its conductivity, then the heats of formation of substances in such solutions may be found as follows: $\mathrm{FeCl}_{2} \mathrm{Aq}=+22.2+2 \times 39.1=100.4 \mathrm{Kg}$. cal. $\mathrm{CuSO}_{4} \mathrm{Aq}=-15.8$ $+214.0=198.2 \mathrm{Kg}$. cal.



## TABLE 271,-Heats of Neutralization in Kilogram-Calories.

The heat generated by the neutralization of an acid by a base is equal, for each gram-molecule of water formed, to 13.7 Kg . cal. plus the heat produced by the amount of un-ionized salt formed, plus the sum of the heats produced in the completion of the ionizations of the acid and the base. (See also p. 209).

| Base. | $\mathrm{HCl} \cdot \mathrm{aq}$ | $\mathrm{HNO}_{3} \cdot \mathrm{aq}$ | $\mathrm{H}_{2} \mathrm{SO}_{4} \cdot \mathrm{aq}$ | HCN•aq | $\mathrm{CH}_{3} \mathrm{COOH} \cdot \mathrm{aq}$ | $\mathrm{H}_{2} \cdot \mathrm{CO}_{3} \cdot \mathrm{aq}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| KOH ${ }^{\text {aq }}$ | 13.7 | 13.8 | 15.7 | 2.9 | $13 \cdot 3$ | 10.1 |
| $\mathrm{NaOH} \cdot \mathrm{aq}$ | 13.7 | 13.7 | 15.7 | 2.9 | 13.3 | 10.2 |
| $\mathrm{NH}_{4} \mathrm{OH} \cdot \mathrm{aq}$ | 12.4 | 12.5 | 14.5 | 1.3 | 12.0 | 8. |
| $\frac{1}{2} \mathrm{Ca}(\mathrm{OH})_{2} \cdot \mathrm{aq}$ | 14.0 | 13.9 | 15.6 | 3.2 | 13.4 | 9.5 |
| ${ }_{1}^{\frac{1}{2} \mathrm{Zn}(\mathrm{OH})_{2} \cdot \mathrm{aq}}$ | 9.9 | 9.9 | 11.7 | 8.1 | 8.9 | $5 \cdot 5$ |
| ${ }_{2} \mathrm{Cu}(\mathrm{OH})_{2} \cdot \mathrm{aq}$ | $7 \cdot 5$ | $7 \cdot 5$ | 9.2 | - | 6.2 |  |

TABLE 272.-Heat of Dilution, $\mathrm{H}_{2} \mathrm{SO}_{4}$.
In Kilogram-calories by the dilution of one gram-molecule of sulphuric acid by $m$ gram-molecules of water.

| mg. Cal. . . | 1 6.38 | 2 9.42 | $\stackrel{3}{3} 11.14$ | ${ }_{1}^{5} 3.11$ | 19 16.26 | 49 16.68 | 99 16.86 | 199 17.06 | $\begin{aligned} & 399 \\ & 17 \cdot 31 \end{aligned}$ | ${ }^{1} 599$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

[^38]TABLES 273-275.
RADIATION CONSTANTS.

## table 273.-Radiation Formulæ and Constants for Perfect Radiator.

The radiation per sq. cm. from a "black body" (exclusive of convection losses) at the temperature $T^{\circ}$ (absolute, $\mathbf{C}$ ) to one at $t^{\circ}$ is equal to

$$
J=\sigma\left(T^{4}-t^{4}\right) \quad \text { (Stefan-Boltzmann); }
$$

where $\sigma=1.374 \times \mathrm{ro}^{-12}$ gram-calories per second per sq. centimeter.

$$
\begin{aligned}
& =8.26 \times 10^{-11} \quad " \quad " \quad \text { " minute } \\
& =5.75 \times 10^{-12} \text { watts per sq. centimeter. }
\end{aligned}
$$

The distribution of this energy in the spectrum is represented by Planck's formula:

$$
J_{\lambda}=C_{1} \lambda^{-5}\left[e^{\frac{C_{2}}{\lambda T}}-\mathrm{I}\right]^{-1}
$$

where $J \lambda$ is the intensity of the energy at the wave-length $\lambda$ ( $\lambda$ expressed in microns, $\mu$ ) and $c$ is the base of the Napierian logarithms.
$C_{1}=9.226 \times 10^{3}$ for $J$ in $\frac{\text { gram. cal. }}{\text { sec. } \mathrm{cm}^{2} .^{2}}=3.86 \times 10^{4}$ for $J$ in $\frac{\text { watts }}{\mathrm{cm}^{2}}$
$C_{2}=14350$ for $\lambda$ in $\mu$
$J_{\max }=3.11 \times 10^{-16} T^{5}$ for $J$ in $\frac{\text { gram. cal. }}{\text { see. cm. }}=\mathrm{I} .30 \times 10^{-15} T^{5}$ tor $J$ in $\frac{\text { watts }}{\mathrm{cm}^{2}}$
$\lambda_{\text {max }} T=2910$ for $\lambda$ in $\mu$
$\mathrm{h}=$ Planck's unit $=$ elementary "Wirkungs quantum" $=6.83 \times 1 \mathrm{o}^{-27} \mathrm{ergs}$. sec.
$\mathrm{k}=$ constant of entropy equation $=1.42 \times 10^{-16}$ ergs./degrees.
TABLE 274. - Radiation in Gram-Calories per 24 Hours per sq. cm. from a Perfect Radiator at $t^{\circ} \mathbf{C}$ to an absolutely Cold Space ( $-273^{\circ} \mathrm{C}$ ).
Computed from the Stefan-Boltzmann formula.

| $t^{\circ} \mathrm{C}$ | $J$ | $t^{\circ} \mathrm{C}$ | $J$ | $t^{\circ} \mathrm{C}$ | $J$ | $t^{\circ} \mathrm{C}$ | $J$ | $t^{\circ} \mathrm{C}$ | $J$ | $t^{\circ} \mathrm{C}$ | $J$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| -273 | 0 | -120 | 65 | -10 | 571 | +12 | 787 | +34 | 1059 | +56 | 1400 |
| -220 | 1 | -110 | 84 | -8 | 588 | +14 | 808 | +36 | 1087 | +58 | 1430 |
| -210 | 2 | -100 | 107 | -6 | 606 | +16 | 831 | +38 | 1115 | +60 | 1470 |
| -200 | 3 | -90 | 134 | -4 | 625 | +18 | 855 | +40 | 1145 | +70 | 1650 |
| -190 | 5 | -80 | 165 | -2 | 643 | +20 | 879 | +42 | 1174 | +80 | 1850 |
| -180 | 9 | -70 | 201 | 0 | 662 | +22 | 903 | +44 | 1204 | +90 | 2070 |
| -170 | 13 | -60 | 245 | +2 | 682 | +24 | 928 | +46 | 1234 | +100 | 2310 |
| -160 | 19 | -50 | 294 | +4 | 701 | +26 | 953 | +48 | 1265 | +200 | 5960 |
| -150 | 27 | -40 | 350 | +6 | 722 | +28 | 979 | +50 | 1298 | +1000 | $313 \times 10^{8}$ |
| -140 | 38 | -30 | 416 | +8 | 744 | +30 | 1005 | +52 | 1330 | +2000 | $318 \times 10^{4}$ |
| -130 | 50 | -20 | 488 | +10 | 765 | +32 | 1032 | +54 | 1363 | +5000 | $921 \times 10^{5}$ |

TABLE 275. - Valnes of $J_{\lambda}$ for Various Temperatures Centigrade.
Ekholm, Met. Z. 1902, used $C_{1}=8346$ and $C_{2}=14349$, and for the unit of time the day.
For $100^{\circ}$, the values for $\mathrm{J} \lambda$ have been multiplied by 10 , for the other temperatures by 100 .

| $\lambda$ | $7=10{ }^{\circ} \mathrm{C}$ | $30^{\circ} \mathrm{C}$ | $15^{\circ} \mathrm{C}$ | $0^{\circ} \mathrm{C}$ | $-30^{\circ} \mathrm{C}$ | $-80^{\circ} \mathrm{C}$ | $\lambda$ | $100^{\circ} \mathrm{C}$ | $30^{\circ} \mathrm{C}$ | $15^{\circ} \mathrm{C}$ | $0^{\circ} \mathrm{C}$ | $-30^{\circ} \mathrm{C}$ | $-80^{\circ} \mathrm{C}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu$ 2 | I | 0 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | 0 | ${ }_{18}^{\mu}$ | 511 | 2961 | 2557 | 2175 | 1491 | 623 |
| 3 | 80 | 41 | 18 | 7 | 1 | $\bigcirc$ | 19 | 443 | 2626 | 2281 | 1954 | 1363 | 594 |
| 4 | 469 | 508 | 272 | 138 | 27 | 1 | 20 | 386 | 2329 | 2034 | 1754 | 1242 | 561 |
| 5 | 1047 | 1777 | 1085 | 628 | 172 | 8 | 21 | 337 | 2068 | 1816 | 1574 | 1129 | 527 |
| 6 | 1526 | 3464 | 2296 | 1454 | 493 | 39 | 22 | 295 | 1840 | 1622 | 1413 | 1026 | 494 |
| 7 | 1768 | 4954 | 348 I | 2353 | 931 | 105 | 23 | 259 | 1639 | 1448 | 1270 | 931 | 460 |
| 8 | 1810 | 5928 | 4352 | 3088 | 1372 | 203 | 24 | 228 | 1462 | 1298 | 1141 | 846 | 428 |
| 9 | 1724 | 6382 | 4834 | 3646 | 1730 | 316 | 25 | 202 | 1307 | 1165 | 1028 | 768 | 398 |
| 10 | 1573 | 6386 | 4979 | 3781 | 1971 | 426 | 26 | 179 | 1170 | 1047 | 926 | 698 | 369 |
| II | 1398 | 6127 | 4833 | 3798 | 2098 | 520 | 28 | 142 | 947 | 850 | 757 | 579 | 317 |
| 12 | 1225 | 5712 | 4633 | 3676 | 2114 | 592 | 30 | 114 | 771 | 696 | 623 | 482 | 272 |
| 13 | 1063 | 5222 | 4300 | 3467 | 2090 | 640 | 40 | 44 | 311 | 285 | 259 | 209 | 130 |
| 14 | 918 | 4713 | 3930 | 3215 | 2004 | 666 | 50 | 20 | 146 | 135 | 124 | 102 | 67 |
| 15 | 792 | 4220 | 3556 | 2944 | 1889 | 673 | 60 | 10 | 77 | 72 | 66 | 55 | 38 |
| 16 | 683 | 3759 | 3198 | 2674 | 1760 | 663 | 80 | 4 | 27 | 25 | 24 | 20 | 14 |
| 17 | 590 | 3340 | 2862 | 2417 | 1626 | 649 | 100 | 2 | 12 | 1 I | 10 | 9 | 7 |

Smithsonian Tables.

Values of $J_{\lambda}$ using for $C_{1}, 9.23 \times 10^{3}, C_{2}, 14350$., $\lambda$ in $\mu$. If the figures given for $J_{\lambda}$ are plotted in cms as ordinates to a scale of abscissac of 1 cm to $1 \mu$, then the area in $\mathrm{cm}^{2}$ between the smooth curve through the resulting points and the axis of abscissae is equivalent to the radiation in calories per sec. from $\mathbf{I ~ c m}{ }^{2}$ of a black body at the corresponding temperature, radiating to absolute zero. The intensities when radiating to a body at a lower temperature may be obtained by subtracting the intensities corresponding to the lower temperature from those of the higher. The nature of the black-body formula is such that when $\lambda T$ is small, a small change in $C_{2}$ produces a great change in $J_{\lambda}$; e.g. when $C_{3} / \lambda T$ is 100 or 10 , the change is 100 and io fold respectively; as $\lambda T$ increases, the change becomes proportional; e.g., when $C_{2} / \lambda T$ is less than 0.05 , the change in $J_{\lambda}$ is proportional to the change in $C_{2}$.

| $\lambda$ | $50^{\circ} \mathrm{K}$. | $100^{\circ} \mathrm{K}$. | $150^{\circ} \mathrm{K}$. | $200^{\circ} \mathrm{K}$. | $250^{\circ} \mathrm{K}$. | $273{ }^{\circ} \mathrm{K}$. | $300^{\circ} \mathrm{K}$. | $373^{\circ} \mathrm{K}$. | $400^{\circ} \mathrm{K}$. | $500^{\circ} \mathrm{K}$. | $600^{\circ} \mathrm{K}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu$ | - | . 0583 | . 0372 | . 0276 | . 0201 | . 0181 | . 0161 | . 0122 | . 01124 | . 0831 | . 0638 |
| 1.5 | - | . 08838 | .0372 .0242 | . 0172 | . 0133 | . 0127 | . 0102 | . 088 | . 0749 | . 0558 | . $0_{3} \mathrm{I}_{43}$ |
| 2.0 | . O 59 I | . 0282 | . 0185 | . 0137 | . O O I | . 0911 | . 0712 | . 0513 | . 0546 | . 03168 | . 00184 |
| 2.5 | . 047 I | . 0221 | . 0142 | . 0103 | . 0710 | . 077 | . 0646 | . 0419 | . 0450 | . 0397 | . 0066 |
| 3.0 | . 0409 | . 0196 | . 0125 | . 062 | . 0618 | . 069 | . 0545 | . 03102 | . 03242 | . 00265 | . 0131 |
| 3.5 | . 0344 | . 0163 | . 0102 | . 072 | . 0813 | . 055 | . 0420 | . 0329 | . 03620 | . 00482 | . 0189 |
| 4.0 | . 0306 | . 0142 | . 094 | . 0614 | . 0552 | . 04.48 | . 0457 | . $0_{3} 60$ | . 00115 | . 00690 | . 0229 |
| 5.0 | . 0243 | . 0111 | . 0714 | . 0517 | . 0430 | . 048 | . $\mathrm{O}_{3} 2 \mathrm{I}$ | . 00134 | . 00226 | . 00952 | . 0249 |
| 6.0 | . 02019 | . 0105 | . 0614 | . 058 | . 048 | . 0318 | . 0341 | .00195 | . 00301 | . 01001 | . 0224 |
| 7.0 | . 01883 | . 096 | . 066 | . 0419 | . 0315 | . 0330 | . 0359 | . 00225 | . 00328 | . 00925 | . 0186 |
| 8.0 | . 01672 | . 085 | . 0518 | . 0436 | . 0322 | . 0339 | . 0371 | . 00232 | . 00321 | . 00801 | . 0149 |
| 9.0 | . 01422 | . 0718 | . 0538 | . 0454 | . 0327 | . 0345 | . 0377 | . 00220 | . 00295 | . 00672 | . 0118 |
| 10.0 | . 01331 | . 0754 | . 0565 | . 0471 | . 0330 | . 0348 | ..$_{37} 8$ | . 00201 | . 00262 | . 00554 | . 00929 |
| 12.0 | . 01115 | . 0624 | . 0413 | . 0894 | . 033 I | . 0347 | . 0370 | . 00157 | . 00196 | . 00374 | . 00585 |
| 14.0 | . 0102 I | . 0661 | . 0418 | . 04102 | . 0329 | . 0341 | . 0358 | . 00117 | . 00144 | . 00254 | . 00380 |
| 16.0 | . 0914 | O5II | . 0422 | . 04100 | . 0325 | . 0334 | . 0.046 | . 0387 | . 00105 | . 00176 | . 00254 |
| 18.0 | . 0957 | . 0517 | . 0424 | . 0492 | . $\mathrm{O}_{3} 2 \mathrm{I}$ | . 0328 | . 03368 | . 03653 | . 03760 | . 00124 | . 00176 |
| 20.0 | . 0816 | . 0522 | . 0424 | . 0482 | . $\mathrm{O}_{3} \mathrm{I} 7$ | . 03224 | . 03290 | . 03493 | . 03575 | . 03902 | . 00125 |
| 25.0 | . 0897 | . 0530 | . 042 I | . 0457 | . 03122 | . $\mathrm{O}_{3} \mathrm{I} 3 \mathrm{I}$ | . 03164 | . 03258 | . 03295 | . 03439 | .03589 |
| 30.0 | . 0726 | . 0532 | . 0416 | . 0438 | . 0466 | . 0479 | . 0497 | . 03146 | . 03164 | . 03237 | . 03311 |
| 40.0 | . 0769 | . 0526 | . 059 | -1.0418 | . 04282 | . 0433 | . 04391 | . 04558 | . 04620 | . 04858 | . 03110 |
| 50.0 | . 0795 | . 0518 | . 0551 | . 0592 | . 04150 | . 04158 | . 04184 | . 04255 | . 0428 I | . 04381 | . 04482 |
| 75.0 | . 0787 | . 0667 | . 0515 | . 0524 | . 05338 | . 05383 | . 05436 | . 05580 | . 05634 | . 05834 | . 04103 |
| 100.0 | . 0755 | . 0629 | . 0657 | . 0688 | . 05119 | . 05134 | . 03150 | . 05197 | . 05214 | . 05277 | . 05342 |


| $\lambda$ | $\begin{gathered} 800^{\circ} \\ \mathrm{K} . \end{gathered}$ | $\begin{gathered} 1000^{\circ} \\ \mathrm{K} . \end{gathered}$ | $\begin{aligned} & \text { I } 500^{\circ} \\ & \mathrm{K} . \end{aligned}$ | $\begin{gathered} 2000^{\circ} \\ \mathrm{K} . \end{gathered}$ | $\begin{gathered} 3000^{\circ} \\ \mathrm{K} . \end{gathered}$ | $\begin{aligned} & 4000^{\circ} \\ & \mathrm{K} . \end{aligned}$ | $\begin{gathered} 5000^{\circ} \\ \mathrm{K} . \end{gathered}$ | $\begin{gathered} 6000^{\circ} \\ K . \end{gathered}$ | $\begin{gathered} 8000^{\circ} \\ \text { K. } \end{gathered}$ | $\begin{gathered} \text { 10000º } \\ \mathrm{K} . \end{gathered}$ | $\begin{gathered} 20000^{\circ} \\ \mathrm{K} . \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu$ 0.1 | - | - | - | 0.0226 | 0.01115 |  | 0.0331 | 0.038 |  |  |  |
| . 2 | - | - | - | O | 0.0012 | 0.46 | 15.4 | 184. | 3660. | 22100. | 820000. |
| 0.3 | - | - | - | 0.0315 | 0.44 | 24.2 | 263. | 1310. | 9640. | 31000. | 3820000. |
| 0.4 | - |  |  | -. 0145 | 5.75 | 115. | 690. | 2280. | 10300. | 25600. | 180000. |
| 0.5 | - | - | - | -. 172 | 20.6 | 226. | 952. | 2490. | 8400. | 17800. | 92300. |
| 0.6 | - | . 0548 | 0.014 | 0.757 | 40.8 | 301. | 1000. | 2240. | 6290. | I1950. | 51460. |
| 0.7 | . 0640 | . 0468 | 0.064 | 1.93 | 59.3 | 328. | 925. | 1860. | 4590. | 8110. | 30700. |
| 0.8 | . 0551 | . 00045 | -. 180 | 3.58 | 71.5 | 321. | 800. | 1490. | 3350. | 5620. | 19400. |
| 0.9 | . 0434 | . 0183 | 0.378 | $5 \cdot 35$ | 77.3 | 295. | 671. | 1177. | 2470. | 3980. | 12820. |
| 1.0 | . 00015 | . 00538 | 0.645 | 7.06 | 77.8 | 262. | 554. | 928. | 1842. | 2880. | 8800. |
| 1.5 | . 0775 | . 0848 | 2.07 | 10.25 | 52.2 | 122. | 210. | 309. | 527. | 758. | 1980. |
| 2.0 | . 0367 | . 221 | 2.43 | 8.19 | 29.0 | 57.6 | 90.2 | 125. | 198. | 275. | 668. |
| 2.5 | . 0719 | . 305 | 2.10 | 5.68 | 16.4 | 29.5 | 43.9 | 58.9 | 90.1 | 121.9 | 284. |
| 3.0 | . 0964 | . 320 | I. 64 | 3.82 | 9.66 | 16.4 | 23.7 | 31.1 | 46.4 | 61.9 | 140.7 |
| 3.5 | . 1050 | . 296 | 1. 22 | 2.60 | 6.02 | 9.84 | 13.8 | 17.9 | 26.3 | 34.7 | $77 \cdot 3$ |
| 4.0 | . 1027 | . 256 | 0.907 | r. 80 | 3.90 | 6.20 | 8.59 | II. 0 | 15.9 | 20.9 | 45.9 |
| 5.0 | . 0839 | . 178 | -. 511 | 0.923 | 1.84 | 2.81 | 3.81 | 4.81 | 6.84 | 8.89 | 19.15 |
| 6.0 | . 0629 | . 119 | 0.302 | -. 514 | 0.973 | I. 45 | I. 935 | 2.42 | 3.40 | 4.39 | 9.34 |
| 7.0 | . 0459 | .08II | -. 188 | 0.307 | 0.560 | 0.820 | I. 165 | 1. 348 | 1.88 | 2.41 | 5.09 |
| 8.0 | . 0335 | . 0562 | -. 122 | -. 194 | 0.344 | 0.498 | 0.653 | -. 808 | I. 20 | I. 43 | 3.00 |
| 9.0 | . 0247 | . 0398 | 0.0824 | -. 128 | 0. 223 | 0.319 | 0.416 | 0.513 | 0.709 | 0.90 | 1.87 |
| 10.0 | . 0184 | . 0288 | 0.0575 | 0.0880 | 0.151 | 0.214 | 0.278 | 0.342 | 0.470 | -. 598 | I. 24 |
| 12.0 | . 01072 | . 0160 | 0.0304 | 0.0553 | 0.0757 | 0. 107 | -. 1373 | 0. 168 | 0.230 | 0.292 | 0.602 |
| 14.0 | . 00660 | . 0096 | 0.0175 | 0.0256 | 0.0421 | 0.0587 | 0.0754 | 0.0921 | 0. 125 | 0.159 | 0.326 |
| 16.0 | . 00425 | . 00606 | 0.0108 | -. 0155 | 0.0253 | 0.0350 | 0.0448 | 0.0546 | 0.0742 | 0.0938 | -. 192 |
| 18.0 | . 00285 | . 00400 | 0.00697 | 0.00997 | 0.0160 | 0.0221 | 0.0282 | 0.0344 | 0.0466 | 0.0585 | 0.120 |
| 20.0 | . 00198 | . 00275 | 0.00470 | 0.00668 | 0.01068 | 0.0147 | 0.01868 | 0.0227 | 0.0307 | 0.0388 | 0.0789 |
| 25.0 | . 0000 | . 00122 | 0.00203 | 0.00284 | 0.00448 | 0.00612 | 0.00777 | 0.00941 | 0.0127 | 0.0160 | 0.0325 |
| 30.0 | . 03464 | .03619 | 0.00101 | 0.00141 | 0.00220 | 0.00299 | 0.00378 | 0.00455 | 0.00616 | 0.00775 | -. 0157 |
| 40.0 | . 03159 | . 03209 | 0.03334 | 0.03459 | -0.03710 | 0.03960 | 0.00121 | 0.00146 | 0.00197 | 0.00247 | 0.00498 |
| 50.0 | . 04684 | . 04888 | 0.03140 | -. 03191 | -0.03294 | -0.03397 | 0.03900 | 0.03603 | 0.03808 | 0.00101 | 0.00204 |
| 75.0 | . 04144 | . 04184 | 0.04286 | 0.04387 | 0.04591 | -. 04794 | 0.04997 | 0.03120 | -. $0_{3} 161$ | 0.03201 | 0.03406 |
| 100.0 | . 05470 | . 05598 | -.05919 | 0.04124 | 0.04188 | 0.04252 | 0.04317 | 0.04381 | 0.04510 | 0.04639 | 0.03128 |

See Forsythe, J. Opt. Soc., $4,33^{1}, 1920$, relative values, 0.4 to $0.76 \mu$ (steps $0.01 \mu$ ), 12 temperatures, 1000 to $5000^{\circ} \mathrm{K}$.

RADIATION EMISSIVITIES.
TABLE 277. - Relative Emissive Powers for Total Radiation.
Emissive power of black body $=1$. Receiving surface platinum black at $25^{\circ} \mathrm{C}$; oxidized surfaces oxidized at $600+{ }^{\circ} \mathrm{C}$. Randolph and Overholzer, Phys. Review, 2, p. 144, 1913.


Remark: For radiation properties of bodies at temperatures so low that the radiations of wave-length greater than $20 \mu$ or thereabouts are important, doubt must exist because of the possible and perhaps probable lack of blackness of the receiving body to radiations of those wave-lengths or greater. For instance, see Table 379 for the transparency of soot.

## TABLE 278. - Emissivities of Metals and Oxides.

Emissivities for radiation of wave-length 0.55 and $0.65 \mu$. Burgess and Waltenberg, Bul. Bureau of Standards, 11, 591, 1914.

In the solid state practically all the metals examined appear to have a negligible or very small temperature coefficient of emission for $\lambda=0.55$ and $0.65 \mu$ within the temperature range $20^{\circ} \mathrm{C}$ to melting point. Nickel oxide has a well-defined negative coefficient, at least to the melting point. There is a discontinuity in emissivity, for $\lambda=0.65 \mu$ at the melting point for some but not all the metals and oxides. This effect is most marked for gold, copper, and silver, and is appreciable for platinum and palladium. Palladium, in addition, possesses for radiation a property analogous to suffusion, in that the value of emissivity $(\lambda=0.65 \mu$ ) natural to the liquid state may persist for a time after solidification of the metal. The Violle unit of light does not appear to define a constant standard. Article contains bibliography.


## RADIATION EMISSIVITIES.

TABLE 279. - Relative Emissivities of Metals and Oxides.
Emissivity of black body taken as 100 .


TABLE 280. - Temperature Scale for Tungsten.
Hyde, Cady, Forsythe, J. Franklin Inst. 181, 418, 1916. See also Phys. Rev. 10, 395, 1917. The color temperature $=$ temperature of black body at which its color matches the given radiation.

| Lumens/watt | Color temperature. | Black-body temperature. | True temperature. | True temperature. | True color. | True brightness. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | $1763^{\circ} \mathrm{K}$. | $1627^{\circ} \mathrm{K}$. | $1729^{\circ} \mathrm{K}$. | $1700^{\circ}$ | $12^{\circ}$ | $100^{\circ}$ |
| 2 | 1917 | 1753 | 1875 | 1800 | 20 | 115 |
| 3 | 2025 | 1840 | 1976 | 1900 | 26 | 128 |
| 4 | 2109 | 1909 | 2056 | 2000 | 31 | 142 |
| 5 | 2179 | 1967 | 2125 | 2100 | 36 | 158 |
| 6 | 2237 | 2017 | 2184 | 2200 | 39 | 175 |
| 7 | 2290 2388 | 2062 | 2238 | 2300 | 4 I | 191 |
| 8 | 2338 2383 | 2102 2140 | 2286 | 2400 | 43 | 208 |
| 10 | 2425 | 2174 | 2373 |  |  |  |

TABLE 281. - Color minus Brightness Temperatures for Carbon.
Hyde, Cady, Forsythe, Phys. Rev. 10, 395, 1917.


## COOLING BY RADIATION AND CONVECTION.

## TABLE 282. - At Ordinary Pressures.

According to McFarlane * the rate of loss of heat by a sphere placed in the centre of a spherical enclosure which has a blackened surface, and is kept at a constant temperature of about $14^{\circ} \mathrm{C}$, can be expressed by the equations

$$
e=.00023^{8}+3.06 \times{ }_{10}-\dot{6} t-2.6 \times{ }_{10}-8 t^{2},
$$

when the surface of the sphere is blackened, or

$$
e=.000168+1.98 \times 10-8 t-1.7 \times 10-8 t^{2},
$$

when the surface is that of polished copper. In these equations, $e$ is the amount of heat lost in c. g.s. units, that is, the quantity of heat, small calories, radiated per second per square centimeter of surface of the sphere, per degree difference of temperature $t$, and $t$ is the difference of temperature between the sphere and the enclosure. The medium through which the heat passed was moist air. The following table gives the results.

| Differ- <br> ence of <br> tempera- <br> ture <br> $t$ | Value of $e$. |  | Polished surface. |
| :---: | :---: | :---: | :---: |
| 5 | Blackened surface. |  |  |
| 5 | .000178 | .000252 | .707 |
| 10 | .000186 | .000266 | .699 |
| 15 | .000193 | .000279 | .692 |
| 20 | .000201 | .000289 | .695 |
| 25 | .000207 | .000298 | .694 |
| 30 | .000212 | .000306 | .693 |
| 35 | .000217 | .000313 | .693 |
| 40 | .000220 | .000319 | .693 |
| 45 | .000223 | .000323 | .690 |
| 50 | .000225 | .000326 | .690 |
| 55 | .000226 | .000328 | .690 |
| 60 | .000226 | .000328 | .690 |

TABLE 283, - At Different Pressures.
Experiments made by J. P. Nicol in Tait's Laboratory show the effect of pressure of the enclosed air on the rate of loss of heat. In this case the air was dry and the enclosure kept at about $8^{\circ} \mathrm{C}$.


* "Proc. Roy. Soc.", ${ }^{1872 .}$
$\dagger$ "Proc. Roy. Soc." Edinb. 1869.


## Smithsonian Tables.

See also Compan, Annal. de chi. et phys. 26, p. 526.

TABLE 284. - Cooling of Platinum Wire in Copper Envelope.
Bottomley gives for the radiation of a bright platinum wire to a copper envelope when the space between is at the highest vacuum attainable the following numbers:-

$$
\begin{aligned}
& t=408^{\circ} \mathrm{C} ., \text { et }=378.8 \times 10^{-4} \text {, temperature of enclosure } 16^{\circ} \mathrm{C} . \\
& t=505^{\circ} \mathrm{C} . \text {, et } \mp 726.1 \times 10^{-4},
\end{aligned}
$$

It was found at this degree of exhaustion that considerable relative change of the vacuum produced very small change of the radiating power. The curve of relation between degree of vacuum and radiation becomes asymptotic for high exhaustions. The following table illustrates the variation of radiation with pressure of air in enclosure.

| Temp. of enclosure $16^{\circ} \mathrm{C} ., t=408^{\circ} \mathrm{C}$. |  | Temp. of enclosure $17^{\circ} \mathrm{C}$, , $t=505^{\circ} \mathrm{C}$. |  |
| :---: | :---: | :---: | :---: |
| Pressure in mm. | et | Pressure in mm. | et |
| 740. <br> 440. <br> 140. <br> 42. <br> 4. <br> 0.444 <br> .070 <br> .034 <br> .012 <br> .0051 <br> .00007 | $\begin{array}{ll} 8137.0 \times 10^{-4} \\ 7971.0 & " ، \\ 7875.0 & " \\ 7591.0 & " \\ 6036.0 & " \\ 2683.0 & " \\ 1045.0 & " \\ 77.3 & " \\ 539.2 & " \\ 436.4 & " \\ 378.8 & " \end{array}$ | 0.094 .053 .034 .013 .0046 $.0005^{2}$ .00019 $\left.\begin{array}{c}\text { Lowest reached } \\ \text { but not measured }\end{array}\right\}$ | $\begin{aligned} & 1688.0 \times 10^{-4} \\ & 1255.0 \text { " } \\ & 1126.0 \text { " } \\ & 920.4 \text { " } \\ & 831.4 \text { " } \\ & 767.4 \text { " } \\ & 746.4 \text { a } \\ & 726.1 \text { " } \end{aligned}$ |

TABLE 285.-Effect of Pressure on Loss of Heat at Different Temperatures.
The temperature of the enclosure was about $15^{\circ} \mathrm{C}$. The numbers give the total radiation in therms per square centimeter per second.

|  | Pressure in mm. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 10.0 | 1.0 | 0.25 | ${ }^{0.025}$ | $\underset{\substack{\text { About } \\ \text { D. } \mathrm{M}}}{ }$ |  |
| $100^{\circ}$ | 0.14 | 0.11 | 0.05 | 0.01 | 0.005 |  |
| 200 300 |  |  | .11 .18 I |  |  |  |
| 300 400 | . 75 | . 38 | .18 | .04 <br> .07 <br> 1 | . 0105 |  |
| 500 | - | . 69 | . 35 | . 13 | . 025 |  |
| 600 700 | - | . 85 | 45 | . 23 | .13 |  |
| 700 800 | - | - | - | . 37 | . 24 |  |
| 800 900 | - | - | - | -56 | . 40 |  |

Note. - An interesting example (because of its practical importance in electric lighting) of the effect of difference of surface condition on the radiation of heat is given on the authority of Mr. Evans and himself in Bottomley's paper. The energy required to keep up a certain degree of incandescence in a lamp when the filament is dull black and when it is "flashed " with coating of hard bright carbon, was found to be as follows : -

> Dull black filament, 57.9 watts.
> Bright " " 39.8 watts.

TABLE 286. - Conduction of Heat across Air Spaces (Ordinary Temperatures).
Loss of heat by air from surfaces takes place by radiation (dependent upon radiating power of surface; for small temperature differences proportional to temperature difference; follows Stefan-Boltzmann formula, see p. 247), conduction, and convection. The two latter are generally inextricably mixed. For horizontal air spaces, upper surface warm, the loss is all radiation and conduction; with warm lower surface the loss is greater than for similar vertical space.

Vertical spaces: The following table shows that for spaces of less than I cm width the loss is nearly proportional to the space width, when the radiation is allowed for; for greater widths the increase is less rapid, then reaches a maximum, and for yet greater widths is slightly less. The following table is from Dickinson and van Dusen, A. S. Refrigerating Engineers J. 3, 1916.

## HEAT CONDUCTION AND THERMAL RESISTANCES, RADIATION ELIMINATED, AIR SPACE 20 CM HIGH

| Air space, cm. | Heat conduction. Cal./hour/ $\mathrm{cm}^{2} /{ }^{\circ} \mathrm{C}$. |  |  |  | Thermal resistance. Same units. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Temperature difference. |  |  |  | Temperature difference. |  |  |  |
|  | $10^{\circ}$ | $15^{\circ}$ | $20^{\circ}$ | $25^{\circ}$ | $10^{\circ}$ | $15^{\circ}$ | $20^{\circ}$ | $25^{\circ}$ |
| 0.5 | 0.46 | 0.46 | 0. 46 | 0.46 | 2.17 | 2.17 | 2.17 | 2.17 |
| 1.0 | 0.24 | 0.24 | -. 24 | 0.24 | 4.25 | 4.20 | 4.15 | 4.10 |
| I. 5 | 0.160 | 0. 172 | -. 182 | -. 192 | 6.25 | 5.80 | 5.50 | 5.20 |
| 2.0 | 0.161 | -. 178 | - 200 | 0.217 | 6.20 | 5.60 | 5.00 | 4.60 |
| 3.0 | 0. 172 | 0. 196 | -. 208 | 0.217 | 5.80 | 5.10 | 4.80 | 4.60 |

Variation with height of air space: Max. thermal resistance $=4.0$ at 1.4 cm air space, 10 cm high; 6.0 at 1.6 cm , 20 cm high; 8.9 at $2.5 \mathrm{~cm}, 60 \mathrm{~cm}$ high.

## TABLE 287. - Heat Convection in Air at Ordinary Temperatures.

In very narrow layers of air between vertical surfaces at different temperatures the convection currents, in the main, flow up one side and down the other, with eddyless (stream-line) motion. It follows that these currents transport heat to or from the surfaces only when they turn and flow horizontally, from which fact it follows, in turn, that the convective heat transfer is independent of the height of the surface. It is, according to the laws of eddyless flow, proportional to the square of the temperature difference, and to the cube of the distance between the surfaces. As the flow becomes more rapid (e.g., for a $20^{\circ}$ difference and a distance of 1.2 cm ) turbulence enters, and the above relations begin to change. For the dimensions tested, convection in horizontal layers was a little over twice that in vertical.

Taken from White, Physical Review, 10, 743, 1917.
Heat Transfer, in the Usual C.G.S. Unit, i.e., Calories per Second per Degree of Thermal Head per Square Cm of Flat Surface, at $22.8^{\circ}$ Mean Temperature.

Where two values are given, they show the range among determinations with different methods of getting the temperature of the outer plate. It will be seen that the value of the convection is practically unaffected by this difference of method.

| Thermal head. | 8 mm gap. |  | 12 mm gap. |  | 24 mm gap. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Total. | Convection. | Total. | Convection. | Total. | Convection. |
| $0.99^{\circ}$ | - | - | $\left.\begin{array}{rll}.000 & 083 & 9 \\ .000 & 084 & 8\end{array}\right\}$ | - | . 000065 | - |
| $1.98{ }^{\circ}$ | $\left\{\begin{array}{r}.000109 \\ 110\end{array}\right.$ | - | $\left.\begin{array}{lll}.000 & 084 & 0 \\ .000 & 085 & 2\end{array}\right\}$ | .0000001 0004 | - | - |
| $4.95^{\circ}$ | . 000 III | . 000001 | $\left\{\begin{array}{rr}.000 & 086 \\ 88 \\ 81\end{array}\right.$ | $\left.\begin{array}{r}.000002 \\ 003 \\ 0\end{array}\right\}$ | .000 090 | over .000 025 |
| $9.89{ }^{\circ}$ | $\left\{\begin{array}{rr}.000 \\ \text { I12 } \\ & 113\end{array}\right.$ | .000003 003 | $\begin{array}{r}.000 \\ 093 \\ 95 \\ \hline 1\end{array}$ | .000 010 | .000 106 | over .000 040 |
| $19.76^{\circ}$ | .000 116 | . 000007 | $\left\{\begin{array}{rr}.000 & 1077 \\ & 1094\end{array}\right.$ | $\left.\begin{array}{r}.000 \\ 024 \\ 026\end{array}\right\}$ | . 000126 | over .000 060 |

## CONVECTION AND CONDUCTION OF HEAT BY GASES AT HIGH TEMPERATURES.*

The loss of heat from wires at high temperatures occurs as if by conduction across a thin film of stationary gas adhering to the wire (vertical and horizontal losses very similar). Thickness of film is apparently independent of temperature of wire, but probably increases with the temperature of the gas and varies with the diameter of the wire according to the formula $b \cdot \log b / a={ }_{2} B$, where $B=$ constant for any gas, $b=$ diameter of film, $a$, of wire. The rate of convection (conduction) of heat is the product of two factors, one the shape factor, $s$, involving only $a$ and $B$, the other a function $\phi$ of the heat conductivity of the gas. If $W=$ the energy loss in watts $/ \mathrm{cm}$, then $W=s\left(\phi_{2}-\phi_{1}\right)$. $s$ may be found from the relation

$$
\frac{s}{\pi} e^{-\frac{2 \pi}{s}}=\frac{a}{B} ; \quad \phi=4.19 \int_{0}^{\tau} k d t
$$

where $k$ is the heat conductivity of the gas at temperature $T$ in calories $/ \mathrm{cm}{ }^{\circ} \mathrm{C} . \phi_{2}$ is taken at the temperature $T_{2}$ of the wire, $\phi_{1}$ at that of the atmosphere. The following may be taken as the conductivities of the corresponding gases at high temperatures:

$$
\begin{aligned}
& \text { For hydrogen............. } k=28 \times 10^{-6} \sqrt{T}\left\{(\mathrm{I}+.0002 T) /\left(\mathrm{I}+77 T^{-1}\right)\right\} \\
& \text { air.................. } \left.\left.k=4.6 \times 10^{-6} \sqrt{T}\right\}(\mathrm{I}+.0002 T) /\left(\mathrm{I}+124 T^{-1}\right)\right\} \\
& \text { mercury vapor........ } k=2.4 \times{ }^{10}{ }^{-6} \sqrt{ } \bar{T}\left\{\mathrm{I} /\left(\mathrm{I}+960 T^{-1}\right)\right\} \text {. }
\end{aligned}
$$

To obtain the heat loss: $B$ may be assumed proportional to the viscosity of the gas and inversely proportional to the density. For air (see Table 289(b)) $B$ may be taken as 0.43 cm ; for $\mathrm{H}_{2}, 3.05 \mathrm{~cm}$; for Hg vapor as 0.078 . Obtain $s$ from section (a) below from $a / B$; then from section (b) obtain $\phi_{2}$ and $\phi_{1}$ for the proper temperatures; the loss will be $s\left(\phi_{2}-\phi_{1}\right)$ in watts $/ \mathrm{cm}$.
(a) $s$ as Function of $a / B$.

| $s$ | $a / B$ | $s$ | $a / B$ | $s$ | $a / B$ | $s$ | $a / B$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.0 | 0.0 | 5.0 | 0.453 | 10 | 1. 696 | 30 | 7.738 |
| 0.5 | $0.735 \times 10^{-6}$ | 5.5 | 0.558 | 12 | 2.263 | 32 | 8.370 |
| 1.0 | $0.594 \times 10^{-3}$ | 6.0 | 0.671 | 14 | 2.844 | 34 | 8.995 |
| 1.5 | $0.725 \times 10^{-2}$ | 6.5 | 0.788 | 16 | 3.438 | 36 | 9.622 |
| 2.0 | $2.75 \times 10^{-2}$ | 7.0 | 0.908 | 18 | 4.040 | 38 | 10.25 |
| 2.5 | 0.0644 | $7 \cdot 5$ | 1.032 | 20 | 4.645 | 40 | 10.87 |
| 3.0 | 0.1176 | 8.0 | 1.160 | 22 | 5.263 | 42 | 11.50 |
| 3.5 | -. 185 | 8.5 | 1.291 | 24 | 5.877 | 44 | 12.14 |
| 4.0 | -. 265 | 9.0 | 1.424 | 26 | 6.505 | 46 | 12.77 |
| 4.5 | 0.354 | 9.5 | I. 561 | 28 | 7.122 | 48 | 13.14 |
| 5.0 | 0. 453 | 10.0 | 1.696 | 30 | $7 \cdot 738$ | 50 | 14.03 |

(b) Table of $\phi$ in Watts per Cm as Function of Absolute Temp. ( $\left.{ }^{\circ} \mathrm{K}.\right)$.

| $T^{\circ} \mathrm{K}$. | $\mathrm{H}_{2}$ | Air | Hg | $T^{\circ} \mathrm{K}$. | $\mathrm{H}_{2}$ | Air | Hg |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\bigcirc$ | 0.0000 | 0.0000 | - | $1500^{\circ}$ | 4.787 | 0.744 |  |
| 100 200 | 0.0329 0.1294 | 0.0041 0.0068 |  | 1700 1900 |  | 0.931 1.138 | 0.228 0.284 |
| 300 | -. 278 | -0.0387 |  | 2100 | 8.655 | 1.363 | $\bigcirc$ |
| 400 | 0.470 | 0.0669 |  | 2300 |  | 1.608 | 0.41 I |
| 500 | - 0.700 | -. 1017 | 0.0165 | 2500 | ${ }_{11}{ }^{\text {P2 }}$ | 1.871 | 0.48 r |
| 700 000 | 1. 2681 | -. 189 | 0.0356 | 2700 | 13.56 | 二 | 0.556 |
| (1000 | 1.961 2.787 | 0.297 0.426 | 0.0621 0.0941 | 2900 3100 | 15.54 17.42 |  | 0.636 0.710 |
| 1300 | 3.726 | 0.576 | -. 1333 | 3300 | 19.50 |  | - |
| 1500 | 4.787 | 0.744 | 0. 1788 | 3500 | 21.79 | - | 0. 898 |

[^39]Smithsonian Tables.

Table 289.
heat losses from incandescent filaments.
(a) Wires of Platinum Sponge Served as Radiators (to Room-temperature Surroundings). Hartman, Physical Review, 7, p. 43i, 1916.

| Diameterwire, cm. | (A) Observed heat losses in watts per cm . |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Absolute temperatures. |  |  |  |  |  |  |  |  |  |  |  |
|  | $900^{\circ}$ | $1000^{\circ}$ | $1100^{\circ}$ | $1200^{\circ}$ | $1300^{\circ}$ | $1400^{\circ}$ | $1500^{\circ}$ | $1600^{\circ}$ | $1700^{\circ}$ | $1800^{\circ}$ | $1900^{\circ}$ | $2000^{\circ}$ |
| 0.0690 | 1.70 | 2.26 | 3.01 | 3.88 | 4.92 | 6.18 | 7.70 | 9.63 | 12.15 | 15.33 |  |  |
| 0.0420 | 1. 35 | 1.75 | 2.26 | 2.84 | 3.53 | 4.29 | 5.33 | 6.60 | 8.25 | 10.20 | 12.45 | 14.75 |
| 0.0275 | I.12 | 1.40 | 1. 76 | 2.23 | 2.73 | 3.23 | 3.91 | 4.67 | 5.72 | 7.00 | 8.64 | 10.45 |
| 0.0194 | 0.92 | 1.15 | I. 39 | 1. 74 | 2.12 | 2.54 | 3.04 | 3.64 | 4.32 | 5.10 | 6.10 | 7.35 |
| (B) Heat losses corrected for radiation, watts per $\mathrm{cm}(\mathrm{A}-\mathrm{C})$. |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.0690 | 0.91 | 1.05 | 1.23 | 1. 36 | I. 45 | 1.51 | I. 54 | 1. 66 | 2.00 | 2.56 | 3.40 | 4.30 |
| 0.0420 | 0.87 | 1.02 | 1.17 | 1.31 | I. 42 | I. 45 | 1.57 | 1. 76 | 2.08 | 2.43 | 2.80 | 3.26 |
| 0.0275 | 0.80 | 0.92 | 1.05 | 1.22 | I. 35 | 1. 37 | 1.46 | 1.50 | 1.67 | 1.91 | 2.32 | 2.70 |
| 0.0194 | 0.70 | 0.81 | 0.89 | 1.03 | 1.15 | 1.23 | 1.31 | 1.40 | 1.47 | 1.51 | 1.64 | 1. 88 |
| (C) Computed radiation, watts per $\mathrm{cm}, \sigma=5.61 \times 10^{-12}$.* |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.0690 | 0.79 | I. 21 | 1.78 | 2.52 | 3.47 | 4.67 | 6.16 | 7.97 | 10. 15 | 12.77 | 15.85 |  |
| 0.0420 | 0.48 | 0.73 | 1.09 | I. 53 | 2.11 | 2.84 | 3.74 | 4.84 | 6.17 | 7.77 | 9.65 | 11.85 |
| 0.0275 | 0.32 | 0.48 | 0.71 | 1.01 | 1.38 | 1.86 | 2.45 | 3.17 | 4.05 | 5.09 | 6.32 | 7.75 |
| 0.0195 | 0:22 | 0.34 | 0.50 | 0.71 | 0.97 | 1.31 | 1. 73 | 2.24 | 2.85 | $3 \cdot 59$ | 4.46 | 5.47 |
| (D) Conduction loss by silver leads, watts per cm. |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.0420 | 0.42 | 0.46 | 0.49 | 0.61 | 0.75 | 0.88 | r. 00 | 1.07 | 1.13 | 1.22 | - | - |
| 0.0275 | 0.18 | 0.21 | 0.28 | 0.35 | 0.43 | 0.48 | 0.55 | 0.57 | 0.60 | 0.67 | - | - |
| 0.0195 | 0.06 | 0.08 | 0.08 | 0.09 | 0.11 | 0.12 | -. 14 | 0.15 | 0.22 | 0.23 |  |  |
| (E) Convection loss by air, watts per cm . |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.0420 | 0.45 | 0. 56 | 0.68 | 0.70 | 0.67 | -0. 57 | O. 59 | 0.69 | 0.95 | I. 21 |  | - |
| 0.0275 | 0.62 | 0.71 | 0.77 | 0.87 | 0.92 | 0.89 | 0.91 | 0.93 | 1.07 | 1.24 | - | - |
| 0.0195 | 0.64 | 0.73 | 0.81 | 0.94 | 1.04 | I. II | 1.17 | 1.25 | I. 29 | 1. 30 |  |  |

* This value is lower than the presently (1919) accepted value of 5.72.
(b) Wires of Bright Platinum 40-50 Cm Long Served as Radiators to Surroundings at $300^{\circ}$ K. Langmutr, Physical Review, 34, p. 401, 1912.

| $\begin{aligned} & \text { Diameter } \\ & \text { wire, } \\ & \text { cm. } \end{aligned}$ | Observed energy losses in watts per cm. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Absolute temperatures. |  |  |  |  |  |  |  |
|  | $500^{\circ}$ | $700^{\circ}$ | $900^{\circ}$ | $1100^{\circ}$ | $1300^{\circ}$ | $1500^{\circ}$ | $1700^{\circ}$ | $1900^{\circ}$ |
| 0.0510 | 0.22 | 0.52 | 0.90 | 1.42 | 2.03 | 2.89 | 4.10 | 5.65 |
| 0.02508 | 0.17 | 0.39 | 0.68 | 1.02 | 1.45 | 2.00 | 2.68 | 3.55 |
| 0.01262 | -. 13 | 0.31 | -. 53 | 0.79 | 1.11 | I. 46 | I. 95 | 2.71 |
| 0.00691 | 0.12 | 0.29 | 0.48 | 0.72 | 0.99 | I. 33 | 1.79 | 2.48 |
| 0.00404 | 0.11 | 0.24 | 0.41 | 0.61 | 0.84 | I. 14 | I. 54 | 2.13 |
| Energy radiated in watts per cm.* |  |  |  |  |  |  |  |  |
| 0.0510 | 0.002 | 0.013 | 0.049 | 0. 137 | 0.323 | 0.67 | 1. 25 | 2.15 |
| 0.02508 | 0.001 | 0.007 | 0.024 | 0.067 | -. 159 | 0.33 | 0.62 | 1. 06 |
| 0.01262 | 0.001 | 0.003 | 0.012 | 0.034 | 0.080 | 0. 17 | 0. 31 | -. 53 |
| 0.00691 | 0.000 | 0.002 | 0.007 | 0.019 | 0.044 | 0.09 | O. 17 | 0. 29 |
| 0.00404 | 0.000 | 0.001 | 0.004 | 0.011 | 0.026 | 0.05 | O. 10 | -. 17 |
| "Convection" losses in watts per cm. |  |  |  |  |  |  |  |  |
| 0.0510 | 0. 22 | 0.51 | 0.85 | 1.28 | 1.71 | 2.22 | 2.85 | 3.50 |
| 0.02508 | -. 17 | 0.38 | 0.66 | 0.95 | 1. 29 | 1. 67 | 2.06 | 2.49 |
| -. 01262 | -. 13 | 0.31 | 0. 52 | 0.75 | 1.03 | 1.29 | 1. 64 | 2.18 |
| 0.00691 | 0.12 | 0.29 | 0.47 | 0.70 | 0.95 | I. 24 | 1.62 | 2.19 |
| 0.00404 | O. II | 0.24 | 0.41 | 0.60 | 0.81 | 1.09 | 1.44 | I. 96 |


| Thickness of theoretical conducting air film. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0.28 | 0.30 |  |  | 0.36 | 0.37 | 0.35 | 0.36 | Means. |
| $\stackrel{0}{0.02508}$ | 0.30 | $\stackrel{.}{0.37}$ | $\stackrel{.}{0.33}$ | 0.41 | 0.45 | ${ }_{0}^{0.35}$ | 0.51 | 0. 56 | 0.43 |
| 0.01262 | 0.42 | -. 42 | 0.44 | -. 49 | 0. 56 | 0. 69 | 0.69 | 0.47 | 0.54 |
| 0.00691 | 0.31 | 0. 32 | 0.38 | 0.40 | 0.43 | 0.47 | -. 38 | -. 26 | 0.37 |
| $\bigcirc$ | 0.27 | 0.43 | 0.43 | $\bigcirc \cdot 47$ | -. 56 | - 0.47 | - 0.40 | 0.25 0.38 | 0.51 0.41 +0.43 |
| Means. | 0.31 | 0.37 | 0.39 | 0.42 | 0.49 | 0.49 | 0.47 | 0.38 | to. 43 |

[^40]
## THE EYE AND RADIATION.

Definitions: A meter-candle is the intensity of illumination due to a standard candle at a meter distance. The millilambert (o.oor lambert) measures the brightness of a perfectly diffusing (according to Lambert's cosine law) surface diffusing I lumen per $\mathrm{cm}^{2}$. A brightness of 10 meter-candles equals x millilambert. 0.001 ml corresponds roughly to night exteriors, 0.1 , to night interiors, 10 ml to daylight interiors and 1000 , to daylight exteriors. A brightness of 100,000 meter-candles is about that of a horizontal plane for summer day with sun in zenith, 500 , on a cloudy day, 4, rst magnitude stars just visible, o.2, full moon in zenith, .oor, by starlight; in winter the intensity at noon may drop about $\frac{3}{3}$.

## TABLE 290. - Spectral Variation of Sensitiveness as a Function of Intensity.

Radiation is easily visible to most eyes from $0.330 \mu$ (violet) to $0.770 \mu$ (red). At low intensities near threshold values (gray, rod vision) the maximum of spectral sensibility lies near $0.503 \mu$ (green) for $90 \%$ of all persons. At higher intensities, after the establishment of cone vision, the max. shifts as far as $0.560 \mu$. See Table 297 for more accurate values of sensitiveness after this shift has been accomplished. The ratio of optical sensation to the intensity of energy increases with increasing energy more rapidly for the red than for the shorter wave-lengths (Purkinje phenomenon); i.e., a red light of equal intensity to the eye with a green one will appear darker as the intensities are equally lowered. This phenomenon disappears above a certain intensity (above to millilamberts). Table due to Nutting, Bulletin Bureau of Standards.

The intensity is given for the spectrum at $0.535 \mu$ (green).

| Intensity (meter-candles) $=$ Ratio to preceding step $=$ | . 00024 | .00225 9.38 | .0360 16 | . 575 | 2.30 4 | 9.22 4 | 36.9 4 | 147.6 4 | 590.4 4 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Wave-length, $\lambda$. | Sensitiveness. |  |  |  |  |  |  |  |  |
| $0.430 \mu$ | 0.081 | 0.093 | 0.127 | 0. 128 | O. II4 | O.II4 | - | - | - |
| 0.450 | 0.33 | 0. 30 | 0.29 | 0.31 | 0.23 | 0.175 | 0.16 | - | - |
| 0.470 | 0.63 | 0.59 | 0. 54 | 0. 58 | 0.51 | 0.29 | 0.26 | 0.23 | - |
| 0.490 | 0.96 | (0.89) | (0.76) | (0.89) | (0.83) | 0.50 | 0.45 | 0.38 | 0.35 |
| -. 505 | 1.00 | 1.00 | 1.00 | 1.00 | 0.99 | (0.76) | 0.66 | 0.61 | 0. 54 |
| 0.520 | 0.88 | 0.86 | 0.86 | 0.94 | 0.99 | (0.85) | 0.85 | 0.85 | 0.82 |
| 0.535 | 0.61 | 0.62 | 0.63 | 0.72 | 0.91 | (0.98) | 0.98 | 0.99 | 0.98 |
| 0.555 | 0.26 | 0.30 | 0.34 | 0.41 |  |  | 0.93 | 0.97 | 0.98 |
| 0.575 | 0.074 | 0. 102 | 0. 122 | 0. 168 | (0.39) | (0.63) | (0.76) | (0.82) | (0.84) |
| 0.590 | 0.025 | 0.034 | 0.054 | 0.091 | 0.27 | 0.49 | 0.61 | 0.68 | 0.69 |
| 0.605 | 0.008 | 0.012 | 0.024 | 0.056 | 0.173 | 0.35 | (0.45) | 0. 54 | 0.55 |
| 0.625 | 0.004 | 0.004 | 0.011 | 0.027 | 0.098 | 0.20 | 0.27 | 0.35 | 0.35 |
| 0.650 | 0.000 | 0.000 | 0.003 | 0.007 | 0.025 | 0.060 | 0.085 | 0.122 | 0.133 |
| , 0.670 | 0.000 | 0.000 | 0. 001 | 0.002 | 0.007 | 0.017 | 0.025 | 0.030 | 0.030 |
| $\lambda$, maximum sensitiveness | 0.503 | 0.504 | 0. 504 | 0. 508 | 0.513 | 0.530 | 0.541 | 0.543 | 0.544 |

## TABLE 291. - Threshold Sensibility as Related to Field Brightness.

The eye perceives with ease and comfort a billion-fold range of intensities. The following data were obtained with the eye fully adapted to the sensitizing field, $B$, the field flashed off, and immediately the intensity, $T$, of a test spot (angular size at eye about $5^{\circ}$ ) adjusted to be just visible. This table gives a measure of the brightness, $T$, necessary to just pick up objects when the eye is adapted to a brightness, B. Intensities are indicated log intensities in millilamberts. Blanchard, Physical Review, 11, p. 81, 1918.

the eye and radiation.

## TABLE 292. - Heterochromatic Threshold Sensibility.

The following table shows the decrease in sensitiveness of the eye for comparing intensities of different colors. The numbers in the body of the table correspond to the line marked $T / B$ of Table 291. The intensity of the field was probably between 10 and 100 millilamberts ( 25 photons).

| Comparison color. |  | $0.693 \mu$ | $0.640 \mu$ | $0.575 \mu$ | $0.505 \mu$ | $0.475 \mu$ | $0.430 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Standard color: $\begin{aligned} & \text { red } \ldots . . . . . . . . . \\ & \\ & \text { yellow . . . . . }\end{aligned}$ | $0.693 \mu$ | 0.044 | 0.088 | 0. 165 | 0. 180 | O. 197 | O. 150 |
|  | $0.575 \mu$ | -. 174 | 0. 160 | 0.032 | 0.166 | -. 174 | -. 134 |
|  | $0.505 \mu$ | 0.211 | 0. 180 | -. 138 | 0.030 | -. 116 | 0.126 |
|  | $0.475 \mu$ | O. 168 | 0.180 | 0.130 | -. 130 | 0.068 | 0.142 |

## TABLE 293. - Contrast or Photometric Sensibility.

For the following table the eye was adapted to a field of 0.1 millilambert and the sensitizing field flashed off. A neutral gray test spot (angular size at eye, $5 \times 2.5^{\circ}$ ) the two halves of which had the contrast indicated ( $\frac{1}{2}$ transparent, $\frac{1}{2}$ covered with neutral screen of transparency $=$ contrast indicated) was then observed and the brightness of the transparent part measured necessary to just perceive the contrast after the lapse of the various times. One eye only used, natural pupil. Blanchard, Physical Review, II, p. 88, 1918. Values are log brightness of brighter field in millilamberts.

| Time in seconds. | - | I | 2 | 5 | 10 | 20 | 40 | 60 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Contrast: $\begin{aligned} & 0.0 \\ & 0.3 \\ & 0.6 \\ & 0.8 \\ & 0.9\end{aligned}$ | -2.80 | -3.47 | $-3.82$ | -4.30 | -4.49 | -4.60 | $-4.89$ | -5.03 |
|  | $-2.63$ | $-3.36$ | $-3.58$ | -3.74 | $-3.85$ | -3.97 | $-4.06$ | $-4.23$ |
|  | -2.40 | -3.00 | $-3.13$ | -3.22 | -3.21 | $-3.33$ | $-3.46$ | $-3.48$ |
|  | -2.10 | $-2.46$ | $-2.49$ | $-2.48$ | $-2.55$ | -2.54 | $-2.67$ | $-2.73$ |
|  | -1.20 | -1.57 | -1.67 | -1. 69 | -1. 59 | -1.63 | -1.73 | -1.78 |

## TABLE 294. - Glare Sensibility.

When an eye is adapted to a certain brightness and is then exposed suddenly to a much greater brightness, the latter may be called glaring if uncomfortable and instinctively avoided. Observers naturally differ widely. The data are the means of three observers, and are log brightnesses in millilamberts. The glare intensity may be taken as roughly 1700 times the cube root of the field intensity in millilamberts. Angle of glare spot, $4^{\circ}$. Blanchard, Physical Review, loc. cit.


## TABLE 295. - Rate of Adaptation of Sensibility.

This table furnishes a measure of the rate of increase of sensibility after going from light into darkness, and the values were obtained immediately from the instant of turning off the sensitizing field. Both eyes were used, natural pupil, angular size of test spot, $4.9^{\circ}$, viewed at 35 cm . Blanchard, loc. cit. Retinal light persists only 10 to 20 m when one has been recently in darkness, then in a dimly lighted room; it persists fully an hour, when a subject has been in bright sunlight for some time. A person who has worked much in the dark "gets his eyes" quicker than one who has not, but his final sensitiveness may be no greater.

| Sensitizing field. | Logarithmic thresholds in millilamberts after |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | o sec. | 1 sec . | 2 sec . | 5 sec . | IO Sec. | 20 sec . | 40 sec . | 60 sec . | 5 min . | 30 min . | 60 min . |
| White, 0.1 ml . | -2.79 | $-3.82$ | -4.13 | -4.50 | -4.75 | -4.96 | -5.16 | -5.32 | -5.68 | -5.91 | -6.06 |
| 1.0 ml . | -2.20 | $-2.99$ | $-3.27$ | -3.79 | $-4.15$ | $-4.51$ | $-4.82$ | $-5.06$ | $-5.52$ | $-5.86$ | -6.04 |
| 10.0 ml | -1.60 | $-2.30$ | $-2.53$ | $-3.08$ | -3.54 | -3.94 | $-4.31$ | -4.61 | -5.22 | $-5.83$ | -6.01 |
| 100.0 ml . | -0.90 | -1.66 | $-2.00$ | $-2.46$ | $-2.64$ | $-2.88$ | $-3.20$ | $-3.84$ | $-4.76$ | $-5.77$ | $-5.97$ |
| Blue 0.1 ml . | -2.82 | $-3.92$ | -4.36 | -4.91 | -5.27 | -5.53 | -5.68 | -5.8I | -6.23 | - | - |
| Green 0.1 ml . Yellow 0.1 ml . | -2.69 -2.61 | -4.08 -3.84 | -4.39 -4.17 | -4.82 -4.41 | -5.11 -4.65 | -5.26 -4.78 | -5.43 | -5.56 | -5.80 -5.39 | - | 二 |
| Red 0.1 mml | -2.61 | -3.84 | - 4.98 | -4.41 | -4.65 -3.57 | -4.78 -3.65 | -5.02 -3.73 | -5.09 | -5.39 | - | - |

## THE EYE AND RADIATION.

TABLE 296. - Apparent Diameter of Pupil and Flux Density at Retina.
Flashlight measures of the pupil (both eyes open) viewed through the eye lens and adapted to various field intensities. For eye accommodated to 25 cm , ratio apparent to true pupil, 1.02, for the unaccommodated eye, I.I4. The pupil size varies considerably with the individual. It is greater with one eye closed; e.g., it was found to be for o.or millilambert, 6.7 and 7.2 mm ; for $0.6 \mathrm{ml}, 5.3$ and 6.5 ; for $6.3 \mathrm{ml}, 4.1$ and 5.7 ; for 12.6 ml , 4.1 and 5.7 mm for both and one eye open respectively for a certain individual. At the extreme intensities the two values approach each other. The ratio of the extreme pupil openings is about 1 ,, whereas the light intensities investigated vary over $\mathbf{I}, 000,000$-fold. (Blanchard and Reeves, partly unpublished data.)

| Field millilamberts. | Diameter, mm |  | Effective area, $\mathrm{mm}^{2}$ | Flux at retina, lumens per $\mathrm{mm}^{2}$ |
| :---: | :---: | :---: | :---: | :---: |
|  | Observed. | $\begin{gathered} (1.14 / 1.02) \\ \times \text { Obs } \end{gathered}$ |  |  |
| 0.00001 | 8 | 8.96 | 64 | $8.4 \times 10^{-12}$ |
| 0.001 | 7.6 | 8.51 | 57 | $7.6 \times 10^{-10}$ |
| 0.1 | 6.5 | 7.28 | 42 | $5.6 \times 10^{-8}$ |
| 10 . | 4.0 2.07 | 4.48 2.35 | 16 | 2.1 $5.8 \times 10^{-6}$ $10^{-5}$ |

## TABLE 297. - Relative Visibility of Radiation.

This table gives the relation between luminous sensation (light) and radiant energy. The results of two methods are given: one from measures of the direct equality of brightness, which some consider the true method, as more direct, but criticized because of the difficulty of judging heterochromatic light (Hyde, Forsythe, Cady, A. J. 48, 87, 1918, 29 observers); the other (Coblentz, Emerson, Bul. Bureau of Standards, 14, 219, 1917, 130 observers) depends on the disappearance of flicker when two lights of different color and intensity are alternated rapidly. Color has a lower critical frequency than brightness and disappears first. Data determined for intensities above Purkinje effect. See Table 290. Ratio of light unit (lumen) to energy unit (watt) at $0.55 \mu$, 0.00162 (Ives, Coblentz, Kingsbury).

| ${ }_{\mu}^{\lambda}$ | Vsisibity. |  | ${ }^{\mu}$ | Visibility. |  | ${ }_{\mu}^{\lambda}$ | Visibility. |  | ${ }_{\mu}^{\lambda}$ | Visibility. |  | ${ }_{\mu}^{\lambda}$ | Visibility. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | HFC | CE |  | HFC | CE |  | HFC | CE |  | HFC | CE |  | HFC | CE |
|  | 0,9 | . 010 | . 48 | . 138 | . 125 |  |  |  |  | 154 | . 194 |  |  |  |
| :41 ${ }_{4}$ | -0.62 | -017 | - 5 | - 2128 | . 139 | - 58 | . 845 | . 8068 | . 66 | .094 | .1154 | . 74 | :036 | :0348 |
| . 44 | -0175 | . 0238 | -52 | .515 | : 710 | . 69 | . 730 | . 888 | :68 | .0125 | .03788 | :76 | 0.09 | $\stackrel{.0220}{ }$ |
| .45 | :036 | . 041 | . 53 | . 848 | 862 | . 61 | . 464 | -557 | . 69 | .0062 | :0085 | - | - | - |
| ${ }_{-47}$ | .085 | .086 | ${ }_{\text {. }}^{55}$ | .9968 | 9994 | :63 | ${ }_{.238}^{.341}$ | :427 | ${ }_{7}{ }_{7}$ | .0331 | :0040 | 二 | 二 | - |

## TABLE 298. - Miscellaneous Eye Data.

Light passing to the retina traverses in succession (a) front surface of the cornea (curvature, 7.9 mm ); (b) cornea (equivalent water path for energy absorption, . 06 cm ); (c.) back surface corneal(curv., 7.9 mm ); (d) aqueous humour (equiv. $\mathrm{H}_{2} \mathrm{O}, .34 \mathrm{~cm}, n=\mathrm{I} .337$ ); (e) front surface lens ( $\mathrm{c}, 10 \mathrm{~mm}$ ); ( $f$ ) lens (equiv. $\mathrm{H}_{2} \mathrm{O}, .42 \mathrm{~cm}, n=1.445$ ); (g) back surface lens ( $\mathrm{c} ., 6 \mathrm{~mm}$ ); ( $h$ ) vitreous humour (equiv. $\mathrm{H}_{2} \mathrm{O}, \mathrm{I} .46 \mathrm{~cm}, n=\mathrm{I} .337$ ). An equivalent simple lens has its principal point 2.34 mm behind (a), nodal point 0.48 mm in front of $(g)$, posterior principal focus 22.73 mm behind (a), anterior principal focus 12.83 mm . in front of (a), curvature, 5.125 mm . At the rear surface of the retina (. 15 mm thick) are the rods ( $30 \times 2 \mu$ ) and cones (ro ( 6 outside fovea) $\mu$ long). Rods are more numerous, 2 to 3 between 2 cones, over $3,000,000$ cones in eye. Macula lutea, yellow spot, on temporal side, 4 mm from center of retina, long axis 2 mm . Central depression, fovea centralis, 3 mm diameter, 7000 cones alone present, $6 \times 2$ or $3 \mu$. In region of distinct vision (fovea centralis) smallest angle at which two objects are seen separate is $50^{\prime \prime}$ to $70^{\prime \prime}=3.65$ to $5.14 \mu$ at retina; 50 cones in $100 \mu$ here; $4 \mu$ between centers, $3 \mu$ to cone, $1 \mu$ to interval. Distance apart for separation greater as depart from fovea. No vision in blind spot. nasal side, 2.5 mm from center of eye, 15 mm in diam.

Persistence of vision as related to color (Allen, Phys. Rev. II, 257, 1900) and intensity (Porter, Pr. Roy. Soc. 70, 313, 1912) is measured by increasing speed of rotating sector until flicker disappears: for color, $4 \mu, .03 \mathrm{I}$ sec.; .45 $\mu$,
 .020 sec .; 6 mc , . 014 sec .; 100 mc , . 010 sec ; 142 mc ., .007 sec .

Sensibility to small differences in color has two pronounced maxima (in yellow and green) and two slight ones (extreme blue, extreme red). The sensibility to small differences in intensity is nearly independent of the intensity (Fechner's law) as indicated by the following data due to König:

| $I / I_{0}$ | 1,000,000 | 100,000 | 10,000 | 1000 | 100 | 50 | 10 | 5 | 1 | 0.1 | $I_{0}$ in mc |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{r} d I / I, \text { white. ...... } \\ .60 \mu \ldots \ldots \\ .50 \mu \ldots \ldots \\ .43 \mu \ldots \ldots \end{array}$ | . 036 | . 019 | . 018 | . 018 | . 030 | . 032 | . 048 | . 059 | . 123 | . 377 | . 00072 |
|  | - | . 024 | . 016 | . 020 | . 028 | . 038 | . 061 | . 103 | . 212 | - | . 0056 |
|  | - | - | . 018 | . 018 | . 024 | . 025 | . 036 | . 049 | . 080 | . 133 | . 00017 |
|  |  | - | - | . 018 | . 025 | . 027 | . 040 | . 049 | . 074 | . 137 | . 00012 |

Luminous flux, $F=$ radiant power according to visibility, i.e., capacity to produce sensation of light. Unit, the lumen = flux emitted in a unit solid angle (steradian) by point source of one candle power.

Visibility, $K_{\boldsymbol{\lambda}}$, of radiation of wave-length $\boldsymbol{\lambda}=$ ratio luminous flux to radiant power (energy) producing it. Mean visibility, $K_{m}$, over any range of $\lambda$ or for whole visible spectrum of any source $=$ ratio total flux (lumens) to total radiant power (erg/sec. or watts).

Luminous intensity, $I$, of (approximate) point source $=$ solid angle density of luminous flux in direction considered $=d F / d \omega$ or $F / \omega$ if intensity is uniform. $\omega$ is the solid angle. Unit, the candle.

Illumination on surface is the flux density on the surface $=d F / d S$ or $F / S$ when uniform. $S$ is the area of the surface. Units, meter-candle, foot-candle, phot, lux.
(Lux $=$ one lumen per $\mathrm{m}^{2}$; phot $=$ one lumen per $\mathrm{cm}^{2}$.)
Brightness, $b$, of element of surface from a given point $=d I / d S \cos \theta$, where $\theta$ is the angle between normal to surface and line of sight. Unit, candles per $\mathrm{cm}^{2}$. Normal brightness, $b_{0}$ $=d I / d S=$ brightness in direction normal to surface. Unit, the lambert.

Specific luminous radiation, $E^{\prime}=$ luminous flux density emitted by a surface, or the flux emitted per unit of emissive area, expressed in lumens per $\mathrm{cm}^{2}$. For surfaces obeying Lambert's cosine law, $E^{\prime}=\pi b_{0}$.

The lambert, the cgs unit of brightness, is the brightness of a perfectly diffusing surface radiating or reflecting one lumen per $\mathrm{cm}^{2}$. Equivalent to a perfectly diffusing surface with illumination of one phot. A perfectly diffusing surface emitting one lumen per $\mathrm{ft}^{2}$ has a brightness of 1.076 millilamberts. Brightness in candles per $\mathrm{cm}^{2}$ is reduced to lamberts by multiplying by $\pi$.

A uniform point source of one candle emits $4 \pi$ lumens.
One lumen is emitted by .07958 spherical candle power.
One lumen emitted per $\mathrm{ft}^{2}=\mathrm{r} .076$ millilamberts (perfect diffusion).
One spherical candle power emits 12.57 lumens.
One lux $=1$ lumen incident per $\mathrm{m}^{2}=.000 \mathrm{I}$ phot $=. \mathrm{I}$ milliphot.
One phot $=\mathrm{I}$ lumen incident per $\mathrm{cm}^{2}=10,000$ lux $=1000$ milliphots.
One milliphot $=.001$ phot $=.929$ foot-candle.
One foot-candle $=\mathrm{r}$ lumen incident per $\mathrm{ft}^{2}=1.076$ milliphots $=10.76$ lux.
One lambert $=\mathrm{I}$ lumen emitted per $\mathrm{cm}^{2}$ of a perfectly diffusing surface.
One millilambert $=.929$ lumen emitted per $\mathrm{ft}^{2}$ (perfect diffusion).
One lambert $=.3183$ candle per $\mathrm{cm}^{2}=2.054$ candles per $\mathrm{in}^{2}$.
One candle per $\mathrm{cm}^{2}=3.1416$ lamberts.
One candle per $\operatorname{in}^{2}=.4968$ lambert $=486.8$ millilamberts.
Adapted from 1916 Report of Committee on Nomenclature and Standards of Illuminating Engineering Society. See Tr., Vol. if, 1916.

[^41]No primary photometric standard has been generally adopted by the various governments. In Germany the Hemer lamp is most used; in England the Pentane lamp and sperm candles are used; in France the Carcel lamp is preferred; in America the Pentane and Hefner lamps are used to some extent, but candles are more largely employed in gas photometry. For the photometry of electric lamps, and generally in accurate photometric work, electric lamps, standardized at a national standardizing institution, are commonly employed.

The " International candle" is the name recently employed to designate the value of the candle as maintained by coöperative effort between the national laboratories of England, France, and America; and the value of various photometric units in terms of this international candle is given in the following table (taken from Circular No. 15 of the Bureau of Standards).

> I International Candle $=1$ Pentane Candle.
> I International Candle $=1$ Bougie Decimale.
> I International Candle $=1$ American Candle.
> I International Candle $=1.11$ Hefner Unit.
> i International Candle $=0.104$ Carcel Unit.

Therefore I Hefner Unit $=0.90$ International Candle.
The values of the flame standards most commonly used are as follows:
I. Standard Pentane Lamp, burning pentane . . . . . . 10.0 candles.
2. Standard Hefner Lamp, burning amyl acetate . . . . . 0.9 candles.
3. Standard Carcel Lamp, burning colza oil . . . . . . . 9.6 candles.
4. Standard English Sperm Candle, approximately . . . . i.o candles.

TABLE 301. - Intrinsic Brightness of Various Light Sources.

|  | Barrows. | Ives \& Luckiesh. |  | National Electric Lamp Association. |
| :---: | :---: | :---: | :---: | :---: |
|  | C. P. per Sq. In. of surtace of light. | C. P. per Sq. In. of surface of light. | C. P. per Sq. Mm. of surface of light. | C. P. per Sq. In. of surface of light. |
| Sun at Zenith . . . . | 600,000 | 84,000 | - | 600,000 |
| Crater, carbon arc . . . | 200,000 | 84,000 | 130. | 200,000 |
| Open carbon arc . . . | 10,000-50,000 | - |  | 10,000-50,000 |
| Flaming arc • • - | 5,000 | - ${ }^{-1000}$ | - | 5,000 |
| Magnetite arc - . - . Nernst Glower | 800-1,000 |  | 6.2 |  |
| Nernst Glower ${ }_{\text {Tungsten incandescent, }} \mathbf{1} .15$ w. | 800-1,000 | (115v.6 amp. d.c.) 3,010 | 4.7 | (1.5 w.p.c.) 2,200 |
| Tungsten incandescent, 1.25 w. p.c. | 1,000 | 1,000 | 1.64 | 1,000 875 |
| Tantalum incandescent, $2.0 \mathrm{w} . \mathrm{p} . \mathrm{c}$. | $75^{\circ}$ | 580 | 0.9 | 750 |
| $\begin{aligned} & \text { Graphitized carbon filament, } 2.5 \\ & \text { w. p. c. . } \end{aligned}$ | 625 | 750 | 1.2 | 625 |
| Carbon incandescent, 3.1 w. p. c. . | 480 | 485 | 0.75 | 480 |
| Carbon incandescent, 3.5 w. p. c. | 375 | 400 | 0.63 | 375 |
| Carbon incandescent, 4.0 w. p. c. | 300 | 325 | 0.50 | - |
| Inclosed carbon arc (d. c.) . . | 100-500 | - | - | 100-500 |
| Inclosed carbon arc (a.c.) - | - | - | - | 75-200 |
| Acetylene flame (r ft. burner) . | 75-100 | 53.0 | 0.082 | 75-100 |
| Acetylene flame ( $1 / 4 \mathrm{ft}$. burner) | - | 33.0 | 0.057 | - |
| Welsbach mantle . . . Welsbach (mesh) | $20-25$ | 31.9 | 0.048 | 20-50 |
| Welsbach (mesh) . . . | - | 56.0 | 0.067 |  |
| Cooper Hewitt mercury vapor lamp Kerosene flame . . | 6.7 4.8 | 14.9 9.0 | 0.023 | ${ }_{3-8}{ }^{17}$ |
| Kerosene flame . . . . Candle flame . . | $4-8$ $3-4$ | 9.0 | 0.014 | $3-8$ $3-4$ |
| Gas flame (fish tail) . . . | 3-4 | 2.7 | 0.004 | $3-4$ $3-8$ |
| Frosted incandescent lamp . | 4-8 | 2.7 | - | 2-5 |
| Moore carbon-dioxide tube lamp .l | 0.6 | - | - | 0.3-x.75 |

Taken from Data, 191 .

## TABLE 302. - Visibility of White Lights.


${ }^{1}$ Paterson and Dudding. $\quad{ }^{2}$ Deutsche Seewarte.
${ }^{1}$ micro-calorie through icm. at m . $=0.034$ sperm candle $=0.0385$ Hefner unit (no diaphragm) $=0.043$ Hefner unit (diap. $14 \times 50 \mathrm{~mm}$.). Coblentz Bul. B. of S., 11, p. $87,1914$.

## BRIGHTNESS OF BLACK BODY. CROVA WAVE-LENGTH. MECHANICAL EQUIVALENT OF LIGHT, LUMINOUS INTENSITY AND EFFICIENCY OF BLACK BODY.

The values of $L$, the luminous intensity, are given in light watts/steroradian $/ \mathrm{cm}^{2}$ of radiating surface $=(x / \pi) \int_{0}^{\infty} V_{\lambda} E_{\lambda} d \lambda$, where $V_{\lambda}$ is the visibility of radiation function.

Mechanical equivalent. The unit of power is the watt; of lumininous flux, the lumen. The ratio of these two quantities for light of maximum visibility, $\lambda=0.556 \mu$, is the stimulus coefficient $V m$; its reciprocal is the (least) mechanical equivalent of light, i.e., least since applicable to radiation of maximum visibility. A better tern is "luminous equivalent of radiation of maximum visibility." One lumen $=0.001496$ watts (Hyde, Forsythe, Cady); or I watt of radiation of maximum visibility $(\lambda=0.556 \mu)=668$ lumens.

White light has sometimes bee, defined as that emitted by a black body at $6000^{\circ} \mathrm{K}$.
The Crova wave-length for a black body is that wave-length, $\boldsymbol{\lambda}$, at which the luminous intensity varies by the same fractional part that the total luminous intensity varies for the same change in temperature.

## TABLE 303. - Brightness, Crova Wavelength of Black Body, Mechanical Equivalent of Light.*

| ${ }^{\text {Temp. }} \text {. }$ | Brightness, candles per $\mathrm{cm}^{2}$ | Crova wavelength, | Mech. equiv. watts per $l$. |
| :---: | :---: | :---: | :---: |
| $1700^{\circ}$ | 5.1 | 0. 584 | 0.001478 |
| 1750 | 7.6 | 0.583 | - |
| 1800 | 11.3 | 0. 582 | 0.00149 I |
| 1850 | 16.3 | -0.58r | - |
| 1900 | 23.1 | 0. 580 | 0.001498 |
| 1950 | 32.2 | -0.579 | - |
| 2000 | 44.3 | 0.578 | 0.001498 |
| 2050 | 60.0 | 0.577 | - |
| 2100 | 80.1 | 0.576 | 0.001497 |
| 2150 | 105.7 | 0.576 | - |
| 2200 | 137.6 | 0.575 | 0.001496 |
| 2250 | 177. | 0. 574 | - |
| 2300 | 226. | 0. 574 | 0.001497 |
| 2350 | 284. | 0. 573 | - |
| 2400 | 354. | 0.572 | 0.001497 |
| 2450 | 438. | 0. 572 | - |
| 2500 | 537. | 0.571 | 0.001502 |
| 2550 | 651. | 0.570 | - |
| 2600 | 785. | 0.570 | 0.001511 |
| 2650 | 939. | 0.569 | - |
| Mean..................... |  |  | 0.001496 |

* Hyde, Forsythe, Cady, Phys. Rev. 13, p. 45, I919.

TABLE 304.- Luminous, Total Intensity and Radiant Luminous Efficiency of Black Body.*

| $T$, degrees absolute. | Luminous intensity $L$ watt $/ \mathrm{cm}^{2}$ | Total intensity <br> $\sigma_{0} T^{4}$ watt $/ \mathrm{cm}^{2}$ | Radiant luminous efficiency. |
| :---: | :---: | :---: | :---: |
| 1,200 | $2.34 \times 10^{-5}$ | 3.762 | . 000006 |
| 1,600 | $3.45 \times 10^{-3}$ | 1.189 | . 000290 |
| 1,700 | $8.46 \times 10^{-3}$ | $1.515 \times 10$ | . 000558 |
| 1,800 | $1.88 \times 10^{-2}$ | $1.905 \times 10$ | . 000987 |
| 1,900 | $3.85 \times 10^{-2}$ | $2.365 \times 10$ | . 00163 |
| 2,000 | $7.34 \times 10^{-2}$ | $2.903 \times 10$ | . 00253 |
| 2,100 | $1.32 \times 10^{-1}$ | $3.529 \times 10$ | . 00374 |
| 2,200 | $2.26 \times 10^{-1}$ | $4.250 \times 10$ | . 00532 |
| 2,300 | $3.69 \times 10^{-1}$ | $5.077 \times 10$ | . 00727 |
| 2,400 | $5.79 \times 10^{-1}$ | $6.020 \times 10$ | . 00962 |
| 2,500 | $8.77 \times 10^{-1}$ | $7.087 \times 10$ | . Or 24 |
| 2,600 | 1.29 | $8.291 \times 10$ | . 0156 |
| 3,000 | 4.66 | $1.470 \times 10^{2}$ | . 0317 |
| 4,000 | $3.85 \times 10$ | $4.645 \times 10^{2}$ | . 0829 |
| 5,000 | $1.36 \times 10^{2}$ | 1. $134 \times 10^{3}$ | . 1201 |
| 6,000 | $3.26 \times 10^{2}$ | $2.351 \times 10^{3}$ | . 1386 |
| 7,000 | $6.03 \times 10^{2}$ | $4.356 \times \mathrm{ro}^{3}$ | . 1385 |
| 8,000 | $9.59 \times 10^{2}$ | $7.432 \times 10^{3}$ | . 1290 |
| 10,000 | $1.84 \times 10^{3}$ | $1.854 \times 10^{4}$ | . 1014 |

* Coblentz, Emerson, Bul. Bureau of Standards, 14, p. 255, 1917.

Note. - Minimum energy necessary to produce the sensation of light: Ives, $38 \times 10^{-10}$; Russell, $7.7 \times 10^{-10}$; Reeves, $19.5 \times 10^{-10}$; Buisson, $12.6 \times 10^{-10} \mathrm{erg}$. sec. (Buisson, J. de Phys. 7, 68, 1917.)

TABLE 305. - Color of Light Emitted by Various Sources.*

| Source. | Color, per cent white. | Hue. | Source. | Color, per cent white. | Hue. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Sunlight. | 100 | - | N -filled tungsten, 0.50 wpc . | 45 | 584 |
| Average clear sky | 60 | 472 | N-filled tungsten, 0.35 wpc . | 53 | 584 |
| Standard candle. | 13 | 593 | Mercury vapor arc..... | 70 | 490 |
| Hefner lamp. | 14 | 593 | Helium tube. | 32 | 598 |
| Pentane lamp. | 15 | 592 | Neon tube.. | 6 | 605 |
| Tungsten glow lamp, I .25 wpc | 35 | 588 | Crater of carbon arc, 1.8 amp | 59 | 585 |
| Carbon low lamp, 3.8 wpc . | 25 | 592 | Crater of carbon arc, 3.2 amp | 62 | 585 |
| Nernst glower, r. 50 wpc.... | 31 | 587 586 | Crater of carbon arc, 5.0 amp | 67 | 583 586 |
| N-filled tungsten, I. 00 wpc | 34 | 586 | Acetylene flame (flat)........ | 36 | 586 |

* Jones, L. A., Trans. Ill. Eng. Soc., Vol. 9 (1914).

| Bryant and Hake, Eng. Exp. Station, Univ. of Ill. | Amperes. | $\begin{aligned} & \text { Terminal } \\ & \text { Watts. } \end{aligned}$ | Lumens. | Kw-hours for 100,000 Lumenhours. | Total cost per 100,000 Lumen-hours at 10 cts. per Kw-hour. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Regenerative d.-c., series arc | $5 \cdot 5$ | 385 | I 1,670 | $3 \cdot 3$ | 0.339 |
| Regenerative d.-c., multiple arc | 5.5 | 605 | 11,670 | 5.18 | 0.527 |
| Magnetite d.-c., series arc | 6.6 | 528 | 7,370 | 7.16 | 0.729 |
| Flame arc, d.-c., inclined electrodes | 10.0 | 550 | 8,640 | 6.37 | 0.837 |
| Mercury arc, d.-c., multiple | $3 \cdot 5$ | 385 | 4,400 | 15.92 | 0.89 |
| Flame arc, d.-c., inclined electrodes | 8.0 | 440 | 6,140 | 7.16 | 0.966 |
| Flame arc, d.-c., vertical electrodes | 8.0 | 440 | 6,140 | 7.16 | 0.966 |
| - Luminous arc, d.-c., multiple | 6.6 | 726 | 7,370 | 9.85 | 0.988 |
| Open arc, d.-c., series | 9.6 | 480 | 5,025 | $9 \cdot 55$ | 1.079 |
| Magnetite arc, d.-c., series | 4.0 | 320 | 2,870 | 11.15 | I. 13 |
| Flane arc, a.-c., vertical electrodes | 10.0 | 467 | 5,340 | 8.75 | 1.275 |
| Flame arc, a.-c., inclined electrodes | 10.0 | 467 | 5,340 | 8.75 | 1.275 |
| Open arc, d.-c., series | 6.6 | 325 | 2,920 | 11.15 | 1.305 |
| Tungsten series | 6.6 | 75 | 626 | 12.0 | 1. $3^{84}$ |
| Flame arc, a.-c., inclined electrodes | 8.0 | 374 | 3,910 | $9 \cdot 55$ | 1.405 |
| Inclosed arc, d.-c., Series | 6.6 | 475 | 3,315 | 14.32 | 1.459 |
| Luminous arc, d.-c., multiple | 4.0 | 440 | 2,870 | 15.32 | 1.547 |
| Tungsten, multiple | 0.545 | 60 | 475 | 12.6 | 1.55 |
| Nernst, a.-c., 3-glower | 1.87 | 414 | 2,160 | 19.2 | 1.88 |
| Nernst, d.-c., 3-glower | 1.87 | 414 | 2,160 | 19.2 | 1.90 |
| Inclosed arc, a.-c., series | 7.5 | 480 | 2,410 | 19.9 | 2.05 |
| Inclosed arc, a.-c., series | 6.6 | 425 | 2,020 | 21.3 | 2.193 |
| Tantalum, d.-c., multiple | - | 40 | 199 | 2 I . 1 | 2.31 |
| Tantalum, a.-c., multiple | - | 40 | 199 | 21.1 | 2.504 |
| Carbon, 3.1 w. p. c., multiple | - | 49.6 | 166 | 29.9 | 3.24 |
| Carbon, 3.5 w. p. c., series | 6.6 | 210 | 626 | 33.6 | 3.47 |
| Carbon, 3.5 w. p. c., multiple | - | 56 | 166 | 33.7 | 3.50 |
| Inclosed arc, d.-c., multiple | 5.0 | 550 | 1,535 | 35.8 | 3.66 |
| Inclosed arc, d.-c., multiple | 3.5 | 385 | 1,030 | 37.4 | 3.84 |
| Inclosed arc, a.-c., multiple | 6.0 | 430 | 1,124 | 38.3 | 3.94 |
| Inclosed arc, a.-c., multiple | 4.0 | 285 | 688 | 41.4 | 4.265 |


| Ives, Phys. Rcv., V, p. 390, 1915 (see also VI, p. 332, 1915) ; computed assuming y lumen $=0.00159$ watt. | Commercial Rating | Lumens per Watt. | Luminous Watts Flux $\div$ Watts Input or True Efficiency. |
| :---: | :---: | :---: | :---: |
| Open flame gas burner | Bray 6' high pressure | 0.22 | 0.00035 |
| Petroleum lamp |  | . 26 | . 0004 |
| Acetylene | 1.0 liters per hour | . 67 | . 0011 |
| Incandescent gas (low pressure) | . 350 lumens per B. t. u. per hr. | 1.2 | .0019 |
| Incandescent gas (high pressure) | . 578 lumens per B. t. u. per hr. | 2.0 | . 0031 |
| Nernst lamp |  | 4.8 | . 0076 |
| Moore nitrogen vacuum tube | 220-v. 60-cycle, 113 ft . | 5.21 | . 0083 |
| Carbon incandescent (treated filament) | 4 -watts per mean hor. C. P. | 2.6 | .004 I |
| Tungsten incandescent (vacuum) | 1.25 watts per hor. C. P. | 8. | . 113 |
| Carbon arc, open arc | 9.6 amp . clear globe | I 1.8 | . 019 |
| Mazda, type C | 500 watt multiple .7 w. p. c. | 15. | . 024 |
| Mazda, type C | 600 C. P. -20 amp. 5 w. p. c. | 19.6 | .031 |
| Magnetite arc, series | 6.6 amp . direct current | 21.6 | . 034 |
| Glass mercury arc | 40-70 volt ; 3.5 amperes | 23. | . 036 |
| Quartz mercury arc | 174-197 volt; 4.2 amperes | 42. | . 067 |
| Enclosed white flame carbon arc | Io ampere, A. C. | 26.7 | . 042 |
| Open arc " " " ${ }^{\text {" }}$ " | 6.5 ampere, D. C. | 35.5 | . 057 |
| Open arc " ${ }_{\text {6 }}$ " ${ }^{\text {a }}$ ( inclined | 10 ampere, A. C. | 29. | . 046 |
| Enclosed yellow flame carbon arc | io ampere, D. C. | 27.7 | . 044 |
| " " " | 6.5 ampere, D. C. | 3.4 34.2 | . 054 |
| Open arc, " " , inclined | 10 ampere, A. C. | 41.5 | . 066 |
| " ، " ، | 10 ampere, D. C. | 44.7 | . 071 |

PHOTOGRAPHIC DATA.
TABLE 307. - Numerical Constants Characteristic of Photographic Plates.

Abscissae of figure are $\log E=\operatorname{lrg}$ It (meter-candles-seconds);

Ordinates are densities, $D=1 / T$;
$E=$ exposure $=I$ (illumination 'in meter-candles) $\times i$ seconds;
$D$, the density of deposit $=1 / T$, where $T$ is the ratio of the transmitted to incident intensity on developed plate.
$i=$ inertia $=$ intercept straight line portion of curve on $\log E$ axis.
$S=$ speed $=($ some constant $) / i ; \quad \gamma=$ gamma $=$ tangent of angle $a$.
$L=$ latitude $=$ projected straight line portion of characteristic curve on $\log E$ axis, expressed in exposure units = Anti $\log (b-a)$.
The curve illastrates the characteristic curve of a photographic plate.


Typical Characteristic Curve of Photographic Plate.

## TABLE 308. - Relative Speeds of Photographic Materials.

The approximate exposure may be obtained when the intensity of the image on the plate is known. Let $L$ be the intensity in meter-candles; $E$, the exposure in seconds; $P$, the speed number from the following table; then $E=$ $\mathbf{1}, 350,000 /(L \times P)$ approximately.

| Plate. | Relative speed. | Paper. | Relative speed. |
| :---: | :---: | :---: | :---: |
| Extremely high speed | 100,000 | Fast bromide. |  |
| High speed... | 75,000 | Slow enlarging. | 60.0 |
| Medium speed.... | 60,000 50,000 |  |  |
| Medium speed high cont | 25,000 | Rapid gas-light, medium contrasty | 3.5 |
| Process, slow contrast | 10,000 | Rapid gas-light, contrasty. | I. 0 |
| Lantern plate | 3,000 | Professiona.............. | 1. 25 |

## TABLE 309. - Variation of Resolving Power with Plate and Developer.

The resolving power is expressed as the number of lines per millimeter which is just resolvable, the lines being opaque and separated by spaces of the same width. The developer used for the comparison of plates was Pyro-soda; the plate for the comparison of developers, Seed Lantern. The numbers are all in the same units. Huse, J. Opt. Soc. America, July, 1917.


| Developer. | Resolving power. | Developer. | Resolving power. | Developer. | Resolving power. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Pyro-caustic . | 77 | Pyrocatechin | 62 | Amidol . ............. | 51 |
| Glycin...... | 69 | Pyro-metol.......... | 62 | Process hydroquinone.. | 50 |
| Hydroquinone | 64 64 | Eikon.-hydroquinone . . | $6 \mathrm{6r}$ | Ortol ${ }^{\text {Rodinal }}$ | 49 |
| $\mathrm{MQ}_{25}$. | 64 | Caustic hydroquinone. . | 57 | X-ray powders | 49 |
| Metol. | 63 | Eikonogen............ | 57 | Edinol . ............. | 47 |
| Nepera. | 62 | Kachin . . . . . . . . . . . | 54 |  |  |

Tables 310-311.
PHOTOGRAPHIC DATA.
TABLE 310. - Photographic Efficiencies of Various Lights.

| Source. | $\begin{array}{\|c} \text { Visual } \\ \text { efficiency. } \\ \text { Lumens } \\ \text { per } \\ \text { watt. } \end{array}$ | Photographic efficiency. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | (a) |  |  | (b) |  |  |
|  |  | Ordinary plate. | Orthochromatic plate. | Panchromatic plate. | Ordinary plate. | Orthochromatic plate. | Panchromatic plate. |
| Sun. | 150 | 100 | 100 | 100 | 100 | 100 | 100 |
| Sky.............................. | 0.7 | 181 30 | 155 44 | 130 52 | 0.14 | - 0.21 | -0. 24 |
| " (screened) | 0.07 | 8 I | 85 | 89 | 0.037 | 0.040 | 0.042 |
| Pentane. . . . . . . . . | 0.045 | 18 | 28 | 42 | 0.053 | 0.086 | 0.13 |
|  | 40 | 600 218 | 500 105 | 367 165 | 158 | 132 | 99 |
| "، "، "Nultra" crown glass. | 35 37 | 218 324 | 195 | 165 249 | 50 79 | 46 | 39 62 |
| Carbon arc, ordinary........... | 12 | 126 | 112 | 104 | 10 | 10 | 8.5 |
| "" " white flame | 29 | 257 | 234 | 215 | 52 | 45 | 2.0 |
| " " enclosed. | 9 | 175 | 177 | 165 | 11 | 11 | 10 |
| Carbon arc, "Artisto".......... | 12 | 796 | 1070 | 744 | 62 | 86 | 60 |
| Magnetite arc.................. | 18 | 106 | 115 | 82 | 12 | 14 | 10 |
| Carbon glow-lamp.. | 2.44 | 23 | 32 | 42 | 0.37 | 0.52 | 0.68 |
| Carbon glow-lamp............. | 3.16 | 25 | 35 | 45 | O. 51 | 0. 74 | 0.95 |
| Tungsten vacuum lamp ......... | 8 | 33 | 45 | 50 | 1.74 | 2.2 | 2.7 |
| "، vacuum lamp......... | 9.9 | 37 | 45 | 53 | 2.41 | 3.8 | 3.5 |
| " ${ }_{\text {" }} \begin{aligned} & \text { nitrogen lamp......... } \\ & \text { nitrogen lamp....... }\end{aligned}$ | 16.6 21.6 | 56 64 | 62 68 | 70 76 | 6.1 8.9 | 6.8 9.8 | 7.7 11.0 |
| " blue bulb.............. | 8.9 | - | - | - | 5.5 | 5.2 | 5.6 |
| " blue bulb............. | 11 | 108 | 99 | 106 | 7.8 | 7.3 | 7.9 |
| Mercury arc (Cooper Hewitt).... | 23 | 316 | 354 | 273 | 47 | 54.2 | 42 |

(a) Relative efficiencies based on equal illumination.
(b) Relative efficiencies based on equal energy density.

Taken from Jones, Hodgson, Huse, Tr. Ill. Eng. Soc. 10, p. 963, 1915.

TABLE 311.-Relative Intensification of Various Intensifiers.

| Bleaching solution. | Blackening solution. | Reference | Intensification. |
| :---: | :---: | :---: | :---: |
| Mercuric bromide. . | Amidol developer | $\mathrm{HgBr}_{2}$ solution (Monckhoven sol. A).* | 1.15 |
| Mercuric chloride. | Ammonia | Bleach according to Bennett; blackener.* | 1.15 |
| Potassium bichromate + hydrochloric acid | Amidol developer | Piper.** | 1.45 |
| Mercuric iodide . . . . . . . . . . . . . . . | Schlippe's salt Sodium sulphide | Debenham, B. J., $\dagger$ p.'r86, 'ı7. | 2.50 2.28 2. |
| Uranium formula................ | um sulphide | ${ }_{\text {B. J. Almanac.* }}$ | 2.28 3.50 |
| Potassium permanganate + hydro chloric acid. | Sodium stannate |  | 2.05 |
| Cupric chloride................. Potassium ferricyanide + potassium | Sodium stannate | Desalme, B. J., $\dagger$ p. 215, '12. | 1.93 |
| bromide. <br> Mercuric iodide. | Sodium sulphide <br> Paraminophenol developer | Ordinary sepia developer. <br> $\mathrm{HgI}_{2}$ according to Bennett. | $\begin{aligned} & \text { I. } 33 \\ & \mathbf{1 . 2 3} \end{aligned}$ |

See Nietz and Huse, J. Franklin Inst. March 3, 1918.

* B. J. Almanac, see annual Almanac of British Journal of Photography.
$\dagger$ B. J. refers to British Journal of Photography.

Table 312.

## WAVE-LENGTHS OF FRAUNHOFER LINES.

For convenience of reference the values of the wave-lengths corresponding to the Fraunhofer lines usually designated by the letters in the column headed "index letters," are here tabulated separately. The values are in ten millionths of a millimeter, on the supposition that the 1 line value is 5896.155 . The table is for the most part taken from Rowland's table of standard wavelengths.

| Index Letter. | Line due to - | Wave-length in centimeters $\times$ os $^{8}$. | Index Letter. | Line due to- | Wave-length in centimeters $\times 10^{8}$. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| A | $\left\{\begin{array}{l}0 \\ 0\end{array}\right.$ | 7621.28* ${ }^{\text {7 }}$ (594.06* | G | $\left\{\begin{array}{l}\mathrm{Fe} \\ \mathrm{Ca}\end{array}\right.$ | 4308.081 4307.907 |
| a | - | 7164.725 | g | Ca | 4226.904 |
| $\begin{gathered} \mathrm{B} \\ \mathrm{C} \text { or } \mathrm{H}_{a} \end{gathered}$ | O | $6870.182 \dagger$ | $h$ or $\mathrm{H}_{\delta}$ | H | 4102.000 |
|  | H | 6563.045 | H | Ca | 3968.625 |
| $\boldsymbol{\alpha}$ | O | $6278.303 \ddagger$ | K | Ca | 3933.825 |
| $\mathrm{D}_{1}$ | Na | 5896.155 | L | Fe | 3820.586 |
| $\mathrm{D}_{2}$ | Na | 5890.186 | M | Fe | 3727.778 |
| $\mathrm{D}_{3}$ | He | 5875.985 | N | Fe | 3581.349 |
| $\mathrm{E}_{1}$ | $\{\mathrm{Fe}$ | $5270.55^{8}$ | O | Fe | 3441.155 |
|  | \{ Ca | 5270.438 | P | Fe | 3361.327 |
| $\mathrm{E}_{2}$ | Fe | 5269.723 | Q | Fe | 3286.898 |
| $\mathrm{b}_{1}$ | Mg | 5183.791 | R | ¢ Ca | 318 r .387 |
| $\mathrm{b}_{2}$ | Mg | 5172.856 |  | ¢ Ca | 3179.453 |
| $\mathrm{b}_{3}$ | ( Fe | 5169.220 |  | ( Fe | 3100.787 |
|  | $\{\mathrm{Fe}$ | 5169.069 | $\left.S_{1}\right\}$ | $\{\mathrm{Fe}$ | 3100.430 |
| $\mathrm{b}_{4}$ | \{ Fe | 5167.678 | S | ( Fe | 3100.046 |
|  | ( Mg | 5167.497 | s | Fe | 3047.725 |
| F or $\mathrm{H}_{\beta}$ | H | 4861.527 | T | Fe | 3020.76 |
| d | Fe | 4383.721 | t | Fe | 2994.53 |
| $\mathrm{G}^{\prime}$ or $\mathrm{H}_{\gamma}$ | H | 4340.634 | U | Fe | 2947.99 |
| f | Fe | 4325.939 |  |  |  |

* The two lines here given for A are stated by Rowland to be: the first, a line "beginning at the head of A, outside edge"; the second, a "single line beginning at the tail of A."
$\dagger$ The principal line in the head of B.
$\ddagger$ Chief line in the a group.
See Table 321, Rowland's Solar Wave-lengths (foot of page) for correction to reduce these values to standard system of wave-lengths, Table 314.


# STANDARD WAVE-LENGTHS. 

TABLE 313.—Absolute Wave-length * of Red Cadmium Line in Air, 760 mm . Pressure, $15^{\circ}$ C.
6438.4722 Michelson, Travaux et Mém. du Bur. intern. des Poids et Mesures, $11,1895$.
6438.4700 Michelson, corrected by Benoit, Fabry, Perot, C. R. 144, 1082, 1907.
6438.4009 (accepted primary standard) Benoit, Fabry, Perot, C. R. 144, 1082, 1907.


## TABLE 314.-International Secondary Standards. Iron Arc Lines in Angströms.

Adopted as secondary standards at the International Union for Coöperation in Solar Research (transactions, 1910). Means of measures of Fabry-Buisson (1), Pfund (2), and Eversheim (3). Referred to primary standard $=$ Cd. line, $\lambda=6438.4696$ Angströms (serving to define an Ångström). 760 mm ., $15^{\circ} \mathrm{C}$. Iron rods, 7 mm . diam. length of arc, 6 mm .; 6 amp . for $\boldsymbol{\lambda}$ greater than 4000 Ångströms, 4 amp . for lesser wave-lengths; continuous current, + pole above the,- 220 volts ; source of light, 2 mm . at arc's center. Lines adopted in 1910.

| Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4282.408 | 4547.853 | 4789.657 | 5083.344 | 5405.780 | ${ }_{5}^{5615.66 r}$ | ${ }^{62} 30.734$ |
| 4315.089 4375.934 | 4592.658 460.947 | 4878.225 4903.325 | 5110.415 5167.492 | 5434.527 545.614 | 5658.836 5753.013 | 6265.145 6318.028 |
| 4427.314 | 4647.439 | 4919.007 | 5192.363 | 5497.522 | 6027.059 | $6335 \cdot 34 \mathrm{I}$ |
| ${ }^{4466.556}$ | ${ }^{4691.417}$ | 5001.881 | 5232.957 5266.569 | 5506.784 |  |  |
| +494.572 | 4707.288 4736.786 | 5012.073 5049.827 | 5266.569 5371.495 | 5569.633 5866.722 | 6137.701 619 l . 568 | 6430.859 6494.993 |

TABLE 315.-International Secondary Standards. Iron Arc Lines in Ångströms. Adopted in 1913. (4) Means of measures of Fabry-Buisson, Pfund, Burns and Eversheim.

| Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. | Wave-length. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |
| 3370.789 | 3606.682 | 3753.615 | 3906.482 | 4076.642 | 4233.615 | 6750.250 |
| 3399.337 | 3640.392 | 3805.346 | 3907.937 | 4118.552 | 5709.396 | 5857.759 Ni |
| 3485.345 | 3676.313 | 3843.261 | 3935.818 | 4134.685 | 6546.250 | 5892.882 Ni |
| 3513.821 | 3677.629 | 3850.820 | 3977.746 | 4147.676 | 6592.928 |  |
| 3556.88 I | 3724.380 | 3865.527 | 4021.872 | 4191.443 | 6678.004 |  |

(1) Astrophysical Journal, 28, p. 169, 1908; (2) Ditto, 28, p. 197, 1908; (3) Annalen der Physik, 30, p. 815, 1909. See also Eversheim, ibid. 36, p, 107I, I91! ; Buisson et Fabry, ibid. 38, p. 245, I912; (4) Astrophysical Journal, 39, p. 93, เ914.

TABLE 316.-Neon Wave-Lengths.

| In- | Wave <br> length. | In- | Wave length. | $\operatorname{In}_{\text {tensity. }}$ | Wave length. | $\begin{array}{\|c} \text { In- } \\ \text { tensity. } \end{array}$ | Wave length. | $\begin{gathered} \text { In. } \\ \text { tensity. } \end{gathered}$ | Wave length. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 5 | 3369.904 | 5 | 3515.192 | 2 | 5820.155 | 4 | 6217.280 | 5 | 6717.043 |
| 6 | 3417.906 | 8 | 3520.474 | 10 | 5852.488 | 7 | 6266.495 | 8 | 6929.468 |
| 6 | 3447.705 | 4 | $3593 \cdot 526$ | 6 | 5881.895 | 4 | 6304.789 | 3 | 7024.049 |
| 6 | 3454.197 | 4 | 3593.634 | 8 | 5944.834 | 8 | 6334.428 | 9 | 7032.413 |
| 5 | 3460.526 | 5 | 3600. 170 | 4 | $5975 \cdot 534$ | 8 | 6382.991 | 3 | 7059. I I I |
| 4 | $3464 \cdot 340$ | 5 | 3633.664 | 4 | 6329.997 | 10 | 6402.245 | 5 | 7173.939 |
| 5 | 3466.58 I | 8 | 5330.779 | 7 | 6374.338 | 9 | 6506.528 | 8 | 7245.167 |
| 6 | 3472.578 | 7 | 5341.096 | 8 | 6096.163 | 4 | 6532.883 | 6 | 7438.902 |
| 4 | 3498.067 | 6 | 5400.562 | 9 | 6143.062 | 5 | 6598.953 | 5 | 7488.885 |
| 4 | 3501.218 | 4 | $5764 \cdot 419$ | 5 | 6163.594 | 8 | 6678.276 | 5 | 7535.784 |

International Units (ingströms). Burns, Meggers, Merrill, Bull. Bur. Stds. 14, 765, 1918.

TERTIARY STANDARD WAVE-LENGTHS. IRON ARC LINES.
For arc conditions see Table 314, p. 266. For lines of group $c$ class 5 for best results the slit should be at right angles to the arc at its middle point and the current should be reversed several times during the exposure.

| Wave-lengths. | Class. | Intensity. | Wave-lengths. | Class. | Intensity. | Wave-lengths. | Class. | Intensity. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| *2781. 840 |  | 4 | $4337.05^{2}$ | b3 | 5 | 5332.909 | a | 2 |
| *2806.985 |  | 7 | 4369.777 | b3 | 3 | 5341.032 | a4 | 5 |
| *2831.559 |  | 3 | 4415.128 | bI | 8 r | 5365.404 | a 1 | 2 |
| *2858.34I |  | 3 | 4443.198 | b3 | 3 | 5405.780 | a | 6 |
| *2901.382 |  | 4 | 4461.658 | a3 | 4 | $5434 \cdot 528$ | a | 6 |
| *2926.584 |  | 5 | 4489.746 | a3 | 3 | 5473.913 | a | 4 |
| *2986.46n |  | 3 | 4528.620 | c 4 | 7 | 5497.52 I | a | 4 |
| *3000.453 |  | 4 | 4619.297 | c4 | 4 | 5501.471 | a | 4 |
| *3053.070 |  | 4 | 4786.81 I | c4 | 3 | 5506.784 | a | 3 |
| *3100.838 |  | 2 | 4871.331 | c 5 | 8 | $\ddagger 5535.419$ | a | 2 |
| *3154.202 |  | 4 | 4890.769 | c5 | 7 | 5563.612 | b | 3 |
| *3217.389 |  | 4 | 4924.773 | a | 3 | $5975.35^{2}$ | b | 3 |
| *3257.603 |  | 4 | 4939.685 | a | 3 | 6027.059 | b | 3 |
| *3307.238 |  | 4 | 4973.113 | a | 2 | 6065.495 | b | 4 |
| * 3347.932 |  | 4 | 4994.I33 | a | 3 | 6136.624 | b | 5 |
| *3389.748 |  | 3 | 5041.076 | a | 3 | 6157.734 | b | 4 |
| *3476.705 |  | 5 | 5041.760 | a | 4 | 6165.370 | b | 3 |
| *3506.502 |  | 5 | 5051.64 I | a | 4 | $6173 \cdot 345$ | b | 4 |
| *3553.741 |  | 5 | 5079.227 | a | 3 | 6200.323 | b | 4 |
| *3617.789 |  | 6 | 5079.743 | a | 3 | 6213.44 I | b | 5 |
| *3659.52I |  | 5 | 5098.702 | a | 4 | 6219.290 | b | 5 |
| *3705.567 |  | 6R | 5123.729 | a | 4 | 6252.567 | 3 | 6 |
| *3749.487 |  | 8R | 5127.366 | a | 3 | 6254.269 | b | 4 |
| *3820.430 |  | 8 R | 5150.846 | a | 4 | 6265.145 | b | 5 |
| *3859.913 |  | 7 R | 5151.917 | a |  | 6297.802 | b | 4 |
| *3922.917 |  | 6 R | 5194.950 | a | 5 | $6335 \cdot 342$ | b | 6 |
| $* 3956.682$ * 4000.718 |  | 6 | 5202.34 I | a | 5 | 6430.859 | b | 5 |
| * 4009.718 * 4062.451 |  | 5 | 5216.279 5227.191 | a a | 5 | $6494 \cdot 992$ | b | 6 |
| $\dagger 4132.063$ | bi | 7 | 5242.495 | a | 3 |  |  |  |
| †4175.639 | b | 4 | 5270.356 | a 4 | 8 |  |  |  |
| $\dagger 4202.031$ | br | 7 r | 5328.043 | a I | 7 |  |  |  |
| $\dagger 4250.79 \mathrm{I}$ | b2 | 7 | 5328.537 | a4 |  |  |  |  |

* Measures of Burns.
$\dagger$ Means of St. Joln and Burns.
$\ddagger$ Means of St. John and Goos. Others are means of measures by all three. References: St. John and Ware, Astrophysical Journal, 36, 1912; 38, 1913; Burns, Z. f. wissen. Photog. 12, p. 207, 1913, J. de Phys. 1913, and unpublished data; Goos, Astrophysical Journal, 35,$1912 ; 37,1913$. The lines in the table have been selected from the many given in these references with a view to equal distribution and where possible of classes $a$ and $b$.

For class and pressure shifts see Gale and Adams, Astrophysical Journal, 35, p. 10, 1912. Class $a$ : "This involves the well-known flame lines (de Watteville, Phil. Trans. A 204, p. 139. 1904), i.e. the lines relatively strengthened in low-temperature sources, such as the flame of the arc, the low-current arc, and the electric furnace. (Astrophysical Journal, 24, p. 185, 1906, 30, p. 86, 1909, 34, p. 37, 1911, 35, p. 185, 1912.) The lines of this group in the yellow-green show small but definite pressure displacements, the mean being 0.0036 Anngström per atmosphere in the arc." Class $b$ : "To this group many lines belong; in fact all the lines of moderate displacement under pressure are assigned to it for the present. These are bright and symmetrically widened under pressure, and show mean pressure displacements of 0.009 Angström per atmosphere for the lines in the region $\lambda$ 5975-6678 according to Gale and Adams. Group contains lines showing much larger displacements. The numbers in the class column have the following meaning: I, symmetrically reversed; 2 , unsymmetrically reversed; 3, remain bright and fairly narrow under pressure; 4, remain bright and symmetrical under pressure but become wide and diffuse ; 5, remain bright and are widened very unsymmetrically toward the red under pressure."

For further measures in International units see Kayser, Bericht iiber den gegenwärtigen Stand der Wellenlängenmessungen, International Union for Coöperation in Solar Research, 1913. For further spectroscopic data see Kayser's Handbuch der Spectroscopie.

## REDUCTION OF WAVE-LENGTH MEASURES TO STANDARD CONDITIONS.

The international wave-length standards are measured in dry air at $15^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ pressure. Density variations of the air appreciably affect the absolute wave-lengths when obtained at other temperatures and pressures. The following tables give the corrections for reducing measures to standard conditions, viz.: $\delta=\lambda_{0}\left(n_{0}-n_{0}{ }^{\prime}\right)\left(d-d_{0}\right) / d_{0}$ in ten-thousandths of an Angstrom, when the temperature $t^{\circ} \mathrm{C}$, the pressure $B \mathrm{in} \mathrm{cm}$ of Hg , and the wave-length $\lambda$ in Angstroms are given; $n$ and $d$ are the indices of refraction and densities, respectively; the subscript o refers to standard conditions, none, to the observed; the prime' to the standard wave-length, none, to the new wave-length. The tables were constructed for the correction of wave-length measures in terms of the fundamental standard 6438.4696 A of the cadmium red radiation in dry air, $15^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ pressure. The density factor is, therefore, zero for $15^{\circ} \mathrm{C}$ and 76 cm , and the correction always zero for $\lambda=6438 \mathrm{~A}$. As an example, find the correction required for $\lambda$ when measured as 3000.0000 A in air at $25^{\circ} \mathrm{C}$ and 72 cm . Section (a) of table gives ( $\left.d-d_{0}\right) / d_{0}=-.085$ and for this value of the density factor section (b) gives the correction to $\lambda$ of -.0038 A . Again, if $\lambda$, under the same atmospheric conditions, is measured as 8000.0000 A in terms of a standard $\boldsymbol{\lambda}^{\prime}$ of wave-length 4000.000 A , say, the measurement will require a correction of $(0.0020+0.0008)=+.0028$ A. Taken from Meggers and Peters, Bulletin Bureau of Standards, 14, p. 728, 1918.

TABLE $318(a) .-1000 \times\left(d-d_{0}\right) / d_{0}$.

| $B \mathrm{~cm}$ | 60.0 | 62.5 | 65.0 | 67.5 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $9^{\circ} \mathrm{C}$ | -192 | -160 | -126 | -92 | -59 | $-46$ | -32 | - 19 | -5 | $+8$ | $+22$ | +35 | $+48$ |
| II | -200 | $-167$ | - 133 | -100 | -67 | -53 | -40 | -27 | -13 | - | +13 | +27 | +40 |
| 13 | -206 | $-172$ | -139 | - 106 | -73 | -60 | -46 | -33 | -20 | -7 | $+6$ | +20 | +33 |
| 15 | -2II | $-178$ | $-145$ | -II2 | -79 | -66 | $-53$ | -39 | -26 | $-13$ | $\bigcirc$ | +13 | $+26$ |
| 17 | -216 | -184 | - 151 | -118 | -86 | -73 | -60 | -47 | -34 | -2I | -8 | +5 | +19 |
| 19 | -222 | -189 | -156 | -124 | -92 | -79 | -66 | -53 | -40 | -27 | $-14$ | -1 | +12 |
| 21 | -227 | -195 | -163 | $-130$ | -98 | -85 | -72 | - 59 | -46 | -33 | $-21$ | -8 | +5 |
| 23 | $-232$ | -200 | - 168 | -136 | $-104$ | -91 | -78 | -65 | -52 | -40 | $-27$ | $-14$ | -1 |
| 25 | -238 | -206 | - 174 | $-143$ | -III | -98 | -85 | -72 | -60 | -47 | -34 | -22 | -9 |
| 27 | $-243$ | -2II | - 179 | $-148$ | - I16 | $-104$ | -91 | $-78$ | -66 | $-53$ | $-40$ | $-28$ | -15 |
| 29 | $-248$ | $-216$ | $-185$ | - 154 | -122 | -109 | -97 | -84 | -72 | $-59$ | $-46$ | -34 | -21 |
| 31 | $-253$ | -222 | $-190$ | $-159$ | -128 | -116 | -103 | -91 | $-78$ | -66 | -54 | -4I | -29 |
| 33 | -258 | -227 | $-196$ | $-165$ | -134 | -121 | $-109$ | -97 | -84 | $-72$ | -59 | -47 | -34 |
| 35 | -262 | $-231$ | -200 | $-170$ | - 139 | -127 | -II4 | $-102$ | -90 | $-77$ | -65 | -53 | -4I |

TABLE $318(b) .-\delta=\lambda_{0}\left(n_{0}-n_{0}{ }^{\prime}\right)\left(d-d_{0}\right) / d_{0}$, in Ten-thousandth Angstroms.

| $\begin{aligned} & 1000 \times \\ & \frac{d-d_{0}}{d_{0}} \end{aligned}$ | Wave-lengths in Angstroms. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2000 | 2500 | 3000 | 3500 | 4000 | 4500 | 5000 | 5500 | 6000 | 6500 | 7000 | 7500 | 8000 | 9000 | 10000 |
|  | Corrections in ten-thousandth Angstroms. |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| -260 | -259 | -166 | -rı6 | -84 | -61 | -44 | -30 | -18 | -8 | +1 | +9 | +17 | +24 |  |  |
| -240 | -239 | -154 | -107 | $-78$ | -57 | -41 | -28 | -17 | -7 | +1 |  | +16 | +22 | +35 | +46 |
| -220 | -219 | -141 | -98 | -71 | -52 | -37 | -26 | -15 | -7 | +1 |  | +14 | +20 | +32 | +42 |
| -200 | -199 | $-128$ |  | -65 | -47 |  | -23 | $-14$ |  | +1 |  |  | +19 | +29 |  |
| -180 | -179 | - 115 | -80 | -58 | -42 | -30 | -21 | -13 | -6 | +1 | +6 | +12 | +17 | +26 | +34 |
| - 160 | -159 | $-102$ | -71 | -52 | -38 | -27 | -19 | - 11 | -5 | +1 |  | +10 | +15 | +23 | +31 |
| -140 -120 | - 139 -119 | -90 | -62 -54 | -45 -39 | -33 -28 | -24 -20 | -16 | -10 -8 | -4 | +1 |  | +9 +8 | +13 | +20 +17 | +27 +23 |
| -120 -100 | - 119 -100 | -77 | -54 -45 | -39 -32 | -28 -24 | -20 -17 | -14 -12 | -8 | -4 |  |  | +8 +7 | +11 +9 | +17 +14 | +23 +19 |
| -80 | -80 | $-51$ | $-36$ | -26 | -19 | $-14$ | -9 | -6 | -2 | +o |  | +5 |  | $+12$ | +15 |
| -60 | -60 | -38 | -27 | -19 | - 14 | - 10 | -7 | -4 | -2 | +o | $+2$ | +4 | +6 | +9 | +11 |
| -40 | -40 | -26 | -18 | $-13$ | -9 | -7 | -5 | -3 | -1 | +o | +1 | + | +4 | +6 | +8 |
| - 0 | -20 | -13 | -9 | -6 | -5 0 | -3 | -20 | -1 | -1 | -- | +1 | +1 |  |  | +4 |
| +20 | +20 | +13 |  |  |  |  | +2 | +1 |  |  |  | -2 |  |  | - |
| $+40$ | +40 | $+26$ | +18 | +13 | +9 | +7 | $+5$ | +3 | +1 | -○ |  | -3 | -4 | -6 | -8 |

SPECTRA OF THE ELEMENTS.
The following figure gives graphically the positions of some of the more prominent lines in the spectra of some of the elements. Flame spectra are indicated by lines in the lower parts of the panels, arc spectra in the upper parts, and spark spectra by dotted lines.


The following wave-lengths are in Angstroms.

| Na | 5889.965 | Rb | 4202 | Cu | 4023 | Mg | 5168 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 5895.932 |  | 4216 |  | 4063 |  | 5173 |
| K | 4044 |  | 5648 |  | 5105.543* |  | 518.4 |
|  | 4047 |  | 5724 |  | 5153.25 * $^{*}$ |  | 5529 |
|  | 5802 |  | 6207 |  | $5218.202^{*}$ | Sn | 4525 |
|  | 7668 |  | 6299 |  | 5700 |  | 5563 |
|  | 7702 | Tl | 535 T |  | $5782.090^{*}$ |  | 5589 |
| Li | 4132 | In | 4102 |  | $5782.159^{*}$ |  | 5799 |
|  | 4602 |  | 4511 | Ag | 4055 |  | 6453 |
|  | 6104 | Hg | 4046.8 |  | 4212 | II | 3970 |
|  | 6707.846* |  | 4078.1 |  | 4669 |  | 4102 |
| Cs | 4555 |  | 4358.3 |  | 5209.08 x * |  | 43.40 |
|  | 4593 |  | 4916.4 |  | $5465.489^{*}$ |  | 4861 |
|  | 5664 |  | 4959.7 |  | 5472 |  | 6563 |
|  | 5945 |  | 5460.742 ${ }^{\text {\% }}$ |  | 5623 * | He | $3187.743{ }^{\dagger}$ |
|  | 6011 |  | 5769.598* | Zn | 4680.138** |  | $3888.646 \dagger$ |
|  | 6213 |  | 5790.659* |  | 4722.164** |  | $4026.189 \dagger$ |
|  | 6724 |  | 6152 |  | 4810.535* |  | $4471.477 \dagger$ |
|  | 6974 |  | 6232 |  | 4912 |  | $4713.143 \dagger$ |
| For other elements, see Kayser's Handbuch derSpectroscopie. |  |  |  |  | 6103 |  | $5015.675{ }^{\dagger}$ |
|  |  |  |  |  | $6362.345^{*}$ |  | $5875.618 \dagger$ |
|  |  |  |  |  |  |  | $6678.149 \dagger$ |
| * Fabry and Perot. |  | $\dagger \mathrm{M}$ |  |  |  |  | 7065.188† |

Table of brighter lines only abridged from more extensive table compiled from Kayser and containing $\mathbf{1 0 , 0 0 0}$ lines （Kayser＇s Handbuch der Spectroscopie，Vol．6，1912）．

| Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensities． |  |  | Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensities． |  |  | Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensities |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Arc． | Spark． | Tube． |  |  | Arc． | Spark． | Tube． |  |  | Arc． | Spark． | Tube． |
| 3802.98 | Nb | 15 | 4 | － | 3968.48 | Ca | 30 | 40 | － | 4116.50 | V | 15 | 5 | － |
| 08.21 | I | － | － | 10 | 72.01 | Eu | 20 | 20 | － | 18.48 | Pr | 15 | 10 | 二 |
| 10.73 | Nh | 10 | 20 | － | 74.71 | Er | 15 | 5 | 二 | 23.24 | La | 10 | 15 | － |
| 14.45 | Ra | 20 | 20 |  | 76.85 | Tb | 20 | 10 | － 10 | 28.3 | I | 15 | 8 | － |
| 22.15 | Rh | 12 | 15 | 二 | 81.68 | Em | － | － | 15 | 28.91 | Rh | 15 | то | － |
| 28.47 | Rh | 12 | 10 | － | 8 r .89 | Tb | 15 | \％ |  | 29.75 | Eu | 50 | 50 | － |
| 29.35 | Mg | 15 | 8 | － | 82.60 | Y | 12 | 12 | － | 30.42 | Gd | 15 | 10 |  |
| 32.30 | Mg | 20 | 10 |  | 88.00 | Ny | 50 | 20 | － | 35.29 | Rh | 12 | 10 |  |
| 36.83 38.29 | $\mathrm{Sr}_{\mathrm{S}}$ | － | 15 | 10 | 88.52 91.13 | ${ }_{\mathrm{Zr}}^{\mathrm{La}}$ | 10 8 | 15 | 二 | 35.80 37.13 | $\stackrel{\mathrm{Os}}{\mathrm{Nb}}$ | 15 12 | 5 |  |
| 38.29 | Mg | 20 | 10 | 10 | 98.96 | $\mathrm{Zr}_{\mathrm{Zr}}$ | 8 | 12 | 二 | 37.74 39.74 | Nb | 15 | 4 | 二 |
| 45.45 | Co | 10 | 15 |  | 4000.47 | Dy | 15 | 12 |  | 42.86 | $\stackrel{\mathrm{Y}}{ }$ | 15 | 8 | － |
| 47.98 | Tm | 15 | 10 | － | 05.50 | Tb | 15 | 10 | － | 43.14 | ${ }_{S}^{\text {Pr }}$ | 15 | 10. | － |
| 48.75 | Tb | 15 | 15 | 10 | 05.73 | $\mathrm{P}_{\mathrm{p}}$ |  | 2 |  | 45.12 | ${ }_{\text {S }}$ | － | － | 10 |
| 51.02 56.50 | R h | 10 | 12 | 10 | 08.73 19.62 | $\stackrel{\mathrm{Pr}}{\mathrm{Pb}}$ | 12 12 | 10 | － | 49.20 51.12 | ${ }_{\mathrm{Zr}}^{\mathrm{Er}}$ | $\begin{aligned} & 10 \\ & 15 \end{aligned}$ | 15 4 |  |
| 58.29 | Ni | 20 | 8 | － | 22.70 | Cu | 15 | 10 | － | 52.63 | Nb | 15 | 5 | － |
| 60.86 | Cl | － | 5 | 10 | 23.35 | V |  | 20 |  | 53.11 | S | － | － | 10 |
| 64.11 | Mo | 20 | 10 |  | 23.71 | $\mathrm{Se}^{\mathrm{F}}$ | 12 | 8 | － | 58.62 | A | － | － | 10 |
| 71.65 | La | 8 10 | 15 | － | 25.1 30.80 | $\stackrel{\mathrm{F}}{\mathrm{M}} \mathrm{n}$ | 18 | 8 | 10 | 61.83 | ${ }_{S}^{\text {Ar }}$ | 10 | 20 | － |
| 74.16 | Tb | 15 | 15 | － | 31.70 | La | 8 | 15 | 二 | 62.70 63.64 | Nb | 15 | 10 | 10 |
| 76.66 | Lu | 15 | 10 | － | 33.03 | Ga | 10 | 30 | － | 64.66 | Nb | 12 | 5 | － |
| 88.64 | He |  | － | 10 | 33.06 | Mn | 15 | 8 | 二 | 66.43 | Em | － |  | 20 |
| 88.96 | Nh | 15 | 10 | － | 34.48 | Mn | 15 | 8 |  | 68.14 | Nb | 15 | 5 | － |
| 91.01 | Nh | 20 | 15 | － | 35.62 | V | － | 20 | － | 69.0 | Se | － | 10 | 10 |
| 94.09 | Co | 10 | 15 | 二 | 41.43 42.92 | $\mathrm{Ma}_{\mathrm{La}}$ | 12 8 8 | 8 | － | 72.05 | Ga | 15 | 20 | 二 |
| 94.22 96.36 | Er | 15 | ＋ 15 | 二 | 44.15 | K | 20 | 10 | 二 | 79.04 | Ge | 12 | 20 |  |
| 97.63 | 1 | － | － | 10 | 45.45 | Nh | 20 | 10 |  | 79.43 | ${ }^{\text {Pr }}$ | 15 | 10 | － |
| 3900.53 | Ti | 15 | 10 |  | 45.82 | Fe | 6 | 15 |  | 80.04 | X | － | － | 20 |
| 02.95 | Mo | 15 | 8 | － | 46.00 | Dy | 12 | 4 | － | 84.25 | Lu | 20 | 15 | － |
| 05.5 | $\stackrel{\mathrm{Si}}{\mathrm{Er}}$ | 15 | 4 |  | 46.6 | Se | － | 4 | 10 | 89.52 | ${ }^{\text {Pr }}$ | 15 | 10 |  |
| 06.34 | $\stackrel{\mathrm{Er}}{\mathrm{Er}}$ | 15 | 10 20 |  | 77.21 | ${ }^{\mathrm{K}}$ | 20 | 10 |  | 90.91 | Nb | 15 | 9 |  |
| 07.52 | Sc | 12 | 2 |  | 4 | $\mathrm{Ag}^{\mathrm{Ag}}$ | 11 | 6 | － | 4200.65 01.82 | Rb | 20 | 15 |  |
| 11.85 | Sc | 15 | 6 | － | 57.84 | Pb | 30 | 20 | － | 03.23 | Em | － | － | 10 |
| 14.26 | $\stackrel{\mathrm{Br}}{\mathrm{Sc}}$ | － | － | 10 | 58.97 | Nb | 15 | 10 | － | 05.04 | Eu | 50 | 30 | － |
| 14.94 | ${ }_{\mathrm{Sc}}^{\mathrm{Br}}$ | 12 | － | 10 | 62.75 | $\mathrm{Cu}^{\mathrm{Cu}}$ | 15 | 10 | 二 | 05.32 | Nb | 15 | 4 |  |
| 22.52 25.43 | Tb | － 15 | － | 1 | 62.83 63.47 | $\stackrel{\mathrm{Pr}}{\mathrm{Gr}}$ | 12 | 8 | － | 06．72 | $\mathrm{Pr}^{\mathrm{Pr}}$ | 15 | 12 |  |
| 30.51 | Eu | 50 | 50 | － | 77.34 | La | 10 | 12 | 二 | II． 14 | Rh | 15 | 12 |  |
| 31.10 | I | － | － | 10 | 77.37 | Y | 15 | 5 | － | 11.69 | Dy | 12 | 5 |  |
| 33.67 | Ca | 40 | 50 | － | 77.75 | $\stackrel{\mathrm{Sr}}{\mathrm{D}}$ | 50 | 50 | － | 14.74 | $\stackrel{\mathrm{Nb}}{ }$ | 12 | － | － |
| 39.55 | Tb | 15 | 10 | － | 77.97 | Dy | 12 | II | － | 15.52 | $\stackrel{\mathrm{Sr}}{\mathrm{Rb}}$ | 30 | 30 | － |
| 40.07 40.47 | Rb | 二 | － 15 |  | 78.79 79.73 | $\stackrel{\mathrm{X}}{\mathrm{N}} \mathrm{b}$ | 15 | － | 10 | 15.56 17.95 | $\stackrel{\mathrm{R}}{\mathrm{Nb}}$ | 20 | 10 | 二 |
| 44.68 | Dy | 12 | 10 | － | 80.62 | Ra | 12 | 10 |  | 21.08 | I | － | － | 10 |
| 45.33 | O | － | － | 10 | 86.70 | La | 10 | 15 | － | 23.00 | Pr | 15 | 12 |  |
| 49.10 | ${ }_{\mathrm{Y}}^{\mathrm{L}}$ | 12 | 20 | 二 | 92.68 | V | 15 | － | － | 25.34 | ${ }^{\mathrm{Pr}}$ | 15 | 12 | － |
| 50.35 51.01 | Y | 12 | 12 | － | 99．80 | $\stackrel{\mathrm{V}}{\mathrm{Pr}}$ | 20 | I2 | 二 | 26.56 | Ge | 7 | 50 |  |
| 51.95 | V | － | 15 | 10 | $\begin{array}{r} \\ \hline 00.97\end{array}$ | Nb | 20 | 6 | 二 | 38.21 | X | $\underline{-}$ | － | 10 |
| 58.22 58.66 | $\stackrel{\mathrm{Zr}}{\mathrm{Pd}}$ | 8 | 15 15 10 | 二 | 01.82 | ${ }_{\text {In }}$ | 20 | 12 | 二 | 4 I .04 | $\stackrel{\mathrm{Pr}}{ }$ | 12 | 10 |  |
| 58.66 | Pd | 15 | 10 | － | 02.40 | Y | 12 | 8 | － | 44.34 | Rb | － | 15 | 二 |
| 58.85 66.23 | $\stackrel{\mathrm{R}}{\mathrm{N}} \mathrm{b}$ | 15 12 | $\underline{12}$ | 二 | 03.4 | $\stackrel{\text { F }}{ }$ | － | － | 10 | 45.2 | Pb | 二 | 20 | － |
| 67.59 | X | － | － | 10 | O9．78 II． 80 | V | 15 20 | 10 | 二 | 45.38 46.3 | $\underset{\mathrm{F}}{\mathrm{S}}$ | 二 | 二 | 10 30 |
| 3968.40 | Dy | 15 | 12 | － | 4112.03 | Os | 12 | 4 | － | 4246.85 | Sc | 15 | 20 |  |

Smithsonian TAbles．

| Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensity． |  |  | Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensity． |  |  | Wave－ lengths， inter－ national Ang－ stroms． | Ele－ ment． | Intensity． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Arc． | Spark． | Tube． |  |  | Arc | Spark． | Tube． |  |  | Arc． | Spark． | Tube． |
| 4253.61 | S | － | － | 10 | 4477.77 | ${ }^{\mathrm{Br}}$ | － | － | 10 | 4994．13 | Lu | 20 | － | － |
| 54.34 | Cr | 12 | 12 | － | 81． 17 | Mg | － | 20 | － | 5035．36 | Ni | 12 | 10 | － |
| 54.42 | Nh | 15 | 8 | － | 96.43 | Pr | 15 | 10 | － | 53.30 | W | 12 | 12 | － |
| 59.69 | Bi | － | 20 | － | 98.76 | Pt | 12 | 10 | － | 5135．08 | Lu | 15 | － | － |
| 60.84 | Os | 15 | 5 | － | 4510.15 | Pr | 12 | 10 | － | 56.20 | Sr | 20 | － | － |
| 73.96 | $\mathbf{K r}$ | － | － | 10 | 22.59 | $\mathrm{Eu}^{\text {en }}$ | 20 | 20 | － | ${ }^{1} 1.19$ | I | － | － | 10 |
| 74.80 | Cr | 12 | 10 | － | 24.74 | Sn | 10 | 20 | － | 63.78 | Pd | 15 | － | － |
| 86.97 | La | 10 | 12 | － | 54.97 | Cr | 15 | － | － | 72.68 | Mg | 15 | 15 | － |
| 4301.11 | Nb | 12 | 5 | － | 55.52 | $\stackrel{\mathrm{Ru}}{ }$ | 10 | 12 | － | 83.60 | Mg | 20 | 20 | － |
| 02.12 | Bi | － | 15 | － | 72.74 | H | － | － | 10 | 64.51 | Cr | 12 | 8 | － |
| 02.28 | Y | 12 | － | － | 73.09 | Nb | 12 | 5 | － | 5206.05 | Cr | 12 | 9 | － |
| 03.61 | Nd | 20 | 10 | － | 74.26 | I | － | － | 10 | 08.42 | Cr | 12 | 10 | － |
| 05.49 | Sr | 10 | 20 | － | 85.47 | X | － | － | 10 | 09.08 | Ag | 30 | 20 | － |
| 05.78 | Pr | 15 | 10 | － | 89.35 | Dy | 15 | 5 | － | 24.70 | W | 12 | 12 | － |
| 07.92 | Fe | 6 | 15 | － | 94.09 | Eu | 30 | 20 | － | 56.95 | Sr | 20 | 6 | － |
| 08.1 | Em | － | － | 10 | 4603.03 | X | － | － | 10 | 92.23 | X | － | － | 10 |
| 09.63 | Y | 12 | 12 | － | 06.77 | Nb | 12 | 10 | － | 95.62 | Pd | 15 | － | － |
| 14.11 | Sc | 12 | 12 | － | 07.34 | Sr | 30 | 20 | － | 5330.65 | O | － | － | 10 |
| 19.60 | Kr | － | － | 10 | 09.22 | Em | － | － | 10 | 32.01 | ${ }_{\mathrm{Sr}}$ | － | － | 10 |
| 25.77 | Nd | 15 | 5 | － | 24.28 | X | － | － | 15 | 32.8 | Sn | － | 20 | － |
| 25.78 | Fe | 6 | 15 | － | 25.40 | Em | － | － | 15 | 35.14 | Ny | 5 | 20 | － |
| 26.36 | Nb | 12 | － | － | 27.29 | Eu | 20 | 15 | － | 50.49 | T1 | 20 | 10 | － |
| 30.47 | X | － | － | 15 | 27.98 | H | － | － | 10 | 52.86 | Ny | － | 20 | － |
| 33.77 | La | 12 | 12 | － | 33.86 | H | － | － | 10 | 60.59 | Mo | 15 | 12 | － |
| 40.67 | Ra | 15 | 10 | － | 34.02 | H | － | － | 10 | 69.85 | Se |  | － | 10 |
| 43.69 | Cl | － | 5 | 10 | 44．I I | Sm | － | － | 15 | 74.08 | Se | － | － | 10 |
| 48.01 | A | － | － | 10 | 46.16 | Cr | 12 | 10 | － | 95.27 | Pd | 12 | － | － |
| 49.65 | Em | － | － | 15 | 48.66 | Ni | 15 | － | － | 5419．19 | X | － | － | 10 |
| 55.47 | Kr | － | － | 10 | 61.92 | Eu | 20 | 15 | － | 64.5 | I | － | － | 10 |
| 65.58 | Br | － | 4 | 10 | 66.65 | I | － | － | 10 | 65.49 | Ag | 30 | 20 | － |
| 68.30 | O | － | － | 10 | 71.24 | X | － | － | 10 | 76.69 | Lu | 20 | 10 | － |
| 74.51 | Sc | 10 | 12 | － | 72.12 | Nb | 12 | 10 | － | 76.91 | Ni | 12 | 10 | － |
| 74.8 I | R h | 15 | 12 | － | 75.36 | Nb | 12 | 8 | － | 80.95 | Sr | 20 | 10 | － |
| 74.94 | Y | 15 | 20 | － | 80.138 | Zn | 10 | 20 | － | 96.78 | I | － | － | 10 |
| 79.24 | V | 30 | 30 | － | 80.74 | Em | － | － | 10 | 5504.26 | Sr | 20 | － | － |
| 79.77 | Zr | 10 | 12 | － | 82.18 | Ra | 20 | 15 | － | 06.51 | Mo | 20 | 15 | － |
| 81.66 | Mo | 12 | 6 | － | 87.80 | Zr | 7 | 12 | － | 14.71 | W | 20 | 20 | － |
| 82.8 | Se | － | 8 | 10 | 4704.93 | Br | － | 15 | 10 | 21.80 | Sr | 20 | － | － |
| 83.55 | Fe | 10 | 20 | － | 08.26 | I | － | － | 10 | 33.01 | Mo | 15 | 12 | － |
| 84.73 | V | 20 | 30 | － | 14.42 | Ni | 15 | 8 | － | 42.78 | Pd | 12 | － | － |
| 86.9 | Pb | － | 20 | － | 22.164 | Zn | 10 | 20 | － | 56.49 | Ny | 15 | － | － |
| 89.98 | V | 20 | 20 | － | 22.54 | ${ }_{\text {Bi }}$ | 10 | 20 | 10 | 62.5 | Mo | － | 30 10 |  |
| 93.17 | X | － | － | 10 | 30.86 | Se | － | 15 | 10 | 70.46 80.2 | Mo | I5 | 10 | － |
| 95.24 | V | 15 | 10 | 10 | 38.12 85.49 | $\stackrel{11}{\mathrm{Br}}$ | 二 | 15 | 10 | 5608.9 | Pb | － | 12 | － |
| 95.74 98.03 | Y | 10 | 15 | 10 | 85.49 94.48 | Cl | － | 20 | 10 | 20.64 | As | － | － | 10 |
| 4401.54 | Ni | 15 | 15 | － | 4806.68 | I | － | － | 10 | 25.64 | 1 | － | － | 10 |
| 04.75 | Fe | 8 | 15 | － | 08.23 | I | － | － | 10 | 51.34 | As | － | － | 10 |
| 08.50 | V | 15 | 20 | － | 09.97 | Cl | － | 9 | 10 | 62.93 | $\stackrel{\mathrm{Y}}{\mathrm{Pd}}$ | － | 12 | － |
| 08.83 | Pr | 12 | 10 | － | 10.534 | Zn | 10 | 20 | － | 70.05 | $\stackrel{\mathrm{P}}{\mathrm{V}}$ | 15 | － | － |
| 10.09 | I |  | － | 10 | 11.83 | Sr | 15 | 8 | － | 98.54 | V | 15 | 15 | － |
| 11.71 | Mo | 12 | 6 | － | 19.28 | Mo | 12 | － | － | 5751.40 | Mo | 15 | － | － |
| 20.46 | Os | 15 | 10 | － | 25.93 | Ra | 15 | 10 | － | 99.4 5813.63 | Ra | 二 | 20 15 | － |
| 24.36 | Sm | 20 | 10 | 二 | 32.07 40.6 | Sr Se | 15 | 6 | －10 | 5813.63 52.49 | Ra Ne | 二 | 15 | － |
| 29.23 34.26 | $\stackrel{\mathrm{Pr}}{1}$ | 15 | 12 | －10 | 40.6 44.32 | Se | － | 4 | 10 | 52.49 57.76 | Ni | 15 | － | 15 |
| 34.26 35.58 | Eu | 20 | 20 | 10 | 44.8 44 | Se | － | 6 | 10 | 58.27 | Mo | 12 | 8 | － |
| 37.23 | Nb | 12 | 8 | － | 50.49 | I | － | － | 10 | 75.64 | He | － | － | 10 |
| 42.56 | Pt | 12 | ． 5 | － | 54.89 | Y | 10 | 15 | － | 88.33 | Mo | 15 | 10 | － |
| 46.6 | F | － | － | 20 | 83.71 | Y | 12 | 20 | － | 89.96 | Na | 20 | 20 | － |
| 48.11 | X | － | － | 10 | 4900.13 | Y | 10 | 20 | － | 95.93 | Mo | 15 | 10 | － |
| 51.56 | Nd | 10 | 15 | －－ | 11.7 | Zn | 10 | 20 | － | 95.93 | Na | 20 | 20 | － |
| 53.00 | I | － | － | 10 | 24.0 | Zn | 10 | 20 | － | 5928.82 | $\mathrm{Mo}^{\text {Mo }}$ | 15 | 15 | － |
| 59.8 | Em | － | － | 10 | 57．4I | Dy | 15 | － | 二 | 6090.22 6121.80 | H | 15 | 15 | $\overline{10}$ |
| 4462.2 I | X | － | － | 20 | 4962.27 | Sr． | 15 | － |  | 6121.80 |  |  |  |  |

Note．－This table，somewhat unsatisfactory in its abridged form，is included with the hope to occupy its space later with a better table；e．g．，no mercury lines appear since the scale of intensity used in the original table results in the intensity of all mercury lines falling below the critical value used in this table．

## Smithsonian Tables．

Table 321.

## STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

Wave-lengths are in Ågström units ( $10^{-7} \mathrm{~mm}$.), in air at $20^{\circ} \mathrm{C}$ and 76 cm . of mercury pressure. The intensities run from I, just clearly visible on the map, to 1000 for the H and K lines; below I in order of faintness to 0000 as the lines are more and more difficult to see. This table contains only the lines above 5 .

N indicates a line not clearly defined, probably an undissolved multiple line; s, a faded appearing line; d, a double. In the "substance" column, where two or more elements are given, the line is compound; the order in which they are given indicates the portion of the line due to each element ; when the solar line is too strong to be due wholly to the element given, it is represented, -Fe, for example; when commas separate the elements instead of a dash, the metallic lines coincide with the same part of the solar line, $\mathrm{Fe}, \mathrm{Cr}$, for example.

Capital letters next the wave-length numbers are the ordinary designations of the lines. A indicates atmospheric lines, (wv), due to water vapor, ( $\mathbf{O}$ ), due to Oxygen.

\begin{tabular}{|c|c|c|c|c|c|c|c|c|}
\hline \(\underset{\substack{\text { Wave. } \\ \text { length. }}}{\text { cel }}\) \& Substance. \& Inten. \& Wave-length. \& Substance. \& Inten- \& \(\underset{\substack{\text { Wave. } \\ \text { length. }}}{\text { der }}\) \& Sub-
stance. \& \begin{tabular}{c} 
Inten. \\
sity. \\
\hline
\end{tabular} \\
\hline 3037.510s \& Fe \& 10 N \& 3372.947 \& Ti-Pd \& rod? \& 3533.345 \& Fe \& 6 \\
\hline 3047.72 5 \& Fe \& 20 N \& 3380.722 \& Ni \& 6 N \& 3536.709 \& \(\mathrm{Fe}^{\mathrm{Fe}}\) \& 7 \\
\hline 3053.5305 \& \& 7 7 d? \& \begin{tabular}{l}
3414.911 \\
3423 \\
\hline
\end{tabular} \& \(\stackrel{\mathrm{Ni}}{\mathrm{Ni}}\) \& 15 \& \begin{tabular}{l}
3541.237 \\
3542.232 \\
\hline
\end{tabular} \& \(\underset{\mathrm{Fe}}{\mathrm{Fe}}\) \& 7 \\
\hline 3054.429
3057.552 s \& \({ }_{\text {Ti, }}^{\text {Me }}\), \({ }^{\text {Ni }}\) \& 10
20 \& 3423.848
3433.715 \& \(\stackrel{\mathrm{Ni}, \mathrm{Cr}}{\mathrm{Ni}}\) \& \(8{ }^{7}\) d \& 3542.232
3555.079 \& \(\stackrel{\mathrm{Fe}}{\mathrm{Fe}}\) \& 6 \\
\hline 3057.5528
3059.2125 \& \(\underset{\mathrm{Fe}}{\substack{\text { Ti, } \\ \mathrm{Fe}}}\) \& 20
20 \& \(\underbrace{343.715}_{3440.7625}\) \& \({ }_{\text {Ne }}\) \& 20 \& 3555.079
3558.672 s \& \(\stackrel{\mathrm{Fe}}{\mathrm{Fe}}\) \& 9 \\
\hline 3067.369s \& \(\mathrm{Fe}^{\text {Fe}}\) \& 8 \& \(\left.{ }_{3441.1555}\right\}^{\text {S }}\) \& \(\mathrm{Fe}^{\mathrm{Fe}}\) \& 15 \& 3566.535s \& \(\stackrel{\mathrm{Fe}}{ }\) \& 20 \\
\hline 3073.091 \& \({ }_{\text {Ti, }}\) \& 6 Nd ? \& 3442.118 \& \(\mathrm{Mn}^{\text {m }}\) \& \& \({ }^{3566.522}\) \& \(\stackrel{\mathrm{Ni}}{\mathrm{Fe}}\) \& 10 \\
\hline 3078.7699 \& Ti, \& 8 d ? \& 3444.0208 \& \(\stackrel{\mathrm{Fe}}{\mathrm{Ni}}\) \& 8 N \& \({ }_{3570.2738}\) \& \(\stackrel{\mathrm{Fe}}{\mathrm{Ni}}\) \& 20 \\
\hline 3088.1455 \& \(\mathrm{Ni}_{\mathrm{Ti}}^{\mathrm{Ti}} \mathrm{Fe}\) \& 78 7 \({ }_{8}\) \& \({ }^{3446.406}\) \& \(\stackrel{\mathrm{Ni}}{\mathrm{Co}}\) \& \({ }^{15} \mathrm{~d}\) ? \& 3572.014
3572.712

3 \& $\mathrm{Se}_{\mathrm{Ni}}^{\mathrm{Na}}$ - \& 6 <br>
\hline  \& ${ }_{-, \mathrm{Fe}}$ \& 6d? \& 3449.503
3453.039 \& Ni \& 6 d ? \& ${ }^{3578} 8.832$ \& $\mathrm{Cr}^{\text {crer }}$ \& ${ }^{10}$ <br>
\hline ${ }^{32} 36.7035$ \& Ti \& 78 \& 3458.601 \& $\stackrel{\mathrm{Ni}}{ }$ \& 8 \& 3558.349s \& $\mathrm{Fe}^{\mathrm{Fe}}$ \& 30 <br>
\hline 3239.170 \& Ti \& 7 \& 3466.801 \& $\mathrm{Ni}_{\mathrm{Co}}$ \& 8 \& 3584.800
355.105 \& \& 6 <br>

\hline 3242.125 \& ${ }_{-}^{\text {Ti, }} \mathrm{Ni}$ \& 8 \& | 3462.950 |
| :--- |
| 3466.015 | \& $\stackrel{\mathrm{Co}}{\mathrm{Fe}}$ \& 6 \& 3585.105 \& $\mathrm{Fe}^{\mathrm{Fe}}$ \& 6 <br>

\hline ${ }^{3243.189}{ }^{3247.6885}$ \& ${ }^{-} \mathrm{Cu}$ \& \& 3466.0158
3475.5945 \& $\stackrel{\mathrm{Fe}}{\mathrm{Fe}}$ \& 10 \& 3555.479
355.859 \& $\stackrel{\mathrm{Fe}}{\mathrm{Fe}}$ \& 6 <br>
\hline ${ }_{\text {l }}^{32476.0885}$ \& Fe? \& ${ }_{6} 6$ \& 3475.5949 \& ${ }_{\mathrm{Fe}}$ \& ${ }_{8}^{10}$ \& ${ }^{3555} 5$ \& ${ }_{\text {Fe }}$ \& 8 <br>
\hline 3267.834 s \& V \& 6 \& 3483.923 \& Ni \& 6 d ? \& 3587.370 \& Co \& 7 <br>
\hline 3271.129 \& Fe \& d \& 3485.493 \& Fe Co \& ${ }^{6}$ \& 3588.084 \& $\mathrm{Ni}^{\mathrm{Ni}}$ \& 6 <br>
\hline 3271.791 \& $\mathrm{Ti}, \mathrm{Fe}$ \& 6 d ? \& 3490.7335 \& Fe \& 10 N \& 3593.636 \& $\stackrel{\mathrm{Cr}}{\mathrm{Fr}}$ \& <br>
\hline ${ }_{\text {l }}^{3274.0968}$ \& ${ }_{\text {Co-Fe }}^{\text {Cu }}$ \& ${ }_{7}^{10} \mathrm{~d}$ ? \& 3493.114
3497.982 s \& ${ }_{\text {Ni }}^{\mathrm{Ni}}$ \& ${ }_{8}^{10 \mathrm{~N}}$ \& 3594.784

3597.854 \& $\mathrm{Fe}_{\mathrm{Fe}}^{\mathrm{Ni}}$ \& 6 <br>
\hline 3277.482
3286.898 \& $\stackrel{\mathrm{Co-Fe}}{\mathrm{Fe}}$ \& ${ }_{7}^{7} \mathrm{~N}$ ? \& 3497.982 2

3500.96s \& $\stackrel{\mathrm{Ne}}{\mathrm{Ni}}$ \& 6 d ? \& | 3597.854 |
| :--- |
| 365.479 s | \& ${ }_{\text {Cr }}$ \& 7 <br>

\hline 3295.9515 \& $\mathrm{Fe}, \mathrm{Mn}$ \& 6 \& 3510.466 \& $\mathrm{Ni}^{\text {i }}$ \& 8 \& 3606.8388 s \& $\mathrm{Fe}^{\mathrm{Fe}}$ \& <br>
\hline 3302.510s \& Na \& 6 \& 3512.785 \& Co \& 6 \& 3609.008 s \& $\stackrel{\mathrm{Fe}}{ }$ \& 20 <br>
\hline 3315.807
3318.1605 \& $\stackrel{\mathrm{Ni}}{\mathrm{Ti}}$ \& $7{ }^{7} 7$ d \& ${ }^{3515.9655}$ \& $\stackrel{\mathrm{Fe}}{\mathrm{Ni}}$ \& 7
12 \& 3612.882
3617.9345

l \& $\stackrel{\mathrm{Ni}}{\mathrm{Fe}}$ \& ${ }_{6}^{69}$ ? <br>
\hline 3320.391 \& Ni \& 7 \& 3519.904 \& , \& \& 3618.9195 \& Fe \& 20 <br>
\hline 3336.820 \& Mg \& 8 N \& 3521.410s \& $\stackrel{\mathrm{Fe}}{ }$ \& 8 \& 3619.539 \& $\mathrm{Ni}^{\mathrm{Ni}}$ \& 8 <br>
\hline 3349. 597 \& Ti \& 7 \& 354.677 \& ${ }_{\mathrm{Ni}}^{\mathrm{Fi}}$ \& 20 \& ${ }^{3621.6125}$ \& $\stackrel{\mathrm{Fe}}{\mathrm{Fe}}$ \& 6 <br>

\hline | 3360.327 |
| :--- |
| 3365.908 | \& \& 6 \& \[

$$
\begin{aligned}
& 3526.183 \\
& 3526.988
\end{aligned}
$$
\] \& $\stackrel{\mathrm{Fe}}{\mathrm{Co}}$ \& 6 \& 362.1475

$3631.605 s$ \& $\stackrel{\mathrm{Fe}}{\mathrm{Fe}}$ \& ${ }_{15}$ <br>
\hline 3366.311 \& Ti, Ni \& 6 d ? \& 3529.964 \& $\mathrm{Fe}-\mathrm{Co}$ \& 6 \& 3640.5355 \& $\mathrm{Cr}_{\mathrm{T}-\mathrm{Fe}}$ \& 6 <br>
\hline 3369.713 \& $\mathrm{Fe}, \mathrm{Ni}$ \& 6 \& 3533.156 \& Fe \& 6 \& 3642.820 \& Ti \& 7 <br>
\hline
\end{tabular}

Corrections to reduce Rowland's wave-lengths to standards of Table 314 (the accepted standards, 1913). Temperature $25^{\circ} \mathrm{C}$, pressure 760 mm .
The differences "(Fabry-Buisson-arc-iron) - (Rowland-solar-iron)" lines were plotted, a smooth curve drawn, and the following values obtained:

$$
\begin{array}{lrrrrrrrr}
\text { Wave-length } & 3000 & 3100 . & 3200 . & 3300 & 3400 . & 3500 . & 3600 . & 3700 . \\
\text { Correction } & -.106 & -.115 & -.124 & -.137 & -.148 & -.154 & -.155 & -.140
\end{array}
$$

H. A. Rowland, "A preliminary table of solar-spectrum wave-lengths," Astrophysical Journal, $1-6,1895-1897$.

## Smithsonian Tables.

Table 321 (continued).
STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

| Wave-length. | Substance. | Intensity. | Wave-length. | Substance. | Intensity. | Wave-length. | Substance. | Intensity. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 3647.988s | Fe | 12 | 3826.027s | Fe | 20 | $4045.975^{5}$ | Fe | 30 |
| 3651.247 | Fe,- | 6 | 3827.980 | Fe | 8 | 4055.70 IS | Mn | 6 |
| 3651.614 | Fe | 7 | 3829.5015 | Mg | 10 | 4057.668 | - | 7 |
| 3676.457 | $\mathrm{Fe}, \mathrm{Cr}$ | 6 | 3831.837 | Ni | 6 | 4063.759 s | Fe | 20 |
| 3680.069s | Fe | 9 | 3832.450 S | Mg | 15 | 4068.137 | $\mathrm{Fe}-\mathrm{Mn}$ | 6 |
| 3684.258 s | Fe | 7d? | 3834.364 | $\mathrm{Fe}^{\mathrm{Fe}}$ | 10 | 4071.908 s | Fe | 15 |
| 3685.339 | ${ }_{\mathrm{Ti}}$ | Iod? | 3838.435 s | $\mathrm{Mg}-\mathrm{C}$ | 25 | 4077.885 s | Sr | 8 |
| 3686.141 | Ti-Fe | 6 | 3840.580 s | $\mathrm{Fe}-\mathrm{C}$ | 8 | $4102.000 \mathrm{H} \delta$ | H , In | 40N |
| 3687.610 s | Fe | 6 | 3841.195 | $\mathrm{Fe}-\mathrm{Mn}$ | 10 | 4121.477 s | $\mathrm{Cr}-\mathrm{Co}$ | 6d? |
| 3689.614 | Fe | 6 | 3845.606 | $\mathrm{C}-\mathrm{Co}$ | 8d ? | 4128.251 | $\mathrm{Ce}-\mathrm{V},-$ | 6d |
| 3701.234 | Fe | 8 | 3850.118 | $\mathrm{Fe}-\mathrm{Cr}$ | 10 | 4132.235 | $\mathrm{Fe}-\mathrm{Co}$ | 10 |
| 3705.708s | Fe | $6{ }^{9}$ | 3856.524 s | $\underset{\mathrm{Cr}}{\mathrm{Fe}}$ | 8 | 4137.156 | Fe | 6 |
| 3706.175 | $\underset{\mathrm{Fa}}{\mathrm{Ca}}$ Mn | 6d ? | 3857.805 | $\underset{\mathrm{Cr}-\mathrm{C}}{ }$ | 6d ? | 4140.089 | Fe | 6 |
| 3709.389s | Fe | 8 | 3858.442 | Ni | 7 | 4144.038 | Fe | 15 |
| 3716.5915 | Fe | 7 | 3860.055 s | $\mathrm{Fe}-\mathrm{C}$ | 20 | 4167.438 | - | 8 |
| 3720.084 s | Fe | - 40 | 3865.674 | $\mathrm{Fe}-\mathrm{C}$ | 7 | 4187.204 | Fe | 6 |
| 3722.692 s | Ni | 10 | 3872.639 | Fe | 6 | 4191.595 | Fe | 6 |
| 3724.526 | Fe | 6 | 3878.152 | $\mathrm{Fe}-\mathrm{C}$ | 8 | 4202.198 s | Fe | 8 |
| 3732.545s | $\mathrm{Co}-\mathrm{Fe}$ | 6 | 3878.720 | Fe | 7 Nd ? | 4226.904 sg | Ca | 20 d ? |
| 3733.469s | Fe- | 7 d ? | 3886.4345 | Fe | 15 | 4233.772 | Fe | 6 |
| 3735.0145 | Fe | 40 | 3887.196 | Fe | 7 | 4236.112 | Fe | 8 |
| 3737.2815 | Fe | 30 | 3894.211 | $\overline{\text { F }}$ | 8d | 4250.287 s | Fe | 8 |
| 3738.466 | Fe-Ti | 6 | 3895.803 | Fe | 7 | 4250.945 s | Fe | 8 |
| $3743 \cdot 508$ | $\mathrm{Fe}-\mathrm{Ti}$ | 6 | 3899.850 | $\xrightarrow[\mathrm{Fe}]{\mathrm{Fe}}$ | 8 | 4254.505 s | Cr | 8 |
| 3745.717 s 3746.058 s | $\underset{\mathrm{Fe}}{ }$ | 8 | 3903.090 | $\mathrm{Cr}, \mathrm{Fe}, \mathrm{Mo}$ | 10 | 4260.640 s | Fe | 10 |
| 3746.058 s | Fe | 6 | 3904.023 | Si | 8d | 427 I .934 s | Fe | 15 |
| 3748.408 s | Fe | 10 | 3905.660s | Si | 12 | 4274.958 s | Cr | 7 d ? |
| 3749.6315 | $\stackrel{\mathrm{Fe}}{ }$ | 20 | 3906.628 | Fe | 10 | 4308.08 IsG | Fe | 6 |
| 3753.732 | $\mathrm{Fe}-\mathrm{Ti}$ | 6d ? | 3920.410 | Fe | 10 | 4325.939 s | Fe | 8 |
| 3758.3755 | Fe | 15 | 3923.054 | $\underset{\mathrm{Fe}}{ }$ | 12d? | $4340.634 \mathrm{H} \gamma$ | $\mathrm{H}^{\mathrm{F}}$ | 20 N |
| 3759.447 | Ti | 12d? | 3928.0755 | Fe | 8 | 4376.1075 | $\underset{\mathrm{Fe}}{ }$ | 6 |
| 3760.196 | Fe | 5 | 3930.450 | Fe | 8 | 4383.7205 | Fe | 15 |
| 3761.464 | Ti | 7 | 3933.523 |  | 8N | 4404.927 s | Fe | 10 |
| 3763.945s | Fe | 10 | 3933.825 SK | $\stackrel{\mathrm{Ca}}{\mathrm{Ca}}$ | 1000 | 4415.293 S | Fe | 8 |
| 3765.689 | Fe | 6 | 3934.108 | $\mathrm{Co}, \mathrm{V}-\mathrm{Cr}$ | 8N | 4442.510 | $\mathrm{Fe}^{\mathrm{Fe}}$ | 6 |
| 3767.34 IS | Fe | 8 | 3944.160s | A1 | 15 | 4447.892s | Fe | 6 |
| 3775.717 | Ni | 7 | 3956.819 | Fe | 6 | 4494.738 s | Fe | 6 |
| 3783.674 s | Ni | 6 | 3957.177s | $\mathrm{Fe}-\mathrm{Ca}$ | 7 d 20 | 4528.798 | $\underset{\mathrm{Ti}-\mathrm{Co}}{\mathrm{Fe}}$ | 8 |
| 3788.046 s | Fe |  | 3961.674s | ${ }_{\text {Al }}^{\text {- }}$ | 20 | 4534.139 | Ti-Co | 6d? |
| 3795.147 s 3798.655 s | Fe Fe | 8 | 3968.350 3968.625 SH | $-\mathrm{Ca}$ | 700 | 4549.808 4554.2 I IS | Ti-Co Ba | 6d? |
| $3798.655 s$ 3799.693 s | Fe Fe | 6 7 | 3968.6255 H 3968.886 | Ca | 6 N | 4572.156 s | Ti- | 6 |
| 3805.486 s | Fe | 6 | 3969.413 | Fe | 10 | 4603.126 | Fe | 6 |
| 3806.865 | $\mathrm{Mn}-\mathrm{Fe}$ | 8d ? | 3974.904 | $\mathrm{Co}-\mathrm{Fe}$ | 6d? | 4629.52 Is | Ti-Co | 6 |
| 3807.293 | Ni | 6 | 3977.8915 | Fe | 6 | 4679.027 s | Fe | 6 |
| 3807.681 | $\mathrm{V}-\mathrm{Fe}$ | 6 | 3986.903 s | Fe | 6 | 4703.177 s | Mg | 10 |
| 3814.698 |  | 8 | 4005.408 | Fe | 7 | 4714.599 s | Ni | 6 |
| 3815.987 s | $\mathrm{Fe}^{\text {che }}$ | 15 | 4030.918 s | Mn | Iod? | 4736.963 |  | 7 |
| 3820.586 sL | $\mathrm{Fe}-\mathrm{C}$ Fe | 25 6 | $\begin{aligned} & 4033.224 \mathrm{~s} \\ & 4034.644 \mathrm{~s} \end{aligned}$ | Mn Mn | 8d ? | $\begin{aligned} & 4754.225 \mathrm{~s} \\ & 4783.6 \mathrm{I} 3 \mathrm{~s} \end{aligned}$ | $\begin{aligned} & \mathrm{Mn} \\ & \mathrm{Mn} \end{aligned}$ | 7 |

Corrections to reduce Rowland's wave-lengths to standards of Table 314 (the accepted standards, 1913). Temperature $15^{\circ} \mathrm{C}$, pressure 760 mm . :

Correction -. $155-.140-.141-.144-.148-.152-.156-.161-167-.172-.176-.179-.179$.

## Smithsonian Tables.

STANDARD SOLAR WAVE-LENGTHS. ROWLAND'S VALUES.

| Wave-length. | Substance. | Intensity. | Wave-length. | Substance. | Inten- sity | Wave-length. | $\begin{aligned} & \text { Sub- } \\ & \text { stance } \end{aligned}$ | Intensity. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4861.527sF | H | 30 | 5948.765s | Si | 6 | 6563.045 sC | H | 40 |
| 4890.948s | Fe | 6 | 5985.0405 | Fe | 6 | 6593.16 rs | Fe | 6 |
| 4891.683 | Fe | 8 | 6003.2395 | Fe | 6 | 6867.457sB | A $(\mathrm{O})$ | 6 d ? |
| 4919.1745 | Fe | 6 | 6008.7855 | Fe | 6 | ${ }^{6868.336}$ \}s | A (0) | 6 |
| 4920.655 | Fe | 10 | 6013.7155 | Mn | 6 | $6868.478\}^{\text {s }}$ | A(O) | 6 |
| 4957.785 s | Fe | 8 | 6016.86 Is | Mn . | 6 | 6869.142s | A(0) | 7 |
| 5050.00 Ss | Fe | 6 | 6022.016 s | Mn | 6 | 6869.353s | A(O) | 6 |
| $5167.497 \mathrm{sb}_{4}$ | Mg | 15 | 6024.2815 | $\stackrel{\mathrm{Fe}}{ }$ | 7 | $6870.116\}$ | $\mathrm{A}(\mathrm{O})$ | 73 d |
| 5171.778 s | Fe | 6 | 6065.709 s | Fe | 7 | 6870.249 S ${ }^{\text {c }}$ | A(O) | $7{ }_{8}$ d |
| $5172.856 \mathrm{sb}_{2}$ | $\mathrm{Mg}^{\text {mg }}$ | 3 | 6102.3925 | Fe | 6 | 6871.180 s | A(O) | 8 |
| $5183.79 \mathrm{Isb}_{1}$ | $\mathrm{Mg}^{\mathrm{F}}$ | 30 | 6102.937 s | Ca | 9 | 6871.532 s 6872.486 s | A $(\mathrm{O})$ $\mathrm{A}(\mathrm{O}$ | 10 |
| 5233.122s | Fe | 6 | 6108.3345 | ${ }^{\mathrm{Ni}}$ | 6 | 6872.486 s | A(O) | 11 |
| 5266.738 s | Fe | 6 | 6122.4345 | Ca | ${ }^{10}$ | 6873.08 os | $\mathrm{A}(\mathrm{O})$ | 12 |
| 5269.723 sE | Fe | 8 d ? | 6136.829 s | Fe | 8 | 6874.037 s | A(O) | 12 |
| 5283.802 s | Fe | 6 | ${ }^{6} 37.915$ | Fe | 7 | 6874.899 s | A(O) | 13 |
| 5324.373 s | Fe | 7 | 6141.938 s | $\mathrm{Fe}, \mathrm{Ba}$ | 7 | 6875.830 s | A(O) | 13 |
| 5328.236 | Fe | 8 d ? | 6155.350 |  | 7 | 6876.958 s | A(0) | 13 |
| 5340.121 | Fe | 6 | 6162.390 s | Ca | 15 | 6877.882 s | A(O) | 12 |
| 5341.213 | Fe | 7 | 6169.249 s | Ca | 6 | 6879.288s | A(O) | 12 |
| 5367.669 s | Fe | 6 | 6169.778 s | Ca | 7 | 6880.172s | A(O) | 6 |
| 5370.1668 | Fe | 6 | 6170.730 | $\mathrm{Fe}-\mathrm{Ni}$ | 6 | 6884.076s | A(O) | 10 |
| 5383.578 s | Fe |  | 6191.3938 | Ni | 6 | 6886.000 | A(0) | 11 |
| 5397.344 s | Fe | 7 d ? | 6191.779s | Fe | 9 | 6886.990 s | A(O) | 12 |
| 5405.989 s | Fe | 6 | 6200.527 s | Fe | 6 | 6889.192s | A(O) | 13 |
| 5424.290s | Fe | 6 | 6213.644 s | Fe | 6 | 6890.1515 | A(0) | 14 |
| 5429.911 | Fe | 6d? | 6219.4945 | Fe | 8 | 6892.6 r 8 s | A(O) | 14 |
| 5447.130s | Fe | 6 d ? | 6230.943 s | $\mathrm{V}-\mathrm{Fe}$ | 8 | 6893.560 s | $\mathrm{A}(\mathrm{O})$ | 15 |
| 5528.641 IS | Mg | 8 | 6246.535 s | Fe | 8 | 6896.289s | $\mathrm{A}(\mathrm{O})$ | 14 |
| 5569.848 | Fe | 6 | 6252.773 s | $-\mathrm{Fe}$ | 7 | 6897.208 s | A(0) | 15 |
| 5573.075 | Fe | 6 | 6256.572 s | $\mathrm{Ni}-\mathrm{Fe}$ | 6 | 6900.199 s | $\mathrm{A}(\mathrm{O})$ | 14 |
| 5586.991 | Fe | 7 | 6301.718 | $\mathrm{Fe}^{\text {e }}$ | 7 | 6901.1175 | $\mathrm{A}(\mathrm{O})$ | 15 |
| 5588.985 s | Ca | 6 | 6318.239 | Fe | 6 | 6904.362s | A(0) | 14 |
| 5615.8778 | Fe | 6 | 6335.554 | Fe | 6 | 6905.271s | A(O) | 14 |
| 5688.436 s 57 II .31 I | Na Mg | 6 | 6337.048 6358.898 | $\stackrel{\mathrm{Fe}}{\mathrm{Fe}}$ | 6 | 6908.783 s 6900.676 s | $\mathrm{A}(\mathrm{O})$ | 13 |
| 5763.218 s | Fe | 6 | 6393.820 s | Fe |  | 6913.448s | A(O) | $1{ }_{1}$ |
| 5857.674 s | Ca | 8 | 6400.217 s | Fe | 8 | 6914.337 s | A(O) | 11 |
| 5862.582 s | Fe | 6 | 6411.8658 | Fe | 7 | 6918.370 s | $\mathrm{A}(\mathrm{O})$ | 9 |
| $5890.186 \mathrm{sD}_{2}$ | Na | 30 | 6421.5708 | Fe | 7 | 6919.250 s | $\mathrm{A}(\mathrm{O})$ | 9 |
| $5896.155 \mathrm{D}_{1}$ |  | 20 | 6439.2935 | Ca | 8 | 6923.553s | A(O) | 9 |
| 5901.6828 5914.430 s | A(wv) ,$- A(w v)$ | 6 | 6450.033 s <br> 6494.0045 | Ca | 6 | 6924.4278 7191.755 | A $(\mathrm{O})$ $\mathrm{A},-$ | $6{ }^{9}$ |
| 5919.860s | A(wv) | 7 | 6495.213 | Fe | 8 | 7206.692 | -, A |  |
| 5930.406s | Fe | 6 | 6546.4795 | Ti-Fe | 6 |  |  |  |

Corrections to reduce Rowland's wave-lengths to standards of Table 314 (the accepted standards, 1913). Temperature $15^{\circ} \mathrm{C}$, pressure 760 mm . :

| rection | $\begin{array}{r} 4800 . \\ -179 \end{array}$ |  | $-5$ |  |  | $-$ |  |  | $8$ | $\begin{array}{r} 5700 . \\ -.213 \end{array}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Correction | $\begin{array}{r} 5800 . \\ -.209 \end{array}$ | $\begin{array}{r} 590 \\ -.20 \end{array}$ | $-.213$ | $\begin{array}{r} 6100 . \\ -.214 \end{array}$ | $-.213$ | $\begin{array}{r} 6300 . \\ -.210 \end{array}$ | $\begin{array}{r} 640 \\ -.20 \end{array}$ | $\begin{array}{r} 6500 . \\ -.210 . \end{array}$ | 6600. | - |  |

[^42]
## SPECTRUM SERIES

In the spectra of many elements and compounds certain lines or groups of lines (doublets, triplets, etc.) occur in orderly sequence, each series with definite order of intensity (generally decreasing with decreasing wave-length), pressure effect, Zeeman effect, etc. Such series generally obey approximately a law of the form

$$
\nu=\frac{1}{\lambda}=L-\frac{N}{(m+R)^{2}},
$$

where $\nu$ is the wave-number in vacuo (reciprocal of the wave-length $\lambda$ ) generally expressed in waves per $c_{1} n ; m$ is a variable integer, each integer giving a line of the series; $L$ is the wave number of the limit of the series $(m=\infty)$; $N$, the "Universal Series Constant"; and $R$ is a function of $m$, or a constant in some simple cases.

Balmer's formula (1885) results if $L=N / n^{2}$, where $n$ is another variable integer and $K=0$. Rydberg's formula (1889) makes $R$ a constant, and $L$ is not known to be connected with $N$. Other formulae have been used with more success. Mogendorff (1906) requires $R=$ constant $/ m$, while Ritz (1903) has $R=$ constant $/ m^{2}$. Often no simple formula fits the case; either $R$ must be a more complex function of $m$, or the shape of the formula is incorrect.

Bohr's theory (see also Table 515) gives for Hydrogen

$$
N=\left\{2 \pi^{2} m e^{4}(M+m)\right\} / M h^{3},
$$

where $e$ and $m$ are the charge and mass of an electron, $M$ the atomic weight, and $h$, Planck's constant. The best value for $N$ is 109678.7 international units (Curtis, Birge, Astrophys. J. 32, 1910). The theory has been elaborated by Sommerfeld (Ann. der Phys. IgI6), and the present indications are that $N$ is a complex function varying somewhat from element to element.

Among the series (of singles, doublets, etc.), there is apt to be one more prominent, its lines easily reversible, called the principal series, $P(m)$. With certain relationships to this there may be two subordinate series, the first generally diffuse, $D(m)$, and another, $S(m)$. Related to these there is at times another, the Bergmann series $B(m) . m$ is the variable integer first used above and indicates the order of the line.

The following laws are in general true among these series: (I) In the $P(m)$ the components of the lines, if double, triple, etc., are closer with increasing order; in the subordinate series the distance of the components (in vibration number) remains constant. (2) Further, in two related $D(m)$ and $S(m), \Delta \nu$ (vibration number difference) remains the same. (3) The limits ( $L$ ) of the subordinate series, $D(m)$ and $S(m)$, are the same. (4) $\Delta \nu$ of the subordinate series is the same $\Delta \nu$ as for the first pair of the corresponding $P(m)$. (5) The limits ( $L$ ) of the components of the doublets (triplets, etc.) of the $P(m)$ are the same. (6). The difference between the vibration numbers of the end of the $P(m)$ and of the two corresponding subordinate series gives the vibration number of the first term of the $P(m)$. The first line of the $S(m)$ coincides with the first line of the $P(m)$ (Rydberg-Schuster law).

In the spectrum of an element several of these families of series $P(m), D(m), S(m), B(m)$ may be found. For further informition see Baly's Spectroscopy and Konen's Das Leuchten der Gasen, 1913, from the latter of which is taken the following tables, based greatly upon Dunz's Die Seriengesetze der Linienspektra, Diss., Tübingen, 1911, which has also appeared in book form, Hirzel, Leipzig. The following gives a schematic arrangement of the various series of a family in accordance with some of the above laws:

Let $\{m, a, a\}=N /\left(m+a+a / m^{2}\right)^{2} ; V P(m)=\{m, p, \pi\} ; V D(m)=\{m, d, \partial\rangle \cdot V S(m)=\{m, s, \sigma\rangle$ and $V B(m)=\{m, b, \beta\} ; V$ criginally referred to the variable part of the formula; when $m$ takes a specific value, it becomes a constant term, viz. $V S(\mathrm{r})$.

Then a single line system is represented as follows:

$$
\begin{array}{lr}
P^{\prime}(m)=V S^{\prime}(\mathrm{I})-V P^{\prime}(m) ; & D^{\prime}(m)=V P^{\prime}(\mathrm{I})-V D^{\prime}(m) ; \\
S^{\prime}(m)=V P^{\prime}(\mathrm{I})-V S^{\prime}(m) ; & \left\{B^{\prime}(m)=V D^{\prime}(\mathrm{I})-V B^{\prime}(m)\right\rangle .
\end{array}
$$

A system of double lines would be represented as follows:

$$
\begin{array}{ll}
P_{1}^{\prime \prime}(m)=V S^{\prime \prime}(\mathrm{I})-V P_{1}^{\prime \prime}(m) ; & D_{1}^{\prime \prime}(m)=V P^{\prime \prime}(\mathrm{I})-V D^{\prime \prime}(m) ; \\
P_{2}^{\prime \prime}(m)=V S^{\prime \prime}(\mathrm{I})-V P^{\prime \prime}(m) ; & D_{2^{\prime \prime}}(m)=V P^{\prime \prime}(\mathrm{I})-V D^{\prime \prime}(m) ; \\
S_{1}^{\prime \prime}(m)=V P_{1}^{\prime \prime}(\mathrm{I})-V S^{\prime \prime}(m) ; & \left\{\begin{array}{l}
\left.B_{1}^{\prime \prime}(m)=V D^{\prime \prime}(\mathrm{I})-V B^{\prime \prime}(m)\right\rangle ; \\
S_{2}^{\prime \prime}(m)=V P_{2}^{\prime \prime}(\mathrm{I})-V S^{\prime \prime}(m) ;
\end{array}\right. \\
\left.B_{2}^{\prime \prime}(m)=V D^{\prime \prime}(\mathrm{I})-V B^{\prime \prime}(m)\right\rangle .
\end{array}
$$

And similarly for a series of triplets, etc.
Series Spectra of the Elements. - The ordinary spectrum of $H$ contains 3 series of the same kind: one in the; Schumann region, $\nu=N\left(1 / \mathrm{I}^{2}-1 / n^{2}\right), n, 2,3 \ldots$; one in the visible, $\nu=N\left(1 / 2^{2}-1 / n^{2}\right), n, 3,4,5 . \ldots$; and one in the infrared, $\nu=N\left(1 / 3^{2}-1 / n^{2}\right), n, 4,5,6 \ldots$ He has three systems of series, one "enhanced," including the Pickering series formerly supposed to be due to H . The next two tables give some of the data for other elements.

| $2 \mu$ | $1 \mu$ | $0.5 \mu$ |  | $0.3 \mu \lambda$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1 | 2 |  | $3{ }^{3} 451$ |  |  |
| $1)$ | $0 \mid 2$ | 3145 | $\infty$ |  |  |  |
| 1 | 2 | $3 / 4 / 5$ | $\infty$ |  |  |  |
| $2334 \mid \infty$ |  |  |  |  |  |  |
| 5000 | 10000 | 20000 |  | 30000 |  |  |

Series System of Potassium.

## Bmithsonian Tables.

TABLE 323. - Limits of Some of the Series.

|  | $P_{1}(\infty)$ | $\begin{gathered} D_{1}(\infty) \\ =S_{1}(\infty) \end{gathered}$ | $B_{1}(\infty)$ | $P_{2}(\infty)$ | $D_{2}(\infty)$ $=S_{2}(\infty)$ | $B_{2}(\infty)$ | $P_{3}(\infty)$ | $\begin{gathered} D_{3}(\infty) \\ =S_{3}(\infty) \end{gathered}$ | $B_{3}(\infty)$ | $R(\infty)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | 48,764 | 27,429 | 12,186 | 48,764 | 27,419 | 12,186 | 48,744 | 27,429 | 12,186 | - |
| He | 32,031 | 27,173 | 12,204 | 38,453 | $\left\{\begin{array}{l}29,22 \mathrm{I} \\ 29,222\end{array}\right.$ | 12,208 | - | - | - | - |
| Li | - | - | - | 43,484 | 28,581 | 12,202 | - | - | - | - |
| Na | - | - | - | $*_{4} \mathbf{1}, 445$ | $\left\{\begin{array}{l}24,472 \\ 24,489\end{array}\right.$ | 12,274 | - | - | - | - |
| K | - | - | - | 35,006 | $\left\{\begin{array}{l}21,963 \\ 22,020\end{array}\right.$ | 13,47 1 | - | - | - | - |
| Rb | - | - | - | 33,685 | $\left\{\begin{array}{l}21,020 \\ 20,868 \\ 21,106\end{array}\right.$ | 14,330 | - | - | - | - |
| Cs | - | - | - | 31,407 | $\left\{\begin{array}{l}\text { 19,674 } \\ 20,228 \\ 3,52\end{array}\right.$ | $\begin{aligned} & \text { 16,809 } \\ & 16,907 \end{aligned}$ | - | - | - | - |
| Cu | - | - | - | 62,306 | $\left\{\begin{array}{l}31,523 \\ 31,771\end{array}\right.$ | 12,372 12,366 | - | - | - | - |
| Ag | - | - | - | 61,093 | $\left\{\begin{array}{l}31,721 \\ 30,62 \mathrm{I} \\ 3 \mathrm{I}, 542\end{array}\right.$ | 12,351 | - | - | - | - |
| Mg | - | 26,613 | - | ? | (31,542 | ? | 20,467 | $\left\{\begin{array}{l}39,752 \\ 39,793 \\ 39,813\end{array}\right.$ | 13,707 | - |
| Ca | - | 27,510 | - | ? | $\begin{aligned} & 60,423 \\ & 60,646 \end{aligned}$ | 28,929 | 17,761 | $\left\{\begin{array}{l}3,888 \\ 34,983 \\ 34,089 \\ 34, \mathrm{r} 42\end{array}\right.$ | $\begin{aligned} & 28,929 \\ & 28,950 \\ & 28,964 \end{aligned}$ | 49,353 |
| Sr | -- | 25,745 | - | - | 55,029 55,830 | - | - | $\begin{aligned} & 31,026 \\ & 31,420 \\ & 31,607 \end{aligned}$ | $\begin{aligned} & 27,05 \\ & 27,705 \\ & 27,766 \end{aligned}$ | 45,895 |
| Ba | - | - | - | - | $\left\{\begin{array}{l}49,926 \\ 51,616\end{array}\right.$ | - | ? | 31, | ? | 48,318 |

For the series of $\mathrm{Zn}, \mathrm{Cd}, \mathrm{Hg}, \mathrm{Al}, \mathrm{Sn}, \mathrm{Tl}, \mathrm{O}, \mathrm{S}, \mathrm{Sn}$, see original reference.

* 48 lines have been measured in this series from 16,956 to 41,417.


## TABLE 324. - First Terms of Some of the Series. Vibration Number Differences of Pairs $\Delta \nu$, and Triplets $\Delta \nu_{1}, \Delta \nu_{2}$.

For the $P(m)$ and the $S(m)$ is given only the first or second term, since the term with index o may be omitted as coinciding with the first term of the $S(m)$ or $P(m)$ respectively. Consequently the numbers always proceed from greater to smaller wave-lengths. Which is the common line can always be recognized from the vibration numbers. See figure on the preceding page. The vibration differences can be obtained from Table 323.


TABLE 325．－Index of Refraction of Glass．
Indices of refraction of optical glass made at the Bureau of Standards．Correct probably to 0.0000 ．The com－ position given refers to the raw material which went into the melts and does not therefore refer to the composition of the finished glass．

| Melt． | 123 | ${ }^{241}$ | 135 | 116 | 188 | 151 | 163 | 76 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Wave－length． | Ordinary crown． | Borosili－ cate crown | $\begin{aligned} & \text { Barium } \\ & \text { flint. } \end{aligned}$ | Light barium crown． | Light | Dense barium crown． | Medium flint． | Dense flint． |
| $\mathrm{Hg} \quad 4046.8$ | 1． 53189 | r． 53817 | 1．58851 | 1．59137 | 1． 60507 | 1． 63675 | 1.65788 | 1.60005 |
| $\mathrm{Hg}^{\mathrm{Hg}} 4078 . \mathrm{I}$ | 1．53147 | I． 53775 | I． 58791 | I． 59084 | I． 60430 | 1．63619 | I． 65692 | I． 68894 |
| H 4340．i | 1.52818 | I． 53468 | I． 58327 | 1． 58698 | I． 59860 | 1． 63189 | I． 64973 | I． 68079 |
| Hg 4358.6 | 1． 52798 | I． 53450 | 1． 58299 | 1． 58674 | I． 59826 | 1． 63163 | 1．64931 | 1． 68030 |
| $\mathrm{H}^{\mathrm{H}} 486 \mathrm{I} .5$ | I． 52326 | I． 53008 | I． 57646 | 1．58121 | I． 59029 | I． 62548 | 1． 6394 I | I． 669 II |
| Hg 4916．4 | 1． 52283 | I． 52967 | I． 57587 | I． 5807 I | I． 58958 | I． 62492 | 1． 63854 | I． 66814 |
| Hg 546 r .0 | 1.51929 | 1． 52633 | 1． 57105 | 1． 57657 | 1． 58380 | 1． 62033 | 1． 63143 | 1．66016 |
| Hg 5769.6 | 1．51771 | I． 52484 | I． 56894 | I． 57473 | I． 58 I 28 | 1．61829 | 1． 62834 | I． 65671 |
| Hg 5790．5 | 1.51760 | I． 52475 | I．5688I | 1． 57460 | 1． 58112 | 1．61817 | I． 62815 | I． 6.5650 |
| $\begin{array}{ll}\mathrm{Na} & 5893.2\end{array}$ | 1． 51714 | I． 52430 | I． 56819 | I． 57406 | 1． 58038 | 1．61756 | 1． 62725 | 1． 65548 |
| $\begin{array}{ll}\mathrm{Hg} & 6234.6 \\ \mathrm{H} & 6563.0\end{array}$ | 1.51573 I． 51458 | I． 52297 | I． 56834 I． 56482 | r． 57242 | I． 57818 I． 57638 | 1.61576 I． 61427 | I． 62458 | 1． 65250 |
| $\mathrm{Li} \quad 6708.2$ | 1．51412 | 1． 52145 | 1． 56423 | 1． 57054 | 1． 57567 | 1． 61369 | 1．62157 | I．64913 |
| K 7682．0 | 1． 51160 | 1． 51908 | I． 56100 | 1． 56762 | 1.57183 | 1．61047 | 1.61701 | I． 64405 |
| （Percentage composition） |  |  |  |  |  |  |  |  |
| $\mathrm{SiO}_{2}$ | 67.0 | 64.2 | 53.7 | 48.0 | 53.9 | 37.0 | 45.6 | 39.0 |
| $\mathrm{Na}_{2} \mathrm{O}$ | 12.0 | 9． 4 | ${ }^{1} .7$ | ${ }^{2} .0$ | 1.0 |  | 3.4 | 3.0 |
| $\mathrm{K}_{2} \mathrm{O}$ | 5.0 | 8.3 | 8.3 | 6.1 | 7.6 | 2.7 | 4.1 | 4.0 |
| $\mathrm{B2}_{2} \mathrm{O}_{3}$ | 3.5 | 11.0 | 2.7 | 4.0 | － | 5.0 |  |  |
| $\stackrel{\mathrm{BaO}}{ }$ | 10．6 | 6.1 | 14.3 | 29.5 | 二 | 47.0 | 二 | 二 |
| ${ }_{\mathrm{Ans}_{2} \mathrm{O}_{3}}$ | r． 5 | － | 2.5 | 10.0 | － | 7.7 | 二 | － |
| ${ }_{\mathrm{CaO}}{ }^{\text {A }}$ | 0．4 | 0.4 I． | 二 | $\underline{1.4}$ | 0.3 2.0 | 二 | － 3.0 | － |
| PbO | － | － | 16.7 | 二 | 35.2 | 二 | 44.0 | 49.0 |
| $\mathrm{Sb}_{2} \mathrm{O}_{3}$ |  |  |  |  |  | － |  | 1.0 |

TABLE 326．－Dispersion of Glasses of Table 325.

| Melt． | 123 | 241 | 135 | 116 | 188 | 151 | 163 | 76 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $n_{D}$ | 1.51714 | 1.52430 | I．56819 | I． 57406 | 1． 58038 | 1． 61756 | 1． 62725 | 1． 65548 |
| $n_{F}-n_{C}$ | 0．00868 | 0.00820 | 0.01164 | 0.01014 | 0．01391 | 0.01121 | 0.01700 | 0.01904 |
| $\frac{n_{D}-1}{n_{p}-n_{C}}=v$ | 59.6 | 63.9 | 48.8 | 56.6 | 41．7 | 55.1 | 36.9 | 34.4 |
| $n_{F}-n_{C}$ $n_{D}-n_{F}$ | 0.00612 | 0.00578 | 0.00827 | 0.00715 | 0.00991 | 0.00792 | 0． 01216 | 0.01363 |
| $n_{F}-n_{G^{\prime}}$ | 0.00492 | 0.00460 | 0.0068 I | 0.00577 | 0.00831 | 0.0064 I | 0.01032 | 0.01168 |
| $n_{D}-n_{C}$ | 0.00256 | 0.00242 | 0.00337 | 0.00299 | 0.00400 | 0.00329 | 0.00484 | 0.00541 |

## TABLE 327, - Glasses Made by Schott and Gen, Jena.

The following constants are for glasses made by Schott and Gen, Jena: $n_{\mathbf{A}}, n_{\mathrm{G}}, n_{\mathrm{D}}, n_{\mathrm{F}}, n_{\mathrm{G}}$, are the indices of refraction in air for $\mathrm{A}=0.7682 \mu, \mathrm{C}=0.6563 \mu, \mathrm{D}=0.5893, \mathrm{~F}=0.486 \mathrm{I}, \mathrm{G}^{\prime}=0.434 \mathrm{I}$. $v=\left(n_{\mathrm{D}}-\mathrm{I}\right) /\left(n_{\mathrm{F}}-n_{\mathrm{c}}\right)$. Ultra-violet indices: Simon, Wied. Ann. 53, 1894. Infra-red: Rubens, Wied. Ann. 45, 1892. Table is revised from Landolt, Börnstein and Meyerhoffer, Kayser, Handbuch der Spectroscopie, and Schott and Gen's list No. 75I, igo9. See also Hovestadt's "Jena Glass."

| $\begin{aligned} \text { Catalogue Type } & = \\ \text { Designation } & = \\ \text { Melting Number } & = \\ v \quad & = \end{aligned}$ |  |  | $\mathrm{O}_{546}$ <br> Zinc-Crown. <br> 1092 <br> 60.7 | $\mathrm{O}_{3} 8 \mathrm{r}$ <br> Higher Dispersion Crown $\begin{aligned} & 1151 \\ & 51.8 \end{aligned}$ | $\mathrm{O}_{18} 8_{4}$ <br> Light Silicate Flint. <br> 451 <br> 41.1 | O ro2 Heavy Silicate Flint. 469 33.7 | O 165 Heavy Silicate Flint. 500 27.6 | $\begin{gathered} \mathrm{S}_{57} \\ \text { Heaviest Sili- } \\ \text { cate Flint. } \\ 163 \\ \mathbf{2 2 . 2} \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Cd | $0.2763 \mu$ | 1. 56759 | - | - | - | - | - |
|  | Cd | . 2837 | 1.56372 | - |  |  | - |  |
|  | Cd | . 3403 | 1.54369 | 1. 55262 | 1.63320 | 1.71968 | 1. 85487 | - |
|  | Cd | . 3610 | 1.53897 | 1. 54664 | 1.61388 | 1.70536 | 1.83263 |  |
|  | H | . $4340 \mu$ | 1. 52788 | 1.53312 | 1.59355 | 1.6756x | 1.78800 | 1.94493 |
|  | H | -4861 | 1.52299 | 1.52715 | 1.58515 | 1.66367 | 1.77091 | 1.91890 |
|  | $\mathrm{Na}_{\mathrm{H}}$ | . .6593 | 1.51698 1.51446 1 | 1.52002 1.51712 | 1.57524 | 1.64985 | 1.75130 | 1.88995 $\times 8.8893$ |
|  | K | . 7682 | 1.51143 | 1.51368 | 1.56669 | 1.63820 | 1.73530 | 1.86702 |
|  |  | . $800 \mu$ | 1.5103 | 1.5131 | 1.5659 | 1. 6373 | 1. 7339 | 1.8650 |
|  |  | 1. 200 | 1.5048 | 1.5069 | 1.5585 | 1.6277 | 1.7215 | 1.8481 |
|  |  | 1.600 | 1. 5008 | 1.5024 | 1.5535 | 1.6217 | 1.7151 | 1. 8396 |
|  |  | 2.400 | - |  | 1. 5440 | 1.6131 | - | 1.8286 |

Percentage composition of the above glasses:
$\mathrm{O} 546, \mathrm{SiO}_{2}, 65.4 ; \mathrm{K}_{2} \mathrm{O}, 15.0 ; \mathrm{Na}_{2} \mathrm{O}, 5.0 ; \mathrm{BaO}, 9.6 ; \mathrm{ZnO}, 2.0 ; \mathrm{Mn}_{2} \mathrm{O}_{3}, 0.1 ; \mathrm{As}_{2} \mathrm{O}_{3}, 0.4$; $\mathrm{B}_{2} \mathrm{O}_{3}, 2.5$.
$\mathrm{O}_{3} 8 \mathrm{r}, \mathrm{SiO}_{2}, 68.7$; $\mathrm{PbO}, \mathrm{I} 3.3 ; \mathrm{Na}_{2} \mathrm{O}, \mathrm{I}_{5.7} ; \mathrm{ZnO}, 2.0 ; \mathrm{MnO}_{2}$, o.1; $\mathrm{As}_{2} \mathrm{O}_{5}, 0.2$.
$\mathrm{O}_{184}, \mathrm{SiO}_{2}, 53.7 ; \mathrm{PbO}, 36.0 ; \mathrm{K}_{2} \mathrm{O}, 8.3 ; \mathrm{Na}_{2} \mathrm{O}, \mathrm{I} .0 ; \mathrm{Mn}_{2} \mathrm{O}_{3}, 0.06 ; \mathrm{As}_{2} \mathrm{O}_{3}$, o.3.
O го2, $\mathrm{SiO}_{2}, 40.0 ; \mathrm{PbO}, 52.6 ; \mathrm{K}_{2} \mathrm{O}, 6.5 ; \mathrm{Na}_{2} \mathrm{O}, 0.5 ; \mathrm{Mn}_{2} \mathrm{O}_{3}, 0.09 ; \mathrm{As}_{2} \mathrm{O}_{5}, 0.3$.
O $165, \mathrm{SiO}_{2}, 29.26 ; \mathrm{PbO}, 67.5 ; \mathrm{K}_{2} \mathrm{O}, 3.0 ; \mathrm{Mn}_{2} \mathrm{O}_{3}, 0.04 ; \mathrm{As}_{2} \mathrm{O}_{3}$, o.2.
$\mathrm{S} 57, \mathrm{SiO}_{2}, 2 \mathrm{I} .9 ; \mathrm{PbO}, 78.0 ; \mathrm{As}_{2} \mathrm{O}_{5}$, o. 1.

TABLE 328.- Jena Glasses.

| No. and Type of Jena Glass. | $n_{\text {D }}$ for D | $n_{\mathrm{F}}-n_{\mathrm{c}}$ | $v=\frac{n_{n}-1}{n_{F}-n_{c}}$ | $n_{\text {D }}-n_{A}$ | $n_{F}-n_{\text {d }}$ | $n_{G}{ }^{\prime}-n_{\text {F }}$ | Specific Weight |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| O 225 Light phosphate crown | 1.5159 | .00737 | 70.0 | . 00485 | . 00515 | . 00407 | 2.58 |
| O 802 Boro-silicate crown. | 1.4967 | 0765 | 64.9 | 0504 | 0534 | 0423 | 2.38 |
| UV 3199 Ultra-violet crown . . . | 1.5035 | 0781 | 64.4 | 0514 | 0546 | 0432 | 2.41 |
| O227 Barium-silicate crown . . . | 1.5399 | -909 | 59.4 | 0582 | 0639 | 0514 | 2.73 |
| O 114 Soft-silicate crown . | 1.5151 | -910 | 56.6 | 0577 | $0^{0} 62$ | 0521 | 2.55 |
| O 608 High-dispersion crown | 1.5149 | 0943 | 54.6 | 0595 | -666 | $\bigcirc 543$ | 2.60 |
| UV 3248 Ultra-violet flint. | ${ }^{1.5332}$ | $\bigcirc 964$ | 55.4 | 0611 | 0680 | $\bigcirc 553$ | 2.75 |
| O 381 High-dispersion crown | 1.5262 | 1026 | 51.3 | 0644 | 0727 | $\bigcirc 596$ | 2.70 |
| $\mathrm{O}_{602}$ Baryt light flint | I. 5676 L 5686 | 1072 | 53.0 | ${ }^{0675}$ | $\bigcirc 759$ | 0618 | 3.122 |
| $\mathrm{S}^{389}$ Borate flint ${ }^{\text {a }}$ | 1.5686 | 1102 | 51.6 | 0712 | 0775 | -629 | 2.83 |
| O 726 Extra light flint . | 1. 5398 | 1142 | 47.3 | 0711 | 0810 | 0669 | 2.87 |
| O 154 Ordinary light flint . | 1.5710 | 1327 | 43.0 | 0819 | 0943 | 0791 | 3.16 |
| $\mathrm{O}^{\mathrm{O}} 8848 \mathrm{~B}$ " fint" " | 1.5900 1.6235 | 1438 | 41.1 | 0882 | 1022 | 0861 | 3.28 3.67 |
| O 748 Baryt flint ${ }_{\text {O }}^{\text {O2 Heavy flint }}$. | 1.6235 1.6489 1.854 | 1599 1919 | 39.1 33.8 | ${ }_{1152} 996$ | 1142 1372 1749 | 0965 1180 | 3.67 3.87 |
| $\mathrm{O}_{41}$ " ". | 1.7174 | 2434 | 29.5 | 1439 | 1749 | 1521 | 4.49 |
| $\mathrm{O}_{\mathrm{O}} 165$ " ${ }^{\text {c }}$ ". | 1.7541 | 2743 | 27.5 | 1607 | 1974 | 1730 | 4.78 |
| $\mathrm{S}_{\mathrm{S}} 386$ Heavy flint. | 1.9170 | 4289 | 21.4 | 2451 | 3109 | 2808 | 6.01 |
| S 57 Heaviest flint | 1.9626 | 4882 | 19.7 | 2767 | 3547 | 3252 | 6.33 |

TABLE 329, - Change of Indices of Refraction for 10 C in Units of the Fifth Decimal Place.

| No. and Designation. | Mean <br> Temp. | C | D | F | $\mathrm{G}^{\prime}$ | $\frac{-\Delta n}{n} 100$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| S 57 Heavy silicate flint | $58.8{ }^{\circ}$ | 1.204 | 1.447 | 2.090 | 2.8 ro | 0.0166 |
| O ${ }_{154}$ Light silicate flint . . . | 58.4 | 0.225 | 0.261 | 0.334 | 0.407 | 0.0078 |
| O 327 Baryt flint light ${ }^{\text {225 }}$ Light phosphate crown ${ }^{\text {a }}$ | 58.3 | $\bigcirc$ | 0.014 | 0.080 | 0. 137 | 0.0079 |
| O225 Light phosphate crown . | 58.1 | -0.202 | -0.190 | -0.168 | $-0.142$ | 0.0049 |

TABLE 330, - Index of Refraction of Rock Salt in Air.

| $\lambda(\mu)$. | $\pi$ | Observer. | $\lambda(\mu)$. | $n$ | Observer. | $\lambda(\mu)$. | $n$. | Obser ver. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.185409 | 1.89348 | M | 0.88396 | I. 53401 I | L | 5.8932 | 1.516014 | P |
| . 204470 | 1.76964 | " | . 972298 | I. 532532 |  |  | I. 515553 | I, |
| . 291368 | 1.61 325 | " | . 98220 | I. 532435 | P | 6.4825 | I. 513628 | $P$ |
| . 358702 | 1. 57932 | " | 1.036758 | 1.531762 | L, |  | 1.513467 | L |
| . 441587 | 1. 55962 | " | I.1786 | 1.530372 | P | 7.0718 | 1.511062 | P |
| .486149 | 1.55338 | " | " | 1.530374 | L | 7.6611 | 1. 508318 | " |
|  | 1. 553406 | L | 1.555137 | I. 528211 | P | 7.9558 | 1. 506804 | " |
| 58902 | I. 553399 | P | 1.7680 | I. 527440 | P | 8.8398 | 1.502035 | " |
| . 58902 | I. 544340 | L | " | I. 52744 I | L | 10.0184 | I. 494722 | " |
| . 58932 | 1. 544313 | P | 2.073516 | I. 526554 | 1 | 11.7864 | 1.481816 | " |
| . 656304 | I. 540672 | P | 2.35728 | I. 525863 | P | 12.9650 | I. 471720 | " |
|  | 1. 540702 | L |  | 1.525849 | L | 14.1436 | I. 460547 | " |
| .706548 | 1. 538633 | P | 2.9466 | 1.524534 | P | 14.7330 | I. 454404 | " |
| . 766529 | 1.536712 | P | $3 \cdot 5359$ | 1.523173 | " | 15.3223 | 1.447494 | " |
| . 76824 | 1. 53666 | M | 4. $125{ }^{2}$ | I. 521648 | P | 15.9116 | I. 441032 |  |
| .78576 | 1.536138 | P |  | 1.521625 | L, | 20.57 | I. 3735 | ${ }_{\text {\% }}$ N |
| .88396 | 1.534011 | P | 5.0092 | 1.518978 | P | 22.3 | 1. 340 |  |

$$
\begin{array}{ccc}
n^{2}=a^{2}+\frac{M_{1}}{\lambda^{2}-\lambda_{1}{ }^{2}}+\frac{M_{2}}{\lambda^{2}-\lambda_{2}{ }^{2}}-k \lambda^{2}-h \lambda^{4} \text { or }=b^{2}+\frac{M_{1}}{\lambda^{2}-\lambda_{1}{ }^{2}}+\frac{M_{2}}{\lambda^{2}-\lambda_{2}{ }^{2}}-\frac{M_{3}}{\lambda_{3}{ }^{2}-\lambda^{2}} \\
\text { where } a^{2}=2.330165 & \lambda_{2}{ }^{2}=0.02547414 & b^{2}=5.680137 \\
M_{1}=0.01278685 & k=0.0009285837 & M_{3}=12059.95 \\
\lambda_{1}^{2}=0.0148500 & h=0.000000286086 & \lambda_{3}^{2}=3600 \\
M_{2}=0.005343924 & &
\end{array}
$$

TABLE 331. - Change of Index of Refraction for 10 C in Units of the 5th Decimal Place.

| $0.202 \mu$ | +3.134 | Mi |  |  | Mi | C line | 3.749 | Pl | $0.760 \mu$ | 3 | L |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| . 210 | +r.570 | " | . 508 | -3.517 | ، | D " | -3.739 | P1 | 1.368 | $-3.88$ | L |
| . 224 | -0.187 | " | . 643 | $-3.636$ | " | F " | $-3.648$ | " | 1.88 | $-3.85$ | L |
| . 298 | -2.727 | " |  |  |  | G' " | $-3.5^{8} 5$ | " | $4 \cdot 3$ | $-3.82$ | L |

L Annals of the Astrophysical Observatory of the Smithsonian Institution, Vol. I, 1900.
M Martens, Ann. d. Phys. 6, 1901, 8, 1902.
Mi Micheli, Ann. d. Phys. 7, 1902.

P Paschen, Wied. Ann. 26, 1908.
Pl Pulfrich, Wied. Ann. 45, I892.
RN Rubens and Nichols, Wied. Ann. 60, 1897.

TABLE 332. - Index of Refraction of Sylvite (Potassium Chioride) in Air.

| $\lambda(\mu)$. | $n$ | Observer. | $\lambda(\mu)$. | $n$ | Observer. | $\lambda(\mu)$. | $n$ | Observer. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.185409 | 1.82710 | M | 1.1786 | 1.4783 II | P | 8.2505 | 1.462726 | P |
| . 200090 | 1.71870 | " | " | 1.47824 | W |  | I. 46276 | W |
| . 21946 | 1. 64745 | " | 1.7680 | 1.475890 | P | 8.8398 | 1.460858 | P |
| . 257317 | I. 58125 | " | "6 | 1.47589 | W |  | 1.46092 | W |
| . 281640 | 1.55836 | " | 2.35728 | 1.474751 | P | 10.0184 | I. 45672 | P |
| . 308227 | 1.54136 | * | 2.9466 | 1.473834 | " | " | 1.45673 | W |
| . 358702 | I.52115 | " |  | I. 47394 | W | I 1.786 | 1.44919 | P |
| . 394415 | 1.51219 | " | 3.5359 | 1. 473049 | P |  | 1.4494 I | W |
| . 467832 | 1.50044 | / |  | 1.47304 | W | 12.965 | I. 44346 | P |
| . 508606 | 1. 49620 | " | 4.7146 | 1.47 I 122 | P |  | I. 44385 | W |
| . 58933 | I. 49044 | P | ، | 1.47129 | W | 14.144 | 1.43722 | P |
| . 67082 | 1.48669 | M | 5.3039 | I. 470013 | P | 15.912 17.680 | 1.42617 1.41403 |  |
| .78576 .88398 | 1.483282 1.481422 | P |  | I. 47001 I. 468804 | W | 17.680 20.60 | 1.41403 r .3882 | RN |
| . .983920 | 1.481422 I. 480084 | " | 5.8932 | 1.468804 1.4680 | W | 22.5 | 1. 369 |  |

$$
\begin{align*}
& n^{2}=a^{2}+\frac{M_{1}}{\lambda^{2}-\lambda_{1}{ }^{2}}+\frac{M_{2}}{\lambda^{2}-\lambda_{2}{ }^{2}}-k \lambda^{2}-k \lambda^{4} \text { or }=b^{2}+\frac{M_{1}}{\lambda^{2}-\lambda_{1}{ }^{2}}+\frac{M_{2}}{\lambda^{2}-\lambda_{2}{ }^{2}}+\frac{M_{3}}{\lambda_{3}{ }^{2}-\lambda^{2}} \\
& a^{2}=2.174967 \quad \lambda_{2}{ }^{2}=0.0255550 \quad b^{2}=3.866619 \\
& M_{1}=0.008344206 \quad k=0.0005 \text { I } 3495 \quad M_{3}=5569.715 \\
& \lambda_{1}{ }^{2}=0.0119082 \quad h=0.000000167587 \quad \lambda_{3}{ }^{2}=3292.47  \tag{P}\\
& M_{2}=0.00698382 \\
& \text { W Weller, see Paschen's article. Other references as under Table } 33 \mathrm{I} \text {, above. }
\end{align*}
$$

table 333. - Index of Refraction of Finorite in Air.

| $\lambda(\mu)$ | $n$ | Observer | $\lambda(\mu)$ | $n$ | Observer | $\lambda(\mu)$ | $n$ | Observer. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.1856 | 1.50940 | S | 1.4733 | I. 42641 | P | 4.1252 | I. 40855 | P |
| .19881 | 1. 49629 | 6 | 1.5715 | 1.42596 | 6 | 4.4199 | 1.40559 | * |
| .21441 | 1. 48462 | " | 1.6206 | 1.42582 | 6 | 4.7146 | I. 40238 | 6 |
| . 22645 | 1. 47762 | " | 1.7680 | 1.42507 | 6 | 5.0092 | 1.39898 | 6 |
| . 257 I 3 | 1. 46476 | 6 | 1.9153 | 1.42437 | " | $5 \cdot 3036$ | 1.39529 | 6 |
| .32525 | 1.44987 | " | 1.9644 | 1.42413 | " | $5 \cdot 5985$ | 1.39142 | \% |
| . 34555 | 1.44697 | '6 | 2.0626 | 1.42359 | " | 5.8932 | 1.38719 | 6 |
| . 39681 | I. 44214 | 6 | 2.1608 | 1.42308 | 6 | 6.4825 | 1.37819 | 6 |
| . 48607 | 1.43713 | P | 2.2100 | I.42288 | 6 | 7.0718 | I. 36805 | 66 |
| . 58930 | 1. 43393 | P | 2.3573 | 1.42199 | 6 | 7.6612 | 1. 35680 | 6 |
| .65618 | 1.43257 | S | 2.5537 | 1.42088 | 6 | 8.2505 | I. 34444 | 66 |
| . 68671 | 1.43200 | * | 2.6519 | 1.42016 | 6 | 8.8398 | 1.33079 | 6 |
| . 71836 | I.43157 | ، | 2.7502 | 1.41971 | 6 | 9.4291 | 1.31612 | ${ }^{6}$ |
| .76040 | I.43101 | '6 | 2.9466 | 1.41826 | 6 | 5 I .2 | 3.47 | RA |
| . 8840 | 1. 42982 | P | 3.1430 | 1.41707 | '6 | 61.1 | 2.66 | " |
| 1.1786 | 1.42787 | " | 3.2413 | 1.41612 | 6 | $\infty$ | 2.63 | S |
| 1. 3756 | 1.42690 | * | 3.5359 | 1.41379 | ، |  |  |  |
| I. 4733 | 1.42641 | 6 | 3.8306 | 1.41120 | 6 | Referen | under Tab | 331. |

$n^{2}=a^{2}+\frac{M_{1}}{\lambda^{2}-\lambda_{1}{ }^{2}}-e \lambda^{2}-f \lambda^{4}$ or $=b^{2}+\frac{M_{2}}{\lambda^{2}-\lambda^{2}}+\frac{M_{3}}{\lambda^{2}-\lambda_{r}{ }^{2}}$
where $a^{2}=2.03882$

$$
\begin{align*}
M_{1} & =0.0062183 \\
\lambda_{1}^{2} & =0.007706 \\
e & =0.0031999 \tag{P}
\end{align*}
$$

$$
f=0.000002916
$$

$M_{3}=5114.65$
$\begin{aligned} b^{2} & =6.09651 \\ M_{2} & =0.00613 S 6\end{aligned}$
$\lambda_{r}{ }^{2}=1260.56$
$\lambda_{v}{ }^{2}=0.00884$
$\lambda_{v}=0.0940 \mu$
$\lambda_{r}=35 \cdot 5 \mu$
TABLE 334, - Change of Index of Refraction for $1^{\circ} \mathbf{C}$ in Units of the 5th Decimal Place.
C line, -I.220; D, -I.206; F, -I.170; G, -I.142. (Pl)
TABLE 335. - Index of Refraction of Iceland Spar ( $\mathrm{CaCO}_{3}$ ) in Alr.

| $\lambda(\mu)$ | $n_{0}$ | $n_{e}$ | Observer. | $\lambda(\mu)$ | $n_{0}$ | $n_{e}$ | Obser ver. | $\lambda(\mu)$ | $n_{0}$ | $n{ }_{0}$ | Obser ver. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.198 | - | I. 5780 | M | 0.508 | 1. 6653 | I. 4896 | M | 0.99I | І. 6438 | 1.4802 | C |
| . 200 | 1.9028 | I. 5765 | " | . 533 | 1. 6628 | I. 4884 | " | 1.229 | 1.6393 | 1.4787 | " |
| . 208 | 1. 8673 | 1.566.4 | " | . 589 | 1.6584 | I. 4864 | " | 1. 307 | 1. 6379 | 1.4783 | " |
| . 226 | 1.8130 | 1.5492 | - | . 643 | 1.6550 | I. 4849 | " | 1. 497 | 1. 6346 | 1.4774 | " |
| . 293 | 1.7230 | 1.5151 | C | .656 | I. 6544 | I. 4846 | " | 1. 682 | 1.6313 |  | " |
| . 340 | 1.7008 | I. 5056 | M | . 670 | 1.6537 | I. 4843 | , | 1.749 | - | 1. 4764 | " |
| . 361 | 1.6932 | 1.5022 | C | .760 | I. 6500 | 1.4826 | - | ז. 849 | 1.6280 | - | " |
| . 410 | 1. 6802 | I. 4964 | - | . 768 | 1. 6497 | 1.4826 | M | 1.908 | - | I. 4757 | " |
| . 434 | 1.6755 | I. 4943 | M | . 801 | 1.6487 | 1.4822 | C | 2.172 | 1.6210 | - | ، |
| . 486 | 1.6678 | 1.4907 | " | . 905 | 1. 6458 | 1.48IO | " | 2.324 | - | 1. 4739 | " |

C Carvallo, J. de Phys. (3), 9, 1900.
M Martens, Ann. der Phys. (4) 6, rgor, 8, 1902.
P Paschen, Wied. Ann. 56, 1895.

Pl Pulfrich, Wied. Ann 45, 1892.
RA Rubens-Aschkinass, Wied. Ann. 67, 1899.
S Starke, Wied. Ann. 60, 1897.

TABLE 336. -Index of Refraction of Nitroso-dimethyl-aniline. (Wood.)

| $\boldsymbol{\lambda}$ | $n$ | $\lambda$ | $n$ | $\lambda$ | $n$ | $\lambda$ | $n$ | $\lambda$ | $n$ |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: | :---: |
| 0.497 | 2.140 | 0.525 | 1.945 | 0.584 | 1.815 | 0.636 | 1.647 | 0.713 | 1.718 |
| .500 | 2.114 | .536 | 1.909 | .602 | 1.796 | .647 | 1.758 | .730 | 1.713 |
| .506 | 2.074 | .546 | 1.879 | .611 | 1.783 | .659 | 1.750 | .749 | 1.709 |
| .508 | 2.025 | .557 | 1.857 | .620 | 1.778 | .669 | 1.743 | .763 | 1.697 |
| .516 | 1.985 | .569 | 1.834 | .627 | 1.769 | .696 | 1.723 |  |  |

Nitroso-dimethyl-aniline has enormous dispersion in yellow and green, metallic absorption in violet. See Wood. Phil. Mag. 1903.

Tables 337-338.
INDEX OF REFRACTION.
TABLE 337, - Index of Refraction of Quartz ( $\mathrm{SiO}_{2}$ ).

| Wave- length. | $\begin{aligned} & \text { Index } \\ & \text { Ordinary } \\ & \text { Ray. } \end{aligned}$ | $\begin{array}{\|c} \text { Index } \\ \text { Extraordinary } \\ \text { Ray. } \end{array}$ | Temperature ${ }^{\circ} \mathrm{C}$. | Wave- length. | $\begin{gathered} \text { Index } \\ \text { Ordinary } \\ \text { Ray. } \end{gathered}$ | $\begin{array}{c}\text { Index } \\ \text { Extraordinary } \\ \text { Ray. }\end{array}$ | Tempera ture ${ }^{\circ} \mathrm{C}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{\mu}{\mu .185}$ | 1. 67582 | 1.68999 | 18 | $\mu$ <br> 0.656 | 1.54189 | 1.55091 | 18 |
| . 193 | . 65997 | . 67343 | " | . 686 | . 54099 | . 54998 | ، |
| . 198 | . 65090 | . 66397 | " | . 760 | . 53917 | . 54811 | " |
| . 206 | . 64038 | . 65300 | " | 1.160 | . 5329 |  | - |
| . 214 | . 63041 | . 64264 | " | . 969 | . 5216 |  | - |
| . 219 | . 62494 | . 63698 | " | 2.327 | . 5156 |  |  |
| . 231 | . 61399 | . 62560 | " | .84 .8 | . 5039 |  |  |
| . 257 | . 59622 | . 60712 | " | 3.18 | . 4944 |  |  |
| . 274 | .58752 .56748 .5858 | . 59811 | " | . 63 | . 4799 | Rubens. | - |
| .340 .396 | . 56748 | . 57738 | " | .96 4.20 | .4679 .4569 |  | - |
| . 410 | . 55650 | . 56600 | " | 5.0 | .417 |  | - |
| . 486 | . 54968 | . 55896 | " | 6.45 | . 274 |  | - |
| 0.589 | I. 54424 | 1.55334 | " | 7.0 | 1.167 |  | - |

Except Rubens' values, - means from various authorities.

TABLE 338. - Indices of Refraction for various Alums.*


[^43]
## Smithsonian Tables.

## Selected Monorefringent or Isotropic Minerals.

The values are for the sodium $D$ line unless otkerwise stated and are arranged in the order of increasing indices. Selected by Dr. Edgar T. Wherry from a private compilation of Dr. E. S. Larsen of the U. S. Geological Survey.

| Mineral. | ormul | $\begin{gathered} \text { Index of } \\ \text { refraction } \\ \stackrel{0}{0.589 \mu} . \end{gathered}$ |
| :---: | :---: | :---: |
| Villiamite | ${ }^{\mathrm{NaF}}$ | I. 328 |
| Cryoithionite...... |  | (1) |
| Aluarite............ | ${ }_{\text {CaF2 }} \mathrm{CaF}_{2} \mathrm{AlO}_{2} \mathrm{O}_{3.4} \mathrm{SO}_{3} .24 \mathrm{H}_{2} \mathrm{O}$ | I. |
| Sodalite | ${ }_{5}^{3}{ }_{5} \mathrm{Na}_{2} \mathrm{O} \cdot 3 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{SiO}_{2} \cdot 2 \mathrm{NaCl}$ |  |
| Analcite. | $\mathrm{Na}^{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 4 \mathrm{SiO}_{2} \cdot 2 \mathrm{H}_{2} \mathrm{O}$ |  |
| SYyite. | ${ }_{5} \mathrm{Na}_{2} \mathrm{O} \cdot 3 \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2} \mathrm{O}_{2} \mathrm{SO}_{3}$ |  |
| Haunnite. | ${ }^{\text {a }}$ | $\underset{\substack{\text { I. } 4.900 \\ \text {. } 500 \pm}}{ }$ |
| Leucite Pollucte Peme | ${ }^{\text {Kr }}$ |  |
|  |  | ¢, |
| ${ }^{\text {Bauxite }}$ | ${ }^{\mathrm{Al}_{2} \mathrm{O}_{2}, \mathrm{nH} \mathrm{H}_{2} \mathrm{O}} \mathrm{O}$ |  |
| ${ }_{\text {Pharmacosid }}$ |  | ${ }_{\text {1. } 723}^{\text {1. }}$ ( |
| Berzelite. |  |  |
| Pericasate | 3 COO | 1.736 |
| Helvite. |  | I. I . 739 |
| Prrope ${ }_{\text {Prendite }}$ |  | (1.745 |
| ${ }_{\text {Hesesente }}^{\text {Heseonite }}$ |  | 1.763 |
| Almandite. | ${ }_{3} \mathrm{FeO} . \mathrm{Al}_{2} \mathrm{O} \mathrm{O}_{3} 3 \mathrm{SiO}$ | r.778 |
| Hercynite. |  |  |
| Ganite | $3{ }_{3} \mathrm{MnO} .4 \mathrm{AlO}_{3} .3 \mathrm{SiO}_{2}$ | ¢, c (.8II |
| Lime. ${ }^{\text {Unarovit }}$ |  | (1.830 |
| Andradite. |  | ${ }_{1.857}$ |
| Microlite. |  | I. 923 |
| Pyrochlore. | Contains $\mathrm{CaO}_{2}, \mathrm{Ce}_{2} \mathrm{O}_{3}, \mathrm{TiO}_{2}$, etc | 1.960-2.000 |
| Schorlomite |  | 1.080 |
| Picitite. |  | $2.050 \pm$ |
| Eulytite |  |  |
| Mosesite. | Contains $\mathrm{Hg}_{3} \mathrm{NH}_{4}, \mathrm{Cl}$, etc. | 2.065 |
| Senarmont | $\mathrm{Sb}_{2} \mathrm{O}_{3} \mathrm{Cl}_{3}$ | ${ }_{2}^{2.087}$ |
| Emboite. | ${ }_{\text {Ag }}$ | ci.150 |
| Bunsenite. | NiO | 2.18 (Li light) |
| Lewisite |  |  |
| Bromyrite | ${ }_{\text {AbBr }}$ | ${ }_{2}^{2.253}$ |
| Dysanalite | Contains $\mathrm{CaO}, \mathrm{FeO}, \mathrm{TiO}_{2}$, etc. | ${ }^{2} .330$ |
| Franklinite | $(\mathrm{Zn}, \mathrm{Fe}, \mathrm{Mn}) \mathrm{O}$.(Fe, Mn) $\mathrm{O}_{2} \mathrm{O}_{3}$ | ${ }_{\substack{2 \\ 2.350}}^{2.350}$ (Lil light) |
| Sphaerite | ( Ca |  |
| Diamondit. | ${ }_{\mathrm{H} \mathrm{CO} .2 \mathrm{HgCl}}$ | ${ }^{2} .4790$ (Jilizht) |
| Hauerite. | ${ }_{\text {MnS }}$ | 2. 6900 (Lili light) |
| Aiabandite........ Cuprite....... | ${ }_{\text {Mns }}{ }_{\text {Cuz }}$ |  |

SMITHSONIAN TABLES.

## Miscellaneous Monorefringent or Isotropic Solids.

| Substance. | Spectrum line. | Index of refraction. | Authority. |
| :---: | :---: | :---: | :---: |
| Albite glass. | D | 1.4890 | Larsen, 1009 |
| Amber.... | D | 1. 546 | Mühlheim |
| Ammonium chloride | D | I. 6422 | Grailich |
| Anorthite glass. | D | 1. 5755 1. 635 | Larsen, 1909 E. L. Nichols |
|  | -0.670 ${ }^{\text {d }}$ | 1.635 | ${ }_{\text {U.: }}{ }^{\text {E }}$ Nichols |
| Bell metal. | D | 1.0052 | Beer |
| Boric Acid, melted. | C | I. 4623 | Bedson and Williams |
| "، ${ }^{\text {a }}$ | $\stackrel{\mathrm{F}}{\mathrm{F}}$ | I. 4637 | "، "، |
| Borax, melted. | C | I. 4624 | " ، " |
| "، " | D | I. 4630 | " " " |
| " ${ }^{\text {" }}$ | F | 1.4702 | " " " |
| Camphor. | D | 1. 532 | Kohlrausch |
| Canada balsam.. | D | 1.5402 I. 530 | Mean |
| Ebonite... | red | I. 66 | Ayrton, Perry |
| Fuchsin. | A | 2.03 | Mean |
| " | ${ }_{\text {B }}^{\text {B }}$ | 2.19 | "، |
| " ${ }^{\text {a }}$................ | G | 2.33 1.97 | " |
| " $\quad$.............. | H | 1.32 | " |
| Gelatin, Nelson no. 1 | D | I. 530 | Jones, rimir |
| " ${ }^{\text {a }}$ various | D | I. 516-r. 534 |  |
| Gum Arabic. | red | I. 480 I. 514 | Jamin Wollaston |
| Obsidian. . | D | I. 482 -I. 496 | Various |
| Phosphorus. | D | 2.1442 | Gladstone, Dale |
| Pitch. | red | I. 531 | Wollaston |
| Potassium bromide.... | D | I. 5593 | Topsöe, Christiansen |
| "\% chlorstannate. | D | 1.6574 I .6666 | " ${ }^{\text {" }}$ |
| Resins: Aloes.. | red | 1. 619 | Jamin |
| Canada balsam | red | 1.528 | Wollaston |
| Colophony | red | 1. 548 | Jamin |
| Copal... | red | 1.528 I. 535 | Wollaston |
| Peru balsam. | D | I. 593 | Baden Powell |
| Selenium.. | A | 2.61 | Wood |
| " | B | 2.68 | " |
| " | C | 2.73 | "، |
| Sodium chiorate | D | I. 5150 | Dussaud |
| Strontium nitrate. | D | I. 5667 | Fock |

The values are arranged in the order of increasing indices for the ordinary ray and are for the sodium D line unless otherwise indicated. Selected by Dr. Edgar T. Wherry from a private compilation of Dr. Esper S. Larsen of the U. S. Geological Survey.

| Mineral. | Formula. | Index of refraction. |  |
| :---: | :---: | :---: | :---: |
|  |  | Ordinary ray. | Extraordinary ray. |
| (a) Uniaxial Positive Minerals. |  |  |  |
| Ice. | $\mathrm{H}_{2} \mathrm{O}$ | 1. 309 | 1.313 |
| Sellaite...il | ${ }_{\mathrm{CuO}}^{\mathrm{Mg} 2} \mathrm{SiO}_{2,2 \mathrm{H}_{2} \mathrm{O}}$ | 1. 378 $\mathbf{1 . 4 6 0}$ a | 1.390 |
| Chrysocolla | ${ }_{2}^{\mathrm{CuO} . \mathrm{CaO}_{2} \mathrm{Al}_{2} \mathrm{O}_{3} .5 \mathrm{H}_{2} \mathrm{SiO}} \mathrm{O}_{2} .6 \mathrm{H}_{2} \mathrm{O}$ | $1.460 \pm$ 1.475 | 1.570 1.486 |
| Chabazite. | ( $\mathrm{Ca}, \mathrm{Na}_{2}$ ) $\mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} .4 \mathrm{SiO}_{2} .6 \mathrm{H}_{2} \mathrm{O}$ | r. $480 \pm$ | 1.482 $=$ |
| Douglasite. | ${ }_{2} \mathrm{KCl} . \mathrm{FeCl}_{2.2} \mathrm{H}_{2} \mathrm{O}$ | 1.488 | I. 500 |
| Hydronephelite. | ${ }_{2} \mathrm{Na}_{2} \mathrm{O} \cdot 3.3 \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2.7} 7 \mathrm{HH}_{2} \mathrm{O}$ | 1. 490 | 1. 502 |
| Apophyllite. Quartz . | ${ }_{\mathrm{SiO}}^{2} \mathrm{O} .8 \mathrm{CaO} .16 \mathrm{SiO}_{2} .16 \mathrm{H}_{2} \mathrm{O}$ | 1. $5354 \pm$ | r. 537 1.553 |
| Coquimbite | $\mathrm{Fe}_{2} \mathrm{O}_{3.3} \mathrm{SO}_{3} .9 \mathrm{H}_{2} \mathrm{O}$ | 1. 550 | 1. 556 |
| Brucite. . | $\mathrm{MgO} . \mathrm{H}_{2} \mathrm{O}$ | 1. 559 | 1. 580 |
| Alunite. | $\mathrm{K}, \mathrm{O} \cdot 3.3 \mathrm{Al}_{2} \mathrm{O}_{3.4} 4 \mathrm{SO}_{3} .6 \mathrm{H}_{2} \mathrm{O}$ | 1. 572 | 1. 592 |
| Penniuite. Cacoxenite | ${ }_{2}^{5}\left(\mathrm{Me} 2 \mathrm{O}_{3} . \mathrm{P}_{2} \mathrm{O}_{5.1} \mathrm{Al}_{2} \mathrm{H}_{2} \mathrm{O} \mathrm{O}^{2} \mathrm{SiO}_{2.4} \mathrm{H}_{2} \mathrm{O}\right.$ | 1. 576 | 1. 579 |
| Eudialite. | ${ }_{6} \mathrm{Na}_{2} \mathrm{O} .6(\mathrm{Ca}, \mathrm{Fe}) \mathrm{O} .20(\mathrm{Si}, \mathrm{Zr}) \mathrm{O}_{2} . \mathrm{NaCl}$ | I. 606 | I.645 |
| Dioptasite | $\mathrm{CuO} . \mathrm{SiO}_{2} \mathrm{H}_{2} \mathrm{O}$ | 1. 654 | 1.707 |
| Phenacite. | ${ }_{2} \mathrm{BeO} . \mathrm{SiO}_{2}{ }^{\text {a }}$ | 1. 654 | 1.670 |
| Parisite. | ${ }_{2} \mathrm{CeOF}, \mathrm{CaO} .3 \mathrm{CO}_{2}$ | 1.676 | 1.757 |
| Vesuvianite | ${ }_{2}(\mathrm{Ca}, \mathrm{Mn}, \mathrm{Fe}) \mathrm{O} .(\mathrm{Al}, \mathrm{Fe})(\mathrm{OH}, \mathrm{F}) \mathrm{O} .2 \mathrm{SiO}_{2}$ | 1.694 r .716 | 1.723 1.718 \% \% |
| Xenotime | $\mathrm{Y}_{2} \mathrm{O}_{3} . \mathrm{P}_{2} \mathrm{O}_{5}$ | 1.721 | I.816 |
| Connellite. | $20 \mathrm{CuO} . \mathrm{SO}_{3.2} \mathrm{CuCl}_{2.20 \mathrm{H}_{2} \mathrm{O}}$ | 1. 724 | 1. 746 |
| Benitoite. | ${ }_{6} \mathrm{BaO}, \mathrm{TiO}_{2.3} \mathrm{SiO}_{2}{ }^{\text {a }}$ | 1. 757 | I. 804 |
| Ganomalite |  | 1.910 | 1.945 |
| Zircon. | $\mathrm{ZrO}_{2} . \mathrm{SiO}_{2}$ | $1.923 \pm$ | 1.934 r .968 |
| Powellite | $\mathrm{CaO}^{\mathrm{Ca}} \mathrm{MoO}_{3}$ | r. 967 | r. 978 |
| Calomel. | $\mathrm{HgCl}^{\text {a }}$ | I. 973 | 2.650 |
| Cassiterite Zincite. | $\mathrm{SnO}_{\mathrm{ZnO}}$ | 1.997 | 2.093 |
| Phosgenite | $\stackrel{\mathrm{PbO}}{\mathrm{Z}} . \mathrm{PbCl}_{2} \mathrm{CO}_{2}$ | 2.114 | 2.029 2.140 |
| Penfieldite | $\mathrm{PbO} .2 \mathrm{PbCl}_{2}$ | 2.130 | 2.210 |
| Iodyrite. | ${ }_{\text {AgI }}$ | 2.210 | 2.220 ( ${ }^{2}$ |
| Tapiolite. | $\stackrel{\mathrm{FeO}}{ }(\mathrm{Ta}, \mathrm{Cb})_{2} \mathrm{O}_{5}$ | 2.270 | ${ }^{2.420}$ (Li light) |
| Derbylite | ${ }_{6 \mathrm{FeO}} . \mathrm{Sb}_{2} \mathrm{O}_{3} .5 \mathrm{TiO}_{2}$ | 2.356 2.450 | ${ }_{2}^{2.378} \mathbf{2 . 5 1 0}$ (Li light) |
| Greenockite | CdS | 2.506 | 2.529 2.5129 |
| Rutile.. | $\mathrm{TiO}_{2}$ | 2.616 | 2.903 |
| Moissanite. Cinnabarite | $\underset{\mathrm{HgS}}{\mathrm{CSi}}$ | 2.654 | 2.697 |
| Cinnabarite | HgS | 2.854 | 3.201 |
| (b) Unlaxial Negative Minerals. |  |  |  |
| Chiolite. | ${ }_{2} \mathrm{NaF} . \mathrm{AlF}_{3}$ | 1.349 | 1.342 |
| Hanksite. | ${ }_{11} \mathrm{Na}_{2} \mathrm{O} .0 \mathrm{SO}_{3.2} \mathrm{CO}_{2 . \mathrm{KCl}}$ | 1.481 | I. 46 F |
| Thaumasite. | ${ }_{3} \mathrm{CaO} . \mathrm{CO}_{2} . \mathrm{SiO}_{2} \mathrm{SO}_{3} . \mathrm{I} 5 \mathrm{H}_{2} \mathrm{O}$ | 1.507 | I. 468 |
| Hydrotalcite | $6 \mathrm{MgO} . \mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{CO}_{2} .155 \mathrm{H}_{2} \mathrm{O}$ | 1.512 | 1.498 |
| Milarite. | ${ }_{\mathrm{K}}^{2} \mathrm{O} .4 \mathrm{CaO}_{2} \mathrm{All}_{2} \mathrm{O}_{3.24} \mathrm{SiO}_{2} . \mathrm{H}_{2} \mathrm{O}$ | 1.524 1. 532 | 1. 496 I .529 |
| Kaliophilite | $\mathrm{K}_{2} \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} .2 \mathrm{SiO}_{2}$ | 1.532 I. 537 | 1.529 1. 533 |
| Mellite. | ${ }_{4 l} \mathrm{AlO}_{3} \mathrm{O}_{3}, \mathrm{C}_{12} \mathrm{O}_{9} .18 \mathrm{H}_{2} \mathrm{O}$ | 1. 539 | I. 511 |
| Marialite | $" \mathrm{Ma} "=3 \mathrm{Na}_{2} \mathrm{O} \cdot 3 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 18 \mathrm{SiO}_{2.2} \mathrm{NaCl}$ | 1. 539 | I. 537 |
| Nephelite. | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 2 \mathrm{SiO}_{2}$ | 1. 542 | 1. 538 |

TABLE 341 (Continued). - Selected Uniaxial Minerals.

| Mineral. | Formula. | Index of refraction. |  |
| :---: | :---: | :---: | :---: |
|  |  | Ordinary ray. | Extraordinary ray. |
| (b) Uniaxial Negative Minerals (continued). |  |  |  |
| Wernerite... | $\mathrm{Me}_{1} \mathrm{Ma}_{1}{ }^{ \pm}$ | 1. 578 | 1.551 |
| Beryl. <br> Torbernite. | ${ }^{3} \mathrm{BeO} . \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{SiO}_{2} \mathrm{CuO}_{2} \mathrm{UO}_{3} \cdot \mathrm{P}_{2} \mathrm{O}_{5} 8 \mathrm{H}_{2} \mathrm{O}$ | 1. $5881 \pm$ | 1. $575 \pm$ |
| Meionite. . | $" \mathrm{Me}$ " $=4 \mathrm{CaO} .3 \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2}$ | 1.592 1.597 | 1.582 1.560 |
| Melilite. | Contains $\mathrm{Na}_{2} \mathrm{O}, \mathrm{CaO}, \mathrm{Al}_{2} \mathrm{O}_{3}, \mathrm{SiO}_{2}$, etc. | 1.597 1.634 | 1. 560 |
| Apatite. | ${ }_{9} \mathrm{CaO} .3 \mathrm{P}_{2} \mathrm{O}_{5} . \mathrm{Ca}(\mathrm{F}, \mathrm{Cl})_{2}$ | 1. 634 | 1. 631 |
| Calcite. | $\mathrm{CaO}^{-\mathrm{CO}_{2}}{ }^{\text {a }}$ | 1. 658 | 1. 486 |
| Gehlenite.. |  | 1. 669 | 1.658 |
| Tourmaline Dolomite... | $\xrightarrow[\text { Contains } \mathrm{Na}_{2} \mathrm{O}, \mathrm{FeO}, \mathrm{Al}_{2} \mathrm{O}_{3}, \mathrm{~B}_{2} \mathrm{O}_{3}, \mathrm{SiO}_{2} \text {, etc. }]{\text { CaO. }}$ | 1.669 1.682 | 1.658 1.503 1. 503 |
| Magnesite . | $\mathrm{MgO} . \mathrm{CO}_{2}$ | 1. 700 | 1.603 1.509 |
| Pyrochroite. | $\mathrm{MnO} . \mathrm{H}_{2} \mathrm{O}$ | 1. 723 | I. 681 |
| Corundum. | $\mathrm{Al}_{2} \mathrm{O}_{3}$ | 1. 768 | 1. 760 |
| Smithsonite ... | $\mathrm{ZnO} . \mathrm{CO}_{2}$ $\mathrm{MnO} . \mathrm{CO}_{2}$ | 1.818 I 818 | 1. 618 |
| Jaiosite....... | $\mathrm{K}_{2} \mathrm{O} .3 \mathrm{Fe}_{2} \mathrm{O}_{3.4} \mathrm{SO}_{3} .6 \mathrm{H}_{2} \mathrm{O}$ | 1.818 1.820 | 1.595 1.715 |
| Siderite.. | $\mathrm{FeO} . \mathrm{CO}_{2}{ }^{\text {d }}$ | 1.875 | I. 635 |
| Pyromorphite | ${ }_{9} \mathrm{PbO} .3 \mathrm{P}_{2} \mathrm{O}_{5} . \mathrm{PbCl}_{2}$ | 2.050 | 2.042 |
| Barysilite Mimetite | ${ }_{3} \mathrm{PbOO} .2 \mathrm{SiO}_{2} \mathrm{Pr}_{2}$ | 2.070 | 2.050 |
| Mimetite. | ${ }_{\mathrm{PbO}}^{\mathrm{PbO} .3 \mathrm{PbCl}_{2} \mathrm{O}_{5} .} \mathrm{PbCl}_{2}$ | 2.135 2.150 2. | 2.118 |
| Stolzite. . . | $\mathrm{PbO} \mathrm{WO}_{3}$ | 2.150 2.269 | 2.040 2.182 |
| Geikielite . | $(\mathrm{Mg}, \mathrm{Fe}) \mathrm{O} \cdot \mathrm{TiO}_{2}$ | 2.310 | 1.950 |
| Vanadinite | ${ }_{9} \mathrm{PbO}_{.3} \mathrm{~V}_{2} \mathrm{O}_{5} . \mathrm{PbCl}_{2}$ | 2.354 | 2.299 |
| Wulfenite. | ${ }_{\text {PbO. }}^{\text {Pbo }}$ - $\mathrm{MoO}_{3}$ | 2.402 | ${ }^{2} 304$ (Li light) |
| Massicotite | $\mathrm{PbO}^{\text {P10 }}$ | 2.554 2.665 | 2.493 ( 2.535 li light) |
| Proustite. | $3 \mathrm{Ag}_{2} \mathrm{~S} . \mathrm{As}_{2} \mathrm{~S}_{3}$ | 2.685 2.979 | ${ }_{2.715}^{2.535}$ " ${ }^{\text {c/i }}$ |
| Pyrargyrite | ${ }_{3} \mathrm{Ag}_{2} \mathrm{~S}^{2} . \mathrm{Sb}_{2} \mathrm{~S}_{3}$ | 3.084 | 2.881 " " |
| Hematite... | $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | 3.220 | 2.940 " " |

TABLE 342. - Miscellaneous Uniaxial Crystals.

| Crystal. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

* Topsöe and Christiansen.


## Selected Biaxial Minerals.

The values are arranged in the order of increasing $\beta$ index of refraction and are for the sodium D line except where noted. Selected by Dr. Edga: T. Wherry from private compilation of Dr. Esper S. Larsen of the U. S. Geological Survey.

| Mineral. | Formula. | Index of refraction. |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | $n_{a}$ | $n \beta$ | ${ }^{n} \gamma$ |
| (a) Braxial Positive Minerals. |  |  |  |  |
| Stercorite. | $\mathrm{Na}_{2} \mathrm{O} .\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O} \cdot \mathrm{P}_{2} \mathrm{O}_{5.9} \mathrm{H}_{2} \mathrm{O}$ | 1. 439 | I. 44 I | 1.469 |
| Aluminite. | $\mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{SO}_{3.9} 9 \mathrm{H}_{2} \mathrm{O}$ | I. 459 | I. 464 | 1.470 |
| Tridymite. | $\mathrm{SiO}_{2}$ | I. 469 | I. 470 | I. 473 |
| Thenardite. | $\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{SO}_{3}$ | I. 464 | I. 474 | I. 485 |
| Carnallite. | $\mathrm{KCl} . \mathrm{MgCl}_{2} .6 \mathrm{H}_{2} \mathrm{O}$ | I. 466 | 1. 475 | I. 494 |
| Alunogenite | $\mathrm{Al}_{2} \mathrm{O}_{3} .3 \mathrm{SO}_{3} .16 \mathrm{H}_{2} \mathrm{O}$ | I. 474 | I. 476 | I. 483 |
| Melanterite | $\mathrm{FeO} . \mathrm{SO}_{3.7} \mathrm{H}_{2} \mathrm{O}$ | 1.471 | 1. 478 | 1. 486 |
| Natrolite. | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} .3 \mathrm{SiO}_{2.2} \mathrm{H}_{2} \mathrm{O}$ | I. 480 | I. 482 | I. 493 |
| Arcanite. | $\mathrm{K}_{2} \mathrm{O} . \mathrm{SO}_{3}$ | I. 494 | I. 495 | I. 497 |
| Struvite | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O} .2 \mathrm{MgO} . \mathrm{P}_{2} \mathrm{O}_{5.1} \mathrm{I}_{2} \mathrm{H}_{2} \mathrm{O}$ | I. 495 | I. 496 | I. 504 |
| Heulandite. | $\mathrm{CaO} . \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2.3} \mathrm{H}_{2} \mathrm{O}$ | I. 498 | I. 499 | I. 505 |
| Thomsonite | $(\mathrm{Na} 2, \mathrm{Ca}) \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3.2} \mathrm{SiO}_{2.3} \mathrm{H}_{2} \mathrm{O}$ | I. 497 | I. 503 | I. 525 |
| Harmotomite | $\left(\mathrm{K}_{2}, \mathrm{Ba}\right) \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3.5} \mathrm{SiO}_{2.5} \mathrm{H}_{2} \mathrm{O}$ | I. 503 | I. 505 | 1.508 |
| Petalite..... | $\mathrm{Li}_{2} \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} .8 \mathrm{SiO}_{2}$ | 1. 504 | 1.510 | 1. 516 |
| Monetite | ${ }_{2} \mathrm{CaO} . \mathrm{P}_{2} \mathrm{O}_{5} . \mathrm{H}_{2} \mathrm{O}$ | I. 515 | 1. 518 | 1. 525 |
| Newberyite | ${ }_{2} \mathrm{MgO} . \mathrm{P}_{2} \mathrm{O}_{5.7} \mathrm{HH}_{2} \mathrm{O}$ | I. 514 | I. 519 | I. 533 |
| Gypsum... | $\mathrm{CaO} . \mathrm{SO}_{3.2} \mathrm{H}_{2} \mathrm{O}$ | I. 520 | I. 523 | I. 530 |
| Mascagnite | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{O} \cdot \mathrm{SO}_{3}$ | I. 52 I | 1.523 | 1.533 |
| Albite.... | " Ab " $=\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{SiO}_{2}$ | I. 525 | I. 529 | I. 536 |
| Hydromagnesite | $4 \mathrm{MgO} .3 \mathrm{CO}_{2.4} \mathrm{H}_{2} \mathrm{O}$ | I. 527 | I. 530 | I. 540 |
| Wavellite.... | $3 \mathrm{Al}_{2} \mathrm{O}_{3.2} \mathrm{P}_{2} \mathrm{O}_{5.1} 2\left(\mathrm{H}_{2} \mathrm{O}, 2 \mathrm{HF}\right)$ | I. 525 | I. 534 | I. 552 |
| Kieserite. | $\mathrm{MgO} . \mathrm{SO}_{3} . \mathrm{H}_{2} \mathrm{O}$ | I. 523 | I. 535 | 1.586 |
| Copiapite. | ${ }_{2} \mathrm{Fe}_{2} \mathrm{O}_{3.5} \mathrm{SO}_{3.1} 88 \mathrm{H}_{2} \mathrm{O}$ | I. 530 | I. 543 | 1.595 |
| Whewellite | $\mathrm{CaO} . \mathrm{C}_{2} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 49 I | I. 555 | 1.650 |
| Variscite.. | $\mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{P}_{2} \mathrm{O}_{5.4} \mathrm{H}_{2} \mathrm{O}$ | 1.551 | I. 558 | 1. 582 |
| Labradorite | $\mathrm{Ab}_{2} \mathrm{An}_{3}$ | 1.559 | I. 563 | I. 568 |
| Gibbsite.. | $\mathrm{Al}_{2} \mathrm{O}_{3} \cdot 3 \mathrm{H}_{2} \mathrm{O}$ | I. 566 | I. 566 | 1.587 |
| Wagnerite. | $3 \mathrm{MgO} . \mathrm{P}_{2} \mathrm{O}_{5} \cdot \mathrm{MgF}_{2}$ | I. 569 | 1. 570 | 1.582 |
| Anhydrite. | $\mathrm{CaO} . \mathrm{SO}_{3}$ | 1. 57 I | I. 576 | 1.614 |
| Colemanite. | ${ }_{2} \mathrm{CaO} .3 \mathrm{~B}_{2} \mathrm{O}_{3.5} \mathrm{H}_{2} \mathrm{O}$ | I. 586 | I. 592 | 1.614 |
| Fremontite. | $\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{P}_{2} \mathrm{O}_{5} .\left(\mathrm{H}_{2} \mathrm{O}, 2 \mathrm{HF}\right)$ | 1. 594 | 1.603 | I. 6I 5 |
| Vivianite. | $3 \mathrm{FeO} . \mathrm{P}_{2} \mathrm{O}_{5} .8 \mathrm{H}_{2} \mathrm{O}$ | 1. 579 | 1.603 | 1.633 |
| Pectolite. | $\mathrm{Na}_{2} \mathrm{O} \cdot 4 \mathrm{CaO} .6 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 595 | 1.606 | 1.634 |
| Calamine... | ${ }_{2} \mathrm{ZnO} . \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 614 | I. 617 | 1. 636 |
| Chondrodite. | $4 \mathrm{MgO} .2 \mathrm{SiO}_{2} \cdot \mathrm{Mg}(\mathrm{F}, \mathrm{OH})_{2}$ | 1. 609 | I. 619 | 1. 639 |
| Turquois. | $\mathrm{CuO} .3 \mathrm{Al}_{2} \mathrm{O}_{3.2} \mathrm{P}_{2} \mathrm{O}_{5.9} \mathrm{H}_{2} \mathrm{O}$ | 1.610 | 1.620 | r. 650 |
| Topaz. | ${ }_{2} \mathrm{AlOF} . \mathrm{SiO}_{2}$ | 1.619 | 1.620 | 1.627 |
| Celestite. | $\mathrm{SrO} . \mathrm{SO}_{3}$ | 1.622 | I. 624 | 1.631 |
| Prehnite. | ${ }_{2} \mathrm{CaO} . \mathrm{Al}_{2} \mathrm{O}_{3.3} \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 616 | 1.626 | 1.649 |
| Barite. | $\mathrm{BaO}^{\mathrm{SO}_{3}}$ | 1.636 | 1.637 | 1.648 |
| Anthophyllite | $\mathrm{MgO} . \mathrm{SiO}_{2}$ | 1.633 | I. 642 | 1.657 |
| Sillimanite... | $\mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{SiO}_{2}$ | I. 638 | 1.642 | 1.653 |
| Forsterite. | ${ }_{2} \mathrm{MgO} . \mathrm{SiO}_{2}$ | 1.635 | I. 651 | 1.670 |
| Enstatite | $\mathrm{MgO} . \mathrm{SiO}_{2}$ | 1.650 | 1.653 | 1.658 |
| Euclasite | ${ }_{2} \mathrm{BeO} . \mathrm{Al}_{2} \mathrm{O}_{3.2} \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 652 | I. 655 | 1.671 |
| Triplite. | $3 \mathrm{MnO} . \mathrm{P}_{2} \mathrm{O}_{5} \cdot \mathrm{MnF}_{2}$ | 1.650 | 1.660 | 1.672 |
| Spodumenite | $\mathrm{Li}_{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 4 \mathrm{SiO}_{2}$ | I. 660 | I. 666 | 1.676 |
| Diopside. | $\mathrm{CaO} . \mathrm{MgO} .2 \mathrm{SiO}_{2}$ | I. 664 | 1.671 | I. 694 |
| Olivine... | ${ }_{2}(\mathrm{Mg}, \mathrm{Fe}) \mathrm{O}^{2} \mathrm{SiO}_{2}$ | I. 662 | I. 680 | 1.699 |
| Triphylite... | $\mathrm{Li2}_{2} \mathrm{O} .2(\mathrm{Fe}, \mathrm{Mn}) \mathrm{O} . \mathrm{P}_{2} \mathrm{O}_{5}$ | 1.688 | I. 688 | 1.692 |

INDEX OF REFRACTION.
Selected Biaxial Minerals.

| Mineral. | Formula. | Index of refraction. |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | ${ }^{n}$ | ${ }^{\prime} \beta$ | $n \gamma$ |
| (a) Blaxial Positive Minerals (continued). |  |  |  |  |
| ${ }_{\text {Zoisite }}{ }_{\text {Z }}^{\text {Strengite }}$ |  | I. 700 1.710 | $\xrightarrow{\text { I. } 702} \mathrm{~T}$ | I. 706 |
| Diasporite. | ${ }^{\mathrm{Al}_{2} \mathrm{O}_{3} \mathrm{H}_{3} \mathrm{H}_{2} \mathrm{O}}$ | 1.7102 | (1.710 | - $\begin{aligned} & \text { '1. } 745 \\ & \text { I. } 750 \\ & 1 .\end{aligned}$ |
| Staurolite... Chrysoberyl | ${ }_{\mathrm{Cb}}^{2 \mathrm{FeO} .5 .5 \mathrm{Al}_{2} \mathrm{O}_{3} .4 \mathrm{SiO}_{2} . \mathrm{H}_{2} \mathrm{O}}$ | I. 736 | 1.74i | I. 746 |
| Azurite.... | ${ }_{3} \mathrm{CuO} . \mathrm{A}_{2} \mathrm{CO}_{2} . \mathrm{H}_{2} \mathrm{O}$ |  | I. 748 | I. 757 I. 838 1.88 |
| Scorodite | $\mathrm{Fe}_{2} \mathrm{O}_{3} \mathrm{As}_{2} \mathrm{O}_{5} .4 \mathrm{H}_{2} \mathrm{O}$ | 1.765 | r. 774 | 1. 797 |
| Olivenite. |  | I. 772 I 877 1.872 |  | 1.863 <br> I. 804 <br> 1.858 |
| Titanite.. | $\mathrm{CaO} \cdot \mathrm{TiO}_{2} \cdot \mathrm{SiO}_{2}$ | 1.900 | I. 907 | 2.034 |
| Claudetite | $\mathrm{As}_{2} \mathrm{O}_{3}$ | 1.871 | 1.920 | 2.010 |
| Sulfur.... |  | 1.950 | 2.043 | 2.240 |
| Cotunnite. | ${ }_{\text {MnO. }}^{\mathrm{PbCl}_{2}}$ |  | 2.217 2.220 | 2.260 2.320 |
| Manganite. | $\mathrm{Mn}_{2} \mathrm{O}_{3} \mathrm{H}_{2} \mathrm{O}$ | $2.170^{\circ}$ 2.240 | 2.220 2.240 | ${ }_{2.530}^{2.320}$ ( Li) |
| Raspite. | $\mathrm{PbO} \mathrm{WO}_{3}$ | 2.270 | 2.270 2.2 | ${ }_{2.300}$ |
| Mendipite. | ${ }_{2} \mathrm{PbO}^{2} \mathrm{PbCl}{ }_{2}$ | 2.240 | ${ }^{2.270}$ | 2.310 |
| Tantalite. | ( $\mathrm{Fe}, \mathrm{Mn}$ ) $\mathrm{O} . \mathrm{Ta}_{2} \mathrm{O}_{5}$ | 2.260 | 2.320 | 2.430 (Li) |
| Wolframite | $(\mathrm{Fe}, \mathrm{Mn}) \mathrm{O} . \mathrm{WO}_{3}$ | 2.310 | 2.360 | 2.460 (Li) |
| Crocoite. | $\mathrm{PbO} . \mathrm{CrO}_{3}$ | 2.310 | 2.370 | 2.660 (Li) |
| Pseudobrookite | ${ }_{2} \mathrm{Fe}_{2} \mathrm{O}_{3} .3 \mathrm{TiO}_{2}$ | 2.380 | ${ }^{2} .390$ | 2.420 (Li) |
| Stibiotantalite Montroydite. |  | 2.374 2.370 | 2.404 <br> 2.500 <br> 2.5 | 2.457 2.650 (Li) |
| Brookite... |  | $\begin{array}{r}2.378 \\ 2.583 \\ \hline\end{array}$ | 2. 2.586 | ${ }_{2.74 \mathrm{I}}^{2.650}$ |
| Lithargite. | PbO | 2.510 | 2.610 | 2.710 |

(b) Biaxial Negative Minerals.

| Mirabilite. | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{SO}_{3.1} \mathrm{IOH}_{2} \mathrm{O}$ | 1.394 | 1. 396 | 1. 398 |
| :---: | :---: | :---: | :---: | :---: |
| Thomsenolite. | $\mathrm{NaF} . \mathrm{CaF}_{2} \cdot \mathrm{AlF}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1. 407 | 1.414 | 1.415 |
| Natron | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{CO}_{2} .10 \mathrm{H}_{2} \mathrm{O}$ | 1.405 | 1. 425 | I. 440 |
| Kalinite | $\mathrm{K}_{2} \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} .4 \mathrm{SO}_{3.24} \mathrm{H}_{2} \mathrm{O}$ | 1.430 | 1.452 | I. 458 |
| Epsomite | $\mathrm{MgO} . \mathrm{SO}_{3.7} \mathrm{H}_{2} \mathrm{O}$ | I. 433 | I. 455 | 1.46r |
| Sassolite. | $\mathrm{B}_{2} \mathrm{O}_{3} . \mathrm{H}_{2} \mathrm{O}$ | 1.340 | 1.456 | 1. 459 |
| Borax | $\mathrm{Na}_{2} \mathrm{O} .2 \mathrm{~B}_{2} \mathrm{O}_{3} .10 \mathrm{H}_{2} \mathrm{O}$ | I. 447 | 1.470 | I. 472 |
| Goslarite | $\mathrm{ZnO} . \mathrm{SO}_{3.7} \mathrm{H}_{2} \mathrm{O}$ | 1.457 | 1. 480 | 1.484 |
| Pickeringite | $\mathrm{MgO} . \mathrm{Al}_{2} \mathrm{O}_{3.4} \mathrm{SO}_{3.2} \mathrm{H}_{2} \mathrm{O}$ | 1.476 | 1.480 | 1. 483 |
| Bloedite... | $\mathrm{Na} 2 \mathrm{O} . \mathrm{MgO} .2 \mathrm{SO}_{3.4} \mathrm{H}_{2} \mathrm{O}$ | I. 486 | 1.488 | 1.489 |
| Trona. | ${ }_{3} \mathrm{Na}_{2} \mathrm{O} .4 \mathrm{CO}_{2} .5 \mathrm{H}_{2} \mathrm{O}$ | 1.410 | I. 492 | 1. 542 |
| Thermonatrite | $\mathrm{Na}_{2} \mathrm{O} \cdot \mathrm{CO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.420 | I. 495 | 1. 518 |
| Stilbite.... | $\left(\mathrm{Ca}, \mathrm{Na}_{2}\right) \mathrm{O} . \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2} .5 \mathrm{H}_{2} \mathrm{O}$ | I. 494 | I. 498 | I. 500 |
| Niter. | $\mathrm{K}_{2} \mathrm{O} \cdot \mathrm{N}_{2} \mathrm{O}_{5}$ | I. 334 | 1.505 | I. 506 |
| Kainite | MgO. $\mathrm{SO}_{3} . \mathrm{KCl} .3 \mathrm{H}_{2} \mathrm{O}$ | I. 494 | I. 505 | 1. 516 |
| Gaylussite | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{CaO} .2 \mathrm{CO}_{2.5} \mathrm{H}_{2} \mathrm{O}$ | 1.444 | 1.516 | 1. 523 |
| Scolecite. | $\mathrm{CaO} . \mathrm{Al}_{2} \mathrm{O}_{3} .3 \mathrm{SiO}_{2.3} \mathrm{H}_{2} \mathrm{O}$ | 1.512 | 1. 519 | 1. 519 |
| Laumontite | $\mathrm{CaO} . \mathrm{Al}_{2} \mathrm{O}_{3} .4 \mathrm{SiO}_{2.4} \mathrm{H}_{2} \mathrm{O}$ | 1.513 | 1.524 | 1. 525 |
| Orthoclase. | $\mathrm{K}_{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2}$ | I. 518 | I. 524 | 1. 526 |
| Microcline. | Same as preceding | I. 522 | I. 526 | I. 530 |
| Anorthoclase | $(\mathrm{Na}, \mathrm{K})_{2} \mathrm{O} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2}$ | 1. 523 | I. 529 | I. 531 |
| Glauberite . | $\mathrm{Na}_{2} \mathrm{O} . \mathrm{CaO} .2 \mathrm{SO}_{3}$ | 1.515 | 1. 532 | 1. 536 |
| Cordierite. | $4(\mathrm{Mg}, \mathrm{Fe}) \mathrm{O} .4 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 10 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1. 534 | 1. 538 | 1. 540 |
| Chalcanthite | $\mathrm{CuO} . \mathrm{SO}_{3} .5 \mathrm{H}_{2} \mathrm{O}$ | 1.516 | 1. 539 | I. 546 |
| Oligoclase. . | $\mathrm{Ab}_{4} \mathrm{An}$ | 1. 539 | I. 543 | I. 547 |

INDEX OF REFRACTION.

## Selected Biaxial Minerals.

| Mineral. | Formula. | Index of refraction. |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  | $n a$ | ${ }^{n} \boldsymbol{\beta}$ | ${ }^{n} \gamma$ |
| (b) Biaxial Negative Crystals (continued). |  |  |  |  |
| Beryllonite. | $\mathrm{Na}_{2} \mathrm{O} .2 \mathrm{BeO} . \mathrm{P}_{2} \mathrm{O}_{5}$ | 1.552 | 1. 558 | 1. 56 x |
| Kaolinite. | $\mathrm{Al}_{2} \mathrm{O}_{3.2} \mathrm{SiO}_{2.2} \mathrm{H}_{2} \mathrm{O}$ | I. 561 | 1. 563 | 1. 565 |
| Biotite. | $\mathrm{K}_{2} \mathrm{O} .4(\mathrm{Mg}, \mathrm{Fe}) \mathrm{O} .2 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 6 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 54 I | I. 574 | 1. 574 |
| Autunite. | $\mathrm{CaO} .2 \mathrm{UO}_{3} . \mathrm{P}_{2} \mathrm{O}_{5} .8 \mathrm{H}_{2} \mathrm{O}$ | I. 553 | I. 575 | 1.577 |
| Anorthite | $" \mathrm{An} "=\mathrm{CaO} \cdot \mathrm{Al}_{2} \mathrm{O}_{3} \cdot 2 \mathrm{SiO}_{2}$ | 1. 576 | I. 584 | 1. 588 |
| Lanthanite. | $\mathrm{La}_{2} \mathrm{O}_{3.3} \mathrm{CO}_{2.9} \mathrm{H}_{2} \mathrm{O}$ | I. 520 | 1.587 | 1.613 |
| Pyrophyllite | $\mathrm{Al}_{2} \mathrm{O}_{3.4} \mathrm{SiO}_{2} . \mathrm{H}_{2} \mathrm{O}$ | I. 552 | I. 588 | I. 600 |
| Talc .... | $3 \mathrm{MgO} .4 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 539 | I. 589 | 1.589 |
| Hopeite. | $3 \mathrm{ZnO} . \mathrm{P}_{2} \mathrm{O}_{5.4} 4 \mathrm{H}_{2} \mathrm{O}$ | 1. 572 | I. 590 | 1. 590 |
| Muscovite | $\mathrm{K}_{2} \mathrm{O} .3 \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2.2} \mathrm{H}_{2} \mathrm{O}$ | 1.561 | I. 590 | I. 594 |
| Amblygonite | $\mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{P}_{2} \mathrm{O}_{5.2} \mathrm{LiF}$ | 1.579 | 1.593 | I. 597 |
| Lepidolite... | $\mathrm{Al}_{2} \mathrm{O}_{3.3} \mathrm{SiO}_{2.2}(\mathrm{~K}, \mathrm{Li}) \mathrm{F}$ | 1. 560 | I. 598 | $\underline{1.605}$ |
| Phlogopite. | $\mathrm{K}_{2} \mathrm{O} .6 \mathrm{MgO} . \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2.2} \mathrm{H}_{2} \mathrm{O}$ | 1. 562 | I. 606 | 1.606 |
| Tremolite. | $\mathrm{CaO} .3 \mathrm{MgO} .4 \mathrm{SiO}_{2}$ | 1.609 | 1.623 | 1.635 |
| Actinolite. | $\mathrm{CaO} .3(\mathrm{Mg}, \mathrm{Fe}) \mathrm{O} .4 \mathrm{SiO}_{2}$ | 1.6II | 1.627 | I. 636 |
| Wollastonite | $\mathrm{CaO} . \mathrm{SiO}_{2}$ | 1.616 | 1.629 | 1.63 I |
| Lazulite. | ( $\mathrm{Fe}, \mathrm{Mg}$ ) O. $\mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{P}_{2} \mathrm{O}_{5} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.603 | 1.632 | 1.639 |
| Danburite . | $\mathrm{CaO} . \mathrm{B}_{2} \mathrm{O}_{3.2} \mathrm{SiO}_{2}$ | 1.632 | 1.634 | 1. 636 |
| Glaucophanite | $\mathrm{Na}_{2} \mathrm{O} .2 \mathrm{FeO} . \mathrm{Al}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2}$ | 1.621 | 1.638 | 1.638 |
| Andalusite. | $\mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{SiO}_{2}$ | 1.632 | 1.638 | 1.643 |
| Hornblende | Contains $\mathrm{Na}_{2} \mathrm{O}, \mathrm{MgO}, \mathrm{FeO}, \mathrm{SiO}_{2}$, etc. | 1. 629 | I. 642 | I. 653 |
| Datolite. | ${ }_{2} \mathrm{CaO} .2 \mathrm{SiO}_{2} \cdot \mathrm{~B}_{2} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.625 | 1.653 | 1. 669 |
| Erythrite. | $3 \mathrm{CoO} . \mathrm{As}_{2} \mathrm{O}_{5} .8 \mathrm{H}_{2} \mathrm{O}$ | 1.626 | 1.661 | 1. 699 |
| Monticellite. | CaO. MgO. $\mathrm{SiO}_{2}$ | 1.651 | 1. 662 | 1. 668 |
| Strontianite. | $\mathrm{SrO}^{\text {CO }} \mathrm{CO}_{2}$ | 1. 520 | 1. 667 | 1. 667 |
| Witherite. | $\mathrm{BaO} . \mathrm{CO}_{2}$ | 1. 529 | 1.676 | 1. 677 |
| Aragonite. | $\mathrm{CaO} . \mathrm{CO}_{2} \mathrm{Cl}$ | 1.53 I | 1.682 | 1.686 |
| Axinite..... | $6(\mathrm{Ca}, \mathrm{Mn}) \mathrm{O} .2 \mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{~B}_{2} \mathrm{O}_{3} .8 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.678 | 1.685 | I. 688 |
| Dumortierite. | $8 \mathrm{Al}_{2} \mathrm{O}_{3} . \mathrm{B}_{2} \mathrm{O}_{3} .6 \mathrm{SiO}_{2} . \mathrm{H}_{2} \mathrm{O}$ | 1. 678 | 1.686 | 1.689 |
| Cyanite. | $\mathrm{Al}_{2} \mathrm{O}_{3} \cdot \mathrm{SiO}_{2}$ ( ${ }^{\text {a }}$ | 1.712 | 1.720 | 1.728 |
| Epidote. | $4 \mathrm{CaO} .3(\mathrm{Al}, \mathrm{Fe})_{2} \mathrm{O}_{3} \cdot 6 \mathrm{SiO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | I. 729 | 1.754 | 1.768 |
| Atacamite | $3 \mathrm{CuO} . \mathrm{CuCl}_{2.3} \mathrm{H}_{2} \mathrm{O}$ | 1.83 I | 1.861 | 1.880 |
| Fayalite. . | ${ }_{2} \mathrm{FeO} . \mathrm{SiO}_{2}$ | I. 824 | 1.864 | x. 874 |
| Caledonite | ${ }_{2}(\mathrm{~Pb}, \mathrm{Cu}) \mathrm{O} . \mathrm{SO}_{3} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.818 | 1.866 | 1.909 |
| Malachite. | ${ }_{2} \mathrm{CuO} . \mathrm{CO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.655 | 1.875 | 1.909 |
| Lanarkite. | ${ }_{2} \mathrm{PbO} . \mathrm{SO}_{3}$ | 1.930 | 1.990 | 2.020 |
| Leadhillite | ${ }_{4} \mathrm{PbO} . \mathrm{SO}_{3.2} \mathrm{CO}_{2} \cdot \mathrm{H}_{2} \mathrm{O}$ | 1.870 | 2.000 | 2.010 |
| Cerussite. | ${ }^{\mathrm{PbO}} \mathrm{CO}_{2}$ | 1.804 | 2.076 | 2.078 |
| Laurionite | $\mathrm{PbCl}_{2} \cdot \mathrm{PbO} \cdot \mathrm{H}_{2} \mathrm{O}$ | 2.077 | 2.116 | 2.158 |
| Matlockite. | PbO. $\mathrm{PbCl}_{2}$ | 2.040 | 2.150 | 2.150 |
| Baddeleyite.. | $\mathrm{ZrO}_{2}$ | 2.130 | 2.190 | 2.200 |
| Lepidocrocite. | ${ }_{2} \mathrm{Fe}_{2} \mathrm{Fe}_{2} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O} \mathrm{H}_{2} \mathrm{O}$ in part | 1.930 | 2.210 | 2.510 |
| Limonite. | ${ }_{2} \mathrm{Fe}_{2} \mathrm{Fe}_{3} \mathrm{O}_{3} \cdot \mathrm{H}_{2} \mathrm{O} \mathrm{O}$ | 2.170 | 2.290 | 2.310 (i) |
| Valentinite. | ${ }^{\mathrm{Sb}_{2} \mathrm{O}_{3}}$ | 2.210 2.180 | 2.350 2.350 | $2.350(\mathrm{Li})$ 2.350 |
| Turgite. | ${ }_{2} \mathrm{Fe}_{2} \mathrm{O}_{3} . \mathrm{H}_{2} \mathrm{O}$ in part | 2.450 | 2.550 |  |
| Realgar.... | AsS | 2.460 | 2.590 | $2.610(\mathrm{Li})$ |
| Terlinguaite. . | $\mathrm{Hg}_{2} \mathrm{OCl}$ | 2.350 | 2.640 | $2.670(\mathrm{Li})$ |
| Hutchinsonite | $(\mathrm{Tl}, \mathrm{Ag})_{2} \mathrm{~S} . \mathrm{PbS} .2 \mathrm{As}_{2} \mathrm{~S}_{3}$ | 3.078 | 3.176 | 3.188 |
| Stibnite. . | $\mathrm{Sb}_{2} \mathrm{~S}_{3}$ | 3.194 | 4.303 | 4.460 |

INDEX OF REFRACTION.
TABLE 344. - Miscellaneous Biaxial Crystals.

| Crystal. | Spectrum line. | Index of refraction. |  |  | Authority |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $n_{a}$ | ${ }^{n} \beta$ | ${ }^{n} \gamma$ |  |
| Ammonium oxalate, $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{C}_{2} \mathrm{O}_{4} \cdot \mathrm{H}_{2} \mathrm{O} \ldots$ Ammonium acid tartrate, | D | 1.4381 | 1.5475 | 1. 5950 | Brio |
| $\left(\mathrm{NH}_{4}\right) \mathrm{H}\left(\mathrm{C}_{4} \mathrm{H}_{4} \mathrm{O}_{6}\right) \ldots \ldots{ }^{\text {a }}$ | D | 1. 5188 | 1.5614 |  | T. and C.* |
|  | D | - | I. 581 | 1. 59. | Cloisaux |
| Citric acid, $\mathrm{C}_{6} \mathrm{H}_{8} \mathrm{O}_{7} . \mathrm{H}_{2} \mathrm{O}$ | D | 1.5697 1. 4932 | 1. 6935 | 1.7324 | Liweh |
| Codein, $\mathrm{C}_{18} \mathrm{H}_{2} \mathrm{NO}_{3} \mathrm{H}_{2} \mathrm{O}$ | D | 1. 4932 1. 5390 | 1. 4977 | 1. 5089 | Schrauf |
| Magnesium carbonate, $\mathrm{MgCO}_{3} 3.3 \mathrm{H}_{2} \mathrm{O} \ldots$. . | D | 1.5390 1. 495 | 1.5435 1. 501 | 1. $\overline{526}$ | Grailich |
| "، sulphate, $\mathrm{MgSO}_{4.7} 7 \mathrm{H}_{2} \mathrm{O} \ldots$. | D | 1. 432 | 1. 455 | 1.461 | Means |
| " | Cd, $0.226 \mu$ | 1. 4990 | 1. 5266 | 1. 5326 | Borel |
|  | H, ${ }_{\text {D }}{ }^{\text {O }}$ | 1. 4307 1. 7202 | 1. 4532 | 1. 4584 |  |
| " chromate, $\mathrm{K}_{2} \mathrm{CrO}_{4}$. | D | 1.7202 | 1.7380 1.7254 | 1.8197 | Dufet |
| " | red | 1.6873 | 1.722 | 1. 7305 | Mallard |
|  | D | I. 3346 | 1. 5056 | 1.5064 | Schrauf |
| "، "،.................... | D | 1. 4976 1.4932 | 1. 4992 | 1.5029 | T. and C. |
| Racemic acid, $\mathrm{C}_{4} \mathrm{H}_{6} \dddot{O}_{6} \dddot{\mathrm{H}}_{2} \dddot{O}^{\circ}$ | $\stackrel{C}{\text { yellow }}$ | I. 4911 | 1. 494928 | 1. 4980 | " ." " |
|  | yellow |  | 1. 526 |  | Groth |
| Sodium bichromate, $\mathrm{Na}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} 2 \mathrm{H}_{2} \mathrm{O} \ldots \ldots$ | D | 1.6610 | 1. 555 | - | Dufet |
| " acid tartrate, $\mathrm{NaH}\left(\mathrm{C}_{4} \mathrm{H}_{4} \mathrm{O}_{6}\right) .2 \mathrm{H}_{2} \mathrm{O}$ | red | 1.6610 | 1.6994 I. 5332 | 1.7510 | Dufet Brio |
| Sugar (cane), $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11} \ldots \ldots \ldots \ldots$. | Tl | 1. 5422 | 1. 5685 | 1. 5734 | Calderon |
| " ، | $\mathrm{Li}_{\mathrm{L}}$ | 1. 5397 | I. 5667 | 1. 57116 |  |
|  | ${ }_{\text {Di }}$ | 1. 5379 I. 4953 | 1. 5639 I. 5353 | I. 5693 | " |
| Zinc sulphate, $\mathrm{ZnSO}_{4.7} \mathrm{H}_{2} \mathrm{O} \ldots \ldots . . . . . .$. | $\stackrel{\text { F }}{ }$ | 1.4353 1.4620 | 1.5353 1. 4860 | I. 6046 I. 4897 | Means ${ }_{\text {T and }}$ |
| " " | ${ }_{\text {D }}^{\text {D }}$ | 1. 4568 | 1. 4801 | 1. r 4836 r | ": " " |
|  |  | 1.4544 | 1.4776 | 1. 4812 | " " " |
| * Topsöe and Christiansen. |  |  |  |  |  |

TABLE 345. - Miscellaneous Liquids (see also Table 346), Liquefied Gases, Oils, Fats and Waxes.

| Substance. | $\underset{\circ}{\text { Temp. }}$ | Index for D o. $589 \mu$. | Reference. | Substance. | $\stackrel{\text { Temp. }}{\stackrel{\mathrm{C}}{2}}$ | Index for D -. $589 \mu$. | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Liquefied gases: |  |  |  | Oils: |  |  |  |
|  | 15 | 1.659 | a | Lavendar | 20 | 1. $46{ }^{-1}$ - 466 | e |
| $\mathrm{Cl}_{2}$ | 14 | 1. 367 | b | Linseed | 15 | I. $4820-\mathrm{I} .485{ }^{2}$ | e |
| $\mathrm{CO}_{2}$ | 15 | 1.195 1.325 | b | Maize. ${ }^{\text {Mrast }}$. | 15.5 15.5 | 1. $4757-\mathrm{I} .4768$ | d |
| $\mathrm{C}_{2} \mathrm{~N}_{2}$ | 18 | 1.325 | b | Mustard seed | 15.5 | 1.4750-1.4762 | d |
| $\mathrm{C}_{2}{ }^{2}$ | 6 | I. 180 | b | Neat's foot | 15 | 1.4695-1.4708 | e |
| $\mathrm{H}_{2} \mathrm{~N}_{2}$ | ${ }^{18.5}$ | 1.384 I .205 | b | Olive | 15.5 | 1.4703-1.4718 | d |
| $\mathrm{NH}_{3}$ | 16.5 | I. 325 | b | Peanut | 15.5 | 1.4723-1.4731 | d |
| NO. | -90 | I. 330 | c | Peppermin | 20 | I. 464-1.468 | e |
| $\mathrm{N}_{2} \mathrm{O}$ | 15 | 1. 194 | b | Poppy | 15.5 | 1.4770 | d |
| $\mathrm{O}_{2}$ | -181 | 1.221 | c | Porpoise | 25 | I. 4677 | e |
| $\mathrm{SO}_{2}$ | 15. | I. 350 | b | Rape (Colza) | 15.5 | 1.4748-1.4752 | d |
| HCl | 16.5 | 1. 252 | b | Seal. | 25 | 1.4741 | e |
| HBr | 10 | I. 325 | b | Sesame | 15.5 | 1. 4742 | d |
|  | 16.5 | I. 466 | b | Soja bea | 15.5 | 1.4760-1. 4775 | e |
| Oils: |  |  |  | Sperm | 15.5 | 1.4665-1.4672 | e |
| Almond | 15.5 | 1.4728-1.4753 | d | Sunflow | 15.5 | I. 4739 | d |
| Castor. | 15 | 1.4799-1.4803 | e | Tung. | 19 | I. 503 | e |
| Citronella | 20 | 1.47-1.48 | e | Whale | 40 | I. 4649 | e |
| Clove. | 20 | 1.5301-1. 5360 | e | Fats and Waxes: |  |  |  |
| Cocoanut. | 15.5 | I. 4587 | d | Beef tallow | 40 | I. $4552-\mathrm{I} \cdot 4587$ | e |
| Cod liver. | 15 | 1.4790-1. 4833 | e | Beeswax | 75 | I. 4398 -1. 4451 | e |
| Cotton seed. . | 15.5 | 1.4737-1.4757 | d | Carnauba wax | 84 | 1.4520-1.4541 | e |
| Croton. . . . | 27 | 1.4757-1.4768 | e | Cocoa butter. | 40 | I. $4560-\mathrm{I} .4518$ | e |
| Lard....... . | 20 | I. $460-1.467$ | ${ }_{\text {d }}$ | Lard... | 40 | 1. $4584^{-1.1} .4601$ | ${ }_{\text {e }}$ |
| Lard | 15.5 | 1.4702-1.4720 |  | Mutton | 60 | 1.4510 | e |
| References: (a) Martens; (b) Bleekrode, Pr. Roy. Soc. 37, 339, 1884; (c) Liveing. Dewar, Phil. Mag; 1892-3; (d) Tolman, Munson, Bul. 77, B. of C., Dept. Agriculture, 1905; (e) Seeker, Van Nostrand's Chemical Annual. For the oils of reference d, the average temperature coefficient is $0.000365^{\circ}$ per ${ }^{\circ} \mathrm{C}$. |  |  |  |  |  |  |  |

Indices of Refraction of Liquids Relative to Air.


References: r, Landolt and Börnstein (a, Landolt; b, Korten; c, Brühl; d, Haagen; e, Landolt, Jahn; f, Nasini, Bernheimer; g, Eisenlohr; h, Eykman; i, Auwers, Eisenlohr); 2, Korten; 3, Walter; 4, Ketteler; 5, Landolt; 6, Olds; 7, Baden Powell; 8, Willigen; 9, Fraunhofer; 10, Brühl.

Indices of Refraction relative to Air for Solutions of Salts and Acids.


## INDEX OF REFRACTION.

## Indices of Refraction of Gases and Vapors.

A formula was given by Biot and Arago expressing the dependence of the index of refraction of a gas on pressure and temperature. More recent experiments confirm their conclusions. The formula is $n_{t}-1=\frac{n_{0}-\mathrm{r}}{1+a t} \frac{p}{760}$, where $n_{t}$ is the index of refraction for temperature $t, n_{0}$ for temperature zero, a the coefficient of expansion of the gas with temperature, and $\phi$ the pressure of the gas in millimeters of mercury. For air see l'able 349.

| (a) Indices of refraction. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Spectrum line. | $\begin{gathered} 11^{3}(\mathrm{n}-1) \\ \text { Air. } \end{gathered}$ |  | Spectrum line. | $\begin{gathered} 10^{3}(\mathrm{n}-1) \\ \text { Air. } \end{gathered}$ | Wavelength. | $(\mathrm{n}-1){ }_{10}{ }^{3}$. |  |  |  |
|  |  |  | Air. |  |  | O. | N. | H. |
| A |  |  |  | M | . 2993 | ${ }^{\mu}{ }^{4} 61$ | . 2951 | . 2734 | -3012 | . 1406 |
| B | .291I |  | N | . 3003 | . 5461 | . 2936 | . 2717 | - . 2998 | . 1397 |
| C | . 2914 |  | 0 | . 3015 | . 5790 | . 2930 | . 2710 |  | . 1393 |
| D | . 2912 |  | P | 3023 | . 6563 | . 2919 | . 2698 | . 2982 | . 1387 |
| E | . 2933 |  | Q | -303I | . 4360 | . 2971 | . 2743 | $\mathrm{CO}_{2}$ | . 1418 |
| F | . 2943 |  | R | - 3043 | . 5462 | . 2937 | . 2704 | . 4506 | . 1397 |
| G | . 2962 |  | S | $\begin{aligned} & .3053 \\ & .3064 \\ & .3075 \end{aligned}$ | $\begin{aligned} & .6709 \\ & 6.709 \\ & 8.678 \\ & \hline \end{aligned}$ | .2918 | . 2683 | . 447 I | . 1385 |
| H | . 29 |  | T |  |  | .2881 | . 2643 | . 4804 | .1361 |
| K | $\begin{array}{r} .2980 \\ .2987 \end{array}$ |  | U |  |  | . 2888 | . 2650 | .4579 | . 1361 |
|  |  |  | First 4, Cuthbertsons; the rest, Koch, 1909. |  |  |
| (b) The following are compiled mostly from a table published by Brühl (Zeits. für Phys. Chem. vol. 7, pp. 25-27). The numbers are from the results of experiments by Biot and Arago, Dulong, Jamin, Ketteler, Lorenz, Mascart, Chappius, Rayleigh, and Rivière and Prytz. When the number given rests on the authority of one observer the name of that observer is given. The values are for $0^{\circ}$ Centigrade and 760 mm . pressure. |  |  |  |  |  |  |  |  |  |
| Substance. |  | Kind of light. |  | Indices of refraction and authority. |  | Substance. |  | Kind of light. | Indices of refraction and authority. |  |
| Acetone Ammonia <br> Argon . <br> Benzene |  | $\begin{gathered} \text { D } \\ \text { white } \\ \text { D } \\ \text { D } \\ \text { D } \end{gathered}$ | 1.001079-1.001100 |  | Hydrogen . . |  | white | $1.000138-1.000143$ |  |
|  |  | 1.000381-1.000385 | Hydrogen ${ }^{\text {c }}$ - |  | $\begin{aligned} & \mathrm{D} \\ & \mathrm{D} \end{aligned}$ | 1.000132 Burton. |  |
|  |  | 1.000373-1.000379 | Hydrogen sul-phide . |  |  | 1.000644 Dulong. 1.000623 Mascart. |  |
|  |  | I.000281 Rayleigh. <br> 1.001700-1.001823 |  |  |  |  |  |
|  |  | Methane . . . |  |  | white | 1.000443 Dulong. |  |
| Bromine Carbon dioxide " " |  |  |  | D | I. 001132 Mascart. |  | " . . . |  | DDD | 1.000444 Mascart. |  |
|  |  | white | $\begin{aligned} & 1.000449-1.000450 \\ & 1.000448-1.000454 \end{aligned}$ |  | Methyl alcohol. |  | 1.000549-1.000623 |  |  |
|  |  | D |  |  | Methyl ether .Nitric oxide . |  | I.000891 Mascart. <br> 1.000303 Dulong. <br> 1.000297 Mascart. |  |  |
| $\begin{aligned} & \text { Carbon disul- } \\ & \text { phide } . \end{aligned}$ |  | white | I. 001500 Dulong. <br> 1.001478-1.001485 |  |  |  | $\begin{gathered} \mathrm{D} \\ \text { white } \\ \mathrm{D} \end{gathered}$ |  |
|  |  | D |  |  | $\mathrm{Nitric}_{6}{ }_{6}{ }_{6}$. . |  |  |  |
| $\begin{aligned} & \text { Carbon mon- } \\ & \text { oxide . } \end{aligned}$ |  | white | 1.000340 Dulong. I. 000335 Mascart. |  | Nitrogen . . . |  | white | $1.000295-1.000300$ |  |
|  |  | white |  |  |  |  |  |  |  |  |  |  |  |
| Chlorine |  | white | I. 000772 Dulong. I. 000773 Mascart. |  | $\underset{\text { Nitrous oxide . }}{6}$. |  | white D | 1.000503-1.000507 <br> i. 000516 Mascart |  |
|  |  | D |  |  |  |  |  |  |  |  |  |  |  |
| Chlorofo |  | D | 1.001436-1.001 464 |  | Oxygen |  | white | 1.000272-1.000280 |  |
| Cyanoge |  | white | I.000834 Dulong. <br> 1.000784-1.000825 |  | Pentane |  | $\begin{aligned} & \mathrm{D} \\ & \mathrm{D} \end{aligned}$ | $1.000271-1.000272$1.001711 Mascart. |  |
| "، |  | D |  |  |  |  |  |  |  |  |  |  |  |
| Ethyl alc |  | D | $1.00087 \mathrm{I}-1.000885$ |  | Sulphur dioxide |  | white D | 1.000665 Dulong. |  |
| Ethyl eth |  | D | 1.001 52I-I.OOI 544 <br> r.000036 Ramsay. |  |  |  | I.000686 | etteler. |  |
| Helium |  | D |  |  | Water . . . . |  |  | white | 1.000261 Jamin. |  |
| Hydroch acid. | , $\{$ | white D | $\begin{aligned} & \text { 1.000449 Mascart. } \\ & \text { I.000447 } \end{aligned}$ |  |  | . . . | D | 1.000249-1.0002 59 |  |

Smithsonian Tables.

## index of refraction.

TABLE 349. - Index of Refraction of Air ( $15^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ ).
Corrections for reducing wave-lengths and frequencies in air $\left(15^{\circ} \mathrm{C}, 76 \mathrm{~cm}\right)$ to vacuo.
The indices were computed from the Cauchy formula $(n-1) \mathrm{IO}^{7}=2726.43+12.288 /\left(\lambda^{2} \times 10^{-8}\right)+0.3555 /$ $\left(\lambda^{4} \times{ }^{10} 0^{-16}\right)$. For $0^{\circ} \mathrm{C}$ and 76 cm the constants of the equation become $2875.66,13.412$ and 0.3777 respectively, and for $30^{\circ} \mathrm{C}$ and $76 \mathrm{~cm}, 2589.72,12.259$ and 0.2576 . Sellmeier's formula for but one absorption band closely fits the observations: $n^{2}=\mathrm{I}+0.00057378 \lambda^{2} /\left(\lambda^{2}-595260\right)$. If $n-\mathrm{I}$ were strictly proportional to the density, then $(n-1)_{0} /$ $(n-\mathrm{I}) t$ would equal $\mathrm{I}+a t$ where $\alpha$ should be 0.00367 . The following values of $a$ were found to hold:

| $\lambda$ | $0.85 \mu$ | $0.75 \mu$ | $0.65 \mu$ | $0.55 \mu$ | $0.45 \mu$ | $0.35 \mu$ |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\boldsymbol{\alpha}$ | 0.003672 | 0.003674 | 0.003678 | 0.00368 | 0.00370 | 0.003738 | $0.25 \mu$ |

The indices are for dry air $\left(0.05 \pm \% \mathrm{CO}_{2}\right)$. Corrections to the indices for water vapor may be made for any wavelength by Lorenz's formula, $+0.00004 \mathrm{I}(\boldsymbol{m} / 760)$, where $m$ is the vapor pressure in mm . The corresponding frequencies in waves per cm and the corrections to reduce wave-lengths and frequencies in air at $15^{\circ} \mathrm{C}$ and 76 cm pressure to vacuo are given. E.g., a light wave of 5000 Angstroms in dry air at $15^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ becomes 5001.391 A in vacuo; a frequency of 20,000 waves per cm correspondingly becomes 19994.44. Meggers and Peters, Bul. Bureau of Standards, 14, p. 731, 1918.

| Wavelength, Angstroms. | $\begin{gathered} \text { Dry air } \\ (n-1) \\ \times 10^{7} \\ 15^{7} \mathrm{C} \\ 76 \mathrm{~cm} \end{gathered}$ | $\left.\begin{array}{\|c\|} \text { Vacuo } \\ \text { correction } \\ \text { for } \lambda \text { in air } \\ (n \lambda-\lambda) . \\ \text { Add. } \end{array} \right\rvert\,$ | $\begin{gathered} \text { Fre- } \\ \text { quency } \\ \text { waves per } \\ \text { cm } \\ \frac{I}{\lambda} \\ \text { in air. } \end{gathered}$ | Vacuo correction for $\frac{1}{\lambda}$ in air $\left(\frac{1}{n \lambda}-\frac{1}{\lambda}\right)$. | Wavelength, $\lambda$ Angstroms. | $\begin{aligned} & \text { Dry air } \\ & (n-1) \\ & \times 10^{7} \\ & \times 5^{\circ} \mathrm{C} \\ & 7^{6} \mathrm{~cm} \end{aligned}$ | $\begin{gathered} \text { Vacuo } \\ \text { correction } \\ \text { for } \lambda \text { in air } \\ (n \lambda-\lambda) \\ \text { Add. } \end{gathered}$ | $\begin{gathered} \text { Fre- } \\ \text { quency } \\ \text { waves per } \\ \mathrm{cm} \\ \frac{1}{\lambda} \\ \text { in air. } \end{gathered}$ | Vacuo correction for $\frac{1}{\lambda}$ in air $\left(\frac{1}{n \lambda}-\frac{1}{\lambda}\right)$. Subtract. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2000 | 3256 | 0.651 | 50,000 | 16.27 | 5500 | 2771 | 1. 524 | 18,181 | 5.04 |
| 2100 | 3188 | 0.670 | 47,619 | 15.18 | 5600 | 2769 | 1.551 | 17,857 | 4.94 |
| 2200 | 3132 | 0.689 | 45,454 | 14.23 | 5700 | 2768 | 1. 578 | 17,543 | 4.85 |
| 2300 | 3086 | 0.710 | 43,478 | 13.41 | 5800 5000 | 2766 2765 | 1.604 1. 631 | 17,241 | 4.77 4.68 |
| 2400 | 3047 | 0.73I | 41,666 | 12.69 | 5900 | 2765 | 1.631 | 16,949 | 4.68 |
| 2500 | 3014 | 0.754 | 40,000 | 12.05 | 6000 | 2763 | 1. 658 | 16,666 | 4.60 |
| 2600 | 2986 | 0.776 | 38,461 | 11.48 | 6100 | 2762 | 1. 685 | 16,393 | 4.53 |
| 2700 | 2962 | 0.800 | 37,037 | 10.97 | 6200 | 2761 | 1. 712 I. 730 | 16,129 15,873 | 4.45 4.38 |
| 2800 | 2941 | 0.824 | 35,714 | 10.50 IO. 08 | 6300 6400 | 2760 | 1.739 I. 766 | 15,873 15,625 | 4.38 4.31 |
| 2900 | 2923 | 0.848 | 34,482 | 10.08 | 6400 | 2759 | 1.760 | 15,025 | 4.31 |
| 3000 | 2907 | 0.872 | 33,333 | 9.69 | 6500 | 2758 | 1. 792 | 15,384 | 4.24 |
| 3100 | 2893 | 0.897 | 32,258 | 9.33 | 6600 | 2757 | 1.819 | 15,151 | 4.18 |
| 3200 | 2880 | 0.922 | 31,250 | 9.00 | 6700 | 2756 | 1. 846 | 14,925 | 4.11 |
| 3300 | 2869 | 0.947 | 30,303 | 8.69 | 6800 | 2755 | 1.873 | 14,705 | 4.05 |
| 3400 | 2859 | 0.972 | 29,4! I | 8.41 | 6900 | 2754 | 1.900 | 14,492 | 3.99 |
| 3500 | 2850 | 0.998 | 28,571 | 8.14 | 7000 | 2753 | I. 927 | 14,285 | 3.93 |
| 3600 | 2842 | I. 023 | 27,777 | 7.89 | 7100 | 2752 | I. 954 | 14,084 | 3.88 |
| 3700 | 2835 | r. 049 | 27,027 | 7.66 | 7200 | 2751 | 1.981 | 13,888 | 3.82 |
| 3800 | 2829 | 1. 075 | 26,315 | 7.44 | 7300 | 2751 | 2. 008 | 13,698 I3,513 | 3.77 3.72 |
| 3900 | 2823 | 1. 101 | 25,641 | 7.24 | 7400 | 2750 | 2.035 | 13,513 | 3.72 |
| 4000 | 2817 | I. 127 | 25,000 | 7.04 | 7500 | 2749 | 2.062 | 13,333 | 3.66 |
| 4100 | 2812 | I. 153 | 24,390 | 6.86 | 7600 | 2749 | 2.089 | 13,157 | 3.62 |
| 4200 | 2808 | 1. 179 | 23,809 | 6.68 | 7700 | 2748 | 2.116 | 12,987 | 3.57 3.52 |
| 4300 4400 | 2803 2799 | I. 205 1. 232 | 23,255 22,727 | 6.52 6.36 | 7800 7900 | 2748 2747 | 2.143 2.170 | 12,820 12,658 | 3.52 3.48 |
| 4400 | 2799 | 1. 232 | 22,727 |  |  |  |  |  |  |
| 4500 | 2796 | 1. 258 | 22,222 | 6.21 | 8000 | 2746 | 2. 197 | 12,500 | 3.43 |
| 4600 | 2792 | I. 284 | ${ }^{21,739}$ | 6.07 | 8100 | 2746 | 2.224 | 12,345 | 3.39 |
| 4700 | 2789 | I. 311 | 21,276 | 5.93 5.80 |  |  | 2. 265 | 12,12I |  |
| 4800 4900 | 2786 2784 | 1.338 1. 364 | 20,833 20,406 | 5.80 5.68 | 8500 | 2744 | 2.332 | 11,764 | 3.33 3.23 |
|  |  |  |  |  | 8750 | 2743 | 2.400 | 11,428 | 3.13 |
| 5000 | 278I | I. 391 | 20,000 | 5.56 | 9000 | 2742 | 2.468 | 11,111 | 3.05 |
| 5100 | 2779 | I. 417 | 19,607 | 5.45 | 9250 0500 | 2741 | 2.536 2.604 | 10,810 10,526 | 2.96 2.88 |
| 5200 | 2777 | I. 444 | 19,230 18,867 | 5.34 5.23 | 9500 | 2740 2740 | 2.604 2.671 | 10,526 10,256 | 2.88 2.81 |
| 5300 5400 | 2775 2773 | 1. 471 1. 497 | 18,87 18,518 | 5.23 5.13 | 10750 | 2739 | 2.739 | 10,000 | 2.74 |

[^44]
# MEDIA FOR DETERMINATIONS OF REFRACTIVE INDICES WITH THE MICROSCOPE. 

TABLE 350. - Liquids, $\mathrm{n}_{\mathrm{D}}(0.589 \mu)=1.74$ to 1.87 .

In 100 parts of methylene iodide at $20^{\circ} \mathrm{C}$. the number of parts of the various substances indicated in the following table can be dissolved, forming saturated solutions having the permanent refractive indices specified. When ready for use the liquids can be mixed by means of a dropper to five intermediate refractions. Commercial iodoform ( $\mathrm{CHI}_{3}$ ) powder is not suitable, but crystals from a solution of the powder in ether may be used, or the crystalized product may be bought. A fragment of tin in the liquids containing the $\mathrm{SnI}_{4}$ will prevent discoloration.

| $\mathrm{CHI}_{3}$. | $\mathrm{SnI}_{4}$. | $\mathrm{AsI}_{3}$. | $\mathrm{SbI}_{3}$. | S. | $n_{\text {na }}$ at $20^{\circ}$. |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 12 |  | I. 764 |
|  | 25 |  |  |  | 1.783 |
|  | 25 |  | 12 |  | 1.806 |
|  | 30 |  |  | 6 | 1.820 |
|  | 27 | 13 | 7 |  | 1.826 |
| 40 | 27 | 16 |  |  | 1. 842 |
|  | 3 I | 14 | 8 | 10 | 1. 853 |
| 35 | 31 | 16 | 8 | 10 | 1. 868 |

TABLE 351. -Resin-like Substances, $\mathrm{n}_{\mathrm{D}}(0.589 \mu)=1.68$ to 2.10 .
Piperine, one of the least expensive of the alkaloids, can be obtained very pure in straw-colored crystals. When melted it dissolves the tri-iodides of arsenic and antimony very freely. The solutions are fluid at slightly above $100^{\circ}$ and when cold, resin-like. A solution containing 3 parts antimony jodide to one part of arsenic iodide with varying proportions of piperine is easier to manipulate than one containing either iodide alone. The following table gives the necessary data concerning the composition and refractive indices for sodium light. In preparing, the constituents, in powder of about 1 mm . grain, should be weighed out and then fused over, not in, a low flame. Three-inch test tubes are suitable.

| Per cent Iodides. | 00. | 10. | 20. | 30. | 40. | 50. | 60. | 70. | 80. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Index of refraction | 1.683 | 1.700 | 1.725 | 1.756 | 1.794 | 1.840 | 1.897 | 1.968 | 2.050 |

TABLE 352. - Permanent Standard Resinous Media, $\mathrm{n}_{\mathrm{D}}(0.589 \mu)=1.546$ to 1.682.
Any proportions of piperine and rosin form a homogeneous fusion which cools to a transparent resinous mass. The following table shows the refractive indices of various mixtures. On account of the strong dispersion of piperine the refractive indices of minerals apparently matched with those of mixtures rich in this constituent are 0.005 to 0.01 too low. To correct this error a screen made of a thin film of 7 per cent antimony iodide and 93 per cent piperine should be used over the eye-piece. Any amber-colored rosin in lumps is suitable.

| Per cent Rosin. | 00. | 10. | 20. | 30. | 40. | 50. | 60. | 70. | 80. | 90. | 100. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Index of refraction | 1.683 | 1.670 | 1.657 | 1.643 | 1.631 | 1.618 | 1.604 | 1.590 | 1.575 | 1.560 | 1.544 |

All taken from Merwin, Jour. Wash. Acad. of Sc. 3, p. 35, 1913.

## Smithsonian Tables.

## table 353.

Two constants are required to characterize a metal opticaily, the refractive index, $n$, and the absorption index, $k$, the latter of which has the following significance: the amplitude of a wave after travelling one wave-length, $\lambda^{1}$ measured in the metal, is reduced in the ratio ${ }^{1} 1: e^{-2 \pi k}$ or for any distance $d, \mathrm{I}: \mathrm{e}-\frac{2 \pi \mathrm{dk}}{\lambda^{1}}$; for the same wave-length measured in air this ratio becomes $\mathrm{I}: \mathrm{e} \frac{2 \pi \mathrm{dnk}}{\lambda^{1}}$. $n k$ is sometimes called the extinction coefficient. Plane polarized light reflected from a polished metal surface is in general elliptically polarized because of the relative change in phase between the two rectangular components vibrating in and perpendicular to the plane of incidence. For a certain angle, $\phi$ (principal incidence) the change is $90^{\circ}$ and if the plane polarized incident beam has a certain azimuth $\bar{\psi}$ (Principal azimuth) circularly polarized light results. Approximately, (Drude, Annalen der Physik, 36, p. 546, 1889),

$$
\mathrm{k}=\tan 2 \bar{\psi}\left(\mathrm{I}-\cot ^{2} \bar{\phi}\right) \text { and } \mathrm{n}=\frac{\sin \bar{\phi} \tan \bar{\phi}}{\left(1+\mathrm{k}^{2}\right)^{\frac{1}{2}}}\left(\mathrm{I}+\frac{1}{2} \cot ^{2} \bar{\phi}\right) \text {. }
$$

For rougher approximations the factor in parentheses may be omitted. $\mathrm{R}=$ computed percentage reflection.
(The points have been so selected that a smooth curve drawn through them very closely indicates the characteristics of the metal.)

| Metal. | $\lambda$ | $\overline{\text { ¢ }}$ | $\bar{\psi}$ | Computed. |  |  |  | thority |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | n | k | nk | R |  |
| Cobalt |  |  |  |  |  |  | $\%$ |  |
|  |  |  | ${ }_{29}^{29} 39$ | cintiol |  | , |  | $\stackrel{\text { crer }}{ }$ |
|  | ¢ | ¢79 |  |  | (1.85 |  | ${ }^{69}$ | Ingersoll. |
|  |  |  | ${ }_{26}^{26} 8$ | ${ }_{5}^{3.63}$ | (1.58 | ${ }^{5.73}$ | ${ }_{75}^{73}$ | " |
| Copper | ${ }_{\text {2, } 23}$ | 8348 655 | 26 26 26 |  | $\underset{\substack{\text { I.1.27 } \\ 1.05}}{1.5}$ | $\underset{\substack{7.18 \\ 1.45}}{1.1}$ | \% 720 | Minor. |
|  | - 2.231 | 65 <br> 65 <br> 65 <br> 704 <br> 08 |  |  | cin |  | ce. | $\stackrel{\text { aliner }}{ }$ |
|  | - 5.500 | \% 74.46 | 33 41 40 30 | ${ }_{\substack{\text { a } \\ 0.4 \\ \hline 1.10}}$ | ${ }_{\substack{2,4 \\ 7.4}}^{\substack{2,1\\}}$ | ci. | ${ }^{\text {c/ }}$ | Ingersoll. |
|  |  | 7840 84 84 84 | 4230 42 30 | ${ }_{0}^{0.35}$ | ${ }_{12}^{11.0} 1$ |  | ${ }_{96}^{91}$ | " |
|  | (2.25 | 85 <br> 87 <br> 80 <br> 87 <br> 20 | - | $\xrightarrow[\substack{\text { 1. } 0_{3} \\ 1.87}]{\text { a }}$ |  |  | 97. | Först.Fréa |
| Gold | ¢ |  | 42 <br> $\substack{\text { 42 } \\ 44 \\ 44 \\ \text { 5o }}$ |  |  | (28.3 |  | $\stackrel{\text { cis }}{ }$ |
|  | (i.00 | 81 <br> 85 <br> 85 <br> 85 <br> 85 <br> 85 | ${ }_{4}^{44} 500$ |  | ${ }_{26.7}^{28.0}$ |  |  | " " |
|  | $\underset{\substack{3.00 \\ 5.00}}{ }$ | 87 <br> 88 <br> 88 <br> 15 | ${ }_{4}^{43} \mathbf{4}$ 50 |  | 24.5 |  |  | " ${ }^{\prime \prime}$ |
| Iridium | (inc.1.00 <br> 2.00 | - $\begin{aligned} & 82 \\ & 83 \\ & 83 \\ & 810\end{aligned}$ | 2915 2940 29 | 3.85 <br> 4.30 | ${ }_{\substack{1.60 \\ 1.66}}^{\text {a }}$ | $\underset{\substack{3.2 \\ 7.1}}{ }$ |  | "، " |
|  | (incoin |  | - 30 | - |  | 6.0 |  | " |
| Nickel | (inco | 7200 76 76 7 | cis ${ }_{\text {32 }}^{32}$ | 2. |  | ${ }_{2,53}^{4.6}$ |  | Tool. |
|  | O. 0.589 | 76 <br> 78 <br> 78 <br> 8 <br> 1 | ${ }_{32}{ }_{3}{ }^{41}$ |  | $\xrightarrow{1.86}$ | ${ }_{4}^{3.36}$ | ${ }^{62} 8$ | Drude. |
|  | (1.00 |  | ${ }_{3}^{32}{ }^{3}{ }^{2}$ | ${ }_{\text {2 }}^{\substack{2.63 \\ 3.95}}$ | ¢ | ci.ce | ${ }^{74} 8$. | " ${ }^{\text {c }}$ |
| Platinum |  |  |  | ( $\begin{aligned} & 3.95 \\ & 0.74 \\ & 0.70\end{aligned}$ |  |  |  | Först.-Fresed. |
|  | (i.co | 7430 73 7 50 | 39 <br> 4150 <br> 40 <br> 0 | - 0.75 | ${ }_{\text {c. }}^{6.5}$ | ${ }_{3}^{3.4}$ |  | " " |
| Silver | ${ }_{\substack{\text { S.0.26 }}}^{\substack{\text { S.20, }}}$ | ${ }_{\text {c }}^{7200}$ | ${ }_{4}^{42} 10$ | ${ }_{\text {O }}^{\substack{0.34 \\ 1.44}}$ |  | 3.1. |  | Minor. |
|  |  |  | 1856 1588 158 | ${ }_{\text {1. }}^{1.57}$ | ${ }_{\substack{0.32 \\ 0.38}}^{0.62}$ | ${ }_{0}^{0.97} 0$ | ${ }^{17} 4$ |  |
|  | - 3.332 |  | ¢ 372 | - |  | -0.65 | ${ }_{\text {c }}^{3}$ | " |
|  | - 3.50 | ${ }_{72}{ }_{7}{ }^{36}$ | ${ }^{43} 29$ | O. |  | 2, | ${ }^{37} 9$. | "، |
|  | - 5 . 750 | 75 79 78 88 | ${ }_{4}^{43} 478$ | o. $\begin{aligned} & 0.178 \\ & 0.17\end{aligned}$ | ${ }_{\text {20, }}^{20.6}$ | ${ }_{\substack{\text { c.i.64 } \\ 5.15}}^{\text {3, }}$ | 97. | Ingersoll. |
|  |  |  | ${ }_{4}^{44} 48$ | -0.24 <br> 0.45 | ${ }_{\text {23,7 }}^{29.0}$ | (6.96 | ${ }_{98}^{98}$ |  |
|  | , | - | 43 48 48 48 | ${ }_{\text {O. }}^{\substack{\text { a } \\ 1.65}}$ | 19.9 <br> 12.2 | ${ }_{\text {20.i }}^{15}$ | 99. | Först. |
| Steel |  |  |  | ${ }_{\substack{\text { a } \\ \text { 4.3.9 } \\ 1.30}}$ |  | ${ }_{\substack { \text { che } \\ \begin{subarray}{c}{2.3 \\ 1.34{ \text { che } \\ \begin{subarray} { c } { 2 . 3 \\ 1 . 3 4 } }\end{subarray}}$ |  | Mino |
|  |  | 6685 695 69 | 2845 38 38 |  | ¢ | ${ }_{\substack{1.54 \\ \text { 2.09 }}}^{\text {a }}$ | (30. | " |
|  | ( 5 coi | - 75 | 302 29 29 |  | ¢ | cile |  | Ingersoll. |
|  |  |  | 279 28 30 30 |  |  | $\begin{aligned} & 3.59 .59 \\ & 5.71 \\ & \hline 741 \end{aligned}$ |  | Ingerss |

Drude, Annalen der Physik und Chemie, 39, p. 48ı, 1890; 42, p. 186, 889 r ; 64, p. 159, r898. Minor, Annalen der Physik, 10, p. 58ı, ro03. Tool, Physical Review, 31, p. 1, 1910. Ingersoll, Astrophysical Journal, 32, p. 265, 1910; Försterling and Fréedericksz, Annalen der Physik, 40, p. 201, 1913.

| Metal． | $\lambda$ ． | n． | k． | R． | Ref． | Metal． | $\lambda$ ． | n． | k． | R． | Ref． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Al．＊ | ${ }_{\mu}^{\mu}$ |  |  | 83 | I | Rh．＊ | ${ }_{0}^{\mu}$ |  | 467 | 78 |  |
| Sb．＊ | －0．589 | 1.44 | $5 \cdot 32$ | 3 | 1 | Se．$\ddagger$ | － 0.400 | 2.94 | 2.31 | 7 | 3 |
| Bi．t $\ddagger$ | white | 2.26 | 4 | － | 2 |  | ． 490 | 3.12 | 1.49 | 35 | 5 |
| Cd．＊ | ． 589 | 1.13 | 5.01 | 85 | 1 |  | ． 589 | 2.93 | 0.45 | 25 | 5 |
| Cr．＊ | ． 579 | 2.97 | 4.85 | 70 | 3 |  | ． 760 | 2.60 | 0.06 | 20 | 5 |
| Cb．＊ | ． 579 | 1.80 | 2.11 | 41 | 3 | Si．＊ | ． 589 | 4.18 | 0.09 | 38 | 6 |
| Au．$\dagger$ | ． 257 | 0.92 | 1.14 | 28 | 4 |  | I． 25 | 3.67 | 0.08 | 33 | 6 |
|  | ． 441 | 1.18 | 1． 85 | 42 | 4 |  | 2.25 | 3.53 | 0.08 | 31 | 6 |
|  | ． 589 | 0.47 | 2.83 | 82 | 4 | Na. （liq．） | ． 589 | ． 004 | 2.61 | 99 | 1 |
| I．crys． | ． 589 | 3.34 | 0.57 | 30 | 4 | Ta．＊ | ． 579 | 2.05 | 2.31 | 44 | 3 |
| Ir．＊ | ． 579 | 2.13 | 4.87 | 75 | 3 | Sn．＊ | ． 589 | 1.48 | 5.25 | 82 | 1 |
| Fe．§ | ． 257 | 1.01 | 0.88 | 16 | 4 | W．＊ | ． 579 | 2.76 | 2.71 | 49 | 3 |
|  | ． 441 | 1.28 | I． 37 | 28 | 4 | V．＊ | － 579 | 3.03 | 3.51 | 58 | 3 |
|  | ． 589 | 1.51 | 1.63 | 33 | 4 | Zn．＊ | ． 257 | 0.55 | 0.61 | 20 | 4 |
| Pb．＊ | ． 589 | 2.01 | 3.48 | 62 | 1 |  | ． 441 | 0.93 | 3．19 | 73 | 4 |
| Mg．＊ | ． 589 | 0.37 | 4.42 | 93 | 1 |  | ． 589 | 1.93 | 4.66 | 74 | 4 |
| Mn．＊ | ． 579 | 2.49 | 3．89 | 64 | 3 |  | ． 668 | 2.62 | 5.08 | 73 | 4 |
| Hg．（liq．） | ． 326 | 0.68 | 2.26 | 66 | 4 |  |  |  |  |  |  |
|  | ．441 | 1.01 | 3.42 | 74 |  |  |  |  |  |  |  |
|  | ． 589 | 1.62 | 4.41 | 75 | 4 | $\lambda=\text { wav } \epsilon$ | length | $\begin{aligned} & n=r \\ & \text { dex. } \end{aligned}$ | ractio |  |  |
|  | ． 668 | 1.72 | 4.70 | 77 | 4 | $\mathrm{k}=\mathrm{abso}$ <br> （1）Drude | see T | dex， 20 | $\begin{gathered} =r e \\ (2) \end{gathered}$ |  |  |
| Pt．$\dagger$ | .579 .257 | 1.62 I． 17 | 3.41 I． 65 | 65 | 3 | （I）Drude | see Ph | $k$ und | （2） |  |  |
|  | ． 257 | 1.17 1.94 | 1． 65 3.16 | 37 58 | 4 | $36, \text { p. } 824,$ | 889； | v． | arte | 39, | rh． |
|  | ． 589 | 2.63 | 3.54 | 59 | 4 | deutsch．Ph | sik． | S． 12 | p． 10 | 191 |  |
|  | ． 668 | 2.91 | 3.66 | 59 | 4 | Meier，Ann | es der | Physi | ， 10, | 8 I ， |  |
| Ni．＊ | ． 275 | 1.09 | 1.16 | 24 | 4 | （5）Wood， | hil．M | g．（6） | 3， 60 | 190 | （6） |
|  | ． 441 | 1.16 | 1.23 | 25 | 4 | Ingersoll，se | Table | 205. |  |  |  |
|  | ． 589 | 1.30 | 1.97 | 43 | 4 | as film in v | lectro uo． | tic， | rism |  |  |

TABLE 355．—Reflecting Power of Metals．（See page 298．）

| $\begin{aligned} & \text { Wave- } \\ & \text { length } \end{aligned}$ | 的 | 家 | び | － | ¢ | $\pm$ | $\stackrel{\text { en }}{\sim}$ | \％ | ® | 产 | $\dot{3}$ | ¢゙ | $\stackrel{\sim}{\sim}$ | 方 | $\geqslant$ | $\stackrel{\sim}{\infty}$ | ヘี่ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu$ | Per cents． |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | － | － | － | － | 22 | － | 72 | 46 | － | 76 | 34 | 38 | － | － | 49 |  | － |
| ． 6 | － | 53 | － | － | 24 | － | 73 | 48 | － | 77 | 32 | 45 | 49 | － | 51 | 58 | － |
| ． 8 | － | 54 | － | 67 | 25 |  | 74 | 52 | － | 81 | 29 | 64 | 48 | － | 56 | 60 | 8 |
| 1.0 | 71 82 | 55 | 72 | 67 | 27 | 78 | 74 | 58 | 72 | 84 | 28 | 78 | 50 | 54 | 62 85 | 61 | 80 |
| 2.0 4.0 | 82 | 68 | 87 96 | 72 81 81 | 35 | 87 94 | 77 84 | 82 | 81 88 | 91 92 | 28 | 90 | 52 | 72 | 85 | 69 | 92 97 |
| 7.0 | 96 | 71 | 98 | 93 | 54 | 95 | 91 | 93 | 94 | 94 | 28 | 94 | 68 | 81 | 95 | 88 | 98 |
| 10.0 | 98 | 72 | 98 | 97 | 59 | 96 | － | 94 | 97 | 95 | 28 | － | － | 84 | 96 |  | 98 |
| 12.0 | 98 | － | 99 | 97 | 5 | 96 | － | 95 | 97 | － | － | 95 | － | 85 | 96 | － | 99 |

Coblentz，Bulletin Bureau of Standards，2，p．457，1906，7，p．197，1911．The surfaces of some of the samples were not perfect so that the corresponding values have less weight．The methods for polishing the various metals are described in the original articles．The following more recent values are given by Coblentz and Emerson，Bul．Bur．Stds．I4，p．207，1917；Stellite，an exceedingly hard and untarnish－ able alloy of $\mathrm{Co}, \mathrm{Cr}, \mathrm{Mo}, \mathrm{Mn}$ ，and Fe（ $\mathrm{C}, \mathrm{S}_{1}, \mathrm{~S}, \mathrm{P}$ ）was obtained from the Haynes Stellite Co，Kokomo， Indiana．

$$
\begin{array}{lccccccccccc}
\text { Wave-length, } \mu, & .15 & .20 & .30 & .50 & .75 & 1.00 & 2.00 & 3.00 & 4.00 & 5.00 & 9.00 \\
\text { Tungsten, } & -32 & -42 & .50 & .50 & .52 & .576 & .900 & .943 & .948 & .053 & \overline{.64} \\
\text { Stellite, } & .32 & .42 & .689 & .747 & .792 & .825 & .848 & .880
\end{array}
$$

According to Fresnel the amount of light reflected by the surface of a transparent medium $=\frac{1}{2}(A+B)=\frac{1}{2}\left\{\frac{\sin ^{2}(i-r)}{\sin ^{2}(i+r)}+\frac{\tan ^{2}(i-r)}{\tan ^{2}(i+r)}\right\} ; A$ is the amount polarized in the plane of inci. dence; $B$ is that polarized perpendicular to this; $i$ and $r$ are the angles of incidence and refraction.

TABLE 356. - Light reflected when $i=0^{\circ}$ or Incident Light is Normal to Surface.

| $n$ | $\frac{1}{2}(A+B)$. | $n$. | $\frac{1}{2}(A+B)$. | $n$ | $\frac{1}{2}(A+B)$. | $n$. | $\frac{1}{1}(A+B)$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.00 | 0.00 | 1.4 | 2.78 | 2.0 | 11.1 I | 5. | 44.44 |
| 1.02 | 0.01 | 1.5 | 4.00 | 2.25 | 14.06 | 5.83 | 50.00 |
| 1.05 | 0.06 | 1.6 | $5 \cdot 33$ | 2.5 | 18.37 | 10. | 66.67 |
| I.I | 0.23 | 1.7 | 6.72 | 2.75 | 22.89 | 100. | 96.08 |
| 1.2 | 0.83 | 1.8 | 8.16 | 3. | 25.00 | $\infty$ | 100.00 |
| I. 3 | 1.70 | 1.9 | 9.63 | 4. | 36.00 |  |  |

TABLE 357. - Light reflected when $n$ is near Unity or equals $1+d n$.

| $i$. | A. | $B$. | $\frac{1}{2}(A+B)$. | $\frac{A-B}{A+B}$ |
| :---: | :---: | :---: | :---: | :---: |
| $0^{\circ}$ | 1.000 | 1.000 | 1.000 | 0.0 |
| 5 | 1.015 | .985 | 1.000 | 1.5 |
| 10 | 1.063 | . 939 | I.OOI | 6.2 |
| 15 | I. 149 | . 862 | 1.005 | 14.3 |
| 20 | 1.282 | .752 | 1.017 | 26.0 |
| 25 | 1.482 | .612 | 1.047 | 41.5 |
| 30 | 1.778 | . 444 | I. 11 I | 60.0 |
| 35 | 2.221 | .260 | 1.240 | 79.1 |
| 40 | 2.904 | . 088 | I. 496 | 94.5 |
| 45 | 4.000 | . 000 | 2.000 | 100.0 |
| 50 | 5.857 | .176 | 3.016 | 94.5 |
| 55 | 9.239 | I. 081 | 5.160 | 79.1 |
| 60 | 16.000 | 4.000 | 10.000 | 60.0 |
| 65 | 31.346 | 12.952 | 22.149 | 41.5 |
| 70 | 73.079 | 42.884 | 57.981 | 26.0 |
| 75 | 222.85 | 167.16 | 195.00 | 14.3 |
| 80 | 1099.85 | 971.21 | 1035.53 | 6.2 |
| 85 | 17330.64 | 16808.08 | 17069.36 | 1.5 |
| 90 | $\infty$ | $\infty$ | $\infty$ | 0.0 |

TABLE 358.- Light reflected when $n=1.55$.

| $i$. | $r$ | A. | $B$. | dA.t | $d B . \dagger$ | $\frac{1}{2}(A+B)$ 。 | $\frac{A-B}{A+B}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\bigcirc 1$ | 01 |  |  |  |  |  |  |
| 0 | - 0.0 | 4.65 | 4.65 | 0.130 | 0.130 | 4.65 | 0.0 |
| 5 | 313.4 | 4.70 | 4.61 | . 134 | . 129 | 4.65 | 1.0 |
| 10 | 625.9 | 4.84 | 4.47 | .135 | . 126 | 4.66 | 4.0 |
| 15 | 936.7 | 5.09 | 4.24 | .141 | . 124 | 4.66 | 9.1 |
| 20 | 1244.8 | 5.45 | 3.92 | ${ }^{1} 50$ | .114 | 4.68 | 16.4 |
| 25 | 1549.3 | 5.95 | 3.50 | . 161 | .105 | 4.73 | 25.9 |
| 30 | 1849.1 | 6.64 | 3.00 | . 175 | . 094 | 4.82 | 37.8 |
| 35 | 2143.1 | $7 \cdot 55$ | 2.40 | . 191 | .081 | 4.98 | 51.7 |
| 40 | 2430.0 | 8.77 | 1.75 | . 210 | . 066 | 5.26 | 66.7 |
| 45 | 278.5 | 10.38 | 1.08 | . 233 | . 049 | 5.73 | 81.2 |
| 50 | 29 37.1 | 12.54 | 0.46 | . 263 | . 027 | 6.50 | 92.9 |
| 55 | 3154.2 | 15.43 | 0.05 | . 303 | . 007 | 7.74 | 99.3 |
| 60 | 3358.1 | 19.35 | 0.12 | . 342 | -.013 | 9.73 | 98.8 |
| 65 | 3547.0 | 24.69 | 1. 13 | . 375 | -.032 | 12.91 | 91.2 |
| 70 | 3719.1 | 31.99 | 4.00 | -400 | -. 050 | 18.00 | 77.7 |
| 75 | 38 3 32.9 | 42.00 | 10.38 | .410 | -. 060 | 26.19 | 61.8 |
| 80 | 3926.8 | 55.74 64.41 | 23.34 34.04 | .370 .320 | -. 069 | 3954 49.22 | 41.0 30.8 |
| 82 85 85 | 3945.9 3959.6 | 64.41 74.52 | 34.04 49.03 | .320 .250 | -.067 -.061 | 49.22 61.77 | 30.8 20.6 |
| 86 - | $\begin{array}{rr}39 & 59.6 \\ 40 & 3.6\end{array}$ | 79.52 79.02 | 56.62 | . 209 | -. 055 | 67.82 | 16.5 |
|  | $40 \quad 6.7$ | 83.80 | 65.32 | .163 | -. 046 | 74.56 | 12.4 |
| 88 - | 408.9 | 88.88 | 75.31 | .118 | -.036 | 82.10 | 8.3 |
| 89 - | 4010.2 | 94.28 | 86.79 | .063 | -.022 | 90.54 | 4.1 |
| $90 \quad 0$ | 4010.7 | 100.00 | 100.00 | . 000 | -.000 | 100.00 | 0.0 |

Angle of total polarization $=57^{\circ}$ ıо $.3, A=16.99$.

* This column gives the degree of polarization


## REFLECTING POWER OF METALS．

TABLE 359．－Perpendicular Incidence and Reflection．（See also Tables 352－355．）
The numbers give the per cents of the incident radiation reflected．

|  |  |  |  |  |  |  |  |  | $\begin{aligned} & \text { Copper. } \\ & \text { Commercially Pure. } \end{aligned}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| .251 | － | － | 67.0 | 35.8 | 29.9 | 37.8 | － | 32.9 | 25.9 | 33.8 | 38.8 | － | 34.1 |
| ． 288 | － | － | 70.6 | 37.1 | 37.7 | 42.7 | － | 35.0 | 24.3 | 38.8 | 34.0 |  | 21.2 |
| ． 305 | － | － | 72.2 | 37.2 | 41.7 | 44.2 | － | 37.2 | $25 \cdot 3$ | 39.8 | 31.8 | － | 9.1 |
| ． 316 | － | － | － | － | － | － |  | － | － | － | － | － | 4.2 |
| ． 326 | － | － | 75.5 | 39.3 | － | 45.2 | － | 40.3 | 24.9 | 41.4 | 28.6 | － | 14.6 |
| .338 | － | － | 8 |  | － | 46.5 |  | － | － | － | － | － | 55.5 |
| －357 | － | － | 81.2 | $43 \cdot 3$ | 51.0 | 48.8 | － | 45.0 | 27.3 | 43.4 | 27.9 | － | $74 \cdot 5$ |
| $\cdot 385$ | － | － | 83.9 | $44 \cdot 3$ | 53.1 | 49.6 | － | 47.8 | 28.6 | 45.4 | 27.1 | － | 81.4 |
| ． 420 | － | － | 83.3 | 47.2 | 56.4 | 56.6 | － | 51.9 | 32.7 | 5i． 8 | 29.3 | － | 86.6 |
| ． 450 | 85.7 | 72.8 | 83.4 | 49.2 | 60.0 | 59.4 | 48.8 | 54.4 | 37.0 | 54.7 | 33．1 | － | 90.5 |
| ． 500 | 86.6 | 70.9 | 83.3 | $49 \cdot 3$ | 63.2 | 60.8 | $53 \cdot 3$ | 54.8 | 43.7 | 58.4 | 47.0 | － | 91.3 |
| ． 550 | 88.2 | 71.2 | 82.7 | 48.3 | 64.0 | 62.6 | 59.5 | 54.9 | 47.7 | 61.1 | 74.0 | － | 92.7 |
| ． 600 | 88.1 | 69.9 | 83.0 | 47.5 | 64.3 | 64.9 | 83.5 | $55 \cdot 4$ | 71.8 | 64.2 | 84.4 | － | 92.6 |
| ． 650 | 89． 1 | 71.5 | 82．7 | 51.5 | 65.4 | 66.6 | 89.0 | 56.4 | 80.0 | 66.5 | 88.9 | － | 94.7 |
| ． 700 | 89.6 | 72.5 | 83.3 | 54.9 | 66.8 | 68.8 | 90.7 | 57.6 | 83.1 | 69.0 | 92.3 | － | 95.4 |
| ． 800 | － | － | 84.3 | 63.1 | － | 69.6 | － | 58.0 | 88.6 | 70.3 | 94.9 | － | 96.8 |
| 1.0 | － | － | 84.1 | 69.8 | 70.5 | 72.0 | － | 63.1 | 90.1 | 72.9 | － | － | 97.0 |
| 1.5 | － | － | 85.1 | 79.1 | 75.0 | 78.6 | － | 70.8 | 93.8 | 77.7 | 97.3 | － | 98.2 |
| 2.0 | － | － | 86.7 | 82.3 | 80.4 | 83.5 | － | 76.7 | 95.5 | 80.6 | 96.8 | 91.0 | 97.8 |
| 3.0 | － | － | 87.4 | 85.4 | 86.2 | 88.7 | － | 83.0 | 97．1 | 88.8 | － | 93.7 | 98.1 |
| 4.0 | － | － | 88.7 | 87.1 | 88.5 | 91.1 | － | 87.8 | 97.3 | 91.5 | 96.9 | 95.7 | 98.5 |
| 5.0 | － | － | 89.0 | 87.3 | 89.1 | 94.4 | － | 89.0 | 97.9 | 93.5 | 97.0 | 95.9 | 98.1 |
| 7.0 | － | － | 90.0 | 88.6 | 90.1 | 94.3 | － | 92.9 | 98.3 | 95.5 | 98.3 | 97.0 | 98.5 |
| 9.0 | － | － | 90.6 | 90.3 | 92.2 | 95.6 | － | 92.9 | 98.4 | 95.4 | 98.0 | 97.8 | 98.7 |
| 11.0 | － | － | 90.7 | 90.2 | 92.9 | 95.9 | － | 94.0 | 98.4 | 95.6 | 98.3 | 96.6 | 98.8 |
| 14.0 | － | － | 92.2 | 90.3 | 93.6 | 97.2 | － | 96.0 | 97.9 | 96.4 | 97.9 | － | 98.3 |

Based upon the work of Hagen and Rubens，Ann．der Phys．（1）352，1900；（8） 1 ， 1902 ；（11）873， 1903. Taken partly from Landolt－Börnstein－Meyerhoffer＇s Physikalisch－chemische＇Tabellen．

TABLE 360．－Percentage Diffuse Reflection from Miscellaneons Substances．

| Wave－ length $\mu$ | Lamp－blacks． |  |  |  |  |  |  |  |  |  |  |  | $\begin{aligned} & \dot{\pi} \\ & \text { 感 } \\ & \text { 品 } \end{aligned}$ | $\begin{aligned} & \stackrel{\rightharpoonup}{\stackrel{0}{0}} \\ & \stackrel{y}{0} \\ & \stackrel{y}{u} \\ & \stackrel{\pi}{c} \\ & \hline \end{aligned}$ |  | 苍 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} & \text { 茂 } \\ & \underset{\sim}{2} \end{aligned}$ | E． |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ＊． 60 | 3.2 |  |  |  |  |  | 25. | 52. | 84. | 82. |  | 89. | 15. | ı． 8 | 14. | 30. |
| ＊． 95 | 3.4 | 1.3 | 1.1 | 0.6 | 1.3 | 1.1 |  |  | 88. | 86. | 75. | 93. |  |  | 21. |  |
| $4 \cdot 4$ | 3.2 | 1.3 | ． 9 | ． 8 | 1.2 | 1.4 |  | 51. | 21. | 8. | 18. | 29. |  | 3.7 |  |  |
| 8.8 | 3.8 |  | 1.3 | 1.2 | 1.6 | 2.1 |  | 26. | 2. | 3. | 5. | 11. |  | 2.7 |  | 12. |
| 24.0 | 4.4 | 3.0 | 4.0 | 2.1 | 5.7 | 4.2 |  | 10. | 6. | 5. |  | 7. |  |  |  |  |

＊Not monochromatic（max．）means from Coblentz，J．Franklin Inst．1912．Bulletin Bureau of Standards，9，p．283； 1912，contains many other materials．

REFLECTING POWER OF PIGMENTS.
TABLE 361. - Percentage Reflecting Power of Dry Powdered Pigments.
Taken from "The Physical Basis of Color Technology," Luckiesh, J. Franklin Inst., 1917. The total reflecting power depends on the distribution of energy in the illuminant and is given in the last three columns for noon sun, blue sky, and for a 7.9 lumens/watt tungsten filament.

| Spectrum color. | $\begin{array}{\|l\|} \hline \text { Vio- } \\ \text { let. } \end{array}$ | Blue. |  | Green. |  |  | Yellow. |  | Orange. |  |  | Red. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Wave-length in $\mu$ | 0.44 | 0.46 | 0.48 | 0.50 | 0.52 | 0. 54 | 0. 56 | 0.58 | 0.60 | 0.62 | 0.64 | 0.66 | 0.68 | 0.70 |  |  |  |
| American vermilion. | 8 | 6 | 5 | 5 | 6 | 6 | 9 | II | 24 | 39 | 53 | 61 | 66 | 65 | 14 | 12 | 12 |
| Venetian red. | 5 | 5 | 5 |  |  |  |  |  |  | 24 |  | 30 | 32 | 32 | 11 | 10 | 13 |
| Tuscan red. | 7 | 7 | 7 | 8 | 8 | 8 | 8 | 12 | 16 | 18 | 20 | 22 | 23 | 24 | 11 | 10 | 12 |
| Indian red. | 8 | 7 | 7 | 7 | 7 | 7 | 7 | II | 15 | 18 | 20 | 22 | 23 | 24 | 10 | 9 | II |
| Burnt sienna. | 4 | 4 | 4 | 4 | 5 | 6 | 9 | 14 | 18 | 20 | 21 | 23 | 24 | 25 | II | - | 13 |
| Raw sienna. | 12 | 13 | 13 | 13 | 18 | 26 | 35 | 43 | 46 | 46 | 45 | 44 | 45 | 43 | 33 | 30 | 37 |
| Golden ochre.... | 22 | 22 | 23 | 27 | 40 | 53 | 63 | 71 | 75 | 74 |  | 73 82 | 73 81 81 | 72 80 | 58 | 55 | 63 |
| Chrome yellow ochre. . | 8 | 9 | 7 | 7 | 10 | 19 | 30 | 46 | 60 | 62 | 66 | 82 | 81 | 80 | 33 | 29 | 40 |
| Yellow ochre. . . . . . . . | 20 | 20 | 2 F | 24 | 32 | 42 | 53 | 63 | 64 | 61 | 60 | 59 | 59 | 59 | 49 | 46 | 53 |
| Chrome yellow medium. | 5 | 5 | 6 | 8 | 18 | 48 | 66 | 75 | 78 | 79 | 81 | 81 | 81 | 81 | 54 | 50 | 63 |
| Chrome yellow light. . | 13 | 13 | 18 | 30 | 56 | 82 | 88 | 89 | 90 | 89 | 88 | 87 | 85 | 84 | 76 | 70 | 82 |
| Chrome green light.... | 10 | 10 | 14 | 23 | 26 | 23 | 20 | 17 | 14 | 11 | 9 | 8 | 7 | 6 | 19 | 19 | 18 |
| Chrome green medium.. | 7 | 7 | 10 | 2 I | 21 | 17 | 13 | 11 | 9 | 7 | 6 | 6 | 6 | 5 | 14 | 14 | 12 |
| Cobalt blue. ........... | 59 | 58 | 49 | 35 | 23 | 15 | 11 | 10 | 10 | 10 | 1 | 15 | 20 | 25 | 16 | 18 | 13 |
| Ultramarine blue...... | 67 | 54 | 38 | 21 | 10 | 6 | 4 | 3 | 3 | 4 | 5 | 7 | 10 | 17 | 7 | 10 | 6 |

TABLE 362. - Infra-red Diffuse Percentage Reflecting Powers of Dry Pigments.

| Wavelength in $\mu$ |  | O | $\begin{aligned} & \text { O్ } \\ & \text { Ü } \end{aligned}$ | $\begin{aligned} & \circ \\ & \text { B } \\ & \hline 1 \end{aligned}$ | ¢ | $\begin{aligned} & \text { O厄 } \\ & \text { N } \end{aligned}$ | $\begin{aligned} & \text { Ö } \\ & \text { U } \\ & \text { مि } \end{aligned}$ | Con | O゙ | 억 | $\stackrel{0}{0_{0}}$ | OK | 오N | $\begin{aligned} & \mathbf{O}_{0}^{\circ} \\ & 0 \end{aligned}$ | $\underbrace{}_{\substack{\infty \\ \hline \multirow{2}{c}{\hline}\\ \hline}}$ |  | ² |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.60* | 3 | - | 27 | 52 | 26 | 74 | 70 | 84 | 86 | 82 | 86 | 85 | 86 | 88 | 85 | 76 | 68 |
| 0.95* | 4 | 24 | 45 | - | 41 |  | - | 88 | - | 86 | - |  | 84 | 93 | 89 | 79 | 72 |
| ${ }_{4}^{4.4}$ | 14 | 15 | 33 | 51 | 30 | 34 | 4 I | 21 | 47 | 8 | 16 | 22 | 23 | 29 | 11 | - | - |
| 8.8 24.0 | ${ }^{1} 3$ | - | 5 | 26 10 | 4 9 | 11 | 5 7 | 20 6 | 7 10 | 5 | 9 | 4 | 5 | 10 7 | 4 | - | - |

* Non-monochromatic means from Coblentz, Bul. Bureau Standards 9, p. 283, 1912.

For the reflecting (and transmissive) power of roughened surfaces at various angles of incidence, see Gorton, Physical Review, 7, p. 66, 1916. A surface of plate glass, ground uniformly with the finest emery and then silvered, used at an angle of $75^{\circ}$, reflected 90 per cent at $4 \mu$, approached 100 for longer waves, only 10 at $1 \mu$, less than 5 in the visible red and approached ofor shorter waves. Similar results were obtained with a plate of rock salt for transmitted energy when roughened merely by breathing on it. In both cases the finer the surface, the more suddenly it cuts off the short waves.

## Smithsonian Tables.

## REFLECTING POWER.

## TABLE 363. - Reflecting Power of Powders (White Light).

Various pure chemicals, very finely powdered and surface formed by pressing down with glass plate. White (noon sunlight) light. Reflection in per cent. Nutting, Jones, Elliott, Tr. Ill. Eng. Soc. 9, 593, 1914.

| Alumi | 83.6 | Magnesium carbonate | 86.6 | Sodium chloride............. 78. 1 |
| :---: | :---: | :---: | :---: | :---: |
| Barium sulphate. | 8 ra .1 | "" (block) | 88.0 | Sodium sulphate............ ${ }^{\text {77.9 }}$ |
| Borax | 81.6 | Magnesium oxide | 85.7 | Starch...................... 80.3 |
| Boric acid. | 83.2 | Rochelle salt. | 79.3 | Sugar...................... 87.8 |
| Calcium carbona | 83.8 | Salicylic acid | 81.1 | Tartaric acid............... 79.1 |
| Citric acid. | 8 I .5 | Sodium carbonate | 8 m .8 | Tartaric acid............... ${ }^{\text {g. }}$ |

## TABLE 364. - Variation of Reflecting Power of Surfaces with Angle.

Illumination at normal incidence, if watt tungsten lamp, reflection at angles indicated with normal. Ill. Eng. Soc., Glare Committee, Tr. Ill. Eng. Soc. II, p. 92, 1916.

| Angle of observation. | $0^{\circ}$ | $\mathrm{I}^{\circ}$ | $3^{\circ}$ | $5^{\circ}$ | $10^{\circ}$ | $15^{\circ}$ | $30^{\circ}$ | $45^{\circ}$ | $60^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Magnesium carbonate block | 0.88 | - | - | 0.88 | 0.88 | 0.87 | 0.83 | 0.72 | 0.68 |
| Magnesium oxide. | 0.80 | - | - | 0.80 | 0.80 | 0.80 | 0.77 | 0.75 | 0.66 |
| Matt photographic paper | 0.78 | - |  | -. 78 | 0.78 | 0.78 | 0.78 | 0.76 | 0.72 |
| White blotter | 0.76 | - | - | 0.76 | 0. 76 | 0. 76 | 0.73 | 0.70 | 0.67 |
| Pot opal, ground. . | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 | 0.68 | 0.66 | 0.64 |
| Flashed opal, not ground | II. 3 | 11.3 | II. 3 | 0.31 | 0.22 | 0.21 | 0.20 | 0. 20 | 0. 18 |
| Glass, fine ground | 0.29 | 0. 29 | 0.29 | 0.29 | 0.27 | 0. 20 | 0.14 | 0.13 | 0.12 |
| Glass, course ground | -: 23 | 0.22 | -. 21 | 0.20 | -. 19 | -. 16 | -. 11 | -.11 | 0.12 |
| Matt varnish on foil. | 0.83 | - | 0.78 | -. 72 | 0.62 | 0. 49 | 0.28 | 0.21 | 0.16 |
| Mirror with ground fa | 4.9 |  |  | 4.55 | 3.86 | 3.03 | 0.78 | 0.42 | 0.35 |

The following figures, taken from Fowle, Smithsonian Misc. Col. 58, No. 8, indicate the amount of energy scattered on each side of the directly reflected beam from a silvered mirror; the energy at the center of the reflected beam was taken as 100,000, and the angle of incidence was about $3^{\circ}$.

| Angle of reflection, $3^{\circ} \pm$ Energy . . . . . . . . . . | $\begin{gathered} 0^{\prime} \\ 100,000 \end{gathered}$ | $8^{\prime}$ 600 | 10 244 | 15 146 | 20 107 | 30 66 | $45^{\prime}$ 33 | 60 22 | 100 II |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

Wave-length of max. energy of Nernst lamp used as source about $2 \mu$.

## TABLE 365. - Infra-red Reflectivity of Tungsten (Temperature Variation).

Three tungsten mirrors were used, - a polished Coolidge X-ray target and two polished flattened wires mounted in evacuated soft-glass bulbs with terminals for heating electrically. Weniger and Pfund, J. Franklin Inst.

| Wave length in $\mu$. | Absolute reflectivity at room temperature in per cent. | Per cent increase in reflectivity in going from room temperature to |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $1377{ }^{\circ} \mathrm{K}$ | $1628^{\circ} \mathrm{K}$ | $1853^{\circ} \mathrm{K}$ | $2056^{\circ} \mathrm{K}$ |
| 0.67 | 51 | +6.0 | +7.4 | +8.7 | +9.8 +8.8 |
| 0.80 | 55 | $\bigcirc$ | 0. | $\bigcirc$ | +8.2 0.0 |
| 1.27 1.90 | 70 83 | 0.0 -6.6 | 0.0 -8.2 | 0.0 -9.6 | -11.0 |
| 2.00 | 85 | -7.5 | -9.3 | -10.9 | -12.3 |
| 2.90 | 92 | -7.7 | -9.4 | -II. 1 | -12.5 |
| 4.00 | 93 | - | - | - | -12.5 |

See also Weniger and Pfund, Phys. Rev. 15, p. 427, 1919.

TRANSMISSIBILITY OF RADIATION BY DYES.
Percentage transmissions of aqueous solutions taken from The Physical Basis of Color-Technology, Luckiesh, J. Franklin Inst. 184, 1917.


For the infra-red transmission (to $\mathbf{x} 2 \mu$ ) and reflection powers of a number of aniline dyes, see Johnson and Spence, Phys. Rev. 5, p. 349, 1915.

## Tables 367-369.

TABLE 367.
Coefficients, $a$, in the formula $I_{t}=I_{0} a^{t}$, where $I_{0}$ is the Intensity before, and $I_{t}$ after, transmission through the thickness $t$. Deduced from observations by Müller, Vogel, and Rubens as quoted in Hovestadt's Jena Glass (English translation).

| Unit $t=1 \mathrm{dm}$. | Coefficient of transmission, $\boldsymbol{a}$. |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | . $375{ }^{\mu}$ | $390 \mu$ | . $400 \mu$ | . 434 | . 436 | $\mu$. 4 |  | \% | $3 \mu$ | . $580 \mu$ | . $677 \mu$ |
| O 340, Ord. light flint | . 388 | . 456 | . 614 | . 569 | . 68 |  |  | o | Oo | . 878 | -939 |
| O IO2, H'vy silicate flint |  | . 025 | . 463 | . 502 | . 5 |  |  | 0 | S2 | . 828 | . 794 |
| O 93, Ord. " " |  |  |  |  | . 71 |  |  |  | 1 | . 903 | . 943 |
| O 203, " " crown | .583 | .583 | . 695 | . 66 | . 8 |  |  |  | 72 | . 872 | . 903 |
| O 59S, (Crown) | . |  | , |  | . 79 |  |  |  | 76 | . 818 | . 860 |
| Unit $t=1 \mathrm{~cm}$. | $0.7 \mu$ | $0.95 \mu$ | 1.1 \% | $1.4 \mu$ | $3.7 \mu$ | $2.0 \mu$ | $2.3 \mu$ | $2.5 \mu$ | $2.7 \mu$ | $2.9 \mu$ | 3.1 M |
| S 204, Borate crown | I. 00 | -99 | . 94 | . 90 | . 85 | . 81 | . 69 | . 43 | . 29 | . 18 | - |
| S 179, Med. phosp. cr. |  | . 98 | . 95 | . 90 | . 84 | . 67 | . 49 | . 87 | . 18 | - | - |
| O 1143 , Dense, bor. sil. cr. | . 98 |  | . 97 | - | . 95 | . 93 | . 90 | . 84 | . 71 | . 47 | . 27 |
| O ro92, Crown. | . 99 | . 96 | . 95 | . 99 | . 99 | . 91 | . 82 | . 71 | . 60 | . 48 | . 29 |
| O 1151, " | . 98 | - | . 99 | . 99 | . 98 | . 94 | . 90 | . 79 | . 75 | . 45 | . 32 |
| $)^{(1)} 45 \mathrm{I}$, Light flint | I. 00 | - | . 99 | - | . 98 | . 95 | . 92 | . 84 | . 78 | . 54. | . 34 |
| O 469, Heavy " | . 0 | - | . 98 | - | . 99 | . 98 | . 98 | . 97 | . 90 | . 66 | . 50 |
| O 500, " " | 1.00 | - | 1.00 | - | 1.00 | - | 1.00 | -99 | . 92 | . 74 | . 53 |
| S 163, " " | 1.00 | - | . 98 | - | . 99 | - | . 99 | - | . 94 | . 78 | . 60 |

TABLE 368.
Note : With the following data, $t$ must be expressed in millimeters; i. e. the figures as given give the transmissions for thickness of 1 mm .

| No. and Type of Glass. | Wave-length in $\mu$. |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Visible Specrrum. |  |  |  |  |  |  | Ultra-violet Spectrum. |  |  |  |  |  |
|  | ${ }_{44}{ }^{4}$ | . 578 \% | . $546 \mu$ | . 509 | .480\% | . $436 \mu$ | . $405 \mu$ | .384 | . $36 \mathrm{\mu} \mu$ | 30ر $\mu$ | . $332 \mu$ | $309 \mu$ | 280 $\mu$ |
| F 3815 Dark neutral | . 35 | . 35 | 37 | .35 | . 34 | 30 | . 15 | . 06 |  |  |  |  |  |
|  | . 94 | . 05 |  |  |  | . 43 | . 43 |  |  |  |  |  |  |
| ${ }^{\text {F } 4313}$ Dark yellow | . 98 | . 97 | . 93 | . 83 | . 09 |  |  |  |  |  |  |  |  |
|  | . 98 | 1.97 | . 96 | . 93 | 44 | . 15 |  | . 28 |  |  | . 14 | . 06 |  |
| ${ }_{\text {F }} \mathrm{F}_{4930} 493 \mathrm{Br}$ Green filter | 1.0 | $\stackrel{1.0}{50}$ | ${ }^{1.04}$ | . 62 |  | . 40 | . ${ }^{1}$ | . 28 | . 22 |  | . 14 | . 06 |  |
| F 3873 Blue filter | $\underline{-}$ | - | - | . 18 | . 50 | . 73 | 69 | . 59 | . 36 | . 10 |  |  |  |
| F 3654 Cobalt glass, |  |  |  |  |  |  |  |  |  |  |  |  |  |
| transparent for outer red | - | - | - | . 15 |  | . 85 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |  |  |
| F 3653 Blue, ultraviolet | - | - | - | - | .11 | . 65 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | . 81 | . 18 |
|  | . 99 | 72 | . 99 | . 96 | . 95 | . 96 | . 99 | . 99 | . 89 | . 89 | . 77 | 54 |  |

This and the following table are taken from Jenaer Glas für die Optik, Liste 751, 1909
TABLE 369. - Transmissibility by Jena Uitra-violet Glasses.

| No. and Type of Glass. | Thickness. | $0.397 \mu$ | $0.383 \mu$ | $0.361 \mu$ | $0.346 \mu$ | $0.325 \mu$ | $0.309 \mu$ | $0.280 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| UV 3I99 Ultra-violet | 1 mm . | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.95 | 0. 56 |
|  | 2 mm . | 0.99 | 0.99 | 0.99 | 0.97 | 0.90 | 0.57 |  |
| " " | 1 dm . | 0.95 | 0.95 | 0.89 | 0.70 | 0.36 |  |  |
| UV 3248 | 1 mm . | 1.00 | 1.00 | 1.00 | 1.00 | 0.98 | 0.91 | 0.35 |
| $6_{66}{ }^{6}$ | 2 mm . | 0.98 | 0.98 | 0.98 | 0.92 | 0.78 | 0.38 |  |
| 6 6 | 1 dm . | 0.96 | 0.87 | 0.79 | 0.45 | 0.08 |  |  |

## TRANSMISSIBILITY OF RADIATION BY GLASSES.

The following data giving the percentage transmission of radiation of various substances, mostly glasses, are selected from Spectroradiometric Investigation of the Transmission of Various substances, Coblentz, Emerson and Long, Bul. Bureau Standards, 14, p. 653, 1918.

| Glass or substance, manufacturer. | Thickmm | Transmission per cents. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Wave-lengths in $\mu$. |  |  |  |  |  |  |  |  |  |
|  |  | 0.5 | \%. 0 | 1. 5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| Purple fluorite. | 4.98 | - | - | - | 47 | 48 | 48 | 57 | 60 | 62 | 62 |
| Gold film on Crooke's glass |  | 22 | 3 | 2 | 1 | 1 | 1 | $\bigcirc$ | - | $\bigcirc$ | - |
| crown glass | - | 34 | 8 | 3 | 2 | 1 | I | - | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| Molybdenite. | . 007 | - | 4 I | 43 | 44 | 46 | 46 | 47 | 48 | 48 | 48 |
| $\mathrm{Cr}_{2}\left(\mathrm{SO}_{4}\right)_{3} .18 \mathrm{H}_{2} \mathrm{O} .$. | . 24 | - | 83 | 63 | 37 | 11 | - | - | - | - | - |
| Chrome alum, 10 g to $100 \mathrm{~g} \mathrm{H}_{2} \mathrm{O}$ | 10 |  | 73 | $\bigcirc$ | $\bigcirc$ | - | - |  |  |  |  |
| $\mathrm{CoCl}_{2}$, 10 g to $100 \mathrm{~g} \mathrm{H}_{2} \mathrm{O} \ldots \ldots$. Glasses: | 10 | - | 50 | - | - | - |  | - |  | - | - |
| Copper ruby, flashed. | I. 95 | - | 50 | 64 | 72 | 76 | 40 | 33 | 36 | 7 | - |
| G24, Corning, red. | 5.90 | - | 60 | 70 | 72 | 65 | 2 | 1 | - | - | - |
| Schott's red, No. 2745 | 3.18 | - | 83 | 89 | 89 | 75 | 10 | 10 | - | - | - |
| $\mathrm{G}_{34}$, Corning, orange | 3.55 | - | 50 | 62 | 67 | 68 | 15 | 3 | 1 | $\bigcirc$ | - |
| Pyrex, Corning. . . . | I. 55 | 90 | 90 | 90 | 9 I | 87 | 35 | 13 | 7 | 2 | - |
| Noviol, B, Corning, yellow . | 2.88 | 80 | 75 | 60 | 82 | 75 | 23 | 4 | 4 | - | - |
| Novieweld ${ }^{\text {, Corning, }}$, dk-yellow | 2.2 | 12 | I | ${ }^{2}$ | 6 | ${ }_{13}$ | 6 | 7 | 7 | 1 | $\bigcirc$ |
| Schott's 43III, green. | 3.43 | 50 | 4 | 53 | 79 | 83 | 25 | 9 | $\bigcirc$ | - | - |
| Gr7ron, green, Corning. | 5.11 |  | 1 | 23 | 53 | 68 | 20 | 9 | 8 | $\bigcirc$ | - |
| G174J, Corning, heat abs'b'g. | 2.6 | - | 2 | 4 | 12 | 19 | 11 | 4 | 6 | - | - |
| Gi24JA, Corning. | I. 5 | 52 | - | 1 | 5 | 10 | 3 | 5 | 6 | - | - |
| Cobalt blue | 2.43 | - | 74 | 43 | 63 | 79 | 36 | 27 | 28 | - | - |
| Schott's F3086, blue | 2.58 | - | - | 1 | 2 | 31 | 11 | 5 | 4 | - | - |
| G4013, Corning, blue. . . . . . . | 6.36 | - | - | 15 | 50 | 61 | 11 | I | 2 | $\bigcirc$ | - |
| G584, Corning, blue . | 3.70 | - | - | 24 | 60 | 75 | 45 | 20 | 20 | 1 | - |
| G1711Z, Corning, blue. | 3.23 | - | 23 | 60 | 74 | 78 | 45 | 13 | 12 | 1 | $\bigcirc$ |
| Amethyst, C, Corning | 2.11 | 55 | 91 | 91 | 91 | 88 | 42 | 20 | 25 | 7 | - |
| G172BW5. Corning, red-purple | 4.43 |  | - | - | 2 | 5 | 6 | 8 | 12 | 2 | $\bigcirc$ |
| Crookes' A, A. O. Co. | I. 96 | 90 | 92 | 91 | 90 | 83 | 38 | 23 | 27 | 5 | $\bigcirc$ |
| " sage green $30, \mathrm{~A} . \mathrm{O} . \mathrm{Co}$ | 1.98 | 50 | $\bigcirc$ | - | 4 | 11 | 8 | 8 | 11 | 3 | $\bigcirc$ |
| Lab. 58, A. O. Co. | 2.04 | 72 | 86 | 91 | 91 | 89 | 51 | 35 | 38 | 7 | $\bigcirc$ |
| Fieurzal B, A. O. Co. | 2.04 | 59 | 76 | 80 | 82 | 8 81 | 30 | 20 | 25 51 | 10 | $\bigcirc$ |
| Akopos green, J. K. O. Co. . | 1.58 | 76 | 91 | 91 | 91 | 90 | 70 | 52 | 51 | 10 | $\bigcirc$ |

Manufacturers: Corning Glass Works, Corning, N. Y.; A. O. Co., American Optical Co., Southbridge, Mass.; J. K. O. Co., Julius King Optical Co., New York City. For other glasses see original reference. See also succeeding table, which contains data for many of the same glasses.

TABLE 371．－Transmission of the Radiations from a Gas－filled Tungsten Lamp，the Sun，a Magnetite Arc，and from a Quartz Mercury Vapor Lamp（no Globe）through Various Substances，especially Colored Glasses．

| Color． | Trade name． | Source．＊ | Thick－ ness in mm | Transmission，per cent． |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Quartz mercury vapor．$\dagger$ | Mag－ netite arc．$\dagger$ | Solar radia－ tion． |
| Greenish－yellow． | Fieuzal，B | A．O．C． | 2.04 | 71.6 | 26.9 | 46.0 | 63 |
| ＂${ }^{\text {c }}$ | Fieuzal， 63 | F．H．E．${ }^{\text {F }}$ | 1．80 | 75.5 | 34.3 | 55.0 | 72 |
| ＂ | Fieuzal， 64 | F．H．E． | r． 65 | 50.7 | 22.0 |  |  |
| ＂،＂، | Euphos | B．S． | 3.27 | 78.9 | 25.0 | － |  |
| ＂،＂، | Euphos，B | B．\＆L． | 3.12 | 78.8 | 24.7 | 53.0 | 64 |
| ＂＂＂ | Akopos green Hallauer， 65 | J．K．${ }_{\text {S．}}$ | 1． 58 2.36 1.3 | 84.6 70.3 | 29.5 17.7 | 59.0 | 74 |
| ＂ | Hallauer， 64 | F．H．E． | I． 35 | 58.7 | 25.9 | － | 55 |
| Smoky green． | G 124．IP | C．G．W． | 2.81 | 5.7 0.4 | 0．2 | － | 5 |
| Yellow－green． | Noviweld，30\％ | C．G．W． | 2.14 | 5.1 | 7.8 | － | 9 |
| ＂،＂ | Noviweld，shade 3 Noviweld， | C．G．W． | 2.20 2.20 | 3.4 I． 6 | 4.2 1.2 | 2.7 0.8 |  |
| ＂،＂، | Noviweld，shade ${ }^{\text {Novin }}$－${ }^{\frac{1}{2}}$ Noviweld，shade 6 | C．G．W． | 2.20 2.17 | 1.6 0.9 | 1.2 0.4 | 0.8 0.2 | $\overline{0.9}$ |
| ＂＂ | Noviweld，shade 7 | C．G．W． | 2.17 | 0.8 | 0． 2 | 0.2 | 0.9 |
| Amber． |  | B．S． | 3.12 | 51.6 | 15.2 | － |  |
|  | Saniweld，dark | J．K． | 1．32 | 78.1 | 10.6 | 43.0 | 50 |
| Orange Yellow | G 34 ， | C．G．W． | 3.57 2.00 | 56.9 | 17.0 |  | 47 87 |
|  | Noviol，shade B | C．G．W． | 2.00 2.88 | 74.1 | 32.2 | 56.0 | 75 |
| ＂．．． | Noviol，shade C | C．G．W． | 2.00 |  | 32.2 | 56. | 72 |
| Sage green．．． | Ferrous No． 30 | A．O．C． | 1.95 | $5 \cdot 3$ | 17.5 | 二 | 17 |
| Yellow－green | No． 61 | A．O．C． | 2.10 | 82.7 | 28.6 | － | 72 |
| Blue－green |  | $\xrightarrow{\text { A．O．G．} \mathrm{W} \text { ．}}$ | 1． 93 I． 53 | 3.7 5.3 | 17.3 21.5 | 11.5 |  |
| Black | Smoke，C | B．\＆L． | 2.26 | 65.3 | 31.2 | 52.0 | 60 |
|  | Smoke，D | B．\＆L． | 2.45 | 50.9 | 16.0 | 39.0 | 43 |
| Neutral tint | Crookes，A | A．O．C． | 1.97 | 85.3 | 46.1 | － | 89 |
|  | Crookes，B | A．O．C． | 2.00 | 75.7 | 32.0 | 64.0 | 69 |
|  | ${ }^{\text {Pfund }}$ fund | A．O．${ }_{\text {A．}}^{\text {A．}}$（ | 二 |  | 7.2 1.3 | 1． 2 | 12 |
| Colorless．． | Lab．No． 58 | A．O．C． | 1． 58 | 83.3 | 40.0 | 66 | 88 |
|  | Lab．No． 57 | A．O．C． | 2.00 | － | 51.9 | － |  |
| Amethyst | Shade C | A．O．C． | 2.11 | 82.8 | 44.3 |  | 79 |
| Purple． | Electric smoke | A．O．C． | 1． 89 | 36.6 | 2.2 |  |  |
|  | G 55 A 62 | C．G．W． | 2.85 | 17.4 | 17.0 | － | 16 |
| Blue ．． Blue，dark | ${ }_{\text {G }}{ }_{53}$ D | B．\＆L． | 2.09 | 37.6 | 20.7 | 39 | － |
| Blue－green． | G ${ }_{\text {I }}^{53} \mathrm{I}-\mathrm{IZ}$ | C．G．W． | 2.51 3.21 | 2.9 46.6 | 3.9 41.7 |  |  |
| Blue－green，pale | G 584 | C．G．W． | 3.75 | 24.9 | 25.2 |  |  |
| Red－purple．． | G 172 BW 5 | C．G．W． | 4.93 | 72.4 | 26.5 | － | － |
| Blue－purple | G 585 | C．G．W． | 3.13 | 35.8 | 34.0 | － | $4{ }^{1}$ |
| Red． | Selenium | C．G．W． | 2.90 | 67.8 | 7.9 | 48 | 48 |
|  | Flashed | Schotts B．S． | 3.22 | 69.4 | － 4.8 |  | 46 |
| Colorless | Window | B．S． | 1． 85 | － | 59.5 | 二 | 82 |
| Brow | Crown | B．S． | 1． 56 | 一 | 64.9 | － | 92 |
| Brown． | Mica | B．S． | 1． 30 | － | 35.4 |  | － |
| Colorless． | Mica | B．S． | 0.09 | － | 43.1 | 二 |  |
| Clear．．． | Water | B．S． | 10.0 | 34.2 | $\ddagger 54.0$ | － | － |

＊A．O．C．，Amer．Optical Co．，Southbridge，Mass．；C．G．W．，Corning Glass Works，Corning，N．Y．；B．\＆L．， Bausch \＆Lomb，Rochester，N．Y．；J．K．，Julius King Optical Co．，New York City；F．H．E．，F．H．Edmonds，optician， Washington，D．C．；B．S．，Bureau of Standards；scrap material，source unknown．
$\dagger$ Infra－red radiation absorbed by quartz cell containing Icm layer of water．Taken from Coblentz－Emerson \＆ Long，Bul．Bureau Standards，14，653， 1918.
$\ddagger$ Transmission of 1 cm cell having glass windows．

Table 372.
TRANSMISSIBILITY OF RADIATION.
Transmissibility of the Various Substances of Tables 330 to 338.
Alum : Ordinary alum (crystal) absorbs the infra-red.
Metallic reflection at $9.05 \mu$ and 30 to $40 \mu$.
Rock-salt : Rubens and Trowbridge (Wied. Ann. 65, 1898) give the following transparencies for a 1 cm . thick plate in $\%$ :

| $\lambda$ | 9 | 10 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20.7 | $23.7 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\%$ | 99.5 | 99.5 | 99.3 | 97.6 | 93.1 | 84.6 | 66.1 | 51.6 | 27.5 | 9.6 | 0.6 | 0. |

Pfluger (Phys. Zt. 5. 1904) gives the following for the ultra-violet, same thickness: $280 \mu \mu, 95.5 \%$; $231,86 \%$; $210,77 \%$; $186,70 \%$.
Metallic reflection at $0.110 \mu, 0.156,51.2$, and $8_{7} \mu$.
Sylvite: Transparency of a 1 cm . thick plate (Trowbridge, Wied. Ann. 60, 1897).

| $\lambda$ | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20.7 | $23.7 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\%$ | 100. | 98.8 | 99.0 | 99.5 | 99.5 | 97.5 | 95.4 | 93.6 | 92. | 86. | 76. | 58. | 15. |

Metallic reflection at $0.114 \mu, 0.16 \mathrm{I}, 6 \mathrm{I} .1$, 100 .
Fluorite: Very transparent for the ultra-violet nearly to o. $1 \mu$.
Rubens and Trowbridge give the following for a 1 cm . plate (Wied. Ann. 60, 1897):

| $\lambda$ | $8 \mu$ | 9 | 10 | 11 | $12 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\%$ | 84.4 | 54.3 | 16.4 | 1.0 | 0 |

Metallic reflection at $24 \mu, 3 \mathrm{I} .6,40 \mu$.
Iceland Spar: Merritt (Wied. Ann. 55, 1895) gives the following values of $k$ in the formula $i=i_{0} \mathrm{e}^{-\mathrm{kd}}$ (din cm.):

For the ordinary ray:

| $\lambda$ | 1.02 | 1.45 | 1.72 | 2.07 | 2.11 | 2.30 | 2.44 | 2.53 | 2.60 | 2.65 | $2.74 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $k$ | 0.0 | 0.0 | 0.03 | 0.13 | 0.74 | 1.92 | 3.00 | 1.92 | 1.21 | 1.74 | 2.36 |


| $\lambda$ | 2.83 | 2.90 | 2.95 | 3.04 | $3.3^{\circ}$ | 3.47 | 3.62 | 3.80 | 3.98 | 4.35 | 4.52 | $4.83 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $k$ | 1.32 | 0.70 | 1.80 | 4.71 | 22.7 | 19.4 | 9.6 | 18.6 | $\infty$ | 6.6 | 14.3 | 6.1 |

For the extraordinary ray :

| $\lambda$ | 2.49 | 2.87 | 3.00 | 3.28 | 3.38 | 3.59 | 3.76 | 3.90 | 4.02 | 4.4 I | $4.67 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $k$ | 0.14 | 0.08 | 0.43 | 1.32 | 0.89 | 1.79 | 2.04 | 1.17 | 0.89 | 1.07 | 2.40 |


| $\lambda$ | 4.9 I | 5.04 | 5.34 | $\frac{5.50 \mu}{2}$ |
| :---: | :---: | :---: | :---: | :---: |
| $k$ | I .25 | 2.13 | 4.4 I | I 2.8 |

Quartz: Very transparent to the ultra-violet; Pfluger gets the following transmission values for a plate 1 cm . thick : at $0.222 \mu, 94.2 \% ; 0.214,92 ; 0.203,83.6 ; 0.186,67.2 \%$.
Merritt (Wied. Ann. 55, 1895) gives the following values for $k$ (see formula under Iceland Spar) : For the ordinary ray:

| $\lambda$ | 2.72 | 2.83 | 2.95 | 3.07 | 3.17 | 3.38 | 3.67 | 3.82 | 3.96 | 4.12 | $4.50 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $k$ | 0.20 | 0.47 | 0.57 | 0.31 | 0.20 | 0.15 | 1.26 | 1.61 | 2.04 | 3.41 | 7.30 |

For the extraordinary ray :

| $\lambda$ | 2.74 | 2.89 | 3.00 | 3.08 | 3.26 | $3 \cdot 43$ | 3.52 | 3.59 | 3.64 | 3.74 | 3.91 | 4.19 | $4.36 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $k$ | 0.0 | 0.11 | 0.33 | 0.26 | 0.11 | 0.51 | 0.76 | ı. 58 | 1.83 | 1.62 | 2.22 | 3.35 | S.0 |

For $\lambda>7 \mu$, becomes opaque, metallic reflection at $8.50 \mu, 9.02,20.75-24.4 \mu$, then transparent again.

The above are taken from Kayser's "Handbuch der Spectroscopie," vol. iii.
Smithsonian Tables.

TABLE 373. - Color Screens.
The following light-filters are quoted from Landolt's "Das optische Drehungsvermögen, etc." 1898 . Although only the potassium salt does not keep well it is perhaps safer to use freshly prepared solutions.

| Color. | Thickness. mm. | Water solutions of | Grammes of substance in $100 \mathrm{c} . \mathrm{cm}$. | Optical centre of band. $\mu$ | Transmission. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Red | 20 | Crystal-violet, 5 BO Potassium monochromate | 0.005 10. | 0.6659 | $\left\{\begin{array}{l} \text { begins about } 0.718 \mu . \\ \text { ends sharp at } 0.639 \mu . \end{array}\right.$ |
| Yellow | 20 | Nickel-sulphate, $\mathrm{NiSO}_{4} .7 \mathrm{aq}$. | 30. | 0.5919 | 0.614-0.574 $\mu$, |
| "' | 15 | Potassium monochromate | 10. |  |  |
| Green | 15 | Potassium permanganate | 0.025 |  |  |
| Green | 20 | Copper chloride, $\mathrm{CuCl}_{2} .2 \mathrm{aq}$. |  | 0.5330 | 0.540-0.50 $5 \mu$ |
| Bright $\{$ | 20 | Potassium monochronate | 10. 0.02 | 0.4885 | $\{0.526-0.494$ and |
| blue ? | 20 | Copper-sulphate, $\mathrm{CuSO}_{4} .5 \mathrm{aq}$. | 15. | 0.488 | 10.494-0.45 $\mu$ |
| Dark | 20 | Crystal-violet, 5 BO | 0.005 | 0.4482 | $0.478-0.410 \mu$ |
| blue | 20 | Copper sulphate, $\mathrm{CuSO}_{4} \cdot 5 \mathrm{aq}$. | 15. |  |  |

## TABLE 374. - Color Screens.

The following list is condensed from Wood's Physical Optics :
Methyl violet, $4 \mathrm{R} \cdot$ (Berlin Anilin Fabrik) very dilute, and nitroso-dimethyl-aniline transmits $0.365 \mu$. Methyl violet + chinin-sulphate (separate solutions), the violet solution made strong enough to blot out $0.4359 \mu$, transmits 0.4047 and 0.4048 , also faintly 0.3984 .
Cobalt glass + aesculin solution transmits $0.4359 \mu$.
Guinea green B extra (Berlin) + chinin sulphate transmits $0.4916 \mu$.
Neptune green (Bayer, Elberfeld) + chrysoidine. Dilute the latter enough to just transmit 0.5790 and 0.546 r ; then add the Neptune green until the yellow lines disappear.
Chrysoidine + eosine transmits $0.5790 \mu$. The former should be dilute and the eosine added until the green line disappears.
Silver chemically deposited on a quartz plate is practically opaque except to the ultra-violet region $0.3160-0.3260$ where $90 \%$ of the energy passes through. The film should be of such thickness that a window backed by a brilliantly lighted sky is barely visible.
In the following those marked with a * are transparent to a more or less degree to the ultra-violet:

* Cobalt chloride : solution in water, -absorbs $0.50-.53 \mu$; addition of $\mathrm{CaCl}_{2}$ widens the band to $0.47-50$. It is exceedingly transparent to the ultra-violet down to 0.20 . If dissolved in methyl alcohol + water, alsorbs $0.50-.53$ and everything below 0.35 . In methyl alcohol alone $0.485-$ 0.555 and below $0.40 \mu$.

Copper chloride: in ethyl alcohol absorbs above 0.585 and below 0.535 ; in alcohol $+50 \%$ water, above 0.595 and below $0.37 \mu$.
Neodymium salts are useful combined with other media, sharpening the edges of the absorption bands. In solution with bichromate of potash, transmits $0.535-.565$ and above $0.60 \mu$, the bands very sharp (a useful screen for photographing with a visually corrected objective).
Praseodymium salts: three strong bands at $0.482, .468, .444$. In strong solutions they fuse into a sharp band at $0.435-.485 \mu$. Absorption below 0.34 .
Picric acid absorbs $0.36-42 \mu$, depending on the concentration.
Potassium chromate absorbs $0.40-.35,0.30-.24$, transmits $0.23 \mu$.

* Potassium permanganate : absorbs $0.555^{-} .50$, transmits all the ultra-violet.

Chromium chloride : absorbs above 0.57 , between 0.50 and .39 , and below $0.33 \mu$. These limits vary with the concentration.
Aesculin: absorbs below $0.363 \mu$, very useful for removing the ultra-violet.

* Nitroso-dimethyl-aniline: very dilute aqueous solution absorbs $0.49-.37$ and transmits all the ultra-violet.
Very dense cobalt glass + dense ruby glass or a strong potassium bichromate solution cuts off everything below 0.70 and transmits freely the red.
Iodine : saturated solution in $\mathrm{CS}_{2}$ is opaque to the visible and transparent to the infra-red.


## Smithsonian Tables.

TRANSMISSIBILITY OF RADIATION.
TABLE 375, - Color Screens. Jona Glasses.

|  | Kind of Class. | $\begin{gathered} \text { Maker's } \\ \text { No } \end{gathered}$ | Color. | Region Transmitted. | $\begin{gathered} \text { Thick- } \\ \text { ness. } \\ \text { nm. } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Copper-ruby | 2728 | Deep red | Only red to 0.6 ${ }^{\text {. . . . }}$ | 1.7 |
| Ia | Gold-ruby | $459{ }^{\text {III }}$ | Red | $\left\{\begin{array}{l}\text { Red, yellow; in thin layers also } \\ \text { blue and violet. }\end{array}\right.$ |  |
| 2 | Uranium | $454{ }^{\text {III }}$ | Bright yellow | $\left\{\begin{array}{c}\text { Red, yellow, green to } \mathrm{E}_{b} \text {; in } \\ \text { thin layer also blue }\end{array}\right\}$ | 16. |
| 2 a |  | $455^{\text {II }}$ | $\left\{\begin{array}{l} \text { Bright yellow, fluo- } \\ \text { resces. } \end{array}\right.$ |  |  |
| 3 | Nickel | $440^{\text {III }}$ | Bright yellow-brown | $\left\{\begin{array}{l} \text { Red, yellow, green (weakened), } \\ \text { blue (very weakened) } \end{array}\right\}$ | 11. |
| ${ }_{4}^{4}$ | Chromium | $411^{111}$ $433^{\text {III }}$ | Yellow-green . Greenish-yellow | Yellowish-green | 10. |
| $4{ }_{4}^{4 \mathrm{a}}$ | Green copper | ${ }_{431}{ }^{\text {IIII }}$ | Greenish-yello | Red, green; from $0.65-.50 \mu$ Green, yellow, some red and blue | 2-3 |
| 5 | Chromium. | $432^{\text {III }}$ | Yellow-green | Yellowish-green, some red . . | $2-3$ 2.5 |
| 7 | Copperchromium Green-filter | $433^{111}$ | Grass-green | Green | 5. |
| 7 | Green-filter | $\begin{aligned} & 433^{I I I I I} \\ & 43^{\text {III }} \end{aligned}$ | Dark green . . | Green (in thin sheets some blue) Green | 5. |
| 10 | Copper | 2742 | Blue, as $\mathrm{CuSO}_{4}{ }_{4}^{\text {. }}$. | Green, blue, violet | 5-12 |
| 1 I | Blue-violet | $447^{\text {III }}$ | Blue, as cobalt glass | Blue, violet. ${ }^{\text {a }}$. | 5. |
| " | " " |  | " " ، " | $\left\{\begin{array}{c}\text { Blue, violet, hlue-green (weak- } \\ \text { ened), no red }\end{array}\right\}$ | 2-5 |
| 12 | Cobalt | $424{ }^{\text {III }}$ | Blue . . ${ }^{\text {D }}$ | Blue, violet, extreme red |  |
| 13 | Nickel | $455^{\text {III }}$ | Dark violet . . . | Violet ( $\mathrm{G}-\mathrm{H}$ ), extreme red . . | 6. |
| 14 |  |  | Gray, no recog. | Violet (G-H), some weakened. . | 0.1-8 |
| 15 | Gray | $\begin{aligned} & 444^{\mathrm{IIII}} \\ & 445^{\mathrm{II}} \end{aligned}$ | $\left\{\begin{array}{c}\text { Gray, no recog. } \\ \text { nizable color }\end{array}\right\}$ | All parts of the spectrum weakened |  |

See "Über Farbgläser für wissenschaftliche und technische Zwecke," by Zsigmondy, Z. für Instrumentenkunde, 21, 190I (from which the above table is taken), and "Über Jenenser Lichtfilter," by Grebe, same volume.
(The following notes are quoted from Everett's translation of the above in the English edition of Hovestadt's " Jena Glass.")
Division of the spectrum into complementary colors :
Ist by 2728 (deep red) and 2742 (blue, like copper sulphate).
2nd by $454^{\text {III }}$ (bright yellow) and $447^{\text {III }}$ (blue, like cobalt glass).
$3^{\text {rd }}$ by $433^{\text {III }}$ (greenish-yellow) and $424^{\text {III }}$ (blue).
Thicknesses necessary in above : 2728, 1.6-1.7 mm.; 2742, $5 ; 454^{\mathrm{II}}, 16 ; 447^{\mathrm{III}}, 1.5-2.0 ; 433^{\mathrm{III}}$, $2.5-3.5 ; 424^{\mathrm{III}}, 3 \mathrm{~mm}$.
Three-fold division into red, green and blue (with violet):
2728 , 1.7 mm .; $414^{\mathrm{III}}$, 10 mm .; $447^{\mathrm{III}}, 1.5 \mathrm{~mm}$., or by
2728 , $1.7 \mathrm{~mm} . ; 43^{1 \mathrm{II}}, 2.6 \mathrm{~mm} . ; 447^{\mathrm{III}}$, I. 8 mm .
Grebe found the three following glasses specially suited for the additive methods of three-color projection :

2745 , red ; $438^{\text {III }}$, green; $447^{\text {III }}$, blue violet ;
corresponding closely to Young's three elementary color sensations.
Most of the Jena glasses can be supplied to order, but the absorption bands vary somewhat in different meltings.
See also "Atlas of Absorption Spectra," Uhler and Wood, Carnegie Institution Publications, 1907.
TABLE 376.-Water.
Values of a in $\mathrm{I}=\mathrm{I}_{0} \mathrm{e}^{\text {ad }}, \mathrm{d}$ in $\mathrm{c} . \mathrm{m} . \mathrm{I}_{0} ; \mathrm{I}$, intensity before and after transmission.

| Wave-length $\mu$, | . 186 | . 193 | . 200 | . 210 | . 220 | . 230 | . 240 | . 260 | . 300 | .415 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| a | . 0688 | . 0165 | . 009 | .006I | . 0057 | . 0034 | .0032 | . 0025 | .0015 | . 00035 |
| Wave-length $\mu$, | . 430 | . 450 | .487 | . 500 | . 550 | . 600 | . 650 | . 779 | . 865 | . 945 |
| a | . 00023 | . 0002 | . 0001 | . 0002 | . 0003 | . 0016 | . 0025 | 272 | . 296 | . 5.38 |

First 9; Kreusler, Drud. Ann. 6, 1901; next Ewan, Proc. R. Soc. 57, 1894, Aschkinass, Wied Ann. 55, 1895; last 3, Nichols. Phys. Rev. 1, 1.
See Rubens, Ladenburg, Verh. D. Phys. Ges., p. 19, 1909, for extinction coefs., reflective power and index of refraction, $1 \mu$ to $18 \mu$.

# TRANSMISSION PERCENTAGES OF RADIATION THROUGH MOIST AIR. 

(For bodies at laboratory temperalures; for transmission of shorter-wave energy, see Table 553.)
The values of this table will be of use for finding the transmission of energy through air containing a known amount of water vapor. An approximate value for the transmission may be had if the amount of energy from the source between the wave-lengths of the first column is multiplied by the corresponding transmission coefficients of the subsequent columns. The values for the wave-lengths greater than $18 \mu$ are tentative and doubtful. Fowle, Water-vapor Transparency, Smithsonian Misc. Collections, 68 , No. 8, 1917; Fowle, The Transparency of Aqueous Vapor, Astrophysical J. 42, p. 394, 1915.

| Range of wave-lengths. | Precipitable water in centimeters. |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu \quad \mu$ | . 001 | . 003 | . 006 | . 01 | . 03 | . 06 | . 10 | . 25 | . 50 | 1.0 | 2.0 | 6.0 | 10.0 |
| 0.75 to 1.0 | - | - | - | 100 | 99 | 99 | 98 | 97 | 95 | 93 | 90 | 83 | 78 |
| $1.0 \quad 1.25$ | - | - | - | 99 | 99 | 98 | 97 | 95 | 92 | 89 | 85 | 74 | 69 |
| 1.251 .5 | - | - | - | 96 | 92 | 84 | 80 | 66 | 57 | 51 | 44 | 31 | 28 |
| 1.52 .0 | - | - | - | 98 | 97 | 94 | 88 | 79 | 73 | 70 | 66 | 60 | 57 |
| * 23 | 96 | 92 | 87 | 84 | 77 | 70 | 64 | - |  |  | - | - | - |
| 34 | 95 | 88 | 8.4 | 78 | 72 | 66 | 63 | - | - | - | - | - | - |
| * 45 | 92 | 83 | 76 | 71 | 65 | 60 | 53 | - | - | - | - | - | - |
| 56 | 95 | 82 | 75 | 68 | 56 | 51 | 47 | 35 | - | - | - | - | - |
| $6 \quad 7$ | 85 | 54 | 50 | 31 | 24 | 8 | 4 | 3 | 2 | - | - | $\bigcirc$ | 0 |
| 78 | 9.4 | 84 | 76 | 68 | 57 | 46 | 35 | 16 | 10 | 2 | $\bigcirc$ | $\bigcirc$ | 0 |
| 8 . 9 | 100 | 100 | 100 | 99 | 98 | 96 | 94 | 65 | - | - | - | - | - |
| $\dagger 9$ 10 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | - | - |
| $\dagger$ IO 11 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | - | - |
| 1112 | 100 | 100 | 100 | 100 | 100 | 99 | 98 | 96 | 95 | 93 | - | - | - |
| 12 I3 | 100 | 100 | 100 | 100 | 99 | 99 | 97 | 86 | 82 | - | - | - | - |
| * I3 I4 | 100 | 100 | 100 | 99 | 97 | 94 | 90 | 80 | 60 | - | - | - | - |
| * 14 I5 | - | - | 96 | 93 | 80 | 75 | 50 | 15 | $o$ | $o$ | $o$ | $o$ | $o$ |
| * 1516 | - | - | - | - | 70 | 55 | 40 | $o$ | $o$ | $o$ | $o$ | 0 | $o$ |
| 1617 | - | - | - | - | - | 50 | 20 | $o$ | - | $\bigcirc$ | - | $\bigcirc$ | 0 |
| 17 18 | - | - | - | - | - | 25 | 10 | $o$ | - | $\bigcirc$ | - | - | 0 |
| $18 \quad \infty$ | 98 | 94 | 89 | 82 | 45 | - | $\bigcirc$ | - | $\bigcirc$ | $\bigcirc$ | - | $\bigcirc$ | $\bigcirc$ |

[^45]In the above table italicized figures indicate extrapolated values.
F. Paschen gives (Annalen d. Physik u. Chemie, 51, p. 14, 1894) the absorption of the radiation from a blackened strip at $500^{\circ} \mathrm{C}$ by a layer 33 centimeters thick of water vapor at $100^{\circ} \mathrm{C}$ and atmospheric pressure as follows:

$$
\begin{array}{cccc}
\text { Wave-length. ............... } & 2.20-3.10 \mu & 5.33-7.67 \mu & 7.67-10(?) \mu \\
\text { Percentage absorption......... } & 80 & 94 & 94-13
\end{array}
$$

The following table, due to Rubens and Aschkinass (Annalen d. Physik u. Chemie, 64, p. 598, 1898), gives the absorption of radiation from a zircon burner by a layer 75 centimeters thick of water vapor saturated at $100^{\circ} \mathrm{C}$. This amount of vapor is about equivalent to a layer of water 0.45 millimeter thick or to $1.5 \%$ of the water in a total vertical atmospheric column whose dew point at sea-level is $10^{\circ} \mathrm{C}$. The region of spectrum examined includes most of the region of terrestrial radiation.

| Wave-length. $\ldots \ldots \ldots \ldots .$. | $7.0 \mu$ | $8.0 \mu$ | $9.0-12.0 \mu$ | $12.4 \mu$ | $12.8 \mu$ | $13.4 \mu$ | $14.0 \mu$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Percentage absorption..... | 75 | 40 | 6 | 20 | 13 | 28 | 22 |
| Wave-length........... $14.3 \mu$ | $15.0 \mu$ | $15.7 \mu$ | $16.0 \mu$ | $17.5 \mu$ | $18.3 \mu$ | $20.0 \mu$ |  |
| Percentage absorption.... | 43 | 35 | 65 | 52 | 88 | 80 | 100 |

Smithsonian Tables.

TABLE 378. - Long-wave Absorption by Gases.
Unless otherwise noted, gases were contained in a 20 cm long tube. Rubens, Wartenberg, Verb. d. Phys. Ges. 13, p. 796, 19 Ir .


* Tube 40 cm long.
$\dagger$ Pentane vapor, pressure 36 cm .
TABLE 379. - Properties with Wave-lengths $108 \pm \mu$.
Rubens and Woods, Verh. d. Phys. Ges. '13, p. 88, 19 Ir.
With quartz, 1.7 cm thick: 60 to $80 \mu$, absorption very great; $63 \mu, 99 \% ; 82 \mu, 97.5 ; 97 \mu, 83$.



## 3 IO TABLES 380, 381.-ROTATION OF PLPNE OF POLARIZED LIGHT.

## TABLE 380.-Tartario Acid; Camphor; Santonin; Santonic Acld; Cane Sugas.

A few examples are here given showing the effect of wave-length on the rotation of the plane of polarization. The rotations are for a thickness of one decimeter of the solution. The examples are quoted from Landolt \& Börnstein's "Phys. Chem. Tab." The following symbols are used :-

Right-handed rotation is marked + , left-handed -.

| Line of spectrum. | Wave-length according to Angström in $\mathrm{cms} . \times{ }_{10}{ }^{\ell}$. | Tartaric acid, ${ }^{*} \mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$, dissulved in water. $\begin{gathered} q=50 \text { to } 95, \\ \text { temp. }=24^{\circ} \mathrm{C} . \end{gathered}$ | $\begin{gathered} \text { Camphor, }{ }^{*} \mathrm{C}_{10} \mathrm{H}_{16} \mathrm{O}, \\ \text { dissolved in alcohol. } \\ \text { }=50 \text { to } 95, \\ \text { temp. }=22.9^{\circ} \mathrm{C} . \end{gathered}$ |  | $\begin{aligned} & \text { Santonin, }+\mathrm{C}_{15} \mathrm{H}_{18} \mathrm{O}_{3}, \\ & \text { dissolved in chloroform. } \\ & q=75 \text { to } 96.5, \\ & \text { temp. }=20^{\circ} \mathrm{C} . \end{aligned}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\stackrel{\text { B }}{ }$ | 68.67 |  |  |  | $-140^{\circ} .1+$ | $0.2085 q$ |
| C | 65.62 | $+2^{0} .748+0.09446 q$ | $3^{8} \cdot{ }^{\circ} .549-$ | $0.0852 q$ | $\begin{array}{r} 149.3 \\ \hline \end{array}$ | $0.1555 q$ |
| D | 58.92 | $+1.950+0.13030 q$ | 51.945- | 0.0964 q | $-202.7+$ | 0.3086 q |
| E | 52.69 | $+0.153+0.17514 q$ | 74.331 - | $0.1343 q$ | $-285.6+$ | 0. 5820 q |
| $\mathrm{b}_{1}$ | 51.83 |  |  | - | $-302.38+$ | $0.6557 q$ |
| $\mathrm{b}_{2}$ | 51.72 | $-0.832+0.19147 q$ | 79.348 - | $0.1451 q$ |  |  |
| F | 48.61 | $-3.598+0.239774$ | $99.60 \mathrm{I}-$ | $0.1912 q$ | $-365.55+$ | $0.8284 q$ |
| e | 43.83 | $-9.657+0.31437 q$ | 149.696 | $0.2346 q$ | - 534.98 + | $1.5240 q$ |
|  |  |  | Santonin | $\mathrm{C}_{25} \mathrm{H}_{18} \mathrm{O}_{3}$, | Santonic acid, $\dagger$ |  |
|  |  | Santonin, $\dagger \mathrm{C}_{15} \mathrm{H}_{18} \mathrm{O}_{3}$, dissolved in alcohol. $\begin{gathered} c=1.7^{82 .} \\ \text { temp. }=20^{\circ} \mathrm{C} . \end{gathered}$ | dissolved in alcohol. $\begin{aligned} & c=4.046 \\ & \text { temp. } \\ & 20^{\circ} \mathrm{C} . \end{aligned}$ | dissolved in chloroform | $\mathrm{C}_{15} \mathrm{H}_{20} \mathrm{O}_{4}$, dissolved in chloroform. $c=27.192$. temp. $=20^{\circ} \mathrm{C}$. | $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{17}$, dissolved in water. $p=10 \text { to } 30 .$ |
| B | 68.67 | $-110.4{ }^{\circ}$ | $442^{\circ}$ | $484^{\circ}$ | $-49^{\circ}$ | $47^{\circ} \cdot 56$ |
| C | 65.62 | - 118.8 | 504 | 549 | - 57 | 52.70 |
| D | 58.92 | -161.0 | 693 | 754 | $-74$ | 60.41 |
| E | 52.69 | - 222.6 | 991 | 1088 | $-105$ | 84.56 |
| $\mathrm{b}_{1}$ | 51.83 | -237.1 | 1053 | 1148 | - 112 | - |
| $\mathrm{b}_{2}$ | 51.72 |  | - | - |  | 87.88 |
| F | 48.61 | -261.7 | 1323 | 1444 | $-137$ | 101.18 |
| e | 43.83 | - 380.0 | 2011 | 2201 | - 197 | - |
| G | 43.07 42.26 | - | ${ }_{2381}$ | $2 \overline{610}$ |  | 131.96 |
| g | 42.26 | - | 2381 | 2610 | - 230 |  |
|  |  | * Arndtsen, " Ann. <br> $\dagger$ Narini, "R. Acc. <br> $\ddagger$ Stefan, "Sitzb. d. | $\begin{aligned} & \text { im. Phys." } \\ & \text { Lincei,."(3) } \\ & \text { ien. Akad." } \end{aligned}$ | $\begin{aligned} & 54,1858 . \\ & 13,1882 . \\ & 2,1865 . \end{aligned}$ |  |  |

TABLE 381. - Sodium Chlorate; Quartz.

| Sodium chlorate (Guye, C. R. 108, 1889). |  |  |  | Quartz (Soret \& Sarasin, Arch. de Gen. 1882, or C. R. 95, 1882).* |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Spectrum line. | Wavelength. | $\begin{gathered} \text { Temp. } \\ \text { C. } \end{gathered}$ | Rotation per inn. | Spec trum line. | Wavelength. | Rotation per mm. | Spec- <br> trum <br> line. | Wavelength. | Rotation per mm. |
| $\stackrel{ }{\alpha}$ | 71.769 | $15^{\circ}$. 0 | $2^{\circ} .068$ | A | 76.04 | $12^{\circ} .668$ | $\mathrm{Cd}_{9}$ | 36.090 | $63^{\circ} .628$ |
| B | 67.889 | 17.4 | 2.318 | a | 71.836 | 14.304 | N | 35.818 | 64.459 |
| C | 65.073 | 20.6 | 2.599 | B | 68.67 I | 15.746 | $\mathrm{Cd}_{10}$ | 34.655 | 69.454 |
| D | 59.085 | 18.3 | 3.104 |  |  |  |  | 34.406 | 70.587 |
| E | 53.233 | 16.0 | 3.841 | C | 65621 | 17.318 |  |  |  |
| F | 48.912 | 11.9 | 4.587 | $\mathrm{D}_{1}$ | 58951 | 21.684 | $\mathrm{Cd}_{11}$ | 34.015 | 72.448 |
| G | 45.532 | 10.1 | $5 \cdot 33 \mathrm{I}$ | $\mathrm{D}_{2}$ | 58.891 | 21.727 |  | 33.600 | 74.571 |
| G | 42.834 | 14.5 | 6.005 |  |  |  | Q | 32.858 | 78.579 |
| H | 40.714 | 13.3 | 6.754 | E | 52.691 | 27.543 | $\mathrm{Cd}_{12}$ | 32.470 | 80.459 |
| L | 38.412 | 14.0 | 7.654 | F | 48.607 | 32.773 |  |  |  |
| M | 37.352 | 10.7 | 8.100 | G | 43.072 | 42.604 | R | 31.798 | 84.972 |
| N | 35.818 | 12.9 | 8.86 I |  |  |  | $\mathrm{Cd}_{17}$ | 27.467 | 121.052 |
| P | 33.931 | 12.1 | 9.801 | h | 41.012 | 47.481 | $\mathrm{Cd}_{18}$ | 25.713 | 143.266 |
| Q | 32.341 | 11.9 | 10.787 | H | 39.681 | 51.193 | $\mathrm{Cd}_{23}$ | 23.125 | 190.426 |
| R | 30.645 | 13.1 | 11.921 | K | 39.333 | 52.155 |  |  |  |
| $\mathrm{Cd}_{17}$ | 29.918 28.270 | 12.8 | 12.424 13.426 | L | 196 |  | $\mathrm{Cd}_{24}$ Cd 25 | 22.645 | 201.824 |
| $\mathrm{Cd}_{18}$ | 25.038 | 1 I .6 | 14.965 | M | 37.262 | 58.894 | $\mathrm{Cd}_{26}$ | 2 I .431 | 235.972 |

* The paper is quoted from a paper by Ketteler in "Wied. Ann." vol. 21, p. 444. The wave-lengths are for the Fraunhofer lines, Angström's values for the ultra violet sun, and Cornu's values for the cadinium lines.

Abbreviations: int'n'l, international; emu, electromagnetic units; esu, electrostatic units; cgs, centimeter-gram-second units. (Taken from Circular 60 of U.S. Bureau of Standards, 1916, Electric Units and Standards.)

## Resistance:

I international ohm =
I. $0005^{2}$ absolute ohms
r. 000 int'n'l ohms (France, before 1911)
1.00016 Board of Trade units (England, 1903)
r. 01358 B. A. units
1.00283 "legal ohms" of 1884

1. 06300 Siemens units

I absolute ohm $=$
-. 99948 int'n'l ohms
I "practical" emu
$10^{9} \mathrm{cgs}$ emu

1. $1124 \times 10^{-12} \mathrm{cgs}$ esu

## Current:

I international ampere $=$
0.9999 r absolute ampere

1. 00084 int'n'l amperes (U. S. before 19II)
r. 00130 int'n'l amperes (England, before 1906)
r. 00106 int'n'l amperes (England, 190608)
1.00010 int'n'l amperes (England, 190910)
r.00032 int'n'l amperes (Germany, before 1911)
r.0002 int'n'lamperes (France, before 191I)

I absolute ampere $=$
I "0009 int'n'l amperes
I "practical" emu
o. r cgs emu
$2.9982 \times 10^{9} \mathrm{cgs}$ esu

## Electromotive Force:

I international volt $=$

1. 00043 absolute volts
I. 00084 int'n'l volts (U. S. before 191I)
1.00130 int'n'l volts (England, before 1906)
r. 00106 int'n'l volts (England, 1906-08)
r. 00010 int'n'l volts (England, 1909-10)
2. 00032 int'n'l volts (Germany, before 1911)
1.00032 int'n'l volts (France, before 1911)
r absolute volt $=$
3. 99957 int'n'l volt

I "practical" emu
$10^{8} \mathrm{cgs} \mathrm{emu}$
0.0033353 cgs esu

## Quantity of Electrictity:

(Same as current equivalents.)
I international coulomb $=$
I/3600 ampere-hour
1/96500 faraday

## Capacity:

I international farad =
0. 99948 absolute farad
r absolute farad $=$
$1.0005^{2}$ int'n'l farads
I "practical" emu
$10^{-9} \mathrm{cgs}$ emu
$8.9892 \times 10^{11} \mathrm{cgs}$ esu

## Inductance:

r international henry $=$

1. $0005^{2}$ absolute henries

1 absolute henry $=$
o. 99948 int'n'l henry

I "practical" emu
$10^{9} \mathrm{emu}$
I. $1124 \times 10^{-12} \mathrm{cgs}$ esu

Energy and Power:
(standard gravity $=980.665 \mathrm{~cm} / \mathrm{sec} / \mathrm{sec}$.)
r international joule $=$

1. 00034 absolute joules

I absolute joule $=$
0. 99966 int'n'l joule
$10^{7} \mathrm{ergs}$
0. 737560 standard foot-pound
o. 101972 standard kilogram-meter
o. $277778 \times 10^{-6}$ kilowatt-hour

Resistivity:
I ohm-cm $=0.393700$ ohm-inch
$=10,000 \mathrm{ohm}\left(\right.$ meter, $\left.\mathrm{mm}^{2}\right)$
$=12,732.4$ ohm (meter, mm)
$=393,700$ microhm-inch
$=1,000,000$ microhm-cm
$=6,015,290 \mathrm{ohm}$ (mil, foot)
I ohm (meter, gram) $=5710.0$ ohm (mile, pound)

## Magnetic Quantitiés:

I int'n'l gilbert $=0.99991$ absolute gilbert
I absolute gilbert $=1.00009$ int'n'l gilberts
r int'n'l maxwell $=1.00043$ absolute máxwells
r absolute maxwell $=0.99957$ int'n'l maxwell

| I gilbert | $=0.7958$ ampere-turn |
| ---: | :--- |
| I gilbert per $\mathrm{cm}=$ | 0.7958 ampere-turn per |
|  | cm |
| $=$ | 2.02 I ampere-turns per |
|  | inch |
|  | $=1$ line |
| I maxwell | $=10^{-8}$ volt-second |
| I maxwell per $\mathrm{cm}^{2}$ | $=6.45^{2}$ maxwells per in |

## COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS.

The electromotive forces given in this table approximately represent what may be expected from a cell in good working order, but with the exception of the standard cells all of them are subject to considerable variation.

| (a) Double Fluid Cells. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Name of cell. | Negative pole. | Solution. | Positive pole. | Solution. |  |
| Bunsen . . | Amalgamated zinc | $\left\{\begin{array}{c} \mathrm{I} \text { part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ \\ \\ \mathrm{I} 2 \end{array}\right.$ | Carbon | Fuming $\mathrm{HNO}_{3}$ | 1.94 |
| " | " ${ }^{\circ}$ | * | " | $\mathrm{HNO}_{3}$, density I .38 | 1.86 |
| Chromate . | " " | $\left\{\begin{array}{c}12 \text { parts } \mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \\ \text { to } 25 \text { parts of } \\ \mathrm{H}_{2} \mathrm{SO}_{4} \text { and } 100 \\ \text { parts } \mathrm{H}_{2} \mathrm{O} .\end{array}\right\}$ | " | $\left\{\begin{array}{cc}\text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \\ \\ \text { I2 parts } \mathrm{H}_{2} \mathrm{O}\end{array}\right.$ to | 2.00 |
| " | " " | $\left\{\begin{array}{c} \text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ 12 \text { parts } \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | " | $\left\{\begin{array}{c}12 \text { parts } \mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7} \\ \text { to } 100 \text { parts } \mathrm{H}_{2} \mathrm{O}\end{array}\right\}$ | 2.03 |
| Daniell * . | " " | $\left\{\begin{array}{c} \text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ 4 \text { parts } \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | Copper | $\left\{\begin{array}{c} \text { Saturated solution } \\ \text { of } \mathrm{CuSO}_{4}+5 \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | 1.06 |
| " | " " | $\left\{\begin{array}{c} \text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ \text { I } 2 \text { parts } \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | " | " | 1.09 |
| " | " " | $\left\{\begin{array}{c} 5 \% \text { solution of } \\ \mathrm{ZnSO}_{4}+6 \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | " | " | 1.08 |
| " | " " | $\left\{\begin{array}{c} \text { I part } \mathrm{NaCl} \text { to } \\ 4 \text { parts } \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | " | " | 1.05 |
| Grove . . | ". ${ }^{\text {c }}$ | $\left\{\begin{array}{c}\text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ \text { I2 parts } \mathrm{H}_{2} \mathrm{O}\end{array}\right\}$ | Platinum | Fuming $\mathrm{HNO}_{3}$. | 1.93 |
| " . | " " | Solution of $\mathrm{ZnSO}_{4}$ | " | $\mathrm{HNO}_{3}$, density 1.33 | 1.66 |
| " | " " | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution, } \\ \text { density } 1.136 \end{array}\right\}$ | " | Concentrated $\mathrm{HNO}_{3}$ | 1.93 |
| " | " " | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution, } \\ \text { density I.1 } 36 . \end{array}\right\}$ | " | $\mathrm{HNO}_{3}$, density 1.33 | 1.79 |
| " | " " | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution, } \\ \text { density } \mathrm{I} .06 \end{array}\right\}$ | " | " | 1.71 |
| " | " " | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution, } \\ \text { density } 1.14 \end{array}\right\}$ | " | $\mathrm{HNO}_{3}$, density 1.19 | 1.66 |
| " | " " | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution, } \\ \text { density } 1.06 \end{array}\right\}$ | " | " " " | 1.61 |
| " | " * | NaCl solution . . | " | " density 1.33 | 1.88 |
| Marié Davy | " " | $\left\{\begin{array}{cc} \text { I part } \mathrm{H}_{2} \mathrm{SO}_{4} \text { to } \\ \text { I } 2 \text { parts } \mathrm{H}_{2} \mathrm{O} \end{array}\right\}$ | Carbon | $\left\{\begin{array}{c} \text { Paste of protosul- } \\ \text { phate of mercury } \\ \text { and water } . \end{array}\right\}$ | 1.50 |
| Partz . | " ${ }^{\text {a }}$ | Solution of $\mathrm{MgSO}_{4}$ | " | Solution of $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 2.06 |

[^46]COMPOSITION AND ELECTROMOTIVE FORCE OF VOLTAIC CELLS.

| Name of cell. | Negative pole. | Solution. | Positive pole. | E. M. F in volts. |
| :---: | :---: | :---: | :---: | :---: |
| (b) Single Fluid Cells. |  |  |  |  |
| Leclanche . . . <br> Chaperon . . . <br> Edison-Lelande . <br> Chloride of silver <br> Law . . . . . <br> Dry cell (Gassner) <br> Poggendorff . . <br> J. Regnault . . . <br> Yolta couple | Amal.zinc <br> " " <br> Zinc <br> " <br> " <br> Amal.zinc <br> " " <br> " " <br> Zinc |  |  | 1.46 <br> 0.98 <br> 0.70 <br> 1.02 <br> I. 37 <br> 1.3 <br> 1.08 <br> 2.01 <br> 0.34 <br> 0.98 |
| (c) Standard Crles. |  |  |  |  |
| Weston normal <br> Clark standard | $\left\{\begin{array}{c} \left\{\begin{array}{l} \text { Cadmi'm } \\ \text { am'lgam } \end{array}\right\} \\ \left\{\begin{array}{c} \text { Zinc } \\ \text { am'lgam } \end{array}\right\} \end{array}\right.$ | $\left\{\begin{array}{c} \left\{\begin{array}{c} \text { Saturated solution of } \\ \mathrm{CdSO}_{4} \end{array}\right\} \\ \left\{\begin{array}{c} \text { Saturated solution of } \\ \mathrm{ZnSO}_{4} \end{array}\right\} \end{array}\right.$ |  | 1.018 $3^{*}$ at $20^{\circ}$ <br> at $20^{\circ} \mathrm{C}$ $\begin{array}{r} 1.434 \ddagger \\ \text { at } 15^{\circ} \mathrm{C} \end{array}$ |
| (d) Secondary Cells. |  |  |  |  |
| Lead accumulator <br> Regnier ( r ). <br> Main <br> (2). <br> Edison | Lead . <br> Copper <br> Amal. zinc Amal.zinc <br> Iron | $\left\{\begin{array}{c} \mathrm{H}_{2} \mathrm{SO}_{4} \text { solution of } \\ \text { density } 1.1 \end{array}\right\}$ $\mathrm{CuSO}_{4}+\mathrm{H}_{2} \mathrm{SO}_{4} .$ <br> $\mathrm{ZnSO}_{4}$ solution. <br> $\mathrm{H}_{2} \mathrm{SO}_{4}$ density ab't I.I <br> $\mathrm{KOH} 20 \%$ solution . | $\mathrm{PbO}_{2}$. $" \text { in } \mathrm{H}_{2} \mathrm{SO}_{4}$ <br> A nickel oxide | $\begin{gathered} 2.2 \dagger \\ \left\{\begin{array}{l} 1.68 \text { to } \\ 0.85, \text { av- } \\ \text { erage } 1.3 . \\ 2.36 \end{array}\right. \\ 2.50 \\ \left\{\begin{array}{l} \text { i.1, mean } \\ \text { of full } \\ \text { discharge. } \end{array}\right. \end{gathered}$ |

* The temperature formula is $\mathrm{E}_{\mathrm{t}}=\mathrm{E}_{20}-0.0000406(\mathrm{t}-20)-0.00000095(\mathrm{t}-20)^{2}+0.00000001(\mathrm{t}-20)^{3}$.
$\ddagger$ The value given for the Clark cell is the old one adopted by the Chicago International Electrical Congress in $\mathbf{8} 893$ The temperature formula is $E_{t}=E_{15}-0.00119(t-15)-0.000007(t-15)^{2}$.
$\dagger$ F. Streintz gives the following value of the temperature variation $\frac{\mathrm{dE}}{\mathrm{dt}}$ at different stages of charge:

$$
\begin{array}{cccccccc}
\text { E. M. F. } & 1.9223 & 1.9828 & 2.0031 & 2.0084 & 2.0105 & 2.0779 & 2.2070 \\
\mathrm{dE} / \mathrm{dt} \times \mathrm{IO}^{6} & 140 & 22 \mathrm{~S} & 335 & 285 & 255 & 130 & 73
\end{array}
$$

Dolezalek gives the following relation between E. M. F and acid concentration :

$$
\begin{array}{llllll}
\text { Per cent } \mathrm{H}_{2} \mathrm{SO}_{4} & 64.5 & 52.2 & 35.3 & 21.4 & 5.2 \\
\text { E.M.F., o } \mathrm{C} & 2.37 & \mathbf{2 . 2 5} & 2.10 & 2.00 & 1.89
\end{array}
$$

Smithsonian Tables.

|  | 矿 | 芯 | ¢ | - |  | $\dot{\underline{E}}$ | - |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Distilled water . . . - | $\left\{\begin{array}{c}.01 \\ \text { to } \\ .17\end{array}\right.$ | .269 to .100 | . 148 | .171 | $\left\{\begin{array}{c}.285 \\ \text { to } \\ .345\end{array}\right\}$ | .177 | $\left\{\begin{array}{r}\text {-. } 105 \\ \text { to } \\ \text { +.15 } 56\end{array}\right.$ |
| Alum solution : saturated at $1^{\circ}{ }_{5} \mathrm{C}$. . | - | -. 127 | -. 653 | -. 139 | . 246 | -. 225 | - |
| Copper sulphate solution : \} sp. gr. i. 087 at $\mathrm{I}^{\circ} .6 \mathrm{C}$. | - | . 103 | - | - | - | - | - |
| Copper sulphate solution : saturated at $15^{\circ} \mathrm{C}$. | - | . 070 | - | - | - | - | - |
| $\left.\begin{array}{l}\text { sea salt solution: sp. gr. } \\ \text { I. } 18 \text { at } 20^{\circ} .5 \mathrm{C} \text {. . . . }\end{array}\right\}$ | - | -. 475 | -. 605 | - | -. 856 | -. 334 | -. 565 |
| Sal-ammoniac solution: ) saturated at $15^{\circ} .5 \mathrm{C}$. | - | -. 396 | $-.652$ | -.189 | . 059 | $-.364$ | $-.637$ |
| Zinc sulphate solution: sp. gr. I. 125 at $6^{\circ} .9$ C. . | - | - | - | - | - | - | $-.238$ |
| Zinc sulphate solution: saturated at $15^{\circ} \cdot 3 \mathrm{C}$. | - | - | - | - | - | - | -. 430 |
| One part distilled water $+\lambda$ 3 parts saturated zinc sulphate solution. .. . | - | - | - | - | - | - | -. 444 |
| strong sulphuric acid in distilled water: <br> I to 20 by weight | - | - | - | - | - | - | -. 344 |
| I to io by volume . . | \{ about , | - | - | - | - | _ | - |
| I to 5 by weight . . . . | (-.035) | - | - | - | - | - | - |
| 5 to I by weight . . . . | $\left\{\begin{array}{l}.01 \\ \text { to } \\ 3.0\end{array}\right\}$ | - | - | -. 120 | - | -. 25 | - |
| Concentrated sulphuric acid | $\left\{\begin{array}{l}.55 \\ \text { to } \\ .85\end{array}\right\}$ | I. 113 | - | $\left\{\begin{array}{c}.72 \\ \text { to } \\ 1.252\end{array}\right.$ | $\left.\begin{array}{l}\text { I. } 3 \\ \text { to } \\ \text { I. } 6\end{array}\right\}$ | - | - |
| Concentrated nitric acid | (.85) | - | - |  | . 672 | - | - |
| Mercurous sulphate paste . | - | - | - | - | . 6 | - | - |
| Distilled water containing \} trace of sulphuric acid | - | - | - | - | - | - | -. 241 |

* Everett's " Units and Physical Constants: " Table of

[^47]
## POTENTIAL IN VOLTS.

## Liquids with Liquids in Air.*

during experiment about $16^{\circ} \mathrm{C}$.

|  |  |  | $\begin{aligned} & \text { 苞 } \\ & \text { 范 } \end{aligned}$ |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Distilled water . | . 100 | . 231 | - | - | - | -. 043 | - | . 164 | - | - |
| Alum solution : saturated $\}$ at $16^{\circ} .5 \mathrm{C}$. | - | -. 014 | - | - | - | - | - | - | - | - |
| Copper sulphate solution : sp. gr. 1.087 at $16^{\circ} .6 \mathrm{C}$. | - | - | - | - | - | - | . 090 | - | - | - |
| Copper sulphate solution: $\}$ saturated at $15^{\circ} \mathrm{C}$. | - | - | - | -. 043 | - | - | - | . 095 | . 102 | - |
| Sea salt solution: sp. gr. I. 18 at $20^{\circ} .5 \mathrm{C}$. | - | -. 435 | - | - | - | - | - | - | - | - |
| Sal-ammoniac solution: saturated at $15^{\circ} .5 \mathrm{C}$. | - | -. 348 | - | - | - | - | - | - | - | - |
| Zinc sulphate solution: sp. gr. 1.125 at $16^{\circ} .9 \mathrm{C}$. | - | - | - | - | - | - | - | - | - | - |
| Zinc sulphate solution: $\}$ saturated at $15^{\circ} .3 \mathrm{C}$. | -. 284 | - | - | -. 200 | - | -. 095 | - | - | - | - |
| One part distilled water + \} 3 parts saturated zinc sulphate solution | - | - | - | - | - | -. 102 | - | - | - | - |
| Strong sulphuric acid in distilled water : I to 20 by weight | - | - | - | - | - | - | - | - | - | - |
| I to io by volume | -.358 | - | - | - | - | - | - | - | - | - |
| I to 5 by weight . . . | . 429 | - | - | - | - | - | - | - | - | - |
| 5 to I by weight . . . . | - | -. 016 | - | - | - | - | - | - | - | - |
| Concentrated sulphuric acid | . 848 | - | - | 1. 298 | 1.456 | 1. 269 | - | 1.699 | - | - |
| Concentrated nitric acid . |  |  | - | - | - | - | - | - | - | - |
| Mercurous sulphate paste. | - | - | . 475 | - | - | - | - | - | - | - |
| Distilled water containing trace of sulphuric acid. | - | - | - | - | - | - | - | - | - | .078 |

Ayrton and Perry's results, prepared by Ayrton.

## Smithsonian Tables.

## DIFFERENCE OF POTENTIAL BETWEEN METALS IN SOLUTIONS OF SALTS.

The following numbers are given by G. Magnanini * for the difference of potential in hundredths of a volt between zinc in a normal solution ot sulphuric acid and the metals named at the head of the different columns when placed in the solution named in the first column. The solutions were contained in a U-tube, and the sign of the difference of potential is such that the current will flow from the more positive to the less positive through the external circuit.

| Strength of the solution in gram molecules per liter. |  | Zinc. $\dagger$ | Cadmium. $\dagger$ | Lead. | Tin. | Copper. | Silver. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| No. of molecules. | Salt. | Difference of potential in centivolts. |  |  |  |  |  |
| 0.5 | $\mathrm{H}_{2} \mathrm{SO}_{4}$ | 0.0 | 36.6 | 51.3 | 51.3 | 100.7 | 121.3 |
| 1.0 | NaOH | -32.1 | 19.5 | 31.8 | 0.2 | 80.2 | 95.8 |
| 1.0 | KOH | -42.5 | 15.5 | 32.0 | $-1.2$ | 77.0 | 104.0 |
| 0.5 | $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 1.4 | 35.6 | 50.8 | 51.4 | 101.3 | 120.9 |
| 1.0 | $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ | -5.9 | 24.1 | $45 \cdot 3$ | 45.7 | 38.8 | 64.8 |
| 1.0 | $\mathrm{KNO}_{3}$ | $11.8 \ddagger$ | 31.9 | 42.6 | 31.1 | 81.2 | 105.7 |
| 1.0 | $\mathrm{NaNO}_{3}$ | 11.5 | 32.3 | 51.0 | 40.9 | 95-7 | 114.8 |
| 0.5 | $\mathrm{K}_{2} \mathrm{CrO}_{4}$ | $23.9 \ddagger$ | 42.8 | 41.2 | 40.9 | 94.6 | 121.0 |
| 0.5 | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 72.8 | 61.1 | 78.4 | 68.1 | 123.6 | 132.4 |
| 0.5 | $\mathrm{K}_{2} \mathrm{SO}_{4}$ | I. 8 | 34.7 | 51.0 | 40.9 | 95.7 | 114.8 |
| 0.5 | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | -0. 5 | 37.1 | 53.2 | $57.6 \ddagger$ | 101.5 | 125.7 |
| 0.25 | $\mathrm{K}_{4} \mathrm{FeC}_{6} \mathrm{~N}_{6}$ | -6.1 | 33.6 | 50.7 | 41.2 | $-\ddagger$ | 87.8 |
| 0.167 | $\mathrm{K}_{6} \mathrm{Fe}_{2}(\mathrm{CN})_{12}$ | $41.0 \S$ | 80.8 | 8 I .2 | 130.9 | 110.7 | 124.9 |
| 1.0 | KCNS | -1.2 | 32.5 | 52.8 | 52.7 | 52.5 | 72.5 |
| 1.0 | $\mathrm{NaNO}_{3}$ | $4 \cdot 5$ | 35.2 | 50.2 | 49.0 | 103.6 | 104.6? |
| 0.5 | $\mathrm{Sr}\left(\mathrm{NO}_{3}\right)_{2}$ | 14.8 | 38.3 | 50.6 | 48.7 | 103.0 | 119.3 |
| 0.125 | $\mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}$ | 21.9 | 39.3 | 51.7 | 52.8 | 109.6 | 121.5 |
| 1.0 | $\mathrm{KNO}_{3}$ | - $\ddagger$ | 35.6 | 47.5 | 49.9 | 104.8 | 115.0 |
| 0.2 | $\mathrm{KClO}_{3}$ | 15-10 $\ddagger$ | 39.9 | 53.8 | 57.7 | 105.3 | I 20.9 |
| 0.167 | $\mathrm{KBrO}_{3}$ | $13-20 \ddagger$ | 40.7 | 51.3 | 50.9 | III. 3 | I 20.8 |
| 1.0 | $\mathrm{NH}_{4} \mathrm{Cl}$ | 2.9 | 32.4 | 51.3 | 50.9 | 8 I .2 | 101.7 |
| 1.0 | KF | 2.8 | 22.5 | 41.1 | 50.8 | 61.3 | 61.5 |
| 1.0 | NaCl | - | 31.9 | 51.2 | 50.3 | 80.9 | 101.3 |
| 1.0 | KBr | 2.3 | 31.7 | 47.2 | 52.5 | 736 | 82.4 |
| 1.0 | KCl | - | 32.1 | 51.6 | 52-6 | 8 I. 6 | 107.6 |
| 0.5 | $\mathrm{Na}_{2} \mathrm{SO}_{3}$ | $-8.2$ | 28.7 | 41.0 | 3 I .0 | 68.7 | 103.7 |
| - 11 | NaOBr | 18.4 | 41.6 | 73.1 | $70.6 \ddagger$ | 89.9 | 99.7 |
| 1.0 | $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$ | $5 \cdot 5$ | 39.7 | 61.3 | $54.4 \S$ | 104.6 | 123.4 |
| 0.5 | $\mathrm{C}_{4} \mathrm{H}_{6} \mathrm{O}_{6}$ | 4.1 | 41.3 | 61.6 | 57.6 | 110.9 | 125.7 |
| 0.5 | $\mathrm{C}_{4} \mathrm{H}_{4} \mathrm{KNaO} \mathrm{O}_{6}$ | -7.9 | 31.5 | 51.5 | 42-47 | 100.8 | 119.7 |

[^48]
## Smithsonian Tables.

THERMOELECTRIC POWER．
The thermoelectric＂power of a circuit of two metals is the electromotive force produced by one degree $C$ difference of temperature between the junctions．The thermoelectric power varies with the temperature，thus：thermoelectric power $=Q=d E / d t=A+B t$ ，where $A$ is the thermoelectric power at $\circ^{\circ} \mathrm{C}, B$ is a constant，and $t$ is the mean tem－ perature of the junctions．The neutral point is the temperature at which $d E / d t=0$ ，and its value is $-A / B$ ．When a current is caused to flow in a circuit of two metals originally at a uniform temperature，heat is liberated at one of the junctions and absorbed at the other．The rate of production or liberation of heat at each junction，or Peltier effect， is given in calories per second，by multiplying the current by the coefficient of the Peltier effect．This coefficient in calories per coulomb $=Q T / \mathcal{F}$ ，in which $Q$ is in volts per degree $C, T$ is the absolute temperature of the junction，and $\mathcal{F}=4.19$ ．Heat is also liberated or absorbed in each of the metals as the current flows through portions of varying temperature．The rate of production or liberation of heat in each metal，or the Thomson effect，is given in calories per second by multiplying the current by the coefficient of the Thomson effect．This coefficient，in calories per coulomb $=B T \theta / \mp$ ，in which $B$ is in volts per degree $C, T$ is the mean absolute temperature of the junctions，and $\theta$ is the differ－ ence of temperature of the junctions．（ $B T$ ）is Sir W．Thomson＇s＂Specific Heat of Electricity．＂The algebraic signs are so chosen in the following table that when $A$ is positive，the current flows in the metal considered from the hot junction to the cold．When $B$ is positive，$Q$ increases（algebraically）with the temperature．The values of $A, B$ ，and thermoelectric power in the following table are with respect to lead as the other metal of the thermoelectric circuit． The thermoelectric power of a couple composed of two metals， 1 and 2 ，is given by subtracting the value for 2 from that for $\mathbf{~}$ ；when this difference is positive，the current flows from the hot junction to the cold in I ．In the following table，$A$ is given in microvolts per degree，$B$ in microvolts per degree per degree，and the neutral point in degrees．

The table has been compiled from the results of Becquerel，Matthiessen and Tait；in reducing the results，the electromotive force of the Grove and Daniell cells has been taken as 1.95 and 1.07 volts．The value for constantan was reduced from results given in Landolt－Börnstein＇s tables．The thermoelectric powers of antimony and bismuth alloys are given by Becquerel in the reference given below．

| Substance． | $\underset{\text { Microvolts. }}{A}$ | $\stackrel{B}{\text { Microvolts. }}$ | Thermoelectric power at mean temp．of junctions（microvolts）． |  | Neutral point $-\frac{A}{B}$ | Author－ ity． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $20^{\circ} \mathrm{C}$ | $50^{\circ} \mathrm{C}$ |  |  |
| Aluminum．． | －0．76 | ＋0．0039 | －0．68 | －0． 56 | ＋195 | T |
| Antimony，comm＇l pressed wire．．． | － | － | ＋6．0 | 二 | － | M |
| ＂، axial．．．．．．．．．．．．．．． | － | 二 | ＋22．6 | 二 |  |  |
| ＂ <br> Argentan．．．．．．．．．．．．．．．．．．．．．．．． | －11．94 | －0．0506 | ＋26．4 <br> 12.95 |  | －236 | T |
| Argentan．．．．．．．．．．．．．．．．．．．．．． | －II． 94 | －0．0506 | $-12.95$ | -14.47 -12.7 | －236 | B |
| －Arsenic．．．．．．．．．．．．．．．．．．．．． | － | － | －r3．56 | 二 | － | M |
| Bismuth，comm＇l pressed wire．．．． | 二 | 二 | －97．0 | 二 | 二 | ＂ |
| ، ${ }^{\text {p crystal，axial ．．．．．．．．}}$ | 二 | 二 | －89．0 | 二 | 二 | ＇ |
| ＂crystal，axial．．．．．．．．．．． | － | 二 | －45．0 | － | － | ＂ |
| Cadmium．．．．．．．．．．．．．．．．．．．．．． | ＋2．63 | ＋0．0424 | ＋3．48 | ＋4．75 | －62 | T |
| ＂fuse |  | － |  | $+2.45$ | － | ${ }_{\text {B }}$ ， |
| Calcium． | － | － | － | ＋8．9 | 二 | S＇ |
| Cobalt ．．．． | － | 二 | －22 | $-\overline{10.3}$ | 二 | M |
| Constantan．．．．．．．．．．．．．．．． Copper．．．．．．．．．．．．．．． | ＋1．34 | ＋0．0094 | $\underline{+5.52}$ | -19.3 +r .81 | －$\overline{r a}_{43}$ | T |
|  | ＋1．34 | ＋0．0094 | ＋o．10 | － | $\underline{-}$ | M |
| ＂galvanoplastic | － | － | ＋3．8 | － | － |  |
| Gallium．．．．．．．． | － | － | －0．2 | － | － | S |
| Gold．．．．．．．．．．．．．．．．．．．．．．．． | ＋2．80 | ＋0．0101 | ＋3．0 | ＋3．30 | $\left[\begin{array}{c}-277] \\ +356\end{array}\right.$ | T |
| Iron．．．．．．．．．．．．．．．．．．．．．．．．．．．．． | ＋17．15 | －0．0482 | $\underline{+16.2}$ | ＋14．74 | ＋356 | T |
| ＂${ }^{\text {c }}$ comoforte wire | － | － | ＋17．5 | ＋$\overline{\text { 2 } 2.10 ~}$ | － | B |
| ＂${ }^{\text {commercial．}}$ |  | － | － | ＋9．10 |  | ＂ |
| Lead．． | － | 0.0000 | －0．00 | 0．00 | － |  |
| Magnesium． | ＋2．22 | －0．0094 | $+2.03$ | ＋r．75 | $\underline{+236}$ | T |
| Molybdenum | 二 | 二 | $\underline{+5.9}$ |  |  |  |
| Mercury．．． | 二 | 二 | －0．413 | -3.30 -15.50 | ［－］ | ${ }_{\mathbf{B}}$ |
|  | $-21.8$ | －0．0506 | －22．8 | $-24.33$ | ［－43r］ | T |
|  | －83．57 -3.04 | $\begin{aligned} & +0.2384 \\ & -0.0506 \end{aligned}$ | 二 |  |  |  |

TABLE 386.-Thermoelectric Power (continued).

| Substance. | $\underset{\text { Microvolts. }}{A}$ | $\begin{gathered} B \\ \text { Microvolts. } \end{gathered}$ | Thermoelectric powerat mean temp. ofanctions (microvolts). |  | Neutral $-\frac{A}{B}$. | $\underset{\text { thority }}{\text { Au- }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $20^{\circ} \mathrm{C}$. | $50^{\circ} \mathrm{C}$ |  |  |
| Palladium | -6.18 | $\bigcirc 0.0355$ | -6.9 | -7.96 | -174 |  |
| Phosphorus (red) - |  |  | +29.9 |  |  | M |
| Platinum - . |  |  | +0.9 |  |  |  |
| "، (hardened) | +2.57 +0.60 | $\bigcirc 0.0074$ | +2.42 -.818 | +2.20 +1.15 | 347 -55 | T |
| " wire . | -0.60 | $\bigcirc .0109$ |  | +1.15 | -55 | B |
| " another specimen Platinum-iridium alloys: |  |  |  | -2.14 |  |  |
| $85 \% \mathrm{Pt}+15 \% \mathrm{Ir}$ | +7.90 | +0.0062 | +8.03 | +8.21 | [-1274] | T |
| 90\% Pt $+10 \% \mathrm{Ir}$ | $+5.90$ | -0.0133 | $+5.63$ | +5.23 | 444 |  |
| 95\% Pt $+5 \% \mathrm{Ir}$ | +6.15 | +0.0055 | +6.26 | +6.42 | [-III8] |  |
| $\underset{\text { Silver }}{\text { Selenium }}$. | +2.12 | +0.0147 | +807. +2.41 | +2.86 |  | M |
| ". (purehard) |  | +0.014 | +3.00 | +2.86 |  | M |
| " wire |  |  |  | +2.18 |  | 13 |
| Steel | +11.27 | $\bigcirc 0.0325$ | +10.62 | +9.65 | 347 | T |
| Tantalum |  |  | -2.6 | - |  | - |
| Tellurium $\boldsymbol{\beta}$ |  |  | +500. |  |  | H |
| Thallium ${ }^{\boldsymbol{a}}$ |  |  | +160. |  |  | H |
| Tin (commercial). | - |  | - | +o. | - | H |
| ، | - | - | +o.1 | - | - | M |
|  | . 43 | +0.0055 | -0.33 | -0.16 | 78 | T |
| Tungsten. |  |  | -2.0 +2.79 | +3.51 | -98 | $\bar{T}$ |
| ${ }^{\text {Zinc }}$ pure pressed | +2.3 | +0.023 | +2.79 +3.7 | +3. |  | M |
| B Ed. Becquerel, "Ann. de Chim. et de Phys." [4] vol. 8. S. Bureau of Standards. <br> M Matthiesen, "Pogg. Ann." vol. 103, reduced by Fleming Jenkin. <br> T Tait, "Trans. R. S. E." vol. 27, reduced by Mascart. <br> H Haken, Ann. der Phys. 32, p. 291, 1910. (Electrical conductivity of $\mathrm{Te} \beta=0.04$, Tea I. 7 e. m. units.) Swisher, $191 \%$ |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

TABLE 387.-Thermoelectric Power of Alloys.
The thermoelectric powers of a number of alloys are given in this table, the authority being Ed. Becquerel. They are relative to lead, and for a mean temperature of $50^{\circ} \mathrm{C}$. In reducing the results from copper as, a reference metal, the thermoelectric power of lead to copper was taken as - 1.9.

| Substance. |  |  | Substance. |  |  | Substance. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Antimony Cadmium | $\left.\begin{array}{l} 806 \\ 696 \end{array}\right\}$ | 227 | Antimony Zinc | 2 1$\}$ | 43 | Bismuth Antimony | $\left.\begin{array}{l}4 \\ 1\end{array}\right\}$ | $-51.4$ |
| Antimony | 47 |  | Tin | I) | 43 | Bismuth | 83 |  |
| Cadmium Zinc | 2 1$\}$ | 146 | Antimony | $\left.\begin{array}{l}12 \\ 10 \\ 3\end{array}\right\}$ |  | Antimony | $1\}$ | $-63.2$ |
| Antimony | 806 |  | Cadmium | $\left.\begin{array}{c}10 \\ 3\end{array}\right\}$ | 35 | Bismuth | $10\}$ |  |
| Cadmium | 696 | 137 |  |  |  | Antimony | $1)$ |  |
| Bismuth | 121) | 137 | Antimony <br> Tellurium | $\left.\begin{array}{c}10 \\ 1\end{array}\right\}$ | 10.2 | Bismuth | 12) |  |
| Antimony | $806\}$ |  |  | $10\}$ |  | Antimony | 1 \} | -66.9 |
| Zinc | $406\}$ | 95 | Antimony Bismuth | $\left.\begin{array}{c}10 \\ 1\end{array}\right\}$ | 8.3 | Bismuth | $2\}$ |  |
| Antimony | 8067 |  |  | 41 |  | Tin | $1)$ | 60 |
| Zinc Bismuth | 406 121$\}$ | 8.1 | Antimony Iron | $1\}$ | 2.5 | Bismuth | 10 l |  |
| Antimony | 121) |  | Antimony | 81 | - | Selenium | $1)$ | $-24.5$ |
| Cadmium | 2 |  | Magnesium | I | 4 | Bismuth | $12\}$ |  |
| Lead | $1\}$ | 76 |  | 81 | -0.4 | Zinc | $1)$ | -31.1 |
| Zinc | $1)$ |  | Lead | $1\}$ | -0.4 | Bismuth | 12 ? |  |
| Antimony | 4 2 |  | Bismuth | ) | -43.8 | Arsenic | I $\}$ | $-46.0$ |
| Zinc | $1\}$ | 46 | Bismuth | 2 ) |  | Bismuth | 1 I | 68.1 |
| Tin | $1)$ |  | Antimony | $1)$ | $-33.4$ | Bismuth sulphide | $1)$ | 68.1 |

TABLE 388. - Thermoelectrlc Power against Platinum.
One junction is supposed to be at $0^{\circ} \mathrm{C} ;+$ indicates that the current flows from the $0^{\circ}$ junction into the platinum. The rhodium and iridium were rolled, the other metals drawn.*

| Temperature, ${ }^{\circ} \mathrm{C}$. | Au. | Ag. | $90 \% \mathrm{Pt}+$ $10 \% \mathrm{Pd}$. | $10 \% \mathrm{Pt}+$ $90 \% \mathrm{Pd}$. | Pd. | $90 \% \mathrm{Pt}+$ $10 \% \mathrm{Rh} .$ | $\begin{aligned} & 90 \% \mathrm{Pt}+ \\ & \mathbf{1 0 \% \mathrm { Ru } .} \end{aligned}$ | Ir. | Rh. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| -185 | -0.15 | -0.16 | -0.11 | +0.24 | +0.77 | - | -0.53 | -0.28 | -0.24 |
| -80 | $-0.31$ | $\bigcirc 0.30$ | -0.09 | +0.15 | +0.39 | - | -0.39 | $-0.32$ | -0.31 |
| +100 | +0.74 | +0.72 | +0.26 | -0.19 | -0.56 | - | +0.73 | +0.65 | +0.65 |
| +200 | +1.8 | +1.7 | +0.62 | -0.31 | -1.20 | - | +1.6 | $+1.5$ | +1.5 |
| $+300$ | $+3.0$ | $+3.0$ | +1.0 | $-0.37$ | $-2.0$ | +2.3 | +2.6 | +2.5 | +2.6 |
| +400 | +4.5 | +4.5 | +1.5 | -0.35 | -2.8 | $+3.2$ | +3.6 | +3.6 | +3.7 |
| $+500$ | +6.1 | +6.2 | +1.9 | -0.18 | $-3.8$ | +4.1 | +4.6 | +4.8 | + 5.1 |
| +600 | +7.9 | +8.2 | +2.4 | +0.12 | -4.9 | +5.1 | +5.7 | +6.1 | +6.5 |
| $+700$ | +9.9 | $+10.6$ | +2.9 | +0.61 | -6.3 | +6.2 | +6.9 | $+7.6$ | +8.1 |
| $+800$ | +12.0 | +13.2 | +3.4 | +1.2 | -7.9 | +7.2 | +8.0 | +9.1 | +9.9 |
| +900 | +14.3 | +16.0 | +3.8 | +2.1 | -9.6 | +8.3 | +9.2 | +10.8 | +11.7 |
| +1000 +1100 | +16.8 | - | +4.3 | +3.1 +4. | -11.5 | +9.5 | +10.4 | +12.6 | +13.7 |
| +1100 $+(1300)$ | - | - | +4.8 | +4.2 | -I3.5 | +10.6 | +11.6 | +14.5 | +15.8 |
| +(1300) $+(1500)$ | - | - | - | - | - | +10.1 +13.1 +15.6 | +11.2 +16.9 | +18.6 +23.1 | +20.4 +25.6 |

* Holborn and Day.

TABLE 389, -Thermal E. M. F. of Platinum-Rhodium Alloys Against Pure Platinum, in Millivolts.*

| $t$ | \& p.ct. | $5 \mathrm{p} . \mathrm{ct}$. | so p. ct. |  |  | $15 \mathrm{p} . \mathrm{ct}$. | $20 \mathrm{p} . \mathrm{ct}$. | $33 \mathrm{p} . \mathrm{ct}. \dagger$ | $40 \mathrm{p} . \mathrm{ct}. \dagger$ | $100 \mathrm{p} . \mathrm{ct}$. \% |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Low. | High. | Standard. |  |  |  |  |  |
| $100^{\circ}$ | 0.21 | 0.55 | 0.63 | 0.64 | 0.64 | 0.65 |  | .... | .... | 0.65 |
| 200 | 0.42 | I.IS | 1.41 | 1.43 | 1.43 | 1.50 | . . . | .... | .... | 1.51 |
| 300 | 0.63 | 1.85 | 2.28 | 2.32 | 2.32 | 2.41 | -••• | 2.34 | 2.45 | 2.57 |
| 400 | 0.84 | 2.53 | 3.21 | $3 \cdot 26$ | 3.25 | 3.45 | $3 \cdot 50$ | $3 \cdot 50$ | 3.64 | 3.76 |
| 500 | 1.05 | 3.22 | 4.17 | 4.23 | 4.23 | 4.55 | 4.60 | 4.74 | 4.93 | 5.08 |
| 600 | 1.25 | 3.92 | 5.16 | 5.24 | 5.23 | 5.71 | 5.83 | 6.06 | 6.31 | 6.55 |
| 700 | 1.45 | 4.62 | 6.19 | 6.28 | 6.27 | 6.94 | 7.18 | $7 \cdot 49$ | 7.80 | 8.14 |
| 800 | 1.65 | $5 \cdot 33$ | 7.25 | $7 \cdot 35$ | 7.33 | 8.23 | 8.60 | 9.01 | 9.37 | 9.57 |
| 900 | 1.85 | 6.05 | 8.35 | 8.46 | 8.43 | 9.57 | 10.09 | 10.67 | 11.09 | 11.74 |
| 1000 | 2.05 | 6.79 | 9.47 | 9.60 | 9.57 | 10.96 | 11.65 | 12.42 | 12.94 | 13.74 |
| 1100 | 2.25 | 7.53 | 10.64 | 10.77 | 10.74 | 12.40 | 13.29 | 14.33 | I 4.99 | 15.87 |
| 1200 | 2.45 | 8.29 | 11.82 | 11.97 | 11.93 | 13.87 | 14.96 | 16.39 | 17.13 | 18.10 |
| 1300 | 2.65 | 9.06 | 13.02 | 13.18 | 13.13 | 15.38 | 16.65 | I 8.51 | 19.51 | 20.46 |
| 1400 | 2.86 | 9.82 | 14.22 | 14.39 | 14.34 | 16.98 | I 8.39 | 20.67 | 21.73 | . . . |
| 1500 | 3.06 | 10.56 | 15.43 | 15.61 | I 5.55 | 18.41 | 20.15 | . . . |  |  |
| 1600 | 3.26 | I 1.3I | 16.63 | 16.82 | 16.75 | 19.94 | 21.90 | . . . |  |  |
| 1700 | 3.46 | 12.05 | 17.83 | 18.03 | 17.95 | 21.47 | 23.65 | . . . |  |  |
| I755 | $3 \cdot 56$ | 12.44 | 18.49 | 18.70 | I8.61 | 22.31 | 24.55 | . . . |  |  |

* Carnegie Institution, Pub. 157, 19 ri.
$\ddagger$ Holborn and Day, mean value, 889.


## THERMOELECTRIC PROPERTIES: PRESSURE EFFECTS.

TABLE 390. - Thermoelectric Power; Pressure Effects.
The following values of the thermoelectric powers under various pressures are taken from Bridgman, Pr. Am. Acad. Arts and Sc. 53, p. 269, 1918. A positive emf means that the current at the hot junction flows from the uncompressed to the compressed metal. The cold junction is always at $\circ^{\circ} \mathrm{C}$. The last two columis give the constants in the equation $E=$ thermoelectric force against lead $\left(0^{\circ}\right.$ to $\left.100^{\circ} \mathrm{C}\right)=\left(A t+B \ell^{2}\right) \times 10^{-6}$ volts, at atmospheric pressure, a positive emf meaning that the current flows from lead to the metal under consideration at the hot junction.

| Metal. | Thermo-electric force, volts $\times 10^{9}$ |  |  |  |  |  |  |  |  | Formula coefficients. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Pressure, $\mathrm{kg} / \mathrm{cm}^{2}$ |  |  |  |  |  |  |  |  |  |  |
|  | 2000 |  | 4000 |  | 8000 |  | 12,000 |  |  |  |  |
|  | Temperature, ${ }^{\circ} \mathrm{C}$ |  |  |  |  |  |  |  |  |  |  |
|  | $50^{\circ}$ | $100^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | $20^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | A | B |
| Bi | 53,000 | 85,000 | 110,000 | 185,000 | 255,000 | 425,000 | 185,000 | 452,000 | 710,000 | -74.42 | +.0160 |
| Zn | 6,200 | 14,100 | 13,000 | 28,500 | 26,100 | 58,100 | 14,400 | 38,500 | 87,400 | +3.047 | -.00495 |
| $\mathrm{Tl}^{\text {Cd }}$ | 4,930 | 10,870 | 9,380 | 20,290 | 17,170 | 37,630 | 8,780 | 23,750 | 52,460 | +1.659 | -.00134 ${ }^{1}$ |
| Cd | 2,040 | 7,120 | 4,620 | 14,380 | 10,960 | 28,740 | 6,680 | 19,180 | 45,560 | +12.002 | +.1619 |
| Cons | 2,850 | 5,950 | 5,800 | 11,810 8,800 | 11,530 8,630 | 23,790 | 6,750 | 17,200 12,070 | 35,470 | -34.76 | -. 0397 |
| $\mathrm{Pt}^{\mathrm{Pa}}$ | 2,190 I, 810 | 4,380 | 4,400 3,600 | 8,800 | 8,630 7,370 | 17,090 14,350 | 3,880 | 12,970 | 26,520 | -5.496 | -. 01760 |
| W | 1,190 | 2,530 | 2,360 | 4,990 | 4,690 | 10,120 | 2,700 | 7,050 | 15,140 | +1.594 | + +.01785 |
| Ni | 700 | 1,680 | 1,500 | 3,400 | 3,230 | 7,190 | 1,880 | 5,140 | 11,440 | -17.61 | -.0178 |
| ${ }_{8}{ }_{8}$ | 840 | I,870 | 1,720 | 3,720 | 3,350 | 7,190 | +1,900 | 4,950 | 10,560 | +2.556 | +.00432 |
| ${ }_{8}{ }^{\text {Pb }}$ | 390 | 1,670 | 590 | 3,250 | 5,300 | 5,820 | -990 | 220 | 7,680 | +16.18 | $-.0089^{2}$ |
| ${ }^{\mathrm{Pb}} \mathrm{A}$ | 460 | 1,050 | 920 | 2,120 2,051 | 1,860 1,791 | 4,210 | +880 | 281 2,627 | 6,330 |  |  |
| ${ }_{\mathrm{Cu}}$ | 456 +292 | 1,052 584 | 905 +580 | 2,051 | 1,791 $\mathbf{1}, 124$ | 3,974 2,420 | +990 +596 | 2,627 1,616 | 5,760 | +2.899 +2.777 | +.00467 +.00483 |
| $\delta_{81} \mathrm{Al}$ | -70 | 101 | -91 | r 294 | - 32 | 929 | -68 | 312 | r,962 | -0.416 | +.00008 |
| 8 Mo | 3 | 140 | +187 | 278 | 375 | 555 | +146 | 562 | 833 | +5.892 | $+.02167^{5}$ |
| ${ }_{\text {Man }}$ | ${ }_{-123}^{+38}$ | +87 -232 | +58 -242 | +165 | +70 -480 | $\begin{array}{r}+292 \\ +804 \\ \hline\end{array}$ | -182 -308 | +10 -710 | ${ }_{+}^{+390}$ | +0.230 | -. 00067 |
| $\mathbf{M g}$ | -123 | -167 | - 242 | -452 -362 | -489 -395 | -894 | -308 -259 | -719 | -1,314 | ${ }_{-1.366}^{+0.095}$ | + $000414^{6}$ |
|  | -156 | -348 | -316 | -692 | -630 | -1,360 | -352 | -937 | -2,061 | -17.32 | -. 0390 |

[^49]TABLE 391. - Peltier and Thomson Heats; Pressure Effects.
The following data indicate the magnitude of the effect of pressure on the Peltier and Thomson heats. They refer to the same samples as for the last table. The Peltier heat is considered positive if heat is absorbed by the positive current from the surroundings on flowing from uncompressed to compressed metal. A positive $d^{2} E / d \mathbb{R}^{2}$ means a larger Thomson heat in the compressed metal, and the Thomson heat is itself considered positive if heat is absorbed by the positive current in flowing from cold to hot metal. Same reference and notes as for preceding table.

| Metal. | Peltier heat, <br> ${ }^{10} \times$ Joules/coulomb. |  |  |  |  |  | Thomson heat, ${ }^{10}{ }^{8} \times$ Joules $/$ coulomb $/{ }^{\circ} \mathrm{C}$ |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Pressure $\mathrm{kg} / \mathrm{cm}^{2}$ |  |  |  |  |  | Pressure $\mathrm{kg} / \mathrm{cm}^{2}$ |  |  |  |  |  |
|  | 6000 |  |  | 12,000 |  |  | 6000 |  | 12,000 |  |  |  |
|  | Temperature ${ }^{\circ} \mathrm{C}$ |  |  |  |  |  | Temperature ${ }^{\circ} \mathrm{C}$ |  |  |  |  |  |
|  | $\circ^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | $0^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | $0^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ | $\circ^{\circ}$ | $50^{\circ}$ | $100^{\circ}$ |
| $8 \mathrm{Bi} \dagger$ | +1070 | +1210 | - | +2580 | +2810 | - | +1150 | +650 | - | -520 | -405 | - |
| ${ }_{8} \mathrm{Zn}$ T1 | + +68 +68 | +140 +95 | +190 +124 | +190 | +278 | +412 +220 | +41 +38 + | +48 | +56 | +63 | +133 | +220 +50 |
| ${ }_{8}^{8} \mathrm{Cd} \dagger$. | +66 +19 | +95 +7 | +124 | +112 | +171 | +229 +221 | +38 +109 | +28 +74 | +26 +63 | +79 +105 | +63 +92 | + 50 +93 |
| Constantan $8 \mathrm{Pd} *$ | +46 | +57 | +70 | +90 | +114 | +140 | +5 | +6 | +6 | +13 | +14 | +17 |
| ${ }_{8}^{8} \mathrm{Pt} \mathrm{Pt}^{*}$ | +35 +23 + | +43 +37 | +52 | +68 +45 | +86 | +103 +65 | +3 +4 | $\pm 4$ | +4 | +9 | +9 | +8 |
| ${ }_{8} \mathrm{~W}$ | + +17 +1 | +37 +25 | +35 +32 | +45 +36 | +76 +49 | +65 +65 | +49 +8 |  | 18 +6 | +9 +9 | +17 +14 | +59 +20 |
| ${ }_{8}^{81} \mathrm{Ni}$ | +11 | +17 | +23 | +24 | +37 | +50 | +9 | +7 | +8 | +16 | +15 | +10 |
| ${ }_{8}{ }_{8}$ | +13 | +17 | +23 | +25 | +34 | +44 | +4 | + 5 | +6 | +7 | +8 | +ro |
| $\stackrel{8}{\mathrm{~Pb}}$ | -11 | +18 | 115 +16 | -38 | +38 | +36 | +79 | + 58 | -121 | $-347$ | +120 | -194 |
| Au* | +7 +6 | +10 | +16 | +14 | +20 +18 | +30 +25 | $\begin{array}{r}+2 \\ +4 \\ + \\ \hline\end{array}$ |  | +10 +5 | +6 | +8 +6 | +20 |
| $\mathrm{Cu} \dagger$ | +4 | +10 +6 | +14 +8 | +13 +8 | +18 | +25 +16 | +4 | + | +5 +4 | +6 |  | +7 +8 |
| $8 \mathrm{Al} \dagger$ | $-2$ | $+2$ | +8 | -3 | +7 | +17 | +6 | +0 | +11 | +21 | +16 | +20 |
| 8 Mo | +1 | + | +o | +2 | +4 | +1 | + | -5 | -1 | +2 | -11 | -2 |
| ${ }_{8} \mathrm{~S}^{\text {Sn }} \dagger$... | - | $\pm$ | $\pm 1$ | -5 | + 2 | +2 | $+6$ | +o | - | +29 | +2 | -5 |
| Mangan $\mathrm{Mg} \dagger .$. | -2 -16 | -2 -18 -3 | -2 <br> -21 | -4 -35 | -4 -42 | -4 -48 |  |  |  | +2 | +1 | +1 |
| $8 \mathrm{Co} \dagger$ | $-23$ | -33 | -44 | $-46$ | -67 | -90 | -14 | -II | -10 | -20 | -24 | -28 |

* $\dagger \ddagger \delta$ Same significance as in preceding table.


## Smithsonian Tables.

TABLE 392．－Poltior Etfect．
The coefficient of Peltier effect may be calculated from the constants $A$ and $B$ of Table 386，as there shown．With $Q$（see Table 386）in microvolts per ${ }^{\circ} \mathrm{C}$ ．and $T=$ absolute temperature（ $K$ ）， the coefficient of Peltier effect $=\frac{Q T}{42}$ cal．per coulomb $=0.00086 Q T$ cal．per ampere－hour $=Q T / 1000$ millivolts（＝millijoules per coulomb）．Experimental results，expressed in slightly different units， are here given．The figures are for the heat production at a junction of copper and the metal named，in calories per ampere－hour．The current flowing from copper to the metal named，a posi－ tive sign indicates a warming of the junction．The temperature not being stated by either author， and Le Roux not giving the algebraic signs，these results are not of great value．

| Calories per ampere－hour． |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | ＋ | 为或 | \％ | $\cdots$ | ن் | 碳芯 | － | $\dot{z}$ | $\pm$ | 4 | ベ |
| Jahn＊． | － | － | － | － | －． 62 | － | $-3.61$ | $4 \cdot 36$ | 0.32 | －．4I | －． 58 |
| Le Roux $\dagger$ ． | 13.02 | 4.8 | 19.1 | 25.8 | 0.46 | 2.47 | 2.5 | － | － | － | －39 |

＊＂＂Wied．Ann．＂vol．34，p．767；
$\dagger$＂Ann．de Chim．et de Phys．＂（4）vol．10，p．20\％．
Becquerel＇s antimony is So6 parts $\mathrm{Sb}+406$ parts $\mathrm{Zn}+121$ parts Bi ．
Becquerel＇s bismuth is so parts $\mathrm{Bi}+1$ part Sb ．

TABLE 393．－Peltier Effect，Fo－Constantan，Ni－Cu，O－560 $\mathbf{C}$ ．

| ＇Temperature． | $0^{\circ}$ | $20^{\circ}$ | $130^{\circ}$ | $240^{\circ}$ | $320^{\circ}$ | $560^{\circ}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Fe－Constantan ． | 3．1 | 3.6 | $4 \cdot 5$ | 6.2 | 8.2 | 12.5 | $\left(\mathrm{in} \mathrm{Gram}. \mathrm{Cal} \times.-10^{8}\right.$ |
| $\mathrm{Ni}-\mathrm{Cu}$ ． | 1.92 | 2.15 | 2.45 | 2.06 | 1．91 | 2.38 | per coulomb． |

TABLE 394．－Peltier Electromotive Force in Millivolts．

| Metal against Copper． | \％ | $\stackrel{\sim}{4}$ | U | ธี่ | \％ | ¢ | $\stackrel{\square}{\square}$ | $\dot{5}$ | $\dot{\text { ̇ }}$ | \％ | 0 | $\dot{z}$ | \％ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Le Roux | $-5.64$ | －2．93 | －． 53 | －． 45 | － | － | － | － | － | － | － | － | ＋22．3 |
| Jahn ． | － | $-3.68$ | －．72 | $-.68$ | $-.48$ | － | － | － | － | $+.37$ | － | ＋5．07 | － |
| Edlund ．． | － | －2．96 | －． 16 | －． 08 | ＋． 03 | $+.33$ | ＋． 50 | ＋．56 | ＋．70 | ＋1．02 | ＋2．17 | － | ＋17．7 |
| Caswell ．． | － | － | － | － | ＋． 03 | － | － | － | ＋．70 | $+8_{5}$ | － | ＋6．0 | ＋16．1 |

Le Roux， 1867 ；Jahn， 1888 ；Edlund， $18707 \mathrm{~m}_{1}$ ；Caswell，Phys．Rev．33，p．381， 19 t ．

## Smithsonian Tables．

## TABLE 395.

## THE TRIBO-ELECTRIC SERIES.

In the following table it is so arranged that any material in the list becomes positively electrified when rubbed by one lower in the list. The phenomenon depends upon surface conditions, and circumstances may alter the felative positions in the list.

```
1 Asbestos (sheet).
2 Rabbit's fur, hair, (Hg).
3 Glass (combn. tubing).
3 Vitreous silica, opossum's
        fur.
5 Glass (fusn.).
6 Mica.
\({ }_{7}\) Mica.
8 Glass (pol.), quartz (pol.),
        glazed porcelain.
9 Glass (broken edge),
        ivory.
10 Calcite.
in Cat's fur.
\({ }_{12} \mathrm{Ca}, \mathrm{Mg}, \mathrm{Pb}\), fluor spar,
        borax.
```

24 Amber.
25 Slate, chrome-alum.
26 Shellac, resin, sealing-wax. 27 Ebonite. $28 \mathrm{Co}, \mathrm{Ni}, \mathrm{Sn}, \mathrm{Cu}, \mathrm{As}, \mathrm{Bi}$, Sb, Ag, Pd, C, Te, Eureka, straw, copper sulphate, brass.
29 Para rubber, iron alum.
30 Guttapercha.
$3 \times$ Sulphur.
$32 \mathrm{Pt}, \mathrm{Ag}, \mathrm{Au}$.
33 Celluloid.
34 Indiarubber.

Shaw, Pr. Roy. Soc. 94, p. 16, 1917; the original article shows the alterations in the series sequence due to varied conditions.

TABLE 396،

## AUXILIARY TABLE FOR COMPUTING WIRE RESISTANCES.

For computing resistance in ohms per meter from resistivity, $\rho$, in michroms per cm . cube (see Table 397, etc.). e. $g$. to compute for No. 23 copper wire when $\rho=1.724: 1$ meter $=0.0387+$ $.0271+.0008+.0002=0.0668$ ohms ; for No. 11 lead wire when $\rho=20.4 ;$ 1 meter $=0.0479+$ $.0010=0.0489$ ohms. The following relation allows computation for wires of other gage nuntbers : resistance in ohms per meter of $\mathrm{No} . \mathrm{N}=2(n-3)$ within I $\%: e . g$. resistance of meter of No. $18=2 \times$ No. 15 .

| Gage. No. | Diam. in mm. | Section mm². | $\rho$ in micro-ohms per cm. cube. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. |
|  |  |  | Resistance of wire i meter long in ohms. |  |  |  |  |  |  |  |  |  |
| 0000 | 11.7 | 107.2 | . 04933 | . $\mathrm{O}_{3} 187$ | . $\mathrm{O}_{8} 280$ | .$^{0} 3373$ | .$_{3}{ }^{3} 66$ | . 0.8560 | . $\mathrm{O}_{3} 653$ | . 03746 | . $0_{3} 840$ | . 03933 |
| 0 | 9.27 | 67.43 | . $0_{3} 148$ | . $3_{3} 297$ | . $3_{3445}$ | . $0_{3} 593$ | . $0_{3} 742$ | . $\mathrm{O}_{3} 890$ | . $\mathrm{O}_{2} 104$ | .$_{2} \mathrm{O}_{19}$ | . $\mathrm{O}_{2}{ }^{13}$ | .$_{2148}$ |
| 1 | 7.35 | 42.41 | . 02236 | . $0_{3472}$ | . $0_{3} 707$ | . $\mathrm{O}_{3} 943$ | . $\mathrm{O}_{2} 118$ | . $\mathrm{O}_{2} 141$ | . $\mathrm{O}_{2} 165$ | . $\mathrm{O}_{2} 189$ | .$_{2} 212$ | . $0_{2} 236$ |
| 3 | 5.83 | 26.67 | .$_{3}{ }^{3} 75$ | . $\mathrm{O}_{3750}$ | . $\mathrm{O}_{2} 112$ | . $\mathrm{O}_{2} 150$ | .$_{2} 187$ | . $2_{2} 225$ | . $\mathrm{O}_{2} 262$ | . $\mathrm{O}_{2} 300$ | ..$_{2337}$ | . $0_{2} 375$ |
| 5 | 4.62 | 16.77 | . $0_{3} 596$ | . $2_{2} 119$ | . $0_{2} 179$ | . $\mathrm{O}_{2} 239$ | . $2_{2} 298$ | . $\mathrm{O}_{2} 358$ | . $2_{2417}$ | . 02477 | . $0_{2} 537$ | .$^{2} 2596$ |
| 7 | 3.66 | 10. 55 | . $0_{3} 948$ | . $\mathrm{O}_{2} 190$ | .$_{2} 284$ | . $\mathrm{O}_{2} 379$ | . 02474 | . $\mathrm{O}_{2} 569$ | . $\mathrm{O}_{2} 664$ | . $\mathrm{O}_{2} 758$ | . $0_{2} 853$ | .02948 |
| 9 | 2.91 | 6.634 | . $\mathrm{O}_{2} \mathrm{I}^{1} \mathrm{I}$ | .$_{23}{ }^{\circ 1}$ | .$^{\circ} 2452$ | . $\mathrm{O}_{2} 603$ | . $\mathrm{O}_{2} 754$ | . 02904 | . 0106 | . 0121 | .0136 | .0151 |
| 11 | 2.30 | 4.172 | . $\mathrm{O}_{2} 240$ | . $0_{2479}$ | . $0_{2} 719$ | -. 2959 | . 0120 | . 0144 | . 0168 | . 0192 | . 0216 | . 0240 |
| 13 | 1.83 | 2.624 | . $0_{2} 381$ | . $\mathrm{O}_{2} 762$ | . 0114 | . 0152 | . 0191 | . 0229 | . 0267 | .0305 | . 0343 | .0381 |
| 15 | 1.45 | 1.650 | . $0_{2} 606$ | . 0128 | . 0182 | . 0242 | . 0303 | .0364 | . 0424 | . 0485 | . 0545 | .06о6 |
| 17 | 1.15 | 1.038 | . $2_{2} 963$ | . 0193 | . 0289 | .0385 | . 0492 | . 0578 | . 0674 | . 0771 | . 0867 | . 0963 |
| 19 | .912 | . 6527 | . 2153 | . 0306 | . 0460 | .0613 | . 0766 | . 0919 | . 1072 | . 1226 | . 1379 | . 1532 |
| 21 | .723 | . 4105 | . 0244 | . 0487 | . 073 I | . 0974 | . 1218 | .1462 | .1705 | . 1949 | .2192 | . 2436 |
| 23 | . 373 | .2582 | .0.387 | . 0775 | . 1162 | . 1549 | . 1936 | . 2324 | . 2711 | . 3098 | . 3486 | .3873 |
| 25 | . 455 | .1624 | . 0616 | . 1232 | . 1847 | . 2463 | . 3079 | . 3695 | . 4310 | . 4926 | . 5542 | .6158 |
| 27 | . 361 | . 1021 | . 0979 | . 1959 | . 2938 | . 3918 | .4897 | . 5877 | . 6856 | .7835 | . 8815 | . 9794 |
| 29 | . 286 | .0642 | - 1557 | . 3114 | . 4671 | . 6228 | .7786 | . 9343 | 1.090 | 1.246 | 1.401 | 1.557 |
| 31 | . 227 | .0404 | . 2476 | . 4952 | . 7428 | . 9904 | 1.238 | 1. 486 | 1.733 | 1.981 | 2.228 | 2.476 |
| 33 | . 180 | . 0254 | . 3937 | . 7874 | 1. 181 | 1. 575 | 1.968 | 2.362 | 2.756 | 3.150 | 3.543 | 3.937 |
| 35 | .143 | . 0160 | . 6262 | 1.252 | 1.879 | 2.505 | 3.131 | 3.757 | 4.383 | 5.009 | 5.636 | 6.262 |
| 37 | .113 | . 0100 | . 9950 | 1.990 | 2.985 | 3.980 | 4.975 | 5.970 | 6.965 | 7.960 | 8.955 | 9.950 |
| 39 | . 090 | . 0063 | 1.583 | 3.166 | 4.748 | 6.331 | 7.914 | 9.497 | 11.08 | 12.66 | 14.25 | 15.83 |
| 40 | .oso | . 0050 | 1.996 | 3.992 | 5.988 | 7.984 | 9.980 | 11.98 | 13.97 | 15.97 | 17.96 | 19.96 |

Smithsonian Tables,

The resistivities are the values of $\rho$ in the equation $R=\rho l / s$ ，where $R$ is the resistance in microhms of a length $l \mathrm{~cm}$ of uniform cross section $s \mathrm{~cm}^{2}$ ．The temperature coefficient is $a_{s}$ in the formula $K_{t}=R_{s}\left\{\mathrm{I}+a_{s}\left(b-b_{s}\right)\right\}$ ．The information of column 2 does not necessarily apply to the temperature coefficient．See also next table for tempera－ ture coefficients $0^{\circ}$ to $100^{\circ} \mathrm{C}$ ．

| Substance． | Remarks． | Tempera－ture，oc | $\underset{\mathrm{cm}}{\substack{\text { Microhm- }}}$ | Refer－ ence． | Temperature coefficient． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | $t_{8}$ | $a_{s}$ | Refer－ ence． |
| Advance．． | see constantan | － | － 828 | － | $8^{\circ}$ | － | － |
| Aluminum ． | see p． 334 | ［ 20. | 2.828 0.64 |  | $18^{\circ}$ 25 | +.0039 +.0034 |  |
| ＂ | c．p． | － 189. | 0.64 1.53 | 3 3 | 25 100 | +.0034 +.0040 | 4 |
| ＂ | ＂ | － | 2.62 | 3 | 500 | ＋．0050 | 4 |
| ＂ | ＂ | ＋100． | 3.86 | 3 | － | － |  |
| ＂ |  | 400. | 8.0 | 3 | － | － | － |
| Antimony．． | － | 20. 100. | 41.7 10.5 | 5 6 | ${ }^{20}$ | ＋．0036 | 5 |
| ＂ | liquid | ＋860． | 120. | 7 | － | － | － |
| Arsenic． | diqud | $\bigcirc$ | 35. | 8 | － | － | － |
| Bismuth． | － | 18. | 119.0 | 9 | 20 | ＋．004 | 5 |
|  |  | 100. | 160.2 | 9 | － |  |  |
| $\xrightarrow[\text { Cadmium }]{\text { Brass．．．}}$ | d | 20. | 7. | 5 | 20 | ． 002 | 5 |
| ${ }_{\text {cadmium．}}$ ． | drawn | －160． | 2.72 7.54 | 10 9 | ${ }^{20}$－ | ＋．0038 | － |
| ＂ | ＂ | 100. | 9.82 | 9 | － | － | － |
| ＂ | liquid | 318. | 34.1 | 11 | － | － | － |
| Caesium． |  | －187． | 5.25 | 12 | 二 | － | 二 |
| ＂ | solid | 27. | ${ }_{22.2}^{19 .}$ | 11 | 二 | 二 | － |
| ＂ | solid liquid | 37. | 22.2 36.6 | ${ }_{1}$ | 二 | － | － |
| Calcium | 99.57 pure | 20. | 4.6 | 14 | 二 | ＋．0036 | 14 |
| Calido．． | see constantan | － | － | － | － | － | － |
| Chromium | － | $\bigcirc$ ． | 2.6 | 15 | － | － | － |
| Climax． | － | 20. | 87. | 5 | 20 | ＋．0007 | 5 |
| Cobalt． | 99.8 pure | 20. | 9.7 | 16 | － | ＋－ | － |
| Constantan | $60 \% \mathrm{Cu}, 40 \% \mathrm{Ni}$ | 20. | 49. | 5 | 12 | ＋．000008 | 4 |
| ＂ | 二 | － | 二 | 二 | 25 100 | +.000002 -.000033 | 4 |
| ＂ | － | 二 | 二 | － | 200 | －．-.000020 | 4 |
| ＂ |  | － | － | － | 500 | ＋．000027 | 4 |
| Copper ． | annealed | 20. | 1.724 | 1 | 20 see col．？ | ＋．00393 | 5 |
|  | hard－drawn | 20. | 1.77 | 1 |  | ＋．00382 | 5 |
| ＂ | electrolytic | －206． | 0.144 | 17 | 100 | ＋．0038 | 4 |
| ＂ |  | ＋205． | 2.92 | 17 | 400 | ＋．0042 | 4 |
| ＂ | pure ${ }^{\text {a }}$ | 400. | 4． 10 | 3 | 1000 | ＋．0062 | 4 |
| re | very pure，ann＇ld | 20. | 1.692 | 18 | 二 | 二 |  |
| Eureka．．． | see constantan | 20. | 92. | － | 20 － | ＋．00016 |  |
| Gallium． | － | － | 53. | 12 | － | － | $\checkmark$ |
| German silver | 18\％Ni | 20. | 33. | 5 | 20 | ＋．000．4 | 5 |
| Gold． | 99.9 pure | －183． | 0.68 | 17 | 20 | ＋．0034 | 5 |
|  | － | $\bigcirc$ ． | 2.22 | 11 | 100 ann ${ }^{\text {＇ld }}$ | ＋．0025 | 4 |
| ＂ | pure，drawn | 20. | 2.44 | 9 | 500 ＂＇ | ＋．0035 | 4 |
| Ia | 99.9 pure | 194.5 | 3.77 | $\underline{17}$ | 1000 － | ＋．0049 | 4 |
| Ideal． | see constantan | 二 | － | － | － | － | － |
| Indium． | － | 0. | 8.37 | 19 | － | 二 | － |
| Iridium． | 二 | －186． | 1.92 | 20 | 二 | 二 | － |
| ＂ | － | ＋10． | 8.10 8.3 | 20 | 二 | － | 二 |

[^50]RESISTIVITY OF METALS AND SOME ALLOYS.


RESISTIVITY OF METALS AND SOME ALLOYS．

| Substance | Remarks． | Tempera－ ature， ${ }^{\circ} \mathrm{C}$ | $\underset{\mathrm{cm}}{\text { Michrom- }}$ | Refer－ ence． | Temperature coefficient． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | $t_{s}$ | $a_{8}$ | Refer ence． |
| Osmium．．．． | － | 20. | 60.2 | 3 | － | － | － |
| Palladium． |  | － 20. | 11. | 5 | 20 | $+.0033$ | 5 |
| ＂ | very pure | － 183. | 2.78 7.17 | 17 17 | － | $+.0035$ | 2 C |
| ＂ | ＂＂ | －78． | 7.17 10.21 | 17 17 | － | － | － |
| ． | ＂＂ | 98.5 | 13.79 | 17 | － | － | － |
| Platinum． | ，－ | 20. | 10. | 5 | 20 | $+.003$ | 5 |
| ＂ | wire | －203．1 | 2.44 | 17 | － | ＋．0037 | 2 I |
| ＂ | ＂ | －97．5 | 6.87 10.06 | 17 17 | 二 | － | 二 |
| ＂، |  | 100. | 14.85 | 17 | － | 二 | 二 |
| Potassium． | 二 | 400. | 26. | 3 |  | － |  |
| Potassium． | 二 | －75． | 4.0 | 13 | 二 | － | － |
| R＂ | － | 55. | 8.4 | 13 | － | － |  |
| Rhodium． | － | $-186$. | 0.70 | 20 | － | － | － |
| ،． | － | －78．3 | 3.09 | 20 | － | － | － |
| ＂$\quad$. | － | 10． | 4.69 6.60 | 20 20 | 二 | 二 |  |
| Rubidium． | solid | －190． | 2.5 | 13 | － | － | － |
| ＂ | ＂${ }^{\prime}$ | 0. | 11.6 | 13 | － | － | － |
| ＂ |  | 35. | 13.4 | 13 | 二 | 二 |  |
| Silicium．． | － | 40. 20. | 19．6 ${ }^{\text {58．}}$＝ | 13 | － | 二 |  |
| Silver． | 99.98 pure | 18. | 1.629 | 2 | 20 | ＋．0038 |  |
| ＂ | electrolytic | $-183$. | 0.390 | 17 | 25 | ＋．0030 | 4 |
| ، | ＂ | $-78$. | 1.021 | 17 | 100 | ＋．0036 | 4 |
| ＂ | ＂ | ${ }_{98.15}^{0.15}$ | 1.468 2.062 | 17 17 | 500 | ＋．-0044 | 4 |
| ＂ | ＂ | 192.1 | 2.608 | 17 | － | － | － |
| Sodium | solid | 400. | 3.77 | 3 | 二 | － |  |
|  | ＂، | －75． | 2.8 | ${ }_{13}$ | 二 | 二 |  |
| ＂ | ＂ | O． | 4.3 | 13 | 二 | － |  |
| ＂${ }^{\text {a }}$ | liquid | 116． | 5.4 10.2 | 13 | 二 | － | － |
| Strontium． | － | 20. | 24.8 | ${ }^{1} 8$ | 二 | － |  |
| Tantalum Tellurium． | － | 20.6 | 15.5 | 5 | 20 | ＋．0031 |  |
| Thallium． | pure | 19.6 -183. | 200，000 | 8 | － | 二 | 二 |
| ＂ |  | － 78. | 4.88 11.8 | 17 17 | 二 | 二 | 二 |
| ＂ | ، | 0. | 17.60 | 17 | － | － | － |
| Therlo． | ＂ | 98.5 | 24.7 | 17 | － | － | － |
| Tin．．．． | 二 | 20. 20. | ${ }_{11.5}$ | 5 | 20 | ＋．00001 | 5 |
| ＂ | － | $-184$. | 3.40 | 17 | 2 | － | － |
| ， | － | －78． | 8.8 | 17 | － | － | － |
|  | － | － | 13.0 | 17 | 二 | － | － |
| Titanium． | － | $\underline{\text { 91．}} 4$ | 18.2 3.2 | 17 | － |  |  |
| Tungsten． |  | 20. | 5.51 | 29 | 18 | ＋． 0045 | 2 |
| ＂ | $1000^{\circ} \mathrm{K}$ | 727. | 25.3 | 29 | 500 | $+.0057$ | 4 |
| ＂${ }^{\prime}$ ．．． | ${ }^{15000}{ }^{\circ} \mathrm{K}$ | 1227. | 4 4 .4 | 29 | 1000 | ＋．0089 | 4 |
| ＂ | $3000{ }^{\circ} \mathrm{K}$ | 1727. 2727. | 59.4 98.9 | 29 29 | 二 | 二 | 二 |
| 7．＂ | $3500^{\circ} \mathrm{K}$ | 3227. | 118. | 29 | － | － | － |
| Zinc． | trace ${ }_{6} \mathrm{Fe}$ | －183． | 1.62 | 17 | 20 | ＋．0037 | 5 |
| ＂ | ＂، | －78． | 3.34 | 17 | － | 二 | 二 |
| ＂ | ＂＂ | 92.45 | 8.00 | 17 | 二 | 二 |  |
|  | ＂${ }^{\text {c }}$ | 191.5 | 10.37 | 17 | 二 | 二 |  |
|  | liquid | 440. | 37.2 | 7 | － | － | － |

References to Table 397：（1）See page 334；（2）Jäger，Diesselhorst，Wiss．Abh．D．Phys．Tech．Reich．3，p．269， 1900；（3）Nicolai，1907；（4）Somerville，Phys．Rev．31，p．261，1910；33，p．77，1911；（5）Circular 74 of Bureau of Standards，1918；（6）Eucken，Gelhoff；（7）de la Rive；（8）Matthiessen；（9）Jäger，Diesselhorst；（10）Lees，1908； （II）Mean；（I2）Guntz，Broniewski；（I3）Hackspill；（14）Swisher，r917；（I5）Shukow；（I6）Reichardt，Igor； （17）Dewar，Fleming，Dickson，1898；（18）Wolff，Dellinger，1910；（19）Erhardt，188r；（20）Broniewski，Hackspill， 1911；（21）Dewar，Fleming，1893，1896；（22）Circular 58，Bureau of Standards，1916；（23）Strouhal，Barus， 1883 ； （24）Vincentini，Omodei，1890；（25）Bernini，1905；（26）Glazebrook，Phil．Mag．20，p．343，1885；（27）Grimaldi， 1888；（28）Fleming，1900；（29）Langmuir，Gen．Elec．Rev．19， 1916.

Smithsonian Tables．

The average temperature coefficients are per ${ }^{\circ} \mathrm{C}$ between $0^{\circ}$ and $100^{\circ} \mathrm{C}$. The instantaneous pressure coefficients are the values of the derivative $(\mathrm{I} / r)\{d r / d p\}_{\ell}$, where $r$ is the observed resistance at the pressure $p$ and temperature $t$. The average coefficient is the total change of resistance between 0 and $12,000 \mathrm{~kg} / \mathrm{cm}^{2}$ divided by 12,000 and the resistance at atmospheric pressure and the temperature in question. Table taken from Proc. Nat. Acad. 3, p. 11, 1917. For coefficients at intermediate te,nperatures and pressures, see more detailed account in Proc. Amer. Acad. 52, p. 573, 1917. $\mathrm{Sn}, \mathrm{Cd}, \mathrm{Zn}, \mathrm{Kahlbaum}$ 's " K " grade; $\mathrm{Tl}, \mathrm{Bi}$, electrolytic, high purity; $\mathrm{Pb}, \mathrm{Ag}, \mathrm{Au}, \mathrm{Cu}, \mathrm{Fe}, \mathrm{Pt}$, of exceptional purity. Al better than ordinary, others only of high grade commercial purity.


[^51]Additional data from P. Nat. Acad. Sc., 6, 505, 1920. Data are ro,000 $\times$ mean pressure coefficient, $0-12,000 \mathrm{~kg}$, and $10,000 \times$ instantaneous pressure coefficient at o kg. $1=$ liquid ; $\mathbf{s}=$ solid.

| $\mathrm{Li}, \mathrm{s}, \mathrm{o}^{\circ}$ | $+.0772$ | + .068 | $\mathrm{Ca}, \mathrm{o}^{\circ}$ | +.106 | $+.129$ | Ti, o ${ }^{\circ}$ | $\pm .001$ ? |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Li}, 1,240^{\circ}$ | $+.093$ | + .093 | $\mathrm{Sr},{ }^{\circ}$ | + .680 | + <br> + <br> + | $\mathrm{Zr},{ }^{\circ}$ | $\pm .0040$ |  | . 004 |
| $\mathrm{Na}, \mathrm{s},{ }^{\circ}$ | -. 345 | -. 663 | $\mathrm{Hg}, \mathrm{s}, \mathrm{o}^{\circ}$ | -. 236 b |  | Bi, $1,275^{\circ}$ | . 1015 |  | . 12 |
| $\stackrel{\mathrm{Na}}{\mathrm{K}}$, $1,200^{\circ}$ | -.436 | -. 922 | Hy, $1,25^{\circ}$ | -.219 | . 334 | W, | . 0135 |  | . 1 |
| K, S, $1,165^{\circ}$ | -. 604 | - 1.86 | Ga, s, ${ }^{\text {Ga, }}$, ${ }^{\circ}$ | -. 0247 |  | ${ }_{\mathrm{P}}^{\mathrm{La}, \mathrm{o}^{\circ}}$ | -.0331 -.81 | - |  |

a, $0-9,000 \mathrm{~kg} ; \mathrm{b}, 7,640-12,000 \mathrm{~kg} ; \mathrm{c}, \mathrm{o}-7,000 \mathrm{~kg}$. The $\mathrm{Ga}, \mathrm{Na}, \mathrm{K}, \mathrm{Mg}, \mathrm{Hg}, \mathrm{Bi}, \mathrm{w}, \mathrm{P}$, of exceptional purity.

## TABLE 399. - Resistance of Mercury and Manganin under Pressure.

Mercury, pure and free from air and with proper precautions, makes a reliable secondary electric-resistance pressure gage. For construction and manipulation see "The Measurement of High Hydrostatic Pressure; a Secondary Mercury Resistance Gauge," Pr. Am. Acad. 44, p. 221, 1919.

*This line gives the Specific Mass Resistance at $25^{\circ}$, the other lines the specific volume resistance.
The use of mercury as above has the advantage of being perfectly reproducible so that at any time a pressure can be measured without recourse to a fundamental standard. However, at $\circ^{\circ} \mathrm{C}$ mercury freezes at $7500 \mathrm{~kg} / \mathrm{cm}^{2}$. Manganin is suitable over a much wider range. Over a temperature range o to $50^{\circ} \mathrm{C}$ the pressure resistance relation is linear within $1 / 10$ per cent of the change of resistance up to $13,000 \mathrm{~kg} / \mathrm{cm}^{2}$. The coefficient varies slightly with the sample. Bridgman's samples (German) had values of ( $\Delta R / p R_{0}$ ) $\times 10^{9}$ from 2295 to 2325. These are + instead of - , as with most of the above metals. See "The Measurement of Hydrostatic Pressure up to 20,000 Kilograms per Square Centimeter." Bridgman, Pr. Am. Acad. 47, p. 321, 1911.
temperature coefficients.
Conductivity in mhos or $\frac{1}{\text { ohms per } \mathrm{cm}^{3}{ }^{3}}=\gamma_{t}=\gamma_{0}\left(1-a t+b t^{2}\right)$ and resistivity in microhms-cm $=p_{t}=\rho_{0}\left(x+a t-b t^{2}\right)$.

| Metals and alloys. | Composition by weight. | $\frac{\gamma_{0}}{104}$ | $a \times 10^{6}$ | $p_{0}$ | - |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Gold-copper-silver . | 58.3 $\mathrm{Au}^{\text {+ }}$ +26.5 $\mathrm{Cu}+15.2 \mathrm{Ag}$ $66.5 \mathrm{Au}+15.4 \mathrm{Cu}+18.1 \mathrm{Ag}$ $7.4 \mathrm{Au}+78.3 \mathrm{Cu}+14.3 \mathrm{Ag}$ | 7.58 6.83 $28 . c 6$ | $574 *$ $529 \dagger$ $1830 \ddagger$ | 13.2 14.6 3.6 | I |
| Nickel-copper-zinc. | $\left\{\begin{array}{c} 12.84 \mathrm{Ni}+30.59 \mathrm{Cu}+ \\ 6.57 \mathrm{Zn} \text { by volume . . . } \end{array}\right\}$ | 4.92 | 244§ | 20.3 | I |
| Brass . <br> " hard drawn <br> " annealed | Various . $70.2{ }^{\mathrm{Cu}}+29.8 \dot{\mathrm{Z}}^{\prime} \mathrm{n}$ | 12.2-15.6 12.16 | $\underline{1-2 \times 10^{3}}$ | $\begin{gathered} 6.4-8.4 \\ 8.2 \\ 7.0 \end{gathered}$ | 2 3 3 |
| German silver | $\left\{\begin{array}{l} \text { Various } \\ 60.16 \mathrm{Cu}+25.37 \dot{\mathrm{Z}}_{\mathrm{n}}+ \\ 14.03 \mathrm{Ni}+.30 \mathrm{Fe} \text { with trace } \\ \text { of cobalt and manganese } \end{array}\right\}$ | $3-5$ 3.33 | 360 | $20 .-33$. 30. | 2 |
| Aluminum bronze . | - | 7-5-8.5 | $5-7 \times 10^{2}$ | 12-13 | 2 |
| Phosphor bronze | - | 10-20 | - | 5-10 | 2 |
| Silicium bronze . | - | 41 | - | 2.4 | 5 |
| Manganese-copper. | $30 \mathrm{Mn}+70 \mathrm{Cu}$. . . . . | 1.00 | 40 | 100. | 4 |
| copper | $3 \mathrm{Ni}+24 \mathrm{Mn}+73 \mathrm{Cu}$. | 2.10 | -30 | 48. | 4 |
| Nickelin |  | 3 mOI | 300 | 33. | 4 |
| Patent nickel | $\left\{\begin{array}{l}25 . \mathrm{INi}+74.4 \mathrm{ICu}+ \\ 0.42 \mathrm{Fe}+0.23 \mathrm{Zn+} \\ \text { o. } 3 \mathrm{Mn}+\text { trace of cobalt }\end{array}\right\}$ | 2.92 | 190 | 34. | 4 |
| Rheotan . . . . | $\left\{\begin{array}{c} 53.28 \mathrm{Cu}+25.3 \mathrm{INi}+ \\ 16.89 \mathrm{Zn}+4.46 \mathrm{Fe}+ \\ 0.37 \mathrm{Mn} . . \end{array}\right\}$ | 1.90 | 410 | 53. | 4 |
| Copper-manganeseiron. | $9 \mathrm{rCu}+7.1 \mathrm{Mn}+1.9 \mathrm{Fe}$ | 4.98 | 120 | 20. | 5 |
| Copper-manganeseiron . | $70.6 \mathrm{Cu}+23.2 \mathrm{Mn}+6.2 \mathrm{Fe}$ | I 30 | 22 | 77. | 6 |
| Copper-mangancseiron. | $69.7 \mathrm{Cu}+29.9 \mathrm{Ni}+0.3 \mathrm{Fe}$ | 2.60 | 120 | 38. | 7 |
| Manganin | $8_{4} \mathrm{Cu}+12 \mathrm{Mn}+4 \mathrm{Ni}$ |  |  |  | 27 |
| Constantan | $60 \mathrm{Cu}+40 \mathrm{Ni}$. . . . | $2.04$ | $8$ | 49. | 8 |
|  |  |  |  |  |  |

## Smithsonian Tables.

## CONDUCTING POWER OF ALLOYS.

This table shows the conducting power of alloys and the variation of the conducting power with temperature.* The values of $C_{0}$ were obtained from the original results by assuming silver $=\frac{10^{6}}{1.585}$ mhos. The conductivity is taken as $C_{t}=C_{0}\left(1-a t+b t^{2}\right)$, and the range of temperature was from $\circ^{\circ}$ to $100^{\circ} \mathrm{C}$.
The table is arranged in three groups to show ( $x$ ) that certain metals when melted together produce a solution which has a conductivity equal to the mean of the conductivities of the components, (2) the behavior of those metals alloyed with others, and (3) the behavior of the other metals alloyed together.
It is pomted out that, with a few exceptions, the percentage variation between on and $100^{\circ}$ can be calculated from the formula $P=P_{c} \frac{l}{l}$, where $l$ is the observed and $l$ the calculated conducting power of the mixture at $100^{\circ} \mathrm{C}$., and $P_{c}$ is the calculated mean variation of the metals mixed.

| Alloys. | Weight \% | Volume \% |  | $a \times 1{ }_{10}{ }^{8}$ | $6 \times 10^{9}$ | Variation per $100^{\circ} \mathrm{C}$. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | of first named. |  |  |  |  | Observed. | Calculated. |
| Group 1. |  |  |  |  |  |  |  |
| $\mathrm{Sn}_{6} \mathrm{~Pb}$. | 77.04 | 83.96 | $7 \cdot 57$ | 3890 | 8670 | 30.18 | 29.67 |
| $\mathrm{Sn}_{4} \mathrm{Cd} . .$. | 82.41 | 83.10 | 9.18 | 4080 | 11870 | 28.89 | 30.03 |
| Sn Zn . . . | 78.06 | 77.71 | 10.56 | 3880 | 8720 | 30.12 | $\because 30.16$ |
| PbSn . . . . | 64.13 | 53.41 | 6.40 | 3780 | 8420 | 29.41 | 29.10 |
| $\mathrm{ZnCd}_{2}$. . . . | 24.76 | 26.06 | 16.16 | 3780 | 8000 | 29.86 | 29.67 |
| $\mathrm{SnCd}_{4}$. | 23.05 | 23.50 | 13.67 | 3850 | 9410 | 29.08 | 30.25 |
| $\mathrm{CdPb}_{6}$. | $7 \cdot 37$ | 10.57 | 5.78 | 3500 | 7270 | 27.74 | 27.60 |
| $\cdots \quad$ Group 2. |  |  |  |  |  |  |  |
| Lead-silver $\left(\mathrm{Pb}_{20} \mathrm{Ag}\right)$ <br> Lead-silver ( PbAg ) <br> Lead-silver ( $\mathrm{PbAg}_{2}$ ) | 95.05 | 94.64 | 5.60 | 3630 | 7960 | 28.24 | $\therefore 19.96$ |
|  | 48.97 | 46.90 | 8.03 | 1960 | 3100 | 16.53 | $\begin{array}{r}7.73 \\ \hline\end{array}$ |
|  | 32.44 | 30.64 | 13.80 | 1990 | 2600 | 17.36 | 10.42 |
| $\underset{"}{\text { Tin-gold }} \underset{\left(\mathrm{Sn}_{5} \mathrm{Au}\right)}{\left(\mathrm{Sn}_{12} \mathrm{Au}\right)} .$ | 77.94 | 90.32 | 5.20 ' | 3080 | 6640 | 24.20 | 14.83 |
|  | 59.54 | 79.54 | 3.03 | 2920 | 6300 | 22.90 | $5 \cdot 95$ |
| $\left.\begin{array}{cccccc}\text { Tin-copper } & . & . & . & \\ " & \text { cher } & \dagger & . & . & .\end{array}\right)$ | 92.24 | 93.57 | 7.59 | 3680 | 8130 | 28.71 | 19.76 |
|  | 80.58 | 83.60 | 8.05 | 3330 | 6840 | 26.24 | 14.57 |
|  | 12.49 | 14.91 | $5 \cdot 57$ | 547 | 294 | 5.18 | 3.99 |
|  | 10.30 | 12.35 | 6.41 | 666 | 1185 | 5.48 | 4.46 |
|  | 9.67 | 11.6 I | 7.64 | 691 | 304 | 6.60 | 5.22 |
|  | $4 \cdot 96$ | 6.02 | 12.44 | 995 | 705 | 9.25 | 7.83 |
|  | 1.15 | 1.41 | 39.41 | 2670 | 5070 | 21.74 | 20.53 |
| $\underset{\text { Tin-silver . . . }}{ }$ | 91.30 | 96.52 |  | 3820 | 8190 |  |  |
|  | 53.85 | $75 \cdot 51$ | 8.65 | 3770 | 8550 | 29.18 | I 1.89 |
|  | 36.70 | 42.06 | 13.75 | 1370 | I 340 | 12.40 |  |
|  | 25.00 | 29.45 | 13.70 | 1270 | 1240 | 1 I .49 | 10.08 |
|  | 16.53 | 23.61 | 13.44 | 1880 | 1800 | 12.80 | 12.30 |
|  | 8.89 | 10.88 | 29.61 | 2040 | 3030 | 17.41 | 17.42 |
|  | 4.06 | 5.03 | 38.09 | 2470 | 4100 | 20.61 | 20.62 |

Note. - Barus, in the "Am. Jour. of Sci." vol. 36, has pointed out that the temperature variation of platinum alloys containing less than $10 \%$ of the other metal can be nearly expressed by an equation $y=\frac{n}{x}-m$, where $y$ is the temperature coefficient and $x$ the specific resistance, $m$ and $n$ being constants. If $a$ be the temperature coefficient at $\circ^{\circ} \mathrm{C}$. and $s$ the corresponding specific resistance, $s(a+m)=n$.

For platinum alloys Barus's experiments gave $m=-.000194$ and $n=.0378$.
For steel $m=-.000303$ and $n=.0620$.
Matthiessen's experiments reduced by Barus gave for
Gold alloys $m=-.000045, n=.0072$ 1.
Silver "، $m=-.000112, n=.00538$.
Copper " $m$ 三二..000386, $n=.00055$.

* From the experiments of Matthiessen and Vogt, "Phil. Trans. R. S." v. 154.
$\dagger$ Hard-drawn.
Bmithsonian Tables.

TABLE 401. - Conducting Power of Alloys.

| Grour 3. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Alloys. | Weight \% | Volume \% | $\frac{C_{0}}{10^{4}}$ | $a \times 10^{6}$ | $6 \times 10^{0}$ | Variation per $100^{\circ} \mathrm{C}$. |  |
|  | of first named. |  |  |  |  | Observed. | Calculated. |
| Gold-copper $\dagger$. . . . | 99.23 90.55 | 98.36 81.66 | 35.42 10.16 | 2650 | 4650 | 21.87 | 23.22 |
| " ${ }^{\text {¢ }}$ - . . | 90.55 |  | 10.16 | 749 | 81 | 7.41 | 7.53 |
| $\underset{\text { Gold-silver }}{\text { ¢ }}{ }_{\text {¢ }}{ }_{\text {* }}$. . . . | 87.95 | 79.86 | 13.46 | 1090 | 793 | 10.09 | 9.65 |
| " ${ }^{\text {c }}$ " ${ }^{\text {c . . . . }}$ | 87.95 | 79.86 | 13.61 | 1140 | 1160 | 10.21 | 9.59 |
| " ${ }_{\text {" }}$ " $\quad \dagger$. | 64.80 | 52.08 | 9.48 | 673 | 246 | 6.49 | 6.58 |
|  | 64.80 | 52.08 | $9 \cdot 51$ | 721 | 495 | -6.71 | 6.42 |
| " ${ }^{\prime}$ | 3 3 .33 | 19.86 | 13.69 | 885 | 53 I | 8.23 | 8.62 |
| " ${ }^{\text {* }}$. . | 31.33 |  | 13.73 | 908 | 641 | 8.44 | 8.31 |
|  | 34.83 | 19.17 | 12.94 | 864 | 570 | 8.07 | 8.18 |
| " " $\dagger$. . . | 1.52 | 0.71 | 53.02 | 3320 | 7300 | 25.90 | 25.86 |
| $\underset{\text { Platinum-silver } \dagger \text { ¢ }}{ }{ }_{\text {¢ }}$. | 33.33 | 19.65 | 4.22 | 330 | 208 | 3.10 |  |
|  | 9.81 | 5.05 | 11.38 | 774 | 656 | 7.08 | 7.25 |
| " " $\quad$. | 5.00 | 2.51 | 19.96 | 1240 | 1150 | 11.29 | 11.88 |
| Palladium-silver $\dagger$. | 25.00 | 23.28 | $5 \cdot 38$ | 324 | 154 | $3 \cdot 40$ | 4.21 |
| Copper-silver $\dagger$. . . | 98.08 | 98.35 | 56.49 | 3450 | 7990 | 26.50 | 27.30 |
|  | 94.40 | 95.17 | 51.93 | 3250 | 6940 | 25.57 | 25.41 |
| " ${ }^{\prime}$ | 76.74 | 77.64 | 44.06 | 3030 | 6070 | 24.29 | 21.92 |
| " ${ }^{\prime}$ | 42.75 | 46.67 | 47.29 | 2870 | 5280 | 22.75 | 24.00 |
|  | 7.14 | 8.25 | 50.65 | 2750 | 4360 | 23.17 | 25.57 |
| " " $\dagger$. | 1.31 | 1.53 | 50.30 | 4120 | 8740 | 26.51 | 29.77 |
|  | 13.59 | 27.93 | 1.73 | 3490 | 7010 | 27.92 | 14.70 |
| " " $\dagger$. . . . | 9.80 | 21.18 | 1.26 | 2970 | 1220 | 17.55 | 11.20 |
| " " $\dagger$. . . . | 4.76 | 10.96 | I. 46 | 487 | 103 | 3.84 | 13.40 |
| Iron-copper $\dagger$. | 0.40 | 0.46 | 24.51 | ${ }^{1} 550$ | 2090 | 13.44 | 14.03 |
| Phosphorus-copper $\dagger$. | 2.50 | - | 4.62 | $\begin{array}{r}476 \\ \\ \hline\end{array} 320$ |  | - | - |
| $\dagger \text {. }$ | 0.95 | - | 14.91 | 1320 | $1640$ | - | - |
| Arsenic-copper $\dagger$. |  | - |  | 516 | 989 | - | - |
| " " $\dagger$. | 2.80 | - | 8.12 | 736 | 446 | - | - |
| " ${ }^{\text {c }} \dagger$. | trace | - | 38.52 | 2640 | 4830 | - | - |

* Annealed.
$\dagger$ Hard-drawn.


## TABLE 402. - Allowable Carrying Capacity of Rubber-covered Copper Wires.

(For inside wiring - Nat. Board Fire Underwriters' Rules.)

| B + S Gage | 18 | 16 | 14 | 12 | 10 | 8 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | $\infty$ | 0000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| A mperes | 3 | 6 | 12 | 17 | 24 | 33 | 46 | 54 | 65 | 76 | 90 | 107 | 127 | 150 | 210 |

500,000 circ. mills, $390 \mathrm{amp} . ; 1,000,000 \mathrm{c} . \mathrm{m} ., 650 \mathrm{amp} . ; 2,000,000 \mathrm{c} . \mathrm{m} ., 1,050 \mathrm{ampp}$ For insulated al. wire, capacity $=84 \%$ of cu . Preece gives as formula for fusion of bare wires $I=\operatorname{ad}^{\frac{3}{2}}$, where $d=$ diam. in inches, a for cu. is 10,244 ; al., $75 S_{5} ;$ pt., 5172 ; German silver, 5230 ; platinoid, 4750 ; $\mathrm{Fe}, 3148$; Pb., I 379 ; alloy 2 pts . Pb., I of Sn ., 1318.

## RESISTIVITIES AT HIGH AND LOW TEMPERATURES.

The electrical resistivity ( $\rho$, ohms per cm . cube) of good conductors depends greatly on chemical purity. Slight contamination even with metals of lower $\rho$ may greatly increase $\rho$. Solid solutions of good conductors generally have higher $\rho$ than components. Reverse is true of bad conductors. In solid state allotropic and crystalline fornis grearly modify $\rho$. For liquid metals this last cause of variability disappears. The + temperature coefficients of pure metals is of the same order as the coefficients of expansion of gases. For temperature resistance $(t, \rho)$ plut at low temperatures the graph is convex towards the axis of $t$ and probably approaches tangency to it. However for extremely low temperatures Ounes finds very sudden and great drops in $\rho$. e.g. for Mercury, $\rho_{3.6 \mathrm{~K}}<4 \times 10^{-10} \rho_{\mathrm{o}}$ and for Sn ., $\rho_{3.8 \mathrm{~K}}<{ }^{-10^{-7} \rho_{\mathrm{o}}}$. The $t, \rho$ graph for an alloy may be nearly parallel to the $t$ axis, cf. constantan ; for poor conductors $\rho$ may decrease with increasing t. At the melting-points there are three types of behavior of good conductors: those about doubling $\rho$ and then possessing nearly linear t, $\rho$ graphs (Al., Cu., Sn., Au., Ag., Pb.); those where $\rho$ suddenly increases and then the + temp. coefficient is only approximately constant ; (Hg., Na., K .); those about doubling $\rho$ then having a - , slowly changing to a + temp. coef. (Zn., Cd .) ; those where $\rho$ suddenly decreases and thereafter steadily increases (Sb., Bi.). The values from different authornties do not necessarily fit because of different samples of metals. The Shimank values ( $t$ given to tenths of ${ }^{\circ}$ ) are for material of theoretical purity and are determined by the a rule (see his paper, also Nernst, Ann. d Phys. 36 , p. 403 , 1911 for temperature resistance thermometry). The Shimank and Pirrani values are originally given as ratios to $\rho_{0}$. (Ann. d. Phys. 45, p. $706,1914,46$, p. 176, 1915.) Resistivities are in ohms per cm. cube unless stated. Italicized figures indicate liquid state.

| Gold. |  |  | Copper. |  |  | Silver. |  |  | Zinc. |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\frac{\rho_{t}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\stackrel{\rho_{t}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{\text {t }}$ | $\frac{\rho_{t}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\mathrm{\rho}_{\mathrm{f}}$ |
| -252.8 | 0.018 | . 0081 | -258.6 | 0.014 | .0091 | -258.6 | 0.009 | . 0057 | -252.9 | . 0511 | . 0089 |
| -200. | .601 | . 267 | -252.8 | . 016 | . 0103 | -252.8 | . 014 | . 0090 | -200. | 1.39 | . 242 |
| -192.5 | . 520 | . 231 | -251.1 | . 028 | . 0178 | -189.5 | . 334 | . 222 | -191.1 | 1.23 | . 214 |
| -150. | . 997 | . 444 | -206.6 | .163 | . 1035 | -200. | -357 | . 237 | -150. | 2.00 | . 348 |
| -100. -77.6 | 1.400 1.564 | . 623 | -192.9 -150 | . 249 | .1580 .359 | -150. -100. | . 638 | . 424 | -100. | 2.90 | . 504 |
| -77.6 | 1.564 | . 6806 | -150. | . 567 | - 359 | -100. | . 916 | . 608 | - 77.8 | 3.97 | . 691 |
| -50. 0. 0. | 1.813 2.247 | .806 1.00 | -100. -50. | .904 1.240 | .573 .786 | -76.8 -50. | 1.040 1.212 | . 680 | - 50. | 4.04 | . 703 |
| 100. | 2.97 | 1.32 | o. | 1.578 | 1.00 | O. | 1.506 | 1.00 | 10. | 5.75 7.95 | 1.00 1.38 |
| 200. | 3.83 | 1.70 | 100. | 2.28 | 1.44 | 100. | 2.15 | 1.43 | 300. | 13.25 | 2.30 |
| 500. | 6.62 | 2.94 | 200. | 2.96 | . 8.88 | 200. | 2.80 | 1.86 | 415. | 17.00 | 2.96 |
| 750. | 9.35 | 4.16 | 500. | 5.08 | 3.22 | 400. | 3.46 | 2.30 | 427. | 37.30 | 6.49 |
| 1000. | 12.54 | 5.58 | 750. | 7.03 | 4.46 | 750. | 6.65 | 4.42 | 450. | 37.08 | 6.46 |
| 1063. | 13.50 | 6.01 | 1000. | 9.42 | 5.97 | 960. | 8.4 | 5.58 | 500. | 36.60 | 6.36 |
| 1063. | 30.82 | 13.7 | ${ }^{108} 3$. | 10.20 | 6.47 | 960. | 16.6 | IT.O | 600. | 35.90 | 6.25 |
| 1200. | 32.8 | 14.6 | 1083. | 21.30 | 13.5 | 1000. | 17.01 | 11.3 | 700. | 35.60 | 0.19 |
| 1400. | 35.6 | 15.8 | 1200. | 22.30 | 14.1 | 1200. | 19.36 | 12.9 | 800. | 35.60 | 6. 19 |
| ${ }^{1500}$. | 37.0 | 16.5 | 1400. 1500. | 23.86 | 15.1 15.6 | 1400. | 21.72 | 14.4 | 850. | 35.74 | 6.21 |
|  |  |  | 1500. | 24.62 | 15.6 | 1500. | 23.0 | 15.3 |  |  |  |
| Mercury. |  |  | Potassium. |  |  | Sodium. |  |  | Iron. |  |  |
| ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\rho_{\underline{t}}$ | ${ }^{\circ} \mathrm{C}$ | $\mathrm{P}_{\mathrm{t}}$ | $\rho_{\text {t }}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\mathrm{P}_{\mathbf{t}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\rho_{t}$ |
| $\begin{gathered} -200 . \\ -150 . \\ -100 . \\ -50 . \end{gathered}$ | $5 \cdot 38$ | . 057 | -200. | 1.720 | . 246 | -200. | 0.605 | - 37 | -252.7 | 0.011 | . 0010 |
|  | 10.30 | .109 | -150. | 2.654 | . 379 |  | 1.455 | . 330 | -200. | 2.27 | . 212 |
|  | 15.42 | . 164 | -100. | 3.724 | . 532 | -100. | 2.380 | . 541 | -192.5 | . 844 | . 079 |
|  | 21.4 | . 227 | 50. | 5.124 | . 732 | -50. | 3.365 | . 764 | -100. | 5.92 | . 554 |
| -30.o. | 91.7 | . 975 | o. | 7.000 | 1.00 | o. | 4.40 | 1.000 | -75.1 | 6.43 | . 602 |
|  | 94.1 | 1.000 | 20. | 7.116 | 1.016 | 20. | 4.873 | 1.107 | - 50. | 8.15 | . 763 |
| 50.100. | 98.3 | 1.045 | 60. | 8.790 | 1.256 | 93.5 | 6.290 | 1.429 | - 0. | 10.68 | 1.00 |
|  | 103.1 | 1.096 | 65. | 13.40 | 1.914 | 100. | 9.220 | 2.095 | 100. | 16.61 | 1.554 |
| 200.300. | 114.0 | 1.212 | 100. | 15.31 | 2.187 | 120. | 9.724 | 2.209 | 200. | 24.50 | 2.293 |
|  | 127.0 | 1.350 | 120. | 16.70 | 2.380 | 140. | 10.34 | 2.349 | 400. | 43.29 | 4.052 |
| Manganin. |  |  | German Silver. |  |  | Constantan. |  |  | $90 \% \mathrm{Pt} . \quad 10 \% \mathrm{Rh}$. |  |  |
| ${ }^{\circ} \mathrm{C}$. | $\rho_{\mathrm{t}}$ | $\frac{\rho_{t}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\frac{\rho_{\mathrm{t}}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{\mathrm{t}}$ | $\frac{\rho_{t}}{\rho_{0}}$ | ${ }^{\circ} \mathrm{C}$. | $\rho_{t}$ | $\frac{\rho_{\mathrm{t}}}{\rho_{0}}$ |
| -200.-150. |  |  | -200. |  |  | -200. |  |  |  |  |  |
|  | 38.2 | . 985 | -150. | 28.7 | .957 | -150. | 43.0 | . 975 | $-150$. | 16.29 | . 770 |
| -100.-50. | 38.5 | . 992 | -ron. | 29.3 | -97? | -100. | 43.5 | . 986 | -100. | 18.05 | . 854 |
|  |  |  |  |  | . 990 |  |  |  | - 50. | 19.66 | . 930 |
| 0. | 38.8 | 1.000 | 0. | 30.0 | 1.000 | o. | 44.1 | 1.coo | \%. | 21.14 | 1.000 |
| 100.400. | 38.9 | 1.003 | 100. | 33.1 | 1.103 | 100. | 44.6 | 1.012 | 100. | 24.20 | 1.145 |
|  | 38.3 | . 987 |  |  |  | 400. | 44.8 | 1.016 |  |  |  |

Au. below $\mathbf{o}^{\circ}$, Niccolai, Lincei Rend. (5), 16, p. 757, 906, 1907; above, Northrup, Jour. Franklin Inst. 177, p. 85, 1914. Cu . below, Niccolai, l. c. above, Norihrup, ditto, 177. p. 1, 1914. Ag. below, Niccolai, I. c. above Northrıp. ditto, 178, p. 85 , 1914. Zn. below, Dewar, Fleming, Phil. Mag. 36, p. 271 1, 1893 ; above, Northrup, 175, p. 153.1913 . Hg. below Dewar, Fleming, Proc. Roy. Soc. 66, p. 76, 1900 ; above, Northrup, see Cd. K. below Guntz, Broniewski. C. R. 147, p. ${ }^{1474}, 1008$, 148, p. 204, 1909. Above, Northrup, Tr. Am. Electroch. Soc. p. 185, 1911 . Na, below, means, above, see K. Fe., Manganin, Constantan. Niccolai, l.c. German Silver, $90 \%$ Pt. $90 \%$ Rh., Dewar and Fleming - Phil. Mag. 36, p. 271, 1893.

Table 403 (continued).
RESISTIVITIES AT HIGH AND LOW TEMPERATURES.
(Ohms per cm. cube unless stated otherwise.)


Pt. low, Nernst, 1. c. high, Pirrani, Ber. Dentsch. Phvs. Ges. 12, p. 305, Pb. low, Schimank, Nernst, 1. c. high. Northrup, see Zn. Bi. low, means, high, Northrup, see Zn. Cd. low, Euchen, Gehlhoff, Verh. Deutsch. Phys. Ges. 14, p. 169, 1912, high, Northrup, see Zn. Sn. low, Dewar, Fleming, high, Northrup, see Zn. Carbon, graphite, Metallurg. Ch. Fing. 13, p. 23, 1915. Silica, Campbell, Nat. Phys. Lab. 11, p. 207, 1914. Alundum, Metallurg. Ch. Eng. 12, p. 125, 1914.

* Diamond $1030^{\circ} \mathrm{C}, \rho>10^{7} ; 1380^{\circ}, 7.5 \times 10^{5}, \mathrm{v}$. Wartenberg, 1912.


## TABLE 404.-Volume and Surface Resistivity of Solid Dielectrics.

The resistance between two conductors insulated by a solid dielectric depends both upon the surface resistance and the volume resistance of the insulator. The volume resistivity, $\rho$, is the resistance between tuo opposite faces of a centimeter cube. The surface resistivity, $\sigma$, is the resistance between two opposite edges of a centimeter square of the surface. The surface resistivity usually varies through a wide range with the humidity. (Curtis, Bul. Bur. Standards, 11, 359, 1915, which see for discussion and data for many additional materials.)

| Material. | $\sigma$; megohms $50 \%$ humidity | $\sigma$; megohms $70 \%$ humidity. | $\boldsymbol{\sigma}$ : megohms 90 \% humidity. | $\mathrm{Megohms-cms.}^{\rho}$ |
| :---: | :---: | :---: | :---: | :---: |
| Amber | $6 \times 10^{8}$ | $2 \times 10^{8}$ | $1 \times 10^{5}$ | $5 \times 10^{10}$ |
| Beeswax, yellow . | $6 \times 10^{8}$ | $6 \times 10^{8}$ | $5 \times 10^{8}$ | $2 \times 10^{9}$ |
| Celluloid . . | $5 \times 10^{4}$ | $2 \times 10^{4}$ | $2 \times 10^{8}$ | $2 \times 10^{4}$ |
| Fiber, red . . . . | $2 \times 10^{4}$ | $3 \times 10^{3}$ | $2 \times 10^{2}$ | $5 \times 10^{3}$ |
| Glass, plate . . . . . . . . | $5 \times 10^{4}$ | $6 \times 10$ | $2 \times 10$ | $2 \times 10^{\circ}$ |
| " Kavalier . . . . . . | $4 \times 10^{6}$ | $4 \times 10^{3}$ | $1 \times 10^{3}$ | $8 \times 10^{9}$ |
| Hard rubber, new | $3 \times 10^{9}$ | $1 \times 10^{8}$ | $2 \times 10^{8}$ | $1 \times 10^{12}$ |
| I vory | $5 \times 10^{3}$ | $1 \times 10^{8}$ | $3 \times 10$ | $2 \times 10^{2}$ |
| Khotinsky cement | $7 \times 10^{8}$ | $3 \times 10^{8}$ | $5 \times 10^{5}$ | $2 \times 10^{9}$ |
| Marble, Italian . | $3 \times 10^{8}$ | $2 \times 10^{2}$ | $2 \times 10$ | $1 \times 10^{5}$ |
| Mica, colorless | $2 \times 10^{7}$ | $4 \times 10^{5}$ | $8 \times 10^{3}$ | $2 \times 10^{11}$ |
| Paraffin (parowax) | $9 \times 10^{9}$ | $7 \times 10^{9}$ | $6 \times 10^{9}$ | $1 \times 10^{10}$ |
| Porcelain, unglazed . . . . . | $6 \times 10^{5}$ | $7 \times 10^{3}$ | $5 \times 10$ | $3 \times 10^{8}$ |
| Quartz, fused . . . . . . . | $3 \times 10^{6}$ | $2 \times 10^{8}$ | $2 \times 10^{2}$ | $5 \times 10^{12}$ |
| Rosin . . | $6 \times 10^{8}$ | $3 \times 10^{8}$ | $2 \times 10^{8}$ | $5 \times 10^{10}$ |
| Sealing wax | $2 \times 10^{9}$ | $6 \times 10^{8}$ | $9 \times 10^{7}$ | $5 \times 10^{9}$ |
| Shellac . . . . . . . | $6 \times 10^{7}$ | $3 \times 10^{6}$ | $7 \times 10^{8}$ | $1 \times 10^{17}$ |
| Slate : | $9 \times 10$ | $3 \times 10$ | $1 \times 10$ | $1 \times 10^{2}$ |
| Sulphur . . . . . . . . | $7 \times 10^{9}$ | $4 \times 10^{9}$ | $1 \times 10^{8}$ | $1 \times 10^{11}$ |
| Wood, parafined mahogany . . | $4 \times 10^{6}$ | $5 \times 10^{5}$ | $7 \times 10^{8}$ | $4 \times 10^{7}$ |

## Smithsonian Tables.

TABLE 405.-Variation of Electrical Resistance of Glass and Porcelain with Temperature.
The following table gives the values of $a, b$, and $c$ in the equation

$$
\log R=a+b t+c t^{2}
$$

where $R$ is the specific resistance expressed in ohms, that is, the resistance in ohms per centimeter of a rod one square centimeter in cross section.*

| No. | Kind of glass. | Density. | $a$ | $b$ | $c$ | Range of temp. Centigrade. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Test-tube glass | - | 13.86 | -. 044 | . 000065 | $0^{\circ}-250^{\circ}$ |
| 2 | " " " | 2.458 | 14.24 | -. 055 | . 0001 | 37-131 |
| 3 | Bohemian glass | 2.43 | 16.21 | -. 043 | . 0000394 | 60-174 |
| 4 | Lime glass (Japanese manufacture) . | 2.55 | 13.14 | -.031 | -. 000021 | $10-85$ |
| 5 | " | 2.499 | 14.002 | -. 025 | -.00006 | 35-95 |
| 6 | Soda-lime glass (French flask) | 2.533 | 14.58 | -. 049 | . 000075 | 45-120 |
| 7 | Potash-soda lime glass . . . | 2.58 | 16.34 | -. 0425 | .0000364 | 66-193 |
| 8 | Arsenic enamel flint glass | 3.07 | 18.17 | -. 055 | . 000088 | 105-135 |
| 9 | Flint glass (Thomson's electrometer jar) | 3.172 | 18.021 | -. 036 | -.0000091 | 100-200 |
| 10 | Porcelain (white evaporating dish) . | - | 15.65 | -. 042 | . 00005 | 68-290 |

Composition of some of the above Sprcimens of Glass.


* T. Gray, " Phil. Mag." 1880 , and " Proc. Roy. Soc." $188 \mathbf{2}$.

TABLE 405a. - Temperature Resistance Coefficients of Class, Porcelain and Quartz dr/dt.

| Temperature. | $450^{\circ}$ | $500^{\circ}$ | $575^{\circ}$ | $600^{\circ}$ | $700^{\circ}$ | $750^{\circ}$ | $800^{\circ}$ | $900^{\circ}$ | $1000{ }^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Glass | -32. | -6. | -1.5 | -. 8 |  | -0.1 | -0.06 | - | - |
| Porcelain. |  | - | -16. | $-9.8$ | $-2.8$ | -1. 6 | $-.70$ | -0.30 | -0.12 |
| Quartz. . | - | - | - |  | - | -10. | -6.40 | $-2.60$ | -1.00 |

Somerville, Physical Review, 3 1, p. 261, 1910.

## Smithsonian Tables.

Table 406.
TABULAR COMPARISON OF WIRE GAGES.

*The Steel Wire Gage is the same gage which has been known by the various names: "Washburn and Moen," "Roebling," "American Steel and Wire Co.'s." Its abbreviation should be written "Stl. W. G.," to distinguish it from "S. W. G.," the usual abbreviation for the (British) Standard Wire Gage.
$\dagger$ The American Wire Gage sizes have been rounded off to the usual limits of commercial accuracy. They are given to four significant figures in Tables 410 to 413. They can be calculated with any desired accuracy, being based upon a simple mathematical law. The diameter of No. 0000 is defined as 0.4600 inch and of No. 36 as 0.0050 inch. The ratio of any diameter to the diameter of the next greater number $\sqrt[39]{\frac{.4600}{.050}}=\mathbf{8 . 1 2 2 9 3 2 2}$.
Taken from Circular No. 3r. Copper Wire Tables, U.S. Bureau of Standards which contains more complete tables.
Smithsonian Tables.

# Tables 407-413. WIRE TABLES. 

## TABLE 407. - Introduction. Mass and Volume Resistivity of Copper and Aluminum.

The following wire tables are abridged from those prepared by the Bureau of Standards at the request and with the coöperation of the Standards Committee of the American Institute of Electrical Engineers (Circular No. 3I of the Bureau of Standards). The standard of copper resistance used is "The International Annealed Copper Standard" as adopted Sept. 5, 1913, by the International Electrotechnical Commission and represents the average commercial high-conductivity copper for the purpose of electric conductors. This standard corresponds to a conductivity of $58 . \times 10^{-5} \mathrm{cgs}$. units, and a density of 8.89 , at $20^{\circ} \mathrm{C}$.

In the various units of mass resistivity and volume resistivity this may be stated as

$$
\begin{aligned}
& 0.15328 \text { ohm (meter, gram) at } 20^{\circ} \mathrm{C} \text {. } \\
& 857.20 \text { ohms (mile, pound) at } 20^{\circ} \mathrm{C} \text {. } \\
& 1.7241 \text { microhm-cm. at } 20^{\circ} \mathrm{C} \text {. } \\
& 0.67899 \text { microhmmeinch at } 20^{\circ} \mathrm{C} \text {. } \\
& 10.37 \mathrm{t} \text { ohms (mil, foot) at } 20^{\circ} \mathrm{C} \text {. }
\end{aligned}
$$

The temperature coefficient for this particular resistivity is $\alpha_{20}=0.00393$ or $\alpha_{0}=0.00427$. The temperature coefficient of copper is proportional to the conductivity, so that where the conductivity is known the temperature coefficient may be calculated, and vice-versa. Thus the next table shows the temperature coefficients of copper having various percentages of the standard conductivity. A consequence of this relation is that the change of resistivity per degree is constant, independent of the sample of copper and independent of the temperature of reference. This re-sistivity-temperature constant, for volume resistivity and Centigrade degrees, is 0.00681 michromcm ., and for mass resistivity is 0.000597 ohm (meter, gram).
The density of 8.89 grams per cubic centimeter at $20^{\circ} \mathrm{C}$., is equivalent to 0.32117 pounds per cubic inch.
The values in the following tables are for annealed copper of standard resistivity. The user of the tables must apply the proper correction for copper of other resistivity. Hard-drawn copper may be taken as about 2.7 per cent higher resistivity than annealed copper.
The following is a fair average of the chemical content of commercial high conductivity copper:

| Copper | 99.91\% | Sulphur......... 0.002\% |
| :---: | :---: | :---: |
| Silver. | . 03 | Iron . . . . . . . . . . . 002 |
| Oxygen | . 052 | Nickel . . . . . . . . Trace |
| Arsenic | . 002 | Lead |
| Antimony | . 002 | Zinc |

The following values are consistent with the data above:

$$
\begin{aligned}
& \text { Conductivity at } 0^{\circ} \text { C., in c.g.s. electromagnetic units . . . . . . . . . . . . . . } 62.969 \times 10^{-5} \\
& \text { Resistivity at } \circ^{\circ} \mathrm{C} \text {., in michroms-cms. .................................. . . } 1.588 \text { I } \\
& \text { Density at } 0^{\circ} \text { C......................................................... } 8.90 \\
& \text { Coefficient of linear expansion per degree C............................ } 0.000017 \\
& \text { "Constant mass " temperature coefficient of resistance at } 0^{\circ} \text { C. ..... } 0.00427
\end{aligned}
$$

The aluminum tables are based on a figure for the conductivity published by the U.S. Bureau of Standards, which is the result of many thousands of determinations by the Aluminum Company of America. A volume resistivity of 2.828 michrom-cm., and a density of 2.70 may be considered to be good average values for commercial hard-drawn aluminum. These values give:

| Mass resistivity, in ohms (meter, gram) at $20^{\circ} \mathrm{C}$ (mile, pound) at $20^{\circ} \mathrm{C}$ |  |
| :---: | :---: |
| Mass per cent conductivity |  |
| Volume resistivity, in michro |  |
| in microhm |  |
| Volume per cent conductivity | 61.0 |
| Density, in grams per cubic c |  |
| Density, in pounds per cubic inch | 0.097 |

The average chemical content of commercial aluminum wire is

Aluminum

$99.57 \%$



Iron ................................................................... 0.14
Smithsonian Tables.

Tables 408, 409.
COPPER WIRE TABLES.
TABLE 408. - Temperature Coeftioients of Copper for Different Initial Temperatures (Centigrade) and Different Condnotivities.

| $\begin{aligned} & \text { Ohms } \\ & \text { (meter. gram) } \\ & \text { at } 20^{\circ} \mathrm{C} \text {. } \end{aligned}$ | Per cent conductivity. | $a_{0}$ | $a_{15}$ | $a_{20}$ | $\alpha_{25}$ | $a_{30}$ | $a_{50}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.16134 .15966 | $95 \%$ $96 \%$ | 0.00403 .00408 | $\begin{array}{r} 0.00380 \\ .00385 \end{array}$ | 0.00373 .00377 | 0.00367 .00370 | 0.00360 .00364 | $\begin{array}{r} 0.00336 \\ .00339 \end{array}$ |
| .15802 .15753 | $97 \%$ $97.3 \%$ | $\begin{aligned} & .00413 \\ & .00414 \end{aligned}$ |  | $\begin{array}{r} .0038 \mathrm{x} \\ .00382 \end{array}$ | $\begin{aligned} & .00374 \\ & .00375 \end{aligned}$ | .00367 .00368 | $\begin{aligned} & \text { Cos } 42 \\ & . c o 3 ~ 43 \end{aligned}$ |
| .15640 .15482 | $\begin{aligned} & \mathbf{9 8 \%} \\ & \mathbf{9 9 \%} \end{aligned}$ | .004 17 | .00393 .00397 | .00385 .00389 | $\begin{array}{r} .00378 \\ .00388 \end{array}$ | $\begin{aligned} & . \infty 371 \\ & . \infty 374 \end{aligned}$ | $\begin{aligned} & .00345 \\ & .00348 \end{aligned}$ |
| $\begin{array}{r} 15328 \\ .15176 \end{array}$ | $\begin{aligned} & 100 \% \\ & 101 \% \end{aligned}$ | $\begin{array}{r} .00427 \\ .00431 \end{array}$ | $\begin{aligned} & .004 \text { OI } \\ & .00405 \end{aligned}$ | $\begin{array}{r} .00393 \\ .00397 \end{array}$ | $\begin{aligned} & .00385 \\ & .00389 \end{aligned}$ | $\begin{array}{r} .00378 \\ .00382 \end{array}$ | $\begin{aligned} & .00352 \\ & .00355 \end{aligned}$ |

Note. - The fundamental relation between resistance and temperature is the following:

$$
\mathrm{R}_{\mathrm{t}}=\mathrm{R}_{\mathrm{t}_{1}}\left(\mathrm{I}+\alpha_{\mathrm{t}_{1}}\left[\mathrm{t}-\mathrm{t}_{1}\right]\right)
$$

where $a_{t_{1}}$ is the "temperature coefficient," and $t_{1}$ is the "initial temperature" or "temperature of reference."
The values of $a$ in the above table exhibit the fact that the temperature coefficient of copper is proportional to the conductivity. The table was calculated by means of the following formula, which holds for any per cent conductivity, $n$, within commercial ranges, and for centigrade temperatures. ( $n$ is considered to be expressed decimally: e.g., if per cent conductivity $=99$ per cent, $n=0.99$.)

$$
a_{t_{1}}=\frac{1}{\frac{1}{n(0.00393)}+\left(t_{1}-20\right)}
$$

TABLE 409. - Reduction of Observations to Standard Temperature. (Copper.)

| Temperature C. | Corrections to reduce Resistivity to $20^{\circ} \mathrm{C}$. |  |  |  | Factors to reduce Resistance to $20^{\circ} \mathrm{C}$. |  |  | Temperature C. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ohm (meter, gram). | $\underset{\mathrm{cm} .}{\text { Microhm- }}$ | Ohm (mile, pound). | Microhm inch. | For 96 per cent conductivity. | For 98 per cent conductivity. | For 100 per cent conductivity. |  |
| $\bigcirc$ | +0.011 94 | +0.1361 | + 68.20 | +0.053 58 | 1.0816 | 1.0834 | 1.0853 |  |
| 5 | + . 00896 | +.1021 | + 51.15 | +.040 18 | 1.0600 | 1.0613 | 1.0626 | 5 |
| 10 | +.005 97 | +.068r | + 34.10 | +.026 79 | 1.0392 | 1.0401 | 1.0409 |  |
| 11 | +.00537 | +.0612 | + 30.69 | +.024 II | 1.0352 | 1.0359 | 1.0367 | II |
| 12 | +.004 78 | +. 0544 | a $+\quad 27.28$ $+\quad 237$ | +.02143 | 1.0311 | 1.0318 | 1.0325 | 12 |
| 13 | +.00418 | +. 0476 | + 23.87 | +.018 75 | 1.0271 | 1.0277 | 1.0283 | 13 |
| 14 | +.003 58 | +. 0408 | + 20.46 | +.016 c7 | 1.0232 | 1.0237 | 1.0242 | 14 |
| 15 16 | ( $+\quad .00299$ +.00239 | +.0340 .+ .0272 | $+\quad 17.05$ $+\quad 13.64$ | +.01340 $+\quad .01072$ | 1.0192 1.0153 | 1.0196 $\mathbf{1 . 0 1 5 6}$ | 1.0200 1.0160 | 15 16 |
|  |  |  |  |  |  |  | 1.0119 |  |
| 17 18 | + .00179 | +.0204 +.0136 | 10.23 $+\quad 6.82$ | +.00804 +.00536 | 1.01144 1.0076 | 1.0117 1.0078 | 1.0179 1.0079 | 18 |
| 19 | +.00060 | +. .0068 | + 3.4 I | +.00268 | 1.0038 | 1.0039 | 1.0039 | 19 |
| 20 | - | - | - | - | 1.0000 | 1.0000 | 1.0000 | 20 |
| 21 | -. 00000 | -. 0068 | - 3.41 | -.002 68 | 0.9962 | c. 9962 | 0.9961 | 21 |
| 22 | -. .001 19 | -. .0136 | - 6.82 | -. .00536 | . 9925 | . 9924 | . 9922 | 22 |
| 23 | -. .001 79 | -. 0204 | - 10.23 | -. .008 04 | . 9888 |  |  | 23 |
| 24 25 | - .002 398 | - . 0272 | $\begin{array}{r}1 \\ -\quad 13.64 \\ -\quad 17.05 \\ \hline\end{array}$ | -. 0101072 | .9851 | .9848 | . 98885 | 24 25 |
| 26 | -. 00358 | -. 0408 | - 20.46 | -. .01607 | . 9779 | . 9774 | . 9770 | 26 |
| 27 | -. 00418 | -. 0476 | - 23.87 | -. .01875 | . 9743 | . 9737 | . 9732 | 27 |
| 28 | -. .00478 | -. 0544 | - 27.28 | -. 02143 | . 9707 | . 9701 | .9695 | 28 |
| 29 | -. .005 37 | -. 0612 | - 30.69 | -. 02411 | . 9672 | . 9665 | . 9658 | 29 |
| 30 | -.005 97 | -. 0688 r | - 34.10 | -. 02679 | .9636 | .9629 | . 96222 | 30 35 |
| 35 | -.008 96 | -. 102 I | - 51.15 | -. 04018 | . 9464 |  | .9443 | 35 |
| 40 | -. .ori 94 | - . 136 r | - 68.20 | - . 05358 | . 9298 | . 9285 | . 9271 | 40 |
| 45 | -. 01493 | -.1701 | - 88.25 | - . 068698 | .9138 | . 81896 | . 89.105 | 45 50 |
| 50 | -. 01792 | -. 2042 | -102.30 | -. .080 37 | . 8983 | . 8964 |  | 50 |
|  |  | -. 2382 | - 119.35 | -.093 76 |  |  |  |  |
| 60 65 | - .02389 -.02687 | - .2722 -.3062 | - 136.40 -153.45 | -. 107116 | $\begin{aligned} & .8689 \\ & .8549 \end{aligned}$ | $\begin{aligned} & .8665 \\ & .8523 \end{aligned}$ | $\begin{aligned} & .8642 \\ & .8497 \end{aligned}$ | $\begin{aligned} & 60 \\ & 65 \end{aligned}$ |
|  | -. .22687 |  |  |  |  |  |  |  |
| 70 | -. 02986 | -. 3403 | -170.50 | -. 13395 | $\begin{aligned} & .8413 \\ & 828 x \end{aligned}$ | $\begin{aligned} & .8385 \\ & .8252 \end{aligned}$ | $\begin{aligned} & .8358 \\ & .8223 \end{aligned}$ | 70 75 |
| 75 | -. .03285 | -. 3743 | - 187.55 | -. 14734 | .8281 |  |  | 75 |

## WIRE TABLE, STANDARD ANNEALED COPPER.

American Wire Gage (B. © S.). English Units.

| $\begin{aligned} & \text { Gage } \\ & \text { No. } \end{aligned}$ | Diameter in Mils. at $20^{\circ} \mathrm{C}$. | Cross-Section at $20^{\circ} \mathrm{C}$. |  | Ohms per 1000 Feet.* |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Circular Mils. | Square Inches. | $\left(=0^{\circ} \mathrm{C}\right.$ | $\begin{aligned} & \quad 200 \mathrm{C} \\ & (=680 \mathrm{~F}) \end{aligned}$ | $\left(\begin{array}{c} 50^{\circ} \mathrm{C} \\ \left.={ }_{122^{\circ}} \mathrm{F}\right) \end{array}\right.$ | $\left(\begin{array}{l} 75^{\circ} \mathrm{C} \\ \left.=167^{\circ} \mathrm{F}\right) \end{array}\right.$ |
| 0000 | 460.0 | 211600. | 0.1662 | 0.04516 | 0.049 OI | 0.05479 | 0.05961 |
| 000 | 409.6 | 167800. | . 1318 | .05695 | . 06180 | . 06909 | . 07516 |
| 00 | 364.8 | 133100. | . 1045 | . 0718 I | . 07793 | . 08712 | . 09478 |
| 0 | 324.9 | 105500. | .082 S9 | . 09055 | . 09827 | . 1099 | . 1195 |
| 1 | 289.3 | 83690. | . 06573 | . 1142 | . 1239 | . 13 S 5 | . 1507 |
| 2 | 257.6 | 66370. | . 05213 | . 1440 | . 1563 | . 1747 | . 1900 |
| 3 | 229.4 | 52640. | . 04134 | .1816 | . 1970 | . 2203 | . 2396 |
| 4 | 204.3 | 41740. | . 03278 | . 2289 | .2485 | . 2778 | -3022 |
| 5 | 181.9 | 33100. | . 02600 | .2887 | . 3133 | . 3502 | -3810 |
| 6 | 162.0 | 26250. | . 02062 | . 3640 | . 3951 | . 4416 | .4805 |
| 7 | 144.3 | 20820. | . 01635 | .4590 | .4982 | .5569 | . 6059 |
| 8 | 128.5 | 16510. | . 01297 | . 5788 | . 6282 | .7023 |  |
| 9 | 114.4 | 13090. | . 01028 | . 7299 | .7921 | . 8855 | . 9633 |
| 10 | 101.9 | 10380. | . 008155 | . 9203 | . 9989 | 1.117 | I. 215 |
| 11 | 90.74 | 8234. | . 006467 | I.16I | 1.260 | 1.408 | 1.532 |
| 12 | 80.81 | 6530. | . 005129 | 1.463 | 1.588 | 1.775 | 1.931 |
| 13 | 71.96 | 5178. | . 004067 | 1.845 | 2.003 | 2.239 | 2.436 |
| 14 | 64.08 | 4107. | . 003225 | 2.327 | 2.525 | 2.823 | 3.071 |
| 15 | 57.07 | 3257. | . 002558 | 2.934 | 3.184 | 3.560 | 3.873 |
| 16 | 50.82 | 2583. | . 002028 | 3.700 | 4.016 | 4.489 | 4.884 |
| 17 | 45.26 | 2048. | .001 609 | 4.666 | 5.064 | 5.660 | 6.158 |
| 18 | 40.30 | 1624. | . 001276 | 5.883 | 6.385 | 7.138 | 7.765 |
| 19 | 35.89 | 1288. | . 001012 | 7.418 | 8.051 | 9.001 | 9.792 |
| 20 | 31.96 | 1022. | . 0008023 | 9.355 | 10.15 | 11.35 | 12.35 |
| 21 | 28.45 | 810.1 | .000 6363 | 11.80 | 12.80 | 14.31 | 15.57 |
| 22 | 25.35 | 6.42 .4 | . 0005046 | 14.87 | 16.14 | 18.05 | 19.63 |
| 23 | 22.57 | 509.5 | . 0004002 | 18.76 | 20.36 | 22.76 | 24.76 |
| 24 | 20.10 | 404.0 | . 0003173 | 23.65 | 25.67 | 28.70 | 31.22 |
| 25 | 17.90 | 320.4 | . 0002517 | 29.82 | 32.37 | 36.18 | 39.36 |
| 26 | 15.94 | 254.I | .000 1996 | 37.61 | 40.81 | 45.63 | 49.64 |
| 27 | 14.20 | 201.5 | . 0001583 | 47.42 | 51.47 | 57.53 |  |
| 28 | 12.64 | 159.8 | .000 1255 | 59.80 | 64.90 | 72.55 | 78.93 |
| 29 | 11.26 | 126.7 | . 00009953 | 75.40 | 8 I .83 | 91.48 | 99.52 |
| 30 |  | 100.5 | . 00007894 | 95.08 | 103.2 | 115.4 |  |
| 31 | 8.928 | 79.70 | . 00006260 | I 19.9 | 130.1 | 145.5 | 158.2 |
| 32 | 7.950 | 63.21 | . 00004964 | 151.2 | 164.1 | 183.4 | 199.5 |
| 33 | 7.080 | 50.13 | . 00003937 | 190.6 | 206.9 | 231.3 | 251.6 |
| 34 | 6.305 | 39.75 | . 000003122 | 240.4 | 260.9 | 291.7 | 317.3 |
| 35 | 5.615 | 31.52 | . 00002476 | 303.1 | 329.0 | 367.8 | 400.1 |
| 36 | 5.000 | 25.00 | .000019 64 | $3^{82.2}$ | 414.8 | 463.7 | 504.5 |
| 37 | 4.453 | 19.83 | .000 01557 | 482.0 | 523.1 | 584.8 | 636.2 |
| 38 | 3.965 | 15.72 | . 00001235 | 607.8. | 659.6 | $737 \cdot 4$ | 802.2 |
| 39 | 3.531 | 12.47 | . 000009793 | 766.4 | 831. 8 | 929.8 | 1012. |
| 40 | 3.145 | 9.888 | . 000007766 | 966.5 | 1049. | 1173. | 1276. |

* Resistance at the stated temperatures of a wire whose length is 1000 feet at $20^{\circ} \mathrm{C}$.


## Smithsonian Tables.

WIRE TABLE, STANDARD ANNEALED COPPER (continued).
American Wire Gage (B. \& S.). English Units (continued).

| $\begin{aligned} & \text { Gage } \\ & \text { No. } \end{aligned}$ | Diameter in Mils. at $20^{\circ} \mathrm{C}$. | $\begin{gathered} \text { Pounds } \\ \text { per } \\ 1000 \text { Feet. } \end{gathered}$ | Feet per Pound. | Feet per Ohm.* |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | $\left(\stackrel{0^{\circ} \mathrm{C}}{\left.=3_{3}{ }^{\circ} \mathrm{F}\right)}\right.$ | $\left({ }^{20^{\circ}}{ }_{68} \mathrm{C}\right.$ | $\left(=120^{\circ} \mathrm{C}\right.$ | $\begin{gathered} 75^{\circ}{ }^{\circ} \mathrm{C} \\ \left(=167^{\circ} \mathrm{F}\right) \end{gathered}$ |
| 0000 | 460.0 | 640.5 | 1.561 | 22140. | 20400. | 18250. | 16780. |
| 000 | 409.6 | 507.9 | 1.968 | 17560. | 16180. | 14470. | $13300 .$ |
| $\infty$ | 364.8 |  | 2.482 | 13930. | 12830. | $\text { II } 480 .$ | $10550 .$ |
| $\bigcirc$ | 324.9 | 319.5 | 3.130 | 118040. | $10 \quad 180$. |  |  |
| 1 | 289.3 | 253.3 | $3.9+7$ | $8758$ | 8070. | 7219. | $6636 .$ |
| 2 | 257.6 | 200.9 | 4.977 | 6946. | 6400. | 5725. | 5262. |
| 3 | 229.4 | 159.3 | 6.276 | 5508. | 5075. | 4540. | 4173. |
| 4 | 204.3 | 126.4 | 7.914 | 4368. | 4025. | 3600. | 3309. |
| 5 | 181.9 | 100.2 | 9.980 | 3464. | 3192. | 2855. | 2625. |
| 6 | 162.0 | 79.46 | 12.58 | 2747. | 2531. | 2264. | 2081. |
| 7 | 144.3 | 63.02 | 15.87 | 2179. | 2007. | 1796. | 1651. |
| 8 | 128.5 | 49.98 | 20.01 | 1728. | 1592. | 1424. | 1309. |
| 9 | 114.4 | 39.63 | 25.23 | 1370. | 1262. | 1129. | 1038. |
| 10 | IOI. 9 | 31.43 | 31.82 | 1087. | 1001. | 895.6 | 823.2 |
| 11 | 90.74 | 24.92 | 40.12 | 861.7 | 794.0 | 710.2 | 652.8 |
| 12 | 80.81 | 19.77 | 50.59 | 683.3 | 629.6 | 563.2 | 517.7 |
| 13 | 71.96 | 15.68 | 63.50 | 541.9 | 499.3 | 446.7 | 410.6 |
| 14 | 64.08 | 12.43 | 80.44 | 429.8 | 396.0 | 354.2 | 325.6 |
| 15 | 57.07 | 9.858 | 101.4 | 340.8 | 314.0 | 280.9 | 258.2 |
| 16 | 50.82 | 7.818 | 127.9 | 270.3 | 249.0 | 222.8 | 204.8 |
| 17 | 45.26 | 6.200 | 161.3 | 214.3 | 197.5 | 176.7 | 162.4 |
| 18 | 40.30 | 4.917 | 203.4 | 170.0 | I 56.6 | 140.1 | 128.8 |
| 19 | 35.89 | 3.899 | 256.5 | ${ }^{1} 34.8$ | 124.2 | 111.1 | 102.1 |
| 20 | 31.96 | 3.092 | 323.4 | 106.9 | 98.50 | S8.11 | So. 99 |
| 21 | 28.46 | 2.452 | 407.8 | 84.78 | 78.11 | 69.87 | 64.23 |
| 22 | 25.35 | 1.945 | 514.2 | 67.23 | 61.95 | 55.41 | 50.94 |
| 23 | 22.57 | 1.542 | 648.4 | $53 \cdot 32$ | 49.13 | 43.94 | 40.39 |
| 24 | 20.10 | 1.223 | 817.7 | 42.28 | 35.96 | 34.85 | 32.03 |
| 25 | 17.90 | 0.9699 | 1031. | 33.53 | 30.90 | 27.64 | 25.40 |
| 26 | 15.94 | . 7692 | 1300. | 26.59 | 24.50 | 21.92 | 20.15 |
| 27 | 14.20 | . 6100 | 1639. | 21.09 | 19.43 | 17.38 | 15.98 |
| 28 | 12.64 | . 4837 | 2067. | 16.72 | 15.41 | 13.78 | 12.67 |
| 29 | 11.26 | .3836 | 2607. | I 3.26 | 12.22 | 10.93 | 10.05 |
| 30 | 10.03 | -3042 | 3287. | 10.52 | 9.691 | 8.669 | 7.968 |
| 31 | 8.928 | .2413 | 4145. | 8.341 | 7.685 | 6.875 | 6.319 |
| 32 | 7.950 | .1913 | 5227. | 6.614 | 6.095 | $5 \cdot 452$ | 5.011 |
| 33 | 7.080 | . 1517 | 6591. | 5.245 | 4.833 | 4.323 | 3.974 |
| 34 | 6.305 | .1203 | 8310. | 4.160 | 3.833 | $3 \cdot 429$ | 3.152 |
| 35 | 5.615 | . 09542 | 10 480. | 3.299 | 3.040 | 2.719 | 2.499 |
| 36 | 5.000 | .07568 | 13210. | 2.616 | 2.411 | 2.156 | 1.982 |
| 37 | 4.453 | . 060 O1 | 16660. | 2.075 | 1.912 | 1.710 | 1. 572 |
| 38 | 3.965 | . 04759 | 21010. | 1.645 | 1.516 | I. 356 | 1.247 |
| 39 | 3.531 | . 03774 | 26500. | 1.305 | 1.202 | 1.075 | 0.9886 |
| 40 | 3.145 | . 02993 | 33410. | 1.035 | 0.9534 | 0.8529 | .7840 |

- Length at $20^{\circ} \mathrm{C}$. of a wire whose resistance is $\geq$ ohm at the stated temperatures.

American Wire Gage (B. \& S.). English Units (continued).

| $\underset{\sim}{\text { Gage }}$ | Diameterin Mils ${ }_{20}{ }^{\text {at }} \mathrm{C}$. | Ohms per Pound. |  |  | Pounds per Ohm. |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\left({\left.\stackrel{\circ}{0}{ }_{32^{\circ}} \mathrm{C}_{\mathrm{F} .}\right)}^{(2)}\right.$ | $\left(\stackrel{200^{\circ} \mathrm{C}}{(\stackrel{8}{\circ} \mathrm{~F} .)}\right.$ | $\left(\begin{array}{c} \left.50^{\circ}{ }^{\circ} \mathrm{C} .2^{\circ} \mathrm{F} .\right) \end{array}\right.$ | $\left({ }_{568^{\circ} \mathrm{C}}^{\mathrm{o}} \mathrm{~F} .\right)$ |
| 0000000$\infty$ | 460.0 | $0.0000705^{1}$ | $0.0000765^{2}$ | 0.00008554 | 13070. |
|  | 409.6 | . 000 1121 | . 0001217 | . 0001360 | 8219. |
|  | 364.8 | . 0001783 | . 0001935 | . 0002163 | 5169. |
| 2 | 324.9 | . 0002835 | . 0003076 | . 0003439 | 3251. |
|  | ${ }^{289.3}$ | . 0004507 | .000 4891 | . 0005468 | 2044. |
|  | 257.6 | . 0007166 | . 0007778 | . 0008695 | 1286. |
| 345 | 229.4 | . 001140 | . 001237 | . 001383 | 808.6 |
|  | 204.3 | . 001812 | . 001966 | . 002198 | 508.5 |
|  | 181.9 | . 002881 | . 003127 | . 003495 | 319.8 |
| 678 | 162.0 | . 004 581 | . 004972 | . 005558 | 201.1 |
|  | 144.3 | . 007284 | . 007905 | . 008838 | 126.5 |
|  | 128.5 | . 0115 | . 01257 | . 01405 | 79.55 |
| 91011 | 114.4 | . 01842 | . 01999 | . 02234 | 50.03 |
|  | 101.9 | . 02928 | .031 78 | . 03553 | $3{ }^{1.47}$ |
|  | 90.74 | .04656 | . 05053 | . 05649 | 19.79 |
| 12 | 80.81 | . 07404 | . 08035 | . 08983 | 12.45 |
| 13 | 71.96 | . 1177 | .1278 | . 1428 | 7.827 |
|  | 64.08 | . 1872 | . 2032 | .2271 | 4.922 |
| 15 | 57.07 | . 2976 | . 3230 | -3611 | 3.096 |
|  | 50.82 | . 4733 | .5136 | . 5742 | 1.947 |
| 17 | 45.26 | . 7525 | .8167 | .9130 | 1.224 |
| 18 | 40.30 | 1.197 | 1.299 | 1.452 | 0.7700 |
| 19 | 35.89 | 1. 903 | 2.065 | 2.308 | . 4843 |
|  | 31.96 | 3.025 | 3.283 | 3.670 | . 3046 |
| 2122 | 28.46 | 4.810 | 5.221 | 5.836 | . 1915 |
|  | 25.35 | 7.649 | 8.301 | 9.280 | . 1205 |
| 23 | 22.57 | 12.16 | 13.20 | 14.76 | . 07576 |
| 242526 | 20.10 | 19.34 | 20.99 | 23.46 | . 04765 |
|  | 17.90 15.94 | 30.75 48.89 | 33.37 53.06 | 37.31 59.32 | .02997 .01885 |
|  |  |  | 53.06 | $59.3{ }^{2}$ | . 01885 |
| 272829 | 14.20 | 77.74 | 84.37 | 94.32 | . 01185 |
|  | 12.64 | 123.6 196.6 | 134.2 | 150.0 | . 007454 |
|  | 11.26 | 196.6 | 213.3 | 238.5 | . 004688 |
| 30313 | 10.03 | 312.5 | 339.2 | 379.2 | . 002948 |
|  | 8.928 | 497.0 | 539.3 | 602.9 | . 001854 |
| 32 | 7.950 | 790.2 | 857.6 | 958.7 | .001 166 |
| 333435 | 7.080 | 1256. | 1364. |  |  |
|  | 6.305 | 1998. | 2168. | 2424. | . 0004612 |
|  | 5.615 | 3177. | 3448. | 3854. | . 0002901 |
| 363738 | 5.000 | 5051. | 5482. | 6128. | .000 1824 |
|  | 4.453 | 8032. | 8717. | 9744. | . 0001147 |
|  | 3.965 | 12770. | 13860. | 15490. | . 00007215 |
| 39 | 3.531 | 20310. | 22040. | 24640. | . 00004538 |
|  | 3.145 | 32290. | 35040. | 39 170. | . 00002854 |

Smithsonian Tables.

WIRE TABLE, STANDARD ANNEALED COPPER.
American Wire Gage (B. \& S.) Metric Units.

| $\begin{gathered} \text { Gage } \\ \text { No. } \end{gathered}$ | Diameter in mm . at $20^{\circ} \mathrm{C}$. | $\begin{aligned} & \text { Cross Section } \\ & \text { in mm. } \\ & \text { at } 20^{\circ} \mathrm{C} \text {. } \end{aligned}$ | Ohms per Kilometer.* |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $0^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. | $50^{\circ} \mathrm{C}$. | $75^{\circ} \mathrm{C}$. |
| 0000 | 1 I .68 | 107.2 | 0.1482 | 0.1608 | 0.1798 | 0.1956 |
| 000 | 10.40 | 85.03 | . 1868 | . 2028 | . 2267 | . 2466 |
| -0 | 9.266 | 67.43 | .2356 | . 2557 | .2858 | -3110 |
| $\bigcirc$ | 8.252 | 53.48 | . 2971 | . 3224 | .3604 | -392I |
| 1 | $7 \cdot 348$ | 42.41 | $\cdot 3746$ | . 4066 | .4545 | .4944 |
| 2 | 6.544 | 33.63 | .4724 | .5127 | . 5731 | . 6235 |
| 3 | 5.827 | 26.67 | . 5956 | . 6465 | . 7227 | .7862 |
| 4 | 5.189 | 21.15 | .7511 | .8152 | .9113 | . 9914 |
| 5 | 4.621 | 16.77 | . 9471 | 1.028 | 1.149 | 1.250 |
| 6 | 4.115 | 13.30 | 1. 194 | 1.296 | I. 449 | 1. 576 |
| 7 | 3.665 | 10. 55 | 1. 506 | 1. 634 | 1.827 | 1.988 |
| 8 | 3.264 | 8.366 | I. 899 |  | 2.304 | 2.506 |
| 9 | 2.906 | 6.634 | 2.395 | 2.599 | 2.905 | 3.161 |
| 10 | 2.588 | 5.261 | 3.020 | 3.277 | 3.663 | 3.985 |
| 11 | 2.305 | 4.172 | 3.807 | 4.132 | 4.619 | 5.025 |
| 12 | 2.053 | 3.309 | 4.80 I | 5.21 I | 5.825 | 6.337 |
| 13 | 1.828 | 2.624 | 6.054 | 6.571 | $7 \cdot 345$ | 7.991 |
| 14 | 1.628 | 2.081 | 7.634 | 8.285 | 9.262 | 10.08 |
|  | 1.450 | 1.65 C | 9.627 | 10.45 | 11.68 | 12.71 |
| 16 | 1.291 | 1.309 | 12.14 | 13.17 | 14.73 | 16.02 |
| 17 | 1.150 | 1.038 | 15.31 | 16.61 | 18.57 | 20.20 |
| 18 | 1.024 | 0.8231 | 19.30 | 20.95 | 23.42 | 25.48 |
| 19 | 0.9116 | . 6527 | 24.34 | 26.42 | 29.53 | 32.12 |
| 20 | . 8118 | .5176 | 30.69 | 33.31 | 37.24 | 40.51 |
| 21 | . 7230 | .4105 | 38.70 | 42.00 | 46.95 | 51.08 |
| 22 | . 6438 | .3255 | 48.80 | 52.96 | 59.21 | 64.41 |
| 23 | . 5733 | .2582 | 61.54 | 66.79 | 74.66 | 81.22 |
| 24 | . 5106 | . 2047 | 77.60 | 84.21 | 94.14 | 102.4 |
| 25 | . 4547 | . 1624 | 97.85 |  | 118.7 | 129.1 |
| 26 | . 4049 | . 1288 | 123.4 | 133.9 | 149.7 | 162.9 |
| 27 | . 3606 | . 1021 | 155.6 | 168.9 | 188.8 | 205.4 |
| 28 | . 3211 | .oSo 98 | 196.2 | 212.9 | 238.0 | 258.9 |
| 29 | .2859 | . 06422 | $247 \cdot 4$ | 268.5 | 300.1 | 326.5 |
| 30 | . 2546 | .05093 | 311.9 | 338.6 | ${ }_{37} 3^{\text {S }} 5$ | 411.7 |
| 31 | . 2268 | . 04039 | 393.4 | 426.9 | 477.2 | 519.2 654.7 |
| 32 | . 2019 | .03203 | 496.0 | 538.3 | 601.8 | 654.7 |
|  | .1798 | .02540 | 625.5 | 678.8 | 75.8 .8 | S25.5 |
| 34 | .1601 | . 02014 | 788.7 | 856.0 | 956.9 | 10.41. |
| 35 | . 1426 | .015 97 | 994.5 | 1079. | 1207. | 1313. |
| 36 | . 1270 | .012. 67 | 1254. | 1361. |  | 1655 |
| 37 | .1131 | . 01005 | 1581. | 1716. 2164. | 1919. 2419. |  |
| 38 | . 1007 | .007967 | 1994. | 2164. | 2419. | 2632. |
| 39 | . 08969 | . 006318 | 2514. | 2729. | 3051. | 3319. |
| 40 | . 07987 | .005010 | 3171. | $344^{1}$. | 3 S47. | 4 IS 5. |

*Resistance at the stated temperatures of a wire whose length is i kilometer at $20^{\circ} \mathrm{C}$.

WIRE TABLE, STANDARD ANNEALED COPPER (continued).
American Wire Gage (B. \& S.) Metrio Units (continued).

| $\begin{aligned} & \text { Gage } \\ & \text { No. } \end{aligned}$ | Diameter in mm . at $20^{\circ} \mathrm{C}$. | Kilograms per Kilometer. | Meters per Gram. | Meters per Ohm.* |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | $\circ^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. | $50^{\circ} \mathrm{C}$. | $75^{\circ} \mathrm{C}$. |
| 0000 | 11.68 | 953.2 | 0.001049 | 6749. | 6219. | 5563. | 5113. |
| 000 | 10.40 | 755.9 | .001 323 | 5352. | 4932. | 4412. | 4055. |
| $\infty$ | 9.266 | 599.5 | .001 668 | 4245. | 3911. | 3499. | 3216. |
| 0 | 8.252 | 475.4 | .002103 | 3366. | 3102. | 2774. | 2550. |
| 1 | $7 \cdot 348$ | 377.0 | . 002652 | 2669. | 2460. | 2200. | 2022. |
| 2 | 6.544 | 299.0 | . 003345 | 2117. | 1951. | 1745. | 1604. |
| 3 | 5.827 | 237.1 | . 004217 | 1679. | 1547. | 1384. | 1272. |
| 4 | 5.189 | 188.0 | . 005318 | 1331. | 1227. | 1097. | 1009. |
| 5 | 4.621 | 149.1 | . 006706 | 1056. | 972.9 | 870.2 | 799.9 |
| 6 | 4.115 | 118.2 | .008457 | 837.3 | 771.5 | 690.1 | 634.4 |
| 7 | 3.665 | 93.78 | . 01066 | 664.0 | 611.8 | $547 \cdot 3$ | 503.1 |
| 8 | 3.264 | 74.37 | .01345 | 526.6 | 485.2 | 434.0 | 399.0 |
| 9 | 2.906 | 58.98 | .or6 96 | 417.6 | 384.8 | 344.2 | 316.4 |
| 10 | 2.588 | 46.77 | . 02138 | 331.2 | 305.1 | 273.0 | 250.9 |
| 11 | 2.305 | 37.09 | . 02696 | 262.6 | 242.0 | 216.5 | 199.0 |
| 12 | 2.053 | 29.42 | .03400 | 208.3 | 191.9 | 171.7 | 157.8 |
| 13 | 1.828 | 23.33 | . 04287 | 165.2 | 152.2 | 136.1 | 125.1 |
| 14 | 1.628 | 18.50 | . 05406 | 13 I .0 | 120.7 | 108.0 | 99.24 |
| 15 | 1.450 | 14.67 | . 06816 | 103.9 | 95.71 | 85.62 | 78.70 |
| 16 | 1.291 | 11.63 | . 08595 | 82.38 | 75.90 | 67.90 | 62.41 |
| 17 | 1.150 | 9.226 | . 1084 | 65.33 | 60.20 | 53.85 | 49.50 |
| 18 | 1.024 | 7.317 | . 1367 | 51.81 | 47.74 | 42.70 | 39.25 |
| 19 | 0.9116 | 5.803 | . 1723 | 41.09 | 37.86 | 33.86 | 31.13 |
| 20 | .8118 | 4.602 | . 2173 | 32.58 | 30.02 | 26.86 | 24.69 |
| 21 | .7230 | 3.649 | . 2740 | 25.84 | ${ }^{23.81}$ | 21.30 | 19.58 |
| 22 | . 6438 | 2.894 | . 3455 | 20.49 | 18.88 | 16.89 | 15.53 |
| 23 | . 5733 | 2.295 | . 4357 | 16.25 | 14.97 | 13.39 | 12.31 |
| 24 | . 5106 | 1.820 | . 5494 | 12.89 | 1 I .87 | 10.62 | 9.764 |
| 25 | . 4547 | 1. 443 | . 6928 | 10.22 | 9.417 | 8.424 | 7.743 |
| 26 | .4049 | 1.145 | .8736 | 8.105 | 7.468 | 6.680 | 6.141 |
| 27 | .3606 | 0.9078 | 1.102 | 6.428 | 5.922 | 5.298 | 4.870 |
| 28 | . 3211 | .7199 | 1.389 | 5.097 | 4.697 | 4.201 | 3.862 |
| 29 | .2859 | . 5709 | $1.75{ }^{2}$ | 4.042 | 3.725 | 3.332 | 3.063 |
| 30 | . 2546 | . 4527 | 2.209 | 3.206 | 2.954 | 2.642 | 2.429 |
| 31 | . 2268 | . 3590 | 2.785 | 2.542 | 2.342 | 2.095 | 1.926 |
| 32 | . 2019 | . 2847 | 3.512 | 2.016 | 1. 858 | 1.662 | 1.527 |
| 33 | .1798 | . 2258 | 4.429 | 1.599 | 1.473 | 1.318 | 1.211 |
| 34 | . 1601 | .1791 | 5.584 | 1.268 | 1.168 | 1.045 | 0.9606 |
| 35 | . 1426 | . 1420 | 7.042 | 1.006 | 0.9265 | 0.8288 | .7618 |
| 36 | . 1270 | . 1126 | 8.879 | 0.7974 | . 7347 | . 6572 | . 6041 |
| 37 | .1131 | .08931 | 11.20 | . 6324 | . 5827 | . 5212 | .4791 |
| 38 | . 1007 | .07083 | 14.12 | . 5015 | . 4621 | .4133 | . 3799 |
| 39 | . 08969 | .05617 | 17.80 | - 3977 | $.3664$ | .3278 | .3013 |
| 40 | . 07987 | . 04454 | 22.45 | . 3154 | .2906 | . 2600 | . 2390 |

*Length at $20^{\circ} \mathrm{C}$. of a wire whose resistance is I ohm at the stated temperatures.

WIRE TABLE, STANDARD ANNEALED COPPER (continued).
American Wire Gage (B. \& S.). Metric Units (continued).

| Gage No. | Diameter in mm . at $20^{\circ} \mathrm{C}$. | Ohms per Kilogram. |  |  | Grams per Ohm. |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\circ^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. | $50^{\circ} \mathrm{C}$. | $20^{\circ} \mathrm{C}$. |
| 0000 | 11.68 | 0.0001554 | 0.0001687 | 0.0001886 | 5928000. |
| 000 | 10.40 | . 0002472 | . 0002682 | . 0002999 | 3728000. |
| 00 | 9.266 | .000 3930 | .0004265 | . 0004768 | 2344000. |
| $\bigcirc$ | 8.252 | . 0006249 | .0006782 | . 0007582 | I 474000. |
| 1 | 7.348 | . 0009936 | .001078 | .001 206 | 927300. |
| 2 | 5.544 | . 001580 | .001715 | .001917 | 583200. |
| 3 | 5.827 | . 002512 | .002 726 | .003048 | 366800. |
| 4 | 5.189 | .003995 | .004335 | . 004846 | 230700. |
| 5 | 4.62 I | . 006352 | . 006893 | . 007706 | 145100. |
| 6 | 4. 115 | .01010 | . 01096 | . 01225 | 91230. |
| 7 | 3.665 | .01606 | . 01743 | . 01948 | 57380. |
| 8 | 3.264 | .02553 | .02771 | .03098 | 36080. |
| 9 | 2.906 | . 04060 | . 04406 | . 04926 | 22690. |
| 10 | 2.588 | .06456 | . 07007 | . 07833 | 14270. |
| 11 | 2.305 | . 1026 | . 1114 | .1245 | 8976. |
| 12 | 2.053 | .1632 | .1771 | . 1980 | 56.45 |
| 13 | 1. 828 | . 2595 | . 2817 | .3149 | 3550. |
| 14 | 1. 628 | .4127 | . 4479 | . 5007 | 2233. |
| 15 | 1.450 | . 6562 | .7122 | . 7961 | 1404. |
| 16 | I. 291 | 1.043 | 1.132 | 1.266 | 883.1 |
| 17 | 1.150 | 1. 659 | 1.801 | 2.013 | 555.4 |
| 18 | 1.024 | 2.638 | 2.863 | 3.201 | $349 \cdot 3$ |
| 19 | 0.9116 | 4.194 | 4.552 | 5.089 | 219.7 |
| 20 | .8118 | 6.670 | 7.238 | 8.092 | 138.2 |
| 21 | . 7230 | 10.60 | 11.51 | 12.87 | 86.88 |
| 22 | . 6438 | 16.86 | 18.30 | 20.46 | 54.64 |
| 23 | . 5733 | 26.81 | 29.10 | 32.53 | 34.36 |
| 24 | . 5106 | 42.63 | 46.27 | 51.73 | 21.61 |
| 25 | . 4547 | 67.79 | 73.57 | 82.25 |  |
| 26 | . 4049 | 107.8 | 117.0 | 130.8 | 8.548 |
| 27 | .3606 | 171.4 | 186.0 | 207.9 | $5 \cdot 376$ |
| 28 | . 3211 | 272.5 | 295.8 | 330.6 | $3 \cdot 381$ |
| 29 | .2859 | $433 \cdot 3$ | 470.3 | 525.7 | 2.126 |
| 30 | .2546 | 689.0 | 747.8 | 836.0 |  |
| 31 | . 2268 | 1096. | 1189. | 1329. | 0.5410 .5289 |
| $3^{2}$ | . 2019 | 1742. | 1891. | 2114. | -5289 |
| 33 | . 1798 | 2770. | 3006. | 3361. | .3326 |
| 34 | . $60{ }^{1}$ | 4404. | 4780. | 5344. | . 2092 |
| 35 | . 1426 | 7003. | 7601. | 8497. | .1316 |
| 36 | . 1270 | II 140. | 12090. | 13510. | . 08274 |
| 37 | . 1131 | 17710. | 19220. | $21480 .$ | . 05204 |
| 38 | . 1007 | 28150. | 30560. | 34160 | .032 73 |
| 39 | . 08969 | 44770. | 48590. | 54310. | . 02058 |
| 40 | . 07987 | 71180. | 77260. | 86360. | . 01294 |

Smithsonian Tables.

Hard-Drawn Aluminum Wire at $20^{\circ}$ O. (or, $68^{\circ}$ F.).
American Wire Gage (B. \& S.). English Units.

| Gage No. | Diameter in Mils. | Cross Section. |  | $\begin{gathered} \text { Ohms } \\ \text { per } \\ 1000 \text { Feet. } \end{gathered}$ | $\begin{gathered} \text { Pounds } \\ \text { per } \\ \text { xooo Feet. } \end{gathered}$ | Pounds per Ohm. | $\begin{gathered} \text { Feet } \\ \text { per Ohm. } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Circular Mils. | Square <br> Inches. |  |  |  |  |
| 0000 | 460. | 212000. | 0.166 | 0.0804 | 195. | 2420. | 12400. |
| 000 | 410. | 168 000. | . 132 | . 101 | 154. | 1520. | 9860. |
| 00 | 365. | 133000. | .105 | . 128 | 122. | 957. | 7820. |
| 0 | 325. | 106000. | .0829 | .16I | 97.0 | 602. | 6200. |
| 1 | 289. | 83700. | . 0657 | . 203 | 76.9 | 379. | 4920. |
| 2 | $25^{8}$. | 66400. | .0521 | .256 | 61.0 | 238. | 3900. |
| 3 | 229. | 52600. | . 0413 | . 323 | 48.4 | 150. | 3090. |
| 4 | 204. | $41 \cdot 700$. | .0328 | . 408 | 38.4 | 94.2 | 2450. |
| 5 | 182. | 33100. | . 0260 | . 514 | 30.4 | 59.2 |  |
| 6 | 162. | 26300. | . 0206 | . 648 | 24.1 | 37.2 | 1540. |
| 7 | 144. | 20800. | . 0164 | . 817 | 19.1 | 23.4 | 1220. |
| 8 | 128. | 16500. | .0130 | 1.03 | 15.2 | 14.7 | 970. |
| 9 | 114. | 13100. | .0103 | 1.30 | 12.0 | 9.26 | 770. |
| 10 | 102. | 10 400. | . 00815 | 1.64 | 9.55 | 5.83 |  |
| II | 91. | 8230. | . 00647 | 2.07 | 7.57 | 3.66 | 484. |
| 12 | 8 I. | 6530. | . 00513 | 2.61 | 6.00 | 2.30 | 384. |
| 13 | 72. | 5180. | . 00407 | 3.29 | 4.76 | 1.45 | 304. |
| 14 | 64. | 4110. | . 00323 | 4.14 | 3.78 | 0.911 | 241. |
| 15 | 57. | 3260. | . 00256 | 5.22 | 2.99 | . 573 | 191. |
| 16 | 51. | 2580. | . 00203 | 6. 59 | 2.37 | -360 | 152. |
| 17 | 45. | 2050. | . 00161 | 8.31 | I. 88 | . 227 | 120. |
| 18 | 40. | 1620. | . 00128 | 10.5 | 1.49 | . 143 | 95.5 |
| 19 | 36. | 1290. | . 00101 | 13.2 | 1.18 | . 0897 | 75.7 |
| 20 | 32. | 1020. | . 000802 | 16.7 | 0.939 | . 0564 | 60.0 |
| 21 | 28.5 | 8 I 0. | .000 636 | 21.0 | . 745 | . 0355 | 47.6 |
| 22 | 25.3 | 642. | . 000505 | 26.5 | . 591 | . 0223 | 37.8 |
| 23 | 22.6 | 509. | . 000400 | 33.4 | . 468 | . 0140 | 29.9 |
| 24 | 20.1 | 404. | . 000317 | 42.1 | -371 | . 00882 |  |
| 25 | 17.9 | 320. | . 000252 | 53.1 | . 295 | . 00555 | 18.8 |
| 26 | 15.9 | 254 | . 000200 | 67.0 | . 234 | . 00349 | 14.9 |
| 27 | 14.2 | 202. | . 000158 | 84.4 | .185 | . 00219 | 11.8 |
| 28 | 12.6 | 160. | . 000126 | 106. | . 147 | .001 38 | 9.39 |
| 29 | 11.3 | 127. | . 0000995 | 134. | . 117 | . 000868 | 7.45 |
| 30 | 10.0 | 101. | . 0000789 | 169. | . 0924 | . 000546 | 5.91 |
| 31 | 8.9 | 79.7 | . 0000626 | 213. | . 0733 | . 000343 | 4.68 |
| 32 | 8.0 | 63.2 | . 0000496 | 269. | .058r | . 000216 | 3.72 |
| 33 | 7.1 | 50.1 | .000 0394 | 339. | .0461 | . 000136 | 2.95 |
| 34 | 6.3 | 39.8 | .0000312 | 428. | .0365 | . 0000854 | 2.34 |
| 35 | 5.6 | $3 \mathrm{I} \cdot 5$ | . 0000248 | 540. | . 0290 | . 0000537 | 1.85 |
| 36 | 5.0 | 25.0 | .000 019 6 | 68 r . | . 0230 | . 0000338 | 1.47 |
| 37 | 4.5 | 19.8 | .000 or 56 | 858. | . 0182 | . 0000212 | 1.17 |
| 38 | 4.0 | 15.7 | .000 0123 | 1080. | . 0145 | .000013 4 | 0.924 |
| 39 | $3 \cdot 5$ | 12.5 | .000 00979 | 1360. | .0115 | . 00000840 | .733 |
| 40 | 3.1 | 9.9 . | . 00000777 | 1720. | .009I | .000005 28 | .581 |

Smithsonian Tables.

Hard-Drawn Aluminum Wire at $20^{\circ} \mathrm{O}$.

American Wire Gage (B. \& S.) Metric Units.

| Gage No. | Diameter in mm . | Cross Section in $\mathrm{mm} .^{2}$ | Ohms per Kilometer. | Kilograms per Kilometer. | Grams per Ohm. | Meters per Ohm. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0000 | 11.7 | 107. | 0.264 | 289. | 1100000. | 3790. |
| 000 | 10.4 | 85.0 | -333 | 230. | 690000. | 3010. |
| -0 | 9.3 | 67.4 | .419 | 182. | 434000. | 2380. |
| $\bigcirc$ | 8.3 | 53.5 | .529 | 14. | 273000. | 1890. |
| 1 | $7 \cdot 3$ | 42.4 | . 667 | 114. | 172000. | 1500. |
| 2 | 6.5 | 33.6 | . 841 | 90.8 | 108000. | 1190. |
| 3 | 5.8 | 26.7 | 1.06 | 72.0 | 67900. | 943. |
| 4 | 5.2 | 21.2 | 1.34 | 57.1 | 42700. | 748. |
| 5 | 4.6 | 16.8 | І. 69 | $45 \cdot 3$ | 26900. | 593. |
| 6 | 4.I | 13.3 | 2.13 | 35.9 | 16900. | 470. |
| 7 | $3 \cdot 7$ | 10.5 | 2.68 | 28.5 | 10600. | 373. |
| 8 | $3 \cdot 3$ | 8.37 | $3 \cdot 38$ | 22.6 | 6680. | 296. |
| 9 | 2.91 | 6.63 | 4.26 | 17.9 | 4200. | 235. |
| 10 | 2.59 | 5.26 | $5 \cdot 38$ | I 4.2 | 2640. | 186. |
| II | 2.30 | 4.17 | 6.78 | 11.3 | 1660. | 148. |
| 12 | 2.05 | $3 \cdot 31$ | 8.55 | 8.93 | 1050. | 117. |
| 13 | I. 83 | 2.62 | 10.8 | 7.08 | 657. | 92.8 |
| 14 | 1.63 | 2.08 | 13.6 | 5.62 | 413. | 73.6 |
| 15 | 1. 45 | I. 65 | 17.1 | $4 \cdot 46$ | 260. | 58.4 |
| 16 | 1.29 | I.31 | 21.6 | 3.53 | 16. | 46.3 |
| 17 | I. 15 | 1.04 | 27.3 | 2.80 | 103. | 36.7 |
| 18 | 1.02 | 0.823 | $34 \cdot 4$ | 2.22 | 64.7 | 29.1 |
| 19 | 0.91 | . 653 | $43 \cdot 3$ | 1.76 | 40.7 | 23.1 |
| 20 | . 81 | . 518 | 54.6 | 1.40 | 25.6 | 18.3 |
| 21 | .72 | . 411 | 68.9 | 1.11 | 16.1 | 14.5 |
| 22 | . 64 | .326 | 86.9 | 0.879 |  | 11.5 |
| 23 | . 57 | .258 | 110. | . 697 | 6.36 | 9.13 |
| 24 | $\cdot 51$ | . 205 | 138. | . 553 | 4.00 | 7.24 |
| 25 26 | . 45 | .162 .129 | 174. 220. | . 438 | 2.52 1.58 | 5.74 4.55 |
| 26 | . 40 | . 129 | 22. | -348 | 1.58 | 4.55 |
| 27 | .36 | .102 | $277 \cdot$ | .276 | 0.995 .626 | 3.61 2.86 |
| 28 | .32 | .08io | 349. | . 219 |  | 2.86 2.27 |
| 29 | . 29 | . 0642 | 440. | . 173 | - 394 | 2.27 |
| 30 | . 25 | . 0509 | 555. | .138 | .248 | I. 80 |
| 31 | . 227 | . 0404 | 700. | .109 | . 156 | 1.43 |
| 32 | . 202 | . 0320 | 883. | . 0865 | . 0979 | 1.13 |
|  | . 180 | . 0254 | 1110. | . 0686 | .0616 | -. 899 |
| 34 | . 160 | . 0201 | 1400. | . 0544 | .0387 | . 712 |
| 35 | . 143 | . 0160 | 1770. | . 0431 | . 0244 | . 565 |
| 36 | . 127 | . 0127 | 2230. | . 0342 | . 0153 | . 448 |
| 37 | . 113 | . 0100 | 2820. | . 0271 | . 00963 | -355 |
| 38 | . 101 | .0080 | 3550. | . 0215 | . 00606 | . 252 |
| 39 | . 090 | . 0063 | 4480. | .0171 | .$^{.00381}$ | .223 .177 |
| 40 | . 080 | . 0050 | 5640. | . 0135 | . 00240 | . 177 |

## TABLE 414．－Ratio of Alternating to Direct Current Resistances for Copper Wires．

This table gives the ratio of the resistance of straight copper wires with alternating currents of different frequencies to the value of the resistance with direct currents．

| Diameter of wire in millimeters． | Frequency $f=$ |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 60 | 100 | 1000 | 10，000 | 100，000 | 1，000，000 |
| 0.05 | － | － | － | － | － | ＊1．001 |
| 0.1 | － | － | － | － | ＊1．001 | 1.008 |
| 0.25 | － | － | － | ＊－ | 1.003 | 1.247 |
| 0.5 | － | 二 | 二 | ＊I．001 | 1.047 | 2.240 |
| 1.0 2.0 | 二 | － | － | I． r r 120 | 1.503 | 4.19 |
| 2.0 3. | － | 二 | 1.001 | 1.120 I． 437 | 2.756 4.00 | 8.10 |
| 4. | － | － | 1.021 | 1.842 | 5.24 | 17.4 |
| 5. | － | ＊1．001 | 1.047 | 2.240 | 6.49 | 19.7 |
| 7.5 | 1.001 | 1.002 | 1． 210 | 3.22 | 7.50 | 29.7 |
| 10. | 1.003 | 1.008 | 1． 503 | 4.19 | 12.7 | 39.1 |
| 15. | 1.016 | 1.038 | 2． 136 | 6.14 | 18.8 | － |
| 20. | 1.044 | 1.120 | 2.756 | 8.10 | 25.2 | － |
| 25. | 1． 105 | 1． 247 | 3.38 | 10.1 | 28.3 | － |
| 40. | 1． 474 | I． 842 | 5.24 | 17.4 | － | － |
| 100. | 3.31 | 4.19 | 13.7 | 39.1 | － | － |

Values between 1.000 and I .00 I are indicated by ${ }^{{ }^{1} \text { I．OOI．}}$
The values are for wires having an assumed conductivity of 1.60 microhm－cms；for copper wires at room tempera－ tures the values are slightly less than as given in table．

The change of resistance of wire other than copper（iron wires excepted）may be calculated from the above table by taking it as proportional to $d \sqrt{f / \rho}$ where $d=$ diameter，$f$ the frequency and $\rho$ the resistivity．

If a given wire be wound into a solenoid，its resistance，at a given frequency，will be greater than the values in the table，which apply to straight wires only．The resistance in this case is a complicated function of the pitch and radius of the winding，the frequency，and the diameter of the wire，and is found by experiment to be sometimes as much as twice the value for a straight wire．

TABLE 415．－Maximum Diameter of Wires for High－frequency Alternating－to－direct－current Resistance Ratio of 1.01 ．

| Frequency $\div 10^{6} . .$. | 0.1 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 | 1.2 | 1.5 | 2.0 | 3.0 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Wave－length，meters | 3000 | 1500 | 750 | 500 | 375 | 300 | 250 | 200 | 150 | 100 |
| Material． | Diameter in centimeters． |  |  |  |  |  |  |  |  |  |
| Copper | 0.0356 | 0.0251 | 0.0177 | 0.0145 | 0.0125 | O．OII2 | 0.0102 | 0.0092 | 0.0079 | 0.0065 |
| Silver． | 0.0345 | 0.0244 | 0.0172 | 0．0141 | 0.0122 | 0．0109 | 0.0099 | 0.0089 | 0.0077 | 0.0063 |
| Gold ．．． | 0.0420 | －． 0297 | 0.0210 | 0．0172 | 0．0149 | O． 0133 | 0.0121 | 0.0108 | 0.0094 | 0.0077 |
| Platinum． | 0.1120 0.264 | 0.0793 0.187 | 0.0560 0.132 | O． 0457 O． 1080 | 0.0396 0.0036 | 0.0354 0.0836 | 0.0323 0.0763 | 0．0290 | 0.0250 | 0.0205 |
| Manganin． | 0． 1784 | O． 1261 | 0．0892 | O． 0.0729 | 0．0631 | －0．0564 | 0．0515 | －0．0461 | －0．0591 | 0.0483 0.0325 |
| Constantan． | －．1892 | －． 1337 | 0． 0946 | 0.0772 | 0.0664 | 0．0598 | 0.0546 | 0．0488 | 0．0423 | 0.0345 |
| German silver | －． 1942 | －． 1372 | 0.0970 | 0.0792 | 0.0692 | 0.0614 | 0.0560 | 0.0500 | 0.0434 | 0.0354 |
| Graphite． | 0.765 | －． 54 I | 0.383 | 0.312 | 0.27 I | 0． 242 | 0.221 | －． 197 | －． 17 I | －． 140 |
| Carbon． | 1.60 | I． 13 | 0.801 | 0.654 | －． 566 | 0． 506 | 0.462 | 0.414 | 0.358 | 0． 292 |
| Iron $\mu=1000 . . .$. | －． 00263 | 0．00186 | 0.00131 | 0.00108 | 0．00094 | 0.00083 | 0.00076 | 0．00068 | 0.00059 | 0． 00048 |
| $\mu=500 . . .$. | 0.00373 | 0． 00264 | 0.00187 | 0.00152 | 0.00132 | 0.00118 | 0.00108 | 0.00096 | 0.00084 | 0.00068 |
| $\mu=100 . . .$. | 0.00838 | 0.00590 | 0.00418 | 0.00340 | 0.00295 | 0.00264 | 0.0024 I | 0．00\％ 15 | 0.00186 | 0.00152 |

Bureau of Standards Circular 74，Radio Instruments and Measurements， 1918.

## Smithsonian Tables．

ELECTROCHEMICAL EQUIVALENTS.
Every gram-ion involved in an electrolytic change requires the same number of coulombs or ampere-hours of electricity per unit change of valency. This constant is 96.494 coulombs or 26.804 ampere-hours per gram-hour (a Faraday) corresponding to an electrochemical equivalent for silver of $0.00111800 \mathrm{gram} \mathrm{sec}^{-1} \mathrm{amp}^{-1}$. It is to be noted that the change of valence of the element from its state before to that after the electrolytic action should be considered. The valence of a free, uncombined element is to be considered as 0 . The same current will electrolyze "chemically equivalent" quantities per unit time. The valence is then included in the "chemically equivalent" quantity. The following table is based on the atomic weights of 1917.

| Element. |  | $\begin{gathered} \mathrm{Mg} \\ \text { per } \\ \text { coulomb. } \end{gathered}$ | Coulombs per mg | Grams per amp.hour. | Element. | $\begin{aligned} & \text { " } \\ & \text { 品 } \\ & \text { 品 } \\ & \text { ㄹ̈ㄱ } \end{aligned}$ | $\begin{gathered} \mathrm{Mg} \\ \text { per } \\ \text { coulomb. } \end{gathered}$ | $\begin{gathered} \text { Coulombs } \\ \text { per } \\ \mathrm{mg} \end{gathered}$ | Grams per amp.hour. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Aluminum. | 3 | 0.0936 | 10.682 | -. 3370 | Nickel | 1 | 0.608 r | 1.6444 | 2.1892 |
| Chlorine. | 1 | 0.3675 | 2.721 | r. 3229 | " | 2 | 0.3041 | 3.289 | 1. 0946 |
| " ${ }^{6}$ | 3 | 0.1225 | 8.164 | 0.4410 | " ${ }^{\text {" }}$ | 3 | 0.2027 | 4.933 | -. 7298 |
| ", | 5 | 0.0735 | 13.606 | 0. 2646 | Oxygen | 2 | 0.08291 | 12.062 | 0. 2985 |
| Copper | 7 | 0.0525 | 19.05 | 0.1890 |  | 4 | 0.04145 | 24.123 | O. 1492 |
| Copper | 1 | - 6.6588 | 1.518 | 2.3717 | Platinum. | 2 | 1.OII5 | 0. 9887 | 3.641 |
|  | 2 | 0.3294 | 3.036 | 1. 1858 |  | 4 | 0.5057 | 1.9773 | 1.821 |
| Gold | 1 | 2.044 | 0.4893 | 7.357 | - . | 6 | 0. 3372 | 2.966 | 1.214 |
|  | 3 | 0.6812 | I. 468 | 2.452 | Potassium. | 1 | 0.4052 | 2.468 | 1.459 |
| Hydrogen | 1 | 0.010459 | 5.728 | 0.037607 | Silver. | 1 | 1. 1180 | 0.89445 | 4.0248 |
| Lead. | 1 | 2. 1473 | 0.4657 | 7.7302 | Sodium | 1 | 0. 2384 | 4.195 | 0.8581 |
|  | 2 | 1.0736 | 0.9314 | 3.8651 | Tin. | 2 | 0.6151 | 1.626 | 2.214 |
|  | 4 | - 53368 | r. 8628 | I. 9326 |  | 4 | 0.3075 | 3.252 | I. 107 |
| Mercury | 1 | 2.0789 | 0.4810 | 7.484 | Zinc | 2 | 0.3387 | 2.952 | 1.2194 |
|  | 2 | 1. 0394 | 0.9620 | 3.742 |  |  |  |  |  |

The electrochemical equivalent for silver is $0.00111800 \mathrm{~g} \mathrm{sec}^{-1} \mathrm{amp}^{-1}$. (See p. xxxvii.)
For other elements the electrochemical equivalent $=$ (atomic weight divided by change of valency) times $1 / 06494$ $\mathrm{g} / \mathrm{sec} / \mathrm{amp}$. or $\mathrm{g} /$ coulomb. The equivalent for iodine has been determined at the Bureau of Standards as $0.0013 \times 50$ (1913).

For a unit change of valency for the diatomic gases $\mathrm{Br}_{2}, \mathrm{Cl}_{2}, \mathrm{~F}_{2}, \mathrm{H}_{2}, \mathrm{~N}_{2}$ and $\mathrm{O}_{2}$ there are required
8.619 coulombs $/ \mathrm{cm}^{3} \circ^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ ( $0.1160 \mathrm{~cm}^{3} /$ coulomb)
2.394 ampere-hours $/ l, \circ^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ ( $0.4177 \mathrm{l} /$ ampere-hour).

Note. - The change of valency for $\mathrm{O}_{2}$ is usually 2, etc.
Smithsonian Tables.

## CONDUCTIVITY OF ELECTROLYTIC SOLUTIONS.

This subject has occupied the attention of a considerable number of eminent workers in molecular physics, and a few results are here tabulated. It has seemed better to confine the examples to the work of one experimenter, and the tables are quoted from a paper by F. Kohlrausch,* who has been one of the most reliable and successful workers in this field.

The study of electrolytic conductivity, especially in the case of very dilute solutions, has furnished material for generalizations, which may to some extent help in the formation of a sound theory of the mechanism of such conduction. If the solutions are made such that per unit volume of the solvent medium there are contained amounts of the salt proportional to its electrochemical equivalent, some simple relations become apparent. The solutions used by Kohlrausch were therefore made by taking numbers of grams of the pure salts proportional to their electrochemical equivalent, and using a liter of water as the standard of quantity of the solvent. Taking the electrochemical equivalent number as the chemical equivalent or atomic weight divided by the valence, and using this number of grams to the liter of water, we get what is called the normal or gram molecule per liter solution. In the table, $m$ is used to represent the number of gram molecules to the liter of water in the solution for which the conductivities are tabulated. The conductivities were obtained by measuring the resistance of a cell filled with the solution by means of a Wheatstone bridge alternating current and telephone arrangenient. The results are for $1 S^{\circ} \mathrm{C}$., and relative to mercury at $\circ^{\circ} \mathrm{C}$., the cell having been standardized by filling with mercury and measuring the resistance. They are supposed to be accurate to within one per cent of the true value.

The tabular numbers were obtained from the measurements in the following manner : -
Let $K_{18}=$ conductivity of the solution at $18^{\circ} \mathrm{C}$. relative to mercury at $0^{\circ} \mathrm{C}$.
$K_{18}^{18}=$ conductivity of the solvent water at $18^{\circ} \mathrm{C}$. relative to mercury at $0^{\circ} \mathrm{C}$.
Then $K_{18}-K_{18}^{2 w}=k_{18}=$ conductivity of the electrolyte in the solution measured.
$\frac{k_{18}}{m}=\mu=$ conductivity of the electrolyte in the solution per molecule, or the "specific molecular conductivity."

TABLE 417.- Value of $k_{18}$ for a few Electrolytes.
This short table illustrates the apparent law that the conductivity in very dilute solutions is proportional to the amount of salt dissolved.

| m | KCl | NaCl | $\mathrm{AgNO}_{3}$ | $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ | $\mathrm{K}_{2} \mathrm{SO}_{4}$ | $\mathrm{MgSO}_{4}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.00001 | 1.25 | 1.024 | 1.080 | 0.939 | I. 275 | 1.056 |
| 0.00002 | 2.434 | 2.056 | 2.146 | 1.886 | 2.532 | 2.104 |
| 0.00006 | 7.272 | 6.162 | 6.462 | 5.610 | 7.524 | 6.216 |
| 0.0001 | 12.09 | 10.29 | 10.78 | $9 \cdot 34$ | 12.49 | 10.34 |

TABLE 418. - Electro-Chemical Bquivalents and Normal Solutions.
The following table of the electro-chemical equivalent numbers and the densities of approximately normal solutions of the salts quoted in Table 419 may be convenient. They represent grams per cubic centimeter of the solution at the temperature given.

| Salt dissolved. | Grams per liter. | $m$ | $\begin{gathered} \text { Temp. } \\ \text { C. } \end{gathered}$ | Density. | Salt dissolved. | Grams per liter. | m | Temp. C. | Density. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| KCl | 74.59 | I. 0 | 15.2 | 1.0457 | $\frac{1}{2} \mathrm{~K}_{2} \mathrm{SO}_{4}$ | 87.16 | 1.0 | 18.9 | 1.0658 |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 53.55 | 1.0009 | 18.6 | 1.0152 | ${ }_{2}^{1} \mathrm{Na}_{2} \mathrm{SO}_{4}$ | 71.09 | 1.0003 | 18.6 | 1.0602 |
| NaCl . | 58.50 | 1.0 | 18.4 | 1.0391 | ${ }_{2}^{2} \mathrm{Li}_{2} \mathrm{SO}_{4}$ | 55.09 | 1.0007 | 18.6 | 1.0445 |
| LiCl . | 42.48 | 1.0 | 18.4 | 1.0227 | ${ }_{2}^{2} \mathrm{MgSO}_{4}$ | 60.17 | 1.0023 | 18.6 | 1.0573 |
| ${ }_{\frac{1}{2}}^{1} \mathrm{BaCl}_{2}$ | 104.0 | 1.0 | 18.6 | 1.0888 | $\frac{1}{2} \mathrm{ZnSO}_{4}$ | 80.58 | 1.0 | $5 \cdot 3$ | 1.0794 |
| $\frac{1}{2} \mathrm{ZnCl}_{2}$ | 68.0 | 1.012 | 15.0 | 1.0592 | ${ }_{2}^{1} \mathrm{CuSO}_{4}$ | 79.9 | 1.001 | 18.2 | 1.0776 |
| KI. | 165.9 | 1.0 | 18.6 | 1.1183 | ${ }_{2}^{1} \mathrm{~K}_{2} \mathrm{CO}_{3}$ | 69.17 | 1.0006 | 18.3 | 1.0576 |
| $\mathrm{KNO}_{8}$ | 101.17 | 1.0 | 18.6 | 1.0601 | ${ }_{2}^{1} \mathrm{Na}_{2} \mathrm{CO}_{3}$ | 53.04 | 1.0 | 17.9 | 1.0517 |
| $\mathrm{NaNO}_{3}$ | 85.08 | 1.0 | 18.7 | 1.0542 | KOH . | 56.27 | 1.0025 | 18.8 | 1.0477 |
| $\mathrm{AgNO}_{3}$ - | 169.9 | 1.0 | - | - | HCl | 36.51 | 1.0041 | 18.6 | 1.0161 |
| $\left.{ }^{\frac{1}{2} \mathrm{Ba}} \mathrm{NO}_{3}\right)_{2}$. | 65.28 | 0.5 |  | - 67 | $\mathrm{HNO}_{3}$. | 63.13 | 1.0014 | 18.6 | 1.0318 |
| $\mathrm{KClO}_{3}{ }^{\text {- }}$ | 61.29 | 0.5 | 18.3 | 1.0367 | $\frac{1}{2} \mathrm{H}_{2} \mathrm{SO}_{4}$ | 49.06 | 1.0006 | 18.9 | 1.0300 |
| $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ | 98.18 | 1.0005 | 18.6 | 1.0467 |  |  |  |  |  |


| Salt dissolved. |  | $m=10$ | 5 | 3 | I | 0.5 | 0.1 | . 05 | . 03 | . 08 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }_{2}^{\frac{1}{2} \mathrm{~K}_{2} \mathrm{SO}_{4}}$ | - | - | - | - | - | 672 | 736 | 897 | 959 | 1098 |
| KCl | . | - | - | 827 | 919 | 958 | 1047 | 1083 | 1107 | 1147 |
| KI. | - | - | 770 | 900 | 968 | 997 | 1069 | 1102 | 1123 | 1161 |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | - | - | 752 | 825 | 907 | 948 | 1035 | 1078 | 1101 | 1142 |
| $\mathrm{KNO}_{3}$ | . | - | - | 572 | 752 | 839 | 983 | 1037 | 1067 | 1122 |
| ${ }_{\frac{1}{2}} \mathrm{BaCl}_{2}$ |  | - | - | 487 | 658 | 725 | 861 | 904 | 939 | 1006 |
| $\mathrm{KClO}_{3}$ | - | - | - |  |  | 799 | 927 | (976) | 1006 | 1053 |
| $\frac{1}{2} \mathrm{BaN}_{2} \mathrm{O}_{6}$ | - | - | - | - | - | 531 | 755 | 828 | (870) | 951 |
| ${ }_{2}^{1} \mathrm{CuSO}_{4}$ : | - | - | - | 150 | 241 | 288 | 424 | 479 | 537 | 675 |
| $\mathrm{AgNO}_{3}$ | - | - | 351 | 448 | 635 | 728 | 886 | 936 | (966) | 1017 |
| ${ }^{\frac{1}{2} \mathrm{ZnSO}_{4}}$ | - | - | 82 | 146 | 249 | 302 | 43 I | 500 | 556 | 685 |
| ${ }_{2}^{1} \mathrm{MgSO}_{4}$. | . | - | 82 | 151 | 270 | 330 | 474 | 532 | 587 | 715 |
| ${ }_{\frac{1}{2} \mathrm{Na}_{2} \mathrm{SO}_{4}}$ | - | 60 | 180 | - | 475 | 559 | 734 | 784 | 828 | 906 |
| $\stackrel{\frac{1}{2} \mathrm{ZnCl}_{2}}{\mathrm{NaCl}}$. | - | 60 | 180 | 280 | 514 | 601 | 768 | 817 | 851 | 915 |
| NaCl | - |  | 398 | 528 | 695 | 757 | 865 | 897 | (920) | 962 |
| $\mathrm{NaNO}_{3}$. | - | - | - | 430 | 617 | 694 | 817 | 855 | 877 | 907 |
| $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ | - | 30 | 240 | 381 | 594 | 671 | 784 | 820 | 841 | 879 |
| ${ }_{2}^{1} \mathrm{Na}_{2} \mathrm{CO}_{3}$ | - | 6 |  | 254 | 427 | 510 | 682 | 751 | 799 | 899 |
| $\frac{1}{2} \mathrm{H}_{2} \mathrm{SO}_{4}$. | . | 660 | 1270 | 1560 | 1820 | 1899 | 2084 | 2343 | 2515 | 2855 |
| $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}$ | - | 0.5 | 2.6 | 5.2 | 12 | 19 | 43 | 62 | 79 | 132 |
| HCl |  | 600 | 1420 | 2010 | 2780 | 3017 | 3244 | 3330 | 3369 | 3416 |
| $\mathrm{HNO}_{3}$ |  | 610 | 1470 | 2070 | 2770 | 2991 | 3225 | 3289 | 3328 | 3395 |
| ${ }^{\frac{1}{3} \mathrm{H}_{3} \mathrm{PO}_{4}}$ |  | 148 | 160 | 170 | 200 | 250 | 430 | 540 | 620 | 790 |
| KOH | - | 423 | 990 | 1314 | 1718 | 1841 | 1986 | 2045 | 2078 | 2124 |
| $\mathrm{NH}_{3}$ | - | 0.5 | 2.4 | $3 \cdot 3$ | 8.4 | 12 | 3 I | 43 | 50 | 92 |
| Salt dissolved. |  | . 006 | . 002 | . 001 | . 0006 | . 0002 | . 0001 | .00006 | . 00002 | .0000 |
| ${ }_{2}^{\frac{1}{2} \mathrm{~K}_{2} \mathrm{SO}_{4}}$ | - | 1130 | 1181 | 1207 | 1220 | 1241 | 1249 | 1254 | I 266 | 1275 |
| KCl | . | 1162 | 1185 | 1193 | 1199 | 1209 | 1209 | 1212 | 1217 | 1216 |
| KI |  | 1176 | 1197 | 1203 | 1209 | 1214 | 1216 | 1216 | 1216 | 1207 |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | - | I I 57 | I 180 | 1190 | 1197 | 1204 | 1209 | 1215 | 1209 | 1205 |
| $\mathrm{KNO}_{3}$ | - | 1140 | 1173 | 1180 | 1190 | 1199 | 1207 | 1220 | 1198 | 1215 |
| $\frac{1}{2} \mathrm{BaCl}_{2}$ | - | 1031 | 1074 | 1092 | 1102 | 1118 | 1126 | 1133 | 1144 | 1142 |
| $\mathrm{KClO}_{8} \cdot$ | - | 1068 | 1091 | 1101 | 1109 | 1119 | 1122 | 1126 | 1135 | 1141 |
| ${ }_{\frac{1}{2}} \mathrm{BaN}_{2} \mathrm{O}_{6}$ | - | 982 | 1033 | 1054 | 1066 | 1084 | 1096 | 1100 | 1114 | 1114 |
| $\frac{1}{2} \mathrm{CuSO}_{4}$. | - | 740 | 873 | 950 | 987 | 1039 | 1062 | 1074 | 1084 | 1086 |
| $\mathrm{AgNO}_{3}$ - |  | 1033 | 1057 | 1068 | 1069 | 1077 | 1078 | 1077 | 1073 | IOSo |
| ${ }^{\frac{1}{2} \mathrm{ZnSO}_{4}}$ |  | 744 | 861 | 919 | 953 | 1001 | 1023 | 1032 | 1047 | 1060 |
| $\frac{1}{2} \mathrm{MgSO}_{4}$. |  | 773 | 88I | 935 | 967 | 1015 | 1034 | 1036 | 1052 | 1056 |
| $\frac{1}{2} \mathrm{Na}_{2} \mathrm{SO}_{4}$ |  | 933 | 980 | 998 | 1009 | 1026 | 1034 | 1038 | 1056 | 1054 |
| $\frac{1}{2} \mathrm{ZnCl}_{2}$ |  | 939 | 979 | 994 | 1004 | 1020 | 1029 | 1031 | 1035 | 1036 |
| NaCl |  | 976 | 998 | 1008 | IOI 4 | 1018 | 1029 | 1027 | 1028 | 1024 |
| $\mathrm{NaNO}_{3}$ |  | 921 | 942 | 952 | 956 | 966 | 975 | 970 | 972 | 975 |
| $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ |  | 891 | 913 | 919 | 923 | 933 | 934 | 935 | 943 | $939 *$ |
| $\frac{1}{2} \mathrm{Na}_{2} \mathrm{CO}_{3}$ |  | 956 | 1010 | 1037 | 1046 | 988 | 874 | 790 | 715 | 697* |
| ${ }_{2}^{2} \mathrm{H}_{2} \mathrm{SO}_{4}$. |  | 3001 | 3240 | 3316 | 3342 | 3280 | 3118 | 2927 | 2077 | 1413 * |
| $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}$. |  | 170 | 283 | 3 So | 470 | 796 | 995 | 1133 | 1328 | ${ }^{1} 304 *$ |
| HCl |  | 3438 | $3+55$ | 3455 | 3440 | 3340 | 3170 | 2965 | 2057 | 1254** |
| $\mathrm{HNO}_{3}$ |  | 3421 | 3448 | 3427 | 3408 | 3285 | 3088 | 2863 | 1904 | I144* |
| ${ }_{\frac{1}{3}} \mathrm{H}_{3} \mathrm{PO}_{4}$ |  | 858 | 945 | 968 | 977 | 920 | 837 | 746 | 497 | 402* |
| KOH | - | 2141 | 2140 | 2110 | 2074 | 1892 | 1689 | 1474 | 845 | 747* |
| $\mathrm{NH}_{3}$ |  | 116 | 190 | 260 | 330 | 500 | 610 | 690 | 700 | 560* |

## LIMITING VALUES OF $\mu$. TEMPERATURE COEFFICIENTS.

TABLE 420.-Limiting Values of $\mu$.
This table shows limiting values of $\mu=\frac{k}{m} \cdot 10^{8}$ for infinite dilution for neutral salts, calculated from Table 271 .

| Salt. | $\mu$ | Salt. | $\mu$ | Salt. | $\mu$ | Salt. | $\mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\frac{1}{2} \mathrm{~K}_{2} \mathrm{SO}_{4}$ | 1280 | $\frac{1}{2} \mathrm{BaCl}_{2}$ | 1150 | $\frac{1}{2} \mathrm{MgSO}_{4}$. | 1080 | $\frac{1}{2} \mathrm{H}_{2} \mathrm{SO}_{4}$. | 3700 |
| KCl . | 1220 | $\frac{1}{2} \mathrm{KClO}_{3}$ | 1150 | $\frac{1}{2} \mathrm{Na}_{2} \mathrm{SO}_{4}$. | 1060 | HCl | 3500 |
| KI | 1220 | $\frac{1}{2} \mathrm{BaN}_{2} \mathrm{O}_{6}$. | 1120 | $\frac{1}{2} \mathrm{ZnCl}$ | 1040 | $\mathrm{HNO}_{3}$ - . | 3500 |
| $\mathrm{NH}_{4} \mathrm{Cl}$. . | 1210 | $\frac{1}{2} \mathrm{CuSO}_{4}$ | 1100 | NaCl | 1030 | $\frac{1}{3} \mathrm{H}_{3} \mathrm{PO}_{4}$. | 1100 |
| $\mathrm{KNO}_{3}$. . | 1210 | $\mathrm{AgNO}_{3}$ | 1090 | $\mathrm{NaNO}_{3}$ | 980 | KOH | 2200 |
| - | - | $\frac{1}{2} \mathrm{ZnSO}_{4}$. | 1080 | $\mathrm{K}_{2} \mathrm{C}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$ | 940 | $\frac{1}{2} \mathrm{Na}_{2} \mathrm{CO}_{3}$. | 1400 |

If the quantities in Table 420 be represented by curves, it appears that the values of the specific molecular conductivities tend toward a limiting value as the solution is made more and more dilute. Although these values are of the same order of magnitude, they are not equal, but depend on the nature of both the ions forming the electrolyte.

When the numbers in Table 421 are multiplied by Hittorf's constant, or 0.00011 , quantities ranging between 0.14 and 0.10 are obtained which represent the velocities in millimetres per second of the ions when the electromotive force gradient is one volt per millimetre.

Specific molecular conductivities in general become less as the concentration is increased, which may be due to mutual interference. The decrease is not the same for different salts, but becomes much more rapid in salts of high valence.

Salts having acid or alkaline reactions show marked differences. They have small specific molecular conductivity in very dilute solutions, but as the concentration is increased the conductivity rises, reaches a maximum and again falls off. Kohlrausch does not believe that this can be explained by impurities. $\mathrm{H}_{3} \mathrm{PO}_{4}$ in dilute solution seems to approach a monobasic acid, while $\mathrm{H}_{2} \mathrm{SO}_{4}$ shows two maxima, and like $\mathrm{H}_{3} \mathrm{PO}_{4}$ approaches in very weak solution to a monobasic acid.

Kohlrausch concludes that the law of independent migration of the ions in media like water is sustained.

TABLE 421. - Temperature Coefficients.
The temperature coefficient in general diminishes with dilution, and for very dilute solutions appears to approach a common value. The following table gives the temperature coefficient for solutions containing o.or gram molecule of the salt.

| Salt. | Temp. Coeff. | Salt. | Temp. Coeff. | Salt. | 'Temp. Coeff. | Salt. | Temp. Coeff. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| KCl . . . <br> $\mathrm{NH}_{4} \mathrm{Cl}$. <br> NaCl . . <br> LiCl . . . <br> $\frac{1}{2} \mathrm{BaCl}_{2}$. . <br> $\frac{1}{2} \mathrm{ZnCl}_{2}$. . <br> $\frac{1}{2} \mathrm{MgCl}_{2}$ | $\begin{aligned} & 0.0221 \\ & 0.0226 \\ & 0.0238 \\ & 0.0232 \\ & 0.0234 \\ & 0.0239 \\ & 0.0241 \end{aligned}$ | KI . . . <br> $\mathrm{KNO}_{3}$. <br> $\mathrm{NaNO}_{3}$. . <br> $\mathrm{AgNO}_{3}$. . <br> $\frac{1}{2} \mathrm{Ba}\left(\mathrm{NO}_{3}\right)_{2}$ <br> $\mathrm{KClO}_{3}$. . <br> $\mathrm{KC}_{2} \mathrm{H}_{3} \mathrm{O}_{2}$. | 0.0219 | $\frac{1}{2} \mathrm{~K}_{2} \mathrm{SO}_{4}$ | 0.0223 | $\frac{1}{2} \mathrm{~K}_{2} \mathrm{CO}_{3}$. . | 0.0249 |
|  |  |  | 0.0216 | $\frac{1}{2} \mathrm{Na}_{2} \mathrm{SO}_{4}$ | 0.0240 | $\frac{1}{2} \mathrm{Na}_{2} \mathrm{CO}_{3}$. . | 0.0265 |
|  |  |  | 0.0226 | $\frac{1}{2} \mathrm{Li}_{2} \mathrm{SO}_{4}$ | 0.0242 |  |  |
|  |  |  | 0.0221 | $\frac{1}{2} \mathrm{MgSO}_{4}$ | 0.0236 | $\begin{aligned} & \mathrm{KOH} \\ & \mathrm{HCl} \\ & \mathrm{HCO} \\ & \mathrm{HNO} \\ & \text {. }\end{aligned} \cdot$. | 0.0194 0.0159 0.0162 |
|  |  |  | 0.0224 | $\frac{1}{2} \mathrm{ZnSO}_{3}$ | 0.0234 | ${ }_{2}^{1} \mathrm{H}_{2} \mathrm{SO}_{4}{ }^{-} \cdot{ }^{-}$ |  |
|  |  |  | 0.0219 | $\frac{1}{2} \mathrm{CuSO}_{4}$ | 0.0229 |  |  |
|  |  |  | 0.0229 | - | - |  | 0.0159 |

## THE EQUIVALENT CONDUGTIVITY OF SALTS, ACIDS AND bASES IN AQUEOUS SOLUTIONS.

In the following table the equivalent conductance is expressed in reciprocal ohms. The concentration is expressed in milli-equivalents of solute per litre of solution at the temperature to which the conductance refers. (In the cases of potassium hydrogen sulphate and phosphoric acid the concentration is expressed in milli-formula-weights of solute, $\mathrm{KHSO}_{4}$ or $\mathrm{H}_{3} \mathrm{PO}_{4}$, per liter of solution, and the values are correspondingly the modal, or "formal," conductances.) Except in the cases of the strong acids the conductance of the water was subtracted, and for sodium acetate, ammonium acetate and ammonium chloride the values have been corrected for the hydrolysis of the salts. The atomic weights used were those of the International Commission for 1905, referred to oxygen as 16.00 . Temperatures are on the hydrogen gas scale.

$$
\begin{gathered}
\text { Concentration in } \frac{\text { gram equivalents. }}{1000 \text { liter }} \\
\text { Equivalent conductance in } \frac{\text { reciprocal ohms per centimeter cube }}{\text { gram equivalents per cubic centimeter }} \text {. }
\end{gathered}
$$

| Substance. |  | Equivalent conductance at the following ${ }^{\circ} \mathrm{C}$ temperatures. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 180 | $25^{\circ}$ | $50^{\circ}$ | $75^{\circ}$ | $100^{\circ}$ | ${ }_{1280}$ | ${ }_{156}{ }^{\circ}$ | $218{ }^{\circ}$ | $281^{\circ}$ | $306{ }^{\circ}$ |
| Potassium chloride . | - | 130.1 | 1) | 2.5) | (321.5) | 414 | (519) | 625 | 825 | 1005 | 1120 |
| " " | 10 | 126.3 <br> 122.4 <br> 1 | ${ }_{1415}^{146.4}$ | 215.2 | 295.2 | 377 | 470 | ${ }_{5}^{56}$ | $\begin{aligned} & 779 \\ & 74 \mathrm{I} \end{aligned}$ | 874 | 1008 |
| " " | 80 | 113.5 |  |  |  | 342 |  | 498 | 638 | 723 | 720 |
| iun | 100 | 112.0 | 129.0 | 194.5 | 264.6 | 336 362 3 | 415 | 495 | 760 |  | Ioso |
| , | 2 | 109.6 | - | - | - | 349 | - | 534 | 722 | 895 | 555 |
| " ، ${ }^{\text {، }}$ | 10 | 102.0 | - |  | - | 336 | - | 111 450 | 695 500 | 820 674 | ${ }_{680}^{860}$ |
| " " | 800 | ${ }_{9}^{93.5}$ | - |  | - | 396 <br> 206 | - | 442 |  |  |  |
| Silver nitrate | - | 115.8 | - |  | - | 367 | - | 570 | 780 | 965 | 1065 |
| " | 28 | 112.2 108.0 | - | - | - |  | - |  |  | $\begin{aligned} & 877 \\ & 790 \end{aligned}$ | 935 <br> 818 <br> 8 |
| " " | 20 | 105.1 | - | - | - | 326 | - | 488 | 639 |  |  |
| " " | $8{ }^{40}$ |  | - |  | - | 312 294 | - | 462 43 | 599 552 | $\begin{aligned} & 680 \\ & 614 \end{aligned}$ | 680 604 |
| " " | 100 |  | - |  | - |  |  |  |  |  |  |
| Sodium acetate | - | 78.1 | - | - | - | 285 | - | 450 | ${ }^{660}$ | - | 24 |
| "، " | 10 | ${ }_{71.2}^{74.5}$ | - |  |  | 253 |  | ${ }_{396}^{421}$ | $\begin{aligned} & 578 \\ & 542 \end{aligned}$ | ־ | $\begin{aligned} & 801 \\ & 702 \end{aligned}$ |
| , | 80 | 63.4 | - | - |  |  | - |  |  |  |  |
| Magnesium sulphate ${ }_{\text {/، }}$ | - |  | - | - | - | 426 <br> 302 | - |  | 1080 260 |  |  |
| " ، | ${ }^{2}$ | 794 | - | - | - |  | - | 241 | 143 |  |  |
| " " | 20 | 67.5 | - |  |  | 190 | - |  | 110 88 88 |  |  |
| " | 40 80 80 | 59.3 <br> 52.0 | - |  |  |  | - |  | 75 |  |  |
| " " | 100 | 49.8 | - |  |  |  | - |  | 75 |  |  |
| Ammonium chloride | 20 | ${ }_{\text {d }}^{\substack{43.1 \\ 13.1}}$ |  | - |  |  | - | (628) | (841) |  |  |
| Am"، ${ }^{\text {c }}$ " |  | 126.5 | 146.5 | - |  |  | - |  | Sor | - | 1031 |
| " " | 10 | 122.5 | 141.7 |  |  |  |  |  | ${ }^{758}$ | - | $\begin{aligned} & 925 \\ & 828 \end{aligned}$ |
| Ammonium acetate | $3{ }^{3}$ |  | - | - | - |  | - |  |  |  |  |
| Amm " " | ${ }^{10}$ | lif <br> 18.7 <br> 88.7 | - | - | - | $\begin{aligned} & 300 \\ & 386 \end{aligned}$ |  |  |  |  |  |

From the investigations of Noyes, Melcher, Cooper, Eastman and Kato; Journal of the American Chemical Society, 30, p. 335, 1908.

## Smithisonian Tables.

THE EQUIVALENT CONDUCTIVITY OF SALTS, ACIDS AND BASES IN AQUEOUS SOLUTIONS.

| Substance. |  | Equivalent conductance at the following ${ }^{\circ} \mathrm{C}$ temperatures. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $18^{\circ}$ | $25^{\circ}$ | $50^{\circ}$ | $75^{\circ}$ | $100^{\circ}$ | :280 | $156^{\circ}$ | 2180 | $281^{\circ}$ | $306{ }^{\circ}$ |
| Barium nitrate . | 0 | 116.9 | - | - | - | 385 | - | 600 | 840 | 1120 | 1300 |
| " . " | 2 | 109.7 | - | - | - | 352 | - | 536 | 715 | 828 | 824 |
| " " . . . | 10 | 101.0 | - | - | - | 322 | - | 481 | 618 | 658 | 615 |
| " " . . . | 40 | 88.7 | - | - | - | 280 | - | 412 | 507 | 503 | 448 |
| " "، . . | 80 | 81.6 | - | - | - | 258 | - | 372 | 449 | 430 |  |
| Potassium sulphate | 100 | 79.1 | - | - | - | 249 |  |  |  |  |  |
| Potassium sulphate | 0 | 132.8 | - | - | - | 455 | - | 715 | 1065 | 1460 | 1725 |
| " " . | 2 | 124.8 | - | - | - | 402 | - | 605 | 806 | 893 | 867 |
| " ${ }^{\prime \prime}$. | 10 | 115.7 | - | - | - | 365 | - | 537 | 672 | 687 | 637 |
| " " . . | 40 | 104.2 | - | - | - | 320 | - | 455 | 545 | 519 | 466 |
| " " ${ }^{\prime}$. . | So | 97.2 05.0 | - | - | - | 294 | - | 415 | 482 | 448 | 396 |
| Hydrochloric acid | 100 | 95.0 379.0 | - | - | - | 286 850 | - | 1085 | 1265 | 1380 | 1424 |
| " " | 2 | 373.6 | - | - | - | 826 | - | 1048 | 1217 | 1332 | 1337 |
| " ${ }^{\text {c }}$ | 10 | 368.1 | - | - | - | 807 | - | 1016 | 1168 | 1226 | 1162 |
| " | 80 | 353.0 | - | - | - | 762 | - | 946 | 1044 | 1046 | 862 |
| Nitric acid | 100 | 350.6 | - | - | 706 | 754 | - | 929 | 1006 |  |  |
| Nitric acid | $\bigcirc$ | 377.0 | 421.0 | 570 | 706 | 826 | 945 | 1047 | (1230) | - | (1380) |
| " ، | 2 | 371.2 | 413.7 | 559 | 690 | 806 | 919 | 1012 | 1166 | - | 1156 |
| " " | 10 | 365.0 | 406.0 | 548 | 676 | 786 | 893 | 978 |  |  |  |
| "، " | 50 100 | 353.7 346.4 | 393.3 | 528 | 649 | 750 | 845 | 917 880 |  |  |  |
|  | 100 | 346.4 383.0 | 385.0 $(429)$ | 516 $(591)$ | 632 $(746)$ | 728 | 817 (104I) | 880 1176 | 1505 | - | 454* |
| Sulphuric acid. | - | 383.0 | (429) | (591) | (746) | 891 | (1041) | 1176 | 1505 |  | (2030) |
| ، ، | 10 | 353.9 309.0 | 390.8 337.0 | 501 | 561 | 571 | 551 460 | 536 481 | 563 | - | 37 |
| " | 50 | $253 \cdot 5$ | 273.0 | 323 | 356 | 384 | 417 | 448 | 502 |  |  |
| " " . . | 100 | $233 \cdot 3$ | 251.2 | 300 | 336 | 369 | 404 | 435 | 483 | - | 474* |
|  | 2 | 455.3 | 506.0 | 661.0 | 754 | 784 | 773 | 754 |  |  |  |
| sulphate | 50 100 | 295.5 | 318.3 | 374.4 | 403 | 422 | 446 | 477 |  |  |  |
| Phosphoric acid . . | 100 | 33 | 376 | 329.1 510 | 354 | 375 | 402 | 435 |  |  |  |
| " . " | 2 | 283.1 | 311.9 | 401 | 464 | 498 | 508 | 489 |  |  |  |
| " " . . | 10 | 203.0 | 222.0 | 273 | 300 | 308 | 298 | 274 |  |  |  |
| " " . . | 50 | 122.7 | ${ }^{1} 32.6$ | 157.8 | 168.6 | 168 | ${ }^{1} 58$ | 142 |  |  |  |
| " " | 100 | 96.5 | 104.0 | 122.7 | 129.9 | 128 | 120 | 108 |  |  |  |
| Acetic acid . . . | $\bigcirc$ | (347.0) | - | , | - | (773) | - | (980) | (1165) | - | (1268) |
| " ${ }^{\prime} \times$. ${ }^{\text {c }}$ | 10 | 14.50 8.50 | - | - | - | 25.1 | - | 22.2 | 14.7 8.65 |  |  |
| " " | 30 | 8.50 5.22 | - | - | - | 14.7 9.05 | - | 13.0 8.00 | 8.65 5.34 |  |  |
| " | 100 | 4.67 | - | - | - | 8.10 | - | - | 4.82 | - | 1.57 |
| Sodium hydroxide | $\bigcirc$ | 216.5 | - | - | - | 594 | - | 835 | 1060 |  |  |
| " " | 2 | 212.1 | - | - | - | 582 | - | 814 |  |  |  |
| " ${ }^{\text {" }}$. | 20 | 205.8 | - | - | - | 559 | - | 771 | 930 |  |  |
| Barium hydroxide | 50 | 200.6 | - | - | - | 540 | - | 738 | 873 |  |  |
| $\underset{\text { Barium hydroxide }}{\text { "] }}$ | $\bigcirc$ | 222 | 256 | 389 | (520) | 645 | (760) | 847 |  |  |  |
|  | 10 | 215 207 | 2 | 359 342 | 4 449 | 591 548 | 664 | 722 |  |  |  |
| " " | 50 | 191.I | 215.1 | 308 | 399 | 478 | 549 | 593 |  |  |  |
| " | 100 | 180.1 | 204.2 | 291 | 373 | 443 | 503 | 531 |  |  |  |
|  | $\bigcirc$ | (238) | (271) | (404) | (526) | (647) | (764) | (908) | (114) | - | (1406) |
| Ammonium hydrox- | 10 | 9.66 | - | - | _ | 23.2 | - | 22.3 | 15.6 |  |  |
| ide . . . . . | 30 | 5.66 | 6 | - | 6 | 13.6 | - | 13.0 |  |  |  |
|  | 100 | 3.10 | 3.62 | $5 \cdot 35$ | 6.70. | $7 \cdot 47$ | - | 7.17 | 4.82 | - | 1.33 |

[^52]Snithsonian Tables.

Conditions similar to those of the preceding table except that the atomic weights for 1908 were used.

| Substance. | Concentration. | Equivalent conductance at the following ${ }^{\circ} \mathrm{C}$ temperature. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $0^{\circ}$ | $18^{\circ}$ | $25^{\circ}$ | $50^{\circ}$ | $75^{\circ}$ | $100^{\circ}$ | $128^{\circ}$ | $15^{\circ}$ |
| Potassium nitrate . | $\bigcirc$ | 80.8 | 126.3 | 145.I | 219 | 299 | 384 |  |  |
| " " | 2 | 78.6 | 122.5 | 140.7 | 212.7 | 289.9 | 370.3 | 460.7 | $551$ |
|  | 12.5 | 75.3 | 117.2 | 134.9 | 202.9 | 276.4 | 351.5 | 435.4 | 520.4 |
| " ${ }^{\prime}$ " ${ }^{\text {a }}$ | 50 | 70.7 | 109.7 | 126.3 | 189.5 | 257.4 | 326.1 | 402.9 | 476.I |
| " ${ }^{\text {" }}$ " . . | 100 | 67.2 | 104.5 | 120.3 | 180.2 | 244.1 | 308.5 | 379.5 | 447.3 |
| Potassium oxalate . . | $\bigcirc$ | 79.4 | 127.6 | 147.5 | 230 | 322 | 419 | 538 | 653 |
| " ${ }^{\text {" }}$ " . | 2 | 74.9 | 119.9 | 139.2 | 215.9 | 300.2 | 389.3 | 489.1 | 587 |
| " " | 12.5 | $69 \cdot 3$ | III.I | 129.2 | 199.1 | 275.1 | 354.1 | 438.8 | 524.3 |
| " ${ }^{\prime}$ " . . . | 50 | 63 | 101 | 116.5 | 178.6 | 244.9 | 312.2 | 383.8 | 449.5 |
| " ${ }^{\prime}$ " ${ }^{\text {a }}$. | 100 | 59.3 | 94.6 | 109.5 | 167 | 227.5 | 288.9 | 353.2 | 409.7 |
|  | 200 | 55.8 | 88.4 | 102.3 | ${ }^{1} 55$ | 210.9 | $265 . \mathrm{I}$ | 321.9 | 372.1 |
| Calcium nitrate ${ }_{\text {/، }}$. | $\bigcirc$ | 70.4 | 112.7 | 130.6 | 202 |  | 369 | 474 | 575 |
| " " . . . | $\stackrel{2}{12}$ | 66.5 | 107.1 | 123.7 | 191.9 | 266.7 | 346.5 | 438.4 | 529.8 |
| " " . . . | 12.5 50 | 61.6 | 888.6 | 114.5 102.6 | 176.2 | 244 | 314.6 | 394.5 | 473.7 |
| " " . . | 50 100 | 55.6 51.9 | 82.6 | 102.6 95.8 | 157.2 | 216.2 199.9 | 276.8 255.5 | 343 <br> 315.1 | 405.1 369.1 |
| " " | 200 | 48.3 | 76.7 | 88.8 | 135.4 | 184.7 | $253 \cdot 5$ 234.4 | 288 | 369.1 334.7 |
| Potassium ferrocyanide. | $\bigcirc$ | 98.4 | I 59.6 | 185.5 | 288 | 403 | 527 |  |  |
|  | 0.5 | 91.6 |  | 171.1 |  |  |  |  |  |
| " ${ }^{\prime \prime}$ " | 2. | 84.8 | 137 | 158.9 | 243.8 | 335.2 | 427.6 |  |  |
| "، ، | 12.5 | 71 | 113.4 | 131.6 | 200.3 | 271 | 340 |  |  |
| " ${ }^{\prime \prime}$ | 50 | 58.2 | 93.7 | 108.6 | 163.3 | 219.5 | 272.4 |  |  |
| " ${ }^{\text {" }}$ | 100 | 53 | 84.9 | 98.4 | 148.1 | I98.1 | 245 |  |  |
| " " | 200 | 48.8 | 77.8 | 90.1 | 135.7 | 180.6 | 222.3 |  |  |
| B'" " | 400 | 45.4 | 72.1 | 83.3 | 124.8 | 165.7 | 203.1 |  |  |
| $\underset{\text { Barium ferrocyanide }}{\text { ¢ }}$ | - | 91 | 150 | 176 | 277 | 393 | 52 I |  |  |
| " " | 2 | 46.9 | 75. | 86.2 | 127.5 | 166.2 | $202.3$ |  |  |
| Calcium ferrocyanide ${ }^{\text {" }}$ | 12.5 | 30.4 | 48.8 | 56.5 | 83.1 | 107 | $129.8$ |  |  |
| $\underset{\text { Calcium ferrocyanide }}{\text { Ca }}$ | 2 | 88. 47.1 | 146 75.5 | $\begin{gathered} 171 \\ 86.2 \end{gathered}$ | $271$ | 386 | 512 |  |  |
|  | 2 | 47.1 | 75.5 | 86.2 | ${ }^{1} 30$ |  |  |  |  |
| " ${ }^{\prime \prime}$ | 12.5 50 | 31.2 24.1 | 49.9 38.5 | 57.4 44.4 | 64.6 |  |  |  |  |
| " | 100 | 21.9 | 35.1 | 40.2 | 58.4 | 73.7 | 84.3 |  |  |
| " " . . | 200 | 20.6 | 32.9 | 37.8 | 55 | 68.7 | 77.5 |  |  |
| " . ${ }^{\text {" }}$ | 400 | 20.2 | 32.2 | 37.1 | 54 | 67.5 | 76.2 |  |  |
| Potassium citrate . | - | 76.4 | 124.6 | 144.5 | 228 | 320 | 420 |  |  |
| " | 0.5 | - | 120.1 | 139.4 |  |  |  |  |  |
| " " | 2 | 71 | 115.4 | 134.5 | 210.1 | 293.8 | $3^{81.2}$ |  |  |
| " " | 5 | 67.6 | 109.9 | 128.2 | 198.7 | 276.5 | 357.2 |  |  |
| " " | 12.5 | 62.9 | 101.8 | 118.7 | 183.6 | 254.2 | 326 |  |  |
| " " . . . | 50 | 54.4 | 87.8 | 102.1 | 157.5 | 215.5 | 273 |  |  |
| " " . . | 100 | 50.2 | 80.8 | 93.9 | 143.7 | 196.5 | $247 \cdot 5$ |  |  |
| " " | 300 | 43.5 | 69.8 | 81 | 123.5 | 167 | 209.5 |  |  |
| Lanthanum nitrate | $\bigcirc$ | 75.4 | 122.7 | 142.6 | 223 | 313 | 413 | 534 | 651 |
| " " | 2 | 68.9 | 110.8 | 128.9 | 200.5 | 279.8 | 363.5 | 457.5 | 549 |
| " "، | 12.5 | 61.4 | 98.5 | 114.4 | 176.7 | 243.4 | 311.2 | 383.4 | 447.8 |
| " " | 50 | 54 | 86. 1 | 99.7 | 152.5 | 207.6 | 261.4 | 315.8 | 357.7 |
| " " | 100 | 49.9 | 79.4 | 91.8 | 139.5 | 189.1 | 236.7 | 282.5 | 316.3 |
| " " . . | 200 | 46 | 72.1 | 83.5 | 126.4 | 170.2 | 210.8 | 249.6 | 276.2 |

From the investigations of Noyes and Johnston, Journal of the American Chemical Society, 31, p. 287, 1909.

## Smithsonian tables.

CONDUCTANCE OF IONS. - HYDROLYSIS OF AMMONIUM ACETATE.
TABLE 424. -The Equivalent Conductance of the Separate Ions.

| Ion. | $0^{\circ}$ | $18^{\circ}$ | $25^{\circ}$ | $50^{\circ}$ | $75^{\circ}$ | $100^{\circ}$ | $128^{\circ}$ | $156^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| K. | 40.4 | 64.6 | $74 \cdot 5$ | 115 | 159 | 206 | 263 | 317 |
| Na | 26 | 43.5 | 50.9 | 82 | 116 | 155 | 203 | 249 |
| $\mathrm{NH}_{4}$ | 40.2 | 64.5 | 74.5 | 115 | 159 | 207 | 264 | 319 |
| $\mathrm{Ag} \cdot . .$. . | 32.9 | 54.3 | 63.5 | 101 | 143 | 188 | 245 | 299 |
| $\frac{1}{2} \mathrm{Ba} . . . . .$. | 33 | $55^{2}$ | 65 | 104 | 149 | 200 | 262 | 322 |
| $\frac{1}{2} \mathrm{Ca}$. | 30 | $5 \mathrm{I}^{2}$ | 60 | 98 | 142 | 191 | 252 | 312 |
| ${ }_{3} \mathrm{La}$. | 35 | 61 | 72 | 119 | 173 | 235 | 312 | 388 |
| Cl | 4 I .1 | $65 \cdot 5$ | 75.5 | 116 | 160 | 207 | 264 | 318 |
| $\mathrm{NO}_{3}$. | 40.4 | 61.7 | 70.6 | 104 | 140 | 178 | 222 | 263 |
| $\mathrm{C}_{2} \mathrm{H}_{8} \mathrm{O}_{2}$ | 20.3 | 34.6 | 40.8 | 67 | 96 | 130 | 171 | 211 |
| $\frac{1}{2} \mathrm{SO}_{4}$. | 41 | 682 | 79 | 125 | 177 | 234 | 303 | 370 |
| ${ }_{\frac{1}{2}} \mathrm{C}_{2} \mathrm{O}_{4}{ }^{-}$ | 39 | $63^{2}$ | 73 | 115 | 163 | 213 | 275 | 336 |
| ${ }_{\frac{1}{3}} \mathrm{C}_{6} \mathrm{H}_{5} \mathrm{O}_{7}$ | 36 | 60 | 70 | 113 | 161 | 214 |  |  |
| $\frac{1}{4} \mathrm{Fe}(\mathrm{CN})_{6}$. . . . | 58 | 95 | III | 173 | 244 | 321 |  |  |
| H | 240 | 314 | 350 | 465 | 565 | 644 | 722 | 777 |
| OH . | 105 | 172 | 192 | 284 | 360 | 439 | 525 | 592 |

From Johnson, Journ. Amer. Chem. Soc., 3r, p. 1010, 1909.

TABLE 425. - Hydrolysis of Ammonium Acetate and Ionization of Water.

| Temperature. | Percentage <br> hydrolysis. | Ionization constant <br> of water. | Hydrogen-ion concen- <br> tration in pure water. <br> Equivalents per liter. |
| :---: | :---: | :---: | :---: |
| $t$ | $100_{h}$ | $\mathrm{~K}_{\mathrm{W}} \times \mathrm{ro}^{14}$ | $\mathrm{C}_{\mathrm{H}} \times{ }_{10^{7}}$ |
| 0 | - | 0.089 | 0.30 |
| 18 | $(0.35)$ | 0.46 | 0.68 |
| 25 | - | 0.82 | 0.91 |
| 100 | 4.8 | 48. | 6.9 |
| 156 | 18.6 | 223. | 14.9 |
| 218 | 52.7 | 961. | 21.5 |
| 306 | 91.5 | 168. | 13.0 |

Noyes, Kato, Kanolt, Sosman, No. 63 Publ. Carnegie Iust., Washington.

## Smithsonian Tables.

Tables 426, 427.
DIELECTRIC STRENGTH.
TABLE 426, - Steady Potential Difference in Volts required to produce a Spark in Air with Ball Electrodes.

| Spark <br> length. <br> cm. | $R=0$. <br> Points. | $R=0.25$ <br> $\mathbf{c m}$. | $R=0.5$ <br> $\mathbf{c m}$. | $R=1 \mathbf{c m}$. | $R=2 \mathrm{~cm}$. | $R=3 \mathrm{~cm}$. | $R=\infty$. <br> Plates. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.02 | - | - | 1560 | 1530 |  |  |  |
| 0.04 | - | - | 2460 | 2430 | 2340 |  |  |
| 0.06 | - | - | 3300 | 3240 | 3060 |  |  |
| 0.08 | - | - | 4050 | 3990 | 3810 |  |  |
| 0.1 | 3720 | 5010 | 4740 | 4560 | 4560 | 4500 | 4350 |
| 0.2 | 4680 | 8610 | 8490 | 8490 | 8370 | 7770 | 7590 |
| 0.3 | 5310 | 11140 | 11460 | 11340 | 11190 | 10560 | 10650 |
| 0.4 | 5970 | 14040 | 14310 | 14340 | 14250 | 13140 | 13560 |
| 0.5 | 6300 | 15990 | 16950 | 17220 | 16650 | 16470 | 16320 |
| 0.6 | 6840 | 17130 | 19740 | 20070 | 20070 | 19380 | 19110 |
| 0.8 | 8070 | 18960 | 23790 | 24780 | 25830 | 26220 | 24960 |
| 1.0 | 8670 | 20670 | 26190 | 27810 | 29850 | 32760 | 30840 |
| 1.5 | 9960 | 22770 | 29970 | 37260 |  |  |  |
| 2.0 | 10140 | 24570 | 33060 | 45480 |  |  |  |
| 3.0 | 11250 | 28380 |  |  |  |  |  |
| 4.0 | 12210 | 29580 |  |  |  |  |  |
| 5.0 | 13050 |  |  |  |  |  |  |

Based on the results of Baille, Bichat-Blondot, Freyburg, Liebig, Macfarlane, Orgler, Paschen, Quincke, de la Rue, Wolff. For spark lengths from 1 to 200 wave-lengths of sodium light, see Earhart, Phys. Rev. 15, p. 163; Hobbs, Phil. Mag. 10, p. 607, 1905.

TABLE 427. - Alternating Current Potentials required to produce a Spark in Air with various Ball Electrodes.
The potentials given are the maxima of the alternating waves used. Frequency, 33 cycles per second.

| Spark length. cm . | $R=1 \mathrm{~cm}$. | $R=1.92$ | $R=5$ | $R=7.5$ | $R=10$ | $R=15$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0.08 | 3770 |  |  |  |  |  |
| . 10 | 4400 | 4.880 | 4330 | 4290 | 4245 | 4230 |
| .15 | 5990 | 5940 | 5830 | 5790 | 5800 | 5780 |
| . 20 | 7510 | 7440 | 7340 | 7250 | 7320 | 7330 |
| . 25 | 9045 | 8970 | 8850 | 8710 | 8760 | 8760 |
| 0.30 | 10480 | 10400 | 10270 | 10130 | 10180 | 10150 |
| . 35 | 11980 | 11890 | 11670 | 11570 | 11610 | 11590 |
| . 40 | 13360 | 13300 | 13100 | 12930 | 12980 | 12970 |
| . 45 | 14770 | 14700 | 14400 | 14290 | 14330 | 14320 |
| . 50 | 16140 | 16070 | 15890 | 15640 | 15690 | 15690 |
| 0.6 | 18700 | 18730 | 18550 | 18300 | 18350 | 18400 |
| . 7 | 21350 | 21380 | 21140 | 20980 | 20990 | 21000 |
| . 8 | 23820 | 24070 | 23740 | 23490 | 23540 | 23550 |
| 0.9 | 26190 | 26640 | 26400 | 26130 | 26110 | 26090 |
| 1.0 | 28380 | 29170 | 28950 | 28770 | 28680 | 28610 |
| 1.2 | 32400 | 34100 | 33790 | 33660 | 33640 | 33620 |
| 1.4 | 35850 | 38850 | 38850 | 38580 | 38620 . | 38580 |
| 1.6 | 38750 | 43400 | 43570 | 43250 | 43520 |  |
| r. 8 | 40900 | - | 48300 | 47900 |  |  |
| 2.0 | 42950 | - | - | 52400 |  |  |

Based upon the results of Kawalski, Phil. Mag. 18, p. 699, 1909.
Smithsonian Tables.

TABLE 428. - Potential Necessary to produce a Spart in Air between more widely Separated Electrodes.

|  |  | Steady potentials. |  |  |  |  |  | Steady potentials. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Ball electrodes. |  | Cup electrodes. |  |  |  | Ball electrodes. |  |
|  |  |  |  | Projection. |  |  |  |  |  |
|  |  |  |  | 4.5 mm . | 1.5 mm . |  |  |  |  |
| 0.3 | - | - | - | - | 11280 | 6.0 | 61000 | - | 86830 |
| 0.5 | - | 17610 | 17620 | - | 17420 | 7.0 | - | 52000 |  |
| 0.7 | - | - | 23050 | - | 22950 | 8.0 | 67000 | 52400 | 90200 |
| 1.0 | 12000 | 30240 | 31390 | 31400 | 31260 | 10.0 | 73000 | 74300 | 91930 |
| 1.2 | - | 33800 | 36810 | 3 | 36700 | 12.0 | 82600 | - | 93300 |
| 1.5 | - | 37930 | 44310 | - | 44510 | 14.0 | 92000 | - | 94400 |
| 2.0 | 29200 | 42320 | 56000 | 56500 | 56530 | 15.0 | - | - | 94700 |
| 2.5 | - | 45000 | 65180 | - | 68720 | 16.0 | 101000 | - | 101000 |
| 3.0 | 40000 | 46710 | 71200 | 80400 | SII 40 | 20.0 | 119000 |  |  |
| $3 \cdot 5$ | - |  | 75300 | - | 92400 | 25.0 | 140600 |  |  |
| 4.0 | 48500 | 49100 | 78600 | 101700 | 103800 | 30.0 | 165700 |  |  |
| 4.5 | - | , | 81540 | - | 114600 | 35.0 | 190900 |  |  |
| 5.0 | 56500 | 50310 | 83800 | - | 126500 |  |  |  |  |
| $5 \cdot 5$ | - | - | - | - | 135700 |  |  |  |  |

This table for longer spark lengths contains the results of Voege, Ann. der Phys. 14, 1904, using alternating current and "dull point" electrodes, and the results with steady potential found in the recent very careful work of C. Mürler, Ann. d. Phys. 28, p. 585, 1909.


The specially constructed electrodes for the columns headed "cup electrodes" had the form of ter and having a height of 4.5 mm . and 1.5 mm . respectively, attached to the plane face of the electrodes. These electrodes give a very satiso factory linear relation between the spark lengths and the voltage throughout the range studied.

TABLE 429, - Effect of the Pressure of the Gas on the Dielectric Strength.
Voltages are given for different spark lengths $l$.

| Pressure. <br> $\mathrm{cm} . \mathrm{Hg}$. | $l=0.04$ | $l=0.06$ | $l=0.08$ | $l=0.10$ | $l=0.20$ | $l=030$ | $l=0.40$ | $l=0.50$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2 | - | - | - | - | 744 | 939 | 1110 | 1266 |
| 4 | - | 483 | 567 | 648 | 1015 | 1350 | 1645 | 1915 |
| 6 | - | 582 | 690 | 795 | 1290 | 1740 | 2140 | 2505 |
| 10 | - | 771 | 933 | 1090 | 1840 | 2450 | 3015 | 3580 |
| 15 | - | 1060 | 1280 | 1490 | 2460 | 3300 | 4080 | 4850 |
| 25 | 1110 | 1420 | 1725 | 2040 | 3500 | 4800 | 6000 | 7120 |
| 35 | 1375 | 1820 | 2220 | 2615 | 4505 | 6270 | 7870 | 9340 |
| 45 | 1640 | 2150 | 2660 | 3120 | 5475 | 7650 | 9620 | 11420 |
|  | 1820 | 2420 | 3025 | 3610 | 6375 | 8950 | 11290 | 13455 |
| 65 | 2040 | 2720 | 3400 | 4060 | 7245 | 10210 | 12950 | 15470 |
| 75 | 2255 | 3035 | 3805 | 4565 | 8200 | 11570 | 14650 | 17450 |

This table is based upon the results of Orgler, 1899. See this paper for work on other gases (or Landolt-BörnsteinMeyerhoffer).
For long spark lengths in various gases see Voege, Electrotechn. Z. 28, 1907. For dielectric strength of air and $\mathrm{CO}_{2}$ in cylindrical air condensers, see Wien, Ann. d. Phys. 29, p. 679, 1909.

## Smithsonian Tables.

Tables 430, 431.
DIELECTRIC STRENGTH.
TABLE 430. - Dielectric Strength of Materials.
Potential necessary for puncture expressed in kilovolts per centimeter thickness of the dielectric.


TABLE 431. - Potentials in Volts to Produce a Spark in Kerosene.

| Spark length. mm . | Electrodes Balls of Diam. $d$. |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | 0.5 cm . | 1 cm . | 2 cm . | 3 cm . |
| 0.1 | 3800 | 3400 | 2750 | 2200 |
| . 2 | 7500 | 6450 | 4800 | 3500 |
| $\cdot 3$ | 10250 | 9450 | 7450 | 4600 |
| . 4 | 11750 | 10750 | 9100 | 5600 |
| . 5 | 13050 | 12400 | 11000 | 6900 |
| . 6 | 14000 | 13550 | 12250 | 8250 |
| . 8 | 15500 | 15100 | 13850 | 10450 |
| 1.0 | 16750 | 16400 | 15250 | 12350 |

Determinations of the dielectric strength of the same substance by different observers do not agree well. For a discussion of the sources of error see Mościcki, Electrotechn. Z. 25, 1904.
For more detailed information on the dependence of the sparking distance in oils as a function of the nature of the electrodes, see Edmondson, Phys. Review 6, p. 65, 1898.

## Smithsonian Tables.

TABLE 432. - Dielectric Constant (Specific Inductive Oapacity) of Ciases. Atmospheric Pressure.
Wave-lengths of the measuring current greater than 10000 cm .

| Gas. | Temp.${ }^{\circ} \mathrm{C}$ | Dielectric constant referred to |  | Authority. |
| :---: | :---: | :---: | :---: | :---: |
|  |  | Vacuum $=1$ | Air $=1$ |  |
|  | - | $\begin{aligned} & 1.000590 \\ & 1.000586 \end{aligned}$ | $\begin{aligned} & 1.000000 \\ & 1.000000 \end{aligned}$ | Boltzmann, 1875. Klemencix, 1885. |
|  |  |  |  |  |
| Ammonia . . . . . | 20 | 1.00718 | 1.00659 | Bädeker, 1901 . |
| $\underset{\text { Carbon bisulphide }}{\text { c/ }}$. | $\begin{gathered} 0 \\ 100 \end{gathered}$ | $\begin{aligned} & 1.00290 \\ & 1.00239 \end{aligned}$ | $\begin{aligned} & 1.00231 \\ & 1.00180 \end{aligned}$ | Klemencix. <br> Bädeker. |
|  |  |  |  |  |
| Carbon dioxide | $\begin{aligned} & \circ \\ & 0 \end{aligned}$ | $\begin{aligned} & 1.000946 \\ & 1.000985 \end{aligned}$ | $\begin{aligned} & \mathbf{1 . 0 0 0 3 5 6} \\ & \text { I.000399 } \end{aligned}$ | Boltzmann. Klemencic. |
|  |  |  |  |  |
| Carbon monoxide . . . . <br> 66 | $0$ | $\begin{aligned} & 1.000690 \\ & 1.000695 \end{aligned}$ | $\begin{aligned} & 1.000100 \\ & 1.000109 \end{aligned}$ | Boltzmann. Klemencic. |
|  |  |  |  |  |
| $\underset{\text { Ethylene . . . . . . . . . }}{ }$ | $0$ | $\begin{aligned} & 1.00131 \\ & 1.00146 \end{aligned}$ | $\begin{aligned} & \mathrm{I} .00072 \\ & \mathrm{I} .00087 \end{aligned}$ | Boltzmann. Klemencix. |
|  |  |  |  |  |
| Hydrochloric acid . . . | 100 | 1.00258 | 1.00199 | Bädeker. |
| Hydrogen | $\bigcirc$ | $\begin{aligned} & 1.000264 \\ & 1.000264 \end{aligned}$ | $\begin{aligned} & 0.999674 \\ & 0.999678 \end{aligned}$ | Boltzmann. Klemencic. |
|  |  |  |  |  |
| $\underset{\text { Methane }}{ }{ }_{\text {M }}$. . . . . . . . | $\begin{aligned} & \circ \\ & 0 \end{aligned}$ | $\begin{aligned} & \mathrm{I} .000944 \\ & \mathrm{I} .000953 \end{aligned}$ | $\begin{aligned} & \mathrm{I} .000354 \\ & \mathrm{I} .000367 \end{aligned}$ | Boltzmann. Klemenčic. |
|  |  |  |  |  |
| Nitrous oxide $\left.{ }_{\text {" }}^{\left(\mathrm{N}_{2} \mathrm{O}\right.}\right)$ | $\bigcirc$ | $\begin{aligned} & \text { 1.00I I } 6 \\ & \text { I.00099 } \end{aligned}$ | $\begin{aligned} & \mathrm{I} .00057 \\ & \mathrm{I} .0004 \mathrm{I} \end{aligned}$ | Boltzmann. Klemencic. |
|  | $\bigcirc$ |  |  |  |
| Sulphur dioxide <br> Water vapor, 4 atmospheres | $\bigcirc$ | 1.00993 | 1.00934 | Bädeker. |
|  | - | 1.00905 | 1.00846 | Klemencix. |
|  | 145 | 1.00705 | 1.00646 | Bädeker. |

## TABLE 433, - Variation of the Dielectric Constant with the Temperature.

For variation with the pressure see next table.
If $D_{\theta}=$ the dielectric constant at the temperature $\theta^{\circ} \mathrm{C} ., D_{t}$ at the temperature $t^{\circ} \mathrm{C}$., and $\alpha$ and $\beta$ are quantities given in the following table, then

$$
D_{\theta}=D_{t}\left[\mathrm{I}-\alpha(t-\theta)+\beta(t-\theta)^{2}\right]
$$

The temperature coefficients are due to Bädeker.

| Gas. |  | $a$ | $\beta$ | Range of <br> temp. <br> C. |
| :---: | :---: | :---: | :---: | :---: |
| Ammonia | $\cdot$ | $5.45 \times 10^{-6}$ | $2.59 \times 10^{-7}$ | $10-110$ |
| Sulphur dioxide | $6.19 \times 10^{-6}$ | $1.86 \times 10^{-7}$ | $0-110$ |  |
| Water vapor | $1.4 \times 10^{-4}$ | - | 145 |  |

The dielectric constant of air at atmospheric pressure but with varying temperature may also be calculated from the fact that $D-I$ is approximately proportional to the density.

Tables 434, 435.
DIELECTRIC CONSTANTS (continued).
TABLE 434. - Ohange of the Dielectrio Constant of Gases with the Pressure.

| Gas. | Temperature, ${ }^{\circ} \mathrm{C}$. | Pressure atmos. | Dielectric constant. | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Air . . . | 19 | 20 | 1.0108 | Tangl, 1907. |
| " . . . . . | - | 40 | 1.0218 |  |
| " . . . . . . | - | 60 | 1.0330 | " " |
| " . . . . . . | - | 80 | 1.0439 | " " |
| " • . . . . . | - | 100 | 1.0548 | " " |
| " . . . . . . | II | 20 | 1.0101 | Occhialini, 1905. |
| " • . . . . . | - | 40 | 1.0196 | " |
| " • • • • • | - | 60 | 1.0294 | " " |
| " . . . . . . | - | 80 | 1.0387 | " " |
| " . . . . . . | - | 100 | 1.0482 | " |
| " . . . . . . | - | 120 | 1.0579 | " " |
| " • • • . | - | 140 | 1.0674 | " " |
| " . . | - | 160 | 1.0760 | " " |
|  | - | 180 | $1.0845$ | " " |
| Carbon dioxide . | 15 | 10 | 1.008 |  |
|  | - | 20 | 1.020 |  |
| Nitrous oxide, $\dot{\mathrm{N}}$ |  | 10 | 1.060 | " |
| " " | - | 20 | 1.025 | ' |
| " " | - | 40 | 1.070 | ' |

TABLE 435. - Dielectric Constants of Liquids.
A wave-length greater than 10000 centimeters is denoted by $\infty$.


References on page 358.
Smithsonian Tables.

DIELECTRIC CONSTANTS OF LIQUIDS.
A wave-length greater than 10000 centimeters is desiguated by $\infty$.


Addenda to Table 440, p. 36x, Dielectric Constant of Rochelle Salt :
The polarization of the Rochelle salt dielectric in an electric field is somewhat analagous to the behavior of the magnetization of iron in a magnetic field, showing both saturation and hysteresis. The dielectric constant $D$ depends on the initial and final fields and the hysteresis.

Initial field, $765 \mathrm{v} / \mathrm{cm}$.; Final field, $690 \mathrm{v} / \mathrm{cm}$.; Average D ( $23^{\circ} \mathrm{C}$ ), 40

| 765 | -153 | 40 |
| ---: | ---: | ---: |
| 765 | -765 | 205 |
| 0 | 880 | 157 |

The last value may be fair value for ordinary purposes. The electrodes were tinfoil attached with shellac. The field was applied perpendicular to the a axis. Like piezoelectric properties, the dielectric constant varies with different crystals. It depends on the temperature as follows: (field o to $880 \mathrm{v} / \mathrm{cm}$ )

$$
-70^{\circ} \mathrm{C}, \mathrm{D}=12 ;-40^{\circ}, 14 ;-20^{\circ}, 48 ; 0^{\circ}, 174 ;+20^{\circ}, 88 ;+30^{\circ}, 52
$$

(Data from Valesek, University of Minnesota, 1921.)

## SmITHSONIAN TABLES.

DIELECTRIC CONSTANTS OF LIQUIDS (continued).
TABLE 436. - Tomporatare Coetticients of the Formula :
$D_{\theta}=D_{t}\left[\mathrm{I}-\alpha(t-\theta)+\beta(t-\theta)^{2}\right]$.

| Substance. | a | $\beta$ | $\begin{aligned} & \text { Temp. } \\ & \text { range, }, \end{aligned}$ | Authority. |
| :---: | :---: | :---: | :---: | :---: |
| Amyl acetate. | 0.0024 | - | - | Löwe. |
| Aniline . . | 0.00351 | - | - | Ratz. |
| Benzene. . . . | 0.00106 | 0.0000087 | 10-40 | Hasenöhrl. |
| Carbon bisulphide . | 0.000966 0.000922 | - | - | Ratz. |
|  | 0.000922 | 0.00000060 | 20-181 | Tangl. |
| Chloroform Ethyl ether | 0.00410 | 0.000015 | 22-181 | " |
| Methyl alcohol . | 0.00459 | - | - | Ratz. |
| Oils: Almond . | 0.00163 | 0.000026 | - | Hasenöhrl. |
| Castor | 0.01067 | - | - | Heinke, 1896. |
| Olive | 0.00364 | - | - | "" " |
| Paraffine | 0.000738 | 0.0000072 | - | Hasenöhrl. |
| Toluene . | 0.000921 0.000977 | -00000046 | -113 | Ratz. |
| Water . | 0.000977 $0.004+74$ | 0.00000046 | $\underset{\substack{20-181 \\ 5-20}}{ }$ | Tangl. |
| " | 0.004583 | 0.0000117 | 0-76 | Drude. |
|  | 0.00436 | - | 4-25 | Coolidge. |
| Meta-xylene . | 0.000817 | - | 20-181 | Tangl. |

(See Table 433 for the signification of the letters.)

TABLE 437.-Dielectric Constants of Liquefled Gases.
A wave-length greater than 10000 centimeters is designated by $\infty$.

| Substance. | Temp. |  | $\begin{gathered} \text { Dial. } \\ \text { constant. } \end{gathered}$ | 言 | Substance. |  |  | Dial. constant. | 产 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Air | -191 | $\infty$ | $\stackrel{\text { I. } 432}{1.47-1.50}$ | 1 | Nitrous oxide |  |  |  |  |
| Ammonia | -34 | 75 | ${ }_{\substack{1.47-1.50 \\ 21-23}}$ | 2 | " " ${ }^{2} \mathrm{O}$. | -88 | $\stackrel{\infty}{ }$ | 1.938 1.630 | 8 |
| " ${ }^{\text {c }}$ | 14 | 130 | 16.2 | 4 | " " | +5 | " | 1.578 | " |
| Carbon dioxide . | -5 | $\cdots$ | 1.608 | 5 | Oxygen | +15 | " | 1.520 | ، |
| " " . | 0 +10 | " | 1.583 1.540 | " | Oxygen | -182 | . " | 1.491 1.465 1 | 9 |
| " | +15 | " | 1.526 | " | Sulphur dioxide | 14.5 | 120 | 13.75 | 4 |
| Chlorine | -60 | " | 2.150 | " | "، " | 20 | $\infty$ | 14.0 | 6 |
| " | $-20$ | " | 2.030 | " | " ${ }^{\text {" }}$ | 40 | " | 12.5 | " |
| " | $\bigcirc$ | " | 1. 970 | " | " " | 60 | " | 10.8 | " |
| " | +10 | " | 1.940 2.08 | " | "، " | So 100 | " | 7.9 | " |
| " ${ }^{\text {" }}$. | +14 | 100 | 2.88 1.88 | 4 | " " | 120 | " | 6.4 | " |
| Cyanogen . - ${ }^{\text {d }}$ | 23 | 84 | 2.52 | " | , | 140 | " | 4.8 | " |
| Hydrocyanicacid | 21 |  | about 95 | " | Critical. | 154.2 | " | 2.1 | " |
| Hydrogen sulph. |  | " |  | ${ }_{6}$ |  |  |  |  |  |
|  | $\begin{aligned} & 50 \\ & 90 \end{aligned}$ |  | $\begin{aligned} & 4.92 \\ & 3.76 \end{aligned}$ | ، |  |  |  |  |  |
| I v. Pirani, 1903. <br> 2 Bahn-Kiebitz, 1904. <br> 3 Goodwin-Thompson, 1899. |  |  | $\begin{aligned} & 4 \text { Coolidge, i899. } \\ & 5 \text { Linde, I895. } \\ & 6 \text { Eversheim, } 1904 . \end{aligned}$ |  |  | Schlundt, 1901. <br> Hasenöhrl, 1900. <br> Fleming-Dewar, isg6. |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

TABLE 438, - Standard Solutions for the Callbration of Apparatus for the Measuring of Dlelectric Constants.

| Turner. |  | Drude. |  |  |  | Nernst. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Substance. | Diel. const. at $18^{\circ}$. $\lambda=\infty$. | Acetone in benzene at $199^{\circ}$. $\lambda=75 \mathrm{~cm}$. |  |  |  | Ethyl alcohol in water at $19.5^{\circ}$. $\lambda=\infty$. |  |
|  |  | Per cent by weight. | Density $16{ }^{\circ}$. | Dielectric constant. | Temp.coefficient. |  |  |
| Benzene <br> Meta-xylene . <br> Ethyl ether <br> A niline <br> Ethyl chloride <br> O-nitro toluene <br> Nitrobenzene <br> Water (conduct. $10^{-6}$ ) | 2.288 |  |  |  |  | Per cent by weight. | Dielectric constant. |
|  | 2.376 | $\bigcirc$ | 0.885 | 2.26 | $0.1 \%$ |  |  |
|  | $7.29{ }^{8}$ | 20 | 0.866 | 5.10 | 0.3 |  |  |
|  | 10.90 | 40 | 0.847 0 | 8.43 | 0.4 | 90 | 29.3 |
|  | 27.71 | 60 | 0.830 | 12.1 | 0.5 | 80 | 29.3 33.5 |
|  | 36.45 | 80 100 | 0.813 0.797 | 16.2 20.5 | 0.5 0.6 | 70 | 38.0 |
|  | 81.07 |  |  |  |  | 60 | 43.1 |
|  |  | Wat | er in acetone | $19^{\circ} . \lambda=$ | 75 cm . |  |  |
|  |  | $\bigcirc$ | 0.797 | 20.5 | 0.6\% |  |  |
|  |  | 20 | 0.856 | 31.5 | 0.5 |  |  |
|  |  | 40 | 0.903 | 43.5 | 0.5 |  |  |
|  |  | 80 | 0.940 | 57.0 | 0.5 |  |  |
|  |  | 100 | 0.973 0.999 | 70.6 80.9 | 0.5 0.4 |  |  |

TABLE 439, - Dieloctric Constants of Solids.

| Substance. | Condition. | Wavelength cm. | Dielectric constant. |  | Substance. | Condition. | Wavelength, cm. | Dielectric constant. | 京交 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Asphalt | - | $\infty$ | 2.68 | I |  | Temp. |  |  |  |
| Barium sulphate |  |  |  |  | Iodine (cryst.) . | 23 | 75 | 4.00 | 2 |
| phate Caoutchouc . | - | 75 | 10.2 2.22 | 2 | Lead chloride (powder) |  | " |  |  |
| Diamond . | - | " | 16.5 | 3 1 | " nitrate. | - | , | 42 16 | 2 |
|  | - | 75 | $5 \cdot 50$ |  | " sulphate | - | " | 28 | 2 |
| Ebonite | - | $\infty$ | 2.72 | 4 | " molybde- |  |  |  |  |
| " | - | " | 2.86 | 5 | nate | - | " | 24 | 2 |
| Glass* * • | Density. | 1000 | 2.55 | 6 | Marble ${ }^{\text {(Carrara) }}$ |  |  |  |  |
| Flint (extra | Density |  |  |  | Mica (Carrara) | - | " | $\stackrel{8.3}{5.66-5.97}$ | 2 |
| heavy) . | $4 \cdot 5$ | $\infty$ | 9.90 | 7 | ${ }^{\prime}$. . . . | - | " | 5.80-6.62 | 15 |
| Flint (very |  |  |  |  | Madras, brown | - | " | 2.5-3.4 | 16 |
| light) . . | 2.87 | " | 6.61 | 7 | " green | - | " | 3.9-5.5 | 16 |
| Hard crown | 2.48 | " | 6.96 | 7 | " ruby . | - | " | 4.4 | 16 |
| $\underset{\text { Mirror }}{ }$. | - | " | 6.44-7.46 | 5 | Bengal, yellow | - | " | 2.8 | 16 |
| " | - | " | 5.37-5.90 | 8 | " white. | - | " | 4.2 | 16 |
| " | - | 600 | 5.42-6.20 | 8 | " ruby . | - | " | 4.2-4.7 | 16 |
| Lead (Pow- | 3.0-3. | $\infty$ | 5.4-8.0 | 9 | Canadian amber. | - | " | 3.0 | 16 |
| Jena |  |  |  |  | South America | - | " | 5.9 | 16 |
|  | - | " |  | 10 | Ozokerite (raw) | - | " | 2.21 |  |
| Barium . | - | " | 7.8-8.5 | 10 | Paper (tele- |  |  |  |  |
| Borosilicate | - | " |  |  | " (cable). | - | " | 2.0 | 17 |
| Gutta percha. | - | - | $6.4-7 \cdot 7$ $3 \cdot 3-4.9$ | 11 | Paraffine . . |  | " | $2.0-2.5$ 2.46 | 18 |
|  | Temp. |  | $3 \cdot 3$ |  | , | Melting | " | 2.32 | 19 |
| Ice | -5 | 1200 | 2.85 | 12 | " . . . | 44-46 | / | 2.10 | 20 |
| " | -18 | 5000 | 3.16 | 13 | " . . . | 54-56 | " | 2.14 | 20 |
|  | -190 | 75 | 1.76-1.88 | 14 | " . . . | 74-76 | ، | 2.16 | 20 |

*For the effect of temperature, see Gray-Dobbie, Pr. Roy. Soc. 63, 1898; 67, 1900.
" " " "wave-length, see K. F. Löwe, Wied. Ann. 66, 1898.

Tables 439, 440.
DIELECTRIC CONSTANTS (continued).
TABLE 439. - Dielectric Constants of Sollds (continued).

| Substance. | Condition. | Wavelength, cm. | Diel. constant. | 皆 | Substance. | Condition. | Wavelength, cm. | $\begin{gathered} \text { Diel. } \\ \text { constant. } \end{gathered}$ | 遱 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\underset{\text { Paraffine }}{ }$. . | $47 .{ }^{\circ} 6$ $56 .{ }^{\circ} \mathrm{O}$ | 61 61 | 2.16 2.25 | 21 | Sulphur Amorphous |  |  |  |  |
| Phosphorus: | $56 .{ }^{\circ} 2$ | 61 | 2.25 | 21 | A morphous | - | \% 75 | 3.98 3.80 | 1 |
| Yellow . . | - | 75 | 3.60 | 2 | Cast, fresh | - | $\infty$ | 4.22 | I |
| Solid . . | - | 80 | 4.1 | 22 | " " | - | " | 4.05 | 18 |
| Liquid . | - | 80 | 3.85 | 22 | ast | - | 75 | 3.95 | 2 |
| Porcelain: |  |  |  |  | Cast, old | - | - | 3.60 | 18 |
| Hard |  |  |  |  |  |  | 75 | 3.90 | 2 |
| (Royal B'l'n) | - | " | 5.73 | 15 |  | near | ) |  |  |
| Seger ". | - | " | 6.61 | 15 | Liquid . | melting. | $\} \infty$ | 3.42 | I |
| Figure " " . | - | " | 6.84 | 15 |  | point |  |  |  |
| Selenium . | - | " | 7.44 | 1 | Strontium |  |  |  |  |
| " | - | 75 | 6.60 | 2 | sulphate | - | 75 | 11.3 | 2 |
| " . | - | $\infty$ | 6.13 | 23 | Thallium |  |  |  |  |
| Shellac. |  | 1000 | 6.14 | 23 | carbonate | - | 75 | 17 | 2 |
| Shellac . . | - | $\cdots$ | 3.10 $2.95-3.73$ | 4 | "' nitrate |  | 75 | 16.5 | 2 |
| ' |  | ، | ${ }_{3.67}$ | 25 | Red beech . | \|| fibres | $\infty$ | $4.83-2.51$ | - |
| Amber . |  |  | 2.86 |  | , | $\perp{ }^{\prime}$ | " | 7.73-3.63 | - |
| Amber . | - |  |  |  | Oak . | II " | " | 4.22-2.46 $6.84-3.64$ | - |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| 3 Gordon, 1879. |  |  | 12 Thwing, 1894. |  |  | 20 | Lietkowski, 1900. |  |  |
| 4 Winklema | n, 188 |  | 13 Abegg, 1897. |  |  | 21 I | Hormell, 1902. |  |  |
| 5 Elsas, 189 |  |  | 14 Behn-Kiebitz, 1904. |  |  | 22 Schlundt, 1904. |  |  |  |
| 6 Ferry, 18 |  |  | 15 Starke, 1897. |  |  |  | Vonwiller-Mason, |  |  |
| 7 Hopkinso | 1891. |  | 16 E. Wilson. |  |  |  | 24 Wullner, 1887. |  |  |
| 8 Arons-Ru 9 Gray-Dob | $\begin{aligned} & \text { ens, } 18 \\ & \text { ie, } 1898 \end{aligned}$ |  | 17 Campbell, 1906. |  |  | 25 Donle. |  |  |  |

TABLE 440. - Dielectric Constants of Crystals.
$\mathrm{D} \boldsymbol{\alpha}, \mathrm{D} \beta, \mathrm{D} \boldsymbol{\gamma}$ are the dielectric constants along the brachy, macro and vertical axes respectively.


## Wave-Length in Meters, Frequency in periods per second, and Osollation Constant LC in Microhenries and Microfarads.

The relation between the free wave-length in meters, the frequency in cycles per second, and the capacity-inductance product in microfarads and microhenries are given for circuits between 1000 and 10,000 meters. For values between 100 and 1000 meters, multiply the columns for n by 10 and move the decimal point of the corresponding. LC column two places to the left (dividing by 100); for values between 10,000 and 100,000 , divide the n column by 10 and multiply the LC column by 100 . The relation between wave-length and capacity-inductance may be relied upon throughout the table to within one part in 200.
Example I : What is the natural wave-length of a circuit containing a capacity of 0.00 microfarad, and an inductance of 454 microhenries ? The product of the inductance and capacity is $454 \times 0.001=0.454$. Find 0.454 under LC; opposite under meters is 1270 meters, the natural wave-length of the circuit.
Example 2: What capacity must be associated with an inductance of 880 microhenries in order to tune the circuit to 3500 meters? Find opposite 3500 meters the LC value 3.45 ; divide this by 880, and the quotient, 0.00397 , is the desired capacity in microfarads.
Example 3: A condenser has the capacity of 0.004 microfarad. What inductance must be placed in series with this condenser in order that the circuit shall have a wave-length of 600 meters? From the table, the LC value corresponding to 600 meters is 0.101 . Divide this by 0.004 , the capacity of the condenser, and the desired inductance is 25.2 microhenries.

| Meters. | n | LC | Meters. | n | LC | Meters. | n | LC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1000 | 300,000 | 0.281 | 1300 | 230,800 | 0.476 | 1600 | 187,500 | 0.721 |
| 1010 | 297,000 | 0.287 | 1310 | 229,000 | 0.483 | 1610 | 186,300 | 0.730 |
| 1020 | 294,100 | 0.293 | 1320 | 227,300 | 0.490 | 1620 | 185,200 | 0.739 |
| 1030 | 291,300 | 0.299 | 1330 | 225,600 | 0.498 | 1630 | 184,100 | 0.748 |
| 1040 | 288,400 | 0.305 | 1340 | 223,900 | 0.505 | 1640 | 182,900 | 0.757 |
| 1050 | 285,700 | 0.310 | 1350 | 222,200 | 0.513 | 1650 | 181,800 | 0.766 |
| 1060 | 283,600 | 0.316 | 1360 | 220,600 | 0.521 | 1660 | 180,700 | 0.776 |
| 1070 | 280,400 | 0.322 | 1370 | 218,900 | 0.529 | 1670 | 179,600 | 0.785 |
| 1080 | 277,800 | 0.328 | 1380 | 217,400 | 0.536 | 1680 | 178,600 | 0.794 |
| 1090 | 275,200 | 0.335 | 1390 | 215,800 | 0.544 | 1690 | 177,500 | 0.804 |
| 1100 | 272,700 | 0.341 | 1400 | 214,300 | 0.552 | 1700 | 176,500 | 0.813 |
| 1110 | 270,300 | 0.347 | 1410 | 212,800 | 0.559 | 1710 | 175,400 | 0.823 |
| 1120 | 267,900 | 0.353 | 1420 | 211,300 | 0.567 | 1720 | 174,400 | 0.833 |
| 1130 | 265,500 | 0.359 | 1430 | 209,800 | 0.576 | 1730 | 173,400 | 0.842 |
| 1140 | 263,100 | 0.366 | 1440 | 208,300 | 0.584 | 1740 | 172,400 | 0.852 |
| 1150 | 260,900 | 0.372 | 1450 | 206,900 | 0.592 | 1750 | 171,400 | 0.862 |
| 1160 | 258,600 | 0.379 | 1460 | 205,500 | 0.600 | 1760 | 170,500 | 0.872 |
| 1170 | 256,400 | 0.385 | 1470 | 204,100 | 0.608 | 1770 | 169,400 | 0.882 |
| 1180 | 254,200 | 0.392 | 1480 | 202,700 | 0.617 | 1780 | 168,500 | 0.892 |
| 1190 | 252,100 | 0.399 | 1490 | 201,300 | 0.625 | 1790 | 167,600 | 0.902 |
| 1200 | 250,000 | 0.405 | 1500 | 200,000 | 0.633 | 1800 | 166,700 | 0.912 |
| 1210 | 247,900 | 0.412 | 1510 | 198,700 | 0.642 | 1810 | 165,700 | 0.923 |
| 1220 | 245,900 | 0.419 | 1520 | 197,400 | 0.650 | 1820 | 164,800 | 0.933 |
| 1230 | 243,900 | 0.426 | 1530 | 196,100 | 0.659 | 1830 | 163,900 | 0.943 |
| 1240 | 241,900 | 0.433 | 1540 | 194,800 | 0.668 | 1840 | 163,000 | 0.953 |
| 1250 | 240,000 | 0.440 | I 550 | 193,600 | 0.676 | 1850 | 162,200 | 0.963 |
| 1260 | 238,100 | 0.447 | 1560 | 192,300 | 0.685 | 1860 | 161,300 | 0.974 |
| 1270 1280 | 236,200 234,400 | 0.454 0.461 | 1570 1580 | 191,100 | 0.694 | 1870 | 160,400 | 0.985 |
| 1280 1290 | 234,400 232,600 | 0.461 0.468 | 1580 | 189,900 | 0.703 | 1880 | 159,600 | 0.995 |
| 1290 | 232,600 | 0.468 | 1590 | 188,700 | 0.712 | 1890 | 158,700 | 1.006 |

Adapted from table prepared by Greenleaf W. Picard; copyright by Wireless Specialty Apparatus Company, New York. Computed on basis of 300,000 kilometers per second for the velocity of propagation of electromagnetic waves.

TABLE 441 (concluded).
WIRELESS TELEGRAPHY.
Wave-Length, Frequency and Oscillation Constant.

| Meters. | n | LC | Meters. | n | LC | Meters. | n | LC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1900 | 1 57,900 | 1.016 | 2800 | 107,100 | 2.21 | 7000 | 42,860 | 13.8 |
| 1910 | 157,100 | 1.026 | 2820 | 106,400 | 2.24 | 7100 | 42,250 | 14.2 |
| 1920 | 156,300 | 1.037 | 2840 | 105,600 | 2.27 | 7200 | 41,670 | 14.6 |
| 1930 | 155,400 | 1.048 | 2860 | 104,900 | 2.30 | 7300 | 41,100 | 15.0 |
| 1940 | 154,600 | 1.059 | 2880 | 104,200 | 2.33 | 7400 | 40,540 | 15.4 |
| 1950 | 153,800 | 1.070 | 2900 | 103,400 | 2.37 | 7500 | 40,000 | 15.8 |
| 1960 | 1 53,100 | 1.081 | 2920 | 102,700 | 2.40 | 7600 | 39,470 | 16.3 |
| 1970 | 152,300 | 1.092 | 2940 | 102,000 | 2.43 | 7700 | 38,960 | 16.7 |
| 1980 | 151,500 | 1.103 | 2960 | 101,300 | 2.47 | 7800 | 38,460 | 17.1 |
| 1990 | 150,800 | 1.114 | 2980 | 100,700 | 2.50 | 7900 | 37,980 | 17.6 |
| 2000 | 150,000 | 1.126 | 3000 | 100,000 | 2.53 | 8000 | 37,500 | 18.0 |
| 2020 | 148,500 | 1.148 | 3100 | 96,770 | 2.70 | 8100 | 37,040 | 18.5 |
| 2040 | 147,100 | 1.171 | 3200 | 93,750 | 2.88 | 8200 | 36,590 | 18.9 |
| 2060 | 145,600 | I. 194 | 3300 | 90,910 | 3.07 | 8300 | 36,140 | 19.4 |
| 2080 | 144,200 | 1.218 | 3400 | 88,240 | 3.26 | 8400 | 35,710 | 19.9 |
| 2100 | 142,900 | 1.241 | 3500 | 85.910 | 3.45 | 8500 | 35,290 | 20.3 |
| 2120 | 141,500 | 1.265 | 3600 | 83,330 | 3.65 | 8600 | 34,880 | 20.8 |
| 2140 | 140,200 | 1.289 | 3700 | 81,080 | 3.85 | 8700 | 34,480 | 21.3 |
| 2160 | 1 38,900 | 1.313 | 3800 | 78,950 | 4.06 | 8800 | 34,090 | 21.8 |
| 2180 | 137,600 | 1.338 | 3900 | 76,920 | 4.28 | 8900 | 33,710 | 22.3 |
| 2200 | 136,400 | 1.362 | 4000 | 75,000 | 4.50 | 9000 | 33,330 | 22.8 |
| 2220 | 135,100 | 1.387 | 4100 | 73,170 | 4.73 | 9100 | 32,970 | 23.3 |
| 2240 | I 33,900 | 1.412 | 4200 | 71,430 | 4.96 | 9200 | 32,610 | 23.8 |
| 2260 | 132,700 | 1.438 | 4300 | 69,770 | 5.20 | 9300 | 32,260 | 24.3 |
| 2280 | 131,600 | 1.463 | 4400 | 68,180 | $5 \cdot 45$ | 9400 | 31,910 | 24.9 |
| 2300 | 130,400 | 1.489 | 4500 | 66,670 | 5.70 | 9500 | 31,590 | 25.4 |
| 2320 | 129,300 | 1.515 | 4600 | 65,220 | 5.96 | 9600 | 31,250 | 25.9 |
| 2340 | 128,200 | I. 541 I | 4700 | 63,830 | 6.22 | 9700 | 30,930 | 26.5 |
| 2360 | 127,100 | 1. 568 | 4800 | 62,500 | 6.49 | 9800 | 30,610 | 27.0 |
| 2380 | 126,000 | 1.594 | 4900 | 61,220 | 6.76 | 9900 | 30,310 | 27.6 |
| 2400 | 125,000 | 1.621 | 5000 | 60,000 | 7.04 | 10000 | 30,000 | 28.1 |
| 2420 | 124,000 | 1.648 | 5100 | 58,820 | $7 \cdot 32$ |  |  |  |
| 2440 | 129,000 | 1.676 | 5200 | 57,690 | 7.61 |  |  |  |
| 2460 | 121,900 | 1.703 | 5300 | 56,600 | 7.91 |  |  |  |
| 2480 | 121,000 | 1.731 | 5400 | 55,560 | 8.21 |  |  |  |
| 2500 | 120,000 | 1.759 | 5500 | 54,550 | 8.51 |  |  |  |
| 2520 | 119,000 | 1.787 | 5600 | 53,570 | 8.83 |  |  |  |
| 2540 | 118,100 | 1.816 | 5700 | 52,630 | 9.15 |  |  |  |
| 2560 | 117,200 | 1.845 | 5600 | 51,720 50,850 | 9.47 |  |  |  |
| 2580 | 116,300 | 1.874 | 5900 | 50,850 | 9.81 |  |  |  |
| 2600 | 115,400 | 1.903 | 6000 | 50,000 | 10.1 |  |  |  |
| 2620 | 114,500 | 1.932 | 6100 | 49,180 | 10.5 |  |  |  |
| 2640 | 113,600 | 1.962 | 6200 | 48,550 | 10.8 |  |  |  |
| 2660 | 112,800 | 1.991 | 6300 | 47,620 | 11.1 |  |  |  |
| 2680 | 1111,900 | 2.02 | 6400 | 46,870 | II. 5 |  |  |  |
| 2700 | 111,100 | 2.05 | 6500 | 46,150 | II. 9 |  |  |  |
| 2720 | 110,300 | 2.08 | 6600 | 45,450 | 12.3 |  |  |  |
| 2740 | 109,500 | 2.11 | 6700 | 44,780 | 12.6 |  |  |  |
| 2760 2780 | 108,700 107,900 | 2.14 2.18 | 6800 | 44,120 43,480 | 13.0 13.4 |  |  |  |
|  | 107,900 |  |  |  |  |  |  |  |
| 2800 | 107,100 | 2.21 | 7000 | 42,860 | 13.8 |  |  |  |

Smithsonian Tables.

TABLE 442.

## WIRELESS TELEGRAPHY.

## Radiation Resistances for Various Wave-Lengths and Antenna Heights.

The radiation theory of Hertz shows that the radiated energy of an oscillator may be represented by $E=$ constant $\left(h^{2} / \lambda^{2}\right) I^{2}$, where $h$ is the length of the oscillator, $\lambda$, the wave-length and I the current at its center. For a flat-top antenna $E=1600\left(h^{2} / \lambda^{2}\right) I^{2}$ watts; $1600 h^{2} / \lambda^{2}$ is called the radiation resistance.
( $\mathrm{h}=$ height to center of capacity of conducting system.)

| $\mathrm{W}^{\mathrm{h}=}$ | 40 Ft . | 60 Ft . | 80 Ft . | 100 Ft . | 120 Ft . | 160 Ft . | 200 Ft . | 300 Ft . | 450 Ft . | 600 Ft . | 1200 Ft . |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $m$ | ohm | ohm | ohm | ohm | ohm | ohm | ohm | ohm | ohm | ohm | ohm |
| 200 | 6.0 | 13.4 | 24.0 | 37.0 | 54.0 | 95.0 |  |  |  |  |  |
| 300 | 2.7 | 6.0 | 10.6 | 16.5 | 23.8 | 42.4 |  |  |  |  |  |
| 400 | 1.56 | 3.4 | 6.0 | $9 \cdot 3$ | 13.4 | 23.8 |  |  | 84.0 |  |  |
| 600 | 0.66 | 1.5 | 2.7 | 4.1 | 6.0 | 10.6 | 16.4 | 37.4 | 84.0 | 149.0 84.0 |  |
| 800 | 0.37 | 0.84 | 1.5 | 2.3 | 3.4 | 6.0 | 9.2 6.0 | 21.0 13.5 | 47.0 30.0 | 84.0 54.0 |  |
| 1000 | 0.24 | 0.54 | 0.95 | 1.5 | 2.1 | 3.8 2.6 | 4.1 | 13.5 9.3 | 30.0 21.0 | 54.0 37.0 | 215.0 149.0 |
| 1200 | 0.17 | 0.37 | 0.66 | 1.03 0.66 | 1.5 0.95 | 2.6 | 4.1 2.6 | 9.3 6.0 | 21.0 13.4 | 37.0 24.0 | 149.0 95.0 |
| 1500 2000 | 0.11 | 0.24 0.13 | 0.42 0.24 | 0.66 0.37 | 0.95 0.54 | 1.7 0.95 | 2.6 1.5 | 6.0 3.4 | 13.4 7.5 | 24.0 13.4 | 95.0 54.0 |
| 2500 |  |  | 0.15 | 0.24 | 0.34 | 0.61 | 0.95 | 2.2 | 4.8 | 8.6 | 34.0 |
| 3000 |  |  | 0.11 | 0.17 | 0.24 | 0.42 | 0.66 | 1.5 | 3.4 | 6.0 | 24.0 |
| 4000 |  |  | 0.06 | 0.09 | 0.13 | 0.24 | 0.37 | 0.84 | 1.9 | 3.4 | 13.4 |
| 5000 |  |  |  |  |  |  | 0.24 | 0.53 | 1.20 | 2.2 | 8.6 |
| 6000 |  |  |  |  |  |  | 0.16 | 0.37 | 0.84 | 1.5 | 6.0 |
| 7000 |  |  |  |  |  |  | 0.12 | 0.27 | 0.61 | I.I | $4 \cdot 4$ |

Austin, Jour. Wash. Acad. of Sci. 1, p. 190, 1911.

## TABLE 443.

## THE DIELECTRIC PROPERTIES OF NON-CONDUCTORS.

Phillips Thomas, J. Franklin Inst. 176, 283, 1913.

| Results of tests at unit area and unit thickness of dielectric. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| At 1000 cycles. | Mica. | Paper. | Celluloid. | Ice. |
| Max. breakdown volts per cm. | 1. $06 \times 10^{6}$ | $0.71 \times 10^{6}$ | $1.05 \times 10^{6}$ | . $011 \times 10^{6}$ |
| Specific induc. capacity . . . | 4.00 | 4.90 | 13.26 | 86.40 |
| Max. absorbable energy, watts-sec/ $\mathrm{cm}^{3}$ | o. 198 | -. 108 | 0.640 | . 00040 |
| $90^{\circ}$-angle of lead . . . . . . | $0^{\circ} 57^{\prime}$ | $2^{\circ} 10^{\prime}$ | $3^{\circ} 40^{\prime}$ | $13^{\circ} 39^{\prime}$ |
| Equiv. resistance ohms $/ \mathrm{cm}^{3} \times 10^{11}$ | 3.91 | 9.84 | 48.3 | 1400 |
| Conductivity per cm. cube $\times 10^{-10}$ | 2.56 | 1.02 | 0.207 | . 00722 |
| Percent change in cap. per cycle $\times 10^{+}$ | 2. 18 | 14.31 | 30.7 |  |
| Percent change in resistance per cycle | 0.258 | 0.146 | 0.106 | 0.127 |
| At 15 cycles. |  |  |  |  |
| Specific inductive capacity . . . . |  |  | 18.60 | 429.0 |
| Max. absorbable energy, watt-sec/ $\mathrm{cm}^{3}$. | 0.203 | 0.126 | 0.90 | 0.002 |
| Percent change in capacity per cycle | 0.00 | 0.306 | 1.74 | I. 59 |
| On direct current. |  |  |  |  |
| Conductivity per $\mathrm{cm}^{3}$ | $2.42 \times 10^{-17}$ | $2.27 \times 10^{-1 \%}$ | $71.5 \times 10^{-14}$ | $163.10^{-11}$ |

## Smithsonian Tables.

## MAGNETIC PROPERTIES.

Unit pole is a quantity of magnetism repelling another unit pole with a force of one dyne; $4 \pi$ lines of force radiate from it. $M$, pole strength; $4 \pi M$ lines of force radiate from pole of strength $M$.
$H$, field strength,$=$ no. of lines of force crossing unit area in normal direction; unit $=$ gauss $=$ one line per unit area.
$\mathbf{M}$, magnetic moment, $=M l$, where $l$ is length between poles of magnet.
$I$, intensity of magnetization or pole strength per unit area, $=\mathbf{M} / V=M / A$ where $A$ is cross section of uniformly magnetized pole face, and $V$ is the volume of the magnet. $4 \pi M / A=4 \pi I=$ no. lines of force leaving unit area of pole.
$J$, specific intensity of magnetism, $=I / \rho$ where $\rho=$ density, $\mathrm{g} / \mathrm{cm}^{3}$.
$\phi$, magnetic flux, $=4 \pi M+H A$ for magnet placed in field of strength $H$ (axis parallel to field). Unit, the maxwell.
$B$, flux density (magnetic) induction, $=\phi / A=4 \pi I+H$; unit the gauss, maxwell per cm .
$\mu$, magnetic permeability, $=B / H$. Strength of field in air-filled solenoid $=H=(4 \pi / 10) n i$ in gausses, $i$ in amperes, $n$, number of turns per cm length. If iron filled, induction increased, i.e., no. of lines of force per unit area, $B$, passing through coil is greater than $H ; \mu=B / H$.
$\kappa$, susceptibility; permeability relates to effect of iron core on magnetic field strength of coil; if effect be considered on iron core, which becomes a magnet of pole strength $M$ and intensity of magnetism $I$, then the ratio $I / H=(\mu-1) / 4 \pi$ is the magnetic susceptibility per unit volume and is a measure of the magnetizing effect of a magnetic field on the material placed in the field. $\mu=4 \pi \kappa+1$.
$\chi$, specific susceptibility (per unit mass) $=\kappa / \rho=J / H$.
$\chi_{\mathrm{A}}$, atomic susceptibility, $=\chi \times$ (atomic weight); $\chi_{\mathrm{M}}=$ molecular susceptibility .
$J_{\mathrm{A}}, J_{\mathrm{M}}$, similarly atomic and molecular intensity of magnetization.
Hysteresis is work done in taking $\mathrm{a} \mathrm{cm}^{3}$ of the magnetic material through a magnetic cycle $=\int H d I=(\mathrm{I} / 4 \pi) \int H d B$. Steinmetz's empirical formula gives a close approximation to the hysteresis loss; it is $a B^{1.6}$ where $B$ is the max. induction and $a$ is a constant (see Table 472). The retentivity $\left(B_{r}\right)$ is the value of $B$ when the magnetizing force is reduced to zero. The reversed field necessary to reduce the magnetism to zero is called the coercive force $\left(I I_{c}\right)$.

Ferromagnetic substances, $\mu$ very large, $\kappa$ very large: $\mathrm{Fe}, \mathrm{Ni}$, Co , Heusler's alloy $(\mathrm{Cu} 62.5$, Mn 23.5, Al 14. See Stephenson, Phys. Rev. 1910), magnetite and a few alloys of Mn. $\mu$ for Heusler's alloy, 90 to 100 for $B=2200$; for Si sheet steel 350 to 5300 .

Paramagnetic substances, $\mu>_{\mathrm{I}}$, very small but positive, $\kappa=10^{-3}$ to $10^{-6}$ : oxygen, especially at low temperatures, salts of $\mathrm{Fe}, \mathrm{Ni}, \mathrm{Mn}$, many metallic elements. (See Table 474.)

Diamagnetic substances, $\mu<\mathrm{I}, \kappa$ negative. Most diamagnetic substance known is $\mathrm{Bi},-\mathrm{I} 4$ $\times{ }^{10}{ }^{-6}$. (See Table 474.)

Paramagnetic substances show no retentivity or hysteresis effect. Susceptibility independent of field strength. The specific susceptibility for both para- and diamagnetic substances is independent of field strength.

For Hall effect (galvanomagnetic difference of potential), Ettinghausen effect (galvanomagnetic difference of temperature), Nernst effect (thermomagnetic difference of potential) and the Leduc effect (thermomagnetic difference of temperature), see Tables 487 and 488.

Magneto-strictive phenomena:
Joule effect: Mechanical change in length when specimen is subjected to a magretic field. With increasing field strength, iron and some iron alloys show first a small increment $\Delta l / l=$ ( 7 to 35 ) $\times 10^{-7}$, then a decrement, and for $I=1600, \Delta l / l$ may amount to $-(6$ to 8$) \times 10^{-6}$. Cast cobalt with increasing field first decreases, $\Delta l / l=-8 \times 10^{-6}, H=150$, then increases in length, $\Delta l / l=+5 \times 10^{-6}, H=2000$; annealed cobalt steadily contracts, $\Delta l / l=-25 \times 10^{-6}, H$ $=2000$. Ni rapidly then slowly contracts, $\Delta l / l=-30 \times 10^{-6}, H=100 ;-35 \times 10^{-6}, H=300$; $-36 \times 10^{-6}, H=2000$ (Williams, Phys. Rev. 34, 44, 1912). A transverse field generally gives a reciprocal effect.

Wiedemann effect: The lower end of a vertical wire, magnetized longitudinally, when a current is passed through it, if free, twists in a certain direction, depending upon circumstances (see Williams, Phys. Rev. 32, 281, 1911). A reciprocal effect is observed in that when a rod of soft iron, exposed to longitudinal magnetizing force, is twisted, its magnetism is reduced.

Villari effect; really a reciprocal Joule effect. The susceptibility of an iron wire is increased by stretching when the magnetism is below a certain value, but diminished when above that value.

This table and Table 456 below are taken from a paper by Dr. Hopkinson * on the magnetic properties of iron and steel. which is stated in the paper to have been 240. The maximum magnetization is not tabulated; but as stated in the by $4 \pi$. "Coercive force" is the magnetizing force required to reduce the magnetization to zero. The "demagprevious magnetization in the opposite direction to the "maximum induction" stated in the table. The "energy which, however, was only found to agree roughly with the results of experiment.


* Phil. Trans. Roy. Soc. vol. 176.


## PROPERTIES OF IRON AND STEEL.

The numbers in the columns headed "magnetic properties" give the results for the highest magnetizing force used, paper, it may be obtained by subtracting the magnetizing force ( 240 ) from the maximum induction and then dividing netizing force " is the magnetizing force which had to be applied in order to leave no residual magnetization after dissipated " was calculated from the formula:-Energy dissipated $=$ coercive force $\times$ maximum induction $\div \pi$

| $\begin{gathered} \text { No. } \\ \text { of } \\ \text { Test. } \end{gathered}$ | Description of specimen. | Temper. | Specificelectri-cal resis-tance. | Magnetic properties. |  |  |  | Energy dissipated per cycle. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Maximum induction. | Residual induction. | Coercive force. | Demagnetizive force. |  |
| 1 | Wrought iron : | Annealed | . 01378 | 18251 | 7248 | 2.30 | - | 13356 |
| 2 | Malleable cast iron . |  | . 03254 | 12408 | 7479 | 8.80 | - | 34742 |
| 3 | Gray cast iron . . | - | . 10560 | 10783 | 3928 | 3.80 | - | 13037 |
| 4 | Bessemer steel . |  | . 01050 | 18196 | 7860 | 2.96 | - | 17137 |
| 5 | Whitworth mild steel | Annealed | .oroso | 19840 | 7080 | 1.63 | - | 10289 |
| 6 |  |  | . 01446 | 18736 | 9840 | 6.73 | - | 40120 |
| 7 | " ${ }^{\text {c }}$ | Oil-hard- <br> ened | . 01390 | 18796 | 11040 | 1 I. 00 | - | 65786 |
| 8 | " ، | Annealed | . 01559 | 16120 | 10740 | 8.26 | - | 42366 |
| 9 | " " | $\left\{\begin{array}{l} \text { Oil-hard- } \\ \text { ened } \end{array}\right.$ | . 01695 | 16120 | 8736 | 19.38 | - | 9940 I |
| 10 | $\left.\begin{array}{l}\text { Hadfield's manganese } \\ \text { steel }\end{array}\right\}$ | ¢ | . 06554 | 310 | - | - |  | - |
| 11 | Manganese steel . | As forged | . 05368 | 4623 | 2202 | 23.50 | 37.13 | 34567 |
| 12 |  | Annealed | . 03928 | 10578 | 5848 | 33.86 | 46.10 | 113963 |
| 13 | " | $\left\{\begin{array}{l} \text { Oil-hard- } \\ \text { ened } \end{array}\right.$ | . 05556 | 4769 | 2158 | 27.64 | 40.29 | 41941 |
| 14 | " " . | As forged | . 06993 | 747 | - | - | - | - |
| 15 | " " . | Annealed | .06316 | 1985 | 540 | 24.50 | 50.39 | 15474 |
| 16 | " " | \{ Oil-hard) ened | . 07066 | 733 | - | - | - | - |
| 17 | Silicon steel | As forged | . 06163 | 15148 | 11073 | 9.49 | 12.60 | 45740 |
| 18 | " " . . | Annealed | .06185 | 14701 | 8149 | 7.80 | 10.74 | 36485 |
| 19 | " " | $\left\{\begin{array}{c} \text { Oil-hard- } \\ \text { ened } \end{array}\right.$ | . 06195 | 14696 | 8084 | 12.75 | 17.14 | 59619 |
| 20 | Chrome steel | As forged | . 02016 | 15778 | 9318 | 12.24 | 13.87 | 61439 |
| 21 | " " . . | Annealed | . 01942 | 14848 | 7570 | 8.98 | 12.24 | 42425 |
| 22 | " " | \{ Oil-hardened | . 02708 | 13960 | 8595 | 38.15 | 48.45 | 169455 |
| 23 | " " | As forged | . 01791 | 14680 | 7568 | 18.40 | 22.03 | 85944 |
| 24 | " " . . | Annealed | . 01849 | 13233 | 6489 | 15.40 | 19.79 | 64842 |
| 25 | " " . | \{ Oil-hard- | . 03035 | 12868 | 7891 | 40.80 | 56.70 | 167050 |
| 26 | Tungsten steel . | As forged | . 02249 | 15718 | IOI 44 | I 5.7 I | 17.75 | 78568 |
| 27 | " | Annealed (Hardened | . 02250 | 16498 | 11008 | 15.30 | 16.93 | SO3I 5 |
| 28 | " " | $\left\{\begin{array}{l}\text { in cold } \\ \text { water }\end{array}\right.$ | . 02274 | - | - | - | - | - |
| 29 | " " | $\left\{\begin{array}{c} \text { Hardened } \\ \text { in tepid } \\ \text { water } \end{array}\right.$ | . 02249 | 15610 | 9482 | 30.10 | 34.70 | 149500 |
| 30 | " " (French) | $\left\{\begin{array}{c} \text { Oil hard- } \\ \text { ened } \end{array}\right.$ | . 03604 | 14480 | 8643 | 47.07 | 64.46 | 216864 |
| 3 I | " | Very hard | . 04427 | 12133 | 68.8 | 51.20 | 70.69 | 197660 |
| 32 | Gray cast iron | - | . 11400 | 9148 | 3161 | 13.67 | 17.03 | 39789 |
| 33 | Mottled cast iron | - | . 06286 | 10546 | $510 S$ | 12.24 | - | 41072 |
| 34 | White " " | - | .05661 | $93+2$ | 5554 | 12.24 | 20.40 | 36383 |
| 35 | Spiegeleisen . | - | . 10520 | 385 | 77 | - | - | - |

Smithsonian Tables.

TABLE 446. - Magnotlo Proporties of Iron and Stool.

|  | Electro lytic Iron. | Good Cast Steel. | Poor Cast Steel. | Steel. | Cast Iron. | Electrical Sheets. |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  | Ordinary. | Silicon <br> Steel. |
| C | 0.024 | 0.044 | 0. 56 | 0.99 | 3.11 | 0.036 | 0.036 |
| Chemical composi- $\mathrm{Si}^{\text {chen }}$ | 0.004 | 0.004 | 0.18 | 0.10 | 3.27 | 0.330 | 3.90 |
|  | 0.008 | 0.40 | 0.29 | 0.40 | 0.56 | 0.260 | 0.090 |
| $\square$ | 0.008 | 0.044 | 0.076 | 0.04 | 1.05 | 0.040 | 0.009 |
| (S | 0.001 | 0.027 | 0.035 | 0.07 | 0.06 | 0.068 | 0.006 |
| Coercive force . . . $\{$ | $\begin{gathered} 2.83 \\ {[0.36]} \end{gathered}$ | $\begin{gathered} \mathrm{I} .5 \mathrm{I} \\ {[0.37]} \end{gathered}$ | $\begin{gathered} 7 \cdot 1 \\ (44 \cdot 3) \end{gathered}$ | $\begin{gathered} 16.7 \\ (52.4) \end{gathered}$ | $\begin{aligned} & 11.4 \\ & {[4.6]} \end{aligned}$ | [1.30] | [0.77] |
| Residual B . . . . \} | II 400 [10800] | 10600 [11000] | $\begin{aligned} & 10500 \\ & (10500) \end{aligned}$ | $\begin{aligned} & 13000 \\ & (7500) \end{aligned}$ | $\begin{gathered} 5100 \\ {[5350]} \end{gathered}$ | [9400] | [9850] |
| Maximum permeability $\{$ | $\begin{gathered} 1850 \\ {[14400]} \end{gathered}$ | $\begin{gathered} 3550 \\ {[14800]} \end{gathered}$ | $\begin{gathered} 700 \\ (170) \end{gathered}$ | $\begin{gathered} 375 \\ \text { (110) } \end{gathered}$ | $\begin{gathered} 240 \\ {[600]} \end{gathered}$ | [3270] | [6130] |
| B for $\mathrm{H}=150$. . . 2 | $\begin{gathered} 19200 \\ {[18900]} \end{gathered}$ | $\begin{gathered} 18800 \\ {[19100]} \end{gathered}$ | $\begin{gathered} 17400 \\ (15400) \end{gathered}$ | $\begin{gathered} 16700 \\ (11700) \end{gathered}$ | $\begin{gathered} 10400 \\ {[11000]} \end{gathered}$ | [18200] | [17550] |
| $4 \pi \mathrm{I}$ for saturation . $\{$ | $\begin{gathered} 21620 \\ {[21630]} \end{gathered}$ | $\begin{gathered} 21420 \\ {[21420]} \end{gathered}$ | $\begin{gathered} 20600 \\ (20200) \end{gathered}$ | $\begin{gathered} 19800 \\ (\mathrm{I} 8000) \end{gathered}$ | $\begin{gathered} 16400 \\ {[16800]} \end{gathered}$ | [20500] | [19260] |

E. Gumlich, Zs. für Electrochemie, 15, p. 599 ; 1909.

Brackets indicate annealing at $800^{\circ} \mathrm{C}$ in vacuum. Parentheses indicate hardening by quenching from cherry-red.
TABLE 447.- Cast Iron in Intense Fiolds.

| Soft Cast Iron. |  |  |  | Hard Cast Iron. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | B | I | $\mu$ | H | B | I | $\mu$ |
| 114 | 9950 | 782 | 87.3 | 142 | 7860 | 614 | 55.4 |
| 172 | 10800 | 846 | 62.8 | 254 | 9700 | 752 | 38.2 |
| 433 | 13900 | 1070 | 32.1 | 339 | 10850 | 836 | 30.6 |
| 744 | I 5750 | 1200 | 21.2 | 684 | 13050 | 983 | 19.1 |
| 1234 | 17300 | 1280 | 14.0 | 915 | 14050 | 1044 | 15.4 |
| 1820 | 18170 | 1300 | 10.0 | 1570 | 15900 | 1138 | 10.1 |
| 12700 | 31100 | 1465 | 2.5 | 2020 | 16800 | 1176 | 8.3 |
| 13550 | 32100 | 1475 | 2.4 | 10900 | 26540 | 1245 | 2.4 |
| 13800 | 32500 | 1488 | 2.4 | 13200 | 28600 | 1226 | 2.2 |
| 15100 | 33650 | 1472 | 2.2 | 14800 | 30200 | 1226 | 2.0 |

B. O. Peirce, Proc. Am. Acad. 44, 1909.

TABLE 448. - Corrections for Ring Specimens.
In the case of ring specimens, the average magnetizing force is not the value at the mean radius, the ratio of the two being given in the table. The flux density consequently is not uniform, and the measured hysteresis is less than it would be for a uniform distribution. This ratio is also given for the case of constant permeability, the values being applicable for magnetizations in the neighborhood of the maximum permeability. For higher magnetizations the flux density is more uniform, for lower it is less, and the correction greater.

| Ratio of Radial Width to Diameter of Ring. | Ratio of Average H to H at Mean Radius. |  | Ratio of Hysteresis for Uniform Distribution to Actual Hysteresis. |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Rectangular Cross-section. | Circular <br> Cross-section. | Rectangular Cross-section. | Circular Cross-section. |
| $1 / 2$ | 1.0986 | 1.0718 | 1.112 | 1.084 |
| $1 / 3$ | 1.0397 | 1.0294 | 1.045 | 1.033 |
| 1/4 | 1.0216 | 1.0162 | 1.024 | 1.018 |
| I/ 5 | 1.0137 | 1.0102 | 1.015 | 1.011 |
| 1/6 | 1.0094 | 1.0070 | 1.010 | 1.008 |
| $1 / 7$ | 1.0069 | 1.0052 | 1.008 | 1.006 |
| $1 / 8$ | 1.0052 | 1.0040 | 1.006 | 1.004 |
| $1 / 10$ | 1.0033 | 1.0025 | 1.003 | 1.002 |
| $1 / 19$ | 1.0009 | 1.0007 | 1.001 | 1.001 |

M. G. Lloyd, Bull. Bur. Standards, 5, p. 435; 1908.

## MAGNETIC PROPERTIES OF IRONS AND STEELS.

TABLE 449. - Magnetic Properties of Various Types of Iron and Steel.
From tests made at the Bureau of Standards. $B$ and $H$ are measured in cgs units.

| Values of $B$. |  | 2000 | 4000 | 6000 | 8000 | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Annealed Norway iron | H | . 81 | 1.15 | 1.60 | 2.18 | 3.06 | 4.45 | 7.25 | 23.5 | 116. | - |
|  | $\mu$ | 2470 | 3480 | 3750 | 3670 | 3270 | 2700 | 1930 | 680 | 150 | - |
| Cast semi-steel. . . . . | H | 2.00 | 2.90 | 4.30 | 6.46 | 9.82 | 15.1 | 24.9 | 50.5 | 135. | 325. |
|  | $\mu$ | 1000 | 1380 | 1400 | 1240 | 1020 | 795 | 563 | 317 | 133 | 62. |
| Machinery steel.. . . . . | H | 5.0 | 8.8 | 13.1 | 18.6 | 25.8 | 35.8 | 50.5 | 76.0 | 142. | - |
|  | $\mu$ | 400 | 455 | 460 | 430 | 390 | 340 | 280 | 210 | 127 |  |

TABLE 450. - Magnetic Properties of a Specimen of Very Pure Iron ( $\mathbf{0}$.
From tests at the Bureau of Standards. $B$ and $H$ are measured in cgs units.


TABLE 451. - Magnetic Properties of Electrical Sheets.
From tests at the Bureau of Standards. $B$ and $H$ are measured in cgs units.

| Values of $B$ |  | 2000 | 4000 | 6000 | 8000 | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: | :---: |
| Dynamo steel . . . . . . | H | 1.00 | 1.10 | 1.43 | 2.00 | 3.10 | 4.95 | 9.20 | 34.0 | 114. | - |
|  | $\mu$ | 2000 | 3640 | 4200 | 4000 | 3220 | 2420 | 1520 | 470 | 158 | - |
| $\left.\begin{array}{c}\text { Ordinary trans- } \\ \text { former steel }\end{array}\right\}$ | H | .60 | .87 | 1.10 | 1.48 | 2.28 | 3.85 | 10.9 | 43.0 | 149. | - |
| $\left.\begin{array}{l}\text { High silicon trans- } \\ \text { former steel }\end{array}\right\}$ | $\mu$ | 3340 | 4600 | 5450 | 5400 | 4380 | 3120 | 1280 | 372 | 12 I | - |

Smithsonian Tables.

TABLE 452. - Magnetic Properties of Two Types of American Magnet Steel.
From tests at the Bureau of Standards. $B$ and $H$ are measured in cgs units.

| Values of $B$ |  | 2000 | 4000 | 6000 | 8000 | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tungsten steel. | $\Pi$ $\mu$ | 35.0 57 | 53.3 75 | 63.3 95 | 72.0 111 | 83.4 120 | 109 110 | 200 70 | 二 | - | - |
| Chrome steel. . | $\stackrel{H}{\mu}$ | 34.5 58 | 49.0 82 | 63.5 95 | 88.4 91 | 143 70 | 270 45 | 二 | - | - | - |

> Percentage composition: Tungsten stel, C 0.67 W 5.1 Cr 2.09 Si 0.25 Chrome steel, C 0.8 I W 0.96 Mn 0.38 Si 0.26
> Tungsten steel: $H_{\max }^{200} \quad B_{\max } 1_{4} 4,000 \quad$ Chrome steel: $H_{\max }{ }_{200} \quad B_{\max } 11,050$

TABLE 453. - Magnetic Properties of a Ferro-Cobalt Alloy, Fe $\mathrm{F}_{2} \mathrm{Co}$ (35\% Cobalt).
From tests at the Bureau of Standards. $B$ and $I I$ are measured in cgs units.

| Values of $B$ |  | 2000 | 4000 | 6000 | 8000 | 10,000 | 12,000 | 14,000 | 16,000 | 18,000 | 20,000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| As received. | H | 3.10 | 4.28 | 5.50 | 7.17 | 9.65 | 13.4 | 19.1 | 27.3 | 40.0 | 65.0 |
|  | $\mu$ | 645 | 935 | 1090 | III5 | 1040 | 900 | 730 | 590 | 450 | 310 |
| Annealed at | H | 3.00 | 4.11 | 5.05 | 6.45 | 8.40 | 11.3 | 15.4 | 21.9 | 31.7 | 50.6 |
| $1000^{\circ} \mathrm{C}$ | $\mu$ | 670 | 970 | 1190 | 1240 | 1190 | 1060 | 910 | 730 | 570 | 400 |
| Quenched ${ }^{\circ}$, | II | 10.8 | 13.8 | 19.1 | 28.7 | 43.4 | 65.8 | 104 | 163 | 262 | - |
| from $1000^{\circ} \mathrm{C}$ | $\mu$ | 185 | 290 | 314 | 279 | 230 | 182 | 135 | 98 | 69 | - |
| As receivedAnnealed at $1000^{\circ} \mathrm{C}$Quenched from $1000^{\circ} \mathrm{C}$$B \max \left\{\begin{array}{l}15,000 \\ 15,000 \\ 15,000\end{array}\right.$ |  |  |  |  |  | $\Pi$ max $\{$ | $B_{r}\left\{\begin{array}{l}7750 \\ 7460 \\ 8240\end{array}\right.$ |  | $H_{c}\left\{\begin{array}{c}3.79 \\ 3.95 \\ 14.3\end{array}\right.$ |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |

TABLE 454. - Magnetic Properties of a Ring Sample of Transformer Steel in Very Weak Fields.

From tests made at the Bureau of Standards. $\quad B$ and $H$ are measured in cgs units.

| Values of $H$ | 0.001 | 0.002 | 0.004 | 0.006 | 0.008 | 0.010 | 0.012 | 0.014 | 0.018 | 0.020 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Values of B | 0.45 | 0.91 | 1.85 | 2.87 | 3.94 | 5.05 | 6.30 | 7.51 | 10.19 | 11.64 |
| Values of $\mu$. | 450 | 455 | 462 | 478 | 492 | 505 | 525 | 536 | 566 | 582 |

## TABLE 455. - Magnetic Properties of Iron in Very Weak Fields.

The effect of very small magnetizing forces has been studied by C. Baur and by Lord Rayleigh. The following short table is taken from Baur's paper, and is taken by him to indicate that the susceptibility is finite for zero values of $H$ and for a finite range increases in simple proportion to $H$. He gives the formula $k=15+100 H$, or $I=15 H$ $+100 H^{2}$ The experiments, were made on an annealed ring of round bar 1.013 cms radius, the ring having a radius of 9.432 cms . Lord Rayleigh's results for an iron wire not annealed give $k=6.4+5.1 H H$, or $I=6.4 H+5 . H^{2}{ }^{2}$. The forces were reduced as low as 0.00004 cgs , the relation of $k$ to $I$ remaining constant.

| First experiment. |  |  | Second experiment. |  |
| :---: | :---: | :---: | :---: | :---: |
| H |  | $I$ | II | $k$ |
| . 01580 | 16.46 | 2.63 | . 0130 | 15.50 |
| . 0308 I | 17.65 | 5.47 | . 0847 | 18.38 |
| . 07083 | 23.00 | 16.33 | . 0946 | 20.49 |
| . 13188 | 28.90 | 38.15 | . 1864 | 25.07 |
| .23011 .38422 | 39.81 58.56 | 91.56 224.87 | . 2903 | 32.40 |
| . 3842 | 50.56 | 224.87 | -3397 | 35.20 |

[^53]
## PERMEABILITY OF SOME OF THE SPECIMENS IN TABLE 445.

## TABLE 456.

This table gives the induction and the permeability for different values of the magnetizing force of some of the speci mens in Table 445. The specimen numbers refer to the same table. The numbers in this table have been taken from the curves given by Dr. Hopkinson, and may therefore be slightly in error; they are the mean values for rising and falling magnetizations.

| Magnetizing force. H | Specimen 1 (iron). |  | Specimen 8 (annealed steel). |  | Specimen 9 (same as 8 tempered). |  | Specimen 3 <br> (cast iron). |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $B$ | $\mu$ | $B$ | $\mu$ | $B$ | $\mu$ | $B$ | $\mu$ |
| I | - | - | - | - | - | - | 265 | 265 |
| 2 | 200 | 100 | - | - | - | - | 700 | 350 |
| 3 | - | - | - | - | - | - | 1625 | 542 |
| 5 | 10050 | 2010 | 1525 | 300 | 750 | 150 | 3000 | 600 |
| 10 | 12550 | 1255 | 9000 | 900 | 1650 | 165 | 5000 | 500 |
| 20 | 14550 | 727 | I 1500 | 575 | 5875 | 294 | 6000 | 300 |
| - 30 | 15200 | 507 | 12650 | 422 | 9875 | 329 | 6500 | 217 |
| 40 | 15800 | 395 | 13300 | 332 | 11600 | 290 | 7100 | 177 |
| 50 | 16000 | 320 | 13800 | 276 | 12000 | 240 | 7350 | 149 |
| 70 | 16360 | 234 | 14350 | 205 | 13400 | 191 | 7900 | 113 |
| 100 | 16800 | 168 | 14900 | 149 | 14500 | 145 | 8500 | 85 |
| 150 | 17400 | 116 | 15700 | 105 | 15800 | 105 | 9500 | 63 |
| 200 | 17950 | 90 | 16100 | 80 | 16100 | 80 | IOI90 | 5 I |

$T_{\text {ables.457-8, 463-5 }}$ give the results of some experiments by Du Bois,* on the magnetic properties of iron, nickel, and cobalt under strong magnetizing forces. The experiments were made on ovoids of the metals 18 centimeters long and o. 6 centimeters diameter. The specimens were as follows: (1) Soft Swedish iron carefully annealed and having a density 7.82 . (2) Hard English cast steel yellow tempered at $230^{\circ} \mathrm{C}$.; density 7.78 . (3) Hard drawn best nickel containing $99 \% \mathrm{Ni}$ with some $\mathrm{SiO}_{2}$ and traces of Fe and Cu ; density 8.82. (4) Cast cobalt giving the following composition on analysis: $\mathrm{Co}=93.1, \mathrm{Ni}=5.8, \mathrm{Fe}=0.8, \mathrm{Cu}=0.2, \mathrm{Si}=0.1$, and $\mathrm{C}=0.3$. The specimen was very brittle and broke in the lathe, and hence contained a surfaced joint held together by clamps during the experiment. Referring to the columns, $H, B$, and $\mu$ have the same meaning as in the other tables, $S$ is the magnetic moment per gram, and $I$ the magnetic moment per cubic centimeter. $H$ and $S$ are taken from the curves published by Du Bois; the others have been calculated using the densities given.

MAGNETIC PROPERTIES OF SOFT IRON AT $0^{\circ}$ AND $100^{\circ} \mathrm{C}$.
TABLE 457.

| Soft iron at $\mathrm{o}^{\circ} \mathrm{C}$. |  |  |  |  | Soft iron at $100^{\circ} \mathrm{C}$. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | $S$ | $I$ | $B$ | $\mu$ | H | $S$ | I | B | $\mu$ |
| 100 | 180.0 | 1408 | 17790 | 177.9 | 100 | 180.0 | 1402 | 17720 | 177.2 |
| 200 | 194.5 | 1521 | 19310 | 96.5 | 200 | 194.0 | 1511 | 19190 | 96.0 |
| 400 | 208.0 | 1627 | 20830 | 52.1 | 400 | 207.0 | 1613 | 20660 | 51.6 |
| 700 | 215.5 | 1685 | 21870 | 31.2 | 700 | 213.4 | 1663 | 21590 | 29.8 |
| 1000 | 218.0 | 1705 | 22420 | 22.4 | 1000 | 215.0 | 1674 | 22040 | 21.0 |
| 1200 | 218.5 | 1709 | 22670 | 18.9 | 1200 | 215.5 | 1679 | 22300 | 18.6 |

MAGNETIC PROPERTIES OF STEEL AT $0^{\circ}$ AND $100^{\circ} \mathrm{C}$.
TABLE 458.

| Steel at $0^{\circ} \mathrm{C}$. |  |  |  |  | Steel at $100^{\circ} \mathrm{C}$. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | $S$ | $I$ | $B$ | $\mu$ | H | $S$ | $I$ | B | $\mu$ |
| 100 | 165.0 | 1283 | 16240 | 162.4 | 100 | 165.0 | 1278 | 16170 | 161.7 |
| 200 | 181.0 | 1408 | 17900 | 89.5 | 200 | 180.0 | 1395 | 17730 | 85.6 |
| 400 | 193.0 | 1500 | 19250 | 48.1 | 400 | 191.0 | 1480 | 19000 | 47.5 |
| 700 | 199.5 | 1552 | 20210 | 28.9 | 700 | 197.0 | 1527 | 19890 | 2 S .4 |
| 1000 | 203.5 | 1583 | 20900 | 20.9 | 1000 | 199.0 | 1543 | 20380 | 20.4 |
| 1200 | 205.0 | I 595 | 21240 | 17.7 | 1500 | 203.0 | 1573 | 21270 | 14.2 |
| $3750 \dagger$ | 212.0 | 1650 | 24470 | 6.5 | 3000 | 205.5 | 1593 | 23020 | $7 \cdot 7$ |
|  |  |  |  |  | 5000 | 208.0 | 1612 | 25260 | 5.1 |

* "Phil. Mag." 5 series, vol. xxix.
$\dagger$ The results in this and the other tables for forces above 1200 were not obtained from the ovoids above referred to, but from a small piece of the metal provided with a polished mirror surface and placed, with its polished face normal to the lines of force, between the poles of a powerful electromagnet. The induction was then inferred from the rotation of the plane of a polarized ray of red light reflected normally from the surface. (See Kerr's "Constants," p. 33 r.)


## MAGNETISM AND TEMPERATURE.

## TABLE 459. - Magnetism and Temperature, Critical Temperature.

The magnetic moment of a magnet diminishes with increasing temperature. Different specimens vary widely. In the formula $M t / M_{0}=(\mathrm{r}-a t)$ the value of $a$ may range from .0003 to .001 (see Tables 457-458). The effect on the permeability with weak fields may at first be an increase. There is a critical temperature (Curie point) above which the permeability is very small (paramagnetic?). Diamagnetic susceptibility does not change with the temperature. Paramagnetic susceptibility decreases with increase in temperature. This and the succeeding two tables are taken from Dushman, "Theories of Magnetism," General Electric Review, 1916.

\begin{tabular}{|c|c|c|c|c|c|}
\hline Substance. \& Critical temperature, Curie point. \& Reference. \& Substance. \& Critical temperature, Curie point. \& Reference. <br>
\hline Iron, $\boldsymbol{a}$ form. \& $756^{\circ} \mathrm{C}$ \& 1 \& MnBi . \& 360 to $380^{\circ} \mathrm{C}$ \& <br>
\hline " ${ }^{\beta}$ 仿 form. \& 920 \& 1 \& MnSb. \& 310 " 320 \& 4 <br>
\hline $\xrightarrow{4 \%} \boldsymbol{\gamma}$ form.... \& 1280
536 \& 1 \& MnAs \& 45"، 50 \& 4 <br>
\hline Magnetite ( ${ }^{\text {a }}$ \& 589 \& 1 \& Heusler alloy \& 18 $\begin{array}{r}25 \\ 310\end{array}$ \& 4
5 <br>
\hline " \& 555 \& 3 \& Nickel. \& 340 \& 1 <br>
\hline Cobalt-ferrite ( $\mathrm{Fe}_{2} \mathrm{Co}$ ) \& 520 \& 3 \& \& 376

1075 \& 6 <br>
\hline \& \& \& \& 1075 \& 6 <br>
\hline
\end{tabular}

References: (1) P. Curie; (2) see Williams, Electron Theory of Magnetism, quoted from Weiss; (3) du Bois, Tr. Far. Soc. 8, 211 , 1912; (4) Hilpert, Tr. Far. Soc. 8, 207, 1912; (5) Gumaer; (6) Stifler, Phys. Rev. 33, 263, 191r.

## TABLE 460. - Temperature Variation for Paramagnetic Substances.

The relation deduced by Curie that $\chi=C / T$, where $C$ is a constant and $T$ the absolute temperature, holds for some paramagnetic substances over the ranges given in the following table. Many paramagnetic substances do not obey the law (Honda and Owen, Ann. d. Phys. 32, 1027, 1910; 37, 657, 1912). See the following table.

| Substance. | $\mathrm{C} \times{ }^{10}{ }^{8}$ | Range ${ }^{\circ} \mathrm{C}$ | Reference. | Substance. | C $\times 1{ }^{10}$ | Range ${ }^{\circ} \mathrm{C}$ | Reference. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Oxygen.. | 33,700 | $20^{\circ}$ to $450^{\circ} \mathrm{C}$ | 1 | Gadolinium sulphate. | 21,000 | $-259^{\circ}$ to 17 | 2 |
| Air....... | 7,830 | - - | 1 | Ferrous sulphate. | 11,000 | -259 " 17 | 2 |
| Palladium. | 1,520 | 20 to 1370 | 1 | Ferric sulphate. . ${ }^{\text {a }}$ | 17,000 | -208" 17 | 3 |
| Magnetite | 28,000 | 850 " 1360 | 1 | Manganese chloride. | 30,000 | -258" 17 | 3 |
| Cast iron. | 38,500 | 850 " 1267 | 1 |  |  |  |  |

References: (1) P. Curie, London Electrician, 66, 500, 1912; see also Du Bois, Rap. du Cong. 2, 460, 1900; (2) Perrier, Onnes, Tables annuelles, 3, 288, 1914; (3) Oosterhuis, Onnes, l.c. 2, 389, 1913.

## TABLE 461. - Temperature Effect on Susceptibility of Diamagnetic Elements.

No effect:

$$
\begin{aligned}
& \text { B Cryst. } 400 \text { to } 1200^{\circ} \\
& \text { C Diamond, +r70 to } 200^{\circ} \\
& \text { C "Sugar" carbon } \\
& \text { Si Cryst. }
\end{aligned}
$$

$$
\mathrm{P} \text { white }
$$

$$
\stackrel{\text { Pr }}{\mathrm{S}} \text { Cryst.; ppt. }
$$

$\mathrm{Zn}-170$ to $300^{\circ}$
$\mathrm{Zn}-170$ to $300^{\circ}$
Se -
$\mathrm{Sb}-170$ to $50^{\circ}$
Br -170 to $18^{\circ}$
Zr Cryst. -170 to $500^{\circ}$
$\mathrm{Cd}-170$ to $300^{\circ}$
Cs and Au
$\mathrm{Pb}_{\mathrm{Pb}} \mathbf{3 2 7}$ to $600^{\circ}$ to $350^{\circ}$
Increase with rise in Temperature:
${ }_{B}^{\mathrm{Be}}$ Cryst. $\overline{+170}$ to $400^{\circ}$
C Diamond, 200 to $1200^{\circ}$
I -170 to $114^{\circ}$

## Ag

$\mathrm{Hg}-170$ to $-30^{\circ}$

Decrease with rise in Temperature:
C Amorphous
$\mathrm{Gd}-179$ to $30^{\circ}$
In -170 to $150^{\circ}$
${ }_{\mathrm{C}}^{\mathrm{C}}$ Ceylon graphite
$\mathrm{Ge}-170$ to $900^{\circ}$
$\mathrm{Sb}+50$ to $+631^{\circ}$
Tl -
$\mathrm{Cu}+300$ to $700^{\circ}$
Zr 500 to $1200^{\circ}$
Cd 300 to $700^{\circ}$
I +114 to $+200^{\circ}$
$\mathrm{Pb}-170$ to $327^{\circ}$
$\mathrm{Bi}-170$ to $268^{\circ}$

TABLE 462. - Temperature Effects on Susceptibility of Paramagnetic Elements.
No effect:

| $\mathrm{Li} \quad-$ | $\mathrm{K}-170$ to $150^{\circ}$ |
| :--- | :--- |
| $\mathrm{Na}-170$ to $97^{\circ}$ | $\mathrm{Ca}-170$ to $18^{\circ}$ |
| Al 657 to $1100^{\circ}$ | $\mathrm{V}-170$ to $500^{\circ}$ |

$\mathrm{Cr}-170$ to $500^{\circ}$
$\mathrm{Mn}-170$ to $250^{\circ}$
W -
Al 657 to $1100^{\circ}$
V - 170 to $500^{\circ}$
Rb - 170 to ${ }^{250^{\circ}}$
Os -
Increase with rise in Temperature:
Ti
$\mathrm{V} \quad-40$ to $1100^{\circ}$
500
Cr 500 to $1100^{\circ}$
$\mathrm{Ru}+550$ to $1200^{\circ}$
$\mathrm{Ba}-170$ to $18^{\circ}$
Mo - 170 to $1200^{\circ}$
Rh Ir and Th

## Decrease with rise in Temperature:

| (0) | $\mathrm{Ti}-180$ to $-40^{\circ}$ | Ni 350 to $800^{\circ}$ | Pd and Ta |
| :---: | :---: | :---: | :---: |
| As -170 to $657^{\circ}$ | Mn 250 to $1015{ }^{\circ}$ | Co above $1150^{\circ}$ | Pt and U |
| Mg | $(\mathrm{Fe})$ | Cb -170 to $400^{\circ}$ | Rare earth metals |

Tables 46 I and 462 are due to Honda and Owen; for reference, see preceding table.

MAGNETIC PROPERTIES OF METALS.

TABLE 463. - Cobalt at $100^{\circ} \mathrm{O}$.

| H | $S$ | $I$ | $B$ | $\mu$ |
| :---: | :---: | :---: | :---: | :---: |
| 200 | 106 | 848 | 10850 | $54 \cdot 2$ |
| 300 | 116 | 928 | 11960 | 39.9 |
| 500 | 127 | 1016 | 13260 | 26.5 |
| 700 | 131 | 1048 | 13870 | 19.8 |
| 1000 | 134 | 1076 | 14520 | 14.5 |
| I 500 | 138 | 1104 | 15380 | 10.3 |
| 2500 | 143 | 1144 | 16870 | 6.7 |
| 4000 | 145 | 1164 | 18630 | 4.7 |
| 6000 | 147 | 1176 | 20780 | 3.5 |
| 9000 | 149 | 1192 | 23980 | 2.6 |
| At $0^{\circ} \mathrm{C}$. this specimen gave the following results : |  |  |  |  |
| 7900 | 154 | 1232 | 23380 | 3.0 |

TABLE 464. - Nickel at $100^{\circ} 0$.

| H | $S$ | $I$ | $B$ | $\mu$ |
| :---: | :---: | :---: | :---: | :---: |
| 100 | 35.0 | 309 | 3980 | 39.8 |
| 200 | 43.0 | 380 | 4966 | 24.8 |
| 300 | 46.0 | 406 | 5399 | 18.0 |
| 500 | 50.0 | 441 | 6043 | 12.1 |
| 700 | 51.5 | 454 | 6409 | 9.1 |
| 1000 | 53.0 | 468 | 6875 | 6.9 |
| 1500 | 56.0 | 494 | 7707 | 5.1 |
| 2500 | 58.4 | 515 | 8973 | 3.6 |
| 4000 | 59.0 | 520 | 10540 | 2.6 |
| 6000 | 59.2 | 522 | 12561 | 2.1 |
| 9000 | 59.4 | 524 | 15585 | 1.7 |
| 12000 | 59.6 | 526 | 18606 |  |
| At $0^{\circ} \mathrm{C}$. this specimen gave the following results : |  |  |  |  |
| 12300 | 67.5 | 595 | 19782 | 1.6 |

## TABLE 465. - Magnetite.

The following results are given by Du Bois * for a specimen of magnetite.

| H | $I$ | $B$ | $\mu$ |
| :---: | :---: | :---: | :---: |
| 500 | 325 | 8361 | 16.7 |
| 1000 | 345 | 90.11 | 9.0 |
| 2000 | 350 | 1008.4 | 5.0 |
| 12000 | 350 | 20084 | I. 7 |

Professor Ewing has investigated the effects of very intense fields on the induction in iron and other metals. $\dagger$ The results show that the intensity of magnetization does not increase much in iron after the field has reached an intensity of rooo c. g. s. units, the increase of induction above this being almost the same as if the iron were not there, that is to say, $d B / d H$ is practically unity. For hard steels, and particularly manganese steels, much higher forces are required to produce saturation. Hadfield's manganese steel seems to have nearly constant susceptibility up to a magnetizing force of 10,000 . The following tables, taken from Ewing's papers, illustrate the effects of strong fields on iron and steel. The results for nickel and cobalt do not differ greatly from those given above.

TABLE 466.-Lowmoor Wrought Iron.

| $H$ | $I$ | $B$ | $\mu$ |
| ---: | :---: | :---: | :---: |
| 3080 | 1680 | 24130 | 7.83 |
| 6450 | 1740 | 28300 | 4.39 |
| 10450 | 1730 | 32250 | 3.09 |
| 13600 | 1720 | 35200 | 2.59 |
| 16390 | 1630 | 36810 | 2.25 |
| 18760 | 1680 | 39900 | 2.13 |
| 18980 | 1730 | 40730 | 2.15 |

TABLE 467. - Vicker's Tool Steel.

| $H$ | $I$ | $B$ | $\mu$ |
| :---: | :---: | :---: | :---: |
| 6210 | 1530 | 25480 | 4.10 |
| 9970 | 15570 | 29650 | 2.97 |
| 12120 | 1550 | 31620 | 2.60 |
| 14660 | 1580 | 34550 | 2.36 |
| 15530 | 1610 | 35820 | 2.3 I |

TABLE 468. - Hadfield's Manganese Steel.

|  | $I$ | $B$ | $\mu$ |
| :---: | ---: | ---: | ---: |
|  | 1930 | 55 | 2620 |
| 2380 | 84 | 3430 | 1.36 |
| 3350 | 84 | 4400 | 1.31 |
| 5920 | 111 | 7310 | 1.24 |
| 6620 | 187 | 8970 | 1.35 |
| 7890 | 191 | 10290 | 1.30 |
| 8390 | 263 | 11690 | 1.39 |
| 9810 | 396 | 14790 | 1.51 |

TABLE 469. - Saturation Values for Steels of Different Kinds.

|  |  | H | I | $B$ | $\mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | Bessemer steel containing about 0.4 per cent carbon | 17600 | 1770 | 39880 | 2.27 |
| 2 | Siemens-Marten steel containing about 0.5 per cent carbon | 18000 | 1660 | 38860 | 2.16 |
| 3 | Crucible steel for making chisels, containing about 0.6 per cent carbon | 19470 | 148 So | 38010 | 1.95 |
| 4 | Finer quality of 3 containing about 0.8 per cent carbon . | 18330 | 1580 | 38190 | 2.08 |
| 4 | Crucible steel containing I per cent carbon . . . . . | $19620$ | 14.40 | 37690 | 1.92 2.07 |
| 6 | Whitworth's fluid-compressed steel . . . | 18700 | 1590 | 38710 | 2.07 |

## TABLE 470.

$H=$ true intensity o. magnetizing field, $H^{\prime}=$ intensity of applied field, $I=\mathrm{in}$ tensity of magnetization, $H=H^{\prime}-N /$.

Shuddemagen says: The demagnetizing factor is not a constant, falling for highest values of $/$ to about $1 / 7$ the value when unsaturated; for values of $B$ ( $=H+4 \pi I$ ) less than $10000, N$ is approximately constant; using a solenoid wound on an insulating tube, or a tube of split brass, the reversal method gives values for $N$ which are considerably lower than those given by the step-by-step method; if the solenoid is wound on a thick brass tube, the two methods practically agree.

| RatioofLengthtoDiameter. | Values of $N \times 1{ }^{4}$. |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ellipsoid. | Cylinder. |  |  |  |  |  |
|  |  | Uniform <br> Magneti- <br> zation. | Magnetometric Method <br> (Mann). | Ballistic Step Method. |  |  |  |
|  |  |  |  | Dubois. | Shuddemagen for Range of Practical Constancy. |  |  |
|  |  |  |  | Diameter. |  |  |  |
|  |  |  |  | 0.158 cm . | 0.3175 cm . | 1.111 cm . | 1.905 cm. |
| 5 | 7015 | - | 6800 |  |  |  |  |
| 10 | 2549 | 630 | 2550 | 2160 | - | - | 1960 |
| 15 | 1350 | 280 | 1400 | 1206 | - | - | 1075 |
|  | 848 | 160 | 898 | 775 | $\overline{-}$ | - | 671 |
| 30 | 432 | 70 | 460 | 393 | 388 | 350 | 343 |
| 40 | 266 | 39 | 274 | 238 | 234 | 212 | 209 |
| 50 | 181 | 25 | 182 | 162 | 160 | 145 | 149 |
| 60 | 132 | 18 | 131 | 118 | 116 | 106 | 106 |
| 70 80 | 101 | ${ }^{1} 3.8$ | 99 78 | 89 69 | 88 69 | 66 | 63 |
| 90 | 65 | 7.8 | 63 | 55 | 56 | 66 | 63 |
| 100 | 54 | 6.3 | 51.8 | 45 | 46 | 41 | 4 I |
| 150 | 26 | 2.8 | 25.1 | 20 | 23 | 21 | 21 |
| 200 | 16 | 1. 57 | 15.2 | 11 | 12.5 | 11 | II |
| 300 | 7.5 | 0.70 | 7.5 | 5.0 |  |  |  |
| 400 | 4.5 | 0.39 | - | 2.8 |  |  |  |

C. R. Mann, Physical Review, 3, p. 359; 1896.
H. DuBois, Wied. Ann. 7, p. 942 ; 1902.
C. L. B. Shuddemagen, Proc. Am. Acad. Arts and Sci. 43, p. 185, 1907 (Bibliography).

TABLE 471.
Shuddemagen also gives the following, where $B$ is determined by the step method and $H=H^{\prime}-K B$.

| Ratio of Length to <br> Diameter. | Values of $\mathrm{K} \times 1 \mathrm{o}^{4}$. |  |
| :---: | :---: | :---: |
|  | Diameter 0.3175 cm . | Diameter <br> 1.1 to 2.0 cm . |
| 15 | - | 85.2 |
| 20 | - | 53.3 |
| 25 | - | 36.6 |
| 30 | 30.9 | 27.3 |
| 40 | 18.6 | 16.6 |
| 50 | 12.7 | 11.6 |
| 60 | 9.25 | 8.45 |
| 80 | $5 \cdot 5$ | 5.05 |
| 100 | 3.66 | 3.26 |
| 150 | I. 83 | 1.67 |

## DISSIPATION OF ENERGY IN THE CYCLIC MAGNETIZATION OF VARIOUS SUBSTANCES.

C. P. Steinmetz concludes from his experiments* that the dissipation of energy due to kysteresis in magnetic metals can be expressed by the formula $e=a B^{1.6}$, where $e$ is the energy dissipated and $a$ a constant. He also concludes that the dissipation is the same for the same range of induction, no matter what the absolute value of the terminal inductions may be. His experiments show this to be nearly true when the induction does not exceed $\pm 15000 \mathrm{c} . \mathrm{g} . \mathrm{s}$. units per sq. cm. It is possible that, if metallic induction only be taken, this may be true up to saturation; but it is not likely to be found to hold for total inductions much above the saturation value of the metal. The law of variation of dissipation with induction range in the cycle, stated in the above formula, is also subject to verification. $\dagger$

## Values of Constant a.

The following table gives the values of the constant $a$ as found by Steinmetz for a number of different specimens. The data are taken from his second paper.

| Number of specimen. | Kind of material. | Description of specimen. | Value of a. |
| :---: | :---: | :---: | :---: |
| 1 | ${ }_{\text {Iron }}$. . | Norway iron . . . . . . . . | . 00227 |
| 3 |  | Wrought bar <br> Commercial ferrotype plate | . 00326 |
|  | " . . |  | . 00548 |
| 3 | " . . | Annealed " " | . 00458 |
| 5 6 | " | Thin tin plate . ${ }^{\text {a }}$ | . 00286 |
| 6 | Steel | Medium thickness tin plate | .00425 |
| 8 | Steel. | Soft galvanized wire - . | .00349 |
| 9 |  | Soft annealed cast steel . | . 00457 |
| 10 |  | Very soft annealed cast steel . | .003I8 |
| 11 |  | Same as 8 tempered in cold water . | . 02792 |
| 12 |  | Tool steel glass hard tempered in water | . 07476 |
| 13 |  | " " ${ }^{\text {" }}$ tempered in oil | . 02670 |
| 14 | " . . | (Same as 12, 13, and 14, after having been subjected) | (.01899 |
| 15 | " . . $\}$ | $\left\{\begin{array}{l}\text { to an alternating m. m. f. of from } 4000 \text { to } 6000\end{array}\right.$ | $\left\{\begin{array}{l}.06130 \\ .02700\end{array}\right.$ |
| 17 | Cast iron | $)$ ampere turns for demagnetization . . . .) | (.01445 |
| 18 |  | Gray cast iron . . | . 01300 |
| 20 |  | "، " ${ }^{\text {c }}$ containing $\frac{1}{8} \%$ aluminium | . 01365 |
|  | " " |  | . 01459 |
| 21 | Magnetite . | from the Tilly Foster mines, Brewsters, Putnam (County, New York, stated to be a very pure sample | . 02348 |
| 22 |  | Soft wire - . . ${ }^{\text {a }}$ ( ${ }^{\text {Steinmetz }}$ from | . 0122 |
| 23 | " | $\left\{\begin{array}{l}\text { Annealed wire, calculated by Steinmetz from } \\ \text { Ewing's experiments }\end{array}\right\}$ | . 0156 |
| 24 | " | Hardened, also from Ewing's experiments | .0385 |
| 25 | Cobalt | $\left\{\begin{array}{l}\text { Rod containing about } 2 \% \text { of iron, also calculated } \\ \text { from Ewing's experiments by Steinmetz }\end{array}\right\}$ | . 0120 |
|  | Iron filings | $\left\{\begin{array}{l}\text { Consisted of thin needle-like chips obtained by } \\ \text { milling grooves about } 8 \mathrm{~mm} \text {. wide across a pile of } \\ \text { thin sheets clamped together. About } 30 \% \text { by vol- } \\ \text { ume of the specimen was iron. } \\ \text { ist experiment, continuous cyclic variation of m. m. } \\ \text { f. iSo cycles per second . . . . . . . . . . } \\ \text { 2d experiment, if cycles per second } \\ 3 \mathrm{~d}\end{array}\right.$ |  |
| 26 |  |  | . 0457 |
|  |  |  | . 0396 |
|  |  |  | . 0373 |

Smithsonian Tables.

## ENERGY LOSSES IN TRANSFORMER STEELS．

Determined by the wattmeter method．
Loss per cycle per $c c=A B^{x}+b n B^{y}$ ，where $B=$ flux density in gausses and $n=$ frequency in cycles per second．$x$ shows the variation of hysteresis with $B$ between 5000 and 10000 gausses， and $y$ the same for eddy currents．

| Designation． | Thick－ ness． cm． | Ergs per Gramme per Cycle． |  |  |  | $x$ | $y$ | $a$ | Watts per Pound at 60 Cy － cles and 10000 Gausses． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 10000 Gausses． |  | 5000 Gausses． |  |  |  |  | 若品。 |  |  |
|  |  | Hyste－ resis． |  | Hyste－ resis． |  |  |  |  |  | Hyste－ resis． | Total． |
| Unannealed A |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.0399 | 1599 | 186 | 562 | 46 | 1.51 | 2.02 | 0.00490 | 0.41 | $4 \cdot 35$ | 4.76 |
|  | ． 0326 | 1156 | 134 | 384 | 36 | 1． 59 | I． 89 | ． 00358 | 0.44 | 3.14 | 3.58 |
|  | ．0422 | 1032 | 242 | 356 | 70 | 1.51 | I． 79 | ．00319 | 0.47 | 2.81 | 3.28 |
|  | ．0381 | 1009 | 184 | 353 | 48 | 1.52 | 1.94 | ．00312 | 0.44 | 2.74 | 3.18 |
| Annealed |  |  |  |  |  |  |  |  |  |  |  |
| E | ． 0476 | 735 | 236 | 246 | 58 | 1.58 | 2.02 | ． 00227 | 0.36 | 2.00 | 2.36 |
| F | ．0280 | 666 | 100 | 220 | 27 | 1.60 | I． 88 | ． 00206 | 0.44 | 1.81 | 2.25 |
| G | ． 0394 | 563 | 210 | 193 | 54 | I． 54 | I． 96 | ．00174 | 0.47 | I． 53 | 2.00 |
| $\mathrm{H}^{*}$ | ． 0307 | 412 | 146 | 138.5 | 39 | 1.58 | I． 90 | ． 00127 | －． 54 | 1.12 | 1． 66 |
| 1 | ．0318 | 341 | 202 | 111．5 | 55 | 1． 62 | I． 88 | ． 00105 | 0.70 | 0.93 | 1.63 |
| K＊ | ．0282 | 394 | 124 | 130 | 32 | 1．61 | 1.90 | ． 00122 | －． 54 | 1.07 | 1.61 |
| L | ． 0346 | 381 | 184 | 125 | 50 | I． 61 | 1． 88 | ． 00118 | 0.535 | 1.035 | 1.57 |
| B | ． 0338 | 354 | 200 | 116 | 57 | I． 61 | I． 81 | ． 00110 | 0.61 | 0.96 | 1． 57 |
| M | ． 0335 | 372 | 178 | 127 | 46 | I． 55 | I． 95 | ． 00115 | 0.55 | 1.01 | 1．56 |
| N | ． 0340 | 321 | 210 | 105 | 56 | 1.62 | 1.90 | ． 00099 | 0.63 | 0.87 | 1.50 |
| P | ． 0437 | 334 | I84 | 107 | 50 | 1． 64 | 1.88 | ．00103 | 0.34 | 0.91 | 1.25 |
| Silicon steels |  |  |  |  |  |  |  |  |  |  |  |
| $\underset{N}{\mathrm{Q} \dagger}$ | ．0361 |  | 54 | 98 | 15 | 1.63 | － | ． 00094 | 0.14 | 0.825 | 0.965 |
| R | ． 0315 | 288 | 42 | 93 | 1 I | 1． 64 | － | ． 00089 | 0.15 | 0.78 | 0.93 |
| S | ． 0452 | 278 250 | 72 60 | 90 | 18 | 1．63 | － | ． 00086 | 0.12 | 0.755 | 0.875 |
| U | ． 03346 | 250 270 | 42 | 78 86 | 18 | I． 68 ． 66 | － | ． 00077 | 0.18 | 0.68 | 0.86 |
| V＊ | ． 0310 | 251.5 | 47 | 79 | 13 | I． 68 | － | ． 000078 | 0.17 | 0．735 | 0.855 |
| W＊ | ． 0305 | 197 | 43 | 62.3 | 12.4 | 1． 67 | － | ． 00061 | 0.16 | 0.535 | 0.695 |
| X | ． 0430 | 200 | 65 | 64.2 | 16.6 | 1． 65 | － | ． 00062 | 0.12 | 0.545 | 0.665 |

＊German．
$\dagger$ English．
$\ddagger$ In order to make a fair comparison，the eddy current loss has been computed for a thickness of 0.0357 cm ．（Gage No．29），assuming the loss proportional to the thickness．

Lloyd and Fisher，Bull．Bur．Standards，5，p． 453 ；1909．
Note．－For formule and tables for the calculation of mutual and self inductance see Bulletin Burear of Standards，vol．8，p．1－237， 1912.

## Smithsonian Tables．

Table 474.

## MAGNETIC SUSCEPTIBILITY.

If $\mathfrak{I}$ is the intensity of magnetization produced in a substance by a field strength then the magnetic susceptibility $\mathrm{H}=\mathscr{I} /$. This is generally referred to the unit mass; italicized figures pecially its freedom from iron. The mass susceptibility of a solution containing p per cent by weight of a water-free substance is, if $H_{0}$ is the susceptibility of water, $(\mathrm{p} / 100) \mathrm{H}+(\mathrm{r}-\mathrm{p} / 100) \mathrm{H}_{0}$.

| Substance. | $\mathrm{H} \times{ }_{10}{ }^{6}$ | - | Remarks | Substance. | $\mathrm{H} \times{ }_{10}{ }^{6}$ | Ė心 | Remarks |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{Ag}_{\mathrm{AgCl}} \cdot \cdot \mathrm{P} \cdot$ | -0.19 | $18^{\circ}$ |  | $\mathrm{K}_{2} \mathrm{CO}_{3} \cdot . \quad . \quad$. | -0.50 | $20^{\circ}$ | Sol'n |
| Agir, I A tm . . . . | -0.28 |  |  | Li . . . . . . | +0.38 |  |  |
| Air, I Atm . . . . | +0.024 +0.65 | 15 |  | Mb . ${ }^{\text {Mr }}$ | +0.04 | 18 |  |
| $\mathrm{Al}_{2} \mathrm{~K}_{2}\left(\mathrm{SO}_{4}\right)_{4} \dot{2}_{4} \dot{\mathrm{H}}_{2} \dot{\mathrm{O}}$ | -1.0 |  | Crys. | $\mathrm{MgSO}_{4}{ }^{\circ}$. . . | +0.55 | 18 |  |
| A, I Atm . . . . | -0.10 | $\bigcirc$ |  | Mn | +11. | 18 |  |
| As . - | -0.3 | 18 |  | $\mathrm{MnCl}_{2}$ - . . | +122. | I8 | Sol'n |
| Au | -0.15 | 18 |  | $\mathrm{MnSO}_{4}$. . . . | +100. | 18 |  |
| ${ }_{\mathrm{BaCl}}^{\mathbf{B}} \times \cdot \quad \cdot \quad$. | $-0.71$ | 18 |  | $\mathrm{N}_{2}, 1$ Atm. | 0.001 | 16 |  |
| $\underset{\mathrm{Be}}{ } \mathrm{BaCl}_{2}$. | $\underline{0.36}$ | 20 |  | $\mathrm{NH}_{3} \cdot$. | -1.1 |  |  |
| $\mathrm{Bi} . .$. | +0.79 | 15 | Powd. | Na | +0.51 | 18 |  |
| Br . . . . | -0.38 | 18 |  | ${ }^{\mathrm{Na}} \mathrm{C}_{2} \mathrm{CO}_{3}{ }^{+}$ | -0.50 | 20 |  |
| C, arc-carbon | -2.0 | 18 |  | $\mathrm{Na}_{2} \mathrm{CO}_{3}$. Io $\mathrm{H}_{2} \mathrm{O}$ | -0.46 | 17 | " |
| C , diamond . . | -0.49 | 18 |  | Nb . . . . . | +1.3 | 18 |  |
| $\mathrm{CH}_{4}$, I Atm. . | +0.001 | 16 |  | $\mathrm{NiCl}_{2}$. | +40. | 18 | Sol'n |
| $\mathrm{CO}_{2}$, I Atm. . . . | +0.002 | 16 |  | $\mathrm{NiSO}_{4}$. . . . | + 30. | 20 | " |
| $\mathrm{CS}_{2} \cdot$ - . . | -0.77 | 18 |  | $\mathrm{O}_{2}$, I Atm. . . | +0.120 | 20 |  |
| CaO . | $-0.27$ | 16 | Powd. | Os . . . . . | +0.04 | 20 |  |
| $\mathrm{CaCl}_{2} \cdot{ }^{\text {C }}$ | -0.40 | 19 | " | P, white . . . . | -0.90 | 20 |  |
| $\mathrm{CaCO}_{3}$, marble . | $-0.7$ |  |  | P , red . . . . | -0.50 | 20 |  |
| Cd ${ }^{\text {- }}$ | -0.17 | 18 |  | Pb . . . . . | -0.12 | 20 |  |
| $\mathrm{CeBr}_{3} \cdot \cdot \cdot$ | +6.3 | 18 |  | $\mathrm{PbCl}_{2}$. . . . | -0.25 | 15 | Powd. |
| $\mathrm{Cl}_{2}$, I Atm. - | -0.59 | 16 |  | Pd. | +5.8 | 18 |  |
| $\mathrm{CoCl}_{2}$. | +90. | 18 | Sol'n | $\underset{\mathrm{PrCl}}{3}$. . . . | +13. | 18 | Sol'n |
| $\mathrm{CoBr}_{2} \mathrm{CoI}_{2}$. | $+47$. | 18 |  | ${ }^{\text {Ptt. }}$ P ${ }^{\text {P }}$ | +1.1 | 18 |  |
| $\mathrm{CoSO}_{4}$ | +33 +57. | 19 | " | $\mathrm{PhCl}_{4} \cdot \ldots .$. | 0.0 +1.1 | 22 | Sol'n |
| $\mathrm{Co}\left(\mathrm{NO}_{3}\right)_{2}$. | + 57. | 18 | ' | S . . . . | +0.48 | 18 |  |
| Cr . . | +3.7 | 18 |  | $\mathrm{SO}_{2}$, I Atm. . | -0.30 | 16 |  |
| CsCl | -0.28 | 17 | Powd. | Sb . . . | -0.94 | 18 |  |
| $\mathrm{Cu}^{\text {- }}$ | -0.09 | 18 |  | Se . . . . . | $-0.32$ | 18 |  |
| $\mathrm{CuCl}_{2}$. | +12. | 20 | Sol'n | Si. . . . . . | -0.12 | 18 | Crys. |
| $\mathrm{CuSO}_{4}$. | +10. | 20 | Sol'n | $\mathrm{SiO}_{2}$, Quartz . | -0.44 | 20 |  |
| CuS | +0.16 | 17 | Powd. | -Glass . . | $-0.5 \pm$ |  |  |
| $\mathrm{FeCl}_{3}$ | +90. | 18 | Sol'n | Sn . . . . . | +0.03 | 20 |  |
| $\mathrm{FeCl}_{2}$ | +90. | 18 | " | $\mathrm{SrCl}_{2}$. . | $-0.42$ | 20 | Sol'n |
| $\mathrm{FeSO}_{4}$. | +82. | 20 | " | Ta . . . | +0.93 | I8 |  |
| $\mathrm{Fe}_{2}\left(\mathrm{NO}_{3}\right)_{6}$. | +50. | 18 | " | Te . . . . . | $-0.32$ | 20 |  |
| $\mathrm{FeCn}_{6} \mathrm{~K}_{4}$. | -0.44 |  | Powd. | Th . . . | +0.18 | 18 |  |
| $\mathrm{FeCn}_{6} \mathrm{~K}_{3}$. | +9.1 |  | " | Ti . . . | +3.1 | 18 |  |
| He, I Atm. | -0.002 | $\bigcirc$ |  | Va . . . | +1.5 | 18 |  |
| $\mathrm{H}_{2}$, I Atm. . . . | 0.000 | 16 |  | Wo . . . | +0.33 | 20 |  |
| $\mathrm{H}_{2}, 40$ Atm. . | 0.000 | 16 |  | Zn . - . | -0.15 | 18 |  |
| $\mathrm{H}_{2} \mathrm{O}$. . | -0.79 | 20 |  | $\mathrm{ZnSO} \mathrm{m}_{4}$. . | -0.40 |  |  |
| $\mathrm{HCl}^{\text {e }}$. | -0.80 | 20 |  | Zr - | -0.45 | 18 |  |
| $\mathrm{H}_{2} \mathrm{SO}_{4}$. | +0.78 | 20 |  | $\mathrm{CH}_{3} \mathrm{OH}$. . . | -0.73 |  |  |
| $\mathrm{HNO}_{3}$. | -0.70 | 20 |  | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}$. - | -0.80 |  |  |
| Hg . | -0.19 | 20 |  | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{OH}$. | -0.80 |  |  |
| I . . . | -0.4 | 20 |  | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OC}_{2} \mathrm{H}_{5}$. . | -0.60 | 20 |  |
| In . | $0.1 \pm$ | 18 |  | $\mathrm{CHCl}_{3}$. . . | $-0.58$ |  |  |
| Ir . . . | +0.15 | 18 |  | $\mathrm{C}_{6} \mathrm{H}_{6}$. . | $-0.78$ |  |  |
| K. . | +0.40 | 20 |  | Ebonite . | +1.1 |  |  |
| KCl . - | -0.50 | 20 |  | Glycerine . . | -0.64 | 22 |  |
| KBr . . | -0.40 | 20 |  | Sugar . . | -0.57 |  |  |
| KI . | -0.3S | 20 |  | Paration . | -0.58 |  |  |
| KOH . | -0.35 | 22 | Sol'n | Petroleum. | -0.91 |  |  |
| $\mathrm{K}_{2} \mathrm{SO}_{4}$ - | -0.42 | 20 |  | Toluene . | $-0.77$ |  |  |
| $\mathrm{KMnO}_{4}$ | +2.0 |  |  | Wood . | -0.2-5 |  |  |
| $\mathrm{KNO}_{3}$. | -0.33 | 20 |  | Nylene . . . . | -0.81 |  |  |

Values are mostly means taken of values given in Landolt-Börnstein's Physikalisch-chemische Tabellen. See especially Honda, Annalen der Physik (4), 32, 9 10.
Smithsonian tables.

## MACNETO-OPTIC ROTATION.

Faraday discovered that, when a piece of heavy glass is placed in magnetic field and a beam of plane polarized light passed through it in a direction parallel to the lines of magnetic force, the plane of polarization oi the beam is rotated. This was subsequently found to be the case with a large number of substances, but the amount of the rotation was found to depend on the kind of matter and its physical condition, and on the strength of the magnetic field and the wave-length of the polarized light. Verdet's experiments agree fairly well with the formula -

$$
\theta=c l H I\left(r-\lambda \frac{d r}{d \lambda}\right) \frac{r^{2}}{\lambda^{2}},
$$

where $c$ is a constant depending on the substance used, $l$ the length of the path through the substance, $H$ the intensity of the component of the magnetic field in the direction of the path of the beam, $r$ the index of refraction, and $\lambda$ the wave-length of the light in air. If $H$ be different, at different parts of the path, $l H$ is to be taken as the integral of the variation of magnetic potential between the two ends of the medium. Calling this difference of potential $v$, we may write $\theta=A v$, where $A$ is constant for the same substance, kept under the same physical conditions, when the one kind of light is used. The constant $A$ has been called "Verdet's constant," * and a number of values of it are given in Tables 476-480. For variation with temperature the following formula is given by Bichat : -

$$
R=K_{0}^{\prime}\left(\mathrm{I}-0.00104 t-0.000014 t^{2}\right)
$$

which has been used to reduce some of the results given in the table to the temperature corresponding to a given measured density. For change of wave-length the following approximate formula, given by Verdet and Becquerel, may be used :-

$$
\frac{\theta_{1}}{\theta_{2}}=\frac{\mu_{1}^{2}\left(\mu_{1}^{2}-1\right) \lambda_{2}^{2}}{\mu_{2}^{2}\left(\mu_{2}^{2}-1\right) \lambda_{1}^{2}}
$$

where $\mu$ is index of refraction and $\lambda$ wave-length of light.
A large number of measurements of what has been called molecular rotation have been made, particularly for organic substances. These numbers are not given in the table, but numbers proportional to molecular rotation may be derived from Verdet's constant by multiplying in the ratio of the molecular weight to the density. The densities and chemical formula are given in the table. In the case of solutions, it has been usual to assume that the total rotation is simply the algebraic sum of the rotations which would be given by the solvent and dissolved substance, or substances, separately; and hence that determinations of the rotary power of the solvent medium and of the solution enable the rotary power of the dissolved substance to be calculated. Experiments by Quincke and others do not support this view, as very different results are obtained from different degrees of saturation and from different solvent media. No results thus calculated have been given in the table, but the qualitative result, as to the sign of the rotation produced by a salt, may be inferred from the table. For example, if a solution of a salt in water gives Verdet's constant less than 0.0130 at $20^{\circ}$ C., Verdet's constant for the salt is negative.

The table has been for the most part compiled from the experiments of Verdet, $\dagger$ H. Becquerel, $\ddagger$ Quincke, § Koepsel, \| Arons, $\boldsymbol{T}^{\top}$ Kundt,** Jahn, $\dagger \dagger$ Schönrock, $\ddagger \ddagger$ Gordon, $\S \S$ Rayleigh and Sidgewick, III Perkin, $\boldsymbol{T I}^{\top}$ Bichat.***

As a basis for calculation, Verdet's constant for carbon disulphide and the sodium line $D$ has been taken as 0.0420 and for water as 0.0130 at $20^{\circ} \mathrm{C}$.

* The constancy of this quantity has been verified through a wide range of variation of magnetic field by H. E. J. G. Du Bois (Wied. Ann. vol. 35), p. 137, 1888.
$\dagger$ "Ann. de Chim. et de Phys." [3] vol. 52, p. 129, 1858.
" "Ann. de Chim. et de Phys." [5] vol. 12; "C. R." vols. 90 , p. 1407, 1880, and 100 , p. 1374, 1885.
§ "Wied. Ann." vol. 24, p. 606, 1885.
II "Wied. Ann." vol. 26, p. 456, 1885.
T" "Wied. Ann." vol. 24, p. 161, 1885
** "Wied. Ann." vols. 23, p. 228, 1884, and 27, p. 191, 1886.
$\dagger \dagger$ "Wied. Ann." vol. 43, P. 280, 189 1.
" "Zeits. für Phys. Chem." vol. 11, p. 753, 1893.
§§s ""Proc. Rov. Soc." 36, p. 4, 1883 .
III "Phil. Trans. R. S." 176 , p. 343, 1885.
TI "Jour. Chem. Soc."
*** "Jour. de Phys." vols. 8, p. 204, 1879, and 9, p. 204 and p. 275, 1880.

MAGNETO-OPTIC ROTATION.
Sollds.

| Substance. | Formula. | $\underset{\substack{\text { Wave- } \\ \text { length. }}}{\text {. }}$ | Verdet's Constant. Minutes. | Temp. C. | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Amber - |  | $\stackrel{\mu}{0.589}$ | 0.0095 | 18-20 ${ }^{\circ}$ | Quincke. |
| Blende . . . . . | ZnS |  | 0.2234 | 15 | Becquerel. |
| Diamond . . . . . | ${ }^{\text {C }}$ | " | 0.0127 | 15 |  |
| $\stackrel{\text { Lead borate . . . . }}{\text { Selenium }}$ | $\stackrel{\mathrm{PbBe}_{2} \mathrm{O}_{4}}{ }$ | 0.68 | 0.0600 | 15 | " |
| Sodium borate . . . | ${ }_{\text {Na2 }{ }_{2} \mathrm{~B}_{4} \mathrm{O}_{7}}$ | 0.687 0.589 | 0.4625 0.0170 | 15 | ${ }^{\prime}$ |
| Ziqueline (Cuprite) . . | $\mathrm{Cu}_{2} \mathrm{O}$ | 0.687 | 0.0590 0.5908 | 15 | " |
| Fluorite . . . . . | $\mathrm{CaFl}_{2}$ | 0.2534 | 0.05989 | 20 | Meyer, Ann. der |
|  |  | . 3655 | . 02526 | " | Physik, 30, 1909. |
|  |  | . 43358 | . 01717 | " |  |
|  |  | . 589 | .01329 | " |  |
|  |  | 1.00 | . 00300 | " |  |
|  |  | 2.50 | . 00049 | " |  |
|  |  | 3.000.580 | . 00030 | " |  |
|  |  |  | 0.0161 | 18 | DuBois, Wied. Ann. |
|  |  |  | 0.0220 |  | 5I, 1894. |
|  |  | " | 0.0317 0.0608 | " |  |
|  |  | , | 0.0608 0.0888 | " |  |
|  |  | 0.313 | 0.0674 | 16 | Landau, Phys. ZS. |
|  |  | 0.405 | . 0369 | " | 9, 1908. |
|  |  | 0.436 | . 0311 | " |  |
| Quartz, along axis, i.e., plate cut $\perp$ to axis | $\mathrm{SiO}_{2}$ | 0.2194 .2573 | 0.1587 .1079 | $\stackrel{20}{6}$ | Borel, Arch. sc. phys. 16, 1903. |
|  |  | .2573 .3609 | . .04617 | " |  |
|  |  | . 4800 | . 02574 | " |  |
|  |  | . 5892 | . 01664 | " |  |
|  |  | . 6439 | . 01368 | - |  |
| Rock salt . . . . | NaCl | 0.2599 | 0.2708 | 20 | Meyer, as above. |
|  |  | .3100 | .1561 |  |  |
|  |  | . 4046 | . 0775 | " |  |
|  |  | . 4916 | . 0483 | " |  |
|  |  | . 6708 | . 0245 | " |  |
|  |  | 1.00 | . 01050 | " |  |
|  |  | 2.00 | . 00262 | " |  |
|  |  | 4.00 | . 00069 | 20 |  |
| Sugar, cane: along axis IIA | $\mathrm{C}_{12} \mathrm{H}_{22} \mathrm{O}_{11}$ | 0.451 |  | $\stackrel{20}{10}$ | Voigt, Phys. ZS. 9, |
|  |  | . 540 | . 0076 | " | 1908. |
|  | - | 0.451 | 0.0129 | " |  |
| axis IIA $^{1}$. . |  | . 540 | . 0084 | " |  |
| Sylvite . . . . . | KCl | . 626 | . 0075 | 0 |  |
|  |  | $\begin{gathered} 0.4358 \\ .5461 \end{gathered}$ | $\begin{gathered} 0.0534 \\ .0316 \end{gathered}$ | $\stackrel{20}{ }$ | Meyer, as above. |
|  |  | . 6708 | . 02012 | " |  |
|  |  | . 90 | . 01051 | " |  |
|  |  | 1.20 | . 00608 | " |  |
|  |  | 2.00 | . 00207 | " |  |
|  |  | 4.00 | . 00054 |  |  |

## Smithsonian Tables.

table 477.
MAGNETO-OPTIC ROTATION.
Llquids : Verdet's Constant for $\lambda=0.589 \mu$.

| Substance. | Chemical formula. | Density in grams per c. c. | $\begin{gathered} \text { Verdet's } \\ \text { constant } \\ \text { in minutes. } \end{gathered}$ | Temp. C | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Acetone | $\mathrm{C}_{8} \mathrm{H}_{6} \mathrm{O}$ | 0.7947 | 0.0113 | $20^{\circ}$ | Jahn. |
| Acids: Acetic | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}_{2}$ | 1.0561 | . 0105 | 21 | Perkin. |
| "، Butyric | $\mathrm{C}_{4} \mathrm{H}_{8} \mathrm{O}_{2}$ | 0.9663 | .0116 | ${ }^{1} 15$ | - "، |
| " Formic | $\mathrm{CH}_{2} \mathrm{O}_{2}$ | 1.2273 | . 105 |  | " |
| ". Hydrochloric | $\xrightarrow{\mathrm{HCl}}$ | 1.2072 | . 0224 | " | " |
| "، ${ }_{\text {Hydrobromic }}^{\text {Hydroiodic }}$ | $\underset{\mathrm{HI}}{\mathrm{HBr}}$ | 1.7859 1.9473 | . 0343 | " | " |
| " ${ }_{\text {Hydroiodic }}$ | $\mathrm{HHNO}_{3}$ | 1.9473 1.5190 | . 0515 | " 3 | "' |
| " Sulphuric | $\mathrm{H}_{2} \mathrm{SO}_{4}$ | - | . 0121 | 15 | Becquerel. |
| Alcohols : Amyl | $\mathrm{C}_{5} \mathrm{H}_{11} \mathrm{OH}$ | 0.8107 | . 0128 | $\stackrel{20}{6}$ | Jahn. |
| ". $\begin{gathered}\text { Butyl } \\ \text { Ethyl }\end{gathered}$ | ${ }_{\text {C }}^{\mathrm{C}_{4} \mathrm{H}_{9} \mathrm{H}_{5} \mathrm{OH} \mathrm{OH}}$ | 0.8021 0.7900 | .0124 .0112 | " | " |
| " Ethyl | - ${ }_{\text {C2 }} \mathrm{H}_{5} \mathrm{OH}$ | 0.7900 0.7920 | . 0112 | " | " |
| " Propyl | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{OH}$ | - 0.7842 | . 0120 | " | " |
| Benzene | $\mathrm{C}_{6} \mathrm{H}_{6}$ | 0.8786 | . 0297 | " | " |
| Bromides : Bromoform | CHBr ${ }^{\text {c }}$ | 2.902 I | . 0317 | 15 | Perkin. |
| " Ethyl | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br}$ | 1.4486 | . 0183 |  | " |
| " Ethylene | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{Br}_{2}$ | 2.1871 | . 0268 | " | " |
| "، Methyl | $\mathrm{CHH}_{3} \mathrm{Br}$ | 1.7331 | . 0205 | $\bigcirc$ | "، |
| " Methylene | $\mathrm{CH}_{2} \mathrm{Br}_{2}$ | 2.4971 | . 0276 | 15 | Gordon. |
| Carbon bisulphide | $\mathrm{CS}_{2}$ |  | .0433 .0420 | - | Gordon. Rayleigh. |
| Chlorides: Amyl | CHCl | 0.8740 | . 1140 | 20 | Jahn. |
| "" Arsenic | $\mathrm{AsCl}_{3}$ | - | . 0422 | ${ }^{1} 5$ | Becquerel. |
| " Carbon | $\mathrm{CCl}_{4}$ | - | . 0321 |  |  |
| " Ethyl | ${ }_{\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}}$ | 1.4823 0.9169 | .0164 0.0138 | $\begin{gathered} 20 \\ 6 \end{gathered}$ | Jahn. <br> Perkin. |
| " Ethylene | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{Cl}_{2}$ | I. 2589 | . 0166 | 15 | " |
| "، Methyl | $\mathrm{CH}_{3} \mathrm{Cl}$ |  | . 0170 |  | Becquerel. |
| " Methylene | $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ | ${ }^{1.3361}$ | . 0162 | " | Perkin. |
| " Sulphur bi- | $\mathrm{S}_{2} \mathrm{Cl}_{2}$ |  | . 0393 | " | Becquerel. |
| " ${ }^{\text {" }}$ Tin tetra | $\underset{\mathrm{ZnCl}}{4}$ | - | . 0151 | "* | " |
| Iodides: Ethyl | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | 1.9417 | . 0296 | " | Perkin. |
| " Methyl | $\mathrm{CH}_{3} \mathrm{I}$ | 2.2832 | . 0336 | " | " |
| " Propyl | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{I}$ | 1.7658 | . 0271 | " | " |
| Nitrates: Ethyl | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{O} . \mathrm{NO}_{2}$ | 1.1149 | . 0091 | " | " |
| " Methyl | $\mathrm{CH}_{3} \mathrm{O} \cdot \mathrm{NO}_{2}$ | I. 2157 | . 0078 | " | " |
| " Propyl | $\mathrm{C}_{3} \mathrm{H}_{7} \mathrm{O}_{2} \mathrm{NO}_{2}$ | 1.0622 | . 0100 | " | " |
| $\underset{\text { Paraffins : }}{\text { Heptane }}$ Hexane | $\mathrm{C}_{7} \mathrm{H}_{16}$ | 0.6880 | . 0125 | " | " |
| " Pentane | ${ }^{\mathrm{C}_{5}{ }_{5} \mathrm{H}_{12} 14}$ | 0.6743 0.6332 | . 0125 | " | " |
| Phosphorus, melted |  | - | . 1316 | 33 | Becquerel. |
| Sulphur, melted |  | - | . 0803 | 114 | " |
| Toluene | $\mathrm{C}_{7} \mathrm{H}_{8}$ | 0.858 I | . 0269 | 28 | Schönrock. |
| Water, $\lambda=0.2496 \mu$ | $\mathrm{H}_{2} \mathrm{O}$ |  | .1042 |  | See Meyer, |
| 0.275 |  |  | . 0776 |  | Ann. der |
| $\begin{aligned} & 0.3609 \\ & 0.4046 \end{aligned}$ |  |  | . 0384 |  | Physik, 30, |
| O. 0.500 |  |  | .0293 |  |  |
| 0.589 0.700 |  |  | .or3i |  | I andau, |
| 0.700 1.000 |  |  | .0091 |  | Siertsema, Ingersoll. |
| Xylene $\quad 1.300$ |  |  | . 00264 |  |  |
| Xylene | $\mathrm{C}_{8} \mathrm{H}_{10}$ | 0.8746 | . 0263 | 27 | Schönrock. |

MAGNETO-OPTIC ROTATION.
Solutions of acids and salts in water. Verdet's constant for $\lambda=0.589 \mu$.

| Chemical formula. | Density, $\underset{\text { grams }}{\text { ger.c. }}$ per c. c. | Verdet's constant in minutes. | Temp. C. | * | Chemical formula. | Density, grams per c. c. | Verdet's constant in minutes. | Temp. C. | * |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathrm{C}_{3} \mathrm{H}_{6} \mathrm{O}$ | 0.9715 | 0.0129 | $20^{\circ}$ | J | LiCl | 1.0619 | 0.0145 | $20^{\circ}$ | J |
| HBr | 1.3775 | 0.0244 |  | P |  | 1.0316 | 0.0143 |  | " |
| HCl | 1.1163 | 0.0168 | " | " | $\mathrm{MnCl}_{2}$ | 1.1966 | 0.0167 | 15 | 13 |
| HCl | 1.1573 | 0.0204 | " | " | " | 1.0876 | 0.0150 | 15 | ${ }^{\prime}$ |
| " | 1.0762 | 0.0168 | " | " | $\mathrm{HgCl}_{2}$ | 1.0381 | 0.0137 | 16 | S |
| HI | 1.0158 | 0.0140 |  | J |  | 1.0349 | 0.0137 | ، | ، |
| HI | 1.9057 | 0.0499 | " | P | $\mathrm{NiCl}_{2}$ | 1.4685 | 0.0270 | 15 | B |
|  | 1.4495 | 0.0323 | " | " | ، | 1.2432 | 0.0196 | " | " |
|  | 1.1760 | 0.0205 | " | " | " | 1.1233 | 0.0162 | " | " |
| $\mathrm{HNO}_{3}$ | 1.3560 | 0.0105 | " | " | KCl | 1.6000 | 0.0163 | " | " |
| $\mathrm{NH}_{3}$ | 0.8918 | 0.0153 | 15 | " | " | 1.0732 | 0.0148 | 20 | J |
| $\mathrm{NH}_{4} \mathrm{Br}$ | 1.2805 | 0.0226 |  | " | NaCl | 1.2051 | 0.0180 | 15 | B |
|  | I.1576 | 0.0186 |  |  |  | 1.0546 | 0.0144 |  | " |
| $\mathrm{BaBr}_{2}$ | 1.5399 1.2855 | 0.0215 | 20 | J |  | 1.0418 | 0.0144 | " | J |
| $\mathrm{CdBr}_{2}$ | 1.2555 1.3291 | 0.0176 0.0192 | " | " | $\mathrm{SrCl}_{2}$ | 1.1921 1.0877 | 0.0162 0.0146 | " | " |
|  | 1.1608 | 0.0162 | " | " | $\mathrm{SnCl}_{2}$ | 1.3280 | 0.0266 | 15 | V |
| $\mathrm{CaBr}_{6}$ | 1.2491 | 0.0189 | " | " |  | 1.1112 | 0.0175 | " | " |
|  | 1.1337 | 0.0164 | * | " | $\mathrm{ZnCl}_{2}$ | 1.2851 | 0.0196 | " | " |
| K ${ }_{6}$ | 1.1424 | 0.0163 | " | " | "' | 1.1595 | 0.0161 | '6 | " |
|  | 1.0876 | 0.0151 | " | " | $\mathrm{K}_{2} \mathrm{CrO}_{4}$ | 1.3598 | 0.0098 | " | " |
| NaBr | I.1351 | 0.0165 | " | " | $\mathrm{K}_{2} \mathrm{Cr}_{2} \mathrm{O}_{7}$ | 1.0786 | 0.0126 | " | " |
|  | 1.0824 | 0.0152 | " | " | $\mathrm{Hg}(\mathrm{CN})_{2}$ | 1.0638 | 0.0136 | 16 | S |
| $\mathrm{SrBr}_{3}$ | 1.2901 1.1416 | 0.0186 0.0159 | " | " |  | 1.0605 | 0.0135 | " | " |
| $\mathrm{K}_{2} \mathrm{CO}_{8}$ | 1.1906 | 0.0140 | 20 | ، | ${ }^{1}{ }^{4}$ | 1.5940 I. 5109 | 0.0396 0.0358 | ${ }^{16} 5$ | P |
| $\mathrm{Na}_{2} \mathrm{CO}_{3}$ | 1.1006 | 0.0140 | " | " | " | 1.234 I | 0.0235 | " | " |
|  | 1.0564 | 0.0137 | " | V | CdI | 1.5156 | 0.0291 | 20 | J |
| $\mathrm{NH}_{4} \mathrm{Cl}$ | 1.0718 | 0.0178 | 15 | V | " | 1.1521 | 0.0177 | " | " |
| $\mathrm{BaCl}_{2}$ | 1.2897 | 0.0168 | 20 | J | KI | 1. 6743 | 0.0338 | 15 | B |
|  | 1.1338 | 0.0149 | " |  |  | 1.3398 | 0.0237 |  | ، |
| $\mathrm{CdCl}_{2}$ | I. 3179 | 0.0185 | " | " | , I | 1.1705 | 0.0182 | " | " |
| " | 1.2755 | 0.0179 | " | " | NaI | 1.1939 | 0.0200 | " | J |
| " | 1.1732 | 0.0160 | " | " | $\mathrm{NH}_{4} \mathrm{NO}_{3}$ | I.1191 | 0.0175 | " |  |
| $\mathrm{CaCl}_{2}$ | I.I 504 | 0.0165 | " | " | $\mathrm{KNO}_{3}$ | 1.2803 1.0634 | 0.0121 0.0130 | 15 20 | J |
|  | 1.0832 | 0.0152 | " | " | $\mathrm{NaNO}_{3}$ | 1.1112 | 0.0131 | " | " |
| $\mathrm{CuCl}_{2}$ | I. 5158 | 0.0221 | 15 | B | $\mathrm{U}_{2} \mathrm{O}_{3} \mathrm{~N}_{2} \mathrm{O}_{5}$ | 2.0267 | 0.0053 | " | B |
|  | I. 1330 | 0.0156 |  | " |  | 1.1963 | 0.0115 | " | " |
| $\mathrm{FeCl}_{2}$ | 1.4331 | 0.0025 | 15 | " | $\left(\mathrm{NH}_{4}\right)_{2} \mathrm{SO}_{4}$ | 1. 2286 | 0.0140 | 15 | P |
|  | 1.2141 | 0.0099 |  | " | $\mathrm{NH}_{4} . \mathrm{HSO}_{4}$ | 1.4417 | 0.0085 |  | " |
|  | 1.1093 | 0.0118 | " | " | $\mathrm{BaSO}_{4}$ | 1.1788 | 0.0134 | 20 | ${ }_{6}$ |
| $\underset{64}{\mathrm{Fe}_{2} \mathrm{Cl}_{6}}$ | 1.6933 1.5315 | -0.2026 | " | " | $\mathrm{CdSO}_{4}$ | 1.0938 1.1762 | 0.0133 0.0139 | ، | " |
| " | 1.3230 | -0.034 | " | " | " | 1.0890 | 0.0136 | " | " |
| " | 1.1681 | -0.0015 | " | " | $\mathrm{Ii}_{2} \mathrm{SO}_{4}$ | 1.1762 | 0.0137 | " | " |
| " | I.0864 | 0.0081 | " | " | $\mathrm{MnSO}_{4}$ | 1.2441 | 0.0138 | " | " |
| " | 1.0445 | 0.0113 | " | " | $\mathrm{K}_{2} \mathrm{SO}_{4}$ | 1.0475 | 0.01 .33 | " | " |
| " | 1.0232 | 0.0122 | '، | " | $\mathrm{Na}_{2} \mathrm{SO}_{4}$ | 1.0661 | 0.0135 | " | " |

* J, Jahn, P, Perkin, V, Verdet, B, Becquerel, S, Schönrock; see p. 378 for references.


## Smithsonian Tables.

Gases.


See also Siertsema, Ziting. Kon. Akad. Watt., Amsterdam, 7, 1899; 8, 1900.
Du Bois shows that in the case of substances like iron, nickel, and cobalt which have a variable magnetic susceptibility the expression in Verdet's equation, which is constant for substances of constant susceptibility, requires to be divided by the susceptibility to obtain a constant. For this expression he proposes the name "Kundt's constant." These experiments of Kundt and Du Bois show that it is not the difference of magnetic potential between the two ends of the medium, but the product of the length of the medium and the induction per unit area, which controls the amount of rotation of the beam.

## TABLE 480. - Verdet's and Kundt's Constants.

The following short table is quoted from Du Bois' paper. The quantities are stated in c. g. s. measure, circular measure (radians) being used in the expression of "Verdet's constant " and "Kundt's constant."

| Name of substance. | Magnetic susceptibility. | Verutis constant. |  | Wave-length of light in cms. | Kundt's constant. |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Number. | Authority. |  |  |
| Cobalt . . | - | - | - | $6.44 \times 10^{-5}$ | $3 \cdot 99$ |
| Nickel • - | - | - | - | ' | 3.15 |
| Iron - . | +0.0126 $\times 10^{-5}$ | ${ }^{-}{ }^{-} \times 10^{-5}$ | Tecquerel | 6.56 '، | 2.63 |
| Oxygen : I atmo. | $+0.0126 \times 10^{-5}$ | $0.000179 \times 10^{-5}$ | Becquerel. | 5.89 " | 0.014 |
| Sulphur dioxide | -0.0751 | $0.302$ |  | 5 ${ }^{\text {a }}$ | -4.00 |
| Water d - | -0.0694 " | $0.377$ | Arons | " | -5.4 |
| Nitric acid | -0.0633 " | 0.356 | Becquerel. | " | $-5.6$ |
| Alcohol . | -0.0566 " | 0.330 | De la Rive. | " | -5.8 |
| Ether . ${ }^{\text {a }}$ | -0.0541 " | 0.315 | " | ، | -5.8 |
| Arsenic chloride | -0.0876 " | 1.222 "، | Becquerel. | " | -14.9 |
| Carbon disulphide | -0.0716 " |  | Rayleigh. | " | -17.1 |
| Faraday's glass | -0.0982 " | 1.738 " | Becquerel. | " | -17.7 |

## Smithsonian Tables.

TABLE 481. - Values of Kerr's Constant.*
Du Bois has shown that the rotation of the major axis of vibration of radiations normally reflected from a magnet is algebraically equal to the normal component of magnetization multiplied into a constant $K$. He calls this constant $K$, Kerr's constant for the magnetized substance forming the magnet.

| Color of light. | Spectrum line. | Wavelength $\underset{\times 10^{8}}{\text { in }}$ | Kerr's constant in minutes per c. g. s. unit of magnetization. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Cobalt. | Nickel. | Iron. | Magnetite. |
| Red . | Li $\boldsymbol{\alpha}$ | 67.7 | -0.0208 | -0.0173 | -0.01 54 | +0.0096 |
| Red . . | - | 62.0 | -0.0198 | -0.0160 | -0.0138 | +0.0120 |
| Yellow . . . . | D | 58.9 | -0.0193 | -0.01 54 | -0.01 30 | +0.0133 |
| Green . . . | $b$ | 51.7 | -0.0179 | -0.0159 | -0.0111 | +0.0072 |
| Blue . . . . . | F | 48.6 | -0.0180 | $-0.0163$ | -0.0101 | +0.0026 |
| Violet . . . . . | G | 43.1 | -0.0182 | -0.0175 | -0.0089 | - |

* H. E. J. G. Du Bois, " Phil. Mag." vol. 29.

TABLE 482. - Dispersion of Kerr Effect.

| Wave-length. | $0.5 \mu$ | $1.0 \mu$ | $1.5 \mu$ | $2.0 \mu$ | $2.5 \mu$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Steel . . . | $-11^{\prime}$. | $-16^{\prime}$. | $-14^{\prime}$. | $-1 I^{\prime}$. | $-9^{\prime .0}$ |
| Cobalt . . . | -9.5 | -11.5 | -9.5 | -11. | -6.5 |
| Nickel . . . | -5.5 | -4.0 | 0 | +1.75 | +3.0 |

Field Intensity $=10,000$ C. G. S. units. (Intensity of Magnetization $=$ about 800 in steel, 700 to 800 in cobalt, about 400 in nickel). Ingersoll, Phil. Mag. 11, p. 41, 1906.

TABLE 483. - Dispersion of Kerr Effect.

| Mirror. | Field <br> (C. G.S.) | $.41 \mu$ | $.44 \mu$ | $.48 \mu$ | $.52 \mu$ | $.56 \mu$ | $.60 \mu$ | $.64 \mu$ | $.66 \mu$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Iron . . | 21,500 | -.25 | -.26 | -.28 | -.31 | -.36 | -.42 | -.44 | -.45 |
| Cobalt.. | 20,000 | -.36 | -.35 | -.34 | -.35 | -.35 | -.35 | -.35 | -.36 |
| Nickel . . | 19,000 | -.16 | -.15 | -.13 | -.13 | -.14 | -.14 | -.14 | -.14 |
| Steel . . | 19,200 | -.27 | -.28 | -.31 | -.35 | -.38 | -.40 | -.44 | -.45 |
| Invar . . | 19,800 | -.22 | -.23 | -.24 | -.23 | -.23 | -.22 | -.23 | -.23 |
| Magnetite | 16,400 | -.07 | -.02 | +.04 | +.06 | +.08 | +.06 | +.04 | +.03 |

Foote, Phys. Rev. 34, p. 96, 1912.
See also Ingersoll, Phys. Rev. 35, p. 312, 1912, for "The Kerr Rotation for Transverse Magnetic Fields," and Snow, l. c. 2, p. 29, 1913, "Magneto-optical Parameters of Iron and Nickel."

## Smithsonian Tables.

RESISTANCE OF METALS. MAGNETIC EFFECTS.
TABLE 484.-Variation of Resistance of Bismuth, with Temperature, in a Transverse Magnetic Field.

| Proportional Values of Resistance. |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | $-192^{\circ}$ | $-135^{\circ}$ | $-100^{\circ}$ | $-37^{\circ}$ | $0^{\circ}$ | +18 ${ }^{\circ}$ | $+60^{\circ}$ | $+100^{\circ}$ | $+183^{\circ}$ |
| 0 | 0.40 | 0.60 | 0.70 | 0.88 | 1.00 | 1.08 | 1.25 | 1.42 | 1.79 |
| 2000 | 1.16 | 0.87 | 0.86 | 0.96 | 1.08 | 1.11 | 1.26 | 1.43 | 1.80 |
| 4000 | 2.32 | I. 35 | 1.20 | 1.10 | I. 18 | 1.21 | 1.31 | I. 46 | 1.82 |
| 6000 | 4.00 | 2.06 | 1.60 | 1.29 | I. 30 | 1.32 | 1.39 | $\underline{1} 51$ | 1.85 |
| 8000 | 5.90 | 2.88 | 2.00 | 1. 50 | 1.43 | I. 42 | 1.46 | 1.57 | 1.87 |
| 10000 | 8.60 | 3.80 | 2.43 | 1.72 | r .57 | 1.54 | 1.54 | 1.62 | $\underline{1.89}$ |
| 12000 | 10.8 | 4.76 | 2.93 | 1.94 | 1.71 | 1.67 | 1.62 | 1.67 | 1.92 |
| 14000 | 12.9 | 5.82 | 3.50 | 2.16 | 1.87 | I. 80 | 1.70 | 1.73 | 1.94 |
| 16000 | 15.2 | 6.95 | 4.11 | 2.38 | 2.02 | 1.93 | 1. 79 I 88 | 1.80 | 1.96 |
| 18000 | 17.5 | 8.15 | 4.76 | 2.60 | 2.18 | 2.06 | 1.88 | 1.87 | 1.99 |
| 20000 | 19.8 | 9.50 | 5.40 | 2.81 | 2.33 | 2.20 | 1.97 | 1.95 | 2.03 |
| 25000 | 25.5 | 13.3 | 7.30 | $3 \cdot 50$ | 2.73 | 2.52 | 2.22 | 2.10 | 2.09 |
| 30000 | 30.7 | 18.2 | 9.8 | 4.20 | 3.17 3.62 | 2.86 3.25 | 2.46 2.69 | 2.28 2.45 | 2.17 2.25 |
| 35000 | 35.5 | 20.35 | 12.2 | 4.95 | 3.62 | 3.25 | 2.69 | 2.45 | 2.25 |

TABLE 485. - Increase of Resistance of Nickel due to a Transverse Magnetic Field, expressed as $\%$ of Resistance at $0^{\circ}$ and $\mathbf{H}=\mathbf{0}$.

| H | $-190^{\circ}$ | $-75^{\circ}$ | $0^{\circ}$ | $+18^{\circ}$ | $+100^{\circ}$ | $+182^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | +o | 0 | 0 | 0 | 0 | 0 |
| 1000 | +0.20 | +0.23 | +0.07 | +0.07 | +0.96 | +0.04 |
| 2000 | +0.17 | +0.16 | +0.03 | +0.03 | +0.72 | -0.07 |
| 3000 | 0.00 | -0.05 | -0.34 | -0.36 | -0.14 | -0.60 |
| 4000 | -0.17 | -0.15 | -0.60 | -0.72 | -0.70 | -1.15 |
| 6000 | -0.19 | -0.20 | -0.70 | -0.83 | - 1.02 | -1.53 |
| 8000 | -0.19 | -0.23 | -0.76 | -0.90 | -1.15 | - I .66 |
| 10000 | -0.18 | -0.27 | -0.82 | -0.95 | -1.23 | -1.76. |
| 12000 | -0.18 | -0.30 | -0.87 | -1.00 | -1.30 | -1.85 |
| 14000 | -0.18 | -0.32 | -0.91 | -1.04 | -1. 37 | -1.95 |
| 16000 | -0.17 | -0.35 | -0.94 | -1.09 | - 1.44 | -2.05 |
| 18000 | -0.17 | -0.38 | -0.98 | -1.13 | -1.51 | -2.15 |
| 20000 | -0.16 | -0.4I | - 1.03 | -1.17 | -1.59 | $-2.25$ |
| 25000 | -0.14 | -0.49 | -1.12 | -1.29 | - 1.76 | -2.50 |
| 30000 | -0.12 | -0.56 | - I .22 | -1.40 | $-1.95$ | $-2.73$ |
| 35000 | -0.10 | -0.63 | $-1.32$ | -1.50 | -2.13 | -2.98 |

F. C. Blake, Ann. der Physik, 28, p. 449; 1909.

TABLE 486. - Ohange of Resistance of Varions Metals in a Transverse Magnetic Field. Room Temperature.

| Metal. | Field Strength in Gausses. | Per cent Increase. | Authority. |
| :---: | :---: | :---: | :---: |
| Nickel | 10000 | - 1.2 | Williams, Phil. Mag. 9, 1905. |
|  |  | -1.4 | Barlow, Pr. Roy. Soc. 7 I, 1903. |
| " | 6000 | $-\mathrm{I} .0$ | Dagostino, Atti Ac. Linc. 17, 1908. |
| Cobalt | 10000 | -1.4 -0.53 | Grummach, Ann. der Phys. 22, 1906. |
| Cadmium | "، | +0.03 | " |
| Zinc | " | +0.01 | " |
| Copper | "' | +0.004 | " |
| Silver | " | +0.004 | ، |
| Tin | " | +0.003 +0.002 | ، |
| Palladium | $\because$ | +0.001 | ، |
| Platinum | " | +0.0005 | " |
| Lead | "' | +0.0003 | "، |
| Magnesium | 6000 | +0.0003 +0.01 | Dagostino, l.c. |
| Manganin | ¢ ${ }^{\text {a }}$ | +0.01 | Dagostino.l.c. |
| Tellurium Antimony | ? | +0.02 to 0.34 +0.02 to 0.16 | Goldhammer, Wied Ann. 31, 1887. |
|  | Different spec | ens show very | Grummach, l.c. |
| Iron | diverse result | sually an in- | Barlow, l.c. |
| , | crease in weak <br> in strong. | ds, a decrease | Williams, l.c. |
| Nickel steel | Alloys behave | milarly to iron. | Williams, l. c. |

Effects are considered positive when, the magnetic field being directed away from the observer, and the primary current of heat or electricity directed from left to right, the upper edge of the specimen has the higher potential or higher temperature.
$E=$ difference of potential produced ; $T=$ difference of temperature produced ; $I=$ primary current; $\frac{d t}{d x}=$ primary temperature gradient ; $B=$ breadth, and $D=$ thickness, of specimen $H=$ intensity of field. C. G. S. units.

Hall effect (Galvanomagnetic difference of Potential), $E=R \frac{R I I I}{D}$
Ettingshausen effect (" " "Temperature), $T=P_{D^{H}}{ }_{D}$
Nernst effect (Thermomagnetic " "Potential), $E=Q H B \frac{d t}{d x}$
Leduc effect (
" " Temperature), $T=S H B \frac{d t}{d x}$

| Substance. | Values of $R$. | $P \times 1{ }_{10}$ 。 | $Q \times$ ro6. | $s \times{ }_{10}{ }^{\text {s }}$. |
| :---: | :---: | :---: | :---: | :---: |
| Tellurium | +400 to 800 | +200 | +360000 | +400 |
| Antimony | + 0.9 " 0.22 | +2 | +9000 to 18000 | +200 |
| Steel - . | +.012""0.033 | -0.07 | -700" 1700 | +69 |
| Heusler alloy | +.010" 0.026 | - | +1600" 7000 |  |
| Iron ${ }^{\text {a }}$ | +.007" 0.011 | -0.06 | -1000" 1500 | +39 |
| $\underset{\text { Cinc }}{\text { Cobalt }}$. | +.0016"0.0046 | +0.01 | +1800" 2240 | +13 |
| $\underset{\text { Cadmium }}{\text { Cal }}$. . . . . . | +.00055 |  | -54"240 | +13 |
| Iridium . | +.00040 | - | up to -5.0 | +5 |
| Lead . | +.00009 | - | -5.0 (?) |  |
| Tin. . - | -. 00003 | - | -4.0 (?) |  |
| Platinum . - | -. 0002 | - |  | -2 |
| Copper ${ }_{\text {German silver }}$. | -.00052 | - | -90 to 270 | -18 |
| $\underset{\text { German silver . . . . . }}{\text { Gold }}$ | $\begin{gathered} -.00054 \\ -.00057 \text { to } .00071 \end{gathered}$ |  |  |  |
| Constantine. | $-.0009$ |  |  |  |
| Manganese . | -. 00093 |  |  |  |
| Palladium | -.0007 to . 0012 | - | +50 to 130 | -3 |
| Silver | -.0008".0015 | - | -46"430 | -41 |
| Sodium . | -. 0023 |  |  |  |
| Magnesium . | 一.00094 to . 0035 |  |  |  |
| Aluminum | -.00036 ".0037 |  |  |  |
| Nickel . | -.0045".024 | +0.04 to 0.19 | +2000" 9000 | -45 |
| Carbon Bismuth . |  | $\begin{array}{r} +5 \\ +3 \text { to } 40 \end{array}$ | + 100 + up to 132000 | -200 |

TABLE 488. - Variation of Hall Constant with the Temperature.

| Bismuth. ${ }^{1}$ |  |  |  |  |  | Antimony. ${ }^{2}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| H | $-182^{\circ}$ | $-90^{\circ}$ | $-23^{\circ}$ | +11.5 ${ }^{\circ}$ | $+100^{\circ}$ | H | $-186^{\circ}$ | $\rightarrow 79^{\circ}$ | +21.5 ${ }^{\circ}$ | $+58^{\circ}$ |
| 1000 | 62.2 | 28.0 | 17.0 | I 3.3 | 7.28 | 1750 | 0.263 | 0.249 | 0.217 |  |
| 2000 | 55.0 | 25.0 | 16.0 | 12.7 | 7.17 | 3960 | 0.252 | 0.243 | 0.211 |  |
| 3000 | 49.7 | 22.9 | 15.1 | 12.1 | 7.06 | 6160 | 0.245 | 02.35 | 0.209 | 0.203 |
| 4000 | 45.8 | 21.5 | 14.3 | 11.5 | 6.95 |  |  |  |  |  |
| 5000 | 42.6 | 20.2 | 13.6 | 11.0 | 6.84 |  |  |  |  |  |
| 6000 | 40.1 | 18.9 | 12.9 | 10.6 | 6.72 |  |  |  |  |  |
| Bismuth. ${ }^{3}$ |  |  |  |  |  |  |  |  |  |  |
| H | +14.5 ${ }^{\circ}$ | +10 |  |  | $9^{\circ}$ |  | $9^{\circ}$ | $9^{\circ}$ | $269{ }^{\circ}$ | $270^{\circ}$ |
| 890 | 5.28 | 2.57 |  |  | 42 |  | II | 97 | 0.83 | 0.77* |

${ }^{1}$ Barlow, Ann. der Phys. 12, 1903.
${ }^{3}$ Traubenberg, Ann. der Phys. 17, 1905.
${ }^{2}$ Everdingen, Comm. Phys. Lab. Leiden, 58.

* Melting-point.

Both tables taken from Jahn, Jahrbuch der Radioactivität und Electronik, 5, p. 166; 1908, who has collected data of all observers and gives extensive bibliography.

Smithsonian Tables.

## RÖNTGEN (X-RAYS) RAYS.

## TABLE 489. - Cathode and Canal Rays.

Cathode (negative) rays consist of negatively charged particles (charge $4.77 \times 10^{-10}$ esu, $1.591 \times 10^{-30} \mathrm{emu}$, mass, $9 \times 10^{-28} \mathrm{~g}$ or $\mathrm{I} / 1800 \mathrm{H}$ atom, diam. $4 \times 10^{-13} \mathrm{~cm}$ ) emitted at low pressures in an electric discharge tube perpendicularly to the cathode ( $\therefore$ can be focused) with velocities ( $10^{9}$ to $10^{10} \mathrm{~cm} / \mathrm{sec}$.) depending on the acting potential difference. When stopped by suitable body they produce heat, ionization (inversely proportional to velocity squared), photographic action, X-rays, phosphorescence, pressure. The bulk of energy is transformed into heat ( $\mathrm{Pt}, \mathrm{Ta}$, W may be fused). In an ordinary X-ray tube carrying $10^{-3}$ ampere the energy given up may be of the order of $100 \mathrm{cal} / \mathrm{m}$. Maximum thickness of glass or Al for appreciable transmission of high speed particles is .0015 cm . Maximum velocity $V_{d}$ with which a cathode ray of velocity $V_{0}$ may pass through a material of thickness $d$ is given by $V_{0}{ }^{4}-V_{d^{4}}=a d \times 10^{40}$; $a=2$ for air, 732 for Al and 2540 for Au , cm-sec. units (Whiddington, 1912). Cathode rays have a range of only a few millimeters in air.

Canal (positive) rays move from the anode with velocities about $10^{8} \mathrm{~cm} / \mathrm{sec}$. in opposite direction to the cathode rays, carry a positive charge, a mass of the order of magnitude of the H molecule, cause strong ionization, fluorescence ( LiCl fluoresces blue under cathode, red under canal ray bombardment), photographic action, strong pulverizing or disintegrating power and by bombardment of the cathode liberate the cathode rays.

## TABLE 490. - Speed of Cathode Rays.

The speed of the cathode particles in $\mathrm{cm} / \mathrm{sec}$. as dependent upon the drop of potential to which they owe the speed, is given by the formula $v=5.95 \sqrt{E} \cdot 10^{7}$. The following table gives values of $5.95 \sqrt{E}$.


For voltages 1000 to 10,000 multiply 2 d line by 10 , etc.

## TABLE 491. - Cathodic Sputtering.

The disintegration of the cathode in an electric discharge tube is not a simple phenomenon: The particles taking part in the sputtering must be either large or of high speed or both (2000+ gauss field required for their deviation). It depends upon the nature of the residual gas. $\mathrm{H}, \mathrm{N}$, $\mathrm{CO}_{2}$ are not generally favorable; Ar is especially favorable, also $\mathrm{He}, \mathrm{Ne}, \mathrm{Kr}$ and Xe . Raised temperature favors it. The relative sputtering from various metals is shown in the following table (Crookes, Pr. R. S. 1891); the residual gas was air, pressure about . 05 mm Hg .


For further data on cathode, canal and X-rays, see X-rays by G. W. C. Kaye, Longmans, 1917, upon which much of the above and the following data for X-rays is based. See also J. J. Thomson, Positive Rays, Longmans, 1913.

X-rays are produced whenever and wherever a cathode ray hits matter. They are invisible, of the same nature as, and travel with the velocity of light, affect photographic plates, excite phosphorescence, ionize gases and suffer deviation neither by magnetic nor electric fields as do cathode rays. In an ordinary X-ray tube (vacuum order 0.001 to 0.01 mm Hg ) the cathode (concave for focusing, generally of aluminum) rays are focused on an anticathode of high atomic weight ( $\mathrm{W}, \mathrm{Pt}$, high a tomic weight, high melting point, low vapor pressure, to avoid sputtering, high thermal conductivity to avoid heating). Depth to which cathode rays penetrate, order of $0.2 \times 10^{-5} \mathrm{~cm}$ in $\mathrm{Pb}, 90,000$ volts (Ham, 1910), $24 \times 10^{-5} \mathrm{~cm}$ in Al, 22,000 volts (Warburg, 1915). Note: High speed H and He molecules ( $2 \times 10^{8} \mathrm{~cm} / \mathrm{sec}$.) can penetrate 0.001 to 0.006 mm mica; He a particles ( $2 \times 10^{9} \mathrm{~cm} / \mathrm{sec}$.), 0.04 mm glass.

The X-rays from an ordinary bulb consist of two main classes:
Heterogeneous ("general," "independent") radiation, which depends solely on the speed of the parent cathode rays. It is always present and its range of hardness (wave-lengths) depends on the range of speeds of the cathode rays. Its energy is proportional to the 4th power of these speeds.

Homogeneous ("characteristic," "monochromatic") radiation ( $K, L, M$, etc. radiations, see Table 498 for wave-lengths), characteristic of the metal of the anticathode. Generated only when cathode rays are sufficiently fast. There is a critical velocity for each characteristic radiation from each material, proportional to the atomic weight of the anticathode. The critical velocity for the $K$ radiation is $V_{K}=A \times 10^{8}$, when $A$ is the atomic weight of the radiator (e.g. anticathode); $V_{L}=1 / 2(A-48) \mathrm{IO}^{8}$.

The following relation has been found to hold experimentally between the voltage $V$ through which the cathode particles fall and the maximum frequency $\nu$ of the X-rays produced: eV $=h \nu$, where $e$ is the electronic charge and $h$, Planck's constant. Blake and Duane (Phys. Rev. $10,624,1917$ ) found for $h, 6.555 \times 10^{-27} \mathrm{erg}$ second.

As the speed of the cathode rays is increased, shorter and shorter wave-lengthed "independent" X-rays are produced until the critical speed is reached for the "characteristic" rays; with faster speeds, the cathode rays become at first increasingly effective for the characteristic radiation, then less so as the independent radiation again predominates.

When cathode rays hit the anticathode some 75 per cent are reflected, the more the heavier its atomic weight. The chances of the remainder hitting an atom so as to generate an X-ray are slight; only $\mathrm{I} / 1000$ or $\mathrm{I} / 2000$ of the original energy goes into X-rays. If $E_{x}$ and $E_{c}$ are the energies of the X and the parent cathode rays, $A$ the atomic weight of the anticathode, $\beta$ the velocity of the cathode rays as fraction of the light value ( $3 \times 10^{10} \mathrm{~cm} / \mathrm{sec}$.), Beatty showed (Pr. R. S. 1913) that $E_{x}=E_{c}\left(.5 \mathrm{I} \times 10^{4} A \beta^{2}\right)$; this refers only to the independent radiations; when characteristic radiations are excited their energy must be added and the tube becomes considerably more efficient. No quantitative expression for the latter has been developed.

When an X-ray strikes a substance three types of radiation result: scattered (sometimes called secondary) X-rays, characteristic X-rays and corpuscular rays (negatively charged particles). The proportions of the rays depend on the substance and the quality of the primary rays. When the substance is of low atomic weight, by far the greater portion of the X -rays, if of a penetrating type, are scattered. With elements of the Cr-Zn group most of the resulting radiation is "characteristic." With the Cu group the scattered radiation ( $\mathrm{I} / 200$ ) is negligible. Heavier elements, both scattered and characteristic X-rays. Corpuscular radiation greater, mass for mass, for elements of high atomic weight and may mask and swamp the characteristic radiation. Hence an X-ray tube beam, heterogeneous in quality, allowed to fall on different metals, $-\mathrm{Cu}, \mathrm{Ag}, \mathrm{Fe}$, Pt, etc., - excites characteristic X-rays of wide range of qualities. Exciting ray must be harder than the characteristic radiation wished. The higher the atomic weight of the material struck (radiator), the more penetrating the quality of the resulting radiation as shown by the following table, which gives $\lambda$, the reciprocal of the distance in cm in Al , through which the rays must pass in order that their intensity will be reduced to $I / 2.7$ of their original intensity.

TABLE 493. - Röntgen Secondary Rays.

| Radiator. | Cr | Fe | Co | Ni | Cu | Zn | As | Se | Sr | Ag | Sn |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Atomic weight $\lambda$ A........... | 52. 367. | 55.8 239. | 59.0 193. | 58.7 160. | 63.6 129. | 65.4 106. | 75.0 61. | 79.2 51. | $\begin{aligned} & 87.6 \\ & 35.2 \end{aligned}$ | 108. 6.75 | $\begin{aligned} & 119 . \\ & 4.33 \end{aligned}$ |

With the radiator at $45^{\circ}$ to the primary X-rays at most only about 50 per cent of the energy goes to characteristic rays and only about $\mathrm{I} / \mathrm{Io}$ of the latter escape the surface of the radiator. The $\beta$ radiations of radioactive elements may possibly be regarded (Rutherford) as a characteristic radiation produced by the expulsion of the a particles. The hardness of some corresponds to the $K$ and $L$ radiations.

For more complete data on X-rays, see X-rays, G. W. C. Kaye, Longmans, 1917, upon which these X-ray tables are greatly based.
Smithsonian tables.

## RÖNTGEN (X-RAYS) RAYS.

TABLE 494. - Corpuscular Rays.
Corpuscular rays are given off in greatest abundance when radiator emits its characteristic radiation. Intensity increases with atomic weight (.th power, Moore, Pr. Phys. Soc.). Greater number emitted at right angles to incident rays. Velocity range ( 6 to 8.5 ) $10^{\circ} \mathrm{cm} / \mathrm{sec}$. $v_{0}=$ velocity when leaving radiator $=10^{8}(A=$ Atomic weight $)=$ critical velocity necessary to excite characteristic radiation, therefore corpuscular rays have practically the same velocity as the original generating cathode rays. Are of uniform quality when excited by characteristic rays and follow exponential law of absorption in gases. If $\lambda$ is the absorption coefficient and $A$ the atomic weight, $\lambda A^{4}=\lambda 0_{0}{ }^{4}=$ constant (Whiddington, Beatty). $\lambda$ is defined by $I=I_{0} e^{-\lambda d}$ where $I$ and $I_{0}$ are the intensities after and before absorption and $d$ the thickness of the absorptive layer in cm . The following values for $\lambda$ in air for characteristic radiations from various substances are due to Sadler. (At $0^{\circ} \mathrm{C}$ and 76 cm Hg .)

| Metal emitting corpuscles. | Exciting characteristic radiation from |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Ni | Cu | Zn | As | Se | Sr | Mo | Rh | Ag | Sn |
| Al. | - | - | - | 29.6 | - | 20.0 | 15.2 | - | 8.90 |  |
|  | 38.9 | 37.0 | 35.8 | 30.2 | 26.4 | 21.5 20.8 | 15.5 | 10.9 | 8.84 | 6.41 |
|  |  |  | 36.2 | 30.4 | - |  | 15.2 | 10.8 | 8.81 | 6.67 |

## TABLE 495. - Intensity of X-Rays. Ionization.

The intensity of the radiation from an X-ray bulb is proportional to the current. Except at low voltages it equals $K i\left(v^{2}-v_{0}{ }^{2}\right)$ where $i$ is the current, $\nu$ the applied voltage, $v_{0}$ the break-down voltage and $K$ a constant for the tube (Krönke). The intensity of X-rays is most accurately measured by the ionization they produce. This may be referred to the International Radium Standard (see Table 508). It is proportional to the 4 th power of the speed of the parent cathode rays (Thomson), (true only of independent rays, Beatty, r913). The saturation current due to X-ray ionization is usually of the order of $10^{-10}$ to $10^{-15}$ ampere. When X-rays pass through a substance, only once in a while is an atom struck, only perhaps I in a billion, and ionized. The ionization is probably an indirect process through the mediation of corpuscular rays. In the absence of secondary radiations the ionization is proportional to the mass of the gas (that is, its pressure at constant temperature). It depends on the nature of the gas, but is little affected by the quality of the rays. The following results are due to Crowther, 1908.

| Gas or vapor. | Ionization relative to air $=1$. |  |  |
| :---: | :---: | :---: | :---: |
|  | Density, air $=\mathbf{I}$. | Soft X-rays 6 mm spark. | Hard X-rays 27 mm spark. |
| Hydrogen $\mathrm{H}_{2} \ldots$ | 0.07 | 0.01 | 0.18 |
| $\xrightarrow{\text { Carbon dioxide } \mathrm{CO}_{2} \ldots}$ Ethyl chloride $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Cl}$ | 1. 53 | 1.57 18.0 | I. 49 |
| Carbon tetrachloride $\mathrm{CCO}_{4}$ | 2.24 5.35 | 18.0 67. | ${ }_{71}^{17.3}$ |
| Ethyl bromide $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br} .$. | 3.78 |  | 118. |
| Methyl iodide $\mathrm{CH}_{3} \mathrm{I}$. | 4.96 | 145. | 125. |
| Mercury methyl $\mathrm{Hg}\left(\mathrm{CH}_{3}\right)_{2}$ | 7.93 | 425. | - |

## RÖNTGEN（X－RAYS）RAYS．

## TABLE 496．－Mass Absorption Coefficients，$\lambda / d$ ．

The quality by which X－rays have been generally classified is their＂hardness＂or penetrating power．It is greater the greater the exhaustion of the tube，but for a given tube depends solely upon the potential difference of the elec－ trodes．With extreme exhaustion the X－rays have an appreciable effect after passing through several millimeters of brass or Al．The penetrability of the characteristic radiation is in general proportional to the 5 th power of the atomic weight of the radiator．The absorption of any substance is equal to the sum of the absorptions of the individual atoms and is independent of the chemical combination，its physical state and probably of the temperature．Most of the following table is from the work of Barkla and Sadler，Phil．Mag．17，739，1909．For starred radiators，$L$ radiations used；for others the $K$ ．

If $I_{0}$ be the intensity of a parallel beam of homogeneous radiation incident normally on a plate of absorbing material of thickness $t$ ，then $I=I_{0} e^{-\lambda x}$ gives the intensity $I$ at the depth $x$ ．Because of the greater homogeneity of the secondary X－rays they were used in the determination of the following coefficients．The coefficients $\lambda$ have been divided by the density $d$ ．

| Radiator． | Absorber． |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | c | Mg | ${ }^{\text {al }}$ | Fe | Ni | Cu | $\mathrm{Zn}^{\text {n }}$ | $\mathrm{Ag}^{8}$ | Sn | Pt | Au |
| $\mathrm{Cr}_{\mathrm{r}}$ | $\begin{aligned} & 15.3 \\ & 10.1 \\ & 10.1 \\ & \hline 6.6 \\ & 5.6 \\ & 4.3 \\ & . .5 \\ & 2.06 \\ & .46 \\ & .35 \\ & .37 \\ & .29 \\ & \hline 20 \\ & \hline \\ & \hline \\ & \hline \end{aligned}$ |  |  | rot． | 129. | ${ }^{4} 3$. | 170. | 58. | 74. | （517．） | （507．） |
|  |  |  |  | ${ }^{60} 6$ | ${ }^{64 .}$ | ${ }^{\text {955．}}$ |  |  | ${ }_{392}^{472 .}$ | ${ }^{380}$ 285． | ${ }_{3}^{366 .}$ |
|  |  |  |  | cis． | ${ }_{5}^{56 .}$ | ${ }_{53}^{62 .}$ | 74． | ${ }^{2262}$ 224． | ${ }^{3282}$ 272． | ${ }^{236}{ }^{236}$. | 253． 210 |
|  |  |  |  | cos， |  |  | － 50. | （125． | － 2725 |  |  |
|  |  |  |  |  | ${ }_{14}^{100}$ | 150. | － | 88． | （122． | －${ }^{96}$ |  |
|  |  |  |  | ${ }^{\text {17．}}$ | $\stackrel{23}{23}$ | $\stackrel{\text { 24．}}{ }$ | $\underline{ }$ |  | $\stackrel{10}{-}$ | ${ }_{47}{ }_{47}{ }^{56}$. | 52. |
|  |  |  |  | － | － | 二 | 二 | ${ }_{46}{ }^{56}$ | 二 | 二 |  |
| ${ }_{\text {W }}{ }_{\text {di }}$＊ |  |  |  | 二 | － | 127． | 二 | ${ }_{\text {3 }}^{35} \times$ | 二 | ${ }_{133}$ |  |
|  |  |  |  | 二 | 二 | ${ }_{\substack{177 \\ 130}}$ | 二 | ${ }_{1}^{106}$ | － | （13） |  |
|  |  |  |  | 二 | 二 | ${ }^{1227}$ 127： | 二 | 行， | 二 | $\xrightarrow[\substack{125 \\ \\ 125 \\ 135}]{ }$ |  |
|  |  |  |  | ＝ | － | ${ }^{77}$ |  | ${ }_{4}^{42}$ | 二 |  |  |

## TABLE 497．－Absorption Coefficients of Characteristic Radiations in Gases．

The penetrating power of X－rays ranges in normal air from I to $10,000 \mathrm{~cm}$ or more．The absorptive power of I cm air $=1 / 820$ that of water．$\lambda$（see preceding table for definition）for air for soft bulb（ 1.5 to 5 cm spark gap， 4 to 10 m air）ranges from ．0010 to ．0018；for hard bulb（ 30 cm spark gap， 4 to 10 m air）， .00029 ．（Eve and Day，Phil． Mag．1912．）The absorption coefficient for gases for characteristic or monochromatic radiations varies directly with the pressure．For different characteristic radiations it is proportional to the coefficients in air．It varies with the 5 th power of the atomic weight of the radiator．The following table is taken from Kaye＇s X－rays and is based on the work of Barkla and Collier（Phil．Mag．1912）and Owen．All are for the gas at $0^{\circ} \mathrm{C}$ and 76 cm Hg ．

|  | Air |  | $\mathrm{CO}_{2}$ |  | $\mathrm{SO}_{2}$ |  | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{Br}$ |  | $\mathrm{CH}_{3} \mathrm{I}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\lambda$ | $\lambda / d$ | $\lambda$ | $\lambda / d$ | $\lambda$ | $\lambda / d$ | $\lambda$ | $\lambda / d$ | $\lambda$ | $\lambda / d$ |
| Fe ． | ． 0202 | 15.6 | ． 0456 | 23.1 | ． 24 | 83.3 | ． 512 | ${ }_{8}^{105 .}$ | 2.16 | 339. |
| Ni． | ． 0136 | 10．5 | ．0319 | 16.1 | ． 166 | 89.4 57.6 | ． 325 | 66．3 | 1.80 | 282. |
|  | ． 0109 | 8.43 | ． 0227 | 1 I .5 | ． 134 | 46.5 | ． 260 | 53． 1 | ${ }_{\text {I }}^{1.54}$ | 241. |
| As． | ． 0090 | 6.96 4.10 | ． 0184 | 9．31 5.00 coin | ．112 | 38.9 <br> 22.9 | － 2128 | ${ }_{26.9}^{43.9}$ |  | ${ }_{118}^{198 .}$ |
|  | ．0044 | 3.40 | ． 00788 | 3.96 3.96 | ． 0546 | 19.1 | ．110 | 22.4 | ． 619 |  |
| $\stackrel{\mathrm{Br}}{\mathrm{Sr}}$ | ． 0039 | 3．02 | － |  | ． 050 | ${ }^{17.4}$ | ． 096 | 19.6 66.3 | ． 553 | 86.5 53.0 |
|  | －0023 | 1．78 0.98 | ． 000428 | 2．12 | －．0281 | 9.76 5.56 | ． 2125 | 66.3 42.9 | ． 197 | 53.0 30.9 |
| Ag． | ． 00077 | 0.59 | － | $\underline{1.42}$ | ． 0079 | ${ }_{2}$ | ． 108 | 22.0 | .113 | 17.7 |

Kaye has shown that an element excited by sufficiently rapid cathode rays emits Röntgen rays characteristic of that substance．These were analyzed and the wave－lengths determined by Moseley（Phil．Mag．27，703，1914），using a crystal of potassium ferrocyanide as a grating．He noted the K series，showing two lines，and the L series with several． He found that every element from Al to Au was characterized by integer $N$ ，which determines its X －ray spectrum； $N$ is identified with the number of positive units associated with its atomic nucleus．The order of these atomic num－ bers $(N)$ is that of the atomic weights，except where the latter disagrees with the order of the chemical properties． Known elements now correspond with all the numbers between $I$ and 92 except 6 ．There are here six possible elements still to be discovered（atomic nos．43，61，72，75，85）．

The frequency of any line in an X－ray spectrum is approximately proportional to $A(N-b)^{2}$ ，where $A$ and $b$ are constants．All $\mathbb{X}$－ray spectra of each series are similar in structure，differing only in wave－lengths． $\mathrm{Q}_{K}=\left(0 / \frac{2}{3} 0\right)$ ； $Q_{L}=\left(v / \mathrm{s}_{\mathrm{d}}^{\mathrm{s}} v_{0}\right)$ where $v$ is the frequency of the $\alpha$ line and $v_{0}$ the fundamental Rydberg frequency．The atomic number for the $K$ series $=\mathrm{Q}_{K}+\mathrm{I}$ and for the $L$ series， $\mathrm{Q}_{L}+7.4$ approximately．$v_{0}=3.29 \times 10^{15}$

Moseley＇s work has been extended，and the following tables indicate the present（1919）knowledge of the X－ray spectra．
（a）K Series（Wave－lengths，$\lambda \times 10^{8} \mathrm{~cm}$ ）．

| Element， atomic number． | $\beta_{2}$ | $\beta_{1}$ | $a_{4}$ | $\begin{gathered} a_{3} a_{4} \\ \text { (not } \\ \text { separable) } \end{gathered}$ | $\alpha_{3}$ | $a_{1}$ | $\begin{gathered} a_{1} a_{2} \\ \text { (not } \\ \text { separable) } \end{gathered}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 11 Na | － | － | － | － | － | － | 11.951 |  | － |
| $\begin{array}{ll}12 & \mathrm{Mg} \\ 13\end{array}$ | 二 | 9.477 7 | 9.845 8.400 | 二 | 9．856 | 二 | 9．915 |  |  |
| ${ }_{14}{ }_{4} \mathrm{Si}$ | 二 | 9． 6.759 | 7.080 | － | 7.088 | － | 7.131 |  | － |
| $15 \quad \mathrm{P}$ | － | 5.808 | 6.122 |  | 6.129 | － | 6.168 |  |  |
| 16 S |  | 5.018 | 5.314 |  | 5.317 |  | 5．360 |  |  |
| ${ }_{18}^{17} \mathrm{Cl}$ | － | 4.394 | － | 4.692 | － | 二 | 4.712 |  | － |
| $\begin{array}{ll}18 & \mathrm{Ar} \\ 19 & \mathrm{~K}\end{array}$ |  |  |  |  |  |  | － |  | 738 |
| ${ }_{20}{ }^{19} \mathrm{C}$ | 3.074 | 3.449 3.086 | 二 | 3.724 3.328 | 二 | 3.735 3.355 | 二 |  | ． 738 |
| ${ }^{21} \mathrm{Sc}$ |  | 2.778 |  | 3.011 |  | 3.028 |  |  | ．032 |
| $\begin{array}{ll}22 & \mathrm{Ti} \\ 23 & \mathrm{Va}\end{array}$ | 2.492 | 2.309 2.281 | 二 | 2.729 | 二 | ${ }^{2} .742$ | － |  | ． 746 |
|  |  | 2.281 |  |  |  | 2.498 | － |  | ． 502 |
| Element， atomic number． | $\beta_{2}$ | $\beta_{1}$ | $a_{1}$ | $\alpha_{2}$ | Element， atomic number． | $\beta_{2}$ | $\beta_{1}$ | $a_{1}$ | $a s$ |
| 24 Cr | 2.069 | 2.079 | 2.284 | 2.288 | 43 | － | － | － | － |
| $\begin{array}{ll}25 & \mathrm{Mn} \\ 26 & \mathrm{Fe}\end{array}$ | 1.802 | 1．902 | 2.093 | 2.097 | $\begin{array}{ll}44 & \mathrm{Ru} \\ 45 & \mathrm{Rh}\end{array}$ | － 537 | 0． 574 | 0．645 | $\overline{6}$ |
| 27 Co | 1． 602 | I． 613 | r． 78 r | 1.932 1.785 | $\begin{array}{ll}46 & \mathrm{R} \\ 46\end{array}$ | －0． 537 | ． 501 | ． 662 | ． 567 |
| 28 Ni | 1.488 | I． 497 | 1.653 | 1． 657 | 47 Ag | ． 491 | ． 501 | －562 | ． 567 |
| 29 Cu | 1． 379 | 1．391 | I． 539 | I． 543 | 48 Cd |  | ． 479 | ． 538 | ． 543 |
| ${ }_{30}{ }^{\circ} \mathrm{Zn}$ | 1.281 | 1． 294 | I． 433 | 1． 437 | 49 In | ． 440 | ． 453 | ． 510 | ． 515 |
| $\begin{array}{ll}31 & \mathrm{Ga} \\ 32 & \mathrm{Ge}\end{array}$ | 1．121 | I． 206 r． 131 | 1.338 1.257 | I． 342 I． 251 I | $\begin{array}{lll}50 & \mathrm{Sn} \\ 5 \mathrm{I} & \mathrm{Sb}\end{array}$ | ． 408 | .432 .416 | ． 487 | －472 |
| 33 As | 1.038 | ＋ x .052 | I． 170 | 1.251 1.174 | ${ }_{52} 5 \mathrm{Te}$ | － | ． 404 | .456 | －472 |
| ${ }_{34} \mathrm{Se}$ | － | －． 993 | I． 104 | I． 109 | 53 I | － | ． 388 | ． 437 | － |
| 35 Br | 0.914 | ． 929 | 1.035 | 1． 040 | 54 X | － | － | － | － |
| 36 Kr | $\overline{813}$ | － | － | － | 55 Cs | － | ． 352 | － 398 | ． 402 |
| ${ }_{37}^{37} \mathrm{Rb}^{\text {R }}$ | ． 813 | ． 825 | 0.922 | 0.926 | 56 Ba | － | － 343 | － 388 | － 393 |
| $\begin{array}{ll}38 & \mathrm{Sr} \\ 39 & \mathrm{Y}\end{array}$ | .767 .733 | .779 .746 | ． 871 | ． 876 | $\begin{array}{ll}57 & \mathrm{La} \\ 58 & \mathrm{Ce}\end{array}$ | 二 | .329 .314 . | .372 .355 .3 | .376 .360 |
| 40 Zr | － | ． 705 | ． 788 | ． 793 | 59 Pr | 二 | －301 | －342 | ． 347 |
| $\begin{array}{ll}4 \mathrm{I} & \mathrm{Nb} \\ 42\end{array}$ | ． 657 | ． 669 | ． 749 | － 754 | 60 Nd | － | ． 292 | －330 | － 335 |
| 42 Mo | － | ． 633 | ． 710 | ． 714 | 74 W |  | ． 177 | ． 203 | ． 335 |

Smithsonian Tables．
(b) L Series (Wave-lengths, $\lambda \times 10^{8} \mathrm{~cm}$ ).


Smithsonian Tables.
（b）L Series（Wave－lengths，$\lambda \times 10^{8} \mathrm{~cm}$ ）．

|  |  | $\beta_{4}$ | $\beta_{1}$ | $\beta_{2}$ | $\beta_{3}$ | $\beta_{5}$ | $\gamma_{1}$ | $\gamma_{2}$ | $\gamma_{3}$ | $\gamma_{4}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 66 | Dy | 1.721 | 1.709 | 1.622 | 1． 683 | － | 1.470 | 1． 422 | 1.418 | － |
| 67 | Ho | 1.657 | 1.646 | 1． 568 | 1.620 | － | 1． 415 | 1． 369 | I． 365 | － |
| 68 | Er | 1． 599 | 1． 586 | 1． 514 | I． 560 | － | I． 367 | 1． 323 | 1． 316 | － |
| 70 | Ad | 1． 490 | 1.474 | 1.414 | 1．451 | 1． 422 | I． 267 | 1． 228 | 1． 223 | － |
| 71 | Cp | 1.437 | 1.421 | 1． 368 | I． 399 | － | I． 224 | I． 188 | I． 183 | － |
| 73 | Ta | 1． 343 | 1.323 | 1． 280 | 1.303 | － | 1． 135 | 1． 101 | 1.097 | － |
| 74 | W | I． 296 | 1． 278 | 1.241 | I． 258 | － | I． 105 | I． 064 | 1.058 | － |
| 76 | Os | I． 214 | 1． 194 | 1．167 | I． 176 | － | 1.021 | － |  | － |
| 77 | Ir | 1． 176 | 1.154 | 1． 133 | 1． 138 | 1.101 | 0.989 | 0.962 | 0.956 | 0.917 |
| 78 | Pt | 1． 142 | 1． 120 | 1． 101 | 1．098 | 1.072 | 0.958 | 0.933 | 0.929 | 0.900 |
| 79 | Au | 1.102 | 1.080 | 1． 065 | I． 059 | 1.035 | 0.922 |  | 0.894 | 0.869 |
| 80 | Hg | － | 1.049 | 1．042 | － | － | 0.896 | － |  | － 80 |
| 8 I | T1 | 1.036 | 1.012 | 1.006 | 0.998 | 0.977 | 0.864 | 0.844 | 0.840 | 0.808 |
| 82 | Pb | － 1.008 | 0.983 | 0.983 | 0.968 | － | 0.842 | 0.820 | 0.816 | 0.792 |
| 83 | ${ }_{\mathrm{Pi}}$ | 0.977 | 0.950 | 0.954 | 0.937 | 0.923 | 0.810 | －0．794 | 0.790 | 0． 762 |
| 84 | Po | － | 0.920 | ， | － | － | － |  | － | － |
| 88 | Ra | 二 | － 76 | － 707 |  | － |  |  |  | － |
| 90 | ${ }_{\mathbf{U}}^{\mathrm{Th}}$ | 二 | 0.766 0.720 | 0.797 0.756 | $\begin{aligned} & 0.758 \\ & 0.710 \end{aligned}$ | － | 0.654 0.615 |  |  | 二 |
| 92 | U | － | 0.720 | 0.756 | 0.710 | － | 0.615 |  |  | － |

（c）M Series（Wave－Lengths，$\lambda \times 10^{8} \mathrm{Cm}$ ）．

|  |  | $a$ | $\beta$ | $\gamma_{1}$ | $\gamma_{2}$ | $\delta_{1}$ | $\delta_{2}$ | $\boldsymbol{\epsilon}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 79 | Au | 5.838 | 5.623 | 5.348 | 5.284 | 5.146 | 5.102 | － |
| 81 | Tl | 5.479 | 5.256 | － | － | － | 4.826 | 4.735 |
| 82 | Pb | 5.303 | 5.095 | 4.910 | － | － | 4.695 | － |
| 83 | Bi | 5.117 | 4.903 | 4． 726 | － | 4．56I | 4.532 | 4.456 |
| 90 | $\mathrm{Th}^{\text {a }}$ | 4． 139 | 3.941 | 3.812 | 3.678 | － | － | － |
| 92 | U | 3.905 | 3.715 | － | 3.480 | 3.363 | 3.324 |  |

Reference：Jahrbuch der Radioaktivität und Elektronik，13，296， 1916.
（d）Tungsten X－ray Spectrum（Wave－tengths，$\lambda \times 10^{8} \mathrm{~cm}$ ）．
The wave－lengths of the tungsten X－ray spectrum have been measured more frequently than those of any other element．The following values are perhaps the most accurate that have hitherto been published．Compton，Physical Review，7，646，1916（errata，8，753，1916）．

| Line． | $\lambda$ | Line． | $\lambda$ | Line． | $\lambda$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1.0249 |  | 1． 2185 |  | 1． 3363 |
| $b$ | 1． 0399 | $f$ | 1.2420 | $k$ | I． 4735 |
| $c^{\prime \prime}$ | 1． 0582 | $g$ | 1． 2601 | $l$ | I． 4844 |
| ${ }^{\text {c }}$ d | 1． 0652 | $h$ | 1． 2787 |  |  |
| d | 1． 0959 | $i$ | 1． 2985 |  |  |

Other references on the X－ray spectrum of tungsten：Gorton，Physical Review，7，203，1916；Hull，Proc．Nat． Acad．Sci．2，265，1916；Dershem，Physical Review，11，461，1918；＇Overn，Physical Review，14，137， 1919.
The following values for tungsten are from Duane and Patterson，Phys．Rev．16，p．526， 1920 ：

| Critical Absorption wave－lengths $\times 10^{8} \mathrm{~cm}$ ． |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Ka | .17806 | L，$a_{1}$ | 1.2136 | $1 . \alpha_{2}$ | 1.0726 | $\mathrm{La}_{3}$ | 1.024 |  |  |
| Emission wave－length $\times 10^{8} \mathrm{~cm}$ ． |  |  |  |  |  |  |  |  |  |
| K $a_{2}$ | ．2134 ${ }^{\text {r }}$ | $\mathrm{Ka}_{1}$ | ． 20860 | K $\beta$ | ． 18420 | K $\lambda$ | 17901 |  |  |
| 1. | 1.6756 | $\mathrm{L}_{2}$ | 1.4839 | $\mathrm{L}_{1}$ | 1.47306 | $\mathrm{L} \eta$ | 1.4176 |  |  |
| ${ }_{\text {L }} \mathrm{L}_{1} \beta_{4}$ | 1.2985 | ${ }_{\text {L }} \mathrm{L}_{1} \mathrm{r}_{1}$ | 1．27892 | ${ }_{L} \beta_{3}$ | 1.2601 | $\mathrm{L}^{2} \mathrm{~g}_{2}$ | 1.24193 | L $\boldsymbol{\beta}_{5}$ | 1.2040 |
| $L_{\gamma_{1}}$ | 1.09608 | $\mathrm{L}_{2}$ | 1.0655 | $\mathrm{Lr}_{3}$ | 1.0596 | L $\gamma_{4}$ | 1.0261 |  |  |

## Smithsonian tables．

A marked increase in the absorption of X-rays by a chemical element occurs at frequencies close to those of the X-rays characteristic of that element. The absorption coefficient is much greater on the short wave-length side. In the K series the $a$ lines are much stronger than the corresponding $\beta$ and $\gamma$ lines, but the wave-lengths of the $\alpha$ lines are greater. There is a marked increase in the absorption at wave-lengths considerably shorter than the $a$ lines and near the $\beta$ lines. Bragg came to the conclusion that the critical absorption frequency lay at or above the $\gamma$ of the K series. The $\gamma$ line has a frequency about I per cent higher than the corresponding $\beta$ line. For the L series there are 3 characteristic marked absorption changes (de Broglie).

The critical absorption wave-lengths of the following table are due to Blake and Duane, Phys. Rev. 10, 697, 1917. The equation $\nu=\nu_{0}(N-3.5)^{2}$ where $\nu$ is Rydberg's fundamental frequency ( $109,675 \times$ the velocity of light) and $N$ the atomic number, represents the data with considerable accuracy. The nuclear charge is obtained by $Q=2 e(N-3.5)$.

| Element. | Atomic number. | ÅU | Element. | Atomic number. | ÅU | Element. | Atomic number. | ÅU |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Bromine. | 35 | .9179 | Ruthenium | 44 | . 5584 | Tellurium.. | 52 | . 3896 |
| Krypton | 36 | - | Rhodium.. | 45 | . 5324 | Iodine.... | 53 | . 3727 |
| Rubidium. | 37 | . 8143 | Palladium. | 46 | . 5075 | Xenon.. . . | 54 | - |
| Strontium. | 38 | . 7696 | Silver.... . | 47 | . 4850 | Caesium... | 55 | . 3444 |
| Yttrium. | 39 | . 7255 | Cadmium.. | 48 | . 4632 | Barium.... | 56 | . 3307 |
| Zirconium.... | 40 | . 6872 | Indium... | 49 | . 4434 | Lanthanum | 57 | . 3188 |
| Columbium . . | 41 | . 6503 | Tin.. . . . . | 50 | . 4242 | Cerium.... | 58 | . 3073 |
| Molybdenum. | 42 | .6180 | Antimony. | 51 | . 4065 |  |  |  |

Smithsonian Tables.

Radioactivity is a property of certain elements of high atomic weight. It is an additive property of the atom, dependent only on it and not on the chemical compound formed nor affected by physical conditions controlling ordinary reactions, viz: temperature, whether solid or liquid or gaseous, etc.

With the exception of actinium, radioactive bodies emit $\boldsymbol{\alpha}, \boldsymbol{\beta}$, or $\boldsymbol{\gamma}$ rays. $\boldsymbol{a}$ rays are easily absorbed by thin metal foil or a few cms. of air and are positively charged atoms of helium emitted with about $1 / 15$ the velocity of light. They are deflected but very slightly by intense electric or magnetic fields. The $\beta$ rays are on the average more penetrating, are negatively charged particles projected with nearly the velocity of light, easily deflected by electric or magnetic fields and identical in type with the cathode rays of a vacuum tube. The $\gamma$ rays are extremely penetrating and non-deviable, analogous in many respects to the very penetrating Röntgen rays. These rays produce ionization of gases, act on the photographic plate, excite phosphorescence, produce certain chemical reactions such as the formation of ozone or the decomposition of water. All radioactive compounds are luminous even at the temperature of liquid air.
Table 506 is based very greatly on Rutherford's Radioactive Substances and their radiations (Oct. 1912). To this and to Landolt-Börnstein Physikalisch-chemische Tabellen the reader is referred for references. In the three radioactive series each successive product (except Ur. Y, and Ra. $\mathrm{C}_{2}$ ) results from the transformation of the preceding product and in turn produces the following. When the change is accompanied by the ejection of an a particle (helium, atomic weight $=4.0$ ) the atomic weight decreases by 4. The italicized atomic weights are thus computed. Each product with its radiation decays by an exponential law; the product and its radiation consequently depend on the same law. $I=I_{0} e^{-\lambda t}$ where $I_{0}=$ radioactivity when $t=O, I$ that at the time $\mathfrak{t}$, and $\lambda$ the transformation constant. Radioactive equilibrium of a body with its products exists when that body is of such long period that its radiation may be considered constant and the decay and growth of its products are balanced.
International radium standard: As many radioactivity measures depend upon the purity of the radium used, in 1912 a committee appointed by the Congress of Radioactivity and Electricity, Brussels, 1910, compared a standard of 21.99 mg . of pure Ra. chloride sealed in a thin glass tube and prepared by Mme. Curie with similar standards by Hönigschmid and belonging to The Academy of Sciences of Vienna. The comparison showed an agreement of 1 in 300 . Mme. Curie's standard was accepted and is preserved in the Bureau international des poids et mesures at Sèvres, near Paris. Arrangements have been made for the preparation of duplicate standards for governments requiring them.

TABLE 500. - Relative Phosphorescence Excited by Radium.
(Becquerel, C. R. 129, p. 912, 1899.)


The screen of black paper absorbed most of the a rays to which the phosphorescence was greatly due. For the last column the intensity without screen was taken as unity. The $\gamma$ rays have very little effect.

TABLE 501. - The Production of a Particles (Helium).
(Geiger and Rutherford, Philosophical Magazine, 20, p. 691, 19ro.)


TABLE 502. - Heating Effect of Radium and its Emanation.
(Rutherford and Robinson, Philosophical Magazine, 25, p. 312, 1913.)

| Heating effect in gram-calories per hour per gram radium. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | a rays. | $\beta$ rays. | $\gamma$ rays. | Tonal. |
| Radium. | 25.1 | - | - | 25.1 28.6 |
|  | 28.6 30.5 | - | - | 30.5 |
| Radium B + C . | 39.4 | 4.7 | 6.4 | 50.5 |
| Totals | 123.6 | 4.7 | 6.4 | 134.7 |

[^54]Tables 503-505.
RADIOACTIVITY.
TABLE 503.-Stopping Powers of Various Substances for $\alpha$ Rays.
s, the stopping power of a substance for the a rays is approximately proportional to the square root of the atomic weight, w.

|  | $\begin{gathered} \mathrm{H}_{2} \\ .24 \\ .26 \end{gathered}$ | Air 1.0 1.0 | $\begin{gathered} \mathrm{O}_{2} \\ \mathrm{I} .05 \\ \mathrm{I} .05 \end{gathered}$ | $\mathrm{C}_{2} \mathrm{H}_{2}$ I 111 I .17 | $\begin{gathered} \mathrm{C}_{2} \mathrm{H}_{4} \\ 1.35 \\ \mathbf{1} .44 \end{gathered}$ | $\begin{aligned} & \text { Al } \\ & \text { I. } 45 \\ & \mathbf{1 . 3 7} \end{aligned}$ | $\begin{gathered} \mathrm{N}_{2} \mathrm{O} \\ 1.46 \\ 1.52 \end{gathered}$ | $\begin{gathered} \mathrm{CO}_{2} \\ 1.47 \\ 1.5 \mathrm{I} \end{gathered}$ | $\mathrm{CH}_{3} \mathrm{Br}$ 2.09 2.03 | $\begin{gathered} \mathrm{CS}_{2} \\ 2.18 \\ 1.95 \end{gathered}$ | $\begin{aligned} & \mathrm{Fe} \\ & 2.26 \\ & \mathrm{I} .97 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Substance | Cu | Ni | Ag | Sn | $\mathrm{C}_{6} \mathrm{H}_{6}$ | $\mathrm{C}_{5} \mathrm{H}_{12}$ | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ | $\mathrm{CCl}_{4}$ | Pt | Au | Pb |
| s . | 2.43 | 2.46 | 3.17 | $3 \cdot 37$ | 3.37 | 3.59 | 3.13 | 4.02 | 4.16 | 4.45 | 4.27 |
| $\downarrow$ w . . . | 2.10 | 2.20 | 2.74 | 2.88 | $3 \cdot 53$ | 3.86 | 3.06 | $3 \cdot 59$ | 3.68 | 3.70 | 3.78 |

Bragg, Philosophical Magazine, 11, p. 67, 1906.

TABLE 504, - Absorption of $\beta$ Rays by Various Substances.
$\mu$, the coefficient of absorption for $\beta$ rays is approximately proportional to the density, D. See Table 500 for $\mu$ for Al.

| Substance $\mu / D$ Atomic Wt. | $\begin{gathered} \mathrm{B} \\ 4.65 \\ \text { II } \end{gathered}$ | $\begin{gathered} C \\ 4.4 \\ 12 \end{gathered}$ | $\begin{aligned} & \mathrm{Na} \\ & 4.95 \\ & 23 \end{aligned}$ | $\begin{array}{r} \mathrm{Mg} \\ 5 . \mathrm{I} \\ 24 \cdot 4 \end{array}$ | $\begin{aligned} & \mathrm{Al} \\ & 5.26 \\ & 27 \end{aligned}$ | $\begin{aligned} & \mathrm{Si} \\ & 5 \cdot 5 \\ & 28 \end{aligned}$ | $\begin{gathered} P \\ \text { C. } \\ 31 \end{gathered}$ | $\begin{gathered} \mathrm{S} \\ 6.6 \\ 32 \end{gathered}$ | $\begin{aligned} & \mathrm{K} \\ & 6.53 \\ & 39 \end{aligned}$ | $\begin{aligned} & \mathrm{Ca} \\ & 6.47 \\ & 40 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Substance $\mu / \mathrm{D}$ Atomic Wt. | $\begin{array}{r} \mathrm{Ti} \\ 6.2 \\ 48 \end{array}$ | $\begin{gathered} \mathrm{Cr} \\ 6.25 \\ 52 \end{gathered}$ | $\begin{gathered} \mathrm{Fe} \\ 6.4 \\ 56 \end{gathered}$ | $\begin{gathered} \text { Co } \\ 6.48 \\ 59 \end{gathered}$ | $\begin{array}{r} \mathrm{Cu} \\ 6.8 \\ 63 \cdot 3 \end{array}$ | $\begin{gathered} \mathrm{Zn} \\ 6.95 \\ 65.5 \end{gathered}$ | $\begin{array}{r} \mathrm{Ar} \\ 8.2 \\ 75 \end{array}$ | $\begin{aligned} & \mathrm{Se} \\ & 8.65 \\ & 79 \end{aligned}$ | $\begin{array}{r} \mathrm{Sr} \\ 8.5 \\ 87.5 \end{array}$ | $\begin{array}{r} \mathrm{Zr} \\ 8.3 \\ 90.7 \end{array}$ |
| Substance $\mu / \mathrm{D}$ Atomic Wt. | $\begin{gathered} \mathrm{Pd} \\ 8.0 \\ 106 \end{gathered}$ | $\begin{aligned} & \mathrm{Ag} \\ & 8.3 \\ & 108 \end{aligned}$ | $\begin{aligned} & \mathrm{Sn} \\ & 9.46 \\ & 118 \end{aligned}$ | $\begin{gathered} \mathrm{Sb} \\ 9.8 \\ \mathrm{I} 20 \end{gathered}$ | $\begin{gathered} \text { I } \\ 10.8 \\ 126 \end{gathered}$ | $\begin{aligned} & \mathrm{Ba} \\ & 8.8 \\ & 137 \end{aligned}$ | $\begin{aligned} & \mathrm{Pt} \\ & 9.4 \\ & 195 \end{aligned}$ | $\begin{aligned} & \mathrm{Au} \\ & 9.5 \\ & 197 \end{aligned}$ | $\begin{array}{r} \mathrm{Pb} \\ 10.8 \\ 207 \end{array}$ | $\begin{gathered} \mathrm{U} \\ 10.1 \\ 2.40 \end{gathered}$ |

For the above data the $\beta$ rays from Uranium were used.
Crowther, Philosophical Magazine, 12, p. 379, 1906.
TABLE 505 , - Absorption of $\gamma$ Rays by Various Substances.

| Substance. | Density. | Radium rays. |  | Uranium rays. |  | $\underset{\mu(\mathrm{cm})^{-1}}{\text { Th. }}$ | $\underset{\mu(\mathrm{cm})^{-1}}{\text { Meso. Th }_{2}}$ | Range of thickness cm . |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\mu(\mathrm{cm})^{-1}$ | 100 $\mu$ /D | $\mu(\mathrm{cm})^{-1}$ | $100 \mu / \mathrm{D}$ |  |  |  |
| Hg | 13.59 | . 642 | 4.72 | . 832 | 6.12 |  |  | . 3 to 3.5 |
| Pb . . | 11.40 | . 495 | $4 \cdot 34$ | .725 | 6.36 | . 462 | . 620 | .0" 7.9 |
| Cu . | 8.81 | -351 | 3.98 | .416 | 4.72 | . 294 | . 373 | .0 7.6 <br> 0.6  |
| Brass | 8.35 | . 325 | 3.89 | -392 | 4.70 | .271 .250 | . 355 |  |
| Fe . | 7.62 | -304 | 3.99 | -360 | 4.72 4.70 | .250 .236 | . 316 |  |
| Sn | 7.24 | .281 | 3.88 | -341 | 4.70 4.65 | . 233 | . 305 |  |
| Zn . | 7.07 2.85 | . 228 | 3.93 4.14 | .329 .134 | 4.65 4.69 | . 096 | -300 | .0  <br> .0  <br> .0  |
| Al . | 2.77 | . 111 | 4.06 | .130 | 4.69 | .092 | . 119 | .0"11.2 |
| Glass | 2.52 | . 105 | 4.16 | . 122 | 4.84 | .o89 | . 113 | . 0 " 11.3 |
| S . . . | 1.79 | . 078 | $4 \cdot 38$ | . 092 | 5.16 | . 066 | . 083 | . $0^{\prime \prime} 11.6$ |
| Paraffin . | . 86 | . 042 | 4.64 | . 043 | 5.02 | .031 | . 050 | .0" II. 4 |

In determining the above values the rays were first passed through one cm . of lead.
Russell and Soddy, Philosophical Magazine, 28, p. 130, 19 ri.

## RADIOACTIVITY．

$P=1 / 2$ period $=$ time when body is one half transformed．$\quad \lambda=$ transformation constant（see previous page）． The initial velocity of the $a$ particle is deduced from the formula of Geiger $V^{3}=a R$ ，where $R=$ range and assuming the velocity for $R a C$ of range 7.06 cm ．at $20^{\circ}$ is $2.06 \times 10^{\circ} \mathrm{cm}$ per sec．，i．e．，$v=1.077 R^{\frac{1}{3}}$ ．
Uranium－radium Group．

|  | Atomic weights． | $\mathrm{I}_{P}^{\mathrm{I} 2} \underset{P}{\text { period; }}$ | Transforma－ tion constants．$\lambda=\frac{.6931}{P}$ | Rays． | a rays． |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | Range． <br> ${ }^{760}{ }^{\text {ma }}{ }^{\circ} \mathrm{C}$ ， | Initial velocity． | Kinetic energy． | Whole no． of ions produced． |
|  |  |  |  |  | cm | cm per $s$ | Ergs． | By an $a$ particle． |
| Uranium ${ }_{\text {I }}$ ．． | 238.2 | $5 \times 10^{9} \mathrm{y}$ ． | 1． $4 \times 10^{-10} \mathrm{y}$. | ${ }_{\beta}^{+}{ }_{\beta}^{+}$ | ${ }^{2} .50$ | ${ }^{1.45 \times 109}$ | $.^{6} \times{ }^{10-5}$ | $1.26 \times 1{ }^{10}$ |
| Uranium $\mathbf{X}_{1} \ldots$ | 234.2 | 24.6 d． | $\begin{array}{r} .0282 \mathrm{~d} \\ .0 \mathrm{sec} . \end{array}$ |  |  |  |  |  |
| Uranium $\mathbf{X}_{2} \ldots$ | 234.2 234.2 | 1.15 m. 106 yr. |  |  | － | －$\times 10$ | 倍 $0^{-5}$ | － |
| Uranium Y．．． | 230．2？ | 1.5 d ． | .46 d ． | $\underset{\beta}{a}$ | 2.90 | ${ }^{1.53 \times 10}$ | $.72^{2} \times 10^{-5}$ | $1.37 \times 10^{5}$ |
| Ionium．． | 230.2 | $10^{5} \mathrm{yr}$ ． | $7.0 \times 10^{6} \mathrm{y}$ ． | $a$ | 3.11 | $1.56 \times 10^{9}$ | $.75 \times 10^{-5}$ | $1.40 \times 10^{5}$ |
| Radium．．．．．．． | 226 | 1730 y ． | ． 00040 y ． | $\alpha+\beta$ | 3.30 | r．61＂ | ． $79 \times$ | r． 50 <br> I .74 <br> ra |
| Ra Emanation． Radium A．．．． | ${ }^{222}$ | 3.85 d ． | .180 d |  | 4.16 | I .73 r .82 | ． 92 ＂ |  |
| Radium B．． | 214 | 26．8 2.0 | ． 23258 m ． | $\stackrel{+}{a}+\gamma$ | 4.75 |  | 1．01 | 1．88－＂ |
| Radium $\mathrm{C}_{1}$ ． | 214 | 19.5 m ． | ． 0355 m ． | $\alpha+\beta$ | － | 二 | 二． | 二 |
| $\mathrm{Ra} \mathrm{C}_{2} \ldots \ldots$ | 210？ | ${ }_{10}^{1.4} \mathrm{~m}^{-6} \mathrm{~s}$ ． | .495 m ． | $\underset{\boldsymbol{\beta}}{\boldsymbol{\beta}}$ | 6－1 | － |  |  |
| Ra D，radio－${ }^{\text {Radin }}$ |  | $10^{-6} \mathrm{~s}$ ． ？ | 700000 s. | $a$ | 6.94 | $\left\|\begin{array}{c} 2.06 \times 10^{9} \\ - \\ 1.68 \times 10^{9} \end{array}\right\|$ | $1.35 \times 10^{-5}$ | $2.37 \times 10^{5}$ |
| lead．．．．．． | 210 | 15.8 y ． |  | $\begin{aligned} & \text { slow } \beta \\ & \beta+\gamma \\ & \underset{a}{\beta} \end{aligned}$ | $\overline{\bar{Z}_{3}}$ |  |  |  |
| Ra E．．．．．．．．． | 210 210 | ${ }^{4} .85 \mathrm{~d}$ ． | $143 \mathrm{~d} \text {. }$ |  |  |  | ${ }_{87} \overline{\times}{ }^{-5}$ | ${ }_{1}{ }^{1}$ |
| Ra F．Polonium | 210 | 136 d ． | ． 00510 d ． |  |  |  | ． $87 \times 10^{-5}$ | $1.63 \times 10^{5}$ |

Actinium Group．

| Actinium． | A，230？ | ？ | － | a？ | 3.56 | $1.64 \times 10^{9}$ | ． $82 \times 10^{-5}$ | $1.55 \times 10^{5}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Radio－Act | A | 19.5 d ． | ． 0355 d． | $\alpha+\beta$ | 4.2 | 1．7 7 ¢ ${ }^{\text {c }}$ | ． $9 \times 1$ | 1.8 ＂ |
| Actinium X | $A-4$ | 10.2 d ． | ． 068 d． | $\alpha$ | 4.26 | 1．76＂ | ． 94 ＂ | 1.79 |
| Act．Emanation | $A-8$ | 3.9 s． | .178 s． | $a$ | 5.57 | r．91＂ | r． 12 ＂ | 2.04 |
| Actinium A．．．． | $A-12$ | .002 s ． | ． 350 s ． | a | 6.27 | I． 98 | I .2 I | 2.20 |
| Actinium B． | $A-16$ | 36 m ． | ． 0193 m ． | slow $\beta$ | ． |  |  |  |
| Actinium $\mathrm{C}_{1}$ | $A-16$ | 2.1 m ． | $.33 \mathrm{~m}$ |  | 5.15 | 1． $85 \times 10^{9}$ | $1.05 \times 10^{-5}$ | $1.94 \times 10^{5}$ |
| Actinium D <br> Actinium $\mathrm{C}^{\prime} \ldots$ | $A-20$ $A-20$ | 4.7 m ． | ${ }^{1} 47$ | $\beta+\gamma$ | $\underline{6.45}$ | $\left[\begin{array}{ll} 1.03 \text { - } & \\ 2.00 & " \end{array}\right]$ | 1．23－＂ | $1.94 \times 1$ |

Thorium Group．


See The Constants of Radioactivity，Wendt，Phys．Rev．7，p．389， 1916.
$\boldsymbol{\mu}=$ coefficient of absorption for $\boldsymbol{\beta}$ rays in terms of cms．of aluminum；$\mu_{1}$ ，of the $\gamma$ rays in cms of Al ，so that if $J_{0}$ is the incident intensity，$J$ that after passage through $d \mathrm{cms}, J=J_{o e^{-} d \mu}$ ．

| Uranium－radium Group． |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | $\beta$ rays． |  | $\gamma$ rays． | Remarks． |
|  | Absorption coefficient $=\mu$ | Velocity <br> light $=1$ | Absorption coefficient $=\mu_{1}$ |  |
| Ur $1 . .$. | －－ | － | － | I gram U emits $2.37 \times 10^{4} \mathrm{a}$ particles per |
| Ur $\mathrm{X}_{1}$ ．． | 510 | Wide range | 24，70，． 140 | sec． <br> $\beta$ rays show no groups of definite veloci－ |
| Ur $\mathrm{X}_{2} \ldots \ldots$. | 14.4 | － | － | ties．Chemically allied to Th． |
| Ur $2 \ldots \ldots \ldots$ | － | － | － | Not separable from Ur I ． |
| Ur Y | 300 | － | － | Probably branch product．Exists in small quantity． |
| Io． | － | － | － | Chemical properties of and non－separable from Thorim |
| Ra．．．．．．．．． | 200 | ．52，．65 | 354，16，． 27 | from Thorium． <br> Chemical properties of Ba ．I gr emits |
|  |  |  | 354，16，． 27 | per sec．in equilib． $13.6 \times 10^{10} a$ par－ ticles． |
| Ra Em．．．．． | － | － | － | Inert gas，density 111 H ，boils $-65^{\circ} \mathrm{C}$ ， density solid $5-6$ ，condenses low pres－ |
| Ra A．．．．．．． | － | － | － | Like solid，has ${ }^{\text {s }}$ ，${ }^{\circ}{ }^{\circ} \mathrm{C}$（ charge，volatile in H, |
|  |  |  |  | $400^{\circ}$ ，in O about $550^{\circ}$ ． |
| Ra B．．．．．．． | 13，80， 890 | ． 36 to ． 74 | 230，40， 51 | Volatile about $400^{\circ} \mathrm{C}$ in H．Separated |
| $\mathrm{Ra} \mathrm{C}_{1} \ldots \ldots .$. $\mathrm{Ra} \mathrm{C}_{2} \ldots \ldots$. | 13， 53 | ． 80 to .98 | ． 115 | Volatile in H about $430^{\circ}$ ，in O about $1000^{\circ}$ ． |
|  |  |  |  | Probably branch product．Separated by recoil from RaC ． |
| Ra D | 130 |  | 45，．99 | Separated with Pb ，not yet separable from it．Volatile below $1000^{\circ}$ ． |
|  | 43 | Wide range | Like Ra D | Separated with Bi Probably changes to |
|  |  |  |  | Separated with Bi．Probably changes to Pb ．Volat ile about $1000^{\circ}$ ． |
| Actinium Group． |  |  |  |  |
| Act．．．．．．．．．． |  |  |  | Probably branch product Ur series． Chemically allied to Lanthanum． |
| Rad．Act．．．． | 170 | 二 | 25，－ 190 | Chemical properties analogous to Ra ． |
| Act Em．．．． | － | 二 | 二 | Inert gas，condenses between $-120^{\circ}$ and $-150^{\circ}$ ． |
| Act A．．．．．． | － | － | － | Analogous to Ra A．Volatile above $400^{\circ}$ ． |
| Act $\mathrm{B} \ldots . .$. Act $\mathrm{C}_{1} \ldots \ldots$. | Very soft | 二 | 120，31，． 45 | ＂＂＂Ra B．＂＂ $700^{\circ}$ ． |
| Act D．．．．．． | 28.5 | － | ． 198 | （Obtained by recoil．） |
| Thorium Grour． |  |  |  |  |
| Th．．．．．．．．．． | － | － | － |  |
| Mes．Th．I．． | － | ． 37 to ． 66 | － | spontaneously phosphorescent． <br> Chemical properties analogous to Ra from which non－separable． |
| Mes．Th．2．． <br> Rad．Th． | 20 to 38.5 | － | 26，．116 | Chemically allied to Th ，non－separable |
| Rad．Th．．．．． |  | － |  | Chemically allied to Th，non－separable from it． |
| Th．X．．．．．． <br> Th．Em． | About 330 | ${ }^{.47}$＿． 51 | － |  |
| Th．Em．．．．． | － | － | － | Inert gas，condenses at low pressure be－ tween $-120^{\circ}$ and $-150^{\circ}$ ． |
| Th．A．．．．．．． | 10 | 63－72 | 560， 32,36 | ＋charged，collected on－electrode． |
| Th．B．．．．．． | 110 | .63 ． 72 | 160，32，． 36 | Chemically analogous to Ra B．Volatile above $630^{\circ} \mathrm{C}$ ． |
| Th．CI，．．．． | 15.6 | － | Weak | Chemically analogous to Ra C ．Volatile above $730^{\circ}$ ． |
| Th．C＇．．．．．． | － | － | － | $\mathrm{Th} . \mathrm{C}^{1}$ and $\mathrm{Th} . \mathrm{D}$ are probably respectively $\boldsymbol{\beta}$ and $a$ ray products from $\mathrm{Th} . \mathrm{C}_{3}$ ． |
| Th．D．．．．．． | 24.8 | ．3，．4，．93－5 | ． 096 | Got by recoil from Th．C．Probably transforms to Bi ． |
| $\underset{\mathrm{Rb} . . . . . . . . . . . . ~}{\text { K．}}$ | $\begin{gathered} 38,102 \\ 380,1020 \end{gathered}$ | 二 | － | $\begin{aligned} \text { Activity } & =1 / 1000 \text { of Ur. } \\ & =1 / 500 \text { of Ur. } \end{aligned}$ |

Smithsonian Tables．

## TABLE 507. - Total Number of Ions produced by the $\alpha, \beta$, and $\gamma$ Rays.

The total number of ions per second due to the complete absorption in air of the $\beta$ rays due to 1 gram of radium is $9 \times 10^{14}$, to the $\gamma$ rays, $13 \times 10^{14}$.

The total number of ions due to the $\alpha$ rays from 1 gram of radium in equilibrium is $2.56 \times 10^{16}$. If it be assumed that the ionization is proportional to the energy of the radiation, then the total energy emitted by radium in equilibrium is divided as follows: 92.I parts to the $\alpha, 3.2$ to the $\beta, 47$ to the $\gamma$ rays. (Rutherford, Moseley, Robinson.)

## TABLE 508.-Amount of Radium Emanation. Curie.

At the Radiology Congress in Brussels in 1910, it was decided to call the amount of emanation in equilibrium with I gram of pure radium one Curie. [More convenient units are the millicurie ( $10^{-3}$ Curie) and the microcurie ( $10^{-6}$ Curie) ]. The rate of production of this emanation is $1.24 \times 10^{-9}$ $\mathrm{cu} . \mathrm{cm}$. per second. The volume in equilibrium is $0.59 \mathrm{cu} . \mathrm{mm} .\left(760 \mathrm{~cm} ., \mathrm{O}^{0} \mathrm{C}\right.$.) assuming the emanation mon-atomic.

The Mache unit is the quantity of Radium emanation without disintegration products which produces a saturation current of $10^{-3}$ unit in a chamber of large dimensions. I curie $=2.5 \times 10^{9}$ Mache units.

The amount of the radium emanation in the air varies from place to place; the amount per cubic centimeter of air expressed in terms of the number of grams of radium with which it would be in equilibrium varies from $24 \times 10^{-12}$ to $350 \times 10^{-12}$.

# Table 509. - Vapor Pressure of the Radium Emanation in cms. of Mercury. <br> (Rutherford and Ramsay, Phil. Mag. 17, p. 723, 1909, Gray and Ramsay, Trans. <br> Chem. Soc. 95, p. 1073, 1909.) <br>  

## TABLE 510. - References to Spectra of Radioactive Substances.

Radium spectrum :
Radium emanation spectrum :
Polonium spectrum :
Demarçay, C. R. I3I, p. 258, i900.
Rutherford and Royds, Phil. Mag. 16, p. 3 13, 1908 ; Watson, Proc. Roy. Soc. A 83, p. 50, 1909.
Curie and Debierne, Rad. 7, p. 38, 1910, C. R. 150, p. 386, 191а

## Smithsonian Tables.

The probability of a molecular velocity $x$ is $(4 / \sqrt{\pi}) x^{2} e^{-x^{2}}$, the most probable velocity being taken as unity. The number of molecules at any instant of speed greater than $c$ is $2 N(h m / \pi)^{\frac{1}{2}}\left\{\int_{c} e^{-h m e z} d c+c e^{-h m c 2}\right\}$ (see table), where $N$ is the total number of molecules. The mean velocity $G$ (sq. rt. of mean sq.) is proportional to the mean kinetic energy and the pressure which the molecules exert on the walls of the vessel and is equal to $15,800 \sqrt{T / m} \mathrm{~cm} / \mathrm{sec}$, where $T$ is the absolute temperature and $m$ the molecular weight. The most probable velocity is denoted by $W$, the average arithmetical velocity by $\Omega$.

$$
G=W \sqrt{3 / 2}=1.225 W ; \quad \Omega=W \sqrt{4 / \pi}=1.128 W ; \quad G=\Omega \sqrt{3 \pi / 8}=1.086 \Omega .
$$

The number of molecules striking unit area of inclosing wall is ( $1 / 4$ ) $N \Omega$ (Meyer's equation), where $N$ is the number of molecules per unit volume; the mass of gas striking is (I/4) $\Omega$ where $\rho$ is the density of the gas. For air at normal pressure and room temperature $\left(20^{\circ} \mathrm{C}\right)$ this is about $14 \mathrm{~g} / \mathrm{cm}^{2} / \mathrm{sec}$. See Langmuir, Phys. Rev, 2, 1913 (vapor pressure of W) and J. Amer. Ch. Soc. 37, 1915 (Chemical Reactions at Low Pressures), for fertile applications of these latter equations. The following table is based on Kinetic Theory of Gases, Dushman, Gen. Elec. Kev. 18, 1915, and Jeans, Dynamical Theory of Gases, 1916.

| Gas. | $\begin{aligned} & \text { Molec- } \\ & \text { ular } \\ & \text { weight. } \end{aligned}$ | Sq. rt. mean sq. $G \times 10^{-2} \mathrm{~cm} / \mathrm{sec}$. |  |  | Arithmetical average velocity, $\Omega \times 10^{-2} \mathrm{~cm} / \mathrm{sec}$. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $273{ }^{\circ}$ | $293{ }^{\circ}$ | $373^{\circ}$ | $223{ }^{\circ}$ | $273{ }^{\circ}$ | $293{ }^{\circ}$ | $373^{\circ}$ | $1000^{\circ}$ | $1500^{\circ}$ | $2000^{\circ}$ | $6000^{\circ}$ |
| Air... | 28.96 | 485 | 502 | 567 | 404 | 447 | 463 | 522 | 855 | 1047 | 1209 | 209.4 |
| Ammonia. | 17.02 | 633 | 655 | 740 | 527 | 583 | 604 | 681 | 1115 | 1367 | 1577 | 2734 |
| Argon. | 39.88 | 413 | 428 | 483 | $3+4$ | 381 | 395 | 445 | 729 | 892 | 1030 | 1784 |
| Carbon monoxide. . | 28.00 | 493 | 511 | 576 | 410 | 454 | 471 | 531 | 870 | 1065 | 1230 | 2130 |
| Carbon dioxide. . . | 44.00 | 393 | 408 | 459 | 327 | 362 | 376 | 434 | 694 | 850 | 981 | 1700 |
| Helium. . . . . . . . . | 4.00 | 1311 | 1358 | 1533 | 1092 | 1208 | 1252 | 1412 | 2300 | 2840 | 3270 | 5680 |
| Hydrogen. | 2.01 | 1838 | 1904 | 2149 | 1534 | 1696 | 1755 | 1980 | 3241 | 3970 | 4583 | 79.40 |
| Krypton. | 82.92 | 286 | 296 | 335 | 238 | 263 | 272 | 308 | 502 | 618 | 712 | 1236 |
| Mercury. . . . . . . . | 200.6 | 184 | 191 | 215 | 154 | 170 | 176 | 199 | 325 | 398 | 459 | 796 |
| Molybdenum. . . . | 96.0 | - | - | - | - | - |  | 19 | 469 | 575 | 664 | 1150 |
| Neon. . | 20.2 | 584 | 605 | 683 | 486 | 538 | 557 | 629 | 1030 | 1260 | 1460 | 2520 |
| Nitrogen. | 28.02 | 493 | 511 | 577 | 410 | 454 | 471 | 531 | 869 | 1064 | 1229 | 2128 |
| Oxygen.. | 32.00 | 461 | 478 | 539 | 384 | 425 | 4.40 | 497 | 813 | 996 | 1150 | 1992 |
| Tungsten. . . . . . . | 184.0 | - | - | - | - | - | - | - | 339 | 416 | 480 | 832 |
| Water vapor. | 18.02 | 615 | 637 | 720 | 512 | 566 | 587 | 662 | 1084 | 1317 | 1533 | 2634 |
| Xenon... | 130.2 | 228 | 236 | 267 | 190 | 210 | 218 | 2.46 | 400 | 493 | 570 | 986 |

Free electron, malecular weight $=1 / 1835$ when $H=1 ; G=1.114 \times 10^{7}$ at $\circ^{\circ} \mathrm{C}$ and $\Omega=1.026 \times 10^{7}$ at $0^{\circ} \mathrm{C}$.

## TABLE 512. - Molecular Free Paths, Collision Frequencies and Diameters.

The following table gives the average free path $L$ derived from Boltzmann's formula $\mu(.3502 \rho \Omega), \mu$ being the viscosity, $\rho$ the density, and from Meyer's formula $\mu(.3097 \rho \Omega$ ). Experimental values (Verh. d. Phys. Ges. I4, 596, r912; 15, 373, 1913) agree better with Meyer's values, although many prefer Boltzmann's formula. As the pressure decreases, the free path increases, at one bar (ordinary incandescent lamp) becoming 5 to 10 cm . The diameters may be determined from $L$ by Sutherland's equation $\{\mathrm{r} .402 / \sqrt{2} \pi N L(\mathrm{r}+C / T)\}^{\frac{1}{2}}, N$ being the number of molecules per unit vol. and $C$ Sutherland's constant; from van der Waal's $b,\{3 b / 2 V V \pi\}$; from the heat conductivity $k$, the specific heat at constant volume $c v,\{.146 \rho G c v / N k\} \frac{1}{2}$ (Laby and Kaye); a superior limit from the maximum density in solid and liquid states (Jeans, Sutherland, ig16) and an inferior limit from the dielectric constant $\left.D,\left\{(D-1)_{2} / \pi, V\right\}\right\}$, or the index of refraction $n,\left\{\left(n^{2}-1\right)_{2} / \pi N\right\}^{\frac{1}{3}}$. The table is derived principally from Dushman, l.c.

| Gas. | $L \times 10^{6}(\mathrm{~cm})$ <br> Average free path.* |  |  | Collision frequency.$\begin{gathered} \Omega / L \\ \times 10^{-6} \end{gathered}$$20^{\circ} \mathrm{C} *$ | $10^{9} \times$ Molecular diameters (cm): |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | ```From L (vis- cosity) \mu``` | From van der Waal's b | From heat conductivity $k$ | Limiting |  |
|  | Boltzmann. |  | Meyer.$20^{\circ} \mathrm{C}$ |  |  |  |  |  |
|  | $0^{\circ} \mathrm{C}$ | $20^{\circ} \mathrm{C}$ |  |  |  |  | density <br> $\rho$ | Min. <br> $D$ or $n$ |
| Ammonia. | 5.92 | 6.60 | 5.83 | 9150 | 2.97 | 3.08 | - | - | - 6 |
| Argon. . . . . . . . . | 8.98 | 9.88 | 8.73 | 4000 | 2.88 | 2.94 | 2.86 | 2.87 | 2.66 |
| Carbon monoxide. | 8.46 | 9.23 | 8.16 | 5100 | 3. 19 | 3.12 | - | 3. 27 | 2.74 2.90 |
| " dioxide... | 5.56 | 6.15 | 5.44 | 6120 | 3.34 | 3.23 | 3.40 | 3.35 | 2.90 |
| Helium. | 25.25 | 27.45 | 33.10 | 4540 | 1. 90 | 2.65 | 2.30 | 1.98 | 1.92 |
| Hydrogen........ | 16.00 | 17.44 | 15.40 | 10060 | 2.40 | 2.34 $(3.60)$ | 2.32 3.14 | 2.40 3.35 |  |
| Krypton. . . . . . . . | 9.5 | (14.70) |  | - | - | (3.60) | 3.14 | 3.35 | (2.70) |
| Mercury. . . . . . . . | - | (14.70) | (13.0) | - | - 15 | 3.01 | - | - | - |
| Nitrogen.... . . . . | 8.50 | 9.29 | 8.21 | 5070 | 3.15 | 3.15 | 3.53 | 3.23 | 2.95 |
| Oxygen . . . . . . . . . | 9.05 | 9.93 | 8.78 | 4430 | 2.98 | 2.92 4.02 | 3.42 | 2.99 3.55 | 2.71 (3.18) |
| Xenon.... . . . . . . | 5.6 | - | - | - | - | 4.02 | 3.42 | 3.55 | (3.18) |

[^55]Smithsonian Tables.

TABLE 513. - Cross Sections and Lengths of Some Organic Molecules.
According to Langmuir (J. Am. Ch. Soc. 38, 2221, r916) in solids and liquids every atom is chemically combined to adjacent atoms. In most inorganic substances the identity oi the molecule is generally lost, but in organic compounds a more permanent existence of the molecule probably occurs. When oil spreads over water evidence points to a layer a molecule thick and that the molecules are not spheres. Were they spheres and an attraction existed between them and the water, they would be dissolved instead of spreading over the surface. The presence of the - COOH , - CO or - OH groups generally renders an organic substance soluble in water, whereas the hydrocarbon chain decreases the solubility. When an oil is placed on water the -COOH groups are attracted to the water and the hydrocarbon chains repelled but attracted to each other. The process leads the oil over the surface antil all the -COOH groups are in contact if possible. Pure hydrocarbon oils will not spread over water. Benzene will not mix with water. When a limited amount of oil is present the spreading ceases when all the water-attracted groups are in contact with water. If weight $w$ of oil spreads over water surface $A$, the area covered by each molecule is $A M / w N$ where $M$ is the molecular weight of the oil $(O=16), N$, Avogadro's constant. The vertical length of a molecule $l=M / a \rho N=W / \rho A$ where $\rho$ is the oil density and $a$ the horizontal area of the molecule.

| Substance. | $\begin{gathered} \text { Cross } \\ \text { section } \\ \text { in } \\ \mathrm{cm}^{2} \\ \times \mathrm{IO}^{16} \end{gathered}$ | $\begin{aligned} & l \text { in } \mathrm{cm} \\ & \left(\begin{array}{l} \text { (length) } \\ \times 10^{8} \end{array}\right. \end{aligned}$ | Substance. | $\begin{gathered} \text { Cross } \\ \text { section } \\ \text { in } \\ \mathrm{cm}^{2} \\ \times \mathrm{Io}^{16} \end{gathered}$ | $\begin{gathered} l \text { in } \mathrm{cm} \\ \left(\begin{array}{c} \text { (length) } \\ \times 10^{8} \end{array}\right. \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Palmitic acid $\mathrm{C}_{15} \mathrm{H}_{31} \mathrm{COOH}$ | 24 | 19.6 | Cetyl alcohol $\mathrm{C}_{16} \mathrm{H}_{33} \mathrm{OH}$ | 21 | 21.9 |
| Stearic acid $\mathrm{C}_{17} \mathrm{H}_{35} \mathrm{COOH}$. | 24 | 21.8 | Myricyl alcohol $\mathrm{C}_{30} \mathrm{H}_{61} \mathrm{OH}$ | 29 | 35.2 |
| Cerotic acid $\mathrm{C}_{25} \mathrm{H}_{51} \mathrm{COOH}$ | 25 | 29.8 | Cetyl palmitate $\mathrm{C}_{15} \mathrm{H}_{31} \mathrm{COOCO} \mathrm{C}_{6} \mathrm{H}_{33}$. | ${ }_{6}^{21}$ | 44.0 |
| Oleic acid ${ }_{\text {c }}{ }_{17} \mathrm{H}_{33} \mathrm{COOH}$. ${ }^{\text {a }}$ | 48 | 10.8 10.7 | Tristearin $\left(\mathrm{C}_{18} \mathrm{H}_{35} \mathrm{O}_{2}\right)_{3} \mathrm{C}_{3} \mathrm{C}_{5} \mathrm{H}_{5} \ldots \ldots \ldots$. | 69 137 | 23.7 11.9 |
| Linolenic acid $\mathrm{C}_{17} \mathrm{H}_{29} \mathrm{COOH}$ | 66 | 7.6 | Triolein ( $\left.\mathrm{C}_{18} \mathrm{H}_{33} \mathrm{O}_{2}\right)_{3} \mathrm{C}_{3} \mathrm{H}_{5}$. | 145 | 11.9 |
| Ricinoleic acid $\mathrm{C}_{17} \mathrm{H}_{32}(\mathrm{OH}) \mathrm{COOH}$ | 90 | 5.8 | Castor oil $\left(\mathrm{C}_{17} \mathrm{H}_{32}(\mathrm{OH}) \mathrm{COO}\right)_{3} \mathrm{C}_{3} \mathrm{H}_{5}$. Linseed oil $\left(\mathrm{C}_{17} \mathrm{H}_{31} \mathrm{COO}\right){ }_{3} \mathrm{C}_{3} \mathrm{H}_{5}$. | 280 | 5.7 11.0 |

## TABLE 514. - Size of Diffracting Units in Crystals. T

The use of crystals for the analysis of X-rays leads to estimates of the relative sizes of molecular magnitudes. The diffraction phenomenon is here not a surface one, as with gratings, but one of interference of radiations reflected from the regularly spaced atomic units in the crystals, the units fitting into the lattice framework of the crystal. In cubical crystals $\{100\}$ this framework is built of three mutually perpendicular equidistant planes whose distance apart in crystallographic parlance is $d_{100}$. This method of analysis from the nature of the diffraction pattern leads also to a knowledge of the structure of the various atoms of the crystal. See Bragg and Bragg, X-rays and Crystal Structure, 1918.

| Crystal. | Elementary diffracting element. | Side of cube. | Molecules or atoms in unit cube. |
| :---: | :---: | :---: | :---: |
| KCl | Face-centered cube * | $\stackrel{\text { cm }}{6.30} \times 10^{-8}$ | molecules |
| NaCl |  | $5.56 \times 10^{-8}$ |  |
| ZnS , | " ${ }^{\text {" }}$ " | $5.46 \times 10^{-8}$ | " |
| $\mathrm{CaF}_{2}$ | " "، $\ddagger$ | $5.40 \times 10^{-8}$ | " |
|  |  |  |  |
| Fe | Body-centered cube | $2.86 \times 10^{-8}$ | 2 atoms |
| ${ }_{\mathrm{N}}^{\mathrm{N}}$ | Face-centered cube | $4.05 \times 10^{-8}$ | 4 "، |
|  | Body-centered cuse | $\stackrel{4.30}{ } \times 1{ }^{\text {a }}$ | 2 ، |
|  | Face-centered cube | $3.52 \times 10^{-8}$ | 4 |

* Each atom is so nearly equal in diffracting power (atomic weight) in KCl that the apparent unit diffracting element is a cube (simple) of $\frac{x}{8}$ this size. Elementary body-centered cube, - atom at each corner, one in center; e.g., $\mathrm{Fe}, \mathrm{Ni}$ (in part), Na, Li? Elementary face-centered cube, - atom at each corner, one in center of each face; e.g., Cu, Ag, Au, $\mathrm{Pb}, \mathrm{Al}, \mathrm{Ni}$ (in part), etc. Simple cubic lattice, - atom in each corner. Double face-centered cubic or diamond lattice -C (diamond); $\mathrm{Si}, \mathrm{Sb}, \mathrm{Bi}, \mathrm{As}$ ?, Te ?
$\dagger$ Diamond lattice. $\ddagger$ Cubic-holohedral. § Cubic-pyritohedral.
Metals taken from Hull, Phys. Rev. 10, p. 661, 1917
T See Table 528 for best values of calcite and rock-salt grating spaces.
Note: - (Hull, Science 52, 227, 1920). Ca, face-centered cube, side 5.56 A , each atom 12 neighbors 3.93 A distant. Ti, centered cube, cf. Fe, side $3.14 \mathrm{~A}, 8$ neighbors 2.72 A . $\mathrm{Zn}, 6$ nearest neighbors in own plane. $2.67 \mathrm{~A}, 3$ above, 3 below, 2.92 A . Cd, cf. $\mathrm{Zn}, 2.98 \mathrm{~A}, 3.30 \mathrm{~A}$. In, face-centered tetragonal, 4 nearest $3.24 \mathrm{~A}, 4$ above, 4 below, 3.33 A . $\mathrm{Ru}, \mathrm{cf} . \mathrm{Zn}, 2.69 \mathrm{~A}, 2.64 \mathrm{~A}$. Pd , face-centered cube, side $3.92 \mathrm{~A}, 12$ neighbors. 2.77 A . Ta, centered cube, side $3.27 \mathrm{~A}, 8$ neighbors 2.83 A . Ir, face-centered cube, side $3.80 \mathrm{~A}, 12$ neighbors, $2.69 \mathrm{~A}\left(\mathrm{~A}=10^{-8} \mathrm{~cm}\right)$.

Note :- (Bragg, Phil. Mag. 40, 169, 1920). Crystals empirically considered as tangent spheres of diameter in table, atom at center of sphere. When lattice known allows estimation of dimensions of crystal unit. Table foot of next page (atomic numbers, elements, diameter in Angstroms, $10^{-8} \mathrm{~cm}$ ).

ELECTRONS. RUTHERFORD ATOM. BOHR ATOM. MAGNETIC FIELD OF ATOM.
References: Millikan, The Electron, 1917; Science, 45, 421, 1917; Humphreys, Science, 46, 273, 1917; Lodge Nature, 10,15 and 82. 1919; Thomson, Conduction of Electricity through Gases; Campbell, Modern Electrical Theory; Lorentz, The Theory of Electrons; Richardson, The Electron Theory of Matter, 1914.

## Electron: an elementary + or - unit of electricity.

Free negative electron: (corpuscle, J. J. Thomson); mass $=9.01 \times 10^{-28} \mathrm{~g}=1 / 1845 \mathrm{H}$ atom, probably all of electrical origin due to inertia of self-induction.

Theory shows that when speed of electron $=1 / r o$ velocity of light its mass should be appreciably dependent upon that speed. If $m_{0}$ be mass for small velocity $v, m$ be the transverse mass for $v, v /($ velocity of light $)=\beta$, then $m=$ $m_{0}\left(\mathrm{I}-\beta^{2}\right)^{\frac{1}{4}}$, Lorentz, Einstein;

| for $\beta=0.01$ | 0.10 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $m / m_{0}=1.00005$ | 1.005 | 1.02 | 1.048 | 1.091 | 1.155 | 1.250 | 1.400 | 1.667 |

(Confirmed by Bucherer, Ann. d. Phys. 1009, Wolz, Ann. d. Phys. Radium ejects electrons with $3 /$ ro to $98 /$ roo velocity of light.) $m$, due to charge $=2 E^{2} / 3 a, E=$ charge, $a=$ radius, whence radius of electron $=2 \times 10^{-13} \mathrm{~cm}=1 / 50,000$ atomic radius. Cf. (radius of earth)/(radius of Neptune's orbit) $=1 / 360,000$.

Positive electron: heavy, extraordinarily small, never found associated with mass less than that of H atom. If mass all electrical (?) radius must be $1 / 2000$ that of the - electron. No experimental evidence as with - electron, since bigh enough speeds not available. Penetrability of atom by $\beta$ particle (may penetrate 10,000 atomic systems before it happens to detach an electron) and $a$ particles ( 8000 times more massive than - electron, pass through 500,000 atoms without apparent deflection by nucleus more than 2 or 3 times) shows extreme minuteness. Upper limit: not larger than $10^{-12} \mathrm{~cm}$ for Au (heavy atom) or $10^{-13}, \mathrm{H}$ (light atom) (Rutherford). Cf. (radius sun)/(radius Neptune's orbit) $=1 / 3000$, but sun is larger than planets. (Hg atoms by billions may pass through thin-walled highly-evacuated glass tubes without impairing vacuum, therefore massive parts of atoms must be extremely small compared to volume of atom.)

Rutherford atom: number of free + charges on atomic nuclei of different elements $=$ approximately $\frac{1}{2}$ atomic weight (Rutherford, Phil. Mag. 21, 1911, deflection of a particles); Barkla concluded free - electrons outside nucleus same in number (Phil. Mag. 2 1, 1911, X-ray scattering). If mass is electromagnetic, then lack of exact equivalence may be due to overlapping fields in heavy crowded atoms, a sort of packing effect; the charge on $U=92$, at. wt. $=238.5$. Moseley (Phil. Mag. 26, 1912; 27, 1914) photographed and analyzed X-ray spectra, showing their exact similarity in structure from element to element, differing only in frequencies, the square roots of these frequencies forming an arithmetical progression from element to element. Moseley's series of increasing $\mathbf{X}$-ray frequencies is with one or two exceptions that of increasing atomic weights. and these exceptions are less anomalous for the $\bar{X}$-ray series than for the atomic-weight series. It seems plausible then that there are 92 elements (from H to U ) built up by the addition of some electrical element. Moseley assigned successive integers to this series (see Table 531) known now as atomic numbers.

Moseley's discovery may be expressed in the form

$$
\frac{n_{1}}{n_{2}}=\frac{E_{1}}{E_{2}} \text { or } \frac{\lambda_{2}}{\lambda_{1}}=\frac{E_{1}{ }^{2}}{E_{2}{ }^{2}}
$$

where $E$ is the nuclear charge and $\wedge$ the wave-length. Substituting for the highest frequency line of $W, \Lambda_{2}=0.167$ $\times 10^{-8} \mathrm{~cm}$ (Hull), $E_{2}=74=N_{w}$, and $E_{1}=1$, then $\lambda_{1}=$ highest possible frequency by element which has one + electron; $\lambda_{1}=91.4 m \mu$. Now the H ultra-violet series highest frequency line $=91.2 m \mu$ (Lyman); i.e.. this ultraviolet line of H is nothing but its $K \mathbf{X}$-ray line. Similarly, it seems equally certain that the ordinary Balmer series of $\mathbf{H}$ (head at $365 m \mu$ ) is its $L$ X-ray series and Paschen's infra-red series its $M \mathbf{X}$-ray series.

There may be other - electrons on the nucleus (with corresponding + charges) since they seem to be shot out by radioactive processes. They may serve to hold the + charges together. He, atomic no. $=2$, has 2 free + charges, at. wt. $=4$; may imagine nucleus has $4+$ electrons held together by $2-$ electrons, with $2-$ electrons outside nucleus. H has one + and one - electron.

The application of Newton's law to Moseley's law leads to $E_{1} / E_{2}=a_{2} / a_{1}$, where the $a$ 's are the radii of the inmost - electronic orbits, i.e., the radii of these orbits are inversely proportional to the central charges or atomic numbers.
(Note: When an $a$ particle ( + charge $=2 e$ ) is emitted by a radioactive element, its atomic number decreases by 2, the emission of a - charged particle increases its atomic number by r.)

Bohr atom: (Phil. Mag. 26, $1,476,857,1913 ; 29,332,1915 ; 30,394,1915$ ). The experimental facts and the law of circular electronic orbits limit the electrons to orbits of particular radii. When an electron is disturbed from its orbit, e.g., struck out by a cathode ray, or returns from space to a particular orbit, energy must be radiated. It is suggestive that the emission of a $\beta$ ray requires a series of $\gamma$ ray radiations. $H$ does not radiate unless ionized and then gives out a spectrum represented by Balmer's formula $\nu=N\left(1 / n_{1}{ }^{2}-1 / n^{2}\right)$ where $\nu$ is the frequency, $N$, a constant, and $n_{1}$ for all the lines in the visible spectrum has the value $2, n$, the successive integers, $3,4.5 \ldots$; if $n_{1}=1$ and $n$, $2,3,4, \ldots$.., Lyman's ultra-violet series results; if $n_{1}=3, n, 4,5,6, \ldots$, Paschen's infra-red series. These considerations led Bohr to his atom and he assumed: (a) a series of circular non-radiating orbits governed as above; (b) radiation taking place only when an electron jumps from one to another of these orbits, the amount radiated and its frequency

## Smithsonian Tables.

(This Table supplements Table 514).

| 3 Li | 3.00 | 13 Al | 2.70 | 25 | Mn | $2.95 \dagger$ |  |  | $2.35 *$ |  | Xe | 2.70 * |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4 Gl | 2.30 | 14 Si | 2.35 | 26 | Fe | 2.80 | 37 | Rb | 4.50 |  | Cs | 4.75 |
| 6 C | 1.54 | 16 S | 2.05 | 27 | Co | 2.75 | 38 | Sr | $3 \cdot 90$ |  |  | 4.20 |
| 7 N | 1.30 | 17 Cl | 2.10 | 28 | Ni | 2.70 | 47 | A5 | 3.55 |  |  | 4.50 |
| 8 O | 1.30 | 18 A | 2.05* | 29 | Cu | 2.75 | $4^{8}$ | Cd | 3.20 |  |  | 3.50 |
| 9 F | 1.35 | 19 K | 4.15 | 30 | Zn | 2.65 | 50 | Sn | 2.80 | 83 | Bi | 2.96 |
| 10 Ne | 1.30* | - 20 Ca | 3.40 | 33 | As | 2.52 | 51 |  | 2.80 |  |  |  |
| 11 Na | 3.55 | 22 Ti | 2.80 | 34 |  | 2.35 | 52 |  | 2.65 |  |  |  |
| 12 Mg | 2.85 | 24 Cr | $2.80 \dagger$ | 35 | Br | 2.38 | 53 | I | 2.80 |  |  |  |

Broughall (Phil. Mag. 4r, p. 872, 1921) computes in the same units from Van der Waal's constant "b," the diameters of $\mathrm{He}, \mathrm{N}, \mathrm{A}, \mathrm{Kr}$, and $\mathbf{X}$ as 2.3, 2.6, 2.9, 3.1, and 3.4. These inert elements correspond to Langmuir's completely filled successive electron shells. The corresponding atomic numbers are 2, 10, 18, 36 and 54 . For Langmuir's theory see J. Am. Ch. Soc., p. 868, 1919, Science 54, p. 59, 192 I.

## BOHR ATOM. MAGNETIC FIELD OF ATOM.

being determined by $h \nu=A_{1}-A_{2}, h$ being Planck's constant and $A_{1}$ and $A_{2}$ the energies in the two orbits; (c) the various possible circular orbits, for the case of a single electron rotating around a single positive nucleus, to be determined by $T=(\mathrm{I} / 2) \tau h n$, in which $T$ is a whole number, $n$ is the orbital frequency, and $T$ is the kinetic energy of rotation.

The remarkable test of this theory is not its agreement with the $H$ series, which it was constructed to fit, but in the value found for $N$. From (a), (b), and (c) it follows that $N=\left(2 \pi^{2} e^{2} E^{2} m\right) / h^{3}=3.294 \times 10^{15}$, within $1 / 10$ per cent of the observed value (Science, 45, p. 327 ).

The radii of the stable orbits $=\tau^{2} h^{2} / 4 \pi^{2} m e^{4}$, or the radii bear the ratios $1,4,9,16,25$. If normal H be assumed to be with its electron in the inmost orbit, then $2 a=1.1 \times 10^{-8}$; best determination gives $2.2 \times 10^{-8}$. The fact that $H$ emits its characteristic radiations only when ionized favors the theory that the emission process is a settling down to normal condition through a series of possible intermediate states, i.e., a change of orbit is necessary for radiation. That in the stars there are 33 lines in the Balmer series, while in the laboratory we never get more than 12, is easily explicable from the Bohr theory.

Bohr's theory leads to the relationship $\nu_{K_{\beta}}-\nu_{K_{a}}=\nu_{L_{\alpha}}$ (see X-ray tables), Rydberg-Schuster law.
For further development, see Sommerfeld, Ann. d. Phys. 51, 1, 1916, Paschen, Ann. d. Phys., October, 1916; Harkins, Recent work on the structure of the atom, J. Am. Ch. Soc. 37, p. 1396, 1915; 39, p. 856, 1916.

Magnetic field of atom: From the Zeeman effect due to the action of a magnetic field on the radiating electron the strength of the atomic magnetic field comes out about $10^{8}$ gauss, 2000 times the most intense field yet obtained by an electromagnet. A similar result is given by the rotation of a number of electrons, $A$ ro ${ }^{3}$, where $A$ is the atomic weight; for Fe this gives $10^{8}$ gauss. For other determinations, see Weiss (J. de Phys. 6, p. 661, 1907; 7, p. 249, 1908), Ritz (Ann. d. phys. 25, p. 660, 1908), Oxley (change of magnetic susceptibility on crystallization, Phil. Tr. Roy. Soc. 215, p. 95, 1915) and Merritt (fluorescence, 1915); Humphreys, "The Magnetic Field of an Atom," Science, 46, p. 276, 1917.

Smithsonian Tables.

Note: The phenomena of Electron Emission, Photo-electric Effect and Contact (Volta) Potential treated in the subsequent tables are extremely sensitive to surface conditions of the metal. The most consistent observations have been made in bigh vacua with freshly cut metal surfaces.

TABLE 516. Electron Emission from Hot Metals.
Among the free electrons within a metal some may have velocities great enough to escape the surface attraction. The number $n$ reaching the surface with velocities above this critical velocity $=N(R T / 2 \pi M)^{\frac{1}{2}}-\frac{W}{R T}$ where $N=$ number of electrons in each $\mathrm{cm}^{3}$ of metal, $R$ the gas constant ( $83.15 \times 10^{6}$ erg-dyne), $T$ the absolute temperature, $M$ the atomic weight of electron (.000546, $\mathrm{O}=16$ ), $w$ the work done when a "gram-molecule" of electrons ( $6.06 \times 10^{23}$ electrons or 96,500 coulombs) escape. It seems very probable that this work is done against the attraction of the electron's own induced image in the surface of the conductor. When a sufficiently high + field is applied to escaping electrons so that none return to the conductor, then the saturation current has been found to follow the equation

$$
i=a \sqrt{T e^{-}}-b / T
$$

assuming $N$ and $w$ constant with the temperature; this is equivalent to the equation for $n$ just given and is known as Richardson's equation. In the following table due to Langmuir (Tr. Am. Electroch. Soc. 29, 125, 1916) izooo = saturation current per $\mathrm{cm}^{2}$ for $T=2000 \mathrm{~K}^{\circ} ; \phi=w / F=R b / F=$ work done when electrons escape from metal in terms of equivalent potential difference in volts; $F=$ Faraday constant $=96,500$ coulombs.

| Metal. | $\begin{gathered} a \\ \mathrm{amp} / \mathrm{cm}^{2} \end{gathered}$ | $b$ | $\begin{gathered} i_{2000} \\ \mathrm{amp} / \mathrm{cm}^{2} \end{gathered}$ | $\begin{gathered} \phi \\ \text { (volts). } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| Tungsten*. | $2.36 \times 10^{7}$ | 52500 | 0.0042 | 4.52 |
| Thorium. | $2.0 \times 10^{8}$ | 39000 | 30.0 | $3 \cdot 36$ |
| Tantalum. | $1.12 \times 10^{7}$ | 50000 | 0.007 | 4.31 |
| Molybdenum. . . . , | $2.1 \times 10^{7}$ | 50000 | . 013 | 4.31 |
| Carbon (untreated) |  | 48000 | - | 4.14 |
| Titanium | 1300? | 28000? | .048? | 2.4 ? |
| Iron. | 2400 ? | 37000? | . 0010 ? | 3.2? |
| Platinum $\dagger$ | $1.25 \times 10^{7}$ | 51060 | . 0035 | 4.4 |
| BaO-SrO, Pt-6 \% Ir core. .... | ${ }_{1.6} \times 1{ }^{4}$ | 20000 | 3.25 | $\mathbf{1 . 7}$ |

* Best determined value of table, pressure less than $10^{-7} \mathrm{~mm} \mathrm{Hg}$.
$\dagger$ Schlichter, $19 \times 5$.


## TABLE 517. Photo-electric Effect.

A negatively charged body loses its charge under the influence of ultra-violet light because of the escape of negative electrons freed by the absorption of the energy of the light. The light must have a wave-length shorter than some limiting value $\lambda_{0}$ characteristic of the metal. The emission of these electrons, unlike that from hot bodies, is independent of the temperature. The relation between the maximum velocity $v$ of the expelled electron and the frequency $\nu$ of the light is $(1 / 2) m \nu^{2}=h \nu-P$ (Einstein's equation) where $h$ is Planck's constant $\left(6.58 \times 10^{-27} \mathrm{erg}\right.$. sec.); $h \nu$ sometimes taken as the energy of a "quanta," $P$, the work which must be done by the electron in overcoming surface forces. $(\mathrm{I} / 2) m \nu^{2}$ is the maximum kinetic energy the electron may have after escape. Richardson identifies the $P$ of Einstein's formula with the $w$ of electron emission of the preceding table. The minimum frequency $\nu_{0}$ (corresponding to maximum wave-length $\lambda_{0}$ ) at which the photo-electric effect can be observed is determined by $h \nu=P . \quad P$ applies to a single electron, whereas $w$ applies to one coulomb ( $6.062 \times 10^{23}$ electrons); therefore $w=\hat{N} P=.00399 \nu_{0}$ ergs. $\phi=$ $\left(12.4 \times 10^{-5}\right) \boldsymbol{\lambda}_{0}$ volts. See Millikan, Pr. Nat. Acad. 2, 78, 1916; Phys. Rev. 7, 355, 1916; 4, 73, 1914; Hennings, Phys. Rev. 4, 228, I914.

## TABLE 518. Ionizing Potentials and Single-line Spectra.

When electrons are accelerated through gases or vapors, especially those with small electron affinity (inert gases, metallic vapors) at well-defined potentials a large transfer of energy takes place between the moving electrons and the gas atoms. There appear to be two types of inelastic encounters under such circumstances: the first accompanied by the emission of a radiation of a single line at a potential called the resonance potential and satisfying the relation $h \nu=e V$ where $V$ is the potential fall, $\nu$ the frequency and $h$ Planck's constant; the second ionizes the gas (ionization potential), exciting the radiation of a composite spectrum. The latter potential satisfies a relation $h \nu=e V$ except that $\nu$ is now the limiting frequency of a series of lines. The following table was communicated by Tate and Foote (see Phil. Mag. 36, 64, 1918).

| Metal. | $\lambda$ | Ionization potential.* |  | $\frac{h}{x}{ }^{10^{27}}$ | $\lambda$ | Resonance potential.* |  | $\frac{h}{x} \dagger_{102 i}$ | Observers. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Obs. | Comp. |  |  | Obs. | Comp. |  |  |
| Na | $2412.63 \pm$ | 5.13 | 5.11 | 6.57 | 5889.97 | 2.12 | 2.09 | 6.63 | Tate and Foote |
| F | $2856.65 \ddagger$ | 4.1 | 4.32 | 6.22 | 7664.94 | I. 55 | 1.61 | 6.31 |  |
| Rb | $2968.40 \pm$ | 4.1 | 4.15 | 6.46 | 7800.29 | I. 6 | I. 58 | 6.62 | Foote, Rognley, Mohler |
| Cs. | $3184.28 \ddagger$ | 3.9 | 3.87 | 6.59 6.67 | 8521.12 | I. 48 2.65 | 1.45 2.70 | 6.69 | Foote and Mohler |
| Mg . | 1621.78 | 7.75 | 7.61 | 6.67 6.66 | 4571.38 | 2.65 | 2.70 | 6.43 6.70 | Foote and Mohler |
| Zn . | 1319.958 | 9.5 | 9.34 | 6.66 | 3075.99 | 4.1 88 | 4.01 | 6.70 | Tate and Foote |
| $\mathrm{Cd}_{\mathrm{Hg}}$ | 1378.698 | 8.92 10.35 | 8.95 10.38 | 6.53 6.53 | 3260.17 2536.72 | 3.88 4.9 | 3.78 4.86 | 6.71 6.60 |  |
| Hg | 1187.968 | 10.35 | 10.38 | 6.53 | 2536.729 | 4.9 | 4.86 | 6.60 | Tate, Davis, Goucher, others |
| T1. | ? | 7.3 | - | - | 11513.22 II | 1.07 | 1.07 | 6.54 | Tate and Mohler |
| Ca. | 2027.56§ | 6.04 | 6.08 | - | 6717.69 d 4226.73 ** | 1.93 3.0 | 1.84 | - | Mohler and Foote |
| As. | - | II. 5 | - | - | ${ }^{4226.73}$ | 3.9 4.7 | 2.92 | - | Foote, Rognley, Mohler |
| Pb. | - | 8.0 | - | - | - | I. 26 | - | - | Mohler and Foote |

Mean of Computed $h=6.55 \times 10^{-27}$ erg. sec.

[^56]
## Smithsonian Tables.

## CONTACT（VOLTA）POTENTIALS．

There has been considerable controversy over the reality and nature of the contact differences of potential between two metals．At present，due to the studies of Langmuir，there is a decided tendency to believe that this Volta differ－ ence of potential is an intrinsic property of metals closely allied to the phenomena just given in Tables 516 to 518 and that the discrepancies among different observers have been caused by the same disturbing surface conditions．The following values of the contact potentials with silver and the relative photo－sensitiveness of a few of the metals are from Henning，Phys．Rev．4，228，1914．The values are for freshly cut surfaces in vacuo．Freshly cut surfaces are more electro－positive and grow more electro－negative with age．That the observed initial velocities of emission of electrons from freshly cut surfaces are nearly the same for all metals suggests that the more electro－positive a metal is the greater the actual velocity of emission of electrons from its surface．

| Contact potential with Ag ． Relative photo－sensitiveness | Ag 0 50 | Cu .05 60 | Fe .19 65 | Brass .21 45 | Sn .27 70 | Zn .59 80 | Al .99 500 | Mg I .42 1000 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

From the equation $w=R T \log \left(N_{A} / \mathrm{N}_{B}\right)$ ，where $w$ is the work necessary per gram－molecule when electrons pass through a surface barrier separating concentrations $N_{A}$ and $N_{B}$ of electrons，it can be shown（Langmuir，Tr．Am． Eletroch．Soc．29， $\mathrm{r}_{4}$ 2，1916，et seq．）that the Volta potential difference between two metals should be

$$
v_{1}-z_{2}=\frac{1}{F}\left\{w_{2}-w_{1}+R T \log \left(N_{A} / N_{B}\right)\right\}=\frac{w_{2}-w_{1}}{F}=\phi_{2}-\phi_{1}
$$

（see Table 517 for significance of symbols），since the number of free electrons in different metals per unit volume is so nearly the same that $R T \log \left(N_{A} / N_{B}\right)$ may be neglected．The contact potentials may thus be calculated from photo－ electric phenomena（see Table 517 for references）．They are independent of the temperature．The following table gives a summary of values of $\phi$ in volts obtained from the various phenomena where an electron is torn from the attrac－ tion of some surface．In the case of ionization potentials the work necessary to take an clectron from an atom of metal vapor is only approximately equal to that needed to separate it from a solid metal surface．
（a）The Electron Affinity of the Elements，in Volts．

| Metal． | Contact． <br> （Henning．） | Thermionic． （Langmuir．） | $\begin{array}{\|c} \text { Photo- } \\ \text { electric } \\ \text { and } \\ \text { contact. } \\ \text { (Millikan.) } \end{array}$ | Photo－ electric． （Richardson） | Miscel－ laneous． | Single－ line spectra． | Adjusted mean． |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Tungsten． | － | 4． 52 | － | － | － | － | 4.52 |
| Platinum． | － |  | － | 4.3 | 4.45 | 二 | $4 \cdot 4$ ？ |
| Tantalum．．． | － | 4.3 I | － |  | － | － | $4 \cdot 3$ |
| Molybdenum | － | 4．31 | － |  | 二 | 二 | 4.3 |
| Silver．． | 4.05 | 4.14 | － | － | － | － | 4.1 |
| Copper． | （4．0） | 一 | － | 4.1 | － | － | 4.0 |
| Eismuth． | －${ }^{7} 8$ | － | 二 | 3.7 | 二 | 二 | 3.7 |
| Iron．． | 3.78 3.86 | 3．2？ | 二 | 3．5 | － | 二 | 3.8 |
| Zinc．．．．． | 3.46 | － | － | 3.4 | － | 4.04 | 3.7 3.4 |
| Thorium．．． | － | $3 \cdot 36$ | － |  | － | － | 3.4 |
| Aluminum． | 3.06 | 二 | － | 2.8 | 二 |  | 3.0 |
| Mitanium．． | $\stackrel{2.63}{-}$ | 2．4？ | － | 3.2 | 二 | 4.35 | 2.7 2.4 |
| Lithium．． | － | 2.4. | 2.35 | 二 | － | 1． 85 | 2.7 2.35 |
| Sodium．． | － | － | 1.82 | 2.1 | － | 2.11 | 1.82 |

（b）It should not be assumed that all the emf of an electrolytic cell is contact emf．Its emf varies with the elec－ trolyte，whereas the contact emf is an intrinsic property of a metal．There must be an emf between the two electrodes of such a cell dependent upon the concentration of the electrolyte used．The following table gives in its first line the electrode potential $e_{h}$ of the corresponding metals（in solutions of their salts containing normal ion concentration）on assumption of no contact emf at the junction of the metals．The second line，$\phi-e_{h}-3.7$ volts，gives an idea of the electrode potentials（arbitrary zero）exclusive of contact emf．


Smithsonian Tables．

The process of ionization is the removal of an electron from a neutral molecule, the molecule thus acquiring a resultant + charge and becoming a + ion. The negative carriers in all gases at high pressures, except inert gases, consist for the most part of carriers with approximately the same mobilities as the + ions. The negative electrons must, therefore, change initially to ions by union with neutral molecules.

The mobility, $U$, of an ion is its velocity in $\mathrm{cm} / \mathrm{sec}$. for an electrical field of one volt per cm . The rates of diffusion, $D$, are given in $\mathrm{cm}^{3} / \mathrm{sec}$. $U=D P / N e$, where $P$ is the pressure, $N$, the number of molecules per unit volume of a gas and $e$ the electronic charge.

Nature of the gas and the mobilitics: (I) The mobilities are approximately proportional to the inverse sq. rts. of the molecular weights of the permanent gases; better yet when the proportionality is divided by the 4th root of the dielectric constant minus unity; (2) The ratio $U+/ U$ - seems to be greater than unity in all the more electronegative gases.

Mobilities of Gaseous Mixtures: Three types: (I) Inert gases have high mobilities; small traces of electronegative gases make values normal. (2) Mixed gases: lowering of mobilities is greater than would be expected from simple law of mixture. (3) Abnormal changes produced by addition of small quantities of electro-negative gases:
e.g.: normal mobility
6 mm C
$6 \mathrm{H}_{5} \mathrm{Br}$ gave
6 mm C
$2 \mathrm{H}_{3} \mathrm{I}$
10 mm C
2 $\mathrm{H}_{5} \mathrm{OH}$ "

$U+=$| 1.37 | $U-1.80$ | Wellisch, Pr. |
| ---: | ---: | ---: |
| 1.37 | 1.80 | Roy.Soc. 82 A, |
| 1.37 | 1.80 | p. $500,1909$. |
| 0.91 | 1.10 |  |
| 1.15 | 1.37 |  |

Temperature Coefficient of Mobility: There is no decided change with the temperature.
Pressure Coefficient of Mobility: Mobility varies inversely with the pressure in air from 100 to $1 / 10$ atmosphere for - ion, to $1 / 1000$, for + ion; below $1 / 10$ atmosphere all observers agree that the negative ion in air increases abnormally rapidly.

Free Electrons: In pure $\mathrm{He}, \mathrm{Ar}$, and N , the negative carriers have a high mobility and are, in part at any rate, free electrons; electrons become appreciable in air at 10 cm pressure.

TABLE 520. -- Ionic Mobilities.

| Dry gas. | Mobilities. |  | $K-1$ | Observer. | Dry gas. | Mobilities. |  | $K-\mathrm{I}$ | Observer. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | + | - |  |  |  | + | - |  |  |
| H. | 6.70 | 7.95 | . 000273 | Zeleny | Nitrous oxide. | 0.82 | 0.90 | . 00107 | Wellisch |
| He | 5.09 | 6.31 | . 000074 | Franck | Ethyl alcohol. | 0.34 | 0. 27 | . 00940 |  |
|  | 1.37 1.27 | - | . 000100 | " | ${ }_{\text {CCl }}{ }_{\text {Ethyl }}$ chio. | 0.30 | 0.31 | . 00426 | "، |
| $\begin{aligned} & \mathrm{N} . \\ & \mathrm{O} \end{aligned}$ | 1.27 1.36 | I. 80 | . .000590 | Zeleny | Ethyl ether. | 0.33 0.29 | 0.31 0.31 | . 0150742 | " |
| $\mathrm{CO}_{2}$ | 0.81 | 0.85 | . 000960 | Wellisch | Methyl bromide | -. 29 | 0.28 | . 01460 | " |
| NH | 0.74 | 0.80 | . 00770 |  | Ethyl formate | -. 30 | 0.31 | . 00870 | " |
| Air | 1.40 | 1.78 | . 000590 | Mean | Ethyl iodide. | 0.17 | 0.16 | - | " |

Franck, Jahr. d. Rad. u. Elek. 9, p. 2, 1912; Wellisch, Pr. Roy. Soc. 82A, p. 500, 1909. The following values are from Yen, Pr. Nat. Acad. 4, 198.

|  | $\mathrm{H}_{2}$ | $\mathrm{N}_{2}$ | Air. | $\mathrm{SO}_{2}$ | $\mathrm{C}_{5} \mathrm{H}_{12}$ | $\mathrm{C}_{2} \mathrm{H}_{6} \mathrm{O}$ | $\mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}$ | $\mathrm{C}_{2} \mathrm{H}_{3} \mathrm{Cl}$ | $\mathrm{CH}_{3} \mathrm{I}$ | $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{I}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $U+\ldots \ldots$ | 5.54 | I. 30 | 1.37 | 412 | . 385 | ${ }^{3} 63$ | . 307 | 304 | 216 | 1.81 |
|  | 8.45 | 1.80 | 1.81 | +14 | . 451 | . 373 | . 331 | . 317 | . 220 | 1.81 |
| $U-/ U+$ | 1.53 | 1. 38 | I. 34 | $1 . \infty$ | 1.17 | 1.03 | 1.07 | I. 04 | 1.05 | 1.00 |

## TABLE 521. - Diffusion Coefficients.

The following table gives the observed and computed ( $D=300 U P / V e=$ very nearly $0.0236 U$ ) values of the diffusion coefficients. The diffusion coefficients are given for some neutral molecules as actually determined for some gases into gases of nearly equal molecular weight. Table taken from Loeb, "The Nature of the Gascous Ion," J. Franklin Inst. 18.4, p. 775, 1917.

| Gas, diffusing. | Gas diffusedinto | $\underset{\text { molecules. }}{D}$ | $\boldsymbol{U}+$ | $D+$ for ions. |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Computed. | Observed. |
| Ar. | Hc | 0. 706 | 5.09 | 1. 20 | - |
| $\mathrm{H}_{2}$. | $\mathrm{N}_{2}$ | . 739 | 6.02 | 0. 143 | 0.12.3 |
| Air | $\mathrm{O}_{2}$ | . 178 | 1. 35 | 0.0319 | 0.028 |
| $\mathrm{O}_{2}$. | $\mathrm{N}_{2}$ | . 171 | 1.27 | . 0299 | 025 * |
| $\mathrm{CO}_{2}$ | $\mathrm{N}_{2} \mathrm{O}$ | 1.5-1.0 | . 82 | . 0193 | 023* |
| $\mathrm{CO}_{2}$ | CO | 1. 31 | .81 | . 0193 | - |
| $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}$ | $\xrightarrow{\mathrm{CO}_{2}}$ | 0.0693 | $.34+$ | . 00805 | - |
| Air. | Ethyl acetate | . 093 | . $30 \dagger$ | .0071 | - |
| $\mathrm{H}_{2} \mathrm{O}$ $\mathrm{NH}_{3}$. | $\stackrel{\mathrm{Air}_{\mathrm{N}}^{\mathrm{N}} 3}{ }$ | . 2.46 | 1.35 0.74 | .0319 .0174 | - |
| $\mathrm{NH}_{3}$. |  | . 190 | 0.74 | . 0174 |  |

* $\mathrm{CO}_{2}$ into $\mathrm{CO}_{2}$. † Ethyl formate. $\ddagger$ Estimated.

Smithsonian tables.

## COLLOIDS.

## TABLE 522. - General Properties of Colloids.

For methods of preparing colloids, see The Physical Properties of Colloidal Solutions, Burton, 1916; for general properties, see Outlines of Colloidal Chemistry, J. Franklin Inst. 185, p. 1, 1918 (contains bibliography).

The colloidal phase is conditioned by sufficiently fine division ( $\mathrm{I} \times 10^{-4}$ to $\mathrm{IO}^{-7} \mathrm{~cm}$ ). Colloids are suspensions (in gas, liquid, solid) of masses of small size capable of indefnite suspension; suspensions in water, alcohol, benzole, glycerine, are called hydrosols, alcosols, benzosols, glycerosols, respectively. The suspended mass is called the disperse phase, the medium the dispersion medium.

Collords tall into 3 quite definite classes: rst, those consisting of extremely finely divided particles $(\mathbf{C u}, \mathrm{Au}, \mathbf{A g}$, etc.) capable of more or less iudefinite suspension against gravity, in equilibrium of somewhat the same aspect as the gases of the atmosphere, depending as in the Brownian movement upon the bombardment of the molecules of the medium: 2nd, those resisting precipitation (hænoglobin, etc.) probably because of charged nuclei and which may be coagulated and precipitated by the neutralization of the charges; 3rd, colloidal as distinguished from the crystalloidal condition, the colloid being very slowly diffusible and incapable unlike crystalloids of penetrating membranes (gelatine, silicic acid, caramel, glue, white of egg, gum, etc.).


TABLE 523. - Molecular Weights of Colloids.

| Determined from diffusion. |  | Determined from freezing point |  |
| :---: | :---: | :---: | :---: |
| Gum arabic. | 1750 | Glycogen (162)*............ | 1625 |
| Tannic acid (322)* | 2730 | Tungstic acid (250)* | 1750 |
| Egg albumen. | 7420 | Gum.... . | 1800 |
| Caramel............ | 13200 | Albumose........ | 2400 6000 |
|  |  | Egg albumen. | 14000 |
|  |  | Starch (162)* | 25000 |

* Formula weight.


## TABLE 524. - Brownian Movement.

The Brownian movement is a microscopically observed agitation of colloidal particles. It is caused by the bombardment of them by the molecules of the medium and may be used to determine the value of Avogadro's number. Perrin, Chaudesaignes, Ehrenhaft and De Broglic found, respectively, $70,64,63$ and $64 \times$ 10 ${ }^{22}$ as the value of this constant. The following table indicates the size and the dependence of this movement on the magnitude of the particles.

| Material. | Diameter $\times 10^{5} \mathrm{~cm}$ | Medium. | $\underset{\mathrm{C}}{\mathrm{Temp}}$ | $\begin{aligned} & \text { Velocity } \\ & \times 10^{5} \\ & \mathrm{~cm} / \mathrm{sec} . \end{aligned}$ | Observer. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Dust particles. | 2.0 | Water | - | none | Zsigmody |
| Gold... | 0.35 | " ${ }^{\text {\% }}$ | 20? | 200. |  |
| Gold. | 0.1 | " |  | 280. | " |
| Gold. . . | 0.06 | '، |  | 700. |  |
| Platinum. | 4 to 5 | Acetone | 18 | 3900. | Svedberg, 1906-9 |
| Platinum.... ${ }_{\text {Rubber }}$ mulsio | 10. | Water | 17 | 3200. | Henri, 1008 |
| Mastic.... | 10. | " | 20? | 1.55 | Perrin, Dabrowski, 1909. |
| Gamboge | 4. 5 2.13 | " | 20 | 2.4 | Chaudesaignes, 1908. |

The movement varies inversely as the size of the particles; in water, particles of diameter greater than $4 \mu$ show no perceptible movement; when smaller than . $1 \mu$, lively movement begins, while at $10 m \mu$ the trajectories amount up to $20 m \mu$.

Smithsonian Tables.

COLLOIDS．
TABLE 525．－Adsorption of Gas by Finely Divided Particles．See also p． 439
Fine division means great surface per unit weight．All substances tend to adsorb gas at surface，the more the higher the pressure and the lower the temperature．Since different gases vary in this adsorption，fractional separation is possible．Pt black can absorb 100 vols． $\mathrm{H}_{2}, 800$ vols． $\mathrm{O}_{2}, \mathrm{Pd} 3000$ vols． $\mathrm{H}_{2}$ ．In gas analysis Pd ，heated to $100^{\circ}$ ，is used to remove $\mathrm{H}_{2}$（higher temperature used for faster adsorption，will take more at lower temperature）．Pt can dissolve several vols．of $\mathrm{H}_{2}, \mathrm{Pd}$ ，nearly 100 at ordinary temperatures；but it seems probable that the bulk of the 100 vols．of $\mathrm{H}_{2}$ taken by Pt and the 3000 by Pd must be adsorbed．In 1848 Rose found the density 21 to 22 for Pt foil，but 26 for mrecipitated Pt ．

The film of adsorbed air entirely changes the behavior of very small particles．They flow like a liquid（cf．fog）． With substances like carbon black as little as 5 per cent of the bulk is $C$ ；a liter of C black may contain 2.5 liters of air．Mitscherlich calculated that when $\mathrm{CO}_{2}$ at atmospheric pressure， $12^{\circ} \mathrm{C}$ ，is adsorbed by boxwood charcoal，it occu－ pies $1 / 56$ original vol．Apparent densities of gases adsorbed at low temperatures by cocoanut charcoal are of the same order（sometimes greater）as liquids．
$\mathrm{Cm}^{3}$ of Gas Adsorbed by a $\mathrm{Cm}^{3}$ of Synthetic Charcoal（corrected to $0^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ ？）（Hemperl and Vater）．

| ${ }^{\circ} \mathrm{C}$ | $\mathrm{H}_{2}$ | Ar | $\mathrm{N}_{2}$ | $\mathrm{O}_{2}$ | CO | $\mathrm{CO}_{2}$ | NO | $\mathrm{N}_{2} \mathrm{O}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{gathered} +20^{\circ} \\ -78 \\ -185 \end{gathered}$ | $\begin{array}{r} 7.3 \\ 19.5 \\ 284.7 \end{array}$ | $\begin{aligned} & 12.6 \\ & 92.6 \end{aligned}$ | $\begin{array}{r} 21.0 \\ 107.4 \\ 632.2 \end{array}$ | $\begin{array}{r}25.4 \\ 122.4 \\ \hline\end{array}$ | $\begin{array}{r} 26.8 \\ 139.4 \\ 697.0 \end{array}$ | $\begin{array}{r}83.8 \\ 568.4 \\ \hline\end{array}$ | 103.6 231.3 - | 109.4 <br> 330.1 |
|  | $\mathrm{CH}_{4}$ | $\mathrm{C}_{2} \mathrm{H}_{6}$ | $\mathrm{C}_{2} \mathrm{H}_{4}$ | $\mathrm{C}_{2} \mathrm{H}_{2}$ | $\mathrm{NH}_{3}$ | $\mathrm{H}_{2} \mathrm{~S}$ | $\mathrm{Cl}_{2}$ | SO2 |
| $\begin{aligned} & +20^{\circ} \\ & { }_{-78} \end{aligned}$ | 41.7 174.3 | $\begin{aligned} & 119.1 \\ & 275.5 \end{aligned}$ | $\begin{aligned} & 139.2 \\ & 360.7 \end{aligned}$ | 135.8 488.5 | 197.0 | 213.0 | $\stackrel{304 .}{ }$ | 337.8 |

$\mathrm{Cm}^{3}$ of Gas Adsorbed by a $\mathrm{Cm}^{3}$ of Cocoanut Charcoal（corrected to $\circ^{\circ} \mathrm{C}, 76 \mathrm{~cm}$ ）（Dewar）．

| ${ }^{\circ} \mathrm{C}$ | He | $\mathrm{H}_{2}$ | $\mathrm{N}_{2}$ | $\mathrm{O}_{2}$ | CO | Ar |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $-185{ }^{\circ}$ | $\mathrm{I}_{15}$ | 4 135 | 15 155 | 18 230 | 21 190 | 12 175 |

See Langmuir，J．Am．Ch．Soc．40，136I，1918；Richardson，39，1829， 1916.
TABLE 526．－Heats of Adsorption．

| Adsorber． | 岂 | － | $\begin{aligned} & \text { む̈ } \\ & \stackrel{y}{0} \\ & \text { U } \end{aligned}$ | 交す | 交品苞 | 号 | 三首会 | 式苞 | 家 | 范 | ㄷ．． | 频边 | 它 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Fuller＇s earth＊． | 57．I | 30.2 | 27.3 | 21.8 | 17.2 | 13.4 | 10.9 | 10.5 | 8.4 | 4.6 | 4.6 | 4.2 | 3.9 |
| Bone charcoal＊． | － | 18.5 | 19.3 | 17.6 | 16.5 | － | 10.6 | － | 14.0 | II． 1 | 8.4 | 13.9 | 8.9 |
| Kaolin＊．．．． | 78.8 | －68 | －68 | 27.6 | 24.5 | － | 20.4 | － | 15.7 | 9.9 | 9.9 | 9.7 | 7.2 |
| Fuller＇s earth $\dagger$ |  | ． 683 | ． 684 | ． 679 | － | － |  | － | ．61 1 | ．610 | ． 621 | ． 625 |  |

＊Small calories liberated when I g of the adsorbent is added to a relatively large quantity of the liquid．
$\dagger$ Volume adsorped from saturated vapor by Ig of fuller＇s earth．
Gurvich，J．Russ．Phys．Ch．Soc． $47,805, \mathrm{I} 915$ ．
TABLE 527．－Molecular Heats of Adsorption and Liquefaction（Favre）．

| Adsorber． | Gas． | Molecular heats of |  | Adsorber． | Gas． | Molecular heats of |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | adsorption． | lique－ faction． |  |  | adsorption． | lique－ faction． |
| Platinum． Palladium Charcoal．． ＂، ＂． | $\mathrm{H}_{2}$ $\mathrm{H}_{2}$ $\mathrm{NH}_{3}$ $\mathrm{CO}_{2}$ $\mathrm{~N}_{2} \mathrm{O}$ | $\begin{gathered} 46200 \\ 1800 \\ 5900-8500 \\ 6800-7800 \\ 7100-10900 \end{gathered}$ | 二 $(5000)$ 6250 $4+00$ | Charcoal． ＂． ＂． | $\mathrm{SO}_{2}$ HCl HBr HI | $10000-10900$ $0200-10200$ $15200-15800$ $21000-23000$ | $\begin{gathered} 5600 \\ (3600 \\ (4000 \\ (4+00) \\ (4+00 \end{gathered}$ |

Smithsonian Tables．

TABLE 528. - Miscellaneous Constants (Atomic, Molecular, etc.).


TABLE 529. - Radiation Wave-length Limits.

| Hertzen waves, longest. . | -0. 0 cm |
| :---: | :---: |
| Infra-red, longest, reststrahlung | 0.03 0.2 cm |
| Infra-red, spectroscopically stu | 0.002 cm |
| Visible, longest. | 0.00008 cm |
| Ultra-violet, Lyman, shortest** | $0.000 ~$ 0.000 006 cm |
| Ultra-violet, Lyman, shortest* | 0.000 006 cm |
| X-rays, longest | 0.00000012 cm 0.000000001 cm |
| $\gamma$ rays, longest. | 0.000000001 cm 0.000000013 cm |
| shortest | 0.0000000007 cm |

TABLE 530．－Periodic System of the Elements．

| 0 | I | II | III | IV | V | VI | VII |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| － | $\mathrm{R}_{2} \mathrm{O}$ | RO | $\mathrm{R}_{2} \mathrm{O}_{3}$ | $\mathrm{RO}_{2}$ | $\mathrm{R}_{2} \mathrm{O}_{5}$ | $\mathrm{RO}_{3}$ | $\mathrm{R}_{3} \mathrm{O}_{7}$ | RO4 Oxides． |  |
| － | － | － | － | RH4 | $\mathrm{RH}_{3}$ | RH | RH | －Hy Hydrides． |  |
| He | Li | Gl | B | C | N | O | F | 二 |  |
| Ne | Na | Mg | Al | Si | P | S | Cl | 二 |  |
| 20 | 23 | 24 | 27 | 28 | 31 | 32 | 35 |  |  |
| A | K | Ca | Sc | Ti | V | Cr | $\begin{aligned} & \mathrm{Mn} \\ & 55 \end{aligned}$ | $\begin{array}{cc}\mathrm{Fe} & \mathrm{N} \\ 56 & \\ 50\end{array}$ |  |
| 40 | 39 | 40 | 44 | 48 | 51 | 52 |  |  |  |
| － | Cu | Zn | Ga | Ge | As | Se | Br | － |  |
| － | 64 | 05 | 70 | 72 | 75 | 79 | 80 | － |  |
| Kr | Rb | Sr | Yt | Zr | Cb | Mo | － | ${ }_{102}^{\mathrm{Ru}} .{ }_{\text {R }} \mathrm{R}$ | $\begin{aligned} & \mathrm{Pd} \\ & 107 \end{aligned}$ |
| 82 | 85 | 88 | 89 | 91 | 94 | 96 | － |  |  |
| － | Ag | Cd | In | Sn | Sb | Te | I | 二 |  |
| － | 108 | 112 | 115 | 119 | 120 | 128 | 127 |  |  |  |
| X | Cs | Ba | La | Ce | Pr | Nd | － | 二 |  |
| 128 | 133 | 137 | 139 | 140 | 141 | 144 | － | 二 |  |
| － | Sa | Eu | Gd | Tb | Ds | Er | － | 二 |  |
| － | 150 | ${ }^{152}$ | 157 | 159 | 162 | 168 | － |  |  |  |
| － | Tm | $\mathbf{Y}$ b | Lu | － | Ta | W | － | $\mathrm{Os} \quad \mathrm{Ir}$ |  |
| － | 168 | 174 | ${ }^{175}$ | － | 181 | 184 | － | $191 \quad 193$ |  |
| － | Au | Hg | Tl | Pb | Bi | Po | － | － |  |
| － | 197 | 201 | 204 | 207 | 308 | 210 | － |  |  |  |
| Em | 二 | ${ }_{2}^{\mathrm{Ra}}$ | $\underset{(227)}{\text { Ac }}$ | ${ }_{232}$ | UrX： | ${ }_{238}^{\text {U }}$ | 二 | 二 |  |
| （222） | － |  |  | 232 |  |  |  |  |  |  |

TABLE 531．－Atomic Numbers．＊

| 1 | Hydrogen |  | Calcium |  | Yttrium |  | Cerium |  | Osmium |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2 | Helium |  | Scandium |  | Zirconium |  | Praseodymium |  | Iridium |
| 3 | Lithium |  | Titanium |  | Niobium $\ddagger$ | 60 | Neodymium | 78 | Platinum |
| 4 | Beryllium |  | Vanadium | 42 | Molybdenum | 61 |  | 79 | Gold |
| 5 | Boron |  | Chromium | 43 |  | 62 | Samarium | 80 | Mercury |
| 6 | Carbon | 25 | Manganese | 44 | Ruthenium |  | Europium | 81 | Thalium |
| 7 | Nitrogen |  | Iron | 45 | Rhodium | 64 | Gadolinium | $\mathrm{S}_{2}$ | Lead |
| 8 | Oxygen |  | Cobalt | 46 | Palladium | 65 | Terbium | 83 | Bismuth |
| 9 | Fluorine | 28 | Nickel | 47 | Silver | 66 | Dysprosium | 84 | Polonium |
| 10 | Neon |  | Copper | 48 | Cadmium | 67 | Holmium | 85 |  |
| 11 | Sodium |  | Zinc | 49 | Indium | 68 | Erbium | 86 | Emanation |
| 12 | Magnesium |  | Gallium |  | Tin | 69 | Thulium | 87 |  |
| 13 | Aluminum |  | Germanium |  | Antimony | 70 | Ytterbium | 88 | Radium |
| 14 | Silicon |  | Arsenic | 52 | Tellurium | 71 | Lutecium | 89 | Actinium |
| 15 | Phosphorus |  | Selenium | 53 | Iodine | 72 |  | 90 | Thorium |
| 16 | Sulphur | 35 | Bromine | 54 | Xenon |  | Tantalum | 91 | Uranium $\mathrm{X}_{2}$ |
| 17 | Chlorine | 36 | Krypton | 55 | Caesium | 74 | Tungsten | 92 | Uranium |
| 18 | Argon | 37 | Rubidium | 56 | Barium | 75 |  |  |  |
| 19 | Potassium | 38 | Strontium | 57 | Lanthanum |  |  |  |  |
| ＊Quoted from Millikan＇s The Electron， 1917. |  |  |  |  |  | $\dagger$ Glucinium． |  | $\ddagger$ Columbium． |  |

Smithsonian Tables．

$\leftarrow$ Indicates the loss of an alpha particle (producing He); the element becomes more electro-positive and the atomic weight decreases by 4, position changing 2 columns to the left.
$\nearrow$ Indicates beta radiation (loss of electron); the element becomes more electro-negative, atomic weight remains the same, position changes one column to the right and up.

Isotopes of an element have the same valency and the same chemical properties (solubility, reactivity, etc.), although their atomic weights may differ. The isotopes of Bi are, e.g., $\mathrm{RaE}, \mathrm{ThC}, \mathrm{AcC}, \mathrm{RaC}$.

In the upper half of the table are the elements possessing high electro-potential, simple spectra, colorless ions. The properties are analogous in the vertical direction (groups). In the lower half are the elements with low electro-potential, complex spectra, colored ions and tending to form complex double salts, the general properties of the elements being more pronounced in the horizontal direction (periods).

On the left side of the table are the electro-negative elements, those of the upper half forming strong acids, those of the lower half weak oxyacids.

On the right side of the table are the electro-positive elements, forming bases, oxysalts, sulfides, etc.
The center of the lower balf is occupied by the amphoteric elements forming weak acids and bases, many complex compounds and double salts, many insoluble and mostly colored compounds.

A very striking point, however, is, as already mentioned, that the similarity among the elements in the upper half is in the vertical direction, and in the lower half in the horizontal direction. This justifies the use of the expressions group-relation and period-relation.
*Table adapted from Hackh, J. Am. Chem. Soc. 40, 1023, 1918, Phys. Rev. 13, 169, 1919.
The following isotopes have been determined by means of mass-spectra. Aston, Phil. Mag. 40, 633, 1920 ; Nature, 106, 468, 1920. The columns give symbol, min. number of isotopes, masses in order of intensity. Numbers in brackets are provisional.


## SMITHSONIAN TABlES.

## ASTRONOMICAL DATA.

## TABLE 533. - Stellar Spectra and Related Characteristics.

The spectra of almost all the stars can be arranged in a continuous sequence, the various types connected in a series of imperceptible gradations. With one unimportant exception, the sequence is linear, the transition between two given types always involving the same intermediate steps. According to the now generally adopted Harvard system of classification, certain principal types of spectrum are designated by letters, - O B , A, F,G,K,M,R and N- and the intermediate types by suffixed numbers. A spectrum halfway between classes B and A is denoted $\mathrm{B}_{5}$, while those differing slightly from Class A in the direction of Class B are called B 8 or B 9 . In Classes M and O the notation Ma, $\mathrm{Mb}, \mathrm{Mc}$, etc., is employed. Classes R and N apparently form a side chain branching from the main series near Class K .

The colors of the stars, the degree to which they are concentrated into the region of the sky, including the Milky Way, and the average magnitudes of their peculiar velocities in space, referred to the center of gravity of the nakedeye stars as a whole, all show important correlations with the spectral type. In the case of colors, the correlation is so close as to indicate that both spectrum and color depend almost entirely on the surface temperature of the stars. The correlation in the other two cases, though statistically important, is by no means as close.

Examples of all classes from O to M are found among the bright stars. The brightest star of Class N is of magnitude 5.3; the brightest of Class R, 7.0.

TABLE 534. - The Harvard Spectral Classification.

| Class. | Principal spectral lines (dark unless otherwise stated). | Example. | Number brighter than 6.25, mag. | Per cent in galactic region. | Color index. | Effective surface temperature, K | Mean peculiar velocity, $\mathrm{km} / \mathrm{sec}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| O B | Bright H lines, bright spark lines of $\mathrm{He}, \mathrm{N}, \mathrm{O}, \mathrm{C}$ <br> $\mathrm{H}, \mathrm{He}$, spark lines of N | $\gamma$ Velorum | 20 | 100 | $-0.3$ | - | - |
|  | and $O$, a few spark lines of metals | $\epsilon$ Orionis | 696 | 82 | -0.30 | 20,000 ${ }^{\circ}$ | 6 |
| A | H series very strong, spark lines of metals. | Sirius | 1885 | 66 | 0.00 | $1 \mathrm{I}, 00{ }^{\circ}$ | 10 |
| F | $H$ lines fainter. Spark and arc lines of metals. | Canopus | 720 720 | 57 | 0.00 +0.33 | 7,500 ${ }^{\circ}$ | 14 |
| G | Arc lines of metals, spark lines very faint. | The sun | 609 | 58 | +0.70 | 5,000 | 15 |
| K | Arc lines of metals, spectrum faint in violet. | Arcturus | 1719 | 56 | +0.70 +1.12 | $4,200^{\circ}$ | 17 |
| M R | Bands of $\mathrm{TiO}_{2}$, flame and arc lines of metals. <br> Bands of carbon, flame and | Antares | 457 | 54 | +1.00 | $3,100^{\circ}$ | 17 |
| R N | Bands of carbon, flame and arc lines of metals. . Bands of carbon, bright | $\begin{gathered} \text { B. D. } \\ -10^{\circ} 5057 \end{gathered}$ | $\bigcirc$ | 63 | +1.7 | 3,000 ${ }^{\circ}$ | 15 |
|  | lines, very little violet light. | 19 Piscium | 8 | 87 | +2.5 | 2,300 ${ }^{\circ}$ | 13 |

Compiled mainly from the Harvard Annals. Temperatures based on the work of Wilsing and Scheiner. Radial velocities from Campbell. Data for classes R and N from Curtis and Rufus. The color indices are the differences of the visual and photographic magnitudes. Negative values indicate bluish white stars; large positive values, red stars. The peculiar velocities are in the radial direction (towards or from the sun). The average velocities in space should be twice as great.

The "galactic region" here means the zone between galactic latitudes $\pm 30^{\circ}$, and including half the area of the heavens.
$96 \%$ of the stars of known spectra belong to classes $\mathrm{A}, \mathrm{F}, \mathrm{G}, \mathrm{K}, 99.7 \%$ including B and M (Innes, 1919).

TABLE 535. - Apex and Velocity of Solar Motion.

| R. A. 1900. | Dec. | Velocity, $\mathrm{km} / \mathrm{sec}$. | Method. | No. of stars. | Authority. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\begin{array}{lll}18 \\ 18 & 02 \\ 17 \\ 17 & 54 \\ 18 & 00\end{array}$ | $\begin{array}{r} +34.3 \\ 25.1 \\ 29.2 \end{array}$ | 19.5 21.4 | Proper motions <br> Radial velocities | $\begin{aligned} & 5+13 \\ & 1193 \\ & 1405 \end{aligned}$ | Boss, Astron. J. 614. 1910 Campbell, Lick Bull. 196. igir Strömberg, Astrophys. J. 1918. |

Smithsonian Tables.

## ASTRONOMICAL DATA.

## TABLE 536. - Motions of the Stars.

The individual stars are moving in all directions, but. for the average of considerable groups, there is evidence of a drift away from the point in the heavens towards which the sun is moving (solar apex). The best determinations of the solar motion, relative to the stars as a whole, are given in Table 535. In round numbers this motion of the sun may be taken as $20 \mathrm{~km} / \mathrm{sec}$. towards the point R. A. 18 h .0 m ., Dec $+30.0^{\circ}$.

After allowance is made for the solar motion, the motions of the stars in space, relative to the general mean, present marked peculiarities. If from an arbitrary origin a series of vectors are drawn, representing the velocities of the various stars, the ends of these vectors do not form a spherical cluster (as would occur if the motions of the stars were at random), but a decidedly elongated cluster, whose form can be approximately represented either by the superposition of two intermingling spherical clusters with different centers (Kapteyn's two-stream hypothesis) or by a single ellipsoidal cluster (Schwarzschild), the actual form, however, being more complicated than is indicated by either of these hypotheses. The direction of the longest axis of the cluster is known as that of preferential motion. The two opposite points in the heavens at the extremities of this axis are called the vertices. The components of velocity of the stars parallel to this axis average considerably larger than those parallel to any axis perpendicular to it.

The preferential motion varies greatly with 'spectral type, being practically absent in Class B, very strong in Class A , and somewhat less conspicuous in Classes F to M , on account of the greater mean velocities of these stars in all directions. The positions of the vertices are nearly the same for all.

Numerous investigators, from the more distant naked-eye stars, find substantially the same position for the vertex, the mean being R.A. $6 \mathrm{~h}, 6 \mathrm{~m}$., Dec. $+9^{\circ}$. The nearer stars, of large proper motion, give a mean of 6 h . 12 m ., $+25^{\circ}$. (See Strömberg's discussion, cited above.)

In addition to these general phenomena, there are numerous clusters of stars whose members possess almost exactly equal and parallel motions, - for example, the Pleiades, the Hyades, and certain large groups in Ursa Major, Scorpius, and Orion. The vertices, and the directions toward which these clusters are moving, are all in the plane of the galaxy.

Several faint stars are known which have radial velocities between 300 and $350 \mathrm{~km} / \mathrm{sec}$. (e.g. A. G. Berlin 1366 R.A. $1000=4^{h 8 m} 6$, Dec. $1000=+22.7^{\circ}$, mag. 8.9 velocity of recession $339 \mathrm{~km} / \mathrm{sec}$.), and it is probable that the actual velocity in space exceeds $500 \mathrm{~km} / \mathrm{sec}$. for some of these.

The gth magnitude star A. G. Berlin I 366 has a radial velocity of $494 \mathrm{~km} / \mathrm{sec}$.
The greatest known proper motion is that of Barnard's star of the ninth magnitude in Ophiuchus, $10.3^{\prime \prime}$ per year, position angle $356^{\circ}$. The parallax of this star is $0.52^{\prime \prime}$, and its radial velocity about -roo $\mathrm{km} / \mathrm{sec}$.

The average radial velocity of the globular clusters is $100 \mathrm{~km} / \mathrm{sec}$. and that of the spiral nebulae 400 km . The globular clusters as a class are approaching the sun. The spiral nebulae, with a few exceptions, are receding. The greatest individual values are -410 km for the cluster N. G. C. 6934 and +1800 km for the nebula N. G.C. 584 .

Average velocities with regard to center of gravity of the stellar system, according to Campbell (Stellar Motion, 1913):

| Type B Stars: | 6.6 | km per sec. | Type G Stars: | 15.0 | km. per sec. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| " ${ }_{\text {" }}^{\text {F }}$ | 10.9 | " ${ }^{\text {" }}$ " ${ }^{\text {، }}$ | " K " | 16.8 | " " " |
| F | 14.4 | " 6 | M | 17.1 | " ${ }^{\prime}$ |

For radial velocities of 119 stars see Astrophysical Journal, 48, p. 261, 1918.

TABLE 537. - Distances of the Stars.

| Distances. | Parsecs.* | Light years. |
| :---: | :---: | :---: |
| Alpha Centauri (nearest star). | 1.32 | 4.3 |
| Barnard's Star. | 1.9 | 6.3 |
| Sirius... | 2.7 | 8.7 |
| Arcturus. | 13.0 | 43.0 |
| The Hyades............. | +40. | 130. 600. |
| Globular Clusters (Shapley): omega Centauri (nearest) | 185. 6,500 | 21,000. |

[^57]
## Smithsonian Tables.

## TABLE 538.-Brightness of the Stars.

Stelar magnitudes give the apparent brightness of the stars on a logarithmic scale, - a numerical increase of one magnitude corresponding to a decrease of the common logarithm of the light by 0.400 , and a change of five magnitudes to a factor of roo. The brightest objects have negative stellar magnitudes. The visual magnitude of the Sun is -26.7; of the mean full Moon, -12.5 ; of Venus at her brightest, -4.3 ; of Jupiter, at opposition, -2.3 ; of Sirius, -1.6 ; of Vega, +0.2 ; of Polaris, +2.1 . (The stellar magnitude of a standard candle 1 m distant is -14.18 .) The faintest stars visible with the naked eye on a clear dark night are of about the sixth magnitude (though a single luminous point as faint as the eighth magnitude can be seen on a perfectly black background). The faintest stars visible with a telescope of aperture $A$ in. are approximately of magnitude $9+5 \log _{10} A$. The faintest photographed with the 60 -inch reflector at Mt. Wilson are of about the 2 sst magnitude. A standard candle, of the same color as the stars, would appear of magnitude +0.8 at a distance of one kilometer.

The actual luminosity of a star is expressed by means of its absolute magnitude, which (Kapteyn's definition) is the stellar magnitude which the star would appear to have if placed at a distance of ten parsecs. The absolute magnitude of the sun is +4.8 (equal to that of $a_{2}$ Centauri); of Sirius is +I .3 ; of Arcturus, -0.4 . The faintest star at present known (Innes), a distant companion to a Centauri, has the (visual) absulute magritude +15.4 , and a luminosity 0.00006 that of the sun. The brightest so far definitely measured, $\boldsymbol{\beta}$ Orionis, has (Kapteyn) the abs. mag. -5.5 and a luminosity 13,000 times the sun's. Canopus, and some other stars, may be still brighter.

Intrinsic brightness of sun's surface $=57,000$ candles per $\mathrm{cm}^{2}$ of surface. (Abbot-Fowle, 1920)
The absolute magnitudes of 6 planetary nebulae average 9.1 ; average diameter, 4000 astronomical units (Solar system to Neptune $=60$ astr. units), van Maanen, Pr. Nat. Acad. 4, p. 39.4, 1918.

## Giant and Dwarf Stars.

The stars of Class B are all bright, and nearly all above the absolute magnitude zero. Stars of comparable brightness occur in all the other spectral classes, but the inferior limit of brightness diminishes steadily for the "later" or redder types. The distribution of absolute magnitudes conforms to the superposition of two series, in each of which the individual stars of each spectral class range through one or two magnitudes on each side of the mean absolute magnitude. In one, - the "giant stars," - this mean brightness is nearly the same for all spectral classes, and not far from absolute magnitude zero. In the other, - the "dwarf stars,"- it diminishes steadily from about abs. mag. -2 for Class Bo to + ro for Class $M$. The two series overlap in Classes $A$ and $F$, are fairly well separated in Class $K$, and sharply so in Class M. Two very faint stars of Classes A and F fall into neither series.

The majority of the stars visible to the naked eye are giants, since these, being brighter, can be seen at much greater distances. The greatest percentage of dwarf stars among those visible to the eye is found in Classes F and G . The dwarf stars of Classes K and M are actually much more numerous per unit of volume, but are so faint that few of the former, and none of the latter, are visible to the naked eye.

Adams and Stromberg have shown that the mean peculiar velocities of the giant stars are all small, - increasing only from about $6 \mathrm{~km} / \mathrm{sec}$. for Class B to 12 for Class M, - while those of the dwarf stars are much greater, increasing within each spectral class by about 1.5 km per unit of absolute magnitude, and reaching fully 30 km for stars of Class M and abs. mag. io. Both giant and dwarf stars show the phenomenon of preferential motion.

## TABLE 539. - Masses and Densities.

The stars differ much less in mass than in any other characteristic. The greatest definitely determined mass is that of the brighter component of the spectroscopic binary $\boldsymbol{\beta}$ Scorpii, which is of 13 times the sun's mass, 400 times its luminosity, and spectrum Br. The smallest known mass is that of the faint component of the visual binary Krueger 60 , whose mass is 0.15 , and luminosity 0.0004 of the sun's, and spectrum M.

The giant stars are in general more massive than the dwarfs. According to Russell (Publ. Astron. Soc. America, $3,327,1917$ ) the mean values are:

Spectrum.
$\mathrm{B}_{2}$
$\mathrm{Ao}_{5}$
$\mathrm{~F}_{5}$ giant
$\mathrm{K}_{5}$

Mass of a Binary System.
 8

Spectrum.
Mass.

| $\mathrm{F}_{2}$ dwarf | $3.0 \times$ Sun |
| :--- | :--- |
| G 2 | 6 |
| K 8 | 6 |

The densities of stars can be determined only if they are eclipsing variables. It appears that the stars of Classes $B$ and A bave densities averasing about one tenth that of the sun and showing a relatively small range about this value, while those of Classes F to K show a wide range in density, from 1.8 times that of the sun (W Urs. Maj.) to 0.000002 (W Crucis).

The surface brightness of the stars probably diminishes by at least one magnitude for each step along the Harvard scale from B to M. It follows that the dwarf stars are, in general, closely comparable with the s.n in diameter, while the stars of Classes B and A, though larger, rarely exceed ten times the sun's diameter. The red ler giant stars, however, must be much larger, and a few, such as Antares, may have diameters exceeding that of the earth's orbit. The densities of these stars must be exceedingly low.

If arranged in order of increasing density, the giant and dwarf stars form a single sequence starting with the giant stars of Class M, proceeding up that series to Class B, and then down the dwarf series to Class M. It is believed by Russell and others that this sequence indicates the order of stellar evolution, - a star at first rising in temperature as it contracts and then cooling off again. The older theory, however, regards the evolutionary sequence as proceeding in all cases from Class B to Class M.

Tropical (ordinary) year Sidereal year Anomalistic year
Eclipse year
$=\left\{365.24219879-0.00000006 \mathrm{I}_{4}(t-\mathrm{1900})\right\}$ days
$=\{365.25636042+0.0000000011(t-1900)\}$ days
$=\{365.25964134+0.0000000304(t-1900)\}$ days
$=\{346.620000+0.00000036(t-$ I900 $)\}$ days

Synodical (ordinary) month $=\{29.530588102-0.00000000294(t-1900)\}$ days
Sidereal month $\quad=\{27.321660890-0.00000000252(t-1900)\}$ days
Sidereal day (ordinary, two successive transits of vernal equinox, might be called equinoctial day)

Sidereal day (two successive transits of same fixed star)
$=86164.09054$ mean solar seconds $=23 \mathrm{~h} .56 \mathrm{~m} .4 .09054$ mean solar time
$=86164.09966$ mean solar seconds

1920, Julian Period $=6633$
January 1, 1920, Julian-day number $=2422325$

```
Solar parallax \(=8.7958^{\prime \prime} \pm 0.002^{\prime \prime}\) (Weinberg)
        \(8.807 \pm 0.0027\) (Hincks, Eros)
        8. 799 (Sampson, Jupiter satellites; Harvard observations)
        8.80 Paris conference
Lunar parallax \(=3422.63^{\prime \prime}=57^{\prime} 2.63^{\prime \prime}\) (Newcomb)
```

Mean distance earth to sun $=149500000$ kilometers $=92900000$ miles
Mean distance earth to moon $=60.2678$ terrestrial radii
$=38441$ I kilometers $=238862$ miles
Light traverses mean radius of earth's orbit in 498.580 seconds
Velocity of light (mean value) in vacuo, 299860 kilometers/sec. (Michelson-Newcomb) $=186324$ statute miles $/ \mathrm{sec}$.
Constant of aberration

Light year
$=20.4874^{\prime \prime} \pm 0.005^{\prime \prime}$
20.47 Paris conference (work of Doolittle and others indicates value not less than 20.51 )

Parsec, distance star whose parallax is I sec. $=3 \mathrm{I} \times 10^{12} \mathrm{~km}=19.2 \times 10^{12} \mathrm{~m}$
General precession
Obliquity of ecliptic
$=50.2564^{\prime \prime}+0.000222(t-1900)^{\prime \prime}$ (Newcomb)
Constant of nutation
$=23^{\circ} 27^{\prime} 8.26^{\prime \prime}-0.4684(t-1900)^{\prime \prime}($ Newcomb)
$=9.2 \mathrm{I}^{\prime \prime}$ (Paris conference)
Gravitation constant
$=666.07 \times 10^{-10} \mathrm{~cm}^{3} / \mathrm{g} \mathrm{sec}{ }^{2} \pm 0.16 \times 10^{-10}$
Eccentricity earth's orbit
$=e=0.01675104-0.0000004180(t-1900)-$ $0.0000000000126(t-1900)^{2}$
Eccentricity moon's orbit
Inclination moon's orbit
Delaunay's $\gamma=\sin \frac{1}{2} I$
$=e_{2}=0.05490056$ (Brown)
$=I=5^{\circ} 8^{\prime} 43 \cdot 5^{\prime \prime}$ (Brown)
Lunar inequality of earth
$=0.04488716$ (Brown)
Parallactic inequality moon
$=L=6.454^{\prime \prime}$
Mean sidereal motion of
moon's node in 365.25 days
Pole of Milky Way
$=Q=124.785^{\prime \prime}$ (Brown)
$=$ R. A., 12 h. 48 m.; Dec. $+27^{\circ}$

TABLE 541. - The First-magnitude Stars.


* Visual binary. $\dagger$ Spectroscopic binary. $\ddagger$ Pair with common proper motion.
§ Wide pair probably optical.
Mass relative to sun of (7) is 3.1 ; of (8), 1.5; of (16), 2.0. For description of types, see Table 534 or Annals of Harvard College Observatory, 28, p. 146, or more concisely 56 , p. 66, and 91, p. 5. The light ratio between successive stellar magnitudes is $\sqrt[5]{100}$ or the number whose logarithm is 0.4000 , viz., 2.512 . The absolute magnitude of a star is its magnitude reduced to a distance corresponding to $0.1^{\prime \prime}$ parallax.


## TABLE 542. - Wolf's Observed Sun-spot Numbers. Annual Means.

Sun-spot number $=k$ ( ( $\circ \times$ number of groups and single spots observed + total number of spots in groups and single spots). $k$ depends on condition of observation and telescope, equaling unity for Wolf with $3-\mathrm{in}$. telescope and power of 64. Wolf's numbers are closely proportional to spotted area on sun. 100 corresponds to about $1 / 500$ of visible disk covered (umbras and penumbras). Periodicity: mean, II.I3, extremes, 7.3 and 17.1 years. Monthly Weather Review, 30, p. 171, 1902; monthly means, revised, $1749-1901$; see A. Wolfer in Astronomische Mitteilungen and Zeitschrift für Meteorologie, daily and monthly values.

| Year. | $\bigcirc$ | I | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1750 | 83 | 48 | 48 | 31 | 12 | 10 | 10 | 32 | 48 | 54 |
| 1760 | 63 | 86 | 61 | 45 | 36 | 2 I | II | 38 | 70 | 106 |
| 1770 | 101 | 82 | 66 | 35 | 31 | 7 | 20 | 92 | 154 | 126 |
| 1780 | 85 | 68 | 38 | 23 | 10 | 24 | 83 | 132 | 131 | 118 |
| J 790 | 90 | 67 | 60 | 47 | 41 | 21 | 16 | 6 | 4 | 7 |
| 1800 | 14 | 34 | 45 | 43 | 48 | 42 | 28 | 10 | 8 | 2 |
| 1810 | $o$ | 1 | 5 | 12 | 14 | 35 | 46 | 41 | 30 | 24 |
| 1820 | 16 | 7 | 4 | 2 | 8 | 17 | 36 | 50 | 62 | 67 |
| 1830 | 71 | 48 | 28 | 8 | 13 | 57 | 122 | 138 | 103 | 86 |
| 1840 | 63 | 37 | 24 | II | 15 | 40 | 62 | 98 | 124 | 96 |
| 1850 | 66 | 64 | 54 | 39 | 21 | 7 | 4 | 23 | 55 | 9. |
| 1860 | 96 | 77 | 59 | 44 | 47 | 30 | 16 | 7 | 37 | 74 |
| 1870 | 139 | III | 102 | 66 | 45 | 17 | 11 | 12 | 3 | 6 |
| 1880 | 32 | 54 | 60 | 64 | 64 | 52 | 25 | 1.3 | 7 | 6 |
| 1890 | 7 | 36 | 73 | 85 | 78 | 64 | 42 | 26 | 27 | 12 |
| 1900 | 10 | 3 | 5 | 24 | 42 | 63 | 54 | 62 | 48 | 4.4 |
| 1910 | 19 | 6 | 4 | I | 10 | 46 | 55 | 99 | 78 | - |

Note: The sun's apparent magnitude is -26.5 , sending the earth $90,000,000,000$ times as much light as the star Aldebaran. Its absolute magnitude is +.4.8.


GEODETICAL AND ASTRONOMICAL TABLES.
TABLE 543.-Length of Degrees on the Earth's Surface.

| At. | Miles per degree |  | Km . per degree |  | $\begin{gathered} \text { At } \\ \text { Lit. } . \end{gathered}$ | Miles per degree |  | Km. per degree |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | of Long. | of Lat. | of Long. | of Lat. |  | of Long. | of Lat. | of Long. | of Lat. |
| $0^{\circ}$ | 69.17 | 68.70 | 111.32 | 110.57 | $55^{\circ}$ | 39.77 | 69.17 | 64.00 | 111.33 |
| 10 | 68.13 | 68.72 | 109.64 | 110.60 | 60 | 34.67 | 69.23 | 55.80 | 111.42 |
| 20 | 65.03 | 68.79 | 104.65 | 110.70 | 65 | 29.32 | 69.28 | 47.18 | 111.50 |
| 30 | 59.96 | 63.88 | 96.49 | 110.85 | 70 | 23.73 | 69.32 | 38.19 | 111.57 |
| 40 | 53.06 | 68.99 | 85.40 | 111.03 | 75 | 17.96 | 69.36 | 28.90 | 111.62 |
| 45 | 49.00 | 69.05 | 78.85 | 111.13 | 80 | 12.05 | 69.39 | 19.39 | 111.67 |
| 50 | 44.55 | 69.11 | 71.70 | 111.23 | 90 | 0.00 | 69.41 | 0.00 | 111.70 |

For more complete table see " Smithsonian Geographical Tables."

## TABLE 544.-Equation of Time.

The equation of time when + is to be added to the apparent solar time to give mean time. When the place is not on a standard meridian ( 75 th , etc.) its difierence in longitude in time from that meridian must be subtracted when east, added when west to get standard time ( 75 th meridian time, etc.). The equation varies from year to year cyclically, and the figure following the $\pm$ sign gives a rough idea of this variation.


TABLE 545.-Planetary Data.

| Body. | Reciprocals of masses. | Mean distance from the sun. Km. | Sidereal period. Mean days. | Equatorial diameter. Km. | Inclination of orbit. | Mean density. $\mathrm{I}_{2} \mathrm{O}=1$ | Gravity surface. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sun | I. | - | - | 1391107 | - | I. 42 | 28.0 |
| Mercury | 6000000. | $58 \times 10^{6}$ | 87.97 | 4842 | $7^{\circ} .003$ | 5.61 | 0.4 |
| Venus | 408000. | 108 " | 244.70 | 12191 | $3 \cdot 393$ | 5.16 | 0.9 |
| Earth* | 329390. | 149 " | 365.26 | 12757 | - | 5.52 | 1.00 |
| Mars | 3093500. | 228 " | 686.98 | 6784 | 1.850 | 3.95 | 0.4 |
| Jupiter | 1047.35 | $778{ }^{\prime \prime}$ | 4332.59 | 142745 | I. 308 | I. 34 | 2.7 |
| Saturn | 3501.6 | 1426 " | 10759.20 | 120798 | 2.492 | . 69 | 1.2 |
| Uranus | 22869. | 2869" | 30685.93 | 49693 | 0.773 | I. 36 | 1.0 |
| Neptune | 19700. | 4495 " | 60187.64 | 52999 | 1.778 | 1.30 | 1.0 |
| Moon | †81.45 | $88 \times 10^{4}$ | 27.32 | 3476 | 5.145 | $3 \cdot 36$ | 0.17 |

[^58]TABLE 546．－Numbers and Equivalent Light of the Stars．
The total of starlight is a sensible but very small amount．This table，taken from a paper by Chapman，shows that up to the zoth magnitude the total light emitted is equivalent to 687 rst－magnitude stars，equal to about the hundredth prrt of full moonlight．If all the remaining stars are included，following the formula，the equivalent addi－ tion would be only three more ist－magnitude stars．The summation leaves off at a point where each additional magni－ tude is adding more stars than the last．But，according to the formula，between the 23 d and 24 th magnitudes there is a turning point，after which each new magnitude adds less than before．The actual counts have been carried so near this turning point that there is no reasonable doubt of its existence．Given its existence，the number of stars is probably finite，a conclusion open to very little doubt．All the indications of the earlier terms must be misleading if the margin between 1 and 2 thousand millions is not enough to cover the whole．（Census of the Sky，Sampson，Observ－ atory，1915．）

| $\underset{m}{\text { Magnitude, }}$ | Number． | $\left\lvert\, \begin{gathered} \text { Equivalent } \\ \text { number } \\ \text { of rst- } \\ \text { magnitude } \\ \text { stars. } \end{gathered}\right.$ | $\underset{m}{\text { Totals to }} \begin{gathered} \text { magnitude } \end{gathered}$ | $\underset{m}{\text { Magnitude, }}$ | Number． | $\begin{gathered} \text { Equivalent } \\ \text { number } \\ \text { of st- } \\ \text { magnitude } \\ \text { stars. } \end{gathered}$ | Totals to $\underset{m}{\text { magnitude，}}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| －1．6．． | Sirius | II | － | 9．0－10．0． | 174，000 | 69 | 380 |
| －0．9． | a Carinæ | 6 | － | 10．0－11．0． | 426，000 | 68 | $44^{8}$ |
| 0.0 | a Centauri | 2 | － | 11．0－12．0． | 961，000 | 60 | 508 |
| 0．0－1．0． | 8 | 14 | 33 | $12.0-13.0$ | 2，020，000 | 51 | 559 |
| 1．0－2．0． | 27 | 17 | 50 | 13．0－14．0．．．．．．．．．．．．． | 3，960，000 | 40 | 599 |
| 2．0－3．0 |  | 18 | 88 | 14．0－15．0．．．．．．．．．．．．． | 7，820，000 | 31 | 630 |
| 3．0－4．0 | 189 | 19 | 87 | ${ }^{15} .0-16.0 . \ldots \ldots . . . . .$. | 14，040，000 | 22 | 652 |
| 4．0－5．0． | 650 | 26 | I13 | 16．0－17．0． | 25，400，000 | 16 | 668 |
| 5．0－6．0． | 2，200 | 35 | 148 | $17.0-18.0$ | 38，400，000 | 10 | 678 684 |
| 6．0－7．0． $7.0-8.0$ | 6，600 | 42 56 | 190 246 | $18.0-19$. $19.0-20$. | 54，000，000 | 6 3 | 684 687 |
| 8．0－9．0． | 65，000 | 65 | 311 | All stars fainter than 20.0 | － | 3 | 690 |

## TABLE 547．－Albedos．

The albedo，according to Bond，is defined as follows：＂Let a sphere $S$ be exposed to parallel light．Then its Albedo is the ratio of the whole amount reflected from $S$ to the whole amount of light incident on it．＂In the following table， $m=$ the stellar magnitude at mean opposition；$g=$ magnitude it would have at full phase and unit distance from earth and sun：$\sigma=$ assumed mean semi－diameter at unit distance；$p=$ ratio of observed brightness at full phase to that of a flat disk of same size and same position，illuminated and viewed normally and reflecting all the incident light according to Lambert＇s law；$g$ depends on law of variation of light with phase；albedo $=p q$ ．Russell，Astrophysical Journal，43，p．173， 1916.

Albedo of the earth：A reduction of Very＇s observations by Russell gives 0.45 in close agreement with the recent value of Aldrich of 0.43 （see Aldrich，Smithsonian Misc．Collections，69，1919）．

| Object． | $m$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |

TABLE 548．－Duration of Sunshine．

| Declination of sun： approx．date： | Dec． 22. | $-15^{\circ}$ Feb． Nov．${ }^{\text {a }}$ ． | $\begin{gathered} -10^{\circ} \\ \text { Feb. } 23 . \\ \text { Fct. } 19 . \end{gathered}$ | $-5^{\circ}$ Mar． Oct． 6. |  | $\begin{gathered} +5^{\circ} \\ \text { Sept. 10. } \\ \mathrm{Aprl}^{20} . \\ \hline \end{gathered}$ | $\left\{\begin{array}{c} +10^{\circ} \\ A_{102}{ }^{166} \\ \text { Aus. } 28 \end{array}\right.$ | $\left\lvert\, \begin{gathered} +15^{\circ} \\ \text { May. } \\ \text { Aug. } 13 . \end{gathered}\right.$ | $\left\lvert\, \begin{gathered} +20^{\circ} \\ \text { Hay } \\ \text { Jan 24. } \end{gathered}\right.$ | June 2r |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| titud | h m | m | h m | ${ }^{\text {h m }}$ | ${ }_{\text {h }} \mathrm{m}$ | b m |  | 1207 | ${ }_{\text {h }}^{\text {h }} \mathrm{m}$ |  |
| 잉 | crer $\begin{gathered}12 \\ 11\end{gathered}$ | ${ }^{11} 45$ |  |  | 12 <br> 12 <br> 12 <br> 12 <br> 12 <br> 1 | （1207 | crin 1207 | （1207 | （120 | 1209 <br> 12 <br> 12 <br> 13 <br> 13 <br> 20 |
| 圱。 | （10 | 1122 | cill |  | 12 12 128 12 120 O | － | ${ }^{12} 5$ | （12 | col | （12 |
|  | （1） | 1025 | （11） |  |  |  | － 1317 | ctic |  |  |
| 55\％ |  | ${ }_{8}^{9} 12$ | 1015 |  | 12120 | （1323 |  | （1513 |  |  |
| 650 | $\stackrel{3}{34}$ | ¢ $\begin{array}{r}79 \\ 630 \\ \hline 10\end{array}$ | ${ }^{\circ} \mathrm{O}$ |  |  | （ | （1515 $\begin{aligned} & 15 \\ & 18 \\ & 1805\end{aligned}$ | $\xrightarrow{17} 1$ | ${ }_{19}{ }^{19} 9$ | $\stackrel{2203}{=}$ |
| 85 ${ }^{75^{\circ}}$ | － | ${ }^{2}-37$ | 7 3 3 104 | 9 ${ }^{\circ}{ }_{46}$ | 12206 | （15 $\begin{array}{r}15 \\ 1644 \\ \hline\end{array}$ | ${ }^{18} 0$ |  |  | 二 |

For more extensive table，see Smithsonian Meteorological Tables．

## Smithsonian Tables．

table 549. - The Solar Constant.
Solar constant (amount of energy falling at normal incidence on one square centimeter per minute on body at earth's mean distance $)=1.932$ calories $=$ mean 696 determinations 1902-12. Apparently subject to variations, usually within the range of 7 per cent, and occurring irregularly in periods of a week or ten days.
Computed effective temperature of the sun: from form of black-body curves, $6000^{\circ}$ to $7000^{\circ}$ Absolute ; from $\lambda$ max. $=2930$ and max. $=0.470 \mu, 6230^{\circ}$; from total radiation, $\mathrm{J}=76.8 \times 10^{-12} \times \mathrm{T}^{4}$, $583^{\circ}$.

## TABLE 550. - Solar spectrum energy (arbitrary units) and its transmission by the earth's atmosphere.

Values computed from $e_{m}=e_{o} a^{m}$, where $e_{m}$ is the intensity of solar energy after transmission through a mass of air $m ; m$ is unity when the sun is in the zenith, and approximately $=s e c$. zenith distance for other positions (see table 556) ; $\mathrm{e}_{0}=$ the energy which would have been observed had there been no absorbing atmosphere; a is the fractional amount observed when the sun is in the zenith.


Transmission coefficients are for period when there was apparently no volcanic dust in the air.

* Possibly too high because of increased humidity towards noon.

TABLE 551. - The intensity of Solar Radiation in different sections of the spectrum, ultra-violet, visual infra-red. Calories.

| Wave-length. | Mount Whitney. |  |  |  |  | Mount Wilson. |  |  |  | Washington. |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $\mu \quad \mu$ | m | $m=1$ | 2 | 3 | 4 | $\mathrm{m}=1$ | 2 | 3 | 4 | $\mathrm{m}=\mathrm{t}$ | 2 | 3 | 4 |
| 0.00 to 0.45 | . 31 | . 25 | . 19 | .16 | . 13 | . 23 | . 16 | .12 | . 09 | .13 | . 06 | . 04 | . 02 |
| 0.45 to 0.70 | . 71 | . 67 | . 62 | . 58 | . 54 | . 65 | . 57 | . 51 | . 45 | . 53 | . 40 | . 30 | . 24 |
| 0.70 to $\infty$ | . 91 | . 87 | .85 | . 82 | . 80 | . 69 | . 68 | . 66 | . 63 | . 69 | . 62 | . 57 | . 53 |
| 0.00 to $\infty$ | 1.93 | 1.78 | 1. 66 | 1.56 | 1.47 | 1.57 | 1.42 | 1.28 | 1.17 | 1.35 | 1.08 | . 90 | . 79 |

TABLE 552. - Distribntion of brightness (Radiation) over the Solar Disk.
(These observations extend over only a small portion of a sun-spot cycle.)

\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}
\hline Wave.
length. \& $\mu$

0

0 \& $$
\begin{gathered}
\mu \\
0.386
\end{gathered}
$$ \& \[

$$
\begin{gathered}
\mu \\
0.433
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.456
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.4^{91}
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.501
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.534
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.604
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.670
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.699
\end{gathered}
$$

\] \& \[

$$
\begin{gathered}
\mu \\
0.866
\end{gathered}
$$

\] \& $\underset{1}{\mu}$ \& \[

$$
\begin{gathered}
\mu \\
\mathbf{~} .225
\end{gathered}
$$

\] \& \[

\stackrel{\mu}{1.655}
\] \& $\mu$

2.097 <br>
\hline is 0.00 \& 144 \& 338 \& 456 \& 515 \& 511 \& 489 \& 463 \& 399 \& 333 \& 307 \& 174 \& 111 \& 77.6 \& 39.5 \& 14.0 <br>
\hline . 0.40 \& 128 \& 312 \& 423 \& 486 \& 483 \& 463 \& 440 \& 382 \& 320 \& 295 \& 169 \& 108 \& 75.7 \& 38.9 \& 13.8 <br>
\hline ర్ల 0.55 \& 120 \& 289 \& 395 \& 455 \& 456 \& 437 \& 417 \& 365 \& 308 \& 284 \& 163 \& 105.5 \& 73.8 \& -38.2 \& 13.6 <br>
\hline ¢ 0.65 \& 112 \& 267 \& 368 \& 428 \& $43^{\circ}$ \& 414 \& 396 \& 348 \& 295 \& 273 \& 159 \& 103 \& 72.2 \& 37.6 \& 13.4 <br>
\hline E\{0.75 \& 99 \& 240 \& 333 \& 390 \& 394 \& 380 \& 366 \& 326 \& 281 \& 258 \& 152 \& 99 \& 69.8 \& 36.7 \& 13.1 <br>
\hline 응 0.825 \& 86 \& 214 \& 296 \& 351 \& 358 \& 347 \& 337 \& 304 \& 262 \& 243 \& 145 \& 94.5 \& 67.1 \& $35 \cdot 7$ \& 12.8 <br>
\hline U 0.875 \& 76 \& 188 \& 266 \& 317 \& 324 \& 323 \& 312 \& 284 \& 247 \& 229 \& 138 \& 90.5 \& 64.7 \& 34.7 \& 12.5 <br>
\hline L 0.92 \& 64 \& 163 \& 233 \& 277 \& 290 \& 286 \& 281 \& 259 \& 227 \& 212 \& 130 \& 86 \& 61.6 \& 33.6 \& 12.2 <br>
\hline 40.95 \& 49 \& 141 \& 205 \& 242 \& 255 \& 254 \& 254 \& 237 \& 210 \& 195 \& 122 \& 81 \& 58.7 \& 32.3 \& 11.7 <br>
\hline
\end{tabular}

Taken from vols. II and III and unpublished data of the Astrophysical Observatory of the Smithsonian Institution. Schwartzchild and Villiger: Astrophysical Journal, 23, 1906.

## Smithsonian Tables.

## ATMOSPHERIC TRANSPARENCY AND SOLAR RADIATION.

## TABLE 553. - Transmission of Radiation Through Moist and Dry Air.

This table gives the wave-length, $\boldsymbol{\lambda}$; a the transmission of radiation by dry air above Mount Wilson (altitude $=1730 \mathrm{~m}$. barometer, 620 mm .) for a body in the zenith; finally a correction factor, $\mathrm{a}_{\mathrm{w}}$, due to such a quantity of aqueous vapor in the air that if condensed it would form a layer 1 cm . thick. Except in the bands of selective absorption due to the air, a agrees very closely with what would be expected from purely molecular scattering. aw is very much smaller than would be correspondingly expected, due possibly to the formation of ions by the ultra-violet light from the sun. The transmission varies from day to day. However, values for clear days computed as follows agree within a per cent or two of those observed when the altitude of the place is such that the effect due to dust may be neglected, e. g. for altitudes greater than tooo meters. If $\mathrm{B}=$ the barometric pressure in mm., w, the amount of precipitable water in cm ., then $a_{B}=a^{\frac{b}{230}} a_{w}^{w} . w$ is best determined spectroscopically (Astrophysical Journal, 35, p. 149, 1912, 37, p. 359,1913 ) otherwise by formula derived from Hann, $w=2.3 \mathrm{e}_{\mathrm{w}} 10^{-\frac{\mathrm{h}}{22(0) 0}}, \mathrm{e}_{\mathrm{w}}$ being the vapor pressure in cm . at the station, h , the altitude in meters. See Table 377 for long-wave transmission.

| $\lambda(\mu)$ .360 <br> a  | $.660)$ | .384 | .4 I 3 | .452 | .503 | .535 | .574 | .624 | .653 | .720 | .986 | 1.74 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathrm{a}_{\mathbf{w}}$ |  |  |  |  |  |  |  |  |  |  |  |  |

Fowle, Astrophysical Journal, 38, 19 I 3.
TABLE 554. - Brightness of (radiation from) Sky at Mt. Wilson (1730 m.) and Fint Island (sea level).


* Includes allowance for bright region near sun. For the dates upon which the observation of the upper portion of table were taken, the mean ratios of total radiation sky/sun, for equal angular areas, at normal incidence, at the island and on the mountain, respectively, were $636 \times 10^{-8}$ and $210 \times 10^{-8}$, on a horizontal surface, $305 \times 10^{-8}$ and $77 \times 10^{-8}$; for the whole sky, at normal incidence, 0.57 and 0.20 ; on a horizontal surface 0.27 and 0.07 . Annals of the Astrophysical Observatory of the Smithsonian Institution, vols. II and III, and unpublished researches (Abbot).

TABLE 555. - Relative Distribution in Normal Spectrum of Sunlight and Sky-light at Mount Wilson.
Zenith distance about $50^{\circ}$.

|  | $\mu$ | $\mu$ | $\mu$ | $\mu$ | $\mu$ | $\mu$ | C | I | b | F |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Place in Spectrum | 0.422 | 0.457 | 0.491 | 0.566 | 0.614 | 0.660 |  |  |  | - |
| Intensity Sunlight | 186 | 232 | 227 | 211 | 191 | 166 |  |  |  |  |
| Intensity Sky-light | 1194 | 986 | 701 | 395 | 231 | 174 |  |  |  |  |
| Ratio at Mt. Wilson | 642 | 425 | 309 | 187 | 121 | 105 | 102 | 143 | 246 | 316 |
| Ratio computed by Rayleigh | - | - | - | - | - | - | 102 | 164 | 258 | $32 S$ |
| Ratio observed by Rayleigh | - | - | - | - | - | - | 102 | 168 | 291 | 369 |

## TABLE 556. - Air Masses.

See Table $\mathbf{1 7 4}$ for definition. Besides values derived from the pure secant formula, the table contains those derived from varions other more complex formula, taking into account the curvature of the earth, refraction, etc. The most recent is that of Bemporad.

| Zenith Dist. | $0^{\circ}$ | $20^{\circ}$ | $40^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $75^{\circ}$ | $80^{\circ}$ | $8_{5}^{\circ}$ | $88^{\circ}$ |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Secant | 1.00 | 1.064 | 1.305 | 2.000 | 2.924 | 3.864 | 5.76 | 11.47 | 28.7 |  |
| Forbes | 1.00 | 1.065 | 1.306 | 1.995 | 2.902 | 3.809 | 5.57 | 10.22 | 18.9 |  |
| Bonguer | 1.00 | 1.064 | 1.305 | 1.990 | 2.900 | 3.805 | 5.56 | 10.20 | 19.0 |  |
| Laplace | 1.00 | - | - | 1.993 | 2.899 | - | 5.56 | 10.20 | 18.8 | -10.8 |
| Bemporad | 1.00 | - | - | 1.995 | 2.904 | - | 5.60 | 10.39 | 19.8 |  |

The Laplace and Bemporad values, Lindholm, Nova Acta R. Soc. Upsal. 3,1913 ; the others, Radau's Actinometric, 1877 .
Smithsonian tables.

TABLE 557. - Mean intensity $J$ for 24 hours of solar radiation on a horizontal surface at the top of the atmosphere and the solar radiation $A$, in terms of the solar radiation, $A_{0}$, at earth's mean distance from the sun.

| Date. | Motion of the sun in longitude. | Relative Mean Vertical intensity ( $\left.\frac{J}{A_{\mathrm{O}}}\right)$. |  |  |  |  |  |  |  |  |  | $\frac{A}{A}$. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | latitude north. |  |  |  |  |  |  |  |  |  |  |
|  |  | 0 | $10^{\circ}$ | $20^{\circ}$ | $30^{\circ}$ | $40^{\circ}$ | $50^{\circ}$ | $60^{\circ}$ | $70^{\circ}$ | $80^{\circ}$ | $90^{\circ}$ |  |
| Jan, i | 0.99 | 0.303 | 0.265 | 0.220 | 0. 169 | O. 117 | 0.066 | 0.018 |  |  |  | 1.0335 |
| Feb. I | 31.54 | .312 | . 282 | . 244 | . 200 | . 150 | . 100 | . 048 | 0.006 |  |  | 1.0288 |
| Mar: I | 59.14 | -320 | . 303 | . 279 | . 245 | . 204 | . 158 | . 108 | . 056 | 0.013 |  | 1.0173 |
| Apr. I | 89.70 | . 317 | . 319 | . 312 | . 295 | . 269 | . 235 | . 195 | . 148 | . 101 | 0.082 | 1.0009 |
| May I | 119.29 | $\cdot 303$ | -318 | . 330 | -329 | -320 | - 302 | . 278 | . 253 | . 255 | . 259 | 0.9841 |
| Junt I | 149.82 | . 287 | .315 | . 334 | -345 | . 349 | -345 | . 337 | . 344 | . 360 | . 366 | 0.9714 |
| July 1 | 179.39 | .283 | . 312 | . 333 | - 347 | -352 | -351 | -345 | -356 | - 373 | - 379 | 0.9666 |
| Aus. I | 209.94 | . 294 | . 316 | . 330 | . 334 | -330 | -318 | -300 | . 282 | . 295 | -300 | 0.9709 |
| Sept. I | 240.50 | -310 | -318 | . 316 | . 305 | . 285 | . 256 | . 220 | . 180 | . 139 | . 140 | 0.9828 |
| Oct. I | 270.07 | -317 | - 308 | . 289 | .26I | . 225 | .183 | .135 | . 084 | . 065 | - | 0.9995 |
| Now. I | 300.63 | - 312 | . 286 | .251 | . 211 | .164 | . 114 | . 063 | . 018 |  |  | 1.0164 |
| Dec. 1 | 330.19 | . 304 | . 267 | . 224 | . 175 | . 124 | . 072 | . 024 |  |  |  |  |
| Year. |  | 0.305 | 0.301 | 0.289 | 0.268 | 0.241 | 0.209 | 0.173 | 0.144 | 0.133 | 0.126 |  |

## TABLE 558،-Mean Monthly and Yearly Temperatares.

Mean temperatures of a few selected American stations, also of a station of very high, two of very low temperature, and one of very great and one of very small range of temperature.

|  | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| I Hebron-Rama (Labr.) | -20.7 | 20.9 | -15.6 | -6.9 | 0.2 | -4.5 |  | +8.0 |  | - 0.8 | - 6.2 | -16.2 | 5.2 |
| 2 Winnipeg (Canada) | 21.6 | 18.8 | . | 1.9 | 0.9 | +17.1 | 8.9 | +17.6 | 11.6 | + 4.1 | - 7.6 | -15.7 | 0.6 |
| 3 Montreal. | -10.9 | -9.1 | 4.3 | 4.8 | 12.6 | +18.3 | -20.5 | 19.3 | +14.7 | 7.8 | - 0.2 | - 7.1 | 5.5 |
| 4 Boston | - 2.8 | 2.2 | 1.2 | 7.3 | +13.6 | +19.1 | +21.8 | -20.6 | -16.9 | 11.1 | + 4.8 | - 0.5 | 9.2 |
| 5 Chicago | 4.8 | - 2.9 | -1.2 | 7.9 | -13.4 | +19.7 | +22.2 | +21.6 | +17.9 | +11.1 |  | - 1.5 | 9.1 |
| 6 Denver ${ }^{\text {a }}$ | 2.1 | + 0.1 | +3.8 | 8.3 | 13.6 | 19.1 | +22.1 |  | +16.6 |  |  |  |  |
| 7 Washington | + 0.7 | + 2.1 | + 52 | +11.7 | +17.7 | ${ }^{22.9}$ | +24.9 | ${ }^{23} 37$ |  |  |  | + 2.3 |  |
| 8 Pikes Peak. | - ${ }^{16.4}$ | $-15.6$ | -13.4 | -10.4 | - 5.3 | -0.4 | + 4.5 |  | -0.3 |  |  | - 14.4 |  |
| 9 St. Louis . | - 0.8 | +1.7 | +6.2 | -13.4 | 18.8 | -24.0 |  |  |  | +14.2 | +6.4 |  | 13.1 |
| 10 San Francisco | +10.1 | +10.9 | 12.0 | +12.6 | -13.7 | +14.7 | +14.6 | -14.8 | +158 | +15.2 | 13.5 | -10.8 | 13.2 |
|  | +12.3 | 9 | . | 21.0 | -25.1 | +29.4 | -3.1 | 32.6 | -29.1 | +2.8 | , | -13.3 | -22.3 |
| 12 New Orleans | +12. |  | 6.7 | ${ }^{20.6}$ | -23.7 | +26.8 | +27.9 | +275 | +25.7 | +21.0 | +15.9 | +13.11 | +20.4 |
| ${ }_{13}{ }^{13}$ Massaua ${ }^{\text {Ft Conger (Greenl'd) }}$ | +25.6 | +26.0 | +27.1 | +29.0 | -31.1 | -33.5 | +34.8 | -34.7 | +33.3 | +31.7 | +29.0 | +27.0 | +30.3 |
| ${ }^{14} 4$ Ft. Conger (Greenl'd) | -39.0 | -40.1 | -33.5 | - 25.3 | $-10.0$ | - 0.4 |  |  | -9.0 | -22.7 | -30.9 | -33.4 | 20.0 |
| 15 16 $\begin{aligned} & \text { Werchojansk } \\ & \end{aligned}$ | [ | -453 +254 | - ${ }^{32.5}$ | -13.7 +26.3 |  |  |  |  |  | -150 | -37.8 | - 47.0 |  |
| 16 Batavia - | +25.3 | +25 4 | +25.8 |  |  |  | +25.7 | 5.9 |  |  |  | +25.6 | +25.9 |

Lat., Long., Alt. respectively: (1) $+5{ }^{\circ}{ }^{\circ} .5,63^{\circ} .0 \mathrm{~W},-;(2)+49.9$, $97.1 \mathrm{~W}, 233 \mathrm{~m} . ;(3)+45.5,73.6 \mathrm{~W}, 57 \mathrm{~m} . ;$ (4) $+42.3,7 \mathrm{rII} \mathrm{W}, 38 \mathrm{~m} . ;(5)+419,87.6 \mathrm{~W}, 25 \mathrm{~mm} . ;$ (6) $+39.7,105.0 \mathrm{~W}, 1613 \mathrm{~m} . ;(7)+38.9,77.0 \mathrm{~W}, 34 \mathrm{~m} . ;$ ( 8 ) +38.8 , $105.0 \mathrm{~W}, 4308 \mathrm{~m}$. ; (9) $+38.6,90.2 \mathrm{~W}, 173 \mathrm{~m} . ;(\mathrm{xo})+37.8,122.5 \mathrm{~W}, 47 \mathrm{~m} . ;(11)+32.7,114.6 \mathrm{~W}, 43 \mathrm{~m} . \mathrm{i}$
 $106.8 \mathrm{E}, 7 \mathrm{~m}$.

Taken from Hann's Lehrbuch der Meteorologie, $z^{\prime}$ 'nd edition, which see for further data.
Note: Highest recorded temperature in world $=57^{\circ} \mathrm{C}$ in Death Valley, California, July 10, 1913. Lowest recorded temperature in world $=-68^{\circ} \mathrm{C}$ at Verkhoyansk, Feb. 1892.

## smithsonian tables.

## THE EARTH＇S ATMOSPHERE．

## TABLE 559．－Miscellaneous Data．Variation with Latitude．

Optical ev dence of atmosphere＇s extent：twilight 63 km ，luminous clouds 83 ，meteors 200 ，aurora $44-360$ ．Jeans computes a density at 170 km of $2 \times 10^{13}$ molecules per $\mathrm{cm}^{3}$ ，nearly all $\mathrm{H}(5 \% \mathrm{He})$ ；at $810 \mathrm{~km}, 3 \times 10^{10}$ molecules per $\mathrm{cm}^{3}$ almost all H ．When in equilibrium，each gas forms an atmosphere whose density decrease with altitude is independent of the other components（Dalton＇s law， $\mathrm{H}_{2} \mathrm{O}$ vapor does not）．The lighter the gas，the smaller the decrease rate．A homogeneous atmosphere， 76 cm pressure at sea－level，of sea－level density，would be 7991 m high．Average sea－level barometer is 74 cm ；corresponding homogeneous atmosphere（truncated cone） 7790 m ，weighs（base， $\mathrm{m}^{2}$ ） $10,120 \mathrm{~kg}$ ；this times earth＇s area is $52 \times 10^{14}$ metric tons or $10^{-6}$ of earth＇s mass．The percentage by vol．and the partial pressures of the dry－air components at sea－level are： $\mathrm{N}_{2}, 78.03,593.02 \mathrm{~mm} ; \mathrm{O}_{2}, 20.99,159.52 ; \mathrm{A}, 0.94,7.144$ ； $\mathrm{CO}_{2}, 0.03,0.228 ; \mathrm{H}_{2}, 0.01,0.076 ; \mathrm{Ne}, 0.0012,0.009 ; \mathrm{He}, 0.0004,0.003$（Hann）．The following table gives the varia－ tion of the mean composition of moist air with the latitude（Hann）．

|  | N 75.99 77.32 77.87 | $\begin{array}{ll} \mathrm{O}_{2} & 20.44 \\ 20.80 \\ & 20.94 \end{array}$ | $\begin{array}{r} \text { A. } 0.92 \\ 0.94 \\ 0.94 \end{array}$ | $\begin{array}{rr}\mathrm{H}_{2} \mathrm{O} & 2.63 \\ 0.92 \\ \\ 0.22\end{array}$ | $\begin{array}{rr}\mathrm{CO}_{2} & 0.02 \\ 0.02 \\ & 0.03\end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |

TABLE 560．－Variation of Percentage Composition with Altitude（Humphreys）．
Computed on assumptions：sea－level temperature $11^{\circ} \mathrm{C}$ ；temperature uniformly decreasing $6^{\circ}$ per km up to II km，from there constant with elevation at $-55^{\circ}$ ．J．Franklin Inst．184，p．388， 1917.

| $\underset{\mathrm{km}}{\mathrm{Height},}$ | Argon． | Nitrogen． | Water vapor． | Oxygen． | Carbon dioxide． | Hydrogen． | Helium． | Total pressure，mm |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 140 | － | 0.01 | － | － | － | 99.15 | 0.84 | 0．00．40 |
| 120 | － | －． 19 | － | － | 二 | 98.74 | 1.07 | $0.005{ }^{2}$ |
| 10 80 | 二 | 2.95 32.18 | 0.05 | 0.11 I 85 | － | 95．58 | 1． 31 | 0． 0067 |
| 80 60 | 0.03 | 32.18 81.22 | 0.17 | 1.85 | － | 64.70 10.68 | 1．10 | －． 0123 |
| 50 | 0．12 | 81.22 86.78 | 0.15 0.10 | 7.89 10.17 | 二 | 10.68 2.76 | 1.23 0.07 | 0．0935 |
| 40 | 0.22 | 86.42 | 0.06 | 12.61 | － | 0.67 | 0.02 | I． 8. |
| 30 | 0.35 | 84.26 | 0.03 | 15.18 | 0.01 | 0.16 | 0.01 | 8.63 |
| 20 | －． 59 | 81.24 | 0.02 | 18． 10 | 0.01 | 0.04 | － | ${ }_{8}^{40.99}$ |
| 15 | 0.77 | 79.52 | 0.01 | 19.66 | 0.02 | 0.02 | － | 89.66 |
| 11 | 0.94 | 78.02 | 0．01 | 20.99 | 0.03 | 0.01 | － | 168.00 |
| 5 | 0.94 | 77.89 | 0.18 | 20.95 | 0.03 | 0.01 | － | 405. |
| － | 0.93 | 77.08 | 1.20 | 20.75 | 0.03 | 0．or | － | 760. |

TABLE 561．－Variation of Temperature，Pressure and Density with Altitude．
Average data from sounding balloon flights（ 65 for summer， 52 for winter data）made at Trappes（near Paris）， Uccle（near Brussels），Strassburg and Munich．Compiled by Humphreys， 16 to 20 m chiefly extrapolated．

| Elevation， km | Summer． |  |  | Winter． |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Temp．${ }^{\circ} \mathrm{C}$ | Pressure， mm of Hg ． | Density， dry air， $\mathrm{g} / \mathrm{cm}^{3}$ | Temp．${ }^{\circ} \mathrm{C}$ | Pressure， mm of Hg ． | Density， dry air， $\mathrm{g} / \mathrm{cm}^{3}$ |
| 20.0 | －51．0 | 44.1 | 0.000092 | －57．0 | 39.5 | 0．000085 |
| 19.0 | －51．0 | 51.5 | ． 000108 | －57．0 | 46.3 | ．000100 |
| 18.0 | －51．0 | 60.0 | ． 000126 | －57．0 | 54.2 | ． 000117 |
| 17.0 | －51．0 | 70.0 | ． 0001.46 | $-57.0$ | 63.5 | ． 000137 |
| 16.0 | －51．0 | 81.7 | ． 000171 | $-57.0$ | 74.0 | ． 000160 |
| 15.0 | －51．0 | 95.3 | ． 000199 | －57．0 | 87.1 | ． 000187 |
| 14.0 | －51．0 | 111.1 | ． 000232 | $-57.0$ | 102.1 | ． 000220 |
| 13.0 | －51．0 | 129.6 | ． 000270 | －57．0 | 119.5 | ． 000257 |
| 12.0 | $-51.0$ | 151.2 | ． 000316 | －57．0 | 140.0 | ． 000301 |
| 11.0 | －49．5 | 176.2 | ． 000366 | －57．0 | 16.4 .0 | ． 000353 |
| 10.0 | －45．5 | 205.1 | ． 000.419 | $-5+5$ | 192.0 | ． 000.408 |
| 9.0 | －37．8 | 237.8 | ． 000470 | －49．5 | 22．4．I | ． 000.466 |
| 8.0 | －29．7 | 274.3 | ． 00052.4 | $-43.0$ | 260.6 | ． 000526 |
| 7.0 | －22．1 | 314.9 | ． 000583 | $-35.4$ | 301.6 | ． 000590 |
| 6.0 | －15．1 | 360.2 | ． 0006.49 | $-28.1$ | $3+7.5$ | ． 000659 |
| 5.0 | －8．9 | 410.6 | ． 000722 | $-21.2$ | 398.7 | ． 000735 |
| 4.0 | $-3.0$ | 466.6 | ． 000803 | $-15.0$ | 455.9 | ． 000821 |
| 3.0 | ＋2．4 | 528.9 | ． 000892 | $-9.3$ | 519.7 | ． 000915 |
| 2.5 | $+5.0$ | 562.5 | ． 00009.42 | －6．7 | $55+3$ | ． 000067 |
| 2.0 | $+7.5$ | 598.0 | ． 000990 | $-4.7$ | 590.8 | ． 001023 |
| 1.5 | ＋10．0 | 635.4 | ． 0010.43 | $-3.0$ | 629.6 | ． 001083 |
| 1.0 | ＋12．0 | 674.8 | ． 001100 | $-1.3$ | 670.6 | ． 001146 |
| 0.5 | ＋14．5 | 716.3 | ． 001157 | 0.0 +0.7 | 75.4 .0 | ． 001215 |
| 0.0 | ＋15．7 | 760.0 | ． 001223 | ＋o． 7 | 760.0 | ． 001290 |

$760 \mathrm{~mm}=29.92 \mathrm{I} \mathrm{in} .=1013.3$ millibars．$\quad 1 \mathrm{~mm}=1.33322387$ nillibars． 1 bar $=1,000,000$ dynes；this value， sanctioned by International Meteorological Conferences，is $1,00,000$ times that sometimes used by physicists．
Smithsonian Tables．

TABLE 562. - Temperature Variation over Earth's Surface (Hann).

| Latitude. | Temperatures ${ }^{\circ} \mathrm{C}$ |  |  |  |  |  | Mean ocean temp. | Landsurface surfa |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Jan. | Apr. | July. | Oct. | Year. | Range. |  |  |
| North pole | $-41.0$ | $-28.0$ | -1.0 | -24.0 | $-22.7$ | 40.0 | -1.7 | - |
| $+80^{\circ}$ | $-32.2$ | $-22.7$ | $+2.0$ | $-19.1$ | -17.1 | 34.2 | $-1.7$ | 20 |
| 70 | $-26.3$ | -14.0. | 7.3 | -9.3 | $-10.7$ | 33.6 | +0.7 | 53 |
| 60 | $-16.1$ | $-2.8$ | 14.1 | +o. 3 | $-1.1$ | 30.2 | 4.8 | 61 |
| 50 | $-7.2$ | +5.2 | 17.9 | 6.9 | $+5.8$ | 25.1 | 7.9 | 58 |
| 40 | $+5.5$ | 13.1 | 24.0 | 15.7 | 14.1 | 18.5 | 14.1 | 45 |
| 30 | 14.7 | 20.1 | 27.3 | 21.8 | 20.4 | 12.6 | 21.3 | 43.5 |
| 20 | 21.9 | 25.2 | 28.0 | 26.4 | 25.3 | 6.1 | 25.4 | 31.5 |
| +10 | 25.8 | 27.2 | 27.0 | 26.9 | 26.8 | 1.4 | 27.2 | 24 |
| Equator | 26.5 | 26.6 | 25.7 | 26.5 | 26.3 | 0.9 | 27.1 | 22 |
| -10 | 26.4 | 25.9 | 23.0 | 25.7 | 25.5 | 3.4 | 25.8 | 20 |
| 20 | 25.3 | 24.0 | 19.8 | 22.8 | 23.0 | 5.5 | 24.0 | 24 |
| 30 | 21.6 | 18.7 | 14.5 | 18.0 | 18.4 | 7.1 | 19.5 | 20 |
| 40 | 15.4 | 12.5 | 8.8 | 11.7 | 11.9 | 6.6 | 13.3 | 4 |
| 50 | 8.4 | $5 \cdot 4$ | 3.0 | 4.8 | 5.4 | $5 \cdot 4$ | +6.4 | 2 |
| 60 | 3.2 | - | $-9.3$ | - | $-3.2$ | 12.5 | 0.0 | $\bigcirc$ |
|  |  | 二 |  | 二 | -12.0 $(-20.6)$ | 19.8 | -1.3 | 71 |
| $\stackrel{80}{ }$ | $(-4.3)$ $(-6.0)$ | - | ( -28.7 ) | - | $(-20.6)$ $(-25.0)$ | (24.4) | - | 100 |
| South pole | (-6.0) | - | (-33.0) | - | (-25.0) | (27.0) | - | (100) |

## TABLE 563. - Temperature Variation with Depth (Land and Ocean).

Table illustrates temperature changes underground at moderate depths due to surface warming (read from plot for Tiflis, Lehrbuch der Meteorologie, Hann and Süring, 1915). Below $20-30 \mathrm{~m}$ (nearer the surface in tropics) there is no annual variation. Increase downwards at greater depths, $0.03 \pm^{\circ} \mathrm{C}$ per $m$ ( $\mathrm{I}^{\circ}$ per 35 m ) $1 . \mathrm{c}$. At Pittsburgh, $1524 \mathrm{~m}, 49.4^{\circ}$. 0294 per m ; Oberschlesien, $2003 \mathrm{~m}, 70^{\circ}$, . 0294 per m ; or W. Virginia, $2200 \mathrm{~m}, 70^{\circ}, .034^{\circ}$ per m (Van Orstrand). Mean value outflow heat from earth's center, o. ooooor $72 \mathrm{~g}-\mathrm{cal} / \mathrm{cm}^{2} / \mathrm{sec}$. or $54 \mathrm{~g}-\mathrm{cal} / \mathrm{cm}^{2} / \mathrm{year}$ ( 39 Laby). Open ocean temperatures: Greatest mean annual range (Schott) $40^{\circ} \mathrm{N}, 4.2^{\circ} \mathrm{C} ; 30^{\circ} \mathrm{S}, 5 . \mathrm{I}^{\circ}$; but $10^{\circ} \mathrm{N}$, only $2.2^{\circ}$; $50^{\circ} \mathrm{S}, 2.0^{\circ}$. Mean surface temp. whole ocean (Krümmel) $17.4^{\circ}$; all depths, $3.9^{\circ}$. Below I km nearly isothermal with depth. In tropics, surface $28^{\circ}$; at $183 \mathrm{~m}, 11^{\circ}$, $80 \%$ all water less than $4.4^{\circ}$. Deep-sea (bottom) temps. range $-0.5^{\circ}$ to $+2.6^{\circ}$. Soundings in S. Atlantic: $0 \mathrm{~km}, 18.9^{\circ} ; .25 \mathrm{~km}, 15^{\circ} ; .5 \mathrm{~km}, 8.3^{\circ} ; \mathrm{Ikm}, 3.3^{\circ} ; 3 \mathrm{~km}, \mathrm{I} .7^{\circ} ; 4.5 \mathrm{~km}, 0.6^{\circ}$.

| $\underset{\mathrm{m}}{\text { Depth, }}$ | Temperature, centigrade. |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
| $\bigcirc$ | $I$ | 4 | 10 | 14 | 21 | 29 | 32 | 32 | 24 | 16 | 9 |  |
| 0. 5 | 4 | 7 | 9 | 13 | 18 | 23 | 26 | 28 | 24 | 18 | 12 | 6 |
| 1. 0 | 6 | ${ }_{8}$ | 8 | 12 | 15 | 20 | 24 | 26 | 23 | 18 | 14 | 10 |
| 1.5 | 9 | 8 | 9 | 11 | 14 | 18 | 21 | 23 | 22 | 18 | 15 | 12 |
| 2.0 | 11 | 10 | 10 | 11 | 13 | 16 | 19 | 21 | 21 | 18 | 16 | 14 |
| 3.0 | 14 | 12 | 12 | 11 | 13 | 14 | 16 | 17 | 18 | 18 | 17 | 15 |
| 4.0 | 15 | 13 | 12 | 12 | 12 | 13 | 14 | 16 | 16 | 17 | 17 | 16 |
| 5.0 | 15 | 14 | 13 | 13 | 13 | 13 | 14 | 14 | 15 | 16 | 16 | 16 |
| 6.0 | 15 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 15 | 15 | 15 |

Smithsonian Tables.

## GEOCHEMICAL DATA.

Eighty-three chemical elements ( 86 including Po, Ac and $\mathrm{UrXX}_{2}$ ) are found on the earth. Besides the eight occurring uncombined as gases, 23 may be found native, $\mathrm{Sb}, \mathrm{As}, \mathrm{Bi}, \mathrm{c}, \mathrm{Cu}, \mathrm{Au}, \mathrm{Ir}, \mathrm{Fe}, \mathrm{Pb}$ ?, $\mathrm{Hg}, \mathrm{Ni}, \mathrm{Os}, \mathrm{Pd}, \mathrm{Pt}, \mathrm{Rh}, \mathrm{Ru}$, $\mathrm{Se}, \mathrm{Ag}, \mathrm{S}, \mathrm{Ta}$ ?, $\mathrm{Te}, \mathrm{Sn}$ ?, Zn ?. Combined the elements form about $\mathbf{y}$ ooo known mineral species. Rocks are in general aggregates of these species. Some few (e. g., quartzite, limestone, etc.) consist of one specie. We have some knowledge of the earth to a depth of 10 miles. This portion may be divided into three parts : the innermost of crystalline or plutonic rocks, the middle, of sedimentary or fragmentary rocks, the outer of clays, gravels, etc. $93 \%$ of it is solid matter, $7 \%$ liquid, and the aimosphere amounts by weight to $0.03 \%$ of it. Besides the 9 major constituents of igneous rock (see 7 th col. of table) 3 are notable by their almost universal occurrence, $\mathrm{TiO}_{2}, \mathrm{P}_{2} \mathrm{O}_{5}$, and MnO . Ho , Gl , and Sc are also widely distributed.

The density of the earth as a whole is 5.52 (Burgess) ; continental surface, 2.67 and outer to miles of crust, 2.40 (Harkness). Computed from average chemical composition: outer ten miles as a whole, 2.77; northern continents 2.73 ; southern, 2.76; Atlantic basin, 2.83 ; Pacific basin, 2.88.

Data of Geochemistry, Clarke, Bul. 616, U. S. Geological Survey, 1916; Washington, J. Franklin. Inst. igo, p. 757, 1920.

Average Composition of Known Terrestrial Matter.

| Atomic number and element. | Average composition. |  |  | Igneous rocks. | Average composition of lithosphere. |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Lithosphere, $93 \%$ | Hydrosphere, $7 \%$ | Average including atmosphere. |  | Compound. | Igneous rocks, $95 \%$ | Shale, $4 \%$ | Sandstone, <br> 0.75\% | Limestone, $0.25 \%$ | Weighted average. |
| 80 | 47.33 | 85.79 | 46.43 | 47.29 | $\mathrm{SiO}_{2}$. | 59.09 | 58.10 | 78.33 | 5.19 | 59.77 |
| 14 Si | 27.74 | - | 27.77 | 28.02 | $\mathrm{Al}_{2} \mathrm{O}_{3}$. | 15.35 | 15.40 | 4.77 | 0.8 I | 14.89 |
| 13 Al | 7.85 | - | 8.14 | 7.96 | $\mathrm{Fe}_{2} \mathrm{O}_{3}$ | 3.08 | 4.02 | 1.07 | . 54 | 2.69 |
| 26 Fe | 4.50 | - | 5.12 | 4.56 | FeO | 3.80 | 2.45 | . 30 | - | 3.39 |
| 20 Ca | 3.47 | 0.05 | 3.63 | 3.47 | MgO | 3.49 | 2.44 | I. 16 | 7.89 | 3.74 |
| 12 Mg | 2.24 | 0. 14 | 2.09 | 2.29 | CaO | 5.08 | 3.11 | 5.50 | 42.57 | 4.86 |
| 11 Na | 2.46 | 1. 14 | 2.85 | 2.50 | $\mathrm{Na}_{2} \mathrm{O}$ | 3.84 | 1.30 | . 45 | . 05 | 3.25 |
| 19 K | 2.46 | 0.04 | 2.60 | 2.47 | $\mathrm{K}_{2} \mathrm{O}$ | 3.13 | 3.24 | 1.31 | . 33 | 2.98 |
| 1 H | 0.22 | 10.67 | 0.127 | 0.16 | $\mathrm{H}_{2} \mathrm{O}$ | 1.14 | 5.00 | 1.63 | . 77 | 2.02 |
| 22 Ti | 0.46 | - | . 629 | . 46 | $\mathrm{TiO}_{2}$. | 1.05 | . 65 | . 25 | . 06 | . 77 |
| 6 C | . 19 | 0.002 | . 027 | . 13 | $\mathrm{ZrO}_{2}$. | 0.039 | - | - | - | . 02 |
| 17 Cl | . 06 | 2.07 | . 055 | . 063 | $\mathrm{CO}_{2}$ | . 102 | 2.63 | 5.03 | 41.54 | . 70 |
| 35 Br | - | 0.008 | 5 | - | $\mathrm{P}_{2} \mathrm{O}_{5}$ | . 30 | . 17 | . 08 | . 04 | . 28 |
| 15 P | 12 | - | 130 | . 13 |  | . 053 | - | - | . 09 | . 10 |
| 16 S | . 12 | . 09 | . 052 | . 103 | $\mathrm{SO}_{3}$ | - | . 64 | . 07 | .05 | . 03 |
| 56 Ba | . 08 | , | . 048 | . 092 | Cl . | . 056 | - | - | . 02 | . 06 |
| 25 Mn | . 08 | - | . 096 | . 078 |  | . 078 | - | - | - | . 09 |
| 38 Sr | . 02 | - | . 018 | . 033 | BaO | . 055 | . 05 | .05 | - | . 09 |
| 7 N | - | - | - | - | SrO....... . | . 022 | - | - | - | . 04 |
| 9 Fl | . 10 | - | . 077 | . 10 | MnO . . . . . | .125 | - | - | . 05 | . 09 |
| etc. | . 50 | - | . 111 | . 091 | NiO...... | . 025 | - | - | - | . 025 |
|  |  |  |  |  | $\mathrm{Cr}_{2} \mathrm{O}_{3} \ldots .$. | . 056 | - | - | - | . 05 |
|  |  |  |  |  | $\mathrm{V}_{2} \mathrm{O}_{3} \ldots \ldots$. | . 032 | - | - | - | . 025 |
|  |  |  |  |  | $\mathrm{Li}_{2} \mathrm{O} \ldots . .$. | . 007 | - | - | - | . .or |
|  |  |  |  |  | C. | - | . 80 | - | - | . 03 |

Average Composition of Meteorites: The following figures give in succession the element, atomic number (bracketed), and the percentage amount in stony meteorites (Merrill, Mem. Nat. Acad. Sc. 14, p. 28, 1916). The "iron" meteorites contain a much larger percentage of iron and nickel, but there is a tendency to believe that with such meteorites the composition is altered by the volatilization or burning up of the other material in passing through the air. Note the greater abundance of elements of even atomic number (97.2 per cent).

| O (8) | 36.53 | Fe (26) | 23.32 |  | (14) | 18.03 |  | (12) | 13.60 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| S (16) | 1.80 | Ca (20) | 1.72 |  | (13) | 1.53 |  | (28) | I. 52 |
| Na (II) | 1.64 | Cr (24) | 0.32 |  | (25) | 0.23 |  | (19) | 0.17 |
| C (6) | 0. 15 | Co (27) | 0. 12 |  | (22) | O. 11 |  | (15) | O. II |
| H (1) | 0.09 | Cu (29) | 0.01 |  | (17) | 0.09 |  | (23) | tr. |
| Ru (44) | tr. | Pd (46) | tr. |  |  | tr. |  |  | tr. |

## For Sea Level and Different Altitudes.

Calculated from U. S. Coast and Geodetic Survey formula, p. 134 of Special Publication No. 40 of that Bureau. $g=9.78039\left(\mathrm{I}+0.005294 \sin ^{2} \phi-0.000007 \sin ^{2} 2 \phi\right) \mathrm{m}$
$g=32.08783\left(\mathrm{I}+0.005294 \sin ^{2} . \phi-0.000007 \sin ^{2} 2 \phi\right) \mathrm{ft}$.

| $\underset{\phi}{\text { Latitude }}$ | $\stackrel{g}{\mathrm{~cm} / \mathrm{sec}^{2}}$ | $\log \delta$ | $\mathrm{ft} . / \mathrm{sec}^{2}$ | $\begin{gathered} \text { Latitude } \\ \phi \end{gathered}$ | $\stackrel{g}{\mathrm{~cm} / \mathrm{sec}^{2}}$ | $\log g$ | $\stackrel{\mathrm{ft} / / \mathrm{sec}^{2}}{ }$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $0^{\circ}$ | 978.039 | 2.9903562 | 32.0878 | $50^{\circ}$ | 981.071 | 2.9917004 | 32.1873 |
| 5 | 978.0.0 .078 | . 9903735 | . 8891 | 51 | - 159 | . 9917394 | . 1902 |
| 10 | . 105 | . 9904254 | .0929 | 52 | 247 .336 | -9917784 | . 1931 |
| 12 | . 262 | . 990455 | . 0951 | 53 | - 336 | . 9918177 .9018558 | .1960 .1988 |
| 14 | . 340 | -990.489 | . 0977 | 54 | . 422 | . 9918558 | . 1988 |
| 15 | ${ }_{97} 8.38{ }_{4}$ | 2.9905094 | 32.0991 | 55 | 981.507 | 2.9918934 | 32. 2016 |
| 16 | . 430 | . 9905298 | . 1007 | 56 | . 592 | -9919310 | . 2044 |
| 17 18 | . ${ }^{43} 8$ | . 9905520 | .1023 .1040 | 57 58 | .675 .757 | . 9919677. | .2071 .2098 |
| 19 | .582 .585 | . 9905985 | -1057 | 59 | . 839 | . 9920403 | . 2125 |
| 20 | 978641 | 2.9906234 | 32. 1076 | 60 | 981.918 | 2.9920752 | 32.2151 |
| 21 | 978 | . 9906500 | . 1095 | 61 | . 995 | -9921073 | . 2176 |
| 22 | . 763 | . 9906775 | . 11116 | 62 | 982.070 | . 9921424 | 2201 .2225 |
| 23 | . 825 | . 9907050 | . 1136 .1558 | 63 64 | . 145 | .9921756 .9922079 | . 2225 |
| 24 | . 892 | -9907348 | .1158 | 64 | . 218 | -9922079 | . 2249 |
| 25 | ${ }_{978} 960$ | 2.9907649 | 32.1180 | 65 | 982.288 | 2.9922388 | 32.2272 |
| 26 | 979.030 | . 9907960 | . 1203 | 66 | - 356 | -9922689 | . 22295 |
| 27 28 | . 101 | .9908275 .9908603 | $\begin{array}{r}1227 \\ .1251 \\ \hline 1250\end{array}$ | 67 68 | .422 .487 | .992298 I .9923268 | .2316 .2338 |
| 29 | . 251 | . 9908940 | . 1276 | 69 | . 549 | . 9923542 | . 2358 |
| 30 | 979.329 | 2.9909286 | 32.1302 | 70 | 982.608 | 2.9923803 | 32.2377 |
| 3 I | - 407 | . 9909632 | - 1327 | 71 | . 665 | - 9924055 | . 2396 |
| 32 | . 487 | . 9909987 | . 1353 | 72 | . 720 | - 9924298 | . 2414 |
| 33 | . 569 | . 9910350 | . 1380 | 73 | .772 .822 | -9924528 | .2431 .2448 |
| 34 | . 652 | .9910718 | . 1407 | 74 | . 822 | . 9924749 | . 2448 |
| 35 | 979.737 | 2.9911095 | 32.1435 | 75 | 982.868 | 2.9924952 | 32.2463 |
| 36 | . 822 | . $991147^{2}$ | . 1463 | 76 | -912 | . 99251478 | - 24777 |
| 37 38 | .908 .995 | . 9911853 | 11491 .1520 | 77 78 | .954 .992 | . 99253332 | .2491 .2503 |
| 39 | 980.083 | . 9912628 | -1549 | 79 | 983.027 | . 9925655 | . 2515 |
| 40 | 980.171 | 2.9913018 | 32.1578 | 80 | 983.059 | 2.9925796 | 32.2525 |
| 4 I | . 261 | . 9913417 | . 1607 | 81 | . 089 | . 9925929 | . 2535 |
| 42 | - 350 | .9913812 | . 1636 | 82 | . 115 | - 9926043 | . 2544 |
| 43 | . $\mathrm{}$. | .9914210 | .1666 .1696 | 83 84 | 139 .160 | .9926149 .9926242 | .2552 .2558 |
| 44 | . 531 | -9914613 | . 1696 | 84 | . 160 | . 9926242 | . 2558 |
| 45 | 980.621 | 2.9915011 | 32.1725 | 85 | 983.178 | 2.992632 I | 32.2564 |
| 46 | . 711 | -9915410 | . 1755 | 86 | . 191 | -9926379 | . 2569 |
| 478 | . 802 | .9915814 | $\begin{array}{r}1785 \\ .1814 \\ \hline 1\end{array}$ | 87 88 | . 203 | . 9926432 | .2572 .2575 |
| 49 | . 988 | . 9916606 | . 1844 | 90 | 983.217 | . 9926494 | . 2577 |

To reduce $\log g$ (cm. per sec. per sec.) to $\log g(f t$. per sec. per sec.) add $\log 0.03280833=8.5159842$ - 10 .
The standard value of gravity, used in barometer reductions, etc., is 980.665 . It was adopted by the International Committee on Weights and Measures in 1gor. It corresponds nearly to latitude $45^{\circ}$ and sea-level.

Free-air Correction for Altitude.
$-0.0003086 \mathrm{~cm} / \mathrm{sec}^{2} / \mathrm{m}$ when altitude is in meters.
$-0.000003086 \mathrm{ft} / \mathrm{sec}^{2} / \mathrm{ft}$ when altitude is in feet.

| Altitude. | Correction. | Altitude. | Correction. |
| :---: | :---: | :---: | :---: |
| 200 m. 300 | $-0.0617 \mathrm{~cm} / \mathrm{sec}^{2}$ | 200 ft . 300 | -0.000617 $\mathrm{ft} . / \mathrm{sec}^{2}$ |
| + +0 | -1234 | 300 400 | . .001234 |
| 500 | . 1543 | 500 | . 001543 |
| 600 | . 1852 | 600 | . 001852 |
| 700 800 | . 2160 .2469 | 700 800 | . 002160 |
| 900 | . 2777 | 900 | . 002469 |

Smithsonian Tables.

The following more recent gravity determinations (Potsdam System) serve to show the accuracy which may be assumed for the values in Table 565, except for the three stations in the Arctic Ocean. The error in the observed gravity is probably not greater than $0.010 \mathrm{~cm} / \mathrm{sec}^{2}$, as the observations were made with the half-second invariable pendulum, using modern methods.

In recent years the Coast and Geodetic Survey has corrected the computed value of gravity for the effect of material above sea-level, the deficiency of matter in the oceans, the deficiency of density in the material below sea-level under the continents and the excess of density in the earth's crust under the ocean, in addition to the reduction for elevation. Such corrections make the computed values agree more closely with those observed. See special publication No. 40 of the U. S. Coast and Geodetic Survey entitled, "Investigations of Gravity and Isostasy," by William Bowie, 1917; also Special Publication No. Io of same bureau entitled, "Effect of Topography and Isostatic Compensation upon the Intensity of Gravity," by J. F. Hayford and William Bowie, 1912.


References: ( I ) Report 16th General Conference International Gcodetic Association, London and Cambridge, 1909, 3 d Vol. by Dr. E. Borráss, 1911; (2) U. S. Coast and Geodetic Survey, Special Publ. No. 40;* (3) U. S. Coast and Geodetic Survey, Report for 1897, Appendix 6.*
*For references (2) and (3), values were derived from comparative experiments with invariable pendulums, the value for Washington being taken as 980.112 . For the latter, Appendix 5 of the Coast and Geodetic Survey Report for 1901, and pages 25 and 244 of the 3 d vol. by Dr. E. Borráss in 1911 of the Report of the 16 th General Conference of the Intern. Geodetic Association, London and Cambridge, 1909. As a result of the adjustment of the net of gravity base stations throughout the world by the Central Bureau of the Intern. Gcodetic Association, the value of the Washington base station was changed to 980.112 .

Smithsonian Tables.

## ACCELERATION OF GRAVITY (g) IN THE UNITED STATES.

The following table is abridged from one for 219 stations given on pp. 50 to 52 , Special Publication No. $40, \mathrm{U}$. S. Coast and Geodetic Survey. The observed values depend on relative determinations and on adopted value of 980.112 for Washington (Coast and Geodetic Survey Office, see footnote, Table 566). There are also given terms necessary in reducing the theoretical value (Table 565) to the proper elevation (free-air) and to allow for topography and isostatic compensation by the Hayford method (see introductory note to Table 566).

To a certain extent, the greater the bulk of material below any station, the less its average density. This phenomenon is known as isostatic compensation. The depth below sea-level to which this compensation extends is about 96 km . Below this depth any mass element is subject to equal (fluid) pressure from all directions.


TABLE 568. - Length of Seconds Pendulum at Sea Level and for Different Latitudes.

|  | Length in cm | Log. | $\underset{\text { in }}{\text { Length }}$ inches. | Log. |  | Length in cm | Log. | $\begin{aligned} & \text { Length } \\ & \text { in } \\ & \text { inches. } \end{aligned}$ | Log. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | 99.096r | 1.996056 | 39.0141 | 1. 591222 | 50 | 99.4033 | 1.997401 | 39. 1351 | 1. 592566 |
| 5 | . 1000 | . 996074 | . 0157 | -591239 | 55 | . 4475 | . 997594 | . 1525 | - 592760 |
| 10 | . 1119 | .996126 | . 0204 | . 591292 | 60 | . 4891 | -997776 | . 1689 | -59294I |
| 15 | . 1310 | . 996210 | . 0279 | . 591375 | 65 | . 5266 | -997939 | . 1836 | -593104 |
| 20 | .1571 | . 996324 | . 0382 | -591490 | 70 | . 5590 | . 998081 | . 1964 | - 593246 |
| 25 | 99.1894 | I. 996465 | 39.0509 | 1.591631 | 75 | 99.5854 | 1. 998196 | 39.2068 | 1.593361 |
| 30 | . 2268 | . 996629 | . 0656 | -591794 | 80 | . 6047 | . 998280 | . 2144 | - 593446 |
| 35 | . 2681 | . 9968 ro | . 0819 | . 591976 | 85 | . 6168 | -998332 | . 2191 | - 593498 |
| 40 | . 3121 | . 997002 | . 0992 | . 592168 | 90 | . 6207 | - 998350 | . 2207 | - 593515 |
| 45 | . 3577 | . 997201 | . 1171 | . 592367 | - | - | - |  |  |

Calculated from Table 565 by the formula $l=g / \pi^{2}$. For each 100 ft . of elevation subtract 0.000953 cm or 0.000375 in . or 0.00003 I 3 ft . This table could also have been computed by either of the following formulae derived from the gravity formula at the top of Table 565.
$l=0.990961\left(\mathrm{I}+0.005294 \sin ^{2} \phi-0.000007 \sin ^{2} 2 \phi\right)$ meters
$l=0.99096 \mathbf{I}+0.005246 \sin ^{2} \phi-0.000007 \sin ^{2} 2 \phi$ meters
$l=39.014135\left(\mathrm{I}+0.005294 \sin ^{2} \phi-0.000007 \sin ^{2} 2 \phi\right)$ inches.
$l=39.014135+0.206535 \sin ^{2} \phi-0.000276 \sin ^{2} 2 \phi$ inches.

## TABLE 569. - Miscellaneous Geodetic Data.

Equatorial radius $\quad=a=6378206$ meter
Polar semi-diameter $\quad=b=6353.225$ miles. 3949.790 miles.

Reciprocal of flattening $=\frac{a}{a-b}=295.0$
Square of eccentricity $=c^{2}=\frac{a^{2}-b^{2}}{a^{2}}=0.006768658$


Difference between geographical and geocentric latitude $=\phi-\phi^{\prime}=$
$688.2242^{\prime \prime} \sin 2 \phi-1.1482^{\prime \prime} \sin 4 \phi+0.0026^{\prime \prime} \sin 6 \phi$.
Mean density of the earth $=5.5247 \pm 0.0013$ (Burgess Phys. Rev. 1902).
Continental surface density of the earth $=2.67$
Mean density outer ten miles of earth's crust $=2.40$
Harkness. See also page 423.
Constant of gravity, $6.66 \times 10^{-8} \mathrm{c} . g . s$. units.
Rigidity $=n=8.6 \times$ ro $^{11}$ c.g.s. units.
Viscosity $=e=10.9 \times$ 10 $^{16}$ c.g.s. units (comparable to steel). $\}_{\text {A. }} \quad$ p. IO5, I914.
Moments of inertia of the earth; the principal moments being taken as $A, B$, and $C$, and $C$ the greatest:

$$
\begin{aligned}
\frac{C-A}{C} & =0.0032652 \mathrm{I}=\frac{1}{306.259} \\
C-A & =0.001064767 E a^{2} \\
A=B & =0.325029 E a^{2} \\
C & =0.326004 E a^{2}
\end{aligned}
$$

where $E$ is the mass of the earth and $a$ its equatorial semi-diameter.

[^59]
## TERRESTRIAL MAGNETISM.

## Secular Change of Declination.

Changes in the magnetic declination between 18 ro , the date of the earliest available observations, and 1920 . Based on tables in "Distribution of the Magnetic Declination in Alaska and Adjacent Regions in 19ro" and "Distribution of the Magnetic Declination in the United States for January 1, 1915," published by the United States Coast and Geodetic Survey. For a somewhat different set of stations, see 6th Revised Edition of the Smithsonian Physical Tables.

| State. | Station. | 1810 | 1820 | 1830 | 1840 | 1850 | 1860 | 1870 | 1880 | 1890 | 1900 | 1910 | 1920 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | - | - | - | - | - | $\bigcirc$ | - | - | - | - | - | - |
| Ala. | Ashlan | 6.0 E | 6.2 E | 6. I E | 5.9 E | 5.6 E | 5.2 E | 4.7 E | 4.1 E | 3.4 E | 3.0 E | 2.9 E | 3.0 E |
|  | Tuscaloosa | 7.15 | 7.3 E | $7 \cdot 3 \mathrm{E}$ | 7.2 E | 6.9 E | 6.6 E | 6.15 | 5.5 E | 4.8 E | 4.4 E | 4.4 E | 4.6 E |
| Alas. | Sitk |  |  | - |  |  | 28.7 E | 29.0 E | 29.3 E | 29.5 E | 29.7 E | 30.2 E | 30.4 E |
|  |  | - |  |  |  |  | 26.2 E | 25.7 E | 25.2 E | 24.8 E | 24.5 E | 24.2 E | 24.2 E |
|  | St. Micha |  |  | - | - | - | 20.4 E | 20.1 E | 19.6 E 24.7 | 19.0 E 23.1 | 18.3 E 22.1 | 17.5 E 21.5 | 17.2 E 2 L .0 E |
| Ariz. | Holb | - | - | - | - | 13.5 E | 13.7 E | 13.8 E | 13.6 E | 13.4 E | 13.5 E | I4. I E | 14.5 E |
|  | Prescot |  | - |  |  | 13.3 E | 13.6 E | 13.7 E | 13.7 E | 13.6 E | 13.7 E | 14.4 E | 14.9 E |
| Ark. | Augusta | 7.7 E | 7.9 E | 8.0 E | 8.0 E | 7.8 E | 7.5 E | 7.15 | 6.5 E | 5.9 E | 5.5 E | 5.6 E | 5.8 E |
|  | Danville |  | - | 9.3 E | 9.3 E | 9.2 E | 9.0 E | 8.6 E | 8.1 E | 7.6 E | 7.2 E | 7.4 E | 7.7 E |
| Cal. | Bagda | - | E | 13.1 E | 13.5 E | 13.9 E | 14.15 | 14.3 E | 14.4 E | 14.4 E | 14.6 E | 15.3 E | 15.7 E |
|  | Moja | 12.4 E | 12.9 E | 13.4 E | 13.8 E | 14.2 E | 14.4 E | 14.6 E | 14.9 E | 14.9 E | 15.15 | 15.8 E | 16.3 E |
|  | Modes | 13.8 E | 14.2 E | ${ }^{1}+7.7 \mathrm{E}$ | 15.1 E | 15.5 E | 15.8 E | 16.15 | 16. 1 E | 16.2 E | 16.6 E | 17.3 E | 17.7 E |
|  | Redding | 15.6 E | 16.1 E | 16.6 E | 17.0 E | 17.4 E | 17.8 E | 18.1 E | 18.2 E | 18.3 E | 18.7 E | 19.4 E | 19.7 E |
| Colo. | Puel |  | - | - | - | 13.7 E | 13.8 E | 13.7 E | 13.5 E | 13.0 E | 12.8 E | 13.3 E | 13.7 E |
|  | Ouray | - | - | - | - | 15.0 E | 15.2 E | 15.2 E | 15.0 E | 14.6 E | 14.6 E | 15.15 | 15.5 E |
| Conn. | Hartio | 5.1W | 5.5W | 6. IW | 6.8 w | 7.5W | 8.1w | 8.7 W | 9.4 W | 9.8w | 10.4W | II. 2 W | 12.1W |
| Del. | Dover | 6w | 1.9W | 2.3 w | 2.8w | 3.4 W | 4.0W | 4.7W | 5.3W | 5.9W | 6.5w | 7.2W | 8.0w |
| D. C. | Washingt | 0.5 E | -0.3E | 0.0 | 0.5 W | 1.0w | 1.7 W | 2.4W | 3.0w | 3.6w | 4. 2 W | 4.9W | 5.6w |
| Fla. | Miam | 5.8 E | 5.7 E | 5.3 E | 4.9 E | 4.4 E | 3.9 E | 3.3 E | 2.7 E | 2.2 E | 1.7 E | 1.5 E | 1.5E |
|  | Bartow | 5.5 E | 5.4 F | 5.2 E | 4.8 E | 4.4 E | 3.8 E | 3.2 E | 2.6 E | 2.1E | 1.6 E | I. 4 E | 1.3 E |
|  | Jacksonville | 5.0 E | 5.0 E | 4.9 E | 4.6 E | 4.2 E | 3.6 E | 3.0 E | 2.4 E | 1.8 E | 1.3 E | I. 1 E | 0.9 E |
|  | Tallahassee | 5.8 E | 5.8 E | 5.7 E | 5.5 E | 5.2 E | 4.8 E | 4.2 E | 3.6 E | 3.0 E | 2.5 E | 2.4 E | 2.4 E |
| Ga. | Millen | 4.9 E | +.8E | $+6 \mathrm{E}$ | 4.3 E | 3.9 E | 3.4 E | 2.7 E | 2.IE | 1.5 E | 0.9 E | 0.7 E | 0. 5 E |
|  | Americus | 5.9 E | 6.0 E | 5.9 E | 5.6 E | 5.2 E | 4.7 E | 4.1 E | 3.5 E | 2.9 E | 2.4 E | 2.2 E | 2.2 E |
| Haw. | Honolu | - | - |  | - | 9.4 E | 9.4 E | 9.5 E | 9.8 E | 10. 1 E | 10.4 E | 10.7 E | II. 1 E E |
| Idaho | Poca | - |  |  |  | 17.7 E | 17.9 E | 18.0 E | 17.9 E | 17.8 E | 17.9 E | 18.5 E | 18.8 E |
|  | Boi |  | - |  | - | 18.0 E | 18.5 E | 18.8 E | 18.8 E | 18.6 E | 18.8 E | 19.5 E | 19.8 E |
|  | Pierce. |  |  |  | 20.2 E | 20.6 E | 21.0 E | 21.2 E | 21.1 E | 21.2 E | 21.4 E | 22.0 E | 22.2 E |
| III. | Kankak | 6.6 E | 6.8 E | 6.8 E | 6.6 E | 6.3 E | 5.8 E | $5 \cdot 3 \mathrm{E}$ | 4.8 E | 4.1 E | $3 \cdot 5 \mathrm{E}$ | 3.3 E | 3.1E |
|  | Rushville | 7.7 E | 8.0 E | 8. I E | 8.0 E | 7.8 E | 7.4 E | 7.0E | 6.4 E | 5.7 E | 5.2 E | 5.1 E | 5.1E |
| lnd. Iowa | Indianap | 5.0 E | 5.1 E | 5.0 E | $4 \cdot 7 \mathrm{E}$ | 4.3 E | 3.8 E | 3.3 E | 2.7 E | 2.1E | 1.5 E | I. 1 E | 0.9E |
|  | Walker |  | 8.9 E | 9.1 E | 9.1 E | 8.9 E | 8.6 E | 8.2 E | 7.5 E | 6.8 E | 6.2 E | 6.2 E | 6.2 E |
| Kans, | Sac City |  | 10.4 E | 10.7 E | 10.8 E | 10.8 E | 10.5 E | 10.2 E | 9.6 E | 8.8 E | 8.4 E | 8.6 E | 8.6 E |
|  | Ness Cit |  |  |  |  | 11.5 E 12.4 | 11.4 E I 2.4 E | 11.2E | 10.8 E 11.9 E | 10.2 E 11.3 | 9.9 E II. 2 E | 10.15 II. 4 E | 10.3 E 11.7 E |
| Ky. | Manches | 3.5 E | 3.6 E | 3.4 E | 3.15 | 12.4 E 2.8 E | 12.4 E 2.2 E | 12.2 E I .6 E | 11.9 E 1.0 E | 11.3 E 0.3 E | 11.2 E 0.3 W | 11.45 $0.6 W$ | II. 7 E 0.8 W |
|  | Louisville. | 4.8 E | 4.9 E | 4.8 E | 4.6 E | 4.3 E | 3.8 E | 3.2 E | 2.5 E | 1.9E | 1.5 E | 1.3 | 1. 2 E |
|  | Princeton | 6.8 E | 6.9 E | 6.9 E | 6.8 E | 6.5 E | 6.0 E | 5.5 E | 4.8 E | 4.2 E | 3.9 E | 3.7 E | 3.8 E |
| La. | Winfield. | 8.6 E | 8.9 E | 9.0 E | 9.0 E | 8.9 E | 8.6 E | 8.2 E | 7.6 E | 7.1 E | 6.8 E | 7.0E | 7.4 E |
| Me. | Eastport | 13.9 W | 14.7 W | 15.5 W | 16.3 W | 17.2 W | $18.0 W$ | 18.5 W | 18.8w | $19.0 W$ | 19.3 W | 20.0W | 21.0W |
|  | Bango | 1.8 W | 12.4 W | 13.2 W | 13.9 W | 14.7 W | 15.4 W | 15.9 W | 16.4 W | 16.7 W | 17.16 | 17.8w | 18.8w |
|  | Portl | 9.3 W | 9.9W | 10.6 w | 11. 2 W | 11.9 W | 12.6 W | 13.10 | 13.6 w | 14.10 | 14.5 W | 15.3 W | 16.3 W |
| Md. | Baltim | 0.9W | I. IW | I. 4 W | 1.9W | 2.4 W | 3.1w | 3.8w | 4.4 W | 5.0w | 5.6w | 6.3 W | 7.0w |
| Mass. | Bosto | 7.3W | 7.8w | 8.4W | 9.1W | 9.8 w | 10. 5 W | II. OW | II. 5 W | 12.0 W | 12.6 W | 13.4 W | 14.4 W |
|  | Pittsfield | 5.7W | 6.2 W | 6.7 W | 7.4W | 8.1w | 8.7 W | 9.3W | 10.0W | 10.4 W | ir.ow | 1 I .8 W | 12.7 W |
| Mich. | Marque |  | 6.7 E | 6.7 E | 6.5 E | 6.1 E | 5.5 E | 4.7 E | 3.8 E | 3.0 E | 2.4 E | 2.15 | 1.7E |
|  | Lapeer |  | 2.6 E | 2.4 E | 2.1 E | 1.6 E | 1.0 E | 0. 3 E | 0. 5 W | 1. 2 W | 1.8w | 2.3 W | 2.8w |
| Minn. | Grand H | - | 5.1 E | 5.0 E | 4.8 E | 4.4 E | 3.8 E | 3.15 | 2.4 E | 1.6 E | 1.15 | - 7 E | 0.3 E |
|  | Marshal |  | 11.6 E | 11.8 E | 11.9 E | 11.7 E | 11.4 E | 10.9 E | 10.3 E | 9.5 E | 8.9 E | 8.8 E | 8.7 E |
|  | Mibbing |  |  | 10.7 E | 11.7 E IO .8 E | 11.6 E | 11.4 E | II.OE | 10.5 E | 9.8 E | 9.3 E | 9.4 E | 9.4 E |
|  |  |  |  | 10.7 E | 10.8 E | 10.6 E | 10.3 E | 9.7 E | 9.0 E | 8.2 E | 7.6 E | 7.7 E | 7.5 E |
| Miss. | Meridia | 7.3 E | 7.4 E | 7.5 E | 7.4 E | 13.1 7.2 E | 12.8 E 6.9 | 12.3 E 6.5 | 11.7 E 5.9 E | 11.0 E 5.2 E | $\begin{array}{r}10.4 \mathrm{E} \\ 4.8 \\ \hline\end{array}$ | 10.6 E 4.9 E | 10.5 E |
|  | Vicksbur | 8.2 E | 8.4 E | 8.5 E | 8.4 E | 8.2 E | 8.0 E | 7.6 E | 7.1E | 6.4 E | 6.0 E | 6.15 | 6.4 E |

TERRESTRIAL MAGNETISM (continued).
Secular Change of Declination (concluded).

| State. | Station. | 1810 | 1820 | 1830 | 1840 | 1850 | 1860 | 1870 | 1880 | 1890 | 1900 | 1910 | 1920 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Mont. | Hermann | - | 9.2 E | . 3 E | 9.2 E | 9.0 E | 8.7 E | 8.3 E | $7 \cdot 7 \mathrm{E}$ | 7.0 E | 6.5 E | 6.5 E | 6.6 E |
|  | Sedalia. | - | 9.9 E | 10.0 E | 10.0 E | 9.9 E | 9.6 E | 9.3 E | 8.7 E | 8.0 E | 7.6 E | 7.8 | 8.0 E |
|  | Miles City |  |  | - | - | 17.6 E | 17.8 E | 17.7 E | 17.4 E | 16.9 E | 16.9 E | 17.3 E | 17.6 E |
|  | Lewistown |  |  | - | 19.5 E | 19.8 E | 20.1 E | 20.18 | 19.9 E | 19.6 E | 19.6 E | 20.1 | 20.4 E |
| Nebr. | Ov |  |  |  | 20.4 E | 20.8 E | 21.15 | 21.2 E | 2 I . IE | 20.9 E | 2I. X E | 21.6 E | 22.0 E |
|  | Val | - |  | 12.7 E | 12.9 E | 12 | 12.8 E 14.1 | 13.9 E | E | II. 4 E | $11.0{ }^{11}$ | 11.2 | 11.5 E I 3.1 E |
|  | Alliance |  | - | - | - | 15.4 E | 15.4 E | 15.3 E | 14.8 E | 14.3 E | 14.2 E | 14.5 | I 4.8 E |
| Nev. | Elko |  |  |  | - | 17.3 E | 17.6 E | 17.7 E | 17.7 E | 17.6 E | 17.8 E | 18.4 | 18.9 E |
|  | Hawthor |  |  |  |  | 16.2 E | 16.6 E | 16.8 E | 17.0 E | 17.0 E | 17.3 E | 18.0 | 18.4 E |
| N. H. | Hanover | 7.1w | 7.5W | 8.2W | 8.9W | 9.7 W | 10.5 W | II. IW | 11.6w | 12.0W | 12.6 W | 13.2 W | 14.2W |
| N. | Trenton | 2.8 W | 3. IW | 3.5W | 4. W W | 4.7 W | 5.4 W | 6.0W | 6.7 W | 7.2W | 7.8w | 8.6w | 9.4W |
| N. M. | Santa Ro |  |  |  | - | 12.7 E | 12.8 E | 12.7 E | 12.4 E | 12.0 E | 11.9 E | 12.5 | 12.9 E |
|  | Laguna |  | - ${ }^{\text {W }}$ | 6 | - | 13.4 E | 13.6 E | 13.6 E | 13.4 E | 13.0 E | 13.0 E | 13.6 E | 14.1 E |
| N. Y | Albany | 5.7W | 5.9W | 6.4 w | 7.0W | 7.8w | 8.5W | 9. 2 W | 10.0W | 10.3W | 10.9 W | II. 6 W | 12.5W |
|  | Elmira | 2.2W | 2.4W | 2.8w | 3.3W | 4. OW | 4.8w | 5.4W | 6.3W | 7.0W | 7.5w | 8. 2 W | 9.0W |
|  | Buffal | O | I. IW | 1. 4 W | 1.9 W | 2.4 W | 3.2W | 3.8w | 4.7 W | 5.4 W | 5.9W | $6.5 W$ | 7.2W |
| N. C. | Newbe | 1. | I. 6 E | 1.3 E | 0.8 E | 0.3 E | 0.3 W | I. OW | 1.7W | 2.3W | 2.9W | 3.4W | 4.0w |
|  | Greensboro | 3.5 E | 3.4 E | 3.15 | 2.7 E | 2.2 E | 1. 6 E | 1.0E | 0.3 E | -. 3W | 0.8w | I. 3W | 1.8w |
|  | Asheville | 4.2 E | 4.2 E | 4.0 E | 3.6 E | 3.15 | 2.6 E | 2.0 E | 1.3E | -0.7E | 0. 2 E | 0.2 W | -. 5 W |
| N. D. | James |  |  | 14.0 E | 14.2 E | 14.2 E | 14.0 E | 13.7 E | 13.2 E | 12.5 E | 12.2 E | 12.4 E | 12.5 E |
|  | Disma |  |  |  | - | 16.4 E | 16.3 E | 16.15 | 15.6 E | 15.0 E | 14.7 E | 15.0 | 15.2 E |
| Ohio | Canton | 2.3 | 2 E | 2.0 E | 1.7 E | 17.7 E 1.2 E | 17.7 E 0.6 E | 17.5 E 0.0 | 17.15 0.76 | 16.5 E I .3 W | 16.3 E I .9 W | 16.7 E 2.5 W | $\begin{array}{r} 16.9 \mathrm{E} \\ 3.1 \mathrm{~F} \end{array}$ |
|  | Urbana | 4.4 E | 4.4 E | 4.3 E | 4.0 E | 3.5 E | 3.0 E | 2.4 E | 1.8 E | I.IE | 0.5 E | 0.1 E | 0.3W |
| Okla. | Okmulge |  |  | - | - | 10.2 E | 10 | 9.8 E | 9.5 E | 9. | 8.7 E | 8.9 E | 9.2E |
|  | Enid. | - |  | - | - | 11.2 E | 11.2E | II.OE | 10.6 E | 10.2 E | 9.8 E | 10.1 | 10.5 E |
| Ore. | Sumpt |  |  |  |  | 19.3 E | 19.7 E | 20.0 E | 20.2 E | 20.2 E | 20.4 E | 21.1 | 2 I .4 E |
|  | Detroit. | 16.7 E | 17.4 E | 18.0 E | 18.6 E | 19.2 E | 19.7 E | 20.1 E | 20.3 E | 20.5 E | 20.8 E | 21.6 E | 21.9E |
| Pa. | Wilkes-Ba | 2.3W | 2. 5 W | 2.9W | 3.4 W | 4. Ow | 4.7W | 5.3W | 6.0w | 6.6w | 7.2 W | 8.0w | 8.8w |
|  | Lockhave | 1. 4 W | 1.5W | 1.9W | 2.4 W | 3.0W | 3.6w | 4.3 W | 5.0w | 5.6w | 6.3W | 7.0 | 7.7W |
|  | Indiana | 0.6 E | 0.5 E | 0.3 E | O. IW | 0.7 W | I. 3 W | $2.0 W$ | 2.6W | 3.3 W | 3.9W | 4.6w | 5.2W |
| P. R. | San Juan | - | . 5 | - | - |  |  |  |  |  | 1. OW | 2.01 | 3.4W |
| R.I. | Newpor | 6.6w | 7.1w | 7.7w | 8.4 W | 9.1W | 9.8 w | 10.3W | 10.8w | 11.3 W | 11.9 W | 12.7 W | 13.7 W |
| S. C. | Marion | 3.4 E | 3.3 E | 3.0 E | 2.6 E | 2.1 E | 1.6 E | 0.9 E | 0.3 E | 0.4 W | r.ow | 1.4W | 1.8w |
|  | Aiken. | 4.8 E | 4.7 E | 4.5 E | 4.2 E | 3.7 E | 3.1 E | 2.5 E | 1.9 E | I. 3 E | 0.7 E | 0.45 | O.IE |
| S. D. | Huron |  | - | - | 13.2 E | 13.2 E | 13.0 E | 12.7 E | 12.3 E | 11.7E | 11.2 E | 11.5 F | II.7E |
|  | Murdo |  |  |  |  | 15.0 E | 14.9 E | 14.7 E | 14.3 E | 13.7 E | 13.4 E | 13.7 E | 13.9 E |
|  | Rapi |  |  |  |  | 16.4 E | 16.4 E | 16.3 E | 15.8 E | 15.3 E | 15.1 E | 15.4 E | 15.7 E |
| Tenn. |  |  | 3.8 E | 3.6 E | $3 \cdot 3 \mathrm{E}$ | 2.9 E | 2.4 E | 1.8 E | I. I E | 0.5 E | 0.0 | 0.3W | 0.5w |
|  |  |  | 6.5 E | 6.4 | 6.2 E | 5.9 E | 5.5 | 4.9 E | 4.3 E | 3.7 E | 3.2 E | 3.0 E | 2.9 E |
| Tex. |  | $7 \cdot 3 \mathrm{E}$ |  | 7.4 | 7.3 E | 7.0 E |  |  | 5.5 E | 4.9 E | 4.4 | 4. | 4.4 E |
|  | San An |  |  |  | 9. | 9.8 |  | 8.9 E 9.5 | 8.4 E 9.2 E | 7.9 E | 7.7 E 8.7 E | 9.15 | 8.6 E 9.7 E |
|  | Pecos |  | - | 10.7 E | II.OE | III.IE | II.IE | II. 0 E | 10.8 E | 10.4 E | 10.3 E | 10.8 E | II. 3 E |
|  | Wythev | 2.9 E | 2.9 E | 2.7 E | 2.4 E | 2.0 E | 1.4 E | 0.8 E | O.1 E | 0. 5 W | I. IW | 1. 5 W | I.9W |
| Wash. | Wilson C |  | - | - | - | 21.2 E | 21.6 E | 21.8 E | 21.9 E | 22.1 E | 22:4E | 23.0 E | 23.3 E |
|  | Seattle. | 18.9 E | 19.5 E | 20. I E | 20.7 E | 2 I .2 E | 21.6 E | 22.0 E | 22.2 E | 22.45 | 22.8 E | 23.5 F | 23.8 E |
| W. Va. Wis. | Sutton | 1.9 E | . 8 E | . 6 E | . 2 E | 0.8 E | 0.2 E | 0.4 W | I.IW | 1.8 W | 2.4 W | 2.9 W | 3.4 W |
|  | Sh |  | 7.4 E | 7.4 E | 7.3 E | 7.0 E | 6.5 E | 5.9 E | 5.0 E | 4.3 E | 3.7 E | 3.4 E | 3.15 |
|  | Floy |  |  |  | - | 11.2 E | 11.3E | 11.2 E I 6.8 E | 10.9 | 10.4 E | 10. 3 | 10.7 | II. 1 E |
| Vt. | Rutla | 6.6w |  | 7.6w | 8.3W | 16.4 E $9 . \mathrm{W}$ | 16.7 E 0.8 W | 16.8 E 10.5 W | 16.7 E II .2 W | 16.4 E | 16.5 E $12 . \mathrm{WW}$ | 17.15 12.8 w | 17.5 E I 3.8 W |
| Va. | Richmo | 0.8 E | 0.6 E | 0.3 E | -.1w | 0.6w | I. 2 W | 1.8 w |  | 3. | 3.7 W | 4.2 | 4.9 W |
|  | Lynchbu | 1. 6 E | 1. 5 E | 1.3 E | 0.9 E | -0.5E | -.1w | 0.7 W | I. 4 W | $2.0 W$ | 2.6w | 3.15 | 3.7 W |
|  | Stanle |  | 8.9 E | 9.0 E | 9.0 E | 8.8 E | 8.4 E | 7.8 E | 7.1 E | 6.3 E | 5.8 E | 5.6 | 5.4 E |
| Wyo. |  |  | - | - | - | 15.8 E | 16.0 E | 16.0 E | 15.8 E | 15.3 E | 15.2 E | 15.7 E | 16.0 E |
|  | Green R | - | - | - | - | 16.8 E | 17.0 E | 17.0 E | 16.8 E | 16.5 E | 16.6 E | 17.2 E | 17.5 E |

TABLE 571. - Dip or Inclination.
This table gives for the epoch January 1, 1915, the values of the magnetic dip, $I$, corresponding to the longitudes west of Greenwich in the heading and the north latitudes in the first column.

| $\begin{aligned} & \lambda \\ & \phi \end{aligned}$ | 65 | $\circ$ 70 | $\circ$ 75 | 80 | 85 | 90 | $\circ$ 95 | 100 | 105 | $\circ$ 110 | $\circ$ 115 | 120 | $\circ$ 125 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | - | - | - | - | - | - | - | - | - | - | - | - | - |
| 19 | - | - | 50.4 | 49.4 | 48.5 | 47.2 | 46.1 | 45.1 | 44. 1 | - | - | - | - |
| 21 | - | - | 52.7 | 51.9 | 5 I .1 | 50.1 | 48.9 | 47.9 | 46.9 | $\square$ | - | - | - |
| 23 | - | - | 55.1 | 54.2 | 53.7 | 52.8 | 51.7 | 50.4 | 49.7 | 48.7 | - | - | - |
| 25 | - | - | 57.6 | 56.8 | 56.1 | 55.2 | 54. 2 | 53.1 | 52.2 | 51.2 | 50.1 | - | - |
| 27 | - | - | 59.8 | 59.3 | 58.3 | 57.6 | 56.6 | 55.6 | 54.6 | 53.6 | 52.4 | - | - |
| 29 | - | - | 61.9 | 61.3 | 60.5 | 59.7 | 58.9 | 57.9 | 56.8 | 55.8 | 54.6 | 53.8 | - |
| 31 | - | 63.6 | 63.8 | 63.4 | 62.8 | 62.0 | 61.1 | 60.1 | 59.0 | 58.1 | 57.0 | 55.8 | - |
| 33 | - | 65.4 | 65.6 | 65.3 | 64.7 | 64.0 | 63.1 | 62.4 | 61.2 | 60.2 | 59.1 | 58.0 | - |
| 35 | - | 67.2 | 67.3 | 67.2 | 66.6 | 66.1 | 65.3 | 64.3 | 63.2 | 62.2 | 61.0 | 60.1 | - |
| 37 | - | 69.1 | 69.2 | 69.0 | 68.9 | 68.1 | 67.3 | 66.4 | 65.2 | 64.2 | 63.1 | 62.1 | - |
| 39 | - | 70.6 | 70.8 | 70.6 | 70.6 | 70.0 | 69.2 | 68.3 | 67.3 | 66.2 | 64.9 | 63.9 | 62.5 |
| 41 | - | 72.2 | 72.3 | 72.5 | 72.2 | 7 I .7 | 71.0 | 70.1 | 69.0 | 68.0 | 66.6 | 65.5 | 64.3 |
| 43 |  | 73.6 | 74.0 | 74.1 | 74.0 | 73.5 | 72.6 | 71.8 | 70.7 | 69.7 | 68.4 | 67.2 | 65.9 |
| $+5$ | 74.3 | 74.9 | 75.4 | 75.5 | 75.5 | 75.2 | 74.5 | 73.5 | 72.4 | 71.3 | 70.2 | 69.0 | 67.8 |
| 47 | 75.6 | 76.3 | 76.8 | 76.9 | 76.9 | 77.0 | 76.1 | 75.1 | 74.2 | 72.9 | 71.7 | 70.5 | 69.5 |
| 49 | 76.5 | 77.4 | 78.2 | 78.5 | 78.5 | 78.3 | $77 \cdot 7$ | 76.7 | 75.7 | 74.5 | 73.2 | 72.1 | 71.2 |

TABLE 572. - Secular Change of Dip.
Values of the magnetic dip for places designated by the north latitudes and longitudes west of Greenwich in the first two columns for January I of the years in the heading. The degrees are given in the third column and the minutes in the suceeding columns.

| Latitude. | Longitude. |  | 1855 | 1860 | 1865 | 1870 | 1875 | $\pm 880$ | 1885 | 1890 | 1895 | 1900 | 1905 | 1910 | 1915 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | - | - | 1 | , | , | , | , | , | , | 1 | , | , | , | , | , |
| 25 | 80 | $55+$ | 32 | 32 | 31 | 29 | 26 | 23 | 18 | 18 | 22 | 31 | 43 | 73 | 108 |
| 25 | 110 | $49+$ | 14 | 26 | 36 | 45 | 52 | 61 | 67 | 74 | 82 | 92 | 102 | 116 | 132 |
| 30 | 83 | $60+$ | 66 | 70 | 73 | 74 | 73 | 67 | 57 | 51 | 53 | 63 | 78 | 101 | 126 |
| 30 | 100 | $57+$ | 4 I | 46 | 55 | 64 | 67 | 62 | 57 | 58 | 65 | 74 | 87 | 103 | 120 |
| 30 | 115 | $54+$ | 47 | 56 | 63 | 65 | 64 | 66 | 69 | 73 | 79 | 85 | 90 | 96 | 102 |
| 35 | 80 | $66+$ | 67 | 68 | 67 | 64 | 55 | 45 | 36 | 31 | 30 | 32 | 40 | 55 | 72 |
| 35 | 90 | $65+$ | 67 | 61 | 53 | 46 | 39 | 34 | 28 | 27 | 27 | 29 | 38 | 51 | 66 |
| 35 | 105 | $62+$ | - ${ }_{56}$ | - | 61 | 47 | 45 | 39 | 39 | 39 | 43 | 49 | 57 | 65 | 72 |
| 35 | 120 | $59+$ | 56 | 59 | 61 | 6 I | 60 | 59 | 6 I | 64 | 66 | 66 | 66 | 66 | 66 |
| 40 | 75 | $71+$ | 82 | 82 | 78 | 73 | 65 | 55 | 43 | 33 | 27 | 24 | 24 | 29 | 36 |
| 40 | 90 | $70+$ | 30 | 31 | 34 | 37 | 36 | 32 | 29 | 26 | 25 | 26 | 30 | 38 | 48 |
| 40 | 105 | $67+$ | - | - | - | 56 | 53 | 51 | 51 | 51 | 52 | 56 | 60 | 63 | 66 |
| 40 | 120 | $64+$ | - | - | - | 51 | 52 | 54 | 57 | 58 | 58 | 54 | 50 | 45 | 42 |
| 45 | 65 | $74+$ | 118 | 112 | 103 | 94 | 82 | 70 | 59 | 48 | 37 | 30 | 26 | 22 | 18 |
| 45 | 75 | $75+$ | 91 | 87 | 83 | 78 | 73 | 61 | 50 | 41 | 31 | 26 | 24 | 24 | 24 |
| 45 | 90 | $74+$ | 86 | 86 | 86 | 84 | 82 | 80 | 73 | 68 | 66 | 64 | 65 | 68 | 72 |
| 45 | 105 | $72+$ | - | - | - | - | - | 30 | 28 | 27 | 26 | 26 | 25 | 25 | 24 |
| 45 | 122.5 | $68+$ | 45 | 44 | 47 | 50 | 50 | 49 | 47 | 44 | 40 | 37 | 33 | 27 | 21 |
| 49 | 92 | $77+$ | 80 | 79 | 78 | 76 | 74 | 74 | 69 | 66 | 65 | 63 | 60 | 58 | 60 |
| 49 | 120 | $72+$ | - | 27 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 17 | 12 | 06 |

Smithsonian Tables.

## TERRESTRIAL MAGNETISM（continued）．

TABLE 573．－Horizontal Intensity．
This table gives for the epoch January 1，1915，the horizontal intensity，$H$ ，expressed in cgs units，corresponding to the langitudes in the heading and the latitudes in the first column．

| ${ }_{\phi}^{\lambda}$ | $65^{\circ}$ | $70^{\circ}$ | $75^{\circ}$ | $80^{\circ}$ | $85^{\circ}$ | $90^{\circ}$ | $95^{\circ}$ | $100^{\circ}$ | $105^{\circ}$ | $115{ }^{\circ}$ | $15^{\circ}$ | ${ }^{120^{\circ}}$ | ${ }^{12} 5^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 19 |  |  |  |  |  |  |  |  |  | ＝ | ＝ | 二 | ＝ |
| $\begin{aligned} & 21 \\ & 23 \\ & 25 \end{aligned}$ | 二 | 二 | －200 | ${ }_{\text {－206 }}^{288}$ | － 28 | $\begin{gathered} 3100 \\ .350 \\ \hline \end{gathered}$ | $\begin{aligned} & 3150 \\ & .350 \\ & .308 \end{aligned}$ | － 32 | ：320 | ． 3 II | 二 | 三 | 二 |
| $\begin{aligned} & { }_{25}^{25} \end{aligned}$ | － | － | ：2734 | ：271 | ：286 | ：282 | －288 | ${ }_{\text {－} 292}$ | － 295 | ． 296 | ${ }_{\text {－} 297}$ | － | － |
| ${ }_{3}^{29}$ | 二 | ． 237 | ${ }_{\text {－} 243}$ | ${ }_{-248}^{258}$ | ${ }_{-265}$ | －272 | ${ }_{\text {－} 276}$ | ${ }_{\text {－}}^{\text {272 }}$ | ${ }_{-286}^{.286}$ | $\stackrel{.287}{.279}$ | ${ }_{\text {－} 288}^{288}$ | －288 | － |
| 3 <br> $\begin{array}{c}31 \\ 35 \\ 35\end{array}$ | 二 | －237 | － 212 | － 2.248 | － 24. | －288 | －255 | －272 | －264 |  | － 28.281 | － 282 |  |
| 35 37 | －－ | ：2023 | －217 | ${ }_{\text {－} 210}^{223}$ | ${ }_{213}^{232}$ | ${ }_{\text {：} 2225}^{235}$ | ${ }_{\text {：} 227}^{241}$ | ${ }_{-234}^{24}$ | －241 | ${ }_{\text {－} 246}^{254}$ | －250 | ${ }_{\text {－253 }}$ |  |
|  | 二 | －178 | ${ }_{\text {－} 178}$ | － 186 | － 180 | － 1206 |  |  |  |  |  |  |  |
| $\begin{aligned} & 43 \\ & 43 \\ & 45 \end{aligned}$ | 二 | －1．156 | $\underset{.156}{1150}$ | ${ }_{\substack{165 \\ 1153}}^{181}$ | ${ }_{\substack{171 \\ 115}}^{1185}$ | －154 | －182 | －184 | －182 | － 2107 | －214 |  | 240 <br> .227 <br> .216 |
| ${ }_{47}^{45}$ | － 1.150 | －154 | ${ }_{\text {－139 }}^{153}$ | ${ }_{\text {－139 }}^{15}$ | ${ }_{145}^{155}$ | －1420 | －150 | ${ }_{\text {－154 }}^{\text {－174 }}$ | ${ }_{.185}^{185}$ | － 180 | － 187 | 2105 | ． 2120 |
| 49 | 135 | ． 130 | ． 126 | ． 123 | ． 123 | ． 129 | ． 136 | ． 14 | ．153 | ${ }^{164}$ | ．174 | ．182 | r89 |

TABLE 574．－Secular Change of Horizontal Intensity．
Values of horizontal intensity，$H$ ，in cgs units for the places designated by the latitude and longitude in the first two columns for January I of the years in the heading．

| Lat． | Long． | 1860 | 1865 | 1870 | 1875 | 1880 | 1885 | 1890 | 1895 | 1900 | 1905 | 1910 | 1915 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| － | 。 |  |  |  |  |  |  |  |  |  |  |  |  |
| 25 | 80 | ． 3086 | ． 3073 | ． 3057 | ． 3042 | ． 3025 | ． 3008 | ． 2990 | ． 2970 | ． 2949 | ． 2917 | ． 2870 | ． 2810 |
| 25 | 110 | － 3216 | － 3202 | － 3187 | ． 3168 | ． 3153 | ． 3141 | ． 3128 | ． 3115 | ． 3102 | ． 3088 | － 3063 | ． 3030 |
| 30 | 83 | ． 2775 | ． 2768 | ． 2760 | ． 2752 | ． 2743 | ． 2732 | ． 2720 | ． 2705 | ． 2686 | ． 2658 | ． 2614 | ． 2560 |
| 30 | 100 |  | － 2978 | ． 2959 | ． 2941 | ． 2924 | ． 2908 | ． 2894 | ． 2882 | ． 2867 | ． 2847 | ． 2817 | ． 2780 |
| 30 | 115 | ． 2996 | ． 2981 | － 2966 | － 2949 | ． 2934 | ． 2922 | － 2910 | ． 2899 | ． 2890 | ． 2880 | ． 2863 | ． 2840 |
| 35 | 80 | ． 2367 | ． 2362 | ． 2357 | ． 2355 | ． 2351 | ． 2347 | ． 2340 | ． 2335 | ． 2325 | ． 2306 | ． 2272 | ． 2230 |
| 35 | 90 |  |  | ． 2460 | ． 2460 | ． 2459 | ． 2456 | ． 2453 | ． 2445 | － 2435 | ． 2418 | ． 2387 | ． 2350 |
| 35 | 105 | － | － | － | ． 2619 | ． 2607 | ． 2598 | ． 2589 | ． 2582 | ． 2572 | ． 2559 | ． 2537 | ． 2510 |
| 35 | 120 |  | 884 | ． 2727 | ． 2714 | ． 2702 | ． 2690 | － 2679 | － 2670 | － 2663 | ． 2657 | － 2645 | ． 2630 |
| 40 | 75 | ． 1876 | ． 1884 | ． 1895 | ． 1904 | ． 1912 | ． 1918 | ． 1923 | － 1924 | －192I | ． 19 II | ． 1889 | ． 1860 |
| 40 | 90 | ． 2080 | ． 2076 | ． 2073 | ． 2070 | ． 2069 | ． 2068 | ． 2066 | ． 2062 | － 2054 | ． 2042 | ． 2019 | ． 1990 |
| 40 | 105 |  |  | ． 2269 | ． 2263 | ． 2258 | ． 2254 | ． 2250 | ． 2245 | ． 2237 | ． 2227 |  | ． 2190 |
| 40 | 120 | － | － | ． 2439 | ． 2430 | ． 2422 | ． 2416 | ． 2409 | ． 2402 | ． 2396 | ． 2390 | ． 238 r | ． 2370 |
| 45 | 65 | ． 1504 | ． 1515 | ． 1527 | ．1543 | ． 1557 | ． 1568 | ． 1579 | ． 1590 | ． 1598 | ． 1600 | ． 1596 | ． 1590 |
| 45 | 75 | ． 1487 | ． 1490 | ． 1497 | ． 1508 | ． 1518 | ． 1529 | ． 1540 | ． 1548 | ． 1552 | ． 1552 | － 1543 | ． 1530 |
| 45 | 90 | ． 1648 | ． 1646 | ． 1644 | ． 1641 | ． 1639 | ． 1637 | ． 1636 | ． 1637 | ． 1636 | ． 1633 | ． 1620 | ． 1600 |
| 45 | 105 | － | － | ． 1895 | ． 1894 | ． 1893 | ． 1891 | ． 1888 | ． 1885 | ． 1881 | ． 1875 | ． 1864 | ． 1850 |
| 45 | 122.5 | ． 2183 | ． 2175 | ． 2166 | ． 2158 | ． 2148 | ． 2140 | ．2134 | ． 2130 | ． 2128 | ． 2128 | ． 2125 | ． 2120 |
| 49 | 92 | ． 1336 | ． 1334 | ． 1330 | ． 1327 | ． 1325 | ． 1324 | ． 1324 | ． 1327 | ． 1330 | ． 11336 | ． 1330 | ． 1320 |
| 49 | 120 | ． 1846 | ． 1845 | ． 1844 | ． 1841 | ． 1836 | ． 1831 | ． 1826 | ． 1824 | ． 1825 | ． 1825 | ． 1823 | ． 1820 |

Smithsonian Tables．

TERRESTRIAL MAGNETISM (continued).
TABLE 575.- Total Intensity.
This table gives for the epoch January 1, 1015, the values of the total intensity, $F$, expressed in cgs units corresponding to the longitudes in the heading and the latitudes in the first column.

| $\stackrel{\lambda}{\phi}$ | $65^{\circ}$ | $70^{\circ}$ | $75^{\circ}$ | $80^{\circ}$ | $85^{\circ}$ | $90^{\circ}$ | $95^{\circ}$ | $100^{\circ}$ | $105^{\circ}$ | $110^{\circ}$ | I15 ${ }^{\circ}$ | $120^{\circ}$ | $125^{\circ}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 400 | . 466 | . 460 | . 465 | . 463 | . 461 | . 453 | - | - | - | - |
| 21 | - | - | . 478 | . 480 | . 482 | . 48.3 | . 479 | . 477 | . 468 | - | - | - | - |
| 23 | - | - | . 495 | - 492 | . 497 | . 498 | . 495 | . 488 | . 481 | . 471 | - | - | - |
| 25 | - | - | . 500 | . 513 | . 513 | . 512 | . 510 | . 503 | - 494 | -484 | .474 | - |  |
| 27 | - | - | . 525 | . 531 | . 525 | . 524 | . 523 | . 517 | . 509 | . 499 | . 487 |  |  |
| 29 | - | - | . 537 | . 537 | . 538 | - 539 | . 536 | . 533 | . 522 | . 511 | . 497 | . 488 | - |
| 31 | - | . 533 | . 548 | . 552 | . 5.56 | . 554 | . 550 | . 546 | . 536 | . 528 | . 514 | . 498 | - |
| 33 | - | . 540 | . 557 | . 565 | . 566 | . 566 | . 564 | . 559 | . 548 | - 543 | . 528 | . 513 | - |
| 35 | - | . 550 | . 562 | . 576 | . 584 | . 580 | . 577 | . 574 | . 557 | . 549 | . 536 | . 528 | - |
| 37 | - | . 566 | . 577 | . 586 | . 592 | . 595 | . 588 | . 585 | . 572 | . 561 | . 552 | . 541 | - |
| 39 | - | . 575 | . 587 | . 590 | . 602 | . 602 | . 597 | . 590 | . 586 | . 575 | . 559 | . 550 | . 531 |
| 41 | - | . 582 | . 585 | . 605 | . 605 | . 608 | . 605 | . 599 | . 592 | . 582 | . 569 | . 559 | . 544 |
| 43 | - | . 588 | . 602 | . 602 | . 620 | . 613 | . 609 | . 605 | . 599 | . 597 | . 58 I | . 570 | . 556 |
| 45 | . 588 | . 591 | . 607 | .611 | .6r9 | . 626 | . 625 | .613 | .612 | . 599 | . 596 | . 586 | - 572 |
| 47 | . 587 | . 604 | . 609 | . 613 | . 622 | .631 | . 624 | . 618 | . 617 | . 612 | . 596 | . 584 | . 577 |
| 49 | . 578 | . 596 | . 616 | . 617 | . 617 | . 636 | . 638 | . 626 | . 619 | . 614 | . 602 | . 592 | . 587 |

TABLE 5.6. - Secular Change of Total Intensity.
Values of total intensity, $F$, in cgs units for places designated by the lat:tudes and longitudes in the first two columns for January I of the years in the heading.

| Lat. | Long. | 1855 | 1860 | 1865 | 1870 | 1875 | 1880 | 1885 | 1890 | 1895 | 1900 | 1905 | 1910 | 1915 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| - | - |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 25 | 80 | . 5476 | . 5453 | . 5427 | . 5396 | . 5363 | . 5324 | . 5285 | . 5253 | . 5227 | . 5208 | . 5178 | . 5160 | . 5131 |
| 25 | 110 | . 4941 | . 4946 | . 4941 | . 4933 | . 4914 | . 4906 | . 4900 | . 4889 | . 4884 | . 4879 | . 4876 | . 486 r | . 4836 |
| 30 | 83 | . 5758 | . 5755 | . 5749 | . 5735 | . 5716 | . 5678 | . 5625 | . 5584 | . 5559 | . 5549 | . 5534 | . 5510 | . 5471 |
| 30 | 100 | - | - | . 5608 | . 5595 | . 5567 | . 5523 | . 5479 | . 5455 | . 5450 | . 5444 | . 5441 | . 5426 | . 5399 |
| 30 | 115 | . 5219 | . 5216 | . 5205 | . 5182 | . 5149 | . 5129 | .5114 | . 5101 | . 5094 | . 5092 | . 5086 | . 5068 | . 5041 |
| 35 | 80 | .6101 | . 6000 | . 6075 | . 60.48 | . 6008 | . 5955 | . 5910 | . 5873 | . 5856 | . 5838 | . 5823 | . 5796 | . 5756 |
| 35 | 90 | - |  | - | . 5993 | . 5966 | . 5946 | . 5914 | . 5904 | . 5885 | . 5868 | . 5861 | . 5834 | . 5800 |
| 35 | 105 | - |  |  | - | . 5720 | . 5675 | . 5656 | . 5636 | . 5634 | . 5630 | . 5627 | . 5604 | . 5567 |
| 35 | 120 | $\overline{618}$ | 6103 | - | . 5157 | . 5428 | . 5401 | . 5383 | . 5369 | . 5356 | . 5342 | . 5330 | . 5306 | . 5276 |
| 40 | 75 | . 6183 | . 6193 | . 6196 | . 6204 | . 6190 | . 6160 | . 6115 | . 6077 | . 6047 | . 6022 | . 5991 | - 5948 | . 5892 |
| 40 | 90 | - | . 6236 | . 62.40 | . 62.46 | . 6233 | . 6209 | . 6190 | . 6169 | . 6151 | . 6133 | .6118 | . 6089 | . 6052 |
| 40 | 105 | - | - | - | . 6040 | . 6011 | . 5988 | . 5978 | . 5967 | . 5958 | . 5955 | . 5944 | . 5912 | . 5871 |
| 40 | 120 | $\overline{6161}$ | 6150 | 6 | . 5739 | . 5720 | . 5709 | . 5707 | . 5692 | . 5676 | . 56.47 | . 5621 | . 558 x | . 5546 |
| 45 | 65 | . 6161 | . 6159 | . 6140 | . 6126 | . 6107 | . 6082 | . 6052 | . 6022 | . 5994 | . 5980 | . 5962 | . 5923 | . 5875 |
| 45 | 75 | . 6369 | . 6347 | . 6330 | . 6320 | . 6329 | . 628 r | . 6247 | . 6228 | .6189 | .6171 | . 6157 | .612I | . 6070 |
| 45 | 90 | - | . 6552 | . 65.44 | . 6522 | . 6495 | . 6474 | . 6415 | . 6377 | . 6366 | . 6349 | . 6344 | . 6315 | . 6264 |
| 45 | 105 | 6 | 60 | - | - | - | . 6296 | . 6276 | . 6261 | . 6245 | . 6232 | . 6206 | . 6170 | . 6118 |
| 45 | 122.5 | . 6037 | . 6019 | . 6010 | . 6000 | . 5978 | . 59.44 | .5913 | . 5883 | . 5855 | . 5837 | . 5820 | . 5784 | . 5745 |
| 49 | 92 | . 6616 |  | . 6578 | . 6540 | . 6508 | . 6498 | . 6448 | . 6421 | . 6427 | . 6424 | . 6426 | . 6380 | . 6349 |
| 49 | 120 | - | .612I | . 6107 | . 6098 | . 6083 | . 6061 | . 6039 | . 6017 | . 6010 | . 6008 | . 5997 | . 5963 | . 5922 |

Smithsonian Tables.

TERRESTRIAL MAGNETISM (continued).
TABLE 577. - Agonic Line.
The line of no declination appears to be still moving westward in the United States, but, as the line of no annual change is only a short distance to the west of it, it is probable that the extreme westerly position will soon be reached.

| $\begin{aligned} & \text { Lat. } \\ & \text { N. } \end{aligned}$ | Longitudes of the agonic line for the years |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1800 | 1850 | 1875 | 1890 | 1905 | 1915 |
| - | - | - | - | 。 | 。 | - |
| 25 | - | - | - | 75.5 | 76.1 | 77.4 |
| 30 | - | - | - | 78.6 | 79.7 | 80.0 |
| 35 | - | 76.7 | 79.0 | 79.9 | 8 r .7 | 82.7 |
|  | 75.2 | 77.3 | 79.7 80.6 8 | 80.5 82.2 | 82.8 83.5 | 84.4 84.0 |
| 7 | 75.3 76.7 | 77.7 78.3 | 80.6 81.3 | 82.2 82.6 | 83.5 83.6 | 8 84.1 |
| 9 | 76.9 | 78.7 | 81.6 | 82.2 | 83.6 | 83.9 |
| 40 | 77.0 | 79.3 | 81.6 | 82.7 | 84.0 | 84.3 |
| I | 77.9 | 80.4 |  | 82.8 | 84.6 | 85.1 |
| 2 | 79.1 | 8 r .0 | 82.6 | 83.7 | 84.8 | 85.3 |
| 3 | 79.4 | 81.2 | 83.1 | 84.3 | 85.0 | 85.4 |
| 4 | 79.8 | - | 83.3 | 84.9 | 85.5 | 85.8 |
|  | - | - | 83.6 | 85.2 | 86.0 | 86.2 |
| 6 | - | - | 84.2 | 84.8 | 86.4 | 86.3 |
| 7 | - | - | 85.1 | 85.4 | 86.4 | 86.6 |
| 8 | - | - | 86.0 | 85.9 86.3 | 86.5 | 87.2 |
| 9 | - | - | 86.5 | 86.3 | 87.2 | 88.0 |

TABLE 578. - Mean Magnetic Character of Each Month in the Years 1906 to 1917.*
Means derived from daily magnetic characters based upon the following scale: $\circ$, no disturbance; I , moderate disturbance, and 2, large disturbance.

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Year Mean. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1906 | 0.45 | 0.90 | 0.68 | 0.63 | 0. 58 | 0. 56 | 0.69 | 0.63 | 0.79 | 0.59 | 0.55 | 0.71 | 0.65 |
| 1907 | 0.69 | 0.83 | 0.58 | 0.55 | 0.72 | 0.67 | 0.67 | 0.66 | 0.68 | 0.71 | 0.61 | 0.53 | 0.66 |
| 1908 | 0.64 | 0.71 | 0.87 | 0.68 | 0.82 | 0.66 | 0.49 | 0.77 | 0.89 | 0.53 | 0.60 | 0.47 | 0.68 |
| 1909 | 0.76 | 0.63 | 0.79 | 0.49 | 0.59 | 0.54 | 0.53 | 0.65 | 0.70 | 0.69 | 0.49 | 0.58 | 0.62 |
| 1910 | 0.58 | 0.71 | 0.8I | 0.68 | 0.72 | 0.53 | 0.55 | 0.81 | 0.80 | 0.96 | 0.77 | 0.76 | 0.72 |
| I9II | 0.78 | 0.89 | 0.78 | 0.76 | 0.70 | 0.53 | 0.61 | 0.53 | 0.50 | 0.59 | 0.49 | 0.45 | 0.63 |
| 1912 | 0.42 | 0.49 | 0.45 | 0.45 | 0.47 | 0.47 | 0.41 | 0.49 | 0.47 | 0.46 | 0.45 | 0.43 | 0.46 |
| 1913 | 0. 51 | 0.53 | 0.53 | 0.54 | 0.45 | 0.45 | 0.42 | 0.46 | 0.58 | 0.57 | 0.42 | 0.36 | 0.48 |
| I914 | 0.46 | 0.50 | 0.62 | 0.50 | 0.37 | 0.52 | 0.61 | 0.6 I | 0.53 | 0.64 | 0.60 | 0.46 | 0.54 |
| 1915 | -. 53 | 0.64 | 0.68 | 0.61 | 0.58 | 0.61 | 0.47 | 0.60 | 0.59 | 0.77 | 0.82 | 0.54 | 0.62 |
| I916 | 0.6 I | 0.56 | 0.86 | 0.68 | 0.75 | 0.67 | 0.62 | 0.75 | 0.75 | 0.76 | 0.83 | 0.65 | 0.71 |
| 1917 | 0.8 I | 0.69 | 0.59 | 0.63 | 0.66 | 0.55 | 0.61 | 0.85 | 0.61 | 0.74 | 0. 53 | 0.72 | 0.67 |

[^60]
## RECENT VALUES OF THE MAGNETIC ELEMENTS AT MAGNETIC OBSERVATORIES.

(Compiled by the Department of Terrestrial Magnetism, Carnegie Institution of Washington.)

| Place. | Latitude. | Longitude. | $\begin{array}{\|c} \substack{\text { Middle } \\ \text { of } \\ \text { year. }} \end{array}$ | Magnetic elements. |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Declination. | Inclination. | Intensity (cgs units). |  |  |
|  |  |  |  |  |  | Hor'l. | Ver'l. | Total. |
|  | 。 | - , |  | - | - |  |  |  |
| Pavlorsk | $59+1 \times$ | 3029 E | 1907 | I 09.9 E | 7037.7 N | . 1650 | . 4694 | . 4975 |
| Sitka | 5703 N | r35 20 W | 1916 | 3024.0 E | 74 26.0 N | - 1558 | . 5592 | . 5805 |
| Katharin | 5650 N | 6038 E | 1907 | $1035.5 \mathrm{E}^{\mathrm{E}}$ | 7052.2 N | - 1762 | . 5081 | $.5378$ |
| Rude Sk | 5551 N | 1227 E | 1915 | 8 44.3 W | 6850.6 N | . 1726 | . 4459 | . 4781 |
| Kasan | 5547 N | 49 O8 $\mathbf{E}$ | 1912 | 809.1 E | 6917.3 N | . 1802 | . 4765 | . 5094 |
| Eskdalemui | 5519 N | 3 I 2 W | 1913 | 1754.9 W | 6937.3 N | .1682 | . 4528 | . 4831 |
| Stonyhur | $53 \mathrm{5I} \mathrm{~N}$ | 228 W | 1915 | 1638.0 W | 6841.4 N | . 1734 | . 4446 | . 4772 |
| W'ilhelm | 5332 N | 8 o9 E | 1911 | II 28.2 W | 6730.7 N | . 1811 | . 4375 | . 4735 |
| Potsda | 52 523 5 | $1304 \underset{\text { E }}{ }$ | 1916 | 807.6 W | 66 27.1 N | . 1870 | . 4290 | . 4680 |
| Seddi | 5217 N | 13 or E | 1916 | 808.9 W | 66 24.1 N | . 1874 | . 4289 | . 4680 |
| Irkutsk | 5216 N | 10416 E | 1905 | $158 . \mathrm{I} \mathrm{E}$ | 7025.0 N | . 2001 | . 5625 | . 5970 |
| Ie Bilt | 5206 N | 5 II E | 1914 | 1222.6 W | 6646.5 N | . 1851 | . 4314 | . 4694 |
| Valencia | 5156 N | 1015 W | 1913 | 2019.6 W | 68 09.2 N | . 1789 | . 4463 | . 4808 |
| Clausth | 5 r 48 N | 1020 E | 1905 | 1040.3 W |  |  | - | . 4808 |
| Bochu | 5129 N | 714 E | 1912 | II 39.4 W |  | - | - | - |
| Ke | 5 I 28 N | - 19 W | 1915 | 15 18.4 W | 6656.6 N | . 1846 | . 4338 | .4714 |
| Green | 5128 N | - 00 | 1916 | 1446.9 W | 6652.8 N | . 1849 | . 4332 | . 4710 |
| Uccle | 5048 N | 4215 | 1911 | 1313.9 W | 66 o. I N | . 1902 | . 4273 | . 4677 |
| Herms | 5046 N | 1614 E | 1913 | 658.2 W |  | - |  | - |
| Beu | 5021 N | 1855 E | 1908 | 6 I 2.3 W |  | - | - |  |
| Falmo | 5009 N | 505 W | 1912 | 17 24.2 W | 6626.6 N | . 1880 | . 4312 | . 4704 |
| Craco | 50 05 <br> 50 0.4 | 1425 <br> 19 <br> 18 | 1912 | 750.3 W |  |  |  |  |
| Val Ioy | $48+9$ | 19 | 1913 1913 | $\begin{array}{r}5 \\ \mathrm{~S} \\ \mathrm{O} \\ 503.2 \mathrm{~W} \\ \hline\end{array}$ | $\begin{array}{lll}64 & 18.4 \\ 64 & 38.9 \\ \mathrm{~N}\end{array}$ |  |  |  |
| Munich | 4809 N | 1137 E | I91I | 923.8 W | 63 06.2 N | . 2063 | . 4068 | . 4615 |
| Kremsmün | 4803 N | $1+08 \mathrm{E}$ | 1904 | 902.4 W | 03 | - | . 4068 | -4561 |
| OGyalla (Pesth) | 4753 N | 18 I 2 E | 1912 | 617.5 W |  | 2106 | - | - |
| Odess | 4626 N | 30.46 E | 1910 | 335.9 W | 6226.9 N | . 2171 | . 4161 | .4693 |
| Pola. . . . . . . | 4452 N | 1351 | 1915 | 739.0 W | 60 05.1 N | . 2217 | . 3853 |  |
| Agincourt (Torc | 4347 N | 79 16 W | 1916 | 633.4 W | 7443.5 N | . 1599 | . 5854 | . 6068 |
| Perpi | 4242 N | 253 E | 1910 | 1244.8 W |  | - | - | - |
| Tiflis | $41+3$ - | 4448 E | 1913 | 309.1 E | 56 5r.I N | 2522 | . 3761 | . 4528 |
| Capodimonte | 4052 N | 14 I5 E | 1911 |  | 56 11.7 N | - | - | - |
| Ebro (Tortosa | 40.49 N | $\bigcirc 3 \mathrm{I}$ E | 1914 | 1251.6 W | 5747.5 N | . 2330 | . 3698 | . 4371 |
| Baldw | 40 I 2 N | 825 W | 1915 | 15 57.5 W | 5834.7 N | . 2305 | . 3773 | . 4422 |
| Chelten | 3847 N | 95 10 W | 1909 | 834.0 E | 6850.2 N | . 2167 | . 5596 | 6001 |
| San Fe | 38 44 <br> 36  | 7650 W | 1916 | 607.6 W | 7049.9 N | . 1934 | . 5662 | . 5889 |
| Tokio. | 3020 | 6 12 W | 1913 | 1451.7 W | 54266 N | . 2494 | - 3489 | . 4289 |
| Tucson. | 35 <br> 32 <br> 15 | 139 115 10 | 1912 Ig 6 | 503.4 W | 4853.7 N | . 3000 | - 3438 | . 4563 |
| Lukiapang | 3119 N | 12102 E | 1909 | 13 2 | 5926.1 N | . 2706 | . 4582 | . 5322 |
| Dehra Dun | 3019 N | 7303 E | 1914 | 218.8 E | 45 <br> 44 <br> 44.9 <br> 22.9 | - 3323 | - 3391 | . 4747 |
| Helwan. | 2952 N | 3120 E | 1913 | 217.0 W | 4422.9 N 4047.6 N | . 3316 | .3246 .2592 | . 4641 |
| Barrackpor | 2246 N | 8822 E | 1914 | -32.2 E | 3058.9 N | . 3740 | . 2246 |  |
| Hongkong | 22 I8 N | II. 410 E | 1916 | 013.8 W | 3051.8 N | . 3716 | . 2220 | . 43838 |
| Honolulu | 2119 N | 158 of W | r916 | 943.8 E | 39 29.2 N | . 2896 | . 2386 | .4328 .3752 |
| Toungo | 1856 | 9627 E | 1914 | 002.6 E | 23 06.1 N | . 3898 | . 1663 | . 4238 |
| Vieque | 1838 N | 7252 E | 1915 | - 40.6 E | 24 2I.I N | . 3637 | . 1669 | . 4047 |
| Antipol | 1809 N | 6526 W | 1916 | 319.4 W | 5056.7 N | . 2315 | . 3470 | . 4468 |
| Kodaikánal | $\begin{array}{lll}14 & 30 \\ 10 & 14 \\ \\ 10 & \end{array}$ | 121 77 78 28 | I9II | 040.9 E | 1618.2 N | . 3820 | . 1117 | . 3981 |
| Batavia-Buitenz | 6 II S | 10649 E | 1914 | I 17.1 W | 411.2 N | . 3757 | . 0275 | . 3767 |
| St. Paul de Loan | 848 S | 1313 E | 1912 | 0 47.3 <br> 16 12.3 | 3119.4 S | - 3668 | . 2232 | . 4229 |
| Samoa (Apia) | 1348 S | 17146 W | 1916 | 959.9 E | 35 29 $294.2 .2 ~ S$ | .2012 $\therefore 3536$ | . 1437 | . 2473 |
| Mauritius | 1855 S | 4732 E | 1907 | 929.7 W | 5405.7 S | . 2533 | . 3479 | . 4319 |
| Pilar | 2006 S | 5733 E | 1916 | 947.6 W | 5254.6 S | . 2320 | . 3069 | . 3847 |
| Santiago | 31 33 31 | 6353 W | 1914 | 840.4 E | 2541.5 S | . 2560 | . 1232 | . 2841 |
| Christchurch | 33 43 3 | 7042 17237 E | 1909 | 1357.9 E | ${ }^{29} 57.2 \mathrm{~S}$ | - |  | - |
| New Year's Isl | $5.4+5 \mathrm{~S}+$ | $6403 \mathrm{~W}+$ | 1906 | 1541.6 E | 67 50 50 | . 224 I | . 5546 | . 5982 |
| Orcadas. | 6045 S | 4232 W | 1912 | 446.5 E | $5+26.0$ S | . 2534 | . 3544 | . 423 I |

[^61]
## APPENDIX.

## DEFINITIONS OF UNITS.

ACTIVITY. Power or rate of doing work; unit, the watt.
AMPERE. Unit of electrical current. The international ampere, "which is one-tenth of the unit of current of the C. G. S. system of electro-magnetic units, and which is represented sufficiently well for practical use by the unvarying current which, when passed through a solution of nitrate of silver in water, and in accordance with accompanying specifications, deposits silver at the rate of 0.0011800 of a gram per second."
The ampere $=1$ coulomb per second $=1$ volt through I ohm $=10^{-1}$ E. M. U. $=3 \times$ $10^{9}$ E. S. U.*
Amperes $=$ volts $/$ ohms $=$ watts $/$ volts $=(\text { watts } / \text { ohms })^{\frac{1}{2}}$.
Amperes $\times$ volts $=$ amperes ${ }^{2} \times$ ohms $=$ watts.
ANGSTROM. Unit of wave-length $=10^{-10}$ meter.
ATMOSPHERE. Unit of pressure.
English normal $=14.7$ pounds per sq. in. $=29.929 \mathrm{in} .=760.18 \mathrm{~mm} \mathrm{Hg} .32^{\circ} \mathrm{F}$.
French " $=760 \mathrm{~mm}$ of $\mathrm{Hg} . \mathrm{o}^{\circ} \mathrm{C}=29.922 \mathrm{in} .=14.70 \mathrm{lbs}$. per sq. in.
BAR. A pressure of one dyne per $\mathrm{cm} .^{2}$ Meteorological "bar" $=10^{6} \mathrm{dynes} / \mathrm{cm}^{2}$.
BRITISH THERMAL UNIT. Heat required to raise one pound of water at its temperature of maximum density, $\mathrm{I}^{\circ} \mathrm{F} .=252$ gram-calories.
CALORIE. Small calorie $=$ gram-calorie $=$ therm $=$ quantity of heat required to raise one gram of water at its maximum density, one degree Centigrade.
Large calorie $=$ kilogram-calorie $=1000$ small calories $=$ one kilogram of water reised one degree Centigrade at the temperature of maximum density.
For conversion factors see page 197.
CANDLE, INTERNATIONAL. The international unit of candlepower maintained jointly by national laboratories of England, France and United States of America.
CARAT. The diamond carat standard in U. $\mathrm{S} .=200$ milligrams. Old standard $=205.3$ milligrams $=3.168$ grains.
The gold carat: pure gold is 24 carats; a carat is $1 / 24$ part.
CIRCULAR AREA. The square of the diameter $=1.2733 \times$ true area.
True area $=0.785398 \times$ circular area.
COULOMB. Unit of quantity. The international coulomb is the quantity of electricity transferred by a current of one international ampere in one second. $=10^{-1} \mathrm{E} . \mathrm{M} . \mathrm{U}$. $=3 \times 10^{\circ} \mathrm{E} . \mathrm{S} . \mathrm{U}$.
Coulombs $=$ (volts-seconds) $/$ ohms $=$ amperes $\times$ seconds.
CUBIT $=18$ inches.
DAY. Mean solar day $=1440$ minutes $=86400$ seconds $=1.0027379$ sidereal day.
Sidereal day $=86164.10$ mean solar seconds.
DIGIT. $3 / 4$ inch; $1 / 12$ the apparent diameter of the sun or moon.
DIOPTER. Unit of "power" of a lens. The number of diopters $=$ the reciprocal of the focal length in meters.
DYNE. C. G. S. unit of force $=$ that force which acting for one second on one gram produces a velocity of one cm per $\mathrm{sec}=1 \mathrm{I} \div$ gravity acceleration in $\mathrm{cm} / \mathrm{sec} . / \mathrm{sec}$.
Dynes $=$ wt. in $g \times$ acceleration of gravity in $\mathrm{cm} / \mathrm{sec} . / \mathrm{sec}$.
ELECTROCHEMICAL EQUIVALENT is the ratio of the mass in grams deposited in an electrolytic cell by an electrical current to the quantity of electricity.
ENERGY. Sce Erg.
ERG. C. G. S. unit of work and energy = one dyne acting through one centimeter.
For conversion factors see page 197.
FARAD. Unit of electrical capacity. The international farad is the capacity of a condenser charged to a potential of one international volt by one international coulomb of electricity $=10^{-9} \mathrm{E} . \mathrm{M} . \mathrm{U} .=9 \times 10^{11} \mathrm{E} . S . \mathrm{U}$.
The one-millionth part of a farad (microfarad) is more commonly used.
Farads $=$ coulombs/volts.

- E. M. U.=C. G. S. electromagnetic units. E. S. U.=C. G. S. electrostatic units.

FOOT-POUND. The work which will raise one pound one foot high. For conversion factors see page 197.
FOOT-POUNDALS. The English unit of work $=$ foot-pounds $/ \mathrm{g}$.
For conversion factors see page 197.
g. The acceleration produced by gravity.

GAUSS. A unit of intensity of magnetic field $=1$ E. M. U. $=\frac{1}{3} \times 10^{-10}$ E. S. U.
GRAM. See page 6 .
GRAM-CENTIMIETER. The gravitation unit of work $=\mathrm{g}$. ergs.
GRAM-MOLECULE $=x$ grams where $x=$ molecular weight of substance.
GRAVITATION CONSTANT $=G$ in formula $G \frac{m_{1} m_{2}}{\mathrm{r}^{2}}=666.07 \times 10^{-10} \mathrm{~cm}^{3} / \mathrm{gr} . \mathrm{sec}^{2}$
HEAT OF THE ELECTRIC CURRENT generated in a metallic circuit without selfinduction is proportional to the quantity of electricity which has passed in coulombs multiplied by the fall of potential in volts, or is equal to (coulombs $\times$ volts)/4.18I in small calories.
The heat in small or gram-calories per second $=\left(\right.$ amperes $^{2} \times$ ohms $) / 4 \cdot 18 \mathrm{I}=$ volts $^{2} /$ $($ ohms $\times 4.18 \mathrm{I})=($ volts $\times$ amperes $) / 4.18 \mathrm{I}=$ watts $/ 4.18 \mathrm{I}$.
HEAT. Absolute zero of heat $=-273.13^{\circ} \mathrm{C}$., $-459.6^{\circ}$ Fahrenheit, $-218.5^{\circ}$ Reaumur.
HEFNER UNIT. Photometric standard; see page 260.
HENRY. Unit of induction. It is "the induction in a circuit when the electromotive force induced in this circuit is one international volt, while the inducing current varies at the rate of one ampere per second." $=10^{9} \mathrm{E} . \mathrm{M} . \mathrm{U} .=1 / 9 \times 10^{-11} \mathrm{E} . \mathrm{S} . \mathrm{U}$.
HORSEPOWER. The English and American horsepower is defined by some authorities as 746 watts and by others as 550 foot-pounds per second. The continental horsepower is defined by some authorities as 736 watts and by others as 75 kilogrammeters per second. See page 197.
JOULE. Unit of work $=10^{7}$ ergs. For electrical Joule see p. xxxvii.
Joules $=\left(\right.$ volts $^{2} \times$ seconds $) /$ ohms $=$ watts $\times$ seconds $=$ amperes ${ }^{2} \times$ ohms $\times$ sec.
For conversion factors see page 197.
JOULE'S EQUIVALENT. The mechanical equivalent of heat $=4.185 \times 10^{7}$ ergs. See page 197.
KILODYNE. 1000 dynes. About i gram.
KINETIC ENERGY in ergs $=$ grams $\times(\mathrm{cm} . / \mathrm{sec} .)^{2} / 2$.
LITER. See page 6.
LUMEN. Unit of flux of light-candles divided by solid angles.
MEGABAR. Unit of pressure $=1000000$ bars $=0.987$ atmospheres.
MEGADYNE. One million dynes. About one kilogram.
METER. See page 6.
METER CANDLE. The intensity of lumination due to standard candle distant one meter.
MHO. The unit of electrical conductivity. It is the reciprocal of the ohm.
MICRO. A prefix indicating the millionth part.
MICROFARAD. One-millionth of a farad, the ordinary measure of electrostatic capacity.
MICRON. $(\mu)=$ one-millionth of a meter.
MIL. One-thousandth of an inch.
MILE. See pages 5, 6.
MILE, NAUTICAL or GEOGRAPHICAL $=6080.204$ feet.
MILLI-. A prefix denoting the thousandth part.
MONTH. The anomalistic month = time of revolution of the moon from one perigee to another $=27.55460$ days.
The nodical month $=$ draconitic month $=$ time of revolution from a node to the same node again $=27.21222$ days.
The sidereal month $=$ the time of revolution referred to the stars $=27.32166$ days (mean value), but varies by about three hours on account of the eccentricity of the orbit and "perturbations."
The synodic month $=$ the revolution from one new moon to another $=29.5306$ days (mean value) $=$ the ordinary month. It varies by about 1.3 hours.

OHM. Unit of electrical resistance. The international ohm is based upon the ohm equal to $10^{\circ}$ units of resistance of the C. G. S. system of electromagnetic units, and " is represented by the resistance offered to an unvarying electric current by a column of mercury, at the temperature of melting ice, 14.4521 grams in mass, of a constant cross section and of the length of 106.3 centimeters." $=10^{\circ}$ E. M. U. $=1 / 9 \times 10^{-11}$ E. S. U.
International ohm $=1.01367$ B. A. ohms $=1.06292$ Siemens' ohms.
B. A. ohm $=0.98651$ international ohms.

Siemens' ohm $=0.94080$ international ohms.
PENTANE CANDLE. Photometric standard. See page 260.
$\mathrm{PI}=\pi=$ ratio of the circumference of a circle to the diameter $=3.14159265359$.
POUNDAL. The British unit of force. The force which will in one second impart a velocity of one foot per second to a mass of one pound.
RADIAN $=180^{\circ} / \pi=57.29578^{\circ}=57^{\circ} 17^{\prime} 45^{\prime \prime}=206265^{\prime \prime}$.
SECOHM. A unit of self-induction $=1$ second $\times 1$ ohm.
THERM = small calorie $=$ (obsolete).
THERMAL UNIT, BRITISH = the quantity of heat required to warm one pound of water at its temperature of maximum density one degree Fahrenheit $=252$ gramcalories.
VOLT. The unit of electromotive force (E. M. F.). The international volt is "the electromotive force that, steadily applied to a conductor whose resistance is one international ohm, will produce a current of one international ampere. The value of the E. M. F. of the Weston Normal cell is taken as I.OI83 international volts at $20^{\circ} \mathrm{C} .=10^{8}$ E. M. U. $=1 / 300$ E. S. U. See page 197.
VOLT-AMPERE. Equivalent to Watt/Power factor.
WATT. The unit of electrical power $=10^{7}$ units of power in the C. G. S. system. It is represented sufficiently well for practical use by the work done at the rate of one Joule per second.
Watts $=$ volts $\times$ amperes $=$ amperes $^{2} \times$ ohms $=$ volts ${ }^{2} /$ ohms (direct current or alternating current with no phase difference).
For conversion factors see page 197.
Watts $\times$ seconds $=$ Joules.
WEBER. A name formerly given to the coulomb.
WORK in ergs $=$ dynes $\times \mathrm{cm}$. Kinetic energy in ergs $=$ grams $\times(\mathrm{cm} . / \mathrm{sec} .)^{3} / \mathbf{2}$.
YEAR. See page 414.
Anomalistic year $=365$ days, 6 hours, 13 minutes, 48 seconds.
Sidereal " $=365$ " 6 ". $9 \quad$ " 9.314 "
Ordinary " $=365$ " 5 " $48 \quad 446+$
Tropical " same as the ordinary year.

## Table 580.

## TEMPERATURE MEASUREMENTS.

The ideal standard temperature scale (Kelvin's thermodynamic scale, see introduction, p. xxxiv) is independent of the properties of any substance, and would be indicated by a gas thermometer using a perfect gas. The scale indicated by any actual gas can be corrected if the departure of that gas from a perfect gas be known (see Table 206, p. 195, - also Buckingham, Bull. Bur. Standards, 3, 237). The thermodynamic correction of the constant-pressure scale at any temperature is very nearly proportional to the constant pressure at which the gas is kept and that for the constant-volume scale is approximately proportional to the initial pressure at the ice-point. The gas thermometer has been carried up to the melting point of palladium, $1822^{\circ} \mathrm{K}$ ( $1549^{\circ} \mathrm{C}$ ) (Day and Sosman, Am. J. Sc., 29, p. 93, 1910).

A proposed international agreement divides the temperature scale into three intervals. The first interval, $-40^{\circ}$ to $450^{\circ} \mathrm{C}$, uses the platinum resistance thermometer calibrated at the melting point of ice, $0^{\circ} \mathrm{C}$, at saturated steam, $100^{\circ} \mathrm{C}$, and sulphur vapor, $444.6^{\circ} \mathrm{C}$, all under standard atmospheric pressure. Points on the temperature scale are interpolated by the Callendar formulæ:

$$
P_{t}=\frac{R_{t}-R_{0}}{R_{100}-R_{0}} 100 \quad \text { or } \quad t-P t=\delta\left\{\frac{t}{100}-\mathbf{I}\right\} \frac{t}{100}
$$

where $t$ is the temperature, R , the resistance, Pt , the platinum temperature, and $\delta$, a constant.
Temperatures in the second interval are measured by a standard platinum-platinum-rhodium couple calibrated say at the freezing points of zinc, $419.4^{\circ} \mathrm{C}$, cadmium, $320.9^{\circ} \mathrm{C}$, antimony, $630^{\circ} \mathrm{C}$, and copper free from oxide, $1083^{\circ} \mathrm{C}$. These points furnish constants for the formula, $\mathrm{e}=\mathrm{a}+\mathrm{bt}+\mathrm{ct}^{2}$ (see Sosman, Am. J. Sc., 30, p. 1, 1910).

For the region above $1100^{\circ} \mathrm{C}$ most experimenters base their results upon certain radiation laws. These laws all apply to a black body and the temperature of a non-black body cannot be determined directly without correction for its emissive power. For standard points the melting points of gold, $1336^{\circ} \mathrm{K}$ and palladium $1822^{\circ} \mathrm{K}$, are convenient,

Above $1336^{\circ} \mathrm{K}$ the optical pyrometer is generally used with a calibration based upon Wien's equation

$$
\mathrm{J}_{\lambda}=\mathrm{c}_{1} \lambda^{-5} \mathrm{e}^{-\frac{\mathrm{c}_{2}}{\lambda \mathrm{~T}}}
$$

By comparing the brightness of a black body at two temperatures and applying this equation, the following formula results:

$$
\log \mathrm{R}=\frac{\mathrm{c}_{2} \log \mathrm{e}}{\lambda}\left\{\frac{\mathrm{I}}{\mathrm{~T}_{2}}-\frac{\mathrm{I}}{\mathrm{~T}_{1}}\right\}
$$

where $R$ is the ratio of the brightnesses, $\lambda$, the wave-length used, $T_{1}$ and $T_{2}$, the two temperatures, and $c_{2}$ $=14.256 \mu$ deg. Thus if R is measured and one temperature known, the other can be calculated.

A table of the standard fixed points is given in Table 207, p. 195. With these determined there comes the difficulty of maintaining this temperature scale both from the standpoint of the standardizing laboratory and the man using the temperature scale in the practical field. In the region of the platinum-resistance thermometer and the thermocouple, standards of either can be obtained from the standardizing laboratories and used in checking up the secondary instruments. It is not very difficult to actually check up a resistance thermometer at any one of the standard points in the region $-40^{\circ} \mathrm{C}$ to $+450^{\circ} \mathrm{C}$. It is a little more difficult to check the thermocouple in the region $4.50^{\circ} \mathrm{C}$ to $1100^{\circ} \mathrm{C}$. Most of the standard fixed points in this region are given by melting points of metals that must be melted so as to avoid oxidation. This requires a neutral atmosphere, or that the sample be covered with some flux that will protect it.

Both the gold and the palladium, used to calibrate the scale above $1300^{\circ} \mathrm{K}$, can be successfully melted in a platinum wound black-body furnace. The whole operation can be carried out in the open air, requiring neither a vacuum nor neutral atmosphere within the furnace. But because of the trouble necessitated by a black-body comparison. much time can be saved if a tungsten lamp with filament of suitable size is standardized so as to have the same brightness for a particular part of the filament, when observed with the optical pyrometer, as the standard black-body furnace for one or more definite temperatures. With such lamps properly calibrated, any one may maintain his own temperature scale for years, if the calibration does not extend higher than that of the palladium point and the standard lamp is not accidentally heated to a higher temperature.
(Soc 1919 Report of Standards Committee on Pyrometry, Forsythe, J. Opt. Soc. of America, 4, p. 205, 1920; The Measurement of High Temperatures, Burgess, Le Chatelier, 1912, The Disappearing Filament Type of Optical Pyrometer, Forsythe, Tr. Faraday Soc., 1919.)

The following additional adsorptio- tables (see page 407, Table 525) may be of use in the "cleaning-up of vacua." See Dushman, General Electric Review, 24, 58, 1921, Methods for the Production and Measwement of High Vacua.

## TABLE 581. - Adsorption of H and He by Cocoanut Charcoal at the temperature of liquid air.

For the preparation of activated charcoal see Dushman, $1 . c .5 \mathrm{~g}$ of charcoal at the temperature of liquid qir will clean up the residual gases in a volume of $3000 \mathrm{~cm}^{3}$ from an initial pressure of I bar ( $\mathrm{bar}=1 \mathrm{dyne} / \mathrm{cm}^{2}$ ) to less than 0.0005 bars at the temperature of liquid air. 5 grams cleaned up $3000 \mathrm{~cm}^{3}$ of H from an initial pressure at room temperature of o.or bar to a final pressure at liquid air temperature of less than 0.0004 bar. The clean-up is rapid at first but then slower taking about an hour to reach equilibrium. The figures of the following table are from Firth, Z. Phys. Ch. 74, 129, 1910; 86, 294, 1913. p is in mm of Hg ; $\mathrm{v}=$ volume adsorbed per g of charcoal reduced to $0^{\circ} \mathrm{C}$ and 76 cm Hg .

| Hydrogen |  |  |  | Helium |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $\mathbf{p}$ | v | p | v | p | v |
|  |  |  |  |  |  |
| 9 | 21.5 | 90 | 59.3 | 120 | 0.337 |
| 17 | 32.1 | 126 | 63.1 | 171 | .465 |
| 30 | 46.5 | 186 | 69.2 | 235 | .81 |
| 5 I | 53.3 | 245 | 76.0 | 428 | 1.17 |
| 59 | 56.0 |  |  | 705 | 1.84 |

TABLE 582. - Adsorption by Ch rcoal at Low Pressures and temperatures.
Extrapolated by Dushman from Claude, see l. c., and C.R. 158, 86I, 1914. Amounts occluded in terms of volume measured at I bar, $0^{\circ} \mathrm{C}$. e.g. at a pressure of 0.0 I bar, I g charcoal would clean $\mathrm{up} \mathrm{I} 30 \mathrm{~cm}^{3}$ hydrogen or $18,000 \mathrm{~cm}^{8}$ nitrogen from a pressure of I bar down to 0.01 bar.

| $\mathrm{H}, \mathrm{T}=77.6^{\circ} \mathrm{K}$ |  | $\mathrm{N}, \mathrm{T}=90.60 \mathrm{~K}$ |  |
| :---: | :---: | :---: | :---: |
| $\mathrm{p}=8$. | $\mathrm{v}=106,000$. | $p=5.3$ | $\mathrm{v}=9,500,000$. |
| I. | 13,250 |  | I,800,000 |
| O.I | I,325 | 0.0 | 180,000 |
| 0.01 | 133 | 0.01 | 18,000 |
| 0.001 | 13 | 0.001 | 1,800 |

## TABLE 583. - Adsorption of Hydrogen by Palladium Black.

Palladium, heated, allows hydrogen to pass through it freely; the gas is first adsorbed and then diffuses through. For the preparation of palladium black, see reference at top of page for Dushman. The following data are from Valentiner, Verh. Deutsch. Phys. Ges., 3, 1003, 19II. Different samples vary greatly. P gives the pressure in mm of Hg , and V the volume at standard pressure and temperature per g of palladium black.

| $-190^{\circ} \mathrm{C}: \mathrm{P}=$ | $\begin{aligned} & .0005 \\ & 2.05 \end{aligned}$ | $\begin{aligned} & .001 \\ & 3.06 \end{aligned}$ | $\begin{gathered} .002 \\ 33.0 \end{gathered}$ | $\begin{gathered} .005 \\ 40.0 \end{gathered}$ | $47.2^{.012}$ | $\underset{63.0}{.025}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $+20^{\circ} \mathrm{C}: \begin{aligned} & \mathrm{P}= \\ & \mathrm{V}=\end{aligned}$ | $\begin{aligned} & .001 \\ & 0.10 \end{aligned}$ | $\begin{gathered} .005 \\ 0.26 \end{gathered}$ | $\begin{aligned} & .037 \\ & 0.40 \end{aligned}$ | $\begin{aligned} & .110 \\ & 0.52 \end{aligned}$ | .315 0.70 | .76 0.92 |

## Smithsonian Tableg.

## INDEX.




| page | Pag |
| :---: | :---: |
| 173-174 | Crystals: diffracting units, X-rays |
| correction to barometer . . . . . . . 143 | clasticity |
| rcel unlt . . . . . . . . . . . . . . . . 260 | refraction indices: alums, quartz |
| hode rays: . . . . . . . . . . . . . . 386 | fluorite, spar |
| energy of - . . . . . . . 386 | rock-salt, silvine . . . 27 |
| penetration depths | refr. indices: mine:als, isotropic . . . . 28 |
| X-rays, generative efticiency for - 387 |  |
| standard, roltages | biaxal |
| eston normal . . . . . . . . xil | ( + ) . 286, 28 |
| Weston portahle . . . . . . . xlili | miscel. uniaxial |
| voltaic, composition, voitages . . . . 312-313 | ial |
| ntipoise . . . . . . . . . . . . . . . . 155 | Cubes of numbers |
| Characteristic X-rays . . . . . . . . . . 387-392 | Cubical expansion coefficients: gases |
| Charcoal, adsorption by . . . . . . . . . . 407 | liquids |
| Charge, elementary electrical . . . . . . . . . 408 | solids |
| Chemical enerky data . . . . . . . . . .24i-246 | Current measures: absolute units |
| Coals, heats of combustion . . . . . . . . . . 242 |  |
| Collision frequencies, molecules . . . . . . . . 399 | adium standard . . . . . . . . . . . 398 |
| Colloids . . . . . . . . . . . . . . .406-407 | point and constant, magnetic . . . . . . 372 |
| Color: eye sensitiveness to . . . . . . . . .256-258 | Cutting-tool lubricants . . . . . . . . . . . . 154 |
| indices of various stars . . . . . . . . . 411 | Cylindrical harmonics (Bessel) ist and and deg. . 66 |
| lights, of various . . . . . . . . . ${ }^{26 \mathrm{I}}$ | general formulæ . 68 |
| ens . . . . . . . . 306-307 |  |
| complimentary colors . . . . . 307 | Day, length of sidereal |
|  | Declination, magnetic: secular change . . . . . $4^{28}$ |
| Combination, heats of Pastion, heats of: carion and misc . . ${ }^{\text {a }}$ - 245-246 | Degree on earth's surface, length of . . . . . . ${ }^{\text {a }}$ (16 |
| combustion, heats of: carbon and misc. cpdi . . . 241 |  |
| explosires . . . . 243-244 | Densities in air, reduction to vacuo |
|  | Densitics: air moist, values of $\mathrm{h} / 760 \cdots$. ${ }^{\text {a }}$, i33-135 |
| Compressibility: $\underset{\text { liquids }}{\text { gases }}$. . . . . . .i04, 128-132 | alcohol ethyl aqueous . . |
| $\underset{\text { solids }}{\text { liquids }}$.. . . . . . . . . . . 107 | methyl aqueous . . . . . . . 126 |
| ctrical: see resistivity $\cdots 322-332$ | alloys ${ }_{\text {aqueous solutions }}$. . . . . . . . ${ }^{114}$ |
| allny . . . . . . $327-328$ | aqueous solutions . . . . . 122, 159-163 |
| ic: . . . . . . . 346 -352 | cane sugar, aqueous . . . . . . . . 109 |
| equivatent . . . . . . . 349 | castor oil . . . . . . . . . . ${ }_{156}$ |
| ionic . . . . . . . . . 352 | earth . . . . . . . . . . . . ${ }_{427}$ |
| sp. molecu.ar . . . . . . 347 | clements chemical . . . . . . . . . 110 |
| limiting values . . . 348 | gases . . . . . . . . . . . . . 127 |
| Conductivity, thermal: alloys, metals. coefs. . . . 348 | glycerol, aqucous . . . . . . . . . 156 |
| Conductivity, thermal: alloys, metals . . . . . 213 | inorganic compounds . . . . . . . . 201 |
| building materials . . . 215 earth | insulators, thermal . . . . . . 215, 216 |
| earth . . . . . . . . 422 | ${ }_{\text {mercury }}$ liquids 10 $^{\circ}$ + $0^{\circ}+360^{\circ}$ - . . . 117 |
| high temp. 217 254 | ${ }_{\text {minerals }}$ mercury $-10^{\circ}$ to $+360^{\circ} \mathrm{C}$. . . . . 121 |
| $\text { insulators } \because \because 214-216$ | organic compounds . . . . . . . . 115 |
| mp. . . . 214 | ${ }_{\text {planets }} \mathbf{0}$. . . . . . . . . . . . . ${ }^{203}$ |
| liquids . . . . . . . 217 | solids various . . . . . . . . . . 413 |
| metals, high temp. . . . . 213 |  |
| $\underset{\text { salt solutions . . . . . } 216}{\text { sat }}$ | sucrose, aqueous . . . . . . . . 156 |
| water apart in ese . . . . . 216 | sulphuric acid, aqueous . . . . . . . 126 |
| Cones, number and distance apart in eye . . . . . 258 | tin, liquid; tin-lead eutectic |
| Constants: mathematical ${ }_{\text {miscellaneous, }}$ itcmic, etc. . . . . I4 | water, $0^{\circ}$ to $4 \mathrm{r}^{\circ} \mathrm{C},-10^{\circ}$ to $250^{\circ} \mathrm{C} .118$, 120 |
| rad!ation, $\sigma, C_{1}, C_{2} . . . . . . .{ }_{247}$ | Dcvelopers and resolving power of piotor 95-98, 112 |
| Contact difference of potential . . . $314,31 \dot{6}^{247}$ | Diamagnetic properties power of photo. plate . . 263 |
| Contrast, eye sensitiveness to |  |
| Conrection, cooling by . . . . . . . . $251-255$ | Diameter molecules . . . . . . 372 |
| pressure effect . . . 251 -252 | some organic molecules . . . . . 400 |
| : general formulae, sce introduction | constant: (sp. inductive capacity) . 356-360 |
| Baumé to densities . . . . . rog | crystals ${ }^{\text {a }}$. . . . . ${ }^{\text {a }} 361$ |
| horse-power . . . . . . . . 197 | gases $\mathrm{f}(\mathrm{t}, \mathrm{p}) \cdot . . . . \cdot 356-357$ |
| Cooling of hodies work-units . . . . . . . . 197 | liquids liquefled . . . . . . . . 357 |
|  | liquefled gases . . . . . . . 359 |
| Copper: mechanical properties $\begin{gathered}\text { wire, altemating current resistance } \cdot .82-83\end{gathered}$ | solids standard colutions . . . . ${ }^{\text {a }}$. 360 |
| wire tables, English units . . . . . 3444 |  |
| metric units . . . . . . 336 | Ijielectrics, volume and surface resistances) . 353-355 |
| Corpuscle (Thomson) . . . . . . . . . . . 339 | Differentials, formulae . . . . . . . . . 12 |
|  | Diffusion: aqueous solutions into water $\quad$. ${ }^{\text {a }}$, 166 |
| Cosines, circular, natural, ( ${ }^{\prime}$ ) . . . . . . . ${ }^{\text {a }}$ ( ${ }^{\text {a }} 36$ | gases . . . . . . . . . . . . 167, 168 |
|  | integral . . . . . . . . . . . . 60 |
| logarithmic, ( ${ }^{\circ}$ ) |  |
| (radians) | ${ }_{\text {vapors }}^{\text {metals }}$. . . . . . . . . . ${ }^{\text {a }}{ }^{168}$ |
| hyperbolic, natural logarithmic . . . . 41-47 | Diffusivities thermal. . . . . . . . . 167, 168 |
| Cotangents, circular, natural, ( ${ }^{\circ}$ ) . . . . . ${ }^{\text {a }}$ (326 | Digit . . . . . . . . . . . . . . . 217 |
| (radians) . . . ${ }^{32-40}$ | Dilution, heat of $\left(\dot{H}_{2} \mathrm{SO}_{4} \dot{)}\right.$. . . . . . . . . ${ }_{2} 435$ |
| logarithmic, $\left(^{\circ}\right.$ ) . . . . $32-36$ |  |
| (radians) • - .37-40 |  |
| Coulomb, electrical equivalents. . . . . ${ }^{\text {a }}$ (-47 | Dip, magnetic, ig is value, secular variation . . 435 |
| Critical data for gases . . . . . . . . . . . 311 | Disk, distribution of brightness over sun's . . . . 4188 |
| Crova wave-length . . . . . . . . . . . 2122 | Distance earth to moon . . . . . . . ${ }^{\text {m }} 18$ |
|  | sun . . . . . . . . . . . . 414 |



| Foot Page |
| :---: |
|  |
| Fork, tuning, temperature coefficient . . . . . . 149 |
| Fromation, heat of, for elements . . . . . . 245, 246 |
|  |  |
|  |
|  |
|  |
| Frec path of molecules . . . . . . . . . . 399 |
| Freezing mixtures . . . . . . . . . . . . . 211 point, lowering of for salt solutions . . . 208 point of water, pressure effect . . . . . 200 |
|  |  |
|  |  |
|  |
|  |
|  |
|  |
|  |
| Frictional electricity series . . . . .8. . . . 322 |
| Functions: $\begin{aligned} & \text { Bessel functions (roots, 68) . . . 66-68 } \\ & \text { cylindrical harmonics . . . . . }\end{aligned}$ |
|  |  |
|  |
|  |
| gamma . . . . . . . . . . . . 62 |
|  |
| probability . . . . . . . . . 56-58 |
| trigonometric, circular $\left(^{\circ}\right.$ ) . . . . . 32 |
| trigonometric, circular (radians) . . . 37 |
| zonal harmonics |
| Fumdamental frequency (Rydberg) . . . . . . . 408 |
| Fundamental standards $\begin{gathered}\text { units }\end{gathered}$. . . . . . . . . . ${ }_{\text {xxxiii }}$ |
|  |  |
|  |
| Fusion, latent heat of . . . . . . . . . . . . 240 |
| Gages, $\begin{aligned} & \text { kire } \\ & \text { Galvano-magnetic } \\ & \text { effects }\end{aligned}$ |
|  |  |
|  |
| Gas constant . . . . . . . . . . . . . . . 408 |
|  |  |
|  |
|  |
| absorption coef: long-wave radiation . . . 309 |
|  |  |
|  |
| conductivity, thermal . . . . . . . . 217 |
| critical data . . . . . . . . . . . . . 212 |
| densities . . . . . . . . . . . . . 127 |
| dielectric constants . . . . . . . . 356-36r |
| strength . . . . . . . 353-355 |
| diffusion . . . . . . . . . . . . . 168 |
| expansion coefficients . . . . . . . . . 405 |
|  |  |
|  |
|  |
| ignition temperatures of mixtures . . . . . 244 |
| magnetic susceptibility . . . . . . . . . 377 magnetic-optical rotation |
| magnetic-optical rotation . . . . . . . . 382refractive indices . . . . . . . . . .292 |
|  |  |
|  |
| solubility in water . . . . . . . . $170-171$sound, velocity of, in . . . |
|  |  |
|  |
| viscosityvolume, $f(t, p)$ . . . . . . . . . . $164-165$ |
|  |  |
|  |
|  |
| Gaussian system of units . . . . . . . . . . . xxxv |
| Geochemical data . . . . . . . . . . . . . . 423 |
| Geodetic data . . . . . . . . . . . . . 424-427 Gilbert |
| Clare sensibllity of eye . . . . . . . . . . . 257 |
| Glasses: refraction indices, American . . . . . 277 <br> German, temp. var. . . 278 <br> resistance electric, temp. var. . . . . . . 332 <br> transparency of . . . . . 302-304, 306-307 |
|  |  |
|  |  |
|  |  |
|  |
|  |
|  |
|  |
| Gravity, acceleration of, altitude variation . . . . 424 latitude variation . . . . 424 observed values . . . 425-426 |
|  |  |
|  |  |
|  |
|  |
| Gsration, radil of . . . . . . . . . . . . . 70 |
| Hall effect. temperature variation . . . . . . . . 385 |




Leduc thermomagnetic effect . . . . . . . . 385
Legal electrical units
PAGE
Length, standards of ..... Xxxiv, 5
$256-258$
flux, definition259
intensities on various days ..... 256
lambert, definition ..... 256
least visible to eye ..... 261
mechanical equivalent ..... 261
photometric standards ..... 260
units
295-297
polarized, reflection ..... - 310rotation of plane by substances
rotation of plane, magnetic $\cdot 378-383$
reflection of: formule ..... 297
function of " $n$ "
$\cdot 297$
$295-298$
reflecting power: metals
pigments ..... 299
powders ..... 300
rough surfaces ..... 299
scattered light ..... 300
300
sensitiveness of eye to ..... 25-258
transparency to: crystals ..... 303
dyes ..... 301 ..... 303-304 ..... 303-304
water water ..... 307
velocity of
wave-lengths: cadmium std. ine . . . 408,414
266
elements ..... 266
Fraunhofer lines ..... $269-271$
265
Std. iron lines ..... 266-267
Lights, brightness of various ..... 260
color of various ..... 261 ..... 262
efficiency of various electric
efficiency of various electric
visibility of white lights ..... 264
260
Light-year ..... 414
Limits of spectrum series ..... 276
Linear expansion coefficients ..... 218-219
Liquids: absorption of gases by ..... 172
capillarity of
combustion heat, fuels . . . . . . . $173^{-1} 74$
h
compressibilities ..... 242
107
conductivity, therinal ..... 217
densities ..... $314-310$
II5-117
mercury, $f(t)$ ..... 118-120
dielectric constant ..... 357-360
strength
355
166
355
166
diffusion, aqueous solutions
221
221
exparsion coefficients ..... 221
fuels, combustion heats ..... 221
242
380
magnetic suscentibility ..... 377
potential dif. with substances ..... $314-316$
sound velocity in ..... 147
specific heats
specific heats
173-174
173-174
surface tensions
surface tensions ..... 217
vapor pressures ..... 175-18
viscosity, absolute
viscosity, absolute ..... 157-159 ..... 157-159
Logarithms: standard 4-place ..... 163
26
1000 to 2000 ..... 24
28
.9000 to 1.0000 ..... 30
Logarithmic functions ..... 40 ..... 420, 434
Longitudes of a few stations
Longitudes of a few stations
Long-wave transmissions ..... 309
408
Loschmidt's number ..... 208
oreng of freaing points by salts.
oreng of freaing points by salts. ..... 154
Lumen ..... 259
Luminosity of black-body, f( $\dagger$ ) ..... 261
Lumar parallax ..... 414
M X-ray spectrum259
Mache radioactivity unit ..... 392
398
Maclauren's theorem ..... 13

|  |  |  |
| :---: | :---: | :---: |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
|  |  |  |
| Magnetic observatories, magnetic elements . . . . 434 <br> Magnetic properties: cobalt, o ${ }^{\circ}$ to $100^{\circ}$ C. . . . 373 |  | steel . . . . . . 77 |
|  |  | white metal . . . . 89 |
|  | Curie point . . . . . . . 372 | aluminum: ${ }_{\text {a }}$. . . $80-8 \mathrm{8I}$ |
|  | deflnitions - . . 365 | brick and brick piers . . . . ${ }^{\text {alloy }}$ 81 |
|  | demaguetizing factor for rods - 374 diamaguetism, $\mathrm{f}(\mathrm{t})$. . 365,372 | cement . . . . . . . . 93 |
|  | ferro-cobalt alloy . . . . 370 | cement mortars . . . . . . 90 |
|  | ${ }_{\text {ferromagnetism }}^{\text {fistersis }}$. . . . . ${ }^{365}$ | clay products . . . . . . concrete. |
|  | hystersis . . . . . . $375-376$ | concrete . . . . . . . . 91 |
|  | fron: cast, intense fields ${ }^{367-376}$ |  |
|  | pure . . . . . . . . 369 | wire . . . . . 82-83 |
|  | soft, o and $100^{\circ} \mathrm{C} . . .371$ | heat treatment for steels . . 76 |
|  | very weak fields . . . . 370 |  |
|  | wrought - . . . . 373 | alloys . . . . . . . 75 |
|  | ${ }_{\text {magnetite, }} 0^{\circ}$, $100^{\circ} \mathrm{C}$ C. . 373 | leather belting . . . . . . 94 |
|  | magneto-strietive effects . . 365 nagnet steel | $\rho$-ratio extension/contraction. IOI |
|  | maxwell | rigidity moduli $\mathrm{f}(\mathrm{t})$. . . . 100 |
|  | nickel, $0^{\circ}$, $100^{\circ}$ C. . . . . 373 | rope, manila . . . . . . . 95 |
|  | paramagnetism, $\mathrm{f}(\mathrm{t})$. . 365, 372 | steel-wire . . . . . . 79 |
|  | permeability . . . 365,371 | rubber, sheet . . . . . . 94 |
|  | saturation values for steels . $\cdot 373$ | eel: . . . . . . . . 76 |
|  | steel: . . . . . . . . 367-376 | alloys . . . . . . . 77 |
|  | energy losses . . . . 376 | heat treatment for . . 76 |
|  | magnet steel . . . . 370 |  |
|  | manganese steel . . . 373 | wire . . . . . . . 78 |
|  | saturation values . . . 373 | wire-rope . . . . . . 79 |
|  | temperature effect . $37 \mathrm{I}-372$ | stone products . . . . 92 |
|  | tool steel transformer ${ }^{\bullet}$ steei $\cdot 37 \mathrm{i},{ }_{376}^{373}$ | terra-cotta piers . . . . 93 |
|  | transformer steel . 371,376 | tungsten . . . . . . 89 |
|  | Steinmetz constant ${ }^{\text {Weak }}$ ( ${ }^{\text {a }}$. . . . 370 | white metal . . . . . 89 |
|  | susceptibility . . ${ }^{\text {6j }}$, 372, 377 | woods: conifers: English unit 99 |
|  | temperature effects . . 371-373 | 7 |
| Magnetism | strlal: agonic line . . . . . . . 425 | hard: English unit - 98 |
|  | declination . . . . . . . 420 dip . . . . . . 422 | : alloys . . . . . . . . . . . . 206 |
|  | inclination $\cdot . . . .422$ | elements . . . . . . . . . . . 198 |
|  | intensity, horizontal . . . 423 | eutectics . . . . . . . . . . 207 |
|  | total . . . . 424 | inorganic compounds . . . . . 20 I |
|  | magnetic character yearly . . 425 | lime-alumina-silica compounds . . 207 |
|  |  |  | organic compounds . . . . . 203 |
|  |  |  | paraffins . . . . . . . . . 203 |
|  |  |  | pressure effect . . . . . . . . 200 |
|  |  |  | water-ice, pressure effect . . . . 200 |
|  |  |  | Meniscus, volume of mercury - . . . $0^{\circ} \cdot 143$ |
|  |  |  | Mercury: density and volume, $-10^{\circ}$ to $360^{\circ} \mathrm{C}$. 121 |
|  |  |  | conductivity thermal, high temp. . . . . 254 |
|  |  | electric resistance standard . . . . . xxxviii |
|  |  | meniscus, volume of . . . . . . . . . 143 |
|  |  | pressure hydrostatic of columns . . . . . 136 |
|  |  | specific heat . . . . . . . . . . . 227 |
|  |  | thermometer . . . . . . . . . . 190-194 |
|  |  | vapor pressure . . . . . . . . . . . 180 |
| Masses, stellar. |  | s: conductivity, thermal . . . . . . . . 213 |
|  |  |  |
|  |  | reflection of light by . . . . . 295-296, 298 |
| velocity I molecule . . . . . . . . . . 408 |  | refraction indices . . . . . . . . 295-296 <br> optical constants . . . . . . . . . 295-298 |
|  |  | resistivity, temperature coefficient . . . 323 |
|  |  | pressure effect . . . . . . 326 |
| Mechanical equivalent of heat metric . . . . . . 5 |  | Volta emf . . . . . . . . . . . 316,404 |
| Mecharical propertles: defligitions li. . . . 261 |  | weight sheet metal . . . . . . . . . 116 |
|  |  | Metallic reflection . . . . . . . . . 295-296, 298 |
|  | tic limit - . 74 | Meteors, chemical composition . . . . . . . . 423 |
|  | Erichson value . . 74 | Meter-candle . . . . . . . . . . . . . 256, 259 |
|  | dness . . - 74 | Metric weights and measures, equivalents . . . 5-10 |
|  |  |  |


| page | pag |
| :---: | :---: |
| Micron, $\mu$. . . . . . . . . . . . . . . . 7, 436 | Pendulum, second: formula; latitude variation . . 427 |
| Milky way, pole of . . . . . . . . . . . 414 | Penetration cathode rays ${ }^{\text {a }}$. . . . . . 387 |
| nerals: densities . . . . . . . . . 11 | high speed molecules . . . . . . . 387 |
| refractive indices: ${ }_{\text {biaxial }}^{\text {isotropic }}$. . . . . . 286 | Pentane candle ${ }_{\text {cher }}$ |
| uniaxial . . . . . ${ }^{284}$ | Periodic system: Hackh . . . . . . . . . . 41 I |
| specific heats . . . . . . . . . . 229 | Mendelejeff - . . . . . . ${ }^{409}$ |
| Minimum energy for light sensation . . . . . . . 261 | Permeability, magnetic . . . . . . . . 365 et seq. |
| Mixtures freezing . . . . . . . . . . . . . . 211 | Persistence of vision |
| Mobilities, ionic - . . . . 405 | Phosphorescence (radio-active excitation) |
| Moduli, -see mechanical properties . . . .74-103 | Phosphorescence (radio-actire excitation) . . . . 394 |
| Mogendorf series formula . . . . . . . . i33-135 | Photoelectricity |
| Moist air, density of $\begin{gathered}\text { maintenance of }\end{gathered}$......... 133-135 | Photographic data : intensification |
| maintenance of transparency to radiation, .36 to $1.7 \mu$. $4^{11}$ | lights, efficiencies . . . . . . 264 |
| transparency to radiation, $\mathrm{H}_{36}$ to $1.7 \mu .41 \mathrm{I}$ | plate characteristics . . . . . 263 |
| Molecular collision frequencies . . . . . . . 399 | olving power |
| conductivities: $\begin{gathered}\text { equivalent } \\ \text { speciflc }\end{gathered} . . . . .349-352$ | Photometric definitions, units |
| crystal units . . . . . . . . . . . 400 | Physiological constants of the eye . . . . . . . 258 |
| diameters . . . . . . . . . . 399, ${ }_{\text {free }} 400$ | $\mathrm{Pl}^{\text {( }}$ ) . . . . . . . 14, 436 |
|  | Pigments, reflecting powers $\mathrm{f}(\lambda)$. . . . . . . . 299 |
| liquefaction . . . . . . . . 407 | Pipes, organ: pitch . . . . . . . . . . . . 149 |
| kinetic energy . . . . . . . . . . . 408 | Pitch: ${ }_{\text {organ }}$ pipes . . . . . . . . . . . . 148 |
|  | voice, limits . . . . . . . . . . . . . 149 |
| mber in $\underset{\text { gram-molecule }}{\mathrm{cm}^{3}, 76 \mathrm{~cm}, o^{\circ} \mathrm{C} . . . . . .} 408$ | Planck's " ${ }^{\text {\% }}$ " |
| velocities . . . . . . . . . . 399 |  |
| weights of colloids . . . . . . . . . 406 | Planetary data |
| Moments of inertia: earth . . . . . . . . . . 427 | Platinum resistance thermom |
|  | thermoelectric thermometer |
| Month | thermoelectric powers against |
| Mcon: albedo | Poisson's ratio |
| distance from earth, parallax , . . . . . 414 | Polcnium radioactive series |
| radiation compared with sun's . . . . . 407 | Polarized light: reflection by . . . . . 295-296, 297 |
| Musical scale $\begin{gathered}\text { sone } \\ \text { touality }\end{gathered}$ | ation of plane |
| tone quality . . . . . . . . . . . . 149 | magnetic |
| Mutual induction . . . . . . . . . . . . . . 376 | Porcelain, resistance, $\mathrm{f}(\mathrm{t})$. . . . . . . . . 332 |
| Nernst thermomagnetic potential difference . . . . 385 | Positive rays |
| Neutral points, thermoelectric . . . . . . . . . 317 | ceils voltarc . . . . . . . $312 \mathrm{r}-3 \mathrm{r}$ |
| Neutralization, heat of . . . . . . . . . . . . 246 | contact . . . . . . 314, 316,40 |
| Nickel, Kerr's constants for . . . . . . . . . 383 | ionizing |
| agnetic properties, o to $100^{\circ}$. . . . . 373 | Peltier . . . . . . . . . . . 321 |
| resistance in magnetic field . . . . . . . 384 | sparking, kerosene . . . . . . 35 |
| Nitrogen thermometer . . . . . . . . . . . . 192 | arious |
| Nitroso-dimethyl-aniline, refractive index . . . . . 280 | resenance |
| Nuclear charge, atomic . . . . . . . . . . 393, 40 I | standard cells |
| Number of stars . . . . . . . . . . . . . . 417 | thermo-electric $\cdot \cdots \cdot{ }^{317-320}$ |
|  | Weston normal . . . . . . . xli |
| Numbers: magnetic character . . . . . . . . . 433 | ble . . . . . . . xliii |
| sun-spot . . . . . . . . . . . . . 415 |  |
| Nutation . . . . . . . . . . . . . . . . 414 | Pressure: air, on moving surfaces . . . . . i ${ }_{50-152}$ |
| Ohservatories, magnetic elements at . . . . . . . 434 | tric, reductions, capillarity - $\dot{8}^{143}$ |
| Ohm: . . . . . . . . . . . . xxxvii, xxxviii, 3 I |  |
| electrical equivalents . . . . . . . . . . 311 | boiling water . . . . |
| Oersted . . . . . . . . . . . . . . . . . xlvi | itical, gases |
| Oils, viscosity of . . . . . . . . . . . . 156, 157 | mercury columns . . . . . . . . . . 136 |
| Optical constants of metals . . . . . . . . . . 295 | volume relations, gases . . . . . . . . 10 |
| Optical rotation magnetic . . . . . . . . . 378-383 | water columns |
| Optical thermometry . . . . . . . . . . . . . 250 | Pressure effect on hoiling points . . . . . . . 200 |
| Organ pipes, pitch . . . . . . . . . . . . . 449 | melting points |
| Organic compounds: boiling points . . . . . . . 203 | resistance electrical thermoelectric powers |
| densities . . . . . . . . . 203 | thermoelectric powers |
| Organic salts, solubilities melting points . . . . . . 203 | aqueeus (steam tables 234) $\cdot$ i83-186 |
| Organic salts, solubilities - . . . . . . . . 170 |  |
| Oscillation constants wireless telegraphy $\begin{gathered}\text { times of wires, temperature variation . . yor } \\ \text { a }\end{gathered}$ | mercury |
| nes . . . . . . . . . . . . . . 149 | solutions |
|  | water vapor |
|  | Probable errors . . . . . . . . . . . . $56-5$ |
| ${ }_{\text {Parsec }}^{\text {P-limit }}$ (proportional limit) . . . . . . 74 et seq. | Probability integrai . . . . . . . . . . . . $56-57$ |
| Parsec . . . . . . . . . . . . . . . 414 | (nverse . . . . . . . . . . 60 |
| Parallax, solar, lunar . . . . . . . . . . . 414 | Proportional limit (P-limit) $\quad . \ldots 20.74$ et seq |
| stellar . . . . . . . . . . 412,415 | Pupil diameter . . . . . . . . . . . . . 258 |
| Paramagnetism . . . . . . . . . . . . . . . 365 | Purkinje phenomenon . . . . . . . . . . . . 256 |
| Partials (sound) . . . . . . . . . . . . . 149 |  |
| Particle, smallest visible . . . . . . . . . . . 406 | Quality, tone . . . . . . . . . . . . . . . 149 |
| itier effect: pressure effect $\because . . . .317,321$ | Quartz: refraction indices . . . . . . . 280 |
| pressure effect . . ....... 320 | transmission of radiation by . . . . . . 30 |



|  |  |  |  |
| :---: | :---: | :---: | :---: |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |








|  | PAGE |
| :---: | :---: |
| Weston normal cell . . . . . . . . . . . . . xll |  |
|  | atomic numbers and spectra $\because \because .390-393$ |
|  | calcite grating space |
| Wire gages, comparison . . . . . . . . . . . . 333 | cathode efficiencies |
| Wire, mechanical properties: copper . . . . . 82-83 | corpuscular radiation . . . . . . 387-38 |
|  | crystals, diffraction with . . . . . . . . 401 |
| steel rope and cable . 79 | energy relations . . . . . . . . . . . 387 |
| Wire resistance, auxiliary table for computing . . . 322 | general radiations . . . . . . . . . . 387 |
| Wire tables: aluminum, English measures . . . . 34 | heterogeneous radiations . . . . . . . . 387 |
| metric measures . . . 343 | homogeneous radiations . . . . . . . . 387 |
| see also . . . . . . . . 334 | independent radiations . . . . . . . . 387 |
| copper, English measures . . . . $335^{\circ}$ | ${ }_{\text {intensity }}^{\text {ionization }}$. . . . . . . . . . . . . 388 |
| metric measures . . . . . 339 | K series of radiations |
| see also . . . . . . . . 334 | L series of radiations . . . . . . . . . 391 |
| temperature coefficients . 334,335 | M series of radiations . . . . . . . . . 392 |
| reduc. to std. . . 335 | monochromatic radiatious . . . . . . ${ }^{\text {c }} 87$ |
| Wires, alternating-current resistance . . . . . . 344 | secondary radiations . . . . . . . . 387 |
| carrying capacity of . - . . . . . . . . 329 | spectra: absorption . . . . . . . . . . 393 |
| high-frequency resistance . . . . . . . 344 | K series . . . . . . . . . . 390 |
| ires, heat losses from incandescent, bright Pt. . 255 | L series . . . . . . . . . . . 391 |
| Pt sponge . 255 | M series . . . . . . . . . 392 |
| ireless telegraphy: antennæ resistances . . . . 364 | wave-lengths ${ }_{\text {tungen }}$ |
| wave-lengths, frequencies, oscil- | ${ }_{\text {wave-lengths and }}^{\text {wavelengt }}$ cathode fall . . . 390-393 |
| lation constants . . . . . 362 | wave-lengths and cathode fall . . . . 387 |
| Wolf sun-spot numbers, 1750 to 1917 . . . . . . 415 | Years . . . . . . . . . . . . . . . 414, 437 |
| Woods: densities . . . . . . . . . 96-99, 112 | Yearly temperature means . . . . . . . . . . 420 |
| mechanical propertles: conifers, Eng. units. 99 | Young's modulus, deffinition . . . . . . . . 74 |
| metric units 97 | Yield point (mechanical property) ${ }^{\text {values }}$. . . . ${ }^{\text {74-103 }}$ |
| hard wds, Eng. units 98 | Yield point (mechanical property) . . . . 74-103 |
| k, conversion factors . . . . . . . . . . . 997 | Zero, absolute, thermodynamic scale . . . . . . 195 |
| , conversion factors . . . . . . . . . . 197 | Zonal harmonics . . . . . . . . . . . . . 64 |

Che fivergide prefif
CAMBRIDGE . MASSACHUSETTS
U.S.A

## DATE DUE SLIP

 UNIVERSITY OF CALIFORNIA MEDICAL SCHOOL LIBRARYTHIS BOOK JS DUE ON THE LAST DATE STAMPED BELOW
DC. 7 - 1041
$\cdots$
SEP 251942
MUV 201945
APR 251946

O6T 20-195?



Library of the University of California Medical Schnol


[^0]:    June, 1919.

[^1]:    ${ }^{1}$ Because of its greater psychological and physical simplicity, and the desirability that the unit chosen should have extensive magnitude, it has been proposed to choose as the fourth fundamental quantity, a quantity of electrical charge, $e$. The standard unit of electrical charge would then be the electronic charge. For thermal needs, entropy has been proposed. While not generally so psychologically easy to grasp as temperature, entropy is of fundamental importance in thermodynamics and has extensive magnitude. (R. C. Tolman, The Measurable Quantities of Physics, Physical Review, 9, p. 237, 1917.)

[^2]:    ${ }^{1}$ Circular 60 of the Bureau of Standards, Electric Units and Standards, 1916. The subse-

[^3]:    "Practical" Electromagnetic System. - This electromagnetic system is based upon the units of $10^{9} \mathrm{~cm}, 10^{-11}$ gram, the sec. and $\mu$ of the ether. It is never used as a complete system of units but is of interest as the historical basis of the present International System. The principal quantities are the resistance unit, the ohm $=10^{9}$ c.g.s. units; the current unit, the ampere $=10^{-1}$ c.g.s. units; and the electromotive force unit, the volt $=10^{8}$ c.g.s. units.

[^4]:    ${ }^{1}$ For example, A. G. Webster, "Theory of. Electricity and Magnetism," 1897; J. H. Jeans, "Electricity and magnetism," 1911; H. A. Lorentz, "The Theory of Electrons," 1909; and O. W. Richardson, "The Electron Theory of Matter," 191.4.

[^5]:    ${ }^{1}$ Dellinger, International System of Electric and Magnetic Units, Bull. Bureau of Standards, 13. p. 599, 1916.

[^6]:    * For these formulx the numbers in the last column are the exponents of F where F refers to the luminous flux. For definitions of these quantities see Table 299, page 259 -
    Smithsonian tables.

[^7]:    * As adopted by American Institute of Electrical Engineers, 1915.
    $\dagger c$ is the velocity of an electromagnetic wave in the ether $=3 \times 10^{10}$ approximately.
    $\ddagger$ This conversion factor should include $\left[\theta^{-1}\right]$.

[^8]:    * Legendre's "Exercises de Calcul Intégral," tome ii.

[^9]:    ＊Specification Values：Alloy＂No． 12 ＂：A．S．T．M．B26－18T，tentative specified minimums for aluminum，copper．
    $\dagger$ Quenched in water from $475^{\circ} \mathrm{C}$ ．after heating in a salt bath．Modulus of elasticity for Duralumin averages $7000 \mathrm{~kg} / \mathrm{mm}^{2}$ or $10,000,000 \mathrm{lb} / \mathrm{in}^{2}$ ．
    $\ddagger$ Specification values：Aluminum castings；U．S．Navy 49 Al，July I， 1915 （Impurities：Fe max．0．5，Si max．0．5）．
    Smithsonian Tables．

[^10]:    ＊Tensilite， $\mathrm{Cu} 67, \mathrm{Zn} 24, \mathrm{Al}_{4.4}, \mathrm{Mn} 3.8, \mathrm{P}$ o．or compressive P －limit： $42.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or $60,000 \mathrm{lb} / \mathrm{in}^{2}$ and x .33 per cent set for $70.3 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$ load．
    $\dagger$ Compressive P－limit 20.0 to $28.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or 28,500 to $40,000 \mathrm{lb} / \mathrm{in}^{2}$
    $\ddagger$ Compressive ultimate strength $54.5 \mathrm{~kg} / \mathrm{mm}^{2}$ or $77,500 \mathrm{lb} / \mathrm{in}^{2}$
    ${ }_{8}^{+}$Compressive P－limit $4.2 \mathrm{~kg} / \mathrm{mm}^{2}$ or $6000 \mathrm{lb} / \mathrm{in}^{2}$ and 40 per cent set for $70.3 \mathrm{~kg} / \mathrm{mm}^{2}$ or $100,000 \mathrm{lb} / \mathrm{in}^{2}$
    f Modulus of elasticity $9840 \mathrm{~kg} / \mathrm{mm}^{2}$ or $14,000,000 \mathrm{lb} / \mathrm{in}^{2}$
    Il Values are for yield point．
    ＋Rolled manganese bronze（U．S．N．） Cu 57 to $60, \mathrm{Zn} 40$ to $37, \mathrm{Fe}$ max． $2.0, \mathrm{Sn} 0.5$ to 1．5； 2.9 per cent increase for thickness 25.4 mm （ I in．）and under．

    非 Ni 9 per cent，B．h．n．$=130$ as rolled；B．h．n．$=50$ as annealed at $930^{\circ} \mathrm{C}$ ．
    U．S．Navy Dept．Spec．46S 3a，June r，1917：German silver Cu 60 to 67 ， Zn 18 to 22，Ni min．15，no mechanical requirements．

    For list of 30 German silver alloys，see Braunt，＂Metallic Alloys，＂p．3r4，—＂best＂（Hiorns），＂hard Sheffield，＂ $\mathrm{Cu}_{46}, \mathrm{Zn} 20, \mathrm{Ni}_{3} 4$.

    88 Platinoid $\mathrm{Cu} 60, \mathrm{Zn}_{24}, \mathrm{Ni}_{14}, \mathrm{~W}$ I to 2 ；high electric resistance alloy with mechanical properties as nickel brass．
    III\｜Specification Values，Naval Brass Castings，U．S．Navy， 46 B rob，Dec．1， 1917 for normal proportions $\mathrm{Cu} 62, \mathrm{Zn}$
    

[^11]:    ＊U S．Navy Spec． 46 M 2 b （ $\mathrm{Cu}_{3}$ to $4.5, \mathrm{Sn} 88$ to $89.5, \mathrm{Sb} 7.0$ to 8.0 ）covers manufacture of anti－friction－metal castings． Composition W．）

    Note．－See also Brass，Lead（yellow brass），Brass，Lead－Tin（Red Brass）；Bronze，Phosphor，etc．，under Copper alloys

[^12]:    Smithsonian Tables．

[^13]:    * Building ordinances of American cities specify allowable working stresses in compression over bearing area of 12.5 per cent (vitrified brick) to 17.5 per cent (common brick) of corresponding ultimate compressive strength shown in table.
    $\dagger$ P. denotes Portland.

[^14]:    * Modulus of rigidity in $\mathrm{to}^{11}$ dynes per sq. cm .

[^15]:    * In this system the subscript $a$ indicates that compression or extension takes place along the crystalline axis, and distortion round the axis. The subscripts $b$ and $c$ correspond to directions equally inclined to two and normal to the third and equally inclined to all three axes respectively.
    ! Voigt, "Wied. Ann.", 31, p. 474, p. 701, 1887; 34, p. 981, 1888; 36, p. 642, 1888.
    $\ddagger$ Koch, "Wied. Ann." 18, p. 325, 1882.
    § Beckenkamp, "Zeit. für Kryst." vol. 10.
    II The subscripts $x, 2,3$ indicate that the three principal axes are the axes of stress; $4,5,6$ that the axes of stress are in the tiree principal planes at angles of $45^{\circ}$ to the corresponding axes.
    II Baumgarten, " Pogg. Ann." 152, p. 369, 1879.

[^16]:    *From the experiments of Roth, "Wied. Ann." vol. 11, 1880 ,

[^17]:    Smithsonian Tables.

[^18]:    *From - $10^{\circ}$ to $0^{\circ}$ the values are due to means from Pierre, Weidner, and Rosetti; from $0^{\circ}$ to $41^{\circ}$, to Chappuis, $42^{\circ}$ to $100^{\circ}$, to Thiesen ; $110^{\circ}$ to $250^{\circ}$, to means from the works of Ramsey, Young, Waterston, and Hirn.

    ## Smithsonian tables.

[^19]:    *The height of the barometer is affected by the relative thermal expansion of the mercury and the glass, in the case of instruments graduated on the glass tube, and by the relative expansion of the mercury and the metallic inclosing case, usually of brass, in the case of instruments graduated on the brass case. This relative expansion is practically proportional to the first power of the temperature. The above tables of values of the coefficient of relative expansion will be found to give corrections almost identical with those given in the International Meteorological Tables. The numbers tabulated under $a$ are the valnes of $a$ in the equation $H_{t}=H_{t}^{\prime}-a\left(t^{\prime}-t\right)$ where $H_{t}$ is the height at the standard temperature, $H t^{\prime}$ the observed height at the temperature $t^{\prime}$, and $a\left(t^{\prime}-t\right)$ the correction for temperature. The standard temperature is $0^{\circ} \mathrm{C}$. for the metric system and $28^{\circ} \cdot 5 \mathrm{~F}$. for the English system. The English barometer is correct for the temperature of melting ice at a temperature of approximately $28^{\circ} .5 \mathrm{~F}$., because of the fact that the brass scale is graduated so as to be standard at $62^{\circ} \mathrm{F}$., while mercury has the standard density at $32^{\circ} \mathrm{F}$.

    EXAMPLE.-A barometer having a brass scale gave $H=765 \mathrm{~mm}$. at $25^{\circ} \mathrm{C}$. ; required, the corresponding reading at $o^{\circ} \mathrm{C}$. Here the value of $\boldsymbol{a}$ is the mean of . 1235 and .125I, or .1243; $\cdot^{\circ}, a\left(t^{\prime}-t\right)$ $=.1243 \times 25=3.11$. Hence $H_{0}=765-3.11=761.89$.
    N. B.-Although $a$ is here given to three and sometimes to four significant figures, it is seldom worth while to use more than the nearest two-figure number. In fact, all barometers have not the same values for $a$, and when great accuracy is wanted the proper coefficients have to be deter. mined by experiment.

[^20]:    *"Smithsonian Meteorological Tables."

[^21]:    *See Dushman, The Production and Measurement of High Vacua, General Elec. Rev. 23, p. 493, 1920

[^22]:    * Quoted from a paper by Jenkin and Ewing, "Phil. Trans. R. S." vol. 167. In this paper it is shown that in cases where "static friction" exceeds " kinetic friction" there is a gradual increase of the coefficient of friction as the speed is reduced towards zero.

[^23]:    * Bureau of Standards, see special table. $\dagger$ Glaser.

[^24]:    * In the case of solutions of salts it has been found (vide Arrhennius, Zeits. für Phys. Chem. vol. 1, p. 285) that the specific viscosity can, in many cases, be nearly expressed by the equation $\mu=\mu_{1}{ }^{n}$, where $\mu_{1}$ is the specific viscosity for a normal solution referred to the solvent at the same temperature, and $n$ the number of gramme molecules in the solution under consideration. The same rule may of course be applied to solutions stated in percentages instead of gramme molecules. The table here given has been compiled from the results of Reyher (Zeits. fuir Phys. Chem. vol. 2, p. 749) and of Wagner (Zeits. für Phys. Chem. vol. 5, p. 31) and illustrates this rule. The numbers are all for $25^{\circ} \mathrm{C}$

[^25]:    * Taken from Winkelmann's papers (Wied. Ann. vols. 22, 23, and 26). The coefficients for $\circ^{\circ}$ were calculated by Winkelmann on the assumption that the rate of diffusion is proportional to the absolute temperature. According to the investigations of Loschmidt and of Obermeyer the coefficient of diffusion of a gas, or vapor, at o ${ }^{\circ} \mathrm{C}$. and a pressure of 76 centimetres of mercury may be calculated from the observed coefficient at another temperature and pressure by the formula $k_{0}=k_{T}\left(\frac{T_{0}}{T}\right)^{n} \frac{7^{6}}{p}$, where $T$ is temperature absolute and $p$ the pressure of the gas. The exponent $n$ is found to be about 1.75 for the permanent gases and about 2 for condensible gases. The following are examples: $\mathrm{Air}-\mathrm{CO}_{2}, n=1.968 ; \mathrm{CO}_{2}-\mathrm{N}_{2} \mathrm{O}, n=2.05 ; \mathrm{CO}_{2}-\mathrm{H}, n=1.742 ; \mathrm{CO}-\mathrm{O}, n=1.785 ; \mathrm{H}-\mathrm{O}$, $n=1.755 ; \mathrm{O}-\mathrm{N}, n=1.792$. Winkelmann's results, as given in the above table, seem to give about 2 for vapors diffusing into air, hydrogen or carbon dioxide.

[^26]:    * This determination of the capillary constants of liquids has been the subject of many careful experiments, but the results of the different experimenters, and even of the same observer when the method of measurement is changed, do not agree well together. The values here quoted can only be taken as approximations to the actual values for the liquids in a state of purity in contact with pure air. In the case of water the values given by Lord Rayleigh from the wave length of ripples (Phil. Mag. 18go) and by Hall from direct measurement of the tension of a flat film (Phil. Mag. 1893) have been preferred, and the temperature correction has been taken as 0.141 dyne per degree centigrade. The values for alcohol were derived from the experiments of Hall above referred to and the experiments on the effect of temperature made by Timberg (Wied. Ann. vol. 30).

    The authority for a few of the other values given is quoted, but they are for the most part average values derived from a large number of results published by different experimenters.

    + From Volkmann (Wied. Ann. vol. 17, p. 353).
    For more recent data see especially Harkins, J. Am. Ch. Soc., 39, p. 55, 1917 (336 liquids). and 42, p. 702, 2543, 1920.

[^27]:    *This table has been compiled from results published by Ramsay and Young (Jour. Chem. Soc. vol. 47, and Phil. Trans. Koy. Soc., 1886).

    + In this formula $a=5.0720301 ; \log b=\overline{2} .6406131 ; \log c=0.6050854 ; \log a=0.003377538 ; \log \boldsymbol{\beta}=\overline{\mathrm{I}} .99682424$ ( $c$ is negative).
    $\ddagger$ Taken from a paper by Dittmar and Fawsitt (Trans. Roy. Soc. Edin. vol. 33).


    ## Smithsonian Tables.

[^28]:    * Compiled from a table by Tammann, "Mém. Ac. St. Petersb." ${ }_{35}$, No. 9, x887. See also Referate, "Zeit. f.

[^29]:    * Greenwood, Pr. Roy. Soc., p. 483, igio.

[^30]:    References：（1）Mond，Langer，Quincke；（2）Ordway；（3）Tilden；（4）Erdmann；（5）R．Weber；（6）Olszewski； （7）Birhaus；（8）Ramsay；（9）Deville；（10）Wroblewski；（11）Day，Sosman，White；（12）Ramme；（13）Meyer； （r4）Lemoine；（15）Carnelly；（16）Mitscherlich；（17）LeChatelier；（18）Carnelly，O＇Shea；（19）Thorpe；（20）Amat； （21）Mendelejeff；（22）Marignac；（23）Besson；（24）Clarke，Const．of Nature；（25）Isambert；（26）Mylius； （27）Hevesy；（28）Retgers；（29）Grünauer；（30）Richards and others．
    ＊Under pressure $\mathrm{r}_{3} 8 \mathrm{~mm}$ mercury．$\dagger$ Decomposes．

[^31]:    ${ }^{*}$ Liquid at $-1 \mathrm{r} .{ }^{\circ} \mathrm{C}$. and 180 atmospheres' pressure (Cailletet).
    $\dagger$ " " + 4.0 " " 46
    $\ddagger$ Boiling-point under 15 mm . pressure.
    In vacuo.

[^32]:    * Boiling-point under 15 mm . pressure.
    $\dagger$ Liquid at $-11 .{ }^{\circ} \mathrm{C}$. and 180 atmospheres' pressure (Cailletet).

[^33]:    * Compiled from a paper by Gerlach, " Zeit. f. Anal. Chem." vol. 26.

[^34]:    * Compiled from the results of Cailletet and Colardeau, Hammerl, Hanamann, Moritz, Pfanndler, Rudorf, and

[^35]:    *Abridged for the most part from Landolt and Börnstein's "Phys. Chem. Tab."

[^36]:     ing; for reference see next page).
    $\dagger$ Iron: 100- $727^{\circ} \mathrm{C}, k_{t}=0.202$; 100-912ㅇ, 0.184; 100-1245 ${ }^{\circ}$, 0.191 (Hering).

[^37]:    * Total heat from $0^{\circ} \mathrm{C}$.
    $\dagger$ U. S. Bureau of Standards, 1913 , in terms of $15^{\circ}$ calorie.
    ₹ 1903, based on electrical measurements, assuming mechanical equivalent $=4.187$, and in terms of the value of the international volt in use after igir.

[^38]:    Smithsonian Tables.

[^39]:    * Langmuir Physical Review, 34, p. 401, 1912.

[^40]:    * Computed with $\sigma=5.32$, black-body efficiency of platinum as follows (Lummer and Kurlbaum): $492^{\circ} \mathrm{K}$. $0.039 ; 654^{\circ}, 0.060 ; 795^{\circ}, 0.075 ; 1108^{\circ}, 0.112 ; 1481^{\circ}, 0.154 ; 1761^{\circ} \mathrm{K} ., 0.180$. For significance of last group of data, see next page. $\dagger$ Weighted mean.

[^41]:    Smithsonian Tables.

[^42]:    Smithsonian Tables.

[^43]:    * According to the experiments of Soret (Arch. d. Sc. Phys. Nat. Genève, r884, r888, and Comptes Rendus, 1885). $\dagger R$ stands for the different bases given in the first column.
    For sther alums see reference on Landolt-Börnstein-Roth Tabellen.

[^44]:    Smithsonian Tables.

[^45]:    * These places require multiplication by the following factors to allow for losses in $\mathrm{CO}_{2}$ gas. Under average sea-level outdoor conditions the $\mathrm{CO}_{2}$ (partial pressure $=0.0003$ atmos.) amounts to about 0.6 gram per cu. m. Paschen gives 3 times as much for indoor conditions.
    $2 \mu$ to $3 \mu$, for ${ }^{2}$ grams in ${ }_{\text {" }} m^{2}$ path (95); for 140 grams in ${ }_{\text {u }}{ }^{2}$ path ( 93 );
    4 " 5 "" "" "" " (93); " " " " " " (70); more $\mathrm{CO}_{2}$ no further effect;
    I3 " I4, slight allowance to be made;
    ${ }_{15}{ }^{15}$ " ${ }^{15} 16,80$, grams in $m_{\text {" }}^{2}$ path reduces energy to zero;
    $\dagger$ These places require multiplication by 0.90 and 0.70 respectively for one air mass and 0.85 and 0.65 for two air masses to allow for ozone absorption when the radiation comes from a celestial body.

[^46]:    * The Minotto or Sawdust, the Meidinger, the Callaud, and the Lockwood cells are modifications of the Daniell, and hence have about the same electromotive force.
    8 mithsonian Tables.

[^47]:    Smithsonian Tables

[^48]:    * "Rend. della R. Acc. di Roma," 1890.
    $\dagger$ Amalgamated.
    $\ddagger$ Not constant.
    § After some time.
    If A quantity of bromine was used corresponding to $\mathrm{NaOH}=\mathbf{r}$.

[^49]:    * Identical wire of Table 398. $\dagger$ Another wire of same sample. $\ddagger$ Different sample.
    \& Results too irregular for interpolation for values at other temperature and pressures; see original article. (1) $-.0556 t^{3}$; (2) $-.0486 t^{3}$, annealed ingot iron; (3) -.05166 $\beta^{3}$; (4) -.04I $\beta^{3}$; (5) -.0425 ; (6) -.04112 $\beta^{3}$.

[^50]:    Smithsonian Tables．

[^51]:    $* 0^{\circ}$ to $20^{\circ}$. $\quad \dagger 0^{\circ}$ to $24^{\circ}$. $\ddagger$ Extrapolated from $50^{\circ}$. § Extrapolated from $75^{\circ}$.

[^52]:    * These values are at the concentration 80.0.

[^53]:    Smithsonian Tables.

[^54]:    Other determinations: Hess, Wien. Ber. 121, p. 1, 1912, Radium (alone) 25.2 cal. per hour per gram. Meyer and Hess, Wien. Ber. 121, p. 603, 1912, Radium in equilibrium, 132.3 gram. cal. per hour per gram. See also, Callendar, Phys. Soc. Proceed. 23, p. ı, 1910; Schweidler and Hess, Ion. i, p. 16ı, 1909; Ångström, Phys. ZS. 6, 685, 1905, etc.
    Smithsonian Tables.

[^55]:    * Pressure $=10^{6}$ bars $=10^{6}$ dynes $\div \mathrm{cm}^{2}=75 \mathrm{~cm} \mathrm{Hg}$.

[^56]:    * Computed from relation $V e=h \nu$ or $V=12334 / \lambda$ volts; $\lambda$ in Angstrom units.
    $\dagger$ Computed from $h=0.5308 \lambda \mathrm{~V}$ ro $0^{-30}$
    $\ddagger$ Limit of principal series.
    $\$$ Limit of principal series of single lines, 1.5 S .
    I| Short wave-length line of first doublet of principal series.
    ** First line principal series single lines $1.55-2 P$.

[^57]:    * Parsec $=206,265$ astronomical units $=3.08 \times 10^{13} \mathrm{~km}=3.26$ light years. $\quad \mathrm{r}$ astronomical unit $=$ distance sun to earth.

    Practically all the stars visible to the naked eye lie within 1000 parsecs of the sun, and most of them are more than 100 parsecs distant. In the vicinity of the sun, the majority of the stars lie within two or three hundred parsecs of the galactic plane; but along this plane the star-filled region extends far beyond 1000 parsecs in all directions, and may reach 30,000 parsecs in the great southern star clouds (Shapley).

    Average parallax 6 planetary nebulae, o.o18" (van Maanen, Pr. Nat. Acad. 4, p. 394, 1918).

[^58]:    * Earth and moon. † Relative to earth. Inclination of axes: Sun $7^{\circ} .25$; Earth $23^{\circ} .45$; Mars $24^{\circ} .6$; Tupiter $3^{\circ} .1$; Saturn $26^{\circ} .8$; Neptune $27^{\circ} .2$. Others doubtful. Approximate rates, frotation: Sun $25 \frac{1}{8} d$; Moon 27ld; Mercury 88d; Venus 225d; Mars $24^{\text {h }} 37^{\mathrm{m}}$; Jupiter $9^{\mathrm{h}} 55^{\text {m }}$; Saturn $10^{\mathrm{h}} 14^{\mathrm{m}}$ 。

[^59]:    Smithsonian Tables.

[^60]:    * Compiled from annual reviews of the "Caractère magnétique de chaque jour" prepared by the Royal Meteorological Institute of the Netherlands for the International Commission for Terrestrial Magnetism. The number of stations supplying complete data for the above years were respectively, $30.32,36,38,34,39,43,42,37,35,35,35$ Data from Sitka, Ekaterinburg, Stonyhurst, Wilhelmshaven, Potsdam-Seddin, De Bilt, Greenwich, Kcw, Val Joyeux, Pola, Cheltenham, Honolulu, Bombay, Porto Rico, and Buitenzorg were employed for all of the years.

[^61]:    * Baldwin Obs'y replaced by Tucson Obs'y, Oct. 1909; mean given for Jan.-Oct. 'o9.

    20 Replaced Zi-ka-wei Obs'y, 1908. $\dagger$ Observations discontinued Apr. 26, 1915.
    $\ddagger$ Provisional values taken for position of Port Cork, p. 298, American Practical Navigator, 1914 edition.

