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THE LUMINIFEROUS
ÆTHER.

BY

DeVOLSON WOOD, C.E., M.A.

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THE LUMINIFEROUS ÆTHER.

Two properties of the luminiferous æther appear to be known and measurable with a high degree of accuracy. One is its ability to transmit light at the rate of 186,300 miles per second,* and the other its ability to transmit from the sun to the earth a definite amount of heat energy.

In regard to the latter, Herschel found, from a series of experiments, that the direct heat of the sun, received on a body at the earth capable of absorbing and retaining it, is competent to melt an inch in thickness of ice every two hours and thirteen minutes. This is equivalent to nearly 71 foot-pounds of energy per second.

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* Professor Michelson found the velocity of light to be 289,740 meters per second in air, and 299,828 meters in a vacuum, giving an index of refraction of 1,000,265 "Journal of Arts and Science," 1879, vol. xviii., p. 390.

In 1838 M. Pouillet found that the heat energy transmitted from the sun to the earth would, if none were absorbed by our atmosphere, raise 1.76 grammes of water 1° C. in one minute on each square centimeter of the earth normally exposed to the rays of the sun.*

This is equivalent to 83.5 foot-pounds of energy per second, and is the value used by Sir William Thomson in determining the probable density of the æther.† Later determinations of the value of the solar constant by MM. Soret, Crova, and Violle have made it as high as 2.2 to 2.5 calories. But the most recent, as well as the most reliable, determination is by Professor S. P. Langley, who brought to his service the most refined apparatus yet used for this purpose, and secured his data under favorable conditions; from which the value is found to be 2.8 ± calories ‡ with some uncertainty still remaining in regard to the first figure

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* *Comptes Rendus*, 1838, tom. vii. pp. 24–26.

† "Trans. Roy. Soc. of Edinburgh," vol. xxi. part 1.

‡ *Am. Journ. of Arts and Science*, March, 1883, p. 195. Also *Comptes Rendus.*

of the decimal. We will consider it as exactly 2.8 in this analysis, according to which, there being 7,000 grains in a pound and 15.432 grains in a gramme, we have for the equivalent energy

$$\frac{2.8\times 15.432}{7{,}000}\times\frac{9}{5}\times\frac{772\times 144}{0.155\times 60}=$$
133 foot-pounds

per second for each square foot of surface normally exposed to the sun's rays, which value we will use. Beyond these facts, no progress can be made without an assumption. Computations have been made of the density, and also of the elasticity, of the æther founded on the most arbitrary, and in some cases the most extravagant, hypotheses. Thus, Herschel estimated the stress (elasticity) to exceed

17×10^9=(17,000,000,000) pounds per square inch;*

and this high authority has doubtless caused it to be widely accepted as ap-

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* "Familiar Lectures," p. 282

proximately correct. But his analysis was founded upon the *assumption* that the density of the æther was the same as that of air at sea-level, which is not only arbitrary, but so contrary to what we should expect from its non-resisting qualities, as to leave his conclusion of no value. That author also erred in assuming that the tensions of gases were as the wave-velocities in each, instead of the mean square of the velocity of the molecules of a self-agitated gas; but this is unimportant, as it happens to be a matter of quality rather than of quantity. Herschel adds, "Considered according to any hypothesis, it is impossible to escape the conclusion that the æther is under great stress." We hope to show that this conclusion is not warranted; that a great stress necessitates a great density; but that both may be exceedingly small. A great density of the æther not only presents great physical difficulties, but, as we hope to show, is inconsistent with the uniform elasticity and density of the æther which it is believed to possess;

and every consideration would lead one to accept the lowest density consistent with those qualities which would enable it to perform functions producing known results.

In a work on the "Physics of Æther," by S. Tolver Preston, it is estimated that the probable inferior limit of the tension of the æther is 500 tons per square inch, a very small value compared with that of Herschel's. But the hypothesis upon which this author founded his analysis was—The tension of the æther exceeds the force necessary to separate the atoms of oxygen and hydrogen in a molecule of water; as if the atoms were forced together by the pressure of the æther, as two Magdeburg hemispheres are forced together by the external air when there is a vacuum between them. This assumption is also gratuitous, and is rejected for want of a rational foundation.

Young remarks: "The luminiferous æther pervading all space is not only highly elastic, but absolutely solid."* We are

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* "Young's Works," vol. i. p. 415.

not certain in what sense this author considered it as solid; but if it be in the sense that the particles retain their relative positions, and do not perform excursions as they do in liquids, it is a mere hypothesis, which may or may not have a real existence. If it be in the sense that the particles suffer less resistance to a transverse than to a longitudinal movement, there are some grounds for the statement, as shown in circularly-polarized light. Bars of solids are more easily twisted than elongated, and, generally, the shearing resistance is less than for a direct stress. It certainly cannot be claimed that the compressibility of the æther (in case we could capture a quantity of it) is less than that of solids.

Sir William Thomson made a more plausible hypothesis, by assuming that "the maximum displacement of the molecules of the æther in the transmission of heat energy was $\frac{1}{50}$ of a wave length of light, the average of which may be taken as $\frac{1}{50000}$ of an inch." Hence the displacement was assumed to be $\frac{1}{2500000}$ of an inch; by means of which he found the weight of a cubic foot to be $\frac{2}{3}\times10^{-20}$ of a pound.* We also notice that one Belli estimated the density of the æther to be $\frac{1}{2}\times10^{-18}$ of a pound; † but M. Herwitz, assuming this value to be too large small and Thomson's as too large, arbitrarily small assumed it as 10^{-18} of a pound per cubic foot; but arbitrary values are of small account unless checked by actual results.

We propose to treat the æther as if it conformed to the Kinetic Theory of Gases, and determine its several properties on the conditions that it shall transmit a wave with the velocity of 186,300 miles per second, and also transmit 133 foot-pounds of energy per second per square foot. This is equivalent to considering it as gaseous in its nature, and at once compels us to consider it as molecular; and, indeed, it is difficult to conceive of a medium transmitting light and energy without being molecular. The

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* *Phil. Mag.*, 1855 [4] ix. p. 39.

† Cf. *Fortschritte der Physik*, 1859.

Electromagnetic Theory of Light suggested by Maxwell, as well as the views of Newton, Thomson, Herschel, Preston, and others, are all in keeping with the molecular hypothesis. If the properties which we find by this analysis are not those of the æther, we shall at least have determined the properties of a substance which might be substituted for the æther, and secure the two results already named. It may be asked, Can the Kinetic theory, which is applicable to gases in which waves are propagated by a to-and-fro motion of the particles, be applicable to a medium in which the particles have a transverse movement, whether rectilinear, circular, elliptical, or irregular? In favor of such an application, it may be stated that the general formulæ of analysis by which wave motion in general, and refraction, reflection, and polarization in particular, are discussed, are fundamentally the same; and in the establishment of the equations the only hypothesis in regard to the path of a particle is—It will move along the path of least resistance.

The expression $V^2 \propto e + \delta$ is generally true for all elastic media, regardless of the path of the individual molecules. Indeed, granting the molecular constitution of the æther, is it not probable that the Kinetic theory applies more rigidly to it than to the most perfect of the known gases? *

The 133 foot-pounds of energy per second is the solar heat energy in a prism whose base is 1 square foot and altitude 186,300 miles, the distance passed over by a ray in one second; hence the energy in 1 cubic foot will be

$$\frac{133}{186{,}300 \times 5{,}280} = \frac{4}{3 \times 10^7} \text{foot-pounds}. \quad (1)$$

Where results are given in tenth-units of high order, as in the last expression, it seems an unnecessary refinement to retain more than two or three figures to the left hand of the *tens;* and we will write such expressions as if they were the exact results of the computations.

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* See also remarks by G. J. Stoney, *Phil. Mag.*, 1868 [4] xxxvi. pp. 132, 133.

If V be the velocity of a wave in an elastic medium whose coefficient of elasticity, or in other words, its tension, is e and density δ, both for the same unit, we have the well-known relation

$$V=\sqrt{\frac{de}{d\delta}}.$$

And for gases we have

$$e=\delta^{\gamma},$$

where $\gamma=1.4$; and the differential of the latter substituted in the former gives

$$V=\sqrt{\frac{\gamma e}{\delta}}. \quad . \quad . \quad . \quad . \quad (2)$$

The tension of a gas varies directly as the kinetic energy of its molecules per unit of volume. If v^2 be the mean square of the velocities of the molecules of a self-agitated gas, we have

$$e \propto \delta v^2, \text{ or } v^2=x\frac{e}{\delta}, \quad . \quad . \quad (3)$$

where x is a factor to be determined. Equations (2) and (3) give

$$v^2=\frac{x}{\gamma}V^2. \quad . \quad . \quad . \quad (4)$$

Assuming, with Clausius, that the heat energy of a molecule due to the action of its constituent atoms, whether of rotation or otherwise, is a multiple of its energy of translation, we have for the energy in a unit of volume producing heat,

$$\tfrac{1}{2}y\delta v^2,$$

where y is a factor to be determined. If c be the specific heat of a gas, w its weight per cubic foot at the place where $g=32.2$, J. Joule's mechanical equivalent, τ its absolute temperature; then the essential energy of a cubic foot of the medium will be $cw\tau\text{J}$; and observing that $w=g\delta$, we have

$$\tfrac{1}{2}y\delta v^2=cg\delta\tau\text{J}, \qquad (5)$$

which, reduced by (4), gives

$$xy=\frac{2cg\gamma\tau\text{J}}{\text{V}^2}, \qquad (6)$$

the second member of which is constant for a given gas. To find its value we have

	Hydrogen.	Air.	Oxygen.
Specific heat* . .	3.4093	0.2375	0.2175
Velocity of sound, feet per second, at $\tau=493.2°$ . .	4,163	1,030	1,040

and $g=32.2$, $\gamma=1.4$, $J=772$. These, substituted in the second member of (6), give

xy for hydrogen........	6.599
" air................	6.706
" oxygen...........	6 596
	3)19.901
Mean........	6.63

This value, which is nearly constant for the more perfect gases, we propose to call *the modulus of the gas*, and represent it by μ; and for the purposes of this paper we will use

$$\mu=6.6.$$

This relation of the product xy being a constant, has, so far as we are informed, been overlooked by physicists, and is

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* Stewart on "Heat," p. 229.

worthy of special notice, since it determines the value of one of the factors when the other has been found. Krönig, Clausius,[*] and Maxwell give for x the constant number 3, but variable values for y.[†]

We are confident that the value of x is not strictly constant; or if it is, it exceeds 3, since the effect of the viscosity of a gas would necessitate a larger velocity to produce a given tension than if it were perfectly free from internal friction. For our purpose, it will be unnecessary to find the separate values of x and y; but if we have occasion to use the former in making general illustrations, we will call it 3, as others have done heretofore. If the correct value of x exceeds 3, it will follow that the velocity of the molecules exceeds the values heretofore computed.[‡]

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[*] *Phil. Mag.*, 1857 [4] xiv. p. 128.

[†] "Theory of Heat," pp. 314 and 317. Maxwell states that the value for y is probably equal to 1.634 for air and several of the perfect gases. This would make $x=4$ nearly.

[‡] Maxwell gives for the mean square of the velocities, or, in other words, the velocity whose square is the mean of the squares of the actual velocities) of the

According to Thomson, Stokes showed that in the case of circularly polarized light the energy was half potential and half kinetic;* in which case $y=2$, and therefore $x=3.3$.

The energy in a cubic foot of the æther at the earth being given by (1) and (5), we have, by the aid of (4),

$$\tfrac{1}{2}y\delta v^2=\tfrac{1}{2}\mu\frac{\delta}{\gamma}V^2=\frac{4}{3\times 10^7}; \quad . \quad . \quad (8)$$

$$\therefore \delta=\frac{4\times 1.4\times 2}{3\times 10^7\times 6.6\times(186{,}300\times 5280)^2}=\frac{2}{35\times 10^{24}}\text{ lb.}, \quad . \quad . \quad (9)$$

which is the mass of a cubic foot of the æther at the earth, and which would weigh at the place where $g=32.2$ about

$$w=\frac{2}{10^{24}}\text{ of a pound}, \quad . \quad . \quad (10)$$

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molecules, in feet per second at 493.2° F. above absolute zero, hydrogen 6,282, oxygen 1,572, carbonic oxide 1,276 carbonic acid 1,570. *Phil. Mag.*, 1878, p. 68. Our equation (4) gives for air 1,593.

* *Phil. Mag.* 1855 [4] ix. p. 87.

compared with which Thomson's value is less than 4,000 times this value. Thomson remarked that the density could hardly be 100,000 times as small—a limit so generous as to include far within it the value given in (9). According to equation (10), a quantity of the æther whose volume equals that of the earth, would weigh about $\frac{1}{20}$ of a pound. If a particle describes the circumference of a circle in the same time that a ray passes over a wave-length λ, the radius of the circle will be, using equation (4),

$$r=\frac{vt}{2\pi}=\sqrt{\frac{x}{\gamma}}.\mathrm{V}.\frac{\lambda}{2\pi\mathrm{V}}=\tfrac{10}{43}\lambda,$$

or the displacement from its normal position will be about $\frac{10}{43}$ of a wave-length, or about $\frac{1}{215000}$ of an inch at the earth.

Eliminating V between (2) and (8) gives

$$e=\frac{8}{3\mu\times10^7}=\frac{4}{10^8} \quad . \quad . \quad . \quad (11)$$

for the tension of the æther per square ot at the earth, and is equivalent to about 1.1 of a pound on a square mile. The tension of the atmosphere at sea-level is more than 30,000,000,000 times this value. It somewhat exceeds the tension of the most perfect vacuum yet produced by artificial means, so far as we are informed. Crookes produced a vacuum of .02 millionth of an atmosphere* without reaching the limit of the capacity of the pumps; and Professor Rood produced one of $\frac{1}{390000000}$ of an atmosphere† without passing the limit of action of his apparatus. The latter gives a pressure per square foot of

$$\frac{14.7\times 144}{390000000}=\frac{1}{180000}$$ of a pound. This, in round numbers, is 140 times the value given in equation (11). Even at this great rarity of the atmosphere, the quantity of matter in a cubic foot of the air

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* "On the Viscosity of Gases at High Exhaustions," by William Crookes, F. R. S., "Phil. Trans. Roy. Soc.," part ii. (1881), p. 400: "Going up to an exhaustion of .02 millionth of an atmosphere, the highest point to which I have carried the measurements, although by no means the highest exhaustion of which the pump is capable."

† *Journ. of Arts and Science*, 1881, vol. xxii., p. 90.

would be some 200 million million times the quantity in a cubic foot of the æther —such is the exceeding levity of the æther.

Admitting that the æther is subject to attraction according to the Newtonian law, and of compression according to the law of Mariotte, we propose to find *the relation between the density of the æther at the surface of an attracting sphere and that at any other point in space*, providing that the sphere be cold and the only attracting body, and the gas considered the only one involved.

Let δ_0, e_0, w_0 be respectively the density, elasticity and weight of a unit of the medium, whether æther, air, or any other gas at the surface of the sphere; δ, e, w, the corresponding quantities at a distance z from the surface of the sphere; r the radius of the sphere, g_0 the acceleration due to gravity at its surface, and g that at distance $r+z$ from the center of the sphere. Then

$$\frac{\delta}{\delta_0}=\frac{e}{e_0}=\frac{w}{g}\div\frac{w_0}{g_0}$$

and

$$g=g_0\frac{r^2}{(r+z)^2};$$

$$\therefore\ e=\frac{e_0}{w_0}\cdot\frac{g_0}{g}w=\frac{e_0}{w_0}\frac{(r+z)^2}{r^2}w. \quad . \quad (12)$$

But

$$de=-wdz=-g\delta dz \quad . \quad . \quad (13)$$

$$\therefore\ \frac{de}{e}=-\frac{g_0\delta_0}{e_0}.\frac{r^2}{(r+z)^2}dz.$$

Integrating between e and e_0, z and o we have

$$e=e_0\varepsilon^{-\frac{g_0\delta_0}{e_0}.\frac{rz}{r+z}}, \quad . \quad . \quad (14)$$

$$\delta=\delta_0\varepsilon^{-\frac{g_0\delta_0}{e_0}.\frac{rz}{r+z}}. \quad . \quad . \quad . \quad (15)$$

Neglecting the attraction of the earth for the æther, and considering the sun as the only attracting body, we have g_0 at the sun 28.6 × 32.2, and at the earth, $z=210r$, $r=441{,}000$ miles, the sun's radius; $\delta=\frac{2}{35}\times10^{-24}$, equation (9), and $e=\frac{4}{33}\times10^{-6}$; and these, in (14) and (15), give

$$e=e_0\varepsilon^{\frac{28.6\times32.2\times2\times33\times10^6}{4\times35\times10^{24}}\times\frac{210}{211}\times\times441,000\times5280}$$

$$=e_0\varepsilon^{\frac{1}{1,000,000}}\text{ nearly,} \quad . \quad . \quad (16)$$

and

$$\delta=\delta_0\varepsilon^{\frac{1}{1,000,000}}\text{ nearly,} \quad . \quad . \quad (16')$$

for the tension and density of the æther at the surface of the sun under the conditions imposed. But the millionth root of ε is practically unity; hence the elasticity and density at the sun is practically the same as at the earth.

Now, starting at the sun with this result, and finding the density at a distance z from it, then making z infinite, we shall get about the 995,000 root of ε, the value of which is also sensibly equal to unity; hence the density at infinity would be sensibly the same as at the surface of the sun, the difference in the densities at the sun and at infinity being less than $\frac{1}{1000000}$ part of that at the sun. In order to make the density vary sensibly with the distance, the attraction of the central body must be something like a million times as great as that of the sun, or have a diameter a million times as large; but there being no such known body, therefore *the density and tension of the æther may be considered uniform throughout space.* Such has been our conception of it, and it is an agreeable surprise to find it so fully confirmed by analysis.

If the density were uniform, the weight of a given volume of it would vary as the force of gravity. At the surface of the sun a cubic foot would weigh [equation (10) multiplied by 28.6, or] 57×10^{-24}; hence, for a height h it would weigh

$$\frac{57}{10^{24}}\int_0^h \frac{r^2}{(r+z)^2}dz = \frac{57}{10^{24}}\cdot\frac{rh}{r+h}. \qquad (17)$$

which for $h = \infty$ becomes $\frac{13}{10^{14}}$ of a pound, which is the pressure upon a square foot of the sun of a column of infinite height under the conditions imposed. This would compress the first foot of the column about $\frac{1}{1000000}$ of its length, and would cause a corresponding increase in the density, the value of which, after this compression, will be found by multiplying the value given in equation (9) by $\frac{999999}{1000000}$, which will leave the result sensibly the same as before. Hence, from this standpoint, we again conclude that the density of the æther may be considered as sensibly uniform throughout space, providing its temperature be essentially uniform.

If we assume that the law of the resistance by which the æther opposes the motion of a body varies as the square of the velocity of the body, we are still unable to assign the coefficient which will give the numerical value; but it is safe to assume that the entire mass of the æther occupying the path of a body moving through it, will not have a velocity imparted to it exceeding that of the body; but, to be on the safe side, we will assume that it imparts a velocity equal to itself. The energy thus imparted will be lost to the body. To simplify the case, consider a planet moving in a circular orbit: r the radius of the planet, d its distance from the sun, D its specific gravity compared with water as unity, v_1 the velocity in its orbit; then the mass of æther occupying the place of the planet during one revolution about the sun will be, using equation (9),

$$\frac{2}{35\times10^{24}}\pi r^2\times 2\pi d,$$

which, multiplied by $\frac{1}{2}v_1^2$, will give the energy imparted to it. The kinetic energy of a planet, neglecting its rotation, will be

$$\frac{4}{3}\pi r^3\times 62\tfrac{1}{2}\mathrm{D}\times\frac{v_1^2}{2g}.$$

Dividing the former, after multiplying it by $\frac{1}{2}v_1^2$, by the latter, gives

$$\frac{1}{7\times10^{24}}\cdot\frac{d}{r\mathrm{D}} \quad . \; . \; . \; . \; . \quad (18)$$

for the fraction of the energy lost during one revolution about the sun. Applying this to the earth, we have

$$d\div r\mathrm{D}=93{,}000{,}000\div 3{,}912\times 5\tfrac{1}{2}=43{,}000;$$

and (18) becomes

$$\frac{6}{10^{22}} \text{ nearly, } \quad . \quad . \quad (19)$$

for the fraction of the energy lost in one year; and hence *at this rate* would require more than 1,666,000 trillion (1,666,000,000,000,000,000,000) years to bring it to rest.

Equation (18) is not applicable to the resistance offered to a comet, on account of the elongated orbit of the latter; but some idea of the effect of the resistance of the æther to the movement of a comet may be found by considering what it would be if the orbit were circular, having for its radius the perihelion distance. According to Professor Morrison, the perihelion distance of the great comet (6), 1882,* was 716,200 miles, its aphelion distance will be 5,000,000,000 miles, the diameter of its nucleus shortly before disappearing on the solar disk was 7,600 miles, the velocity at perihelion

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* "Monthly Notices of the Royal Astronomical Society," vol. xliv. 2, p. 54.

295 miles per second, and at aphelion 75 feet per second. But little is known in regard to the density of comets; but, to be on the safe side we will assume it as $\frac{1}{1000}$ that of water. This data will reduce (18) to 13×10^{-18} for the fraction of energy lost during one of its revolutions about the sun; and as it would make a revolution in, say, 20 hours, it would lose in one of our years about 57×10^{-16} of its energy, *at which rate* it would go on for 170 trillions of years. Similarly, at its aphelion its *rate* of loss would be less than $\frac{1}{6}\times10^{-15}$ of its energy in more than 2,000 years—the time of one revolution in its orbit.

The most careful observations and calculations have failed to detect any effect due to the resistance of matter in space; and the above analysis shows that, within historic times, it has in any case scarcely amounted to an infinitesimal, certainly not sufficient to be measured. And when we consider that our assumptions have been very largely on the unfavorable side, and, further, that the energy imparted to the æther may partly, at least, be restored to the body, we assume that its resistance never can be measured. Laplace, when he found that the force of gravitation, if propagated by an elastic medium, must have a velocity exceeding 100 million times that of light, concluded that astronomers might continue to consider its action as instantaneous (*Mécanique Céleste*, B. x., ch. viii., p. 22, 9,035); so may we, with nearly as much confidence, continue to consider the resistance of the æther as *nil.*

Equation (6) gives

$$c\tau = \frac{6.6(186{,}300 \times 5{,}280)^2}{2 \times 32.2 \times 1.4 \times 772} = 92 \times 10^{12} \quad (20)$$

from which the specific heat of the æther may be found if its temperature were known. M. Fourier, the first to assign a value to *the temperature of space,* assumed it to be somewhat inferior to the temperature at the poles of the earth or about 50° C. to 60° C. below zero.*

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* *Ann. der Chemie*, tome xvii, p. 155.

M. Pouillet, considering the atmosphere as a diathermanous medium, capable of absorbing in different degrees the radiant heat from the sun and the dark heat from the earth, deduced for the heat of space—or, as he and Fourier called it, the stellar heat—approximately—142°C.* (−287° F.), which is about 174° F. above absolute zero. It is well known that Pouillet's data were imperfect, several important elements being neglected, notably that of the humidity of the air; still, it is not only the first, but, so far as we know, the only attempt to formulate this relation. It served to show what has since been indicated by more direct experiments, that the tem-

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* *Comptes Rendus*, 1838, vol. 7, p. 61. Pouillet's formula is

$$a^{t'} = 1.235\frac{2-b}{2-b'} - 0.489,$$

in which b' = the absorptive power by the atmosphere, of the sun's heat,
b = the absorptive power of terrestrial heat,
t' = the temperature of the stellar heat,
$a = 1.0077$.

If $b=1$, its maximum, $b'=0.2$, we find $t'=-235°$ C. (−391° F.), or 71° F. above absolute zero.

perature of space is very low. The delicate experiments of Professor Langley, before referred to, show a great difference in the degree of absorption by our atmosphere of different wave-lengths. The mean of the values for nine different wave-lengths, treated by M. Pouillet's formula, gives 139° F. above absolute zero, and the smallest value of absorption, which was for the infra-red, gives only 71° F. above absolute zero for the heat of space.

The heat of space may be considered as composed of three parts: (1) stellar heat, (2) the heat contained in the dark matter of space, (3) the essential heat of the æther.

1. By the stellar heat we mean the heat received directly from the stars. It is a matter of easy calculation that, if the 50,000,000 of stars supposed to be visible with the most powerful telescopes were all at the distance of the nearest fixed star (*a* Centauri), or 221,000 astronomical units from the earth, and if each radiated the same amount of heat

as our sun, the intensity varying as the inverse squares of the distances, the earth would receive from them all less than $\frac{1}{1000}$ as much heat as it now receives from the sun. And when we consider that only a very few stars are within measurable distances, and that the remote ones may be, when compared with these, well-nigh infinitely distant, it is evident that the amount of heat received from the stars is insignificant, and may be discarded at the earth.

2. It is certain that there is a large amount of dark matter in space, since the meteoric dust and meteorites must come from beyond our atmosphere. The zodiacal light is supposed to be an evidence of meteoric matter between the earth and sun. The tails of comets are visible by some action of light upon some kind of matter. Matter in space not exposed to the rays of the sun will be at about the same temperature as the æther; but if in the rays of the sun and destitute of an atmosphere at the distance of the earth from the sun, its tem-

perature would be very low. If present laws can be extended so far, and the earth were without an atmosphere, and the heat received were not conducted away, it has been computed that the mean temperature at the equator would be about —70° C. (—94° F.); and at the poles—221° C.,* or 114° F. above absolute zero. The last result is obtained on the supposition that the poles receive heat directly from the sun a part of the year; it is further shown that if the poles were never exposed to the rays of the sun, the temperature would fall to that of the æther of space. But the data is not uniform, and there is too large an extension of empirical formulae to satisfy one that the above numerical results are reliable; still they point more and more strongly to a temperature not many degrees above absolute zero.

3. By the essential heat of the æther we mean the temperature which would be indicated by a thermometer graduated

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* "Professional Papers of the Signal Service U. S. A.," Washington, D. C., 1884, No. xii., p. 54.

from absolute zero in a room located in space beyond our atmosphere, whose walls were impervious to the passage of external heat. It is the heat due to the self agitated æther, just as air has a temperature when not exposed to the rays of the sun. If the æther be perfectly diathermanous to the sun's rays, it will receive no heat, on account of the heat of the sun flowing through it, though it may be heated from other sources. As direct evidence of an extremely low temperature of space, we cite the facts in regard to the meteorite which fell at Dharmsalla, India, July 14, 1860.* "The most remarkable thing about it was, while the mass had been inflamed and melted at the surface, the fragments gathered immediately after the fall and held for an instant were *so cold that the fingers were chilled.* This extraordinary assertion, which is contained in the report with no expression of doubt, indicates that the mass of the meteorite retained in its interior the intense cold of the interplanetary space,

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* *Comptes Rendus*, 1861, tome liii., p. 1018.

while the surface was ignited in passing through the terrestrial atmosphere." Since this body had been exposed to the rays of the sun, its temperature must have exceeded that of the space through which it passed, as well as been warmed by the heat developed at its surface, from which it may be inferred that it had been *intensely* cold. Direct investigations, given above, indicate that this temperature is less than 200° F. above absolute zero; and we cannot assert that it is not less than 100° F. above, or even much less.

But, however low be the temperature of the æther, it cannot be absolutely cold, or, in other words, it must have a temperature above absolute zero, for otherwise it would be destitute of elasticity, and hence incapable of transmitting a wave. This is shown by eliminating V between equations (2) and (6), giving

$$c\tau = \frac{\mu}{2g\delta J}e,^{*} \quad . \quad . \quad . \quad (21)$$

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[*] We note that this equation shows that the specific heat for different gases under the same tension, *e*, and

in which if $\tau=0$, e will be zero, all the other factors being finite, and if $e=0$, then $V=0$ in (2). Indeed, this principle is so well recognized in physics, that a proof in this place seems superfluous. Being unable, in the present state of our knowledge, to do more than assign the probable superior limit of the temperature, we will, for the purposes of this analysis, assume $\tau=20°$ F., absolute, being confident that the actual value is between $\frac{1}{10}$ of and 10 times this value. This value in equation (20) gives

$$c=46\times10^{11}=4{,}600{,}000{,}000{,}000 \qquad (22)$$

for the specific heat of the æther, that of water being unity. This number so vastly—we might say infinitely—exceeds that for any known gas, as to justify one, at first thought, in looking with suspicion upon the applicability of the above analysis to this medium. Assumptions in re-

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temperature, τ, varies inversely as the density; and for the same temperature and density the specific heats c will be directly as the tension e. The more perfect gases, as hydrogen, oxygen, and air, conform nearly to this law.

gard to the absolute temperature will scarcely improve the appearance of this number. If it be assumed that the absolute temperature be only one degree, the number in equation (22) would be only twenty times as large; and if the absolute temperature be assumed at 1,000,000° F., the resulting specific heat would still be more than a million times as large as for hydrogen. A few considerations of other properties of the æther may aid one in being reconciled to this paradoxical result. Is the result any more incredible than the fact, everywhere admitted, that every particle of the æther, in transmitting a wave of light, continually makes 590,000,000,000,000 (6×10^{14} nearly) complete cycles of movements every second, for a wave-length of $\frac{1}{50000}$ of an inch? The number of such complete movements in air for the fundamental *c* is only 264; and hence the ratio of the former to the latter of these numbers is nearly 2×10^{12}. The ratio of the specific heat given in (22) to that of hydrogen is nearly $1\frac{1}{3} \times 10^{12}$, which is not so different from that just given for the ratio of cyclical movements in a second of the æther and air. The velocity of sound in air at 493° F. above absolute zero is about 1,090 feet per second; but if the temperature could be reduced to 20° F., absolute, the law being extended so far, the velocity would be only

$$V=109\sqrt{\frac{20}{493}}=217 \text{ feet};$$

but the velocity of light is 982,000,000 feet per second, a number about $4\frac{1}{2}$ million times the former, and near a million of times that of the velocity in air under ordinary conditions. The ratio of the mass of air in a cubic foot at sea-level to that of a cubic foot of the æther as computed, far exceeds any of these ratios. The fact is, the known qualities of the æther in transmitting light and heat so far transcend those of any known terrestrial substance, that we might anticipate the fact that, in regard to magnitude, all its properties will be extremely exceptional when compared with such substances. We must accept substantially the number in equation (22), or subject this medium to different laws than those of gases.

We may deduce this result by another process; thus, since the specific heats of different gases are as the squares of the wave-velocities in the respective substances, the other elements being the same, if the specific heat of air be 0.23, we should have for the specific heat of the æther

$$c=0.23\left(\frac{186300\times 5280}{217}\right)^2=46\times 10^{11},$$

as before. The correct value of the specific heat of air, 0.2375, would give over 47×10^{11}, and nearly 48×10^{11}; but these differences are quite immaterial in this connection, the object being to check the former result, and find chiefly qualitative values.

On the other hand, in order that common air might be able to transmit a wave of the known velocity of light, its specific heat being taken constantly at 0.23, its temperature would be, according to equation (20),

$$\tau = \frac{92 \times 10^{12}}{0.23} = 4 \times 10^{14} \text{ degrees F.}$$

(=400,000,000,000,000° F.).

If the sun were composed of a substance having such specific heat, it could radiate heat at its present rate for more than a hundred millions of centuries without its temperature being reduced 1° F., exclusive of any supply from external sources, or from a contraction of its volume. We know only such substances in the sun as we are able to experiment with in the laboratory; and if there be an exceptional substance in it, we have no means at present of determining its physical properties. It is, moreover, a question whether the æther constitutes an essential part of bodies. We conceive of it only as the great agent for transmitting light and heat throughout the universe.

On account of the enormous value of the specific heat, it will require an inconceivably large amount of heat (mechanically measured) to increase the temperature of one pound of it perceptibly. Thus, if heat from the sun, by passing through a pound of water at the earth, would raise the temperature 100° F. and maintain it at, say, 600° F., absolute, it would, under similar conditions, raise the temperature of one pound of the æther, if its power of absorption be the same as that of water, $\frac{1}{46000000000}$ of a degree.

The distance of the earth from the sun being 210 times the radius of the latter, the amount of heat passing a square foot of spherical surface at the sun will be about 45,000 times the heat received on a square foot at the earth normally exposed to its rays, so that, under the conditions imposed, the temperature would not be a billionth of a degree F. higher at the sun than at the earth. This, then, is a condition favorable to a sensibly uniform temperature, even if heated by the sun's rays. *We* are now inclined to admit that the æther is not perfectly diathermanous to the sun's rays, but that its temperature, however small, may be due directly to the absorption of the heat of central suns; for we begin to realize the fact that the æther may possess many of the qualities of gases, such as a molecular constitution, and hence also mass, elasticity, specific heat, compressibility, and expansibility, although the magnitude of these properties is anomalous. We have already considered its compressibility at the surface of the sun, due to the weight of an infinite column, and found it to be exceedingly small; now, it may be possible that the expansion due to the excess of temperature of a small fraction of one degree at the surface of the sun over that at remote distances will diminish the density as much, or about as much, as pressure increased it, thereby making the density even more exactly uniform than it otherwise would be. According to what we know of refraction, it is impossible for a ray of light to be refracted in passing through the æther only—at least, not by a measurable amount; for not only are the density and elasticity practically uniform, but their ratio is, if possible, even more constant as shown by equations (16) and (16′). But the freedom of the æther molecules may be constrained, or their velocity impeded, by their entanglement with gross matter, such as the gases and transparent solids; in which case refraction may be produced in a ray passing obliquely through strata of varying densities. Neither is it believed that the æther does, or can, reflect light; for if it did, the entire sky would be more nearly luminous. The rays in free space move in right lines.

The masses of the molecules in different gases being inversely as their specific heats, and as the specific heat of hydrogen is 3 4, and the computed mass of one of its molecules $\frac{11}{18}\times 10^{-29}$[*] of a pound,

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[*] Stoney concludes that "it is therefore probable that there are not fewer than something like a unit eighteen (10^{18}) of molecules in a cubic millimeter of a gas at ordinary temperature and pressure" (*Phil. Mag.* 1868 [4] xxxvi. p. 141). According to the Kinetic theory the number of molecules in a given volume under the same pressure and temperature is the same for all gases. The weight of a cubic foot of hydrogen at the temperature of melting ice and under constant pressure being 0.005592 of a pound, and as a cubic foot equals 28,315,000 cubic millimeters, the probable mass of a molecule of hydrogen will be

we have for the computed mass of a molecule of the luminiferous æther,

$$m=\frac{11}{18\times10^{29}}\times\frac{3.4}{46\times10^{11}}=\frac{1}{22\times10^{40}}\text{lb.} \quad (23)$$

The mass of a cubic foot of the æther, equation (9), divided by the mass of a molecule, gives the number of molecules in a cubic foot, which will be

$$n=\frac{2}{35\times10^{24}}\times\frac{22\times10^{40}}{1}=\tfrac{44}{35}\times10^{16}, \quad (24)$$

which call 10^{16}. This number, though large, is greatly exceeded by the estimated number of molecules in a cubic foot

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$$\frac{0.005592}{32.2\times28{,}315{,}000\times10^{25}}=\frac{11}{18\times10^{29}}\text{ lb.}$$

Maxwell gives $\frac{46}{10^2}$ of a gramme$=\frac{3}{7\times10^{28}}$ lb., which is about 3/5 the value given above (*Phil. Mag.* 1873 [4] xlvi. p. 468).

The difference in these results arises chiefly from the calculated number of molecules in a cubic foot of gas under ordinary conditions. Thomson gives as the approximate probable number 17×10^{25}, which is about 3/5 the value given by Stoney. Thomson's value would make the mass of a molecule of æther about $\frac{1}{18}\times10^{-40}$ of a pound, which is not much different from that found above.

of air under standard conditions, which, according to Thomson, does not exceed 17×10^{25}, a number nearly 17,000,000,000 times as large as that in equation (24); and yet, at moderate heights, the number of molecules in a given volume of air will be less than that of the æther.

Assuming that air is compressed according to Boyle's law, and is subjected to the attraction of the earth, equation (15) will give the law of the decrease of the density. Taking the density of air at sea-level at $\frac{1}{400}$ of a pound per cubic foot, $e_0 = 14.7$ lbs. per square inch, $r = 20{,}687{,}000$ feet, equation (15) becomes

$$\delta \times \tfrac{1}{400} \times 10^{-345\frac{z}{r+z}}. \quad . \quad . \qquad (25)$$

If $z = \infty$, $\delta = \frac{1}{400} \times 10^{-345}$, which would be the limit of the density, and it is a novel coincidence that this limit is nearly identical with the value found for the density at the height of one radius of the earth according to the ordinary exponential law, wherein gravity is considered uniform.*

If the number of the molecules in a cubic foot follows the same law, then at the height z there will be

$$17\times 10^{-345\frac{z}{r+z}+25} \quad . \quad . \quad (26)$$

molecules per cubic foot. Similarly, the value of the length of the mean free path would be†

$$2\times 10^{345\frac{z}{r+z}-6}\text{ inches.} \quad . \quad (27)$$

By means of these values, the table which appears on the following page may be formed.

The numbers in the third column multiplied by $\frac{1}{400}$ will give the density (or mass per cubic foot) at the respective altitudes; and the same numbers multi-

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* The ordinary exponential law results from dropping $\frac{z}{r}$ compared with unity in equation (15), giving

$$\delta=\delta_0\varepsilon^{-\frac{z}{26221}}=\delta_0 10^{-\frac{z\text{ ft.}}{60387}}=\frac{1}{400}\times 10^{-\frac{z\text{ miles}}{11.44}},$$

in the last of which, if $z=3956$, the exponent becomes 345.

† *Phil. Mag.* 1873 [4] xlvi. p. 468.

Height.		Density or tension, that at the earth being unity.	Number of molecules in a cubic foot.	Length of the mean free path.
Fractional parts of earth's radius.	Approximate in miles.			
0	0	1	17×10^{25}	2×10^{-6} inch.
$\frac{1}{79}$	50	$10^{-4.3}$	$17 \times 10^{20.7}$	$2 \times 10^{-1.7}$ "
$\frac{1}{39}$	100	$10^{-8.4}$	$17 \times 10^{16.6}$	$2 \times 10^{2.4}$ "
$\frac{1}{20}$	200	$10^{-16.4}$	$17 \times 10^{8.6}$	792,000 miles.
$\frac{1}{14}$	282	10^{-23}	17×10^{2}	31×10^{11} "
$\frac{1}{10}$	395	10^{-31}	17×10^{-6}	31×10^{19} "
$\frac{1}{5}$	800	10^{-57}	17×10^{-32}	31×10^{45} "
1	3956	10^{-172}	17×10^{-147}	31×10^{160} "
2	7912	10^{-230}	17×10^{-205}	31×1^{218} "
∞	∞	10^{-345}	17×10^{-320}	31×10^{333} "

plied by 15 (or, more accurately, 14.7) will give the tension per square inch. According to this law, at an elevation of 300 miles the density of the atmosphere will be somewhat less than the density of the æther as given by equation (9).

To find the height at which the tension of the atmosphere, according to the above law will be the same as that of the æther, we have, by means of equations (11) and (25), substituting in the latter 2116 for $\frac{1}{400}$,

$$2116\times10^{-345\frac{z}{r+z}}=\frac{4}{10^8},$$

which solved gives

$$z=\frac{r}{31.24}=126.6 \text{ miles},$$

so that at the height of 127 miles the tension would be less than that of the æther, the temperature being uniform.

The mean free path, according to the above law, in which gravity varies as the inverse squares is less, and for great heights much less, than would be found according to the ordinary exponential law. Thus Crookes states that the mean free path of a molecule at the height of 200 miles is about 10,000,000 miles*; but according to the above law it becomes about 792,000 miles.

If a cubic inch of air at sea-level were carried to the height of $\frac{1}{7}$ the radius of the earth, and then allowed to expand freely, so as to become of the computed density of the atmosphere at that point, it would fill a space of $4 \times 10^{28.12}$ cubic miles, or a sphere whose radius is 2,398, 000,000 miles, which is nearly equal to the distance of the planet Neptune from the sun; and there would be less than one molecule to the mile. Such are some of the results of extending a law to extreme cases regardless of physical limitations or of the imperfection of the data on which it is founded. For instance, a uniform temperature is assumed, and, impliedly, an unlimited divisibility of the

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* "Phil. Trans. Roy. Soc" London, 1881, Part II. p. 389.

molecules. The latter is necessary in order to maintain a law of continuity. But modern investigations show that not only air, but all the gases, are composed of molecules of definite magnitudes whose dimensions can be approximately determined; and hence if there be only a few molecules in a cubic foot, and much less if there be but one molecule in a cubic mile, it cannot be claimed that the gas will be governed by the same laws as at the surface of the earth.

To find the Height of the Atmosphere.—The atmosphere will terminate at that height where the vertical repulsive force equals the weight of the particles in the topmost layer. As a first approximation, conceive that the molecules are arranged in horizontal layers and vertical columns in a prism whose base is one square foot, and whose height extends to the height of the atmosphere; the base of each column of molecules being one of the molecules in the base of the prism. Considering the number of molecules in a cubic foot of air at standard conditions as 17×10^{25}, and the weight of the same as .08 of a pound, we have for the weight of one molecule of air

$$=\frac{8}{17 \times 10^{27}}\text{*} \quad . \quad . \quad . \quad (28)$$

The number of molecules along one edge of the bottom layer will be $\sqrt[3]{17 \times 10^{25}}$ nearly; and the number in the bottom layer the square of this number or $170\frac{2}{3} \times 10^{16}$, which; according to the hypothesis, will be the number in the top layer; and this multiplied by the weight of one molecule will give e, the weight in the top layer; and equation (14) will give (the temperature of the column being considered uniform)

$$14.7 \times 144 \times 10^{-345\frac{z}{r+z}} = \frac{170\frac{2}{3} \times 10^{16} \times 8}{17 \times 10^{27}};$$

$$\therefore \quad z = \frac{r}{23.35} = 169 \text{ miles.} \quad . \quad (29)$$

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* This may be used as a unit for measuring the mass of a cubic foot of the æther. Thus, dividing the value in equation (10) by that in (28) gives 4250; or the mass of æther in a cubic foot is 4250 times the mass of one molecule of air.

But the temperature is far from being uniform. In regard to a definite mass of a gas, we have the well-known relation

$$\frac{e}{\delta\tau}=\frac{e_0}{\delta_0\tau_0}=\text{a constant}=\frac{pv}{\tau}, \qquad (29')$$

where $p=e=$ the pressure on the base of a prism, and $v=$ the volume.

The value of δ from this equation substituted in (13) gives

$$\frac{de}{e}=-g\frac{\delta_0}{e_0}\cdot\frac{\tau_0}{\tau}dz. \quad . \quad . \quad (30)$$

But with τ an unknown variable this cannot be integrated. If $\tau=\tau_0$ we at once have equation(14). The relation between τ and z is unknown, if indeed there be any algebraic relation between them. It is, however, known that, as a general fact, the temperature decreases with the elevation; although local causes and air-currents often cause this law to be re-reversed for moderate heights. The best that can be done, in this case, is to find an expression that will represent approximately, the mean values of the temperature. It is usually assumed that the average temperature at the earth is about 59° F. or 60 F., and that for latitudes of, say, 40° N. to 40° S. the perpetual frost-line is from 14,000 to 16,000 feet above sea-level; and observations indicate that the *rate* of decrease of temperature decreases with the height. The last fact is suggestive of an exponential law; hence assuming

$$\tau = \tau_0 \varepsilon^{-\frac{z}{a}}, \quad . \quad . \quad . \quad (31)$$

and making $\tau = 493°$ F., absolute, at the height $z = 15{,}840$ feet and $\tau_0 = 520°$ F., absolute, we find $a = 296{,}000$ (or 56 if z be in miles), and our equation becomes

$$\tau = 520 \varepsilon^{-\frac{z \text{ miles}}{56}}. \quad . \quad . \quad . \quad (32)$$

This gives

Height, miles.	τ absolute.	Fahr. scale.	Glaisher's observations.*
0	520° F.	59° F.	59° F.
1-5	518	57	..
2-5	515	54	..
3-5	513	52	..
4-5	512	51	..
1	510	49	41
2	501	40	32
3	493	32	18
4	484	23	8
5	475	14	— 2
6	467	6	..
7	458	— 3	—11.8
50	212	—249	..
75	136	—325	..
100	87	—374	..
120	65	—396	..
150	36	—425	..
224	9	—452	..

The temperatures given in twenty-five or more reports of balloon ascensions, not only give values the mean of which is fairly represented by the celebrated seven-mile ascent of Mr. Glaisher, but his figures, given in the fourth column of the table, represent a more uniform law than

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* "Travels in the Air," by James Glaisher, F. R. S., p. 50.

is common in such reports. Our computed values exceed his observed values at all points except at the surface of the earth, where they agree. In this ascent he reached the point of freezing at the height of two miles, which is lower than the average, as determined by many observations; and, therefore, it appears that equation (31) probably represents the general law better than this single set of observations. The effect, however, of the exponential law is scarcely perceptible within the limits of observation; for the exponent of ε is so small for elevations under seven miles, that it makes the law of decrease of temperature nearly uniform with equal increments of elevation. Thus, omitting fractions, the computed decrease for the first mile is 10°, and the average for seven miles is nearly 9°; but to assume a uniform decrease throughout the column limits its height independently of pressure or other conditions, for it could not extend beyond the point of absolute zero. There is no objection to applying such a law, provided it can be shown to be true—a condition which, at present, is not accepted.

Substituting τ from (31) in (30), and integrating between the limits of z and $z=0$, gives

$$e=e_0\,\varepsilon^{-\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}}-1\right)}\;; \quad . \quad . \quad (33)$$

which ultimately will equal the weight of the molecules in the top layer. Hence, substituting numbers, we have

$$2116=\frac{8\times 170^{\frac{2}{3}}\times 10^{16}}{17\times 10^{27}}\;\varepsilon^{\frac{296000\times .08}{2116}\left(\varepsilon^{\frac{z}{56}}-1\right)};$$

which gives

$$e=86 \text{ miles.} \quad . \quad . \quad . \quad (34)$$

It is evident that the hypothetical column of uniform temperature will be very much shortened by the very low temperature of the higher regions; but there are other conditions which will modify the preceding analysis. The assumptions in regard to layers and columns would not be realized even under statical conditions, and much less for the conditions in nature. Statically, the molecules would arrange themselves more like shot in a pile, each being over the space between the molecules in the layer below, instead of being directly over a molecule. This arrangement would give a less number in the horizontal layers than assumed above. But the hypothesis of constancy in the number of molecules in the layers is open to greater objections. For the distance between them will increase with the elevation on account of the diminution of the pressure of that part of the column above the point considered, and the elastic force will be correspondingly diminished; while, horizontally, in the plane of a layer of the molecules, the elastic force would remain constant. In other words, in the medium arranged as assumed the tension would not be the same in all directions, and hence would be in unstable equilibrium.

As a refinement, we notice that in every heavy fluid the downward pressure at every point exceeds the upward by the weight of a molecule.

Considering, now, that the molecules in the hypothetical layers are distributed uniformly throughout the spaces immediately beneath them, the number in the new top layer will be less than in the former case, and the column will rise to a greater height, and hence will exceed 86 miles; and, in turn, the new column would need another correction, and so on. Assuming that the number in the top layer is 10^{10}, and that the vertical component of the elastic forces follows the law of equation (33), we find

$$z = 95 \text{ miles};$$

and if the number in the top layer be 10^4, we find $z=104$ miles, and for *one* molecule, $z=110$ miles. In a similar manner it would be legitimate to assume that the column was capped by a fraction of a molecule, for that would be equivalent to one molecule at the top of a column having a base of several square feet. We are unable to determine where this process would end in nature; and hence this analysis fails to fix definitely the extreme height of the atmosphere, even for statical conditions.

Assuming that the distance between the contiguous molecules would be inversely as the third root of the densities of the medium, as they would be with sufficient accuracy where the number of molecules in a cubic foot is immense, we have, after substituting e, equation (33), and r, equation (31), in (29′),

$$\frac{\delta}{\delta_0} = \varepsilon^{\left(\frac{z}{a} - \frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}} - 1\right)\right)} = \frac{d_0^3}{d^3},$$

where d_0 is the distance between contiguous molecules at sea-level and d the corresponding distance at the height z. Hence

$$d = d_0 \left(\varepsilon^{\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}} - 1\right) - \frac{z}{a}}\right)^{\frac{1}{3}} \quad . \quad . \quad (35)$$

If $d_0 = \frac{18}{\sqrt[8]{170 \times 10^8}}$, $\frac{ag\delta_0}{e_0} = 11.19$; we have

for $z = 86$ miles, $d = \frac{1}{95}$ of an inch,
" $z = 95$ " $d = 4.5$ inches,
" $z = 104$ " $d = 11.4$ "

These values of *d* are greatly in excess of the distances between contiguous molecules in the horizontal layers, according to assumed conditions. Thus, at the height of 104 miles, it was *assumed* that there were 10^2 molecules on the side of a square foot, in which case the distance between contiguous molecules would be about $\frac{1}{8}$ of an inch instead of 11 inches as above. These results ought not to agree exactly, for one analysis assumes that the atmosphere terminates with each assumed number of molecules, while the other assumes that the law is continuous to any height. It is apparent that the laws represented by equations (33) and (35) both become practically discontinuous at a height at or less than 95 miles. For the sake of giving definiteness to the following remarks, we will assume that the mean height for statical conditions is 95 miles. But the conditions in nature are not statical. The changes in temperature in the column will be continually increasing or decreasing its height: the air-currents also operate to change it, first by increasing or decreasing the temperature from the mean at considerable heights, and, secondly, by operating dynamically to push the top of the column upward; the aerial tides may operate to raise the column still higher, and the molecules themselves are supposed to be flying with great rapidity in all directions. An increase of temperature of one-tenth the mean value, which, at the earth's surface would be about 49° F., would elongate the column about ten miles, and a corresponding decrease would shorten it about the same amount, making it 105 miles in the former case and 85 miles in the latter. The effect of air-currents and aerial tides cannot be so definitely calculated; but it is safe to assume that they may produce a much greater increase of height above the mean than they will depression below the mean ; just as in a highly agitated sea, the depressions below the mean surface-level may be small compared with the height above the same level to which the spray from the top of a wave may be thrown. It seems possible, therefore, that when the temperature, air-currents, and aerial tides conspire to depress the column, the extreme height of the atmosphere may be reduced to less than 85 miles ; and when they conspire to elevate it, it may possibly rise to a height exceeding 120 miles.

If it be certain, as is assumed, that meteors are rendered incandescent by atmospheric friction, and the extreme height at which they are visible could be determined by direct observation, it would fix a height less than the extreme height of the atmosphere, independent of other physical considerations; but the movement of these bodies is so extremely rapid that it is impossible to determine their height with astronomical precision. Still, computations by Professor Herschel give a height of about 118 miles,* and Professor Newcomb estimates it to be about 100 miles.† It is possible that a meteor would sometimes become inflamed by penetrating the atmosphere only a few miles, for although the atmosphere in the upper regions is extremely rare, yet the actual number of molecules in a cubic foot is large. Thus, according to our analysis, for statical conditions, the topmost cubic foot of the 104-mile column would contain about 1,000,000 molecules; and at the height of 95 miles it would contain about 1,000,000,000,000,000 molecules; so that if the relative velocities of the meteor and air be 20 miles per sec-

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* Professor A. S. Herschel gives the height of 20 meteors varying from 40 to 118 miles.—*Nature*, vol. iv. p. 504.

† Newcomb says: "The lightning-like rapidity with which the meteors darted through their course rendered it impossible to observe them with astronomical precision; but the general result was that they were first seen at an average height of 75 miles and disappeared at a height of 55 miles. There was no positive evidence that any meteor commenced at a height greater than 100 miles. These phenomena seem to indicate that our atmosphere really extends to a height of 100 and 110 miles."—"Popular Astronomy," 1878, p. 389.

ond, the meteor would encounter an *enormous* number in the twentieth or even the hundredth part of a second, after first entering the atmosphere.

The height of the auroral arch—supposed to be within our atmosphere—has been computed to be from 33 to 1,000 miles (see article *Aurora*, "Encyclopœdia Britannica"). But it has been shown by experiment, that a vacuum may be produced through which an electrical discharge cannot be passed, and yet the atmosphere at the height of 150 miles under the most favorable condition, that of uniform temperature, is vastly more rare than the most perfect vacuum ever produced by the most perfect Sprengel pump; and at the height of 200 miles under the same conditions the vacuum would be some 10,000,000 times as great as the most perfect vacuum yet made; while, according to the probable law of the decrease of temperature with the elevation, and in accordance with the probable mass of a molecule of air, the extreme height falls far short of 150 miles. It is evident, therefore, that the assumed determination of the height of the atmosphere by means of the auroral arch is, to say the least, unreliable.*

We have pursued this digression in regard to the atmosphere partly for its own sake and partly to show, by way of contrast and accumulative evidence, that the æther is a substance entirely distinct from that of the atmosphere,—that the former cannot be considered as the latter greatly rarefied, as some have supposed. Admitting the validity of the preceding discussion, some of the distinctive properties are:

1. The different modes of the movements of the molecules in the two substances in the propagation of a wave; in one the motion being a to-and-fro movement and in the other a transverse movemovement. These are distinctions recognized by the best writers upon the subject, and are especially noticed by

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* Some writers incline to the view that the aurora is due to a cosmic rather than a terrestrial origin. —*Science*, 1885, p. 395.

Maxwell in an article on *Ether* in the "Encyclopœdia Britannica."

2. It is impossible for a wave to be transmitted in air with the known velocity of light, unless its temperature be increased millions of millions of degrees Fahrenheit above the standard temperature; but such a wave is transmitted in the æther although its temperature is far less than has ever been produced by artificial means.

3. The ratio of the elasticity to the density in the æther is exceedingly large compared with the same ratio in air. The temperature of air being taken at 60° F., and the æther at 20° F., absolute, the ratio is, with sufficient accuracy,

$$\left(\frac{980{,}000{,}000}{1{,}090}\right)^2 = 8\times10^{11}.$$

4. The specific heat of the æther is, at least, many million times that of air, or of any other known gas.

5. The atmosphere is of variable density, elasticity, and temperature, while the æther is well-nigh isometric throughout

space in regard to each of these elements.

6. A molecule of æther is well-nigh infinitesimal compared with one of air.

7. Air is attracted to a planet with such a relative force, that its extreme height is only a few miles.

8. The ratio of the density to the elasticity of the æther is constant; but in the atmosphere, on account of the decrease of temperature with the elevation, the density decreases less rapidly than the elasticity, as may be seen by comparing the first part of equation (35) with equation (33), we have

$$\frac{\delta}{\delta_0}=\varepsilon^{\frac{z}{a}}\cdot\frac{e}{e_0}.$$

On this account a wave would be propagated with less velocity in the higher regions of the atmosphere than in the lower, while a wave in the æther has a sensibly uniform velocity throughout space.

The question may arise, May not the resistance of the æther drag away the remote molecules of the atmosphere, and so scatter them in space along the path of the earth's orbit? Assuming that the atmosphere is moving with the earth through space at the rate of 20 miles per second (which exceeds the actual velocity), and that the resistance of the æther is measured in the same manner as for fluids, we have for the resistance

$$R = kwa\frac{v^2}{2g},$$

where v is the velocity of a molecule of air a its meridian section, w the weight of a unit of volume of the æther, and k a coefficient depending upon the form of the body. Making $k=1$, which is greater than its actual value, and $a=\frac{1}{10^{17}}$ feet, which, again, is in excess of the true area, w the value in equation (10), we find that

$$R = \frac{2}{10^{24}} \times \frac{1}{10^{17}} \times (20 \times 5{,}280)^2.$$

$$\frac{1}{64.4} = \frac{1}{10^{33}} \text{ of a pound nearly.}$$

The attractive force of the earth for a molecule of air is given in equation (28), and hence the attraction of the earth for a molecule of air will exceed 500,000 times the resistance of the æther; hence the molecules of air accompany the earth in its orbit as certainly as does the moon, and are more rigidly bound to it than is its satellite.

The kinetic energy of a molecule of air at standard conditions is about

$$\frac{1}{2}\cdot\frac{8}{32.2\times17\times10^{27}}1{,}600^2=\frac{2}{10^{23}}$$

foot-pound;

and of the æther, according to our results, about

$$\frac{1}{2}\cdot\frac{1}{22\times10^{40}}(273{,}000\times5{,}280)^2=\frac{1}{2\times10^{23}}$$

foot-pound;

which results are nearly the same; but in a pound of the æther there is some 100,000,000,000 times the kinetic energy of a pound of air.

Considering the terrestrial atmosphere

as equivalent to one of uniform density and $5\frac{1}{2}$ miles high, each of whose molecules has a mean square velocity of 1,600 feet per second, and the æther of uniform density, each of whose molecules has the mean square velocity of 286,000 miles per second, a rough approximation shows that the kinetic energy of the æther in a sphere whose radius is 92,000,000 miles (nearly the distance of the earth from the sun) will be only about 100,000 times that in our atmosphere.

The mean free path of a molecule of gas, as given by Loschmidt, is

$$l=\frac{\text{combined volume of the molecules}}{\text{volume of the gas}\times\frac{1}{8}\text{ the diameter of a molecule}},$$

and by Maxwell,

$$l=\frac{\mu}{\rho}.\frac{1}{v}=3\frac{\mu}{\rho}.\frac{z}{\gamma V};$$

(the last member of which we have added), in which ρ is the density of the gas, μ the coefficient of internal friction, and v the velocity whose square is the mean of the squares of the actual velocities of the molecules. In regard to the æther, these equations contain at least three unknown quantities, l, , and the diameter of a molecule, and hence they cannot be completely solved. Comparative results, however, may be found by assuming that the density of the molecules of æther equals those of hydrogen, or is any multiple thereof; for then the diameter of a molecule of the æther might be found (that of hydrogen being 5.6×10^{-10} of a meter); and the combined volume in a cubic foot will equal the number of molecules in a cubic foot multiplied by the volume of one molecule, and hence will be found the length of the mean free path and the coefficient of internal friction.

We conclude, then, that a medium whose density is such that a volume of it equal to about twenty volumes of the earth would weigh one pound, and whose tension is such that the pressure on a square mile would be about one pound, and whose specific heat is such that it would require as much heat to raise the temperature of one pound of it 1° F. as it would to raise about 2,300,000,000 tons of water the same amount, will satisfy the requirements of nature in being able to transmit a wave of light or heat 186,300 miles per second, and transmit 133 foot-pounds of heat-energy from the sun to the earth, each second per square foot of surface normally exposed, and also be everywhere practically non-resisting and sensibly uniform in temperature, density and elasticity. This medium we call the Luminiferous Æther.

ADDENDA.

Granting that the temperature of the æther, however low, is produced by the heat of central sun's passing through it, we may determine the effect upon it of a change of temperature of the source of heat.

The law for perfect gases is—continuing our notation—

$$ev = R\tau \qquad (36)$$

where R is $e_0 v_0 \div \tau_0$, these values being initial. Since v will necessarily be constant we see that e will vary as τ, where τ is the temperature of the æther, and equation (21) becomes

$$\delta = \frac{u}{2gJc} \cdot \frac{e}{\tau} = \text{constant},$$

as it should, since the mean density cannot change, the volume being constant. This equation reveals no new truth, but is consistent with the conditions which we anticipate in nature. The only way in which the density can change by a diminution of elasticity of the æther, is to cause it to be more dense near the attractive bodies, and more rare in space more remote from them; or, in other words, the æther would not be so nearly uniform as at present.

Assuming the density as uniform while the elasticity changes, it appears from equation (2) that the velocity of light through it will vary as the square root of the elasticity. Thus, if the heat of our sun diminishes so as to become one-fourth as intense as at present, and if the elasticity of the æther also becomes one-fourth as much as at present, then will the velocity of light be one-half as great as at present.

We may find the conditions which would cause a gas of the pressure of our atmosphere at sea level and of the same specific heat, to be as nearly uniform throughout space as is the æther. This will be found with sufficient accuracy for our purpose by finding such a value for δ as will make the numerator in equation (15), $\frac{1}{1{,}000{,}000}$, the same as given in (16), where $e_0=2116$ the tension of the air per square foot. We will find

$$\delta_0=\frac{1}{10^{15}}.$$

The volumes being inversely as the densities, the last result combined with equation (36) shows that the required rarity (or density) may be secured by a temperature 10^{15} times that of the present temperature. If the absolute temperature be 500° when the pressure of the air per square foot is 2,000 pounds, then if it be heated to something like

500,000,000,000,000° F.,

the tension would be nearly uniform throughout space. A volume of such air of the size of the earth would weigh less than $\frac{1}{60}$ of a pound at a place where $g=32.2$.

NEWTON *Closes His Principia as follows:*

"And now we might add something concerning a most subtle spirit which pervades and lies hid in all gross bodies; by the force and action of which spirit the particles of bodies mutually attract one another at near distances, and cohere if contiguous; and electric bodies operate to greater distances, as well repelling as attracting the neighboring corpuscles, and light is emitted, reflected, inflected, and heats bodies; and all sensation is excited, and the members of animal bodies move at the command of the will, namely, by the vibrations of this spirit, mutually propagated along the solid filaments of the nerves, from the outward organs of sense to the brain, and from the brain into the muscles. But these are things that cannot be explained in few words, nor are we furnished with that sufficiency of experiments which is required to an accurate determination and demonstration of the laws by which this electric and elastic spirit operates."

The following is a quotation from his "Optics":

"Is not heat conveyed through a vacuum by the vibrations of a much more subtle medium than air? Is not this medium the same by which light is refracted and reflected, and communicates heat to bodies, and is put into fits of easy reflexion and transmission? Do not hot bodies communicate their heat to cold ones by the vibrations of this medium? And is it not exceedingly more rare and subtle than air, and exceedingly more elastic and active? And does it not readily pervade all bodies? And is it not, by its elastic force, expanded through all the heavens?"

Extracts from the Celebrated Lecture of Clerk Maxwell *on Molecules.—Phil. Mag.*, 1873, *p.* 453.

"An atom is a body which cannot be cut in two. A molecule is the smallest possible portion of a particular substance. No one has ever seen or handled a single molecule. Molecular science, therefore, is one of those branches of study which deal with things invisible and imperceptible by our senses, and which cannot be subjected to direct experiment.

"The mind of man has perplexed itself with many hard questions. Is space infinite; and if so, in what sense? Is the material world infinite in extent, and are all places within that extent equally full of matter? Do atoms exist, or is matter infinitely divisible?

"The discussion of questions of this kind has been going on ever since man began to reason; and to each of us, as soon as we obtain the use of our faculties, the same old questions arise as fresh as ever. They form as essential a part of the science of the nineteenth century of our era as of that of the fifth century before it.

"We do not know much about the science organization of Thrace, twenty-two centuries ago, or of the machinery then employed for diffusing an interest in physical research. There were men, however, in those days who devoted their lives to the pursuit of knowledge with an ardor worthy of the most distinguished members of the British Association; and the lectures in which Democritus explained the atomic theory to his fellow-citizens of Abdera realized, not in golden opinions only, but in golden talents, a sum hardly equaled, even in America.

"To another very eminent philosopher, Anaxagoras, best known to the world as the teacher of Socrates, we are indebted for the most important service to the atomic theory, which after its statement by Democritus, remained to be done, Anaxagoras, in fact, stated a theory which so exactly contradicts the atomic theory of Democritus, that the truth or falsehood of the one theory implies the falsehood or truth of the other. The question of the existence or non-existence of atoms cannot be presented with greater clearness than in the alternative theories of these two philosophers.

"Take any portion of matter, say a drop of water, and observe its properties. Like every other portion of matter we have ever seen, it is divisible. Divide it in two, each portion appears to retain all the properties of the original drop, and among others that of being divisible. The parts are similar to the whole in every respect except in absolute size.

Now, go on repeating the process of division till the separate portions of water are so small that we can no longer perceive or handle them. Still we have no doubt that the subdivision might be carried further if our senses were more acute and our instruments more delicate. Thus far all are agreed; but now the question arises, can this subdivision be repeated for ever? According to Democritus and the atomic school, we must answer in the negative. After a certain number of subdivisions the drop would be divided into a number of parts, each of which is incapable of further subdivision. We should thus in imagination arrive at the atom, which, as its name literally signifies, cannot be cut in two. This is the atomic doctrine of Democritus, Epicurus and Lucretius. . . .

"According to Anaxagoras, on the other hand, the parts into which the drop is divided are in all respects similar to the whole drop, the mere size of a body counting for nothing as regards the nature of the substance. Hence, if the whole drop is divisible, so are its parts down to the minutest subdivisions and that without an end.

"The essence of the doctrine of Anaxagoras is that the parts of a body are in all respects similar to the whole. It was therefore called the doctrine of Hornoismeseia. Anaxagoras did not, of course, assert this of the parts of organized bodies such as men and animals; but he maintained that those inorganic substances which appear to us homogeneous are really so, and that the universal experience of mankind testifies that every material body without exception is divisible.

"The doctrine of atoms and that of homogeneity are thus in direct contradiction.

"But we must now go on to molecules. Molecule is a modern word. It does not occur in Johnson's Dictionary. The idea it embodies are those belonging to modern chemistry.

"A drop of water (to return to our former example) may be divided into a certain number, and no more, of portions similar to each other.

"Each of these the chemist calls a molecule of water. But it is by no means an atom, for it contains two different substances, oxygen and hydrogen; and by a certain process the molecule may be actually divided into two parts; one consisting of oxygen and the other of hydrogen. According to the received doctrine, in each molecule of water there are two molecules of hydrogen and one of oxygen. Whether these are not ultimate atoms I shall not attempt to decide.

"We now see what a molecule is, as distinguished from an atom.

"A molecule of a substance is a small body, such that if, on the one hand, a a number of similar molecules were assembled together, they would form a mass of that substance; while, on the other hand, if any portion of this molecule were removed, it would no longer be able, along with an assemblage of other molecules similarly treated, to make up a mass of the original substance. Every substance, simple or compound, has its own molecule. If this molecule be divided, its parts are molecules of a different substance or substances from that of which the whole is a molecule. An atom, if there is such a thing, must be a molecule of an elementary substance. Since, therefore, every molecule is not an atom, but every atom is a molecule, I shall use the word molecule as a more general term.

"We find that now, as in the days of the earliest physical speculations, all physical researches appear to converge towards the same point, and every inquirer, as he looks forward into the dim region towards which the path of discovery is leading him, sees, each according to his sight, the vision of the same quest.

"One may see the atom as a material point, invested and surrounded by potential forces. Another sees no garment of force, but only the bare and utter hardness of mere impenetrability.

"But though many a speculator, as he has seen the vision recede before him into the innermost sanctuary of the inconceivable little, has had to confess that the quest was not for him; and, though philosophers in every age have been exhorting each other to direct their minds to some more useful and attainable aim, each generation, from the earliest dawn of science to the present time, has contributed a due proportion of its ablest intellects to the quest of the ultimate atom. . . .

"The great resistance of liquids to compression makes it probable that their molecules must be about the same distance from each other as that at which two molecules of the same substance in the gaseous form act on each other during an encounter.

"This conjecture has been put to the test by Torenz Meyer, who has compared the densities of different liquids with the calculated relative densities of the molecules of their vapors, and has found a remarkable correspondence between them. . . .

"Now Loschmidt has deduced from the dynamical theory the following remárkable proportion: As the volume of a gas is to the combined volume of all the molecules contained in it, so is the mean path of a molecule to one-eighth of the diameter of a molecule.

"Assuming that the volume of the substance, when reduced to the liquid form, is not much greater than the combined volume of the molecules, we obtain from this proportion the diameter of a molecule. In this way Loschmidt, in 1865, made the first estimate of the diameter of a molecule. Independently of him and of each other, Mr. Stoney in 1868, and Sir W. Thomson in 1870, published results of a similar kind, those of Thomson being deduced not only in this way, but from considerations derived the thickness of soap bubbles and from the electric properties of metals. According to this table, which I have calculated from Loschmidt's data, the size of the molecules of hydrogen is such that about two millions of them in a row would occupy a millimeter, and a million million million millions of them would weigh between four and five grammes.

"In a cubic centimeter of any gas at standard pressure and temperature there are about nineteen million million million molecules. All these numbers of the third rank, I need not tell you, to be regarded as at present conjectural. In order to warrant us in putting any confidence in numbers obtained in this way, we should have to compare together a greater number of independent data than we have as yet obtained, and to show that they lead to consistent results. But in the heavens we discover by their light, and by their light alone, stars so distant from each other that no material thing can ever have passed from one to another; and yet this light, which is to us the sole evidence of the existence of these distant worlds, tells us also that each of them is built up of molecules of the same kinds as those we find on earth. A molecule of hydrogen, for example, whether of Sirius or in Arcturus, executes its vibrations in precisely the same time.

"Each molecule, therefore, throughout the universe bears impressed on it the stamp of a metric system as distinctly as does the meter of the archives at Paris, or the double royal cubic of the Temple of Karnac.

"No theory of evolution can be formed to account for the similarity of molecules; for evolution necessarily implies continuous change, and the molecule is incapable of growth or decay. of generation or destruction.

"None of the process of nature, since

the time when nature began, have produced the slightest difference in the properties of any molecule. We are therefore unable to ascribe either the existence of the molecules or the identity of their properties to the operation of any of the causes which we call natural.

"On the other hand, the exact equality of each molecule to all others of the same kind gives it, as Sir John Herschel has well said, the essential character of a manufactured article, and precludes the idea of its being eternal and self-existent.

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"Thus we have been led along a strictly scientific path, very near to the point at which science must stop. Not that science is debarred from studying the internal mechanism of a molecule which she cannot take to pieces, any more than from investigating an organism which she cannot put together. But in tracing back the history of matter, science is arrested when she assumes herself, on the one hand, that the molecule has been made, and on the other, that it has not been made by any of the processes we call natural.

"Science is incompetent to reason upon the creation of matter itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that, because matter cannot be eternal and self-existent, it must have been created.

"It is only when we contemplate, not matter in itself, but the form in which it actually exists, that our mind finds something on which it can lay hold.

"That matter, as such, should have certain fundamental properties—that it should exist in space and be capable of motion, that its motion should be persistent, and so on, are truths which may, for anything we know, be of the kind which metaphysicians call necessary. We may use our knowledge of such truths for purposes of deduction; but we have no data for speculating as to their origin.

"But that there should be exactly so much matter and no more in every molecule of hydrogen is a fact of a very different order.

"We have here a particular distribution of matter—a collocation—to use the expression of Dr. Chambers, of things, which we have no difficulty in imagining to have been arranged otherwise.

"The form and dimensions of the orbits of the planets, for instance, are not determined by any law of nature, but depend upon a particular collocation of matter. The same is the case with respect to the size of the earth, from which the standard of what is called the metrical system has been derived. But these astronomical and terrestrial magnitudes are far inferior in scientific importance to the the most fundamental of all standards which form the base of the molecular system. Natural causes, as we know, are at work which tend to modify, if they do not at length destroy, all the arrangements and dimensions of the earth and the whole solar system. But, though in course of ages catastrophes have occurred and may yet occur in the heavens, though ancient systems may be dissolved and new systems evolved out of their ruins, the molecules out of which these systems are built—the foundation stones of the material universe—remain unbroken and unworn. They continue this day as they were created—perfect in number and measure and weight; and from the ineffaceable characters impressed on them we may learn that those aspirations after accuracy in measurement, truth in statement, and justice of action, which we reckon among our noblest attributes as men, are ours because they are essential constituents of the image of Him who in the beginning created, not only the heaven and the earth, but the materials of which heaven and earth consist.

TABLE OF MOLECULAR DATA.

		Hydrogen.	Oxygen.	Carbonic Oxide.	Carbonic Acid.
Rank I.	Mass of molecule (hydrogen=1).	1	16	14	22
	Velocity, mean square (feet per second), at 0°C.	6100	1525	1630	1298
Rank II.	Mean path, tenth meters........	965	560	482	379
	Collisions in second (millions)...	17750	7646	9489	9720
Rank III.	Diameter, feet.................	$\frac{19}{10^{10}}$	$\frac{25}{10^{10}}$	$\frac{27}{10^{10}}$	$\frac{30}{10^{10}}$
	Mass, pounds...	$\frac{1}{10^{26}}$	$\frac{17}{10^{26}}$	$\frac{14}{10^{26}}$	$\frac{222}{10^{26}}$

CLERK MAXWELL *on the Dynamical Theory of Gases.—Phil. Mag.*, 1866, (2), *p.* 390.

"Gases in this theory are supposed to consist of molecules in motion, acting on one another with forces which are insensible, except at distances which are small in comparison with the average distance of the molecules. The path of each molecule is therefore sensibly rectilinear, except when two molecules come within a certain distance of each other, in which case the direction of motion is rapidly changed, and the path becomes again sensibly rectilinear as soon as the molecules have separated beyond the distance of mutual action.

"Each molecule is supposed to be a a small body, consisting in general of parts capable of being set into various kinds of motion relative to each other, such as rotation, oscillation, or vibration, the amount of energy existing in this form bearing a certain relation to that which exists in the form of the agitation of the molecules among each other.

"The mass of a molecule is different in different gases, but in the same gas all the molecules are equal.

"The pressure of the gas is on this theory due to the impact of the molecules on the sides of the vessel, and the temperature of the gas depends on the velocity of the molecules.

"The theory, as thus stated, is that which has been conceived with various degrees of clearness, by D. Bernoulli, Le Sage and Prevost, Herapath, Joule, and Krönig, and which owes its principal developments to Professor Clausius."

CLAUSIUS, by a neat application of the theory of probabilities, finds the mean length of the paths described by the separate molecules of gaseous bodies on the occurrence of molecular motions as follows:

Suppose, then, there is a space containing a great number of molecules, and that these are are not regularly arranged, the only condition being that the density is the same throughout, *i. e.* in equal parts of the space there are the same numbers of molecules. The determination of the density may be performed conveniently for our investigation by knowing how far apart two neighboring molecules would be separated from one another if the molecules were arranged cubically, that is, so arranged that the whole space might be supposed divided into a number of equal very small cubic spaces, in whose corners the centers of the molecules were situated. We shall denote this distance, that is, the side of one of these little cubes, by λ, and shall call it the mean distance of neighboring molecules.

If, now, a point moves through this space in a straight line, let us suppose the space to be divided into parallel layers perpendicular to the motion of the point, and let us determine how great is the probability that the point will pass freely through a layer of the thickness x, without encountering the sphere of action of a molecule.

Let us first take a layer of the thickness 1, and let us denote by the fraction of unity a the probability of the point passing through this layer without meeting with any sphere of action; then the corresponding probability for a thickness 2 is a^2; for if such a layer be supposed divided into two layers of the thickness 1, the probability of the points passing free through the first layer, and thereby arriving at the second, must be multiplied by the probability of its passing through the latter one. Similarly, for a layer of the thickness 3, we have a^3, &c., and for a layer of any thickness x we may accordingly write a^x. Let us transform this expression by putting ϵ^x for a, in which e is the base of the natural logarithms, and $-a = \log. \, \varepsilon \, a$, which logarithm must be negative, because a is less than 1. If now we denote the probability of the free passage through a layer of the thickness x by W, we have the equation

$$W = \varepsilon^{-ax} \quad . \quad . \quad (1)$$

and we have only to determine here the constant a.

"Again, let us consider a layer of such

thinness that the higher powers of the thickness may be neglected in comparison with the first. Calling this thickness δ, and the corresponding probability W_δ, the former equation becomes

$$W_\delta = e^{-\alpha\delta} = 1 - \alpha\delta\text{''} \quad . \quad . \quad (2)$$

Continuing this investigation, Clausius finally concludes that: "*the mean length of the path of a molecule is in the same proportion to the radius of the sphere of action as the entire space occupied by the gas, to that portion of the space which is actually filled up by the spheres of action of the molecules.*"—*Phil. Mag.* 1859 (1), *p.* 81.

Illustrations of the Dynamical Theory of Gases. By CLERK MAXWELL.—*Phil. Mag.*, 1860, *January and July.*

On the Dynamical Theory of Gases. By CLERK MAXWELL.—*Phil. Mag.*, 1868 (1), *pp.* 129, 185.

"It is to Professor Clausius, of Zurich, that we owe the most complete dynamical theory of gases," p. 132. The latter part of the article contains an abstruse mathematical investigation in regard to the motions of molecules.

Extract from the Physics of the Æther,

By S. TOLVER PRESTON.

" *The Impalpable Nature of the Æther.* —An intimate connection may be shown to exist between the normal speed of the particles of an æriform medium and the disturbance produced by the passage of masses of matter through the medium. By the movement of translation of a mass through an æriform medium, the resistance encountered depends (as previously treated of in connection with the vibrations of masses and molecules) on the amount of condensation of the medium produced in front, and of rarification produced in the rear of a moving mass, since this is one of the conditions upon which the amount of energy is imparted to the medium. If there were no condensation and no rarefaction of the medium produced by the passage of the mass, then the number of impinging particles which receive motion in front of the moving mass would equal those which lose motion in the rear; but on account of the existence of condensation and rarefaction, the number of particles which receive motion in front is greater than the number which lose motion in the rear, the excess in the number of particles which receive an increment of velocity for which there is no corresponding decrement being represented by the difference between the condensation and the rarefaction, this difference increasing with the velocity of translation of the mass.

"Further, by the passage of a mass through an æriform medium, there is a second physical condition by which energy is imparted to the medium. Although by the passage of the mass the impinging particles of the medium in front and rear experience equal increments and decrements of velocity, the mean value of the velocity therefore remaining unchanged; yet this, as previously referred to, is necessarily attended on the whole by an increase in the sum total of the energy of the particles; so that this forms the second physical cause of the resistance encountered by the passage of a mass through an æriform medium, and this would constitute a cause for a certain resistance, even if there were no condensation whatever of the medium formed in front of the moving mass.

"It is, of course, clear that if the density of the medium were extremely small, the resistance offered under the action of both these causes might be extremely small.

"It is now an important point to observe that the amount of condensation of the medium formed in front, and the amount of rarefaction in the rear, of the moving mass will depend on the normal speed of the component particles of the medium, for the speed with which the condensed wave is carried forward and dissipated depends directly on the speed with which an interchange of motion can take place between the particles, *i. e.* on the normal speed of the particles.

"The actual rate of transmission of the wave, though dependent on and proportional to the normal speed of the particles; will necessarily be to a certain extent slower than the normal speed of the particles, from the fact of the interchange of motion between the particles taking place so obliquely to the line transmission of the wave. In the case of air, for example, the speed of whose component molecules may be taken at 1,600 feet per second, the condensed wave of displacement due to the passage of a mass would be carried forward on a somewhat less speed than this, or at the velocity of a wave of sound. It is evident, therefore, that even if the air had as low a density as the æther, it would, on account of the slow normal speed of its molecules, be completely unfitted to afford passage to masses at planetary rates, for its equilibrium would be totally upset.

"In the case of the æther, on the other hand, the wave of displacement is carried forward at the speed of a wave of light, so that speeds of hundreds of miles per second are actually attained by cosmical masses, without disturbing the equilibrium of the æther, the wave being carried forward and dissipated so rapidly that there is no time for an appreciable condensation to accumulate in front of the moving mass. The motion of the æther particles is so rapid that equilibrium is almost immediately readjusted on the slightest disturbance, and there is not time for any disturbing effect to accumulate. The high normal speed of the particles of the æther is therefore one of the essential physical conditions to adapt this agent to afford free passage to cosmical masses (the planets, &c.) at high speeds, without disturbance of its equilibrium.

"Hence the general conclusion may be drawn that the higher the normal speed of the particles of an æriform medium, the less is the equilibrium of the medium disturbed by the passage of masses through it, or the more impalpable does the medium become. The higher, therefore, the normal speed of the particles of an æriform medium, the more does the presence of the medium elude detection, or the more impalpable the medium becomes, and the less probability is there for its existence to be detected by endeavoring, as it were, to probe it with masses, *i.e.*, to disturb its equilibrium by moving masses of matter through it. This deduction has its direct application in the case of the æther, the known impalpable nature of which is another physical indication of the high normal speed of the particles of this agent.

"*The Physical Qualities Essential to a Powerful Dynamic Agent.*—It might be cosidered at the first thought that, because the æther is so impalpable and its density is so low it would not be an agent suited to produce forcible mechanical effect, or it might be inferred, on the first consideration of the subject, that the thin, impalpable æther would not be suited to act forcibly upon the masses and molecules of matter and produce powerful dynamic effect, such as those exhibited in the case of explosives, &c. Now, this, like many other first impressions, will become totally altered after a due consideration of the subject. There is, unquestionably, a natural tendency to associate ideas of energy with large visible masses of matter in motion. This is not to be wondered at, since these forms of energy appeal directly to the senses, whereas, the movements of molecules or particles of matter do not. If misleading inferences are to be avoided, it is well that this natural tendency should be guarded against; for the motions of molecules and particles of matter might have an intensity of energy far surpassing that of any motions of visible masses; indeed, energy in this form might almost attain any value, however high, and yet would necessarily be wholly incapable of appearing directly to the senses. There is a certain tendency, for example, to ignore, or at least, not adequately to realize the high intensity of the concealed molecular motion which is termed "heat."

Thus, for instance, the energy of a passing shot is fully realized, and yet it may be shown that the energy of the molecular motion ("heat") possessed by the shot at normal temperature, and while at rest, represents about double of energy of the translatory motion of the shot at the distance of discharge. The normal rate of motion (1,600 feet per second) of the molecules of air is almost expositive to its energy; yet, from the fact that these moving molecules are too small to affect the senses directly, there is a natural tendency to overlook the existence of this energy.

The space occupied by the molecules being very small compared with the space unoccupied; if, therefore, we were to imagine the component molecules of a cubic foot of air suddenly to loose their motion, a practical vacuum would be found, and the sudden restoration of equilibrium would produce a dynamic effect resembling an explosion. The stoppage of the motion of the component particles of a cubic foot of æther would be followed by a dynamic effect, the high intensity of which could only be realized by an adequate appreciation of the energy enclosed by this agent.

"In turning to the consideration of the physical qualities essential to a powerful dynamic agent, we may first observe that the existence of a high velocity in the particles of the agent in their normal state is an indispensable condition, for unless this be the fact, an intense development of motion, or an intense dynamic effort could not be produced by the agent; in fact, unless the particles of the agent had a high velocity they would be incapable even of following up the motions in the masses of which they develop motion. Again, this high normal velocity of the particles is the sole condition on which the motion expended by the agent in the production of a forcible dynamic effect can be replenished with speed, and the loss of motion be subdivided or spread over an extensive volume of the agent, or over a large number of the particles of the agent in a short space of time. Secondly, minuteness in the moving particles being the necessary condition to render a high speed practicably to the particles, it follows, therefore, minuteness in the particles, or an extremely subdivided state of the matter forming the agent is a second essential condition to a powerful dynamic agent. It is important to note that this condition is necessarily followed by an absolute concealment of the existence of the motion from the senses, so that for an intense store of motion or energy to exist, the concealment of its existence is a necessary condition. Thirdly, a low density in the agent or the existence of but a small quantity of matter in the unit volume of space may be shown to be an essential condition of a powerful dynamic agent. This will be clear when it is considered that if space were encumbered with a quantity of matter, *i. e.* if the agent were dense, the agent would itself obstruct the very motions it develops, or, in other words, a high velocity could not be imparted without the motion of the moving masses being greatly interfered with and obstructed by the agent; so that, in fact, for the attainment of energy, the agent must rely upon speed rather than upon mass; it being also a noteworthy fact the energy rises as the square of the speed. Moreover, it is an important mechanical point to observe that by the absence of mass the energy becomes more concentrated, or by a reliance upon speed rather than upon mass, a greater quantity of energy admits of being concentrated upon a given spot, whereas the attainment of the same absolute amount of energy by means of large masses, and slow speed would render it impossible for the energy to be concentrated upon a small area (such as against a molecule of matter, for example), which concentration of energy is absolutely essential for the production of intense dynamic effect. The above considerations, therefore, lead to the general deduction that to constitute a powerful dynamic agent the essential physical conditions are: firstly, a high normal speed for the component particles of the agent; secondly, that the particles should be minute, or that the matter forming the agent should be in an extremely subdivided state; the thirdly, that the quantity of matter relatively to the unit volume of space should be small, or that the agent should possess a low density. This deduction has its direct practical application in the case of the æther, where we find precisely these physical quantities developed to an extreme degree.

This is the use of minute masses endued with a high velocity is the proper mechanical proceeding, when an intense dynamic effect is required, is illustrated in practice in many ways. Thus, when for any engineering purpose a powerful mechanical effect is required, recourse is had to gunpowder. The effect observed at the explosion of gunpowder is simply produced by the action of small masses of matter ("molecules"), indued with a high speed. If, therefore, gunpowder, by means of the motion transferred to its molecules by the æther, represent in the act of the explosion the true ideal of a powerful dynamic agent, how much more must this be the case with the æther itself?

Since, therefore, we observe that a high velocity of the component particles and a low density are the qualities essential to a powerful dynamic agent, and since this high velocity of the component particles is precisely the quality which necessarily renders the agent impalpable, it follows, therefore, that the known impalpable nature and low density of the æther, instead of indicating that this agent is unfitted to produce powerful dynamic effect, should then, justly viewed, lead directly to the opposite conclusion.

To illustrate somewhat further the connection which exists between the speed of the component particles of an æriform medium and its impalpability, we may imagine the case of a confined mass of air cooled down to such a degree that the translatory motion of the air would become quite palpable, or by a mere motion of a mass of matter through it, the air might be completely displaced, vacua formed in parts, and the density increased in other parts; indeed, the molecules of air, if almost without translatory motion, might be collected in groups. The air would, in fact, by the almost complete loss of the normal speed of its molecules, have lost its elasticity and the power of eluding the grasp, which the translatory motion of its molecules at normal temperature enable it to do.

It is important, therefore, to observe that the more palpable the mass of air becomes, the less is the store of energy enclosed, or the less would the air be qualified to produce a dynamiceffect; and to apply, therefore, this principle generally, the fact of a medium being palpable would indicate that it was totally unfitted as a dynamic agent, and conversely, the fact of a medium being impalpable, by which the distance of the medium eludes direct detection by the senses, would, by pointing clearly to the high normal speed of the particles of the medium, directly indicate that the medium was well qualified as a dynamic agent.

If we imagine, conversely, the confined mass of air to be heated so as to increase the translatory motion of its molecules, then the air would become more and more impalpable, it would elude the grasp, and it would be more difficult to disturb its equilibrium by moving masses of matter through it, and therefore the presence of the air would be more difficult to detect by this means. At the same time, it is well to know that the more impalpable the mass of air becomes (due to the increase of speed of its molecules), the more intense is the store of energy enclosed, the greater is the pressure exerted, and the more fitted does the air become as a dynamic agent.

"These considerations have their direct application in the case of the æther, the remarkable impalpability of which could not be better illustrated than by the fact that no ordinary rate of motion of masses of matter has been found capable of effecting the transmission of the waves of light by the particles of the æther; in fact, the density of this agent cannot be changed by ordinary means, the readjustment of equilibrium being so rapid, and the agent completely eludes the grasps, or its existence escapes the detection of the senses.

"It is, therefore, a remarkable and noteworthy fact that the very qualities which serve to conceal the existence of the energy and the existence of the pressure, and, indeed, existence of the agent itself for the direct perception of the senses, are precisely the qualities which are absolutely essential to the existence of this energy and pressure, or the existence of an intense magazine of motion. It may, in fact, be observed that the existence of an intense store of energy, and the existence of an intense pressure, are not only *consistent* with the fact that the æther is impalpable, but they are the *necessary* consequences of this fact, for the impalpable quality of an æriform medium is dependent on the rapid motion of its component particles, and this rapid motion cannot exist without the existence of an intense pressure, the pressure, moreover, rising in the high ratio of the *square* of the sheet.

"The existence of an extensive state of subdivision of the matter forming the agent being the essential condition to a high normal speed of the component particles of the agent, this very condition renders the concealment of the motion complete; for the very multiplicity of particles, the mean length of path, or the limits within which the particles can move before being intercepted by other particles, is rendered so small and the pressure thereby rendered uniform and perfectly balanced, that the extent of this energy and pressure must necessarily elude direct detection by the senses.

"The greatest length of path of an æther particle might well, under the simple condition of subdivision of the matter forming the æther, be continued many times within the limits of space that a molecule of matter would occupy, so that as far as any power of detecting the motion by the sense is concerned, the particles might as well be at rest.

"*Concealed Motion.*—Since the concealment of the existence of the physical agent for the senses is the necessary result of the enclosure of a store of motion of a high intensity by the agent, and since, as a fact, having a general application, the concealment of motion is the necessary condition to render possible a high intensity of motion, or the enclosure of a store of energy of a high intensity; and, moreover, since the higher the intensity of the energy the more probability is there that its existence should have an important influence on physical phenomena; the investigation of concealed motion, as a general physical problem, should, therefore, have a special interest.

"As a known and instructive example of concealed motion, which has a considerable intensity, and a most important bearing on physical phenomena, the concealed motion termed "heat" may be referred to.

"As a known illustration of a physical agent enclosing a considerable store of motion, and exerting thereby a considerable pressure, both of which elude the direct perception of the senses, the atmosphere may be cited. The normal speed of the air molecules producing the pressure of fifteen lbs. per square inch, being 1,600 feet per second, the energy enclosed, therefore, is such as if a mass of air next to the earth's surface were surely freed from confinement, the mass would explode in every direction, or its molecules would fly apart with the speed of the bullet. The air, therefore, constitutes an instructive example of concealed motion and may form, as it were, a sort of stepping-stone toward the realization of the æther. If the motion of the air molecules and the attendant pressure be concealed, how much more cause is there for the complete concealment of the existence of the store of motion and the attendant pressure in the case of the æther, the cause for concealment being greater as the moving particles are more minute, and by their multiplicity the motion is confined within narrower limits and the pressure more evenly balanced? In the case of the air, the moving portions of matter (molecules) are sufficiently small, or the state of subdivision of the matter forming the air is sufficiently extensive, to conceal the motion completely from the senses, and to render the pressure of the air upon masses of matter so perfectly balanced on all sides that the pressure is also necessarily concealed. It may serve to contrast the state of subdivision in the two cases to note the fact of the æther being mechanically suited to exert a uniform pressure about an air molecule (as about molecules generally), while the air can only exert a uniform pressure about a mass (collection of molecules), and would be wholly incompetent to control the equilibrium of a molecule of matter, on account of the absence of an adequate degree of subdivision.

When from any cause the motion of the air molecules becomes abnormal, *i. e.* takes place in any one direction in preference to another, and the equilibrium is thus disturbed, and masses of matter are influenced on one side, then the motion and pressure becomes very palpable. Such an abnormal motion of the air molecules occurs in the case of a strong wind or hurricane for example. It may, however, be computed that the energy represented by the translatory motion of the air molecules in the normal state of the air represents an energy about 120 times greater than the energy of the air would possess if moving with the speed of a hurricane (taken at 100 miles an hour), and yet the energy and pressure of the air in its normal state remain concealed on account of the perfect state of equilibrium which exists.

"*Summary of the Physical Qualities of the Æther.*—We may here give a short summary of the special physical qualities of the æther, as serving to show their mutual connections.

"*I. Low Density.*—The low density of the æther, or the small quantity of matter contained in the unit volume of space in the case of the æther, is that quality by which the æther is adapted to afford free passage to masses (such as planets, &c.), the molecules of matter, at high speed, without impediment. Secondly, this quality renders the æther mechanically well adapted as a means for the general interchange of motion between masses of molecules of matter at a distance from each other, it being an admitted principle of mechanics that for the free interchange of motion, or for the production of any distant effect, lightness in the intervening mechanism is the essential point.

"*II. Extreme Minuteness of the Æther Particles.*—This physical quantity is absolutely necessary to enable the æther to penetrate with freedom the molecular interstices of matter. Secondly, this minuteness of the component particles, or extreme state of subdivision of the matter forming the æther, by multiplying the number of the particles, and thereby bringing them into close proximity, is the necessary quality to render the pressure exerted by the æther upon the molecules of matter steady and uniform. Third, this minuteness of the component particles, or extremely subdivided state, is the necessary condition to render a high normal speed for the particles practicable, without disturbing effect.

"*High Normal Speed of Component Particles.*—The physical quality is absolutely essential to constitute a powerful dynamic effect of a high intensity. Secondly, this high normal speed of the particles in the sole condition on which the loss of motion sustained by the æther in producing a given dynamic effect can be subdivided or distributed over a large volume of the æther, whereby a notable local disturbance of the equilibrium of the æther is prevented. Fourth, this quality is essential for the rapid interchange of motion between masses and molecules of matter at a distance from each other, the rapidity of intercommunication or exchange of motion being strictly limited by the normal speed of the particles of the intervening agent. Fifth, this high speed of the component particles is necessary to render possible the existence of a store of energy of a high value, without the encumbrance of a large quantity of matter in space. Sixth, the high normal velocity of the æther particles is the necessary mechanical condition to enable an intense pressure to be exerted by the æther upon the molecules of matter, without the movements (obstructed by these molecules and masses being the agent), exerting the pressure for, in the first place, by this high speed of the component particles an intense pressure is attainable (more especially as the pressure rises as the *square* of the speed) without the necessity for the agent being dense, by which the free passage of masses of matter through the agent would be obstructed. In the second place, the high speed of the component particles enables masses of matter to pass through the agent with the least disturbance of its equilibrium, or with a minimum of resistance from this cause, the agent becoming almost impalpable; the exertion of an intense pressure by the agent being itself the necessary condition to render the agent adapted to control forcibly the molecules of matter in stable equilibrium, as exhibited in the general phenomena of "cohesion," or the aggregation of the molecules of matter generally."

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