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measurements similar to those of M. Rollet for both English and Germans. The value of such statistics for comparative purposes would be very great.

"On the Nature of the Contagium of Rinderpest. Preliminary Communication." By Alexander Edington, M.B., F.R.S.E., Director Colonial Bacteriological Institute, Cape Colony. Communicated by Sir James Crichton Browne, M.D., LL.D., F.R.S. Received March 22,—Read June 3, 1897.

In the following pages it is proposed to communicate to the Royal Society the results of experiments made in South Africa on the infectivity of the blood of animals affected with Rinderpest. The experiments were all made on cattle kept under conditions in which accidental spontaneous infection could with certainty be excluded. These experiments had been concluded in 1896, before the arrival of Dr. R. Koch in South Africa, and their results had been communicated to him on his arrival.

1. The blood of an animal ill with rinderpest, when taken during the febrile stage or previous to death, and injected subcutaneously or intravenously into healthy cattle, produces the typical disease—rinderpest, provided the blood is prevented from coagulating.

2. The onset of coagulation and actual coagulation of the blood exert a marked destructive influence on the virulence of such blood.

3. The best method of obtaining virulent blood is to draw it aseptically from the jugular vein of an animal ill with rinderpest, and to mix it immediately with a 1 per cent. solution of citrate of potash, the latter previously well sterilised, in the proportion of 2—3 parts of blood to 1 part of citrate of potash solution. Such blood, as has been shown, remains fluid.

4. This citrate of potash mixture of blood proves virulent in the first few days, generally not exceeding six days; after six days' keeping the virulence becomes rapidly weakened, so that after nine days the blood mixture is altogether inert.

5. Admixture of glycerine to citrate blood does not *cæteris paribus* interfere with the virulence of such blood. Glycerine added to fresh blood does interfere with the virulence of the latter on account of the coagulation of the blood.

6. The nasal mucus of an infected animal when used fresh and rubbed into the nostrils of normal cattle, produced in all instances typical rinderpest. We have never had a single failure in attempting to produce the disease by this means. By keeping the nasal mucus, even for a few hours, its virulence becomes markedly less.

7. The condition of marked swelling of the lymphatic glands is one of, if not indeed the most evident pathognomic feature of the disease. The contagium exists as a primary infection in the lymphatic glands.

8. A very mild attack of rinderpest, such as is produced by injection of blood of greatly decreased virulence, does not convey absolute immunity, this latter being produced in proportion to the severity of the attack through which the animal had passed primarily. An animal seemingly affected may have a relapse of the disease, which may go on to fatal issue or be mild in type, leading to recovery. Animals in the latter case always acquire immunity of a high degree.

"On the Dielectric Constants of certain Organic Bodies at and below the Temperature of Liquid Air." By JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received June 29, 1897.

Continuing the researches on which we are engaged on the Dielectric quality of matter at very low temperatures, we have examined a number of organic bodies and measured their dielectric constants at and above the temperature of liquid air.

The apparatus and arrangements for effecting this measurement are described in a former communication by us on the same subject.[*]

The frequency of the reversals of the electromotive force used in charging the condenser in the experiments here described was, as before, 120. The condenser used was the gilt cone condenser described in the communication mentioned.

In another paper[†] we have given the results obtained by us on the measurement of the dielectric constants of glycerine, ethylene dibromide, and nitrobenzol at very low temperatures, and shown that in the case of glycerine the very high value of the dielectric constant possessed by this body, above $-100°$ C., is reduced, on cooling to $-185°$ C., to a value not far from $3\cdot0$. We have also shown that a similar great reduction in the value of the dielectric constant takes place in the case of ethyl alcohol when frozen at $-185°$ C.[‡]

[*] See Fleming and Dewar, "On the Dielectric Constants of Certain Frozen Electrolytes at and above the Temperature of Liquid Air," 'Roy. Soc. Proc.,' vol. 61, p. 299.

[†] See Fleming and Dewar, "On the Dielectric Constants of Ice, Glycerine, Ethylene Dibromide, and Nitrobenzol at and above the Temperature of Liquid Air," 'Roy. Soc. Proc.,' vol. 61, p. 316.

[‡] See Dewar and Fleming, "Note on the Dielectric Constants of Ice and Alcohol at very Low Temperatures," 'Roy. Soc. Proc.,' vol. 61, p. 2.

We have now examined, in addition, the following organic bodies, viz., *formic acid, methyl alcohol, amyl alcohol, acetone, chinoline, tetra-ethylammonium hydrate,* and *carbolic acid,* and we find that these bodies have, in the liquid or solid condition and at temperatures above $-100°$ C., high, or very high, dielectric values, but all have their dielectric constants reduced to a value not far from 2·5 when they are cooled to the temperature of liquid air.

In addition, we have measured the dielectric constants of *castor oil* and *olive oil,* and find that they are reduced in value when these oils are cooled to $-185°$ C. We have also measured the dielectric constants of *bisulphide of carbon, ether, ethyl nitrate, solution of sulphur in bisulphide of carbon,* and *absolute alcohol* with 10 per cent. of metallic sodium in it. We find in all these cases that there is a reduction in the value of the dielectric power, large or small, these bodies possess at normal temperatures. These experiments further confirm the view that the presence of the radicles *hydroxyl* (HO), *carbonyl* (CO), and the organic acid radicle (COOH) always produce relatively high dielectric values in the bodies containing them when these bodies are in the liquid condition or at temperatures not very far below their freezing points. When these bodies are, however, frozen and cooled to the temperature of liquid air, all of them suffer a reduction in dielectric power, and their dielectric constants are reduced to values not far from 2·5, or between 2·5 and 2·6, at the temperature of $-185°$ C. or a little below. The action of the low temperature is thus to annul the effect of the radicle.

We have not found, so far, any exception to the rule that pure organic bodies have a dielectric constant of from two to three times that of vacuous space when they are cooled to the temperature of boiling liquid air, no matter what value their constant may have when in the liquid condition.

The following tables give the numerical results, and the observations are delineated graphically in the chart in fig. 1.

All the tables are headed by a statement giving the galvanometer scale deflection in centimetres when the condenser has air as dielectric. This is to be understood as the constant, for the time being, representing the capacity of the condenser when its dielectric is gaseous air at normal pressure and temperature. The numbers in the columns headed " Dielectric constant," under each substance are obtained by dividing the number in the second column of the tables, headed " Mean galvanometer deflection," by the above air capacity constant, after having applied a correction to the galvanometer reading for the charging voltage and for the capacity of the leads. The numbers headed " Mean galvanometer deflection," when corrected for voltage and the capacity of the leads and vibrator, represent, to the same scale as the corrected air capacity constant, the capacity

2 c 2
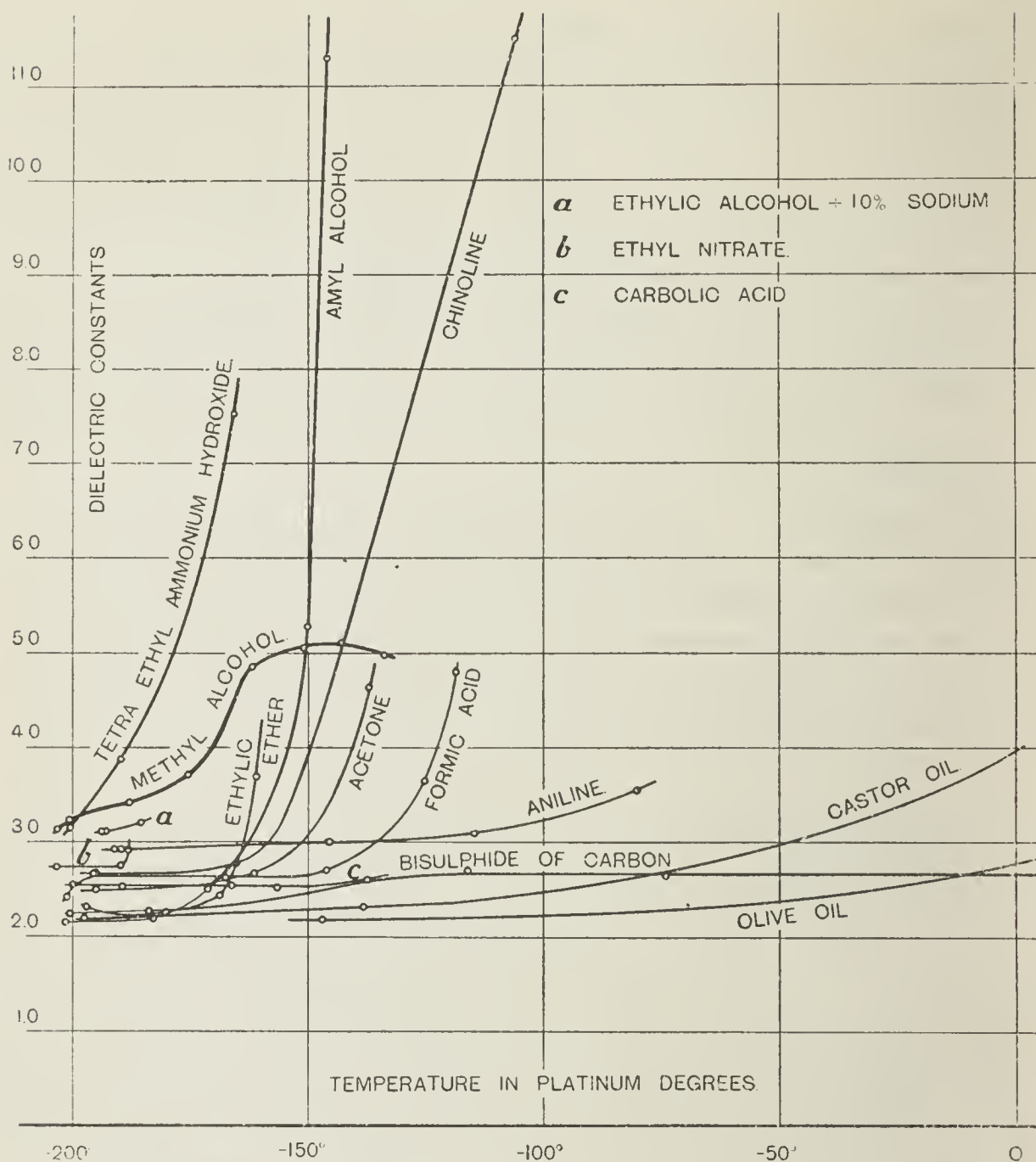
FIG. 1.—Curves showing the Variation in Dielectric Constant with Temperature of Various Organic Bodies.

of the condenser when the particular substance mentioned was being used as dielectric. The temperatures are given in platinum degrees, as explained in our other papers to which reference is made. The last column in the tables gives the electromotive force, in volts, used to charge the condenser. The frequency of reversals was in all cases 120 per second.

The observations were stopped in each case at that temperature at which any sensible true conductivity made its appearance in the dielectric, and this, as we have already shown, takes place in the case of many bodies quite suddenly, and at temperatures far below their melting point. Thus it is impossible to carry up the dielectric constant measurement, by the method we employed, of formic acid or methyl alcohol much above about $-120°$, because at that point

sensible conductivity begins. There is no difficulty, however, in carrying out the measurement in the case of carbon bisulphide, castor oil, or olive oil, over the whole range from −200° up to +15°. At the liquid air temperature all the organic bodies in the following tables are, however, practically perfect insulators.

The following tables give the figures of observation :—

I. *Methyl Alcohol* (CH_4O).

Corrected galvanometer deflection when the condenser had air as dielectric = 3·96 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvano- meter deflection in cm.	Dielectric constant.	Observations.
−203·4	13·2	3·13	Condenser charged
−200·8	13·5	3·23	to 102 volts.
−188·0	14·2	3·41	
−175·4	15·4	3·71	
−161·9	19·75	4·85	
−151·0	3·71	5·05	Condenser charged
−143·0	3·75	5·10	to 18·3 volts.
−134·0	3·78	4·98	

II. *Amyl Alcohol* ($C_5H_{12}O$).

Corrected galvanometer deflection when the condenser had air as dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvano- meter deflection in cm.	Dielectric constant.	Observations.
−204·0	10·4	2·40	Condenser charged to 98·2 volts.
−201·8	1·89	2·14	Condenser charged to
−183·0	1·93	2·19	18·6 volts.
−171·5	2·05	2·50	
−150·2	4·30	5·28	
−146·2	9·00	11·3	
−141·4	19·50	24·7	
−138·8	2·10	34·4	Condenser charged to
−133·3	2·61	43·0	1·43 volts.
−127·7	2·55	42·0	
−123·8	2·50	41·0	

III. *Formic Acid* (CH_2O_2).

Corrected galvanometer deflection when the condenser had air as
dielectric = 3·97 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−201·3	9·88	2·41	Condenser charged to 99·0 volts.
−195·8	1·95	2·66	Condenser charged to
−167·5	1·93	2·62	17·8 volts.
−146·1	1·98	2·70	
−125·2	2·65	3·65	
−118·8	3·45	4·80	

IV. *Absolute Ethylic Alcohol* (C_2H_6O), having 10 per cent. of sodium dissolved in it.

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·04 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−193·0	12·95	3·11	Condenser charged to
−194·0	12·95	3·11	99·7 volts.
−185·6	13·25	3·20	

V. *Acetone* (C_2H_6CO).

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−198·3	11·30	2·62	Condenser charged to 98·8 volts.
−195·2	2·05	2·49	Condenser charged to
−161·5	2·18	2·66	18·7 volts.
−137·2	3·75	4·63	

VI. *Aniline* ($C_6H_5NH_2$).

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·05 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−191·2	12·2	2·92	Condenser charged to
−189·7	12·2	2·92	100 volts.
−145·5	12·55	3·00	
−114·7	12·9	3·09	
−80·0	14·78	3·55	

VII. *Carbolic Acid* (C_6H_6O).

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·34 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−200·0	11·25	2·54	Condenser charged to
−189·5	11·18	2·53	98·2 volts.
−166·2	11·25	2·33	
−156·5	11·15	2·52	
−137·3	11·50	2·60	

VIII. *Tetraethylammonium hydroxide* ($N(C_2H_5)_4HO$).
(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−200·5	13·63	3·15	Condenser charged to 98·7 volts.
−189·8	3·00	3·87	Condenser charged to
−165·7	5·75	7·52	17·8 volts.

IX. *Chinoline* (from Cinchonine).

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·05 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−195·0	11·1	2·67	Condenser charged to
−165·2	11·55	2·77	99·0 volts.
−106·0	8·50	11·5	Condenser charged to
−93·6	9·75	13·3	18·0 volts.

X. *Bisulphide of Carbon* (CS_2).

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−200·7	9·43	2·24	Condenser charged to
−183·8	9·60	2·27	98·2 volts.
−116·2	11·35	2·70	
−74·2	11·10	2·64	
+20·0	11·11	2·64	

XI. *Solution of Sulphur in Bisulphide of Carbon.*

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·04 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−152·8	11·0	2·65	Condenser charged
+20·0	11·5	2·77	to 99·2 volts.

XII. *Ethylic Ether* ($C_4H_{10}O$).

Corrected galvanometer deflection when the condenser had air as
dielectric = 3·96 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in cm.	Dielectric constant.	Observations.
−197·0	9·75	2·31	Condenser charged
−194·0	10·95	2·61	to 100 volts.
−180·2	9·52	2·25	
−168·8	10·25	2·43	
−161·2	15·35	3·69	

XIII. *Ethyl Nitrate* ($C_2H_5NO_3$).

Corrected galvanometer deflection when the condenser had air as dielectric = 4·34 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvano- meter deflection in cm.	Dielectric constant.	Observations.
−203·8	12·25	2·73	Condenser charged
−190·0	12·33	2·75	to 99·8 volts.
−188·4	13·05	2·92	

XIV. *Castor Oil.*

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvano- meter deflection in cm.	Dielectric constant.	Observations.
−197·7	9·30	2·19	Condenser charged
−138·3	9·75	2·31	to 98·2 volts.
+ 20·0	17·5	4·23	

XV. *Olive Oil.*

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvano- meter deflection in cm.	Dielectric constant.	Observations.
−147·2	9·2	2·18	Condenser charged
+ 20·0	12·0	2·86	to 98·2 volts.

The observations on castor oil, olive oil, and bisulphide of carbon are of considerable interest.

In the first place they show that the method we are using gives results at normal temperatures which are in agreement with those of other observers. Thus Dr. J. Hopkinson* found the dielectric constant K of carbon bisulphide at 20° C. to be 2·67 : we find it to be 2·64. The square of the refractive index of carbon bisulphide for the D ray at 10° C. is 2·673, and accordingly this body is generally said to be one of those which obey Maxwell's law, in that its refractive index is nearly equal to the square root of the dielectric constant. If, however, we calculate the square of the refractive index of bisulphide of carbon for waves of infinite wave-length using at least

* See 'Roy. Soc. Proc.,' vol. 43, p. 161, 1887.

two terms of the Cauchy's formula,[*] we find that for carbon bisulphide the value of $(\mu_\infty)^2$ is 2·01, and this is somewhat less than the value (2·67) of K at ordinary temperatures. It is, however, much nearer to the value (2·24) which we find for K at the liquid air temperature. Again, Dr. J. Hopkinson's value for the dielectric constant of castor oil at normal temperature is 4·78, and the square of the refractive index of this body for infinite waves is 2·153. Our value for the dielectric constant of castor oil is 4·23 at 20° C. and 2·19 at −185° C.

Hence, in the case of castor oil at the temperature of liquid air there is practically a very fair agreement between the values of K and $(\mu_\infty)^2$ for a low frequency of electromotive force reversals, whereas at normal temperatures K has nearly twice the value of $(\mu_\infty)^2$.

The same fact holds good for olive oil. At normal temperatures its dielectric constant K is 3·16, and the square of its infinite refractive index $(\mu_\infty)^2$ is 2·131. At the temperature of liquid air we find the dielectric constant of olive oil to be 2·18 for low frequency. Hence, in these cases a large part of the difference between K and $(\mu_\infty)^2$ which exists at normal temperature disappears at very low temperatures, and castor oil and olive oil then make in this respect even a better agreement than carbon bisulphide. One other point is of interest. The temperature variation of dielectric constant for both olive oil and carbon bisulphide appear to be negative at ordinary temperatures,[†] that is to say, their dielectric constants decrease with rise of temperature. At low temperatures, however, we find their constants to have a positive temperature coefficient; in other words, they increase with temperature. Hence, it follows that, like ice and glycerine, they have at some temperature a *maximum* value for their dielectric constant.

The following table shows the relative values of the dielectric constants (K) of certain of these organic bodies at 15° and at −185° C for low frequency. At the same time the value of $(\mu_\infty)^2$ calculated by Cauchy's formula is placed against them as far as we have been able to find it determined.

It is clear, therefore, that in all the above cases a very low temperature extinguishes the high dielectric values many organic bodies have in the liquid condition, and it produces the same effect, therefore, as a sufficient increase in the frequency of the electromotive force reversals. Either of these operations tends to bring down the high value of the dielectric constant to a value much more comparable in magnitude with the square of the optical refractive index as calcu-

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[*] We here make the assumption that even for a highly dispersive body like carbon bisulphide, the Cauchy formula is applicable for calculating $(\mu_\infty)^2$, an assumption perhaps not warranted.

[†] See Cassie, ' Roy. Soc. Proc.,' vol. 46, 1889.

Dielectric Constants of some Organic Bodies at Normal and at very Low Temperatures for Low Frequencies.

Substance.	Dielectric constant (K)		(Infinite Refractive Index)$^2 = (\mu_\infty)^2$.
	at 15° C.	at − 185° C. (Dewar and Fleming.)	
Methyl alcohol..........	34·0 (Thwing) ...	3·13	—
Ethyl alcohol...	25·8 (Nernst)....	3·11	1·831
Amyl alcohol	16·0 (Nernst)....	2·14	1·951
Formic acid	62·0 (Thwing) ...	2·41	—
Acetone	21·85 (Thwing) ...	2·62	—
Ethylic ether	4·25 (Nernst)....	2·31	1·805
Castor oil	4·78 (Hopkinson)	2·19	2·153
Olive oil..............	3·16 ,,	2·18	2·131
Bisulphide of carbon	2·67 ,,	2·24	2·010
Aniline	7·51 (Smale)	2·92	—
Carbolic acid	.. ..	2·54	—
Ethyl nitrate..........	17·72 (Thwing)..	2·73	—

lated by Cauchy's formula for infinite wave-lengths, on the assumption that there is no anomalous dispersion.

The determination of the actual values of the refractive indices of these bodies at the liquid air temperature is a work of great difficulty, and one which we have not yet attempted. There is no question that it is important also to determine whether these very low temperatures have any effect in altering the absorptive power of these organic bodies for ultra-red rays, and removing that anomalous dispersion which appears to exist in some of them beyond the limits of the visible spectrum.

We are much indebted to Mr. J. E. Petavel for assistance in the work of taking the above described observations.

"On the Dielectric Constants of Metallic Oxides dissolved or
suspended in Ice cooled to the Temperature of Liquid
Air."   By James Dewar, M.A., LL.D., F.R.S., Fullerian
Professor of Chemistry in the Royal Institution, and J. A.
Fleming, M.A., D.Sc., F.R.S., Professor of Electrical
Engineering in University College, London.   Received
June 29, 1897.

By the aid of the cone condenser and the method described by us
in another communication,* we have studied the changes produced
in the dielectric constants of ice at and above the temperature of
liquid air when the ice has suspended in it insoluble metallic oxides
or else has dissolved in it soluble metallic oxides or hydrates. We
have also examined the dielectric properties of some of these oxides
and hydrates when dissolved in other menstrua frozen and reduced
to very low temperatures.

The experiments were conducted exactly as described in the com-
munication above mentioned, and the frequency of the electromotive
force reversals was, as before, 120.

In the following tables the four columns of figures give respec-
tively the platinum temperature of the dielectric, the scale deflection
of the galvanometer, representing the capacity of the condenser with
the selected dielectric, when corrected for voltage and capacity of
the leads and vibrator; the deduced dielectric constant, and the
electromotive force at which the charging of the condenser was con-
ducted.

The figure given at the head of each table as the *corrected galva-
nometer deflection with air as dielectric*, represents the capacity of the
condenser with gaseous air at normal pressure and temperature as its
dielectric.

The hydrates dissolved in water or other media, or the oxides in a
very fine state of division, suspended in water, were introduced by
means of a pipette, as the dielectric into the cavity of the cone con-
denser. This liquid dielectric was then frozen and reduced to the
temperature of liquid air by lowering the whole condenser into a
large vacuum vessel holding several litres of liquid air. As soon as
the dielectric was reduced to the temperature of −188° C. the
observations for capacity and temperature began.

In all cases an observation was taken for electric conductivity and
the dielectric measurements were stopped the moment any sensible
conductivity made its appearance.

* See Fleming and Dewar, " On the Dielectric Constants of Certain Frozen
Electrolytes at and above the Temperature of Liquid Air," 'Roy. Soc. Proc.,' vol. 61,
p. 299.

The first experiments were conducted with solutions of various alkaline hydrates taking, to begin with, 5 per cent. aqueous solutions of the hydrates of lithium, sodium, potassium and rubidium. Following on this, an experiment was tried with a 2·85 per cent. aqueous solution of cæsium hydrate. The details of the observations and results are given in Tables I, II, III, IV, and V.

I. *Dielectric Constant of Lithium Hydrate* (LHO).

(5 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·03 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−202·8	9·30	3·00	Condenser charged to 99 volts.
−198·0	2·00	3·23	Condenser charged to 19·8 volts.
−180·6	2·20	3·57	
−144·7	3·20	5·23	
−133·8	4·10	6·74	
−118·2	9·85	16·20 ?	

II. *Dielectric Constant of Sodium Hydrate* (NaHO).

(5 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·02 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric. constant.	Observations.
−201·8	7·70	133·0	Condenser charged to 1·434 volts.
−201·7	7·72	134·0	
−183·0	8·40	145·0	
−174·2	8·27	143·0	
−168·2	8·15	141·0	
−163·8	8·15	141·0	

III. *Dielectric Constant of Potassium Hydrate* (KHO) (*Caustic Potash*).

(5 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·91 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—204·8	6·92	123·0	Condenser charged with 1·434
—200·7	7·07	126·0	volts.
—196·2	7·35	131·0	
—181·5	7·55	135·0	
— 170·1	7·49	133·0	
—158·7	7·33	131·0	
—147·3	7·40	132·0	
—135·9	7·54	134·0	
—127·7	8·01	143·0	

IV. *Dielectric Constant of Rubidium Hydrate* (RbHO).

(5 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·03 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—201·3	3·50	81·6	Condenser charged to 1·434 volts.
—201·5	3·57	82·3	
— 201·5	3·47	80·0	
—198·7	5·65	130·0	
—197·8	6·45	148·0	
—195·8	7·37	169·0	
—183·2	7·50	172·0 ?	
—175·1	8·70	200·0	
—169·8	8·85	202·0	
—146·1	8·97	206·0	
—138·8	9·10	209·0	

V. *Dielectric Constant of Cæsium Hydrate* (CsHO).

(2·85 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−203·5	11·92	2·76	Condenser charged to 100·3 volts.
−178·0	2·40	2·79	Condenser charged to 20·2 volts.
−143·0	3·05	3·57	

In order to examine again the influence of the solvent, we tried a saturated solution of caustic potash (KHO) in ethylic alcohol. We have already shown that a 5 per cent. aqueous solution of caustic potash has an enormously greater dielectric constant at the temperature of liquid air than the alcoholic 5 per cent. solution. And we now find that the saturated alcoholic solution of caustic potash has a small dielectric value, as shown in Table VI.

VI. *Dielectric Constant of Caustic Potash* (KHO) *dissolved in Alcohol*

(Saturated solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielcetric constant.	Observations.
−194·8	14·55	3·40	Condenser charged to 98·2 volts.
−187·0	14·85	3·46	
−171·7	15·25	3·57	
−159·0	15·00	3·50	
−146·2	25·70	5·97 ?	Charged to 18 volts.

We next selected for trial thallium hydrate dissolved in water, with the results shown in Table VII.

VII. *Dielectric Constant of Thallium Hydrate* (TlHO).

(5·74 per cent. solution in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·04 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−203·0	4·82	6·54	Condenser charged to 18 volts.
−192·0	10·50	1·43	
−173·0	2·40	41·4	Condenser charged to 1·43 volts.
−164·3	4·10	70·7	
−148·5	6·60	114·0	
−123·0	6·85	118·0	
−112·8	7·50	130·0	
−105·8	8·30	143·0	

Our next experiment was made with barium hydrate, taking a 5 per cent. mixture suspended in water.

VIII. *Dielectric Constant of Barium Hydrate* (Ba(HO)$_2$).

(5 per cent. suspended in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·03 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·3	9·00	15·1	Condenser charged to 19·5 volts.
−199·5	10·35	17·2	
−196·8	11·90	20·1	
−186·8	12·55	21·2	
−178·0	14·20	23·9	
−174·2	1·11	25·5	Condenser charged to 1·434 volts.
−161·0	1·40	32·1	
−147·2	1·60	36·7	
−139·0	1·71	39·3	
−133·7	1·82	41·7	
−124·2	1·95	44·8	
−121·0	2·17	51·8 ?	

Following on these experiments we commenced a series of measurements on the dielectric constant of ice having suspended in it various insoluble oxides. These oxides, freshly precipitated and

washed, were suspended in distilled water, and, being well shaken up, were introduced into the condenser and frozen. The results are given in the tables below, beginning with aluminic oxide.

IX. *Dielectric Constant of Aluminic Sesquioxide* (Al_2O_3).

(Suspended in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·97 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−205·7	1·92	2·58	Condenser charged to 18·0 volts.
−190·0	1·89	2·53	
−159·8	1·92	2·58	
−132·7	3·25	4·43	

X. *Dielectric Constant of Oxide of Iron* (Fe_2O_3).

(Suspended in water.)

(12·6 per cent. of oxide.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·07 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−199·4	5·2	89·8	Condenser charged to 1·434 volts.
−191·7	6·3	112·0	
−180·0	6·8	121·0	
−165·4	7·0	124·0	
−153·8	7·2	128·0	
−143·7	7·75	134·0	
−136·8	7·8	135·0	
−128·7	8·05	139·0	
−123·2	8·75	151·0 ?	
−118·0	10·3	176·0 ?	

XI. *Dielectric Constant of Oxide of Copper* (CuO).

(Suspended in water.)

(14·55 per cent. of oxide.)

Corrected galvanometer reading when the condenser has air as dielectric = 4·07 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−195·7	9·40	161	Condenser charged to 1·434 volts.
−185·0	9·25	158	
−174·8	9·52	163	
−164·3	9·60	164	
−159·0	9·50	162	
−151·2	9·60	164	
−141·3	9·90	169	
−130·0	10·30	176 ?	
−124 2	11·10	190 ?	
−120·5	12·15	207 ?	

It will be noticed that the dielectric constant of the ice having in suspension particles of oxide of copper has an exceedingly high value, even at the temperature of liquid air, and, moreover, shows no signs of becoming reduced. We suspected that this might be due to the conductivity of the oxide of copper particles, which, though separated and insulated by ice at a low temperature in such fashion that the whole mass is a good insulator, may yet raise the value of the average dielectric constant.

We tried suspending sulphide of copper in ice, but in this case found the material, as a whole, had such conductivity that we could not make any dielectric measurement by the method used. With this exception, all the other frozen oxides and hydrates suspended or dissolved in ice had a very high resistance.

We then tried dissolving the oxide of copper in ammonia.

XII. *Dielectric Constant of Oxide of Copper* (CuO).

(Dissolved in ammonium hydrate.)

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·3	10·2	2·39	Condenser charged to 98·7 volts.
−178·0	2·0	2·34	Condenser charged to 19·8 volts.
−132·2	2·35	2·77	

XIII. *Dielectric Constant of Oxide of Lead* (PbO).

(Suspended in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·04 for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−197·4	4·56	78·5	Condenser charged to 1·434 volts.
−184·8	5·23	90·0	
−159·2	5·40	93·0	
−150·2	5·40	93·0	
−128·3	5·40	93·0	

In contrast with the above results, we tried dissolving the oxide of lead in caustic potash, and prepared a saturated solution of oxide of lead (PbO), dissolved in a 5 per cent. solution of caustic potash.

XIV. *Dielectric Constant of Oxide of Lead* (PbO).

(Dissolved in a 5 per cent. solution of caustic potash.)

Corrected galvanometer deflection with air as dielectric = 3·03 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−189·2	7·47	171	Condenser charged to 1·434 volts.
−170·2	7·45	171	
−158·0	7·52	173	
−148·4	7·60	175	
−138·2	7·45	171 ?	
−127·8	7·77	179	

Finally we tried bismuth oxide suspended in water, with the results shown in Table XV.

XV. *Dielectric Constant of Bismuth Oxide* (Bi_2O_3).

(Suspended in water.)

Corrected galvanometer deflection when the condenser has air as
dielectric = 3·97 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·0	1·97	2·64	Condenser charged to 17·8 volts.
−199·7	1·93	2·62	
−194·0	2·00	2·72	
−185·2	2·00	2·72	
−171·0	2·00	2·72	
−159·0	2·10	2·88	
−152·5	2·45	3·46	
−142·5	4·40	6·13	
−138·0	6·15	8·55	
−134·4	9·90	13·80	
−129·2	14·15	19·9	
−127·3	1·41	24·5	Condenser charged to 1·434 volts.
−122·7	2·15	37·8	
−117·5	3·25	57·2	
−111·0	4·45	78·2	
−107·3	5·10	90·2	

Before drawing conclusions as to the dielectric power of these
oxides and hydrates, it seemed important to try the effect of sus-
pending in ice small quantities of inert particles, and we therefore
selected *finely divided gold* and *precipitated sulphur* as instances of a
good conductor and a good non-conductor in very fine states of divi-
sion. These finely divided materials were suspended in water and
frozen and the dielectric constants taken as follows :—

*Dielectric Constant of Ice, having in suspension a small quantity of finely
divided Gold.*

Corrected galvanometer deflection when the condenser has air as
dielectric = 4·04 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−199·8	10·30	2·60	Condenser charged to 98·5 volts.
−196·0	9·90	2·39	
−161·7	5·25	7·12	Condenser charged to 18·0 volts.
−149·0	11·0	15·0	
−144·5	17·0	23·2	

Dielectric Constant of Ice, having in suspension a small quantity of finely divided Sulphur.

Corrected galvanometer deflection when the condenser has air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−198·2	11·1	2·64	Condenser charged to 98·2 volts.
−182·5	11·3	2·69	
−160·0	4·2	5·44	Condenser charged to 1·43 volts.

The results show that practically no influence is produced upon the dielectric quality of the ice at very low temperatures when it is impregnated either with conducting particles of gold or non-conducting particles of sulphur. The amount of gold in the ice as used by us is no doubt small. In each case the dielectric constant of the material is very close to that of the ice obtained from pure distilled water.

The electrical resistance of the ice slightly impregnated with finely divided gold did not appear to be less than that of ordinary ice. To the tests we applied the one appeared to be as good an insulator as the other.

The foregoing observations are graphically delineated in the diagrams in figs. 1, 2, and 3, according to the magnitude of the dielectric constants found. The following facts may then be noted :—

(i) The presence of cæsium hydrate, lithium hydrate, bismuth oxide, aluminic oxide, finely divided sulphur or finely divided gold, in the percentages used by us, in ice makes little or no difference in its dielectric power when cooled to the temperature of liquid air.

(ii) The presence to about the same extent of the hydrates of potassium, sodium, rubidium, or the oxides of copper, iron, or lead, causes a very great increase in the dielectric power of the ice at that low temperature.

(iii) The dielectric curves are, however, all seen to be tending downwards in such a way as to show that at still lower temperatures it is probable the effect of the oxides or hydrates would be annulled and the dielectric constants of all be reduced to a value not far from that of pure ice.

(iv) The exception to this tendency, so far as yet observed, appears to be in the case of the oxide of copper, which, when suspended in ice, causes it to possess the remarkably high dielectric value of 150 even at the temperature of liquid air.
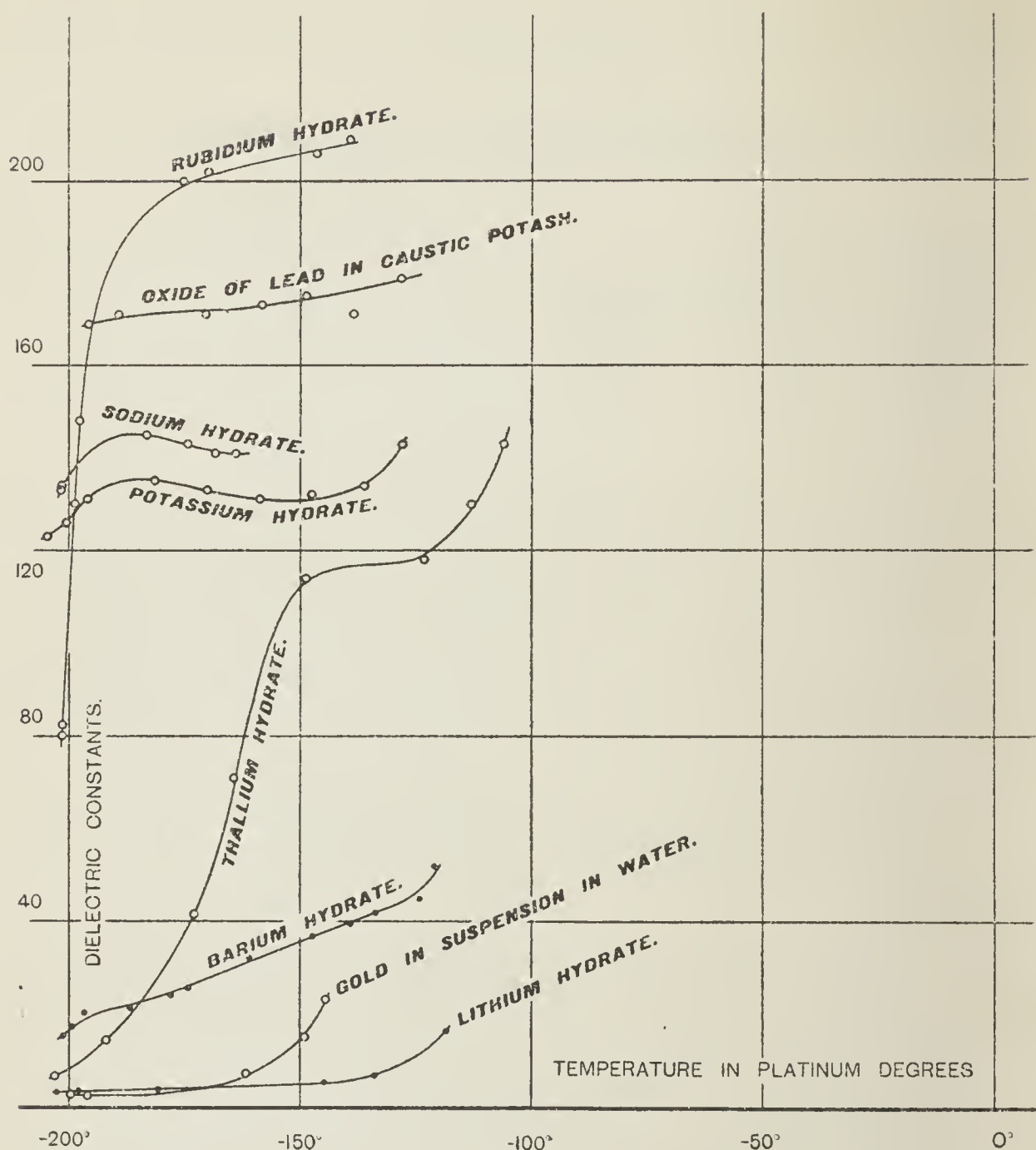
FIG. 1.—Curves showing the variation in Dielectric Constant with Temperature of various Oxides and Hydrates.

It is possible, however, that in this case the conductivity of the yet insulated particles of oxide may account for the result.

(v) The effect of the solvent or menstruum upon the dielectric constant is also exceedingly marked. Thus the oxide of copper suspended in ice has a dielectric constant of about 150 at $-185°$, the oxide of lead suspended in ice has a value of about 80 at the same temperature. If, however, the oxide of copper is dissolved in ammonia and frozen, the dielectric constant of this at $-185°$ falls to $2·2$, whereas if the oxide of lead is dissolved in 5 per cent. solution of caustic potash and frozen, the dielectric constant rises to 170 at the temperature of liquid air.
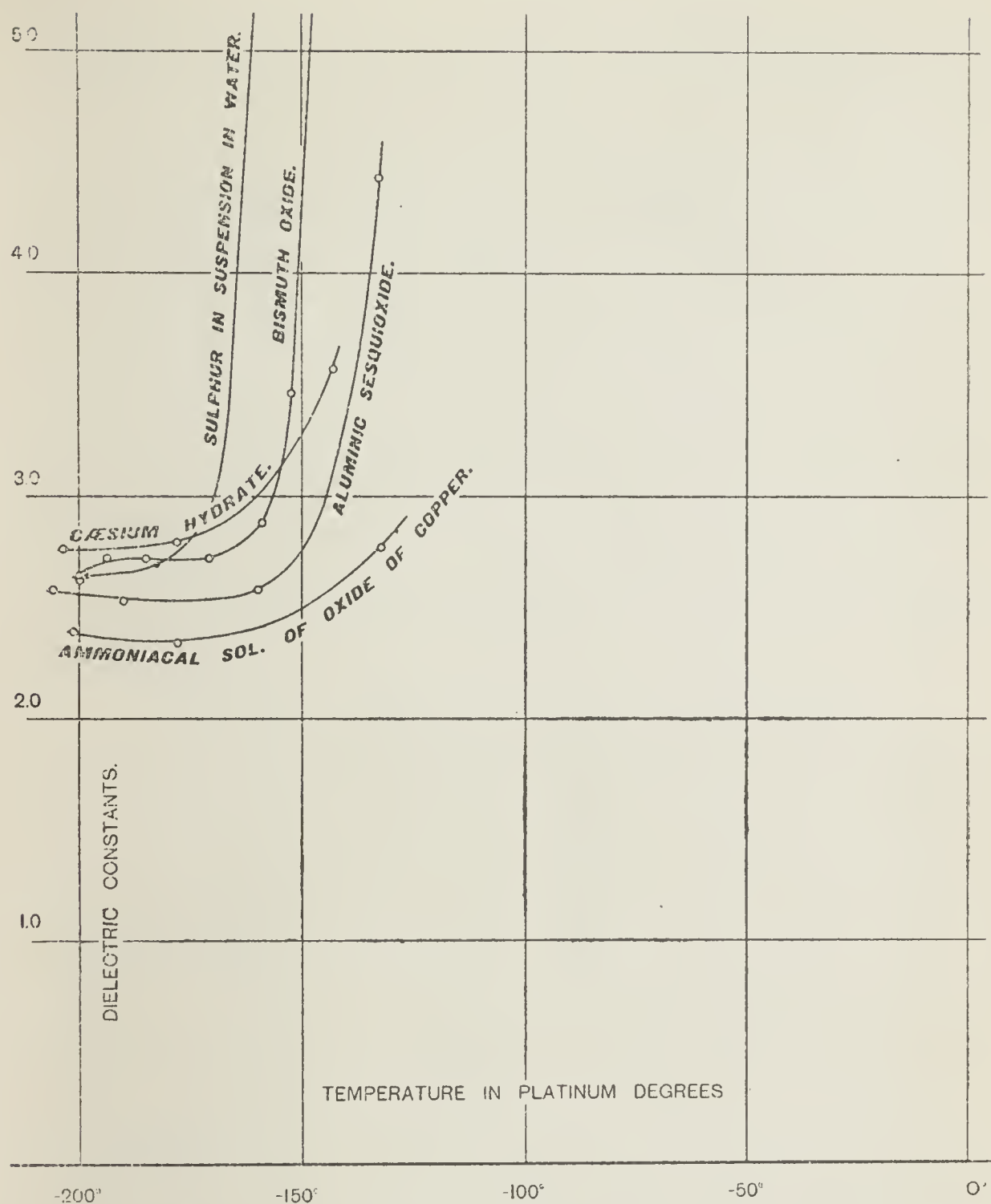
FIG. 2.—Curves showing the variation in Dielectric Constant with Temperature of various Oxides and Hydrates.

The only general conclusion that can as yet be drawn from the experiments described is that the presence of certain oxides or hydrates of metals in ice, even to the extent of not many per cent., has an immense influence in raising the dielectric power of the ice when taken at the temperature of liquid air, whereas the presence of other oxides or hydrates chemically analogous has hardly any influence at all.

In the above described experiments, Mr. J. E. Petavel has given us considerable assistance.
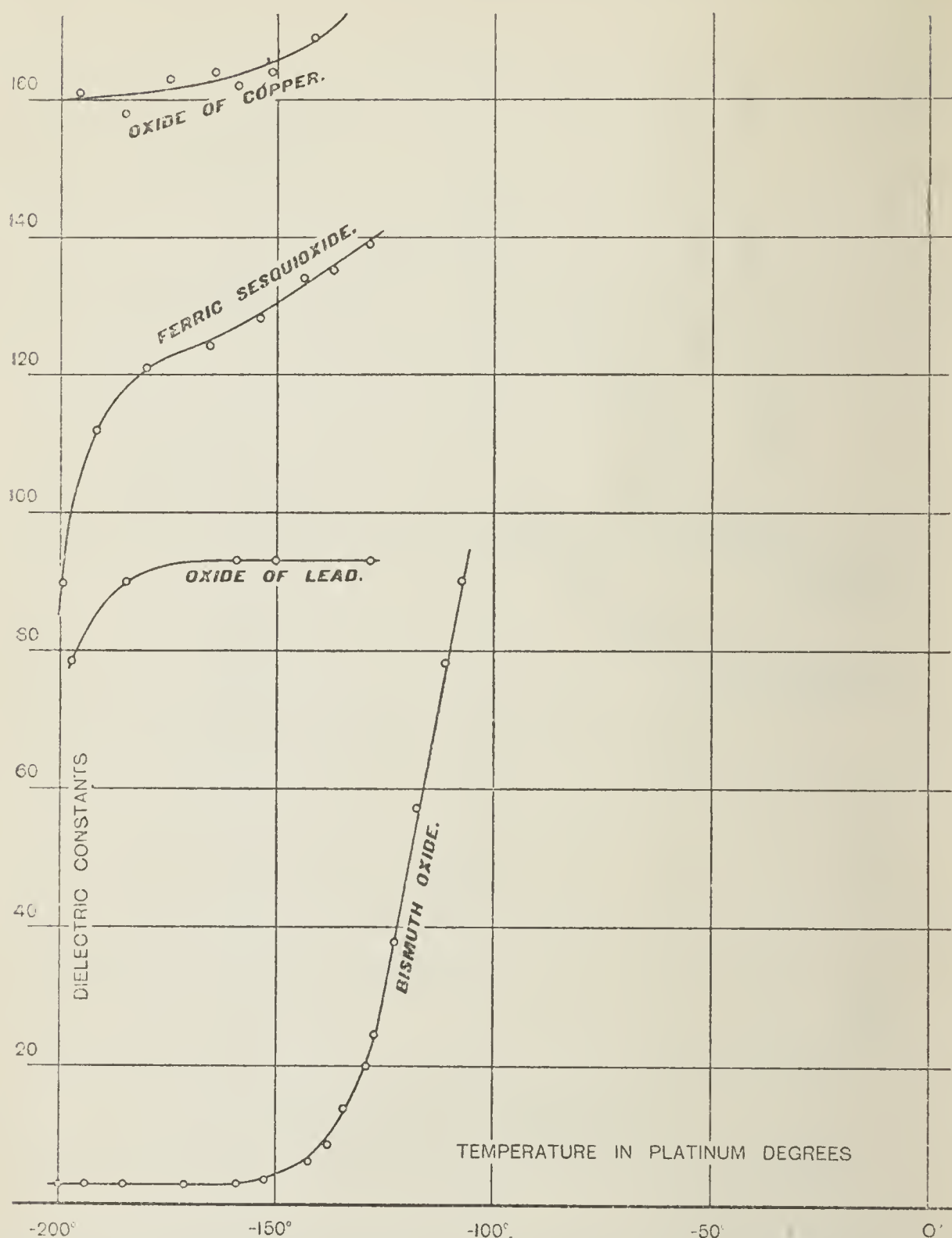
FIG. 3.—Curves showing the variation in Dielectric Constant with Temperature of various Oxides.

"Further Observations on the Dielectric Constants of Frozen Electrolytes at and above the Temperature of Liquid Air." By J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution. Received June 29, 1897.

In continuation of our examination of the dielectric constants of frozen electrolytes at very low temperatures, we have subjected to

test (in the manner described in a former abstract)* another large series of electrolytes.

Referring to the above-mentioned abstract for an account of the details of the method, we merely give in the following Tables the results of our observations on the dielectric constants of many aqueous solutions of metallic salts, which have been taken with the object of determining if possible the causes which create high or low dielectric values at low temperatures.

The dielectric observations were all taken at a frequency of electromotive force reversal of 120.

We have taken, in the first place, a large series of observations on electrolytes with the same base (sodium), but different acid radicles, and then a number with the same acid radicle but different bases. Also, we have examined normal and corresponding acid salts, double salts, and many salts taken in such proportion with water as to yield the so-called cryohydrates.

The following tables give the details of the dielectric measurements.

I. *Dielectric Constant of Sodic Acetate* ($NaC_2H_3O_2$).

(5 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·02 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·0	3·00	3·82	Condenser charged to 19·0 volts.
−200·2	3·03	3·85	
−197·6	3·20	4·08	
−181·5	5·20	6·70	
−158·5	1·72	29·80	Condenser charged to 1·434 volts.
−150·8	2·45	42·50	
−142·8	3·05	52·80	
−113·3	4·17	72·00	
−98·8	5·15	89·0 ?	

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* See Fleming and Dewar, " On the Dielectric Constants of Certain Frozen Electrolytes at and above the Temperature of Liquid Air." 'Roy. Soc. Proc.,' vol. 61, p. 299.

II. *Dielectric Constant of Normal Sodic Carbonate* (Na_2CO_3).

(6 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−198·5	2·10	34·4	Condenser charged to 1·434 volts.
−192·2	2·35	38·4	
−171·0	2·55	41·7	
−159·0	2·60	42·7	
−144·2	2·82	46·2	
−134·8	3·40	55·7	
−122·0	4·70	77·0	
−114·3	5·50	90·2	
−104·0	7·15	118·0	
−94·0	8·90	146·0	

N.B. The condenser was warmed up in the vacuum tube.

III. *Dielectric Constant of Sodic Bicarbonate* ($NaHCO_3$).

(6 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·34 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−195·3	12·20	2·74	Condenser charged to 99·0 volts.
−183·3	3·70	4·24	Condenser charged to 19·8 volts.
−166·7	3·00	48·70	
−113·0	4·40	70·70	Condenser charged to 1·434 volts.
−90·5	4·65	74·70	

N.B.—The condenser was warmed up out of the vacuum tube.

IV. *Dielectric Constant of Sodic Biborate (Borax),* $Na_2O2B_2O_3,10H_2O$.

(15 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−202·0	2·40	39·4	Condenser charged to 1·434 volts.
−195·3	4·10	67·2	
−188·4	4·85	79·5	
−176·0	5·25	86·3	
−152·7	5·50	90·5	
−139·8	5·85	96·0	
−127·0	6·40	105·0	
−121·0	6·30	103·0	
−112·8	7·35	118·0	

N.B.—Condenser warmed up in the vacuum tube.

V. *Dielectric Constant of Sodic Nitrite* $(NaNO_2)$.

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·0	11·80	2·78	Condenser charged to 98·8 volts.
−172·7	2·35	2·77	Condenser charged to 19·8 volts.
−130·3	13·50	16·30	Condenser charged to 19·8 volts.
−120·3	2·35	39·00	Condenser charged to 1·434 volts.
−98·2	3·40	57·00	Condenser charged to 1·434 volts.

VI. *Dielectric Constant of Sodic Hyposulphite* ($Na_2S_2H_2O_4.4H_2O$).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·8	4·40	74	Condenser charged to 1·434 volts.
−183·0	4·75	80	
−163·7	5·05	85	
−143·8	5·75	96	
−130·7	7·02	118	
−122·7	7·20	121	
−114·8	7·67	129	
−107·7	8·65	145	
−98·4	11·15	188 ?	

VII. *Dielectric Constant of Sodic Silicate.*

(5 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as
dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·0	3·42	57·4	Condenser charged to 1·434 volts.
−195·5	6·15	103·0	
−175·0	7·25	122·0	
−164·7	7·45	125·0	
−148·2	7·60	128·0	
−138·8	7·60	128·0	
−129·7	7·80	131·0	
−106·2	8·15	137·0	
−96·0	8·65	145·0	

VIII. *Dielectric Constant of Sodic Chloride* (NaCl).

(23·6 per cent. (cryohodrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·44 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Charging volts.	Observations.
−203·1	9·77	2·78	99·20	90,000 ohms in series
−200·0	9·74	2·62	92·20	for the first two
−192·0	10·20	2·90	99·20	readings, then 1000
−177·0	12·85	3·68	99·20	ohms.
−165·2	16·45	4·73	99·20	The condenser was
−156·5	4·05	5·88	19·80	warmed up out of
−122·7	18·60	27·40	19·80	the vacuum tube.
−108·3	2·25	156·00 ?	1·43	

IX. *Dielectric Constant of Sodic Chlorate* (NaClO₄).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−202·4	5·65	6·68	Condenser charged to 20·2 volts.
−189·8	6·10	7·22	
−173·7	6·35	7·51	
−156·0	8·05	9·57	
−114·3	3·55	59·20	Condenser charged to 1·434 volts.
−98·0	5·45	91·20	

X. *Dielectric Constant of Normal Sodic Sulphate* (Na₂SO₄).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−197·0	4·75	5·68	Condenser charged to 20·0 volts.
−167·3	5·05	6·04	
−129·8	7·15	8·58	
−116·6	8·35	10·00	
−85·8	8·95	10·70	
−69·0	9·65	11·60	

XI. *Dielectric Constant of Sodic Bisulphate* ($NaHSO_4$).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·8	12·1	2·83	Condenser charged to 100·2 volts.
−191·3	5·5	6·82	Condenser charged to 19·3 volts.
−158·7	12·5	15·60	

XII. *Dielectric Constant of Hydro-disodic Phosphate* (Na_2HPO_4).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−199·2	1·83	31·1	Condenser charged to 1·4 volts;
−180·0	1·95	33·0	no resistance in series with
−156·0	2·10	35·4	galvanometer.
−141·3	2·45	41·5	
−133·2	2·97	50·2	
−123·0	3·75	53·5	
−102·2	5·45	92·2	

XIII. *Dielectric Constant of Potassium Ferrocyanide.*

(12 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·02 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—204·3	2·02	35·1	Condenser charged to 1·434 volts.
—203·8	2·01	34·9	
—200·0	2·10	36·4	
—187·2	2·30	39·8	
—168·1	2·46	42·4	
—156·5	2·56	44·3	
—145·8	2·87	49·8	
—129·5	3·95	68·5	
—119·4	4·70	81·7	
—111·4	5·60	97·0	
—107·0	6·65	115·0	
—105·3	7·25	126·0	
—102·0	8·50	147·0	
—98·8	9·60	168·0 ?	

XIV. *Dielectric Constant of Potassium Chromate* ($KCrO_4$).

(36 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·34 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—201·5	8·95	10·2	Condenser charged to 20·0 volts.
—193·7	9·75	11·1	
—177·0	10·62	12·1	
—165·0	10·95	12·5	
—148·8	11·05	12·6 ?	
—135·7	12·20	14·0	
—127·0	12·75	14·6	
—122·0	13·40	15·3	
—112·4	14·65	16·9	
—100·0	1·39	22·3	Condenser charged to 1·434 volts.

XV. *Dielectric Constant of Potassium Bichromate* ($K_2Cr_2O_7$).

(5·3 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—173·0	11·15	2·50	Condenser charged to 99 volts.

N.B.—The supply of liquid air on the occasion of this measurement was not sufficient to lower the temperature any further than —173°, but it is clear that the dielectric constant has a low value.

XVI. *Dielectric Constant of Potassium Bicarbonate* ($KHCO_3$).

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·34 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—196·3	1·90	2·07	Condenser charged to 19·8 volts.
—182·0	1·93	2·11	
—166·5	2 50	2·80	
—147·2	13·00	14·70	
—134·7	1·75	27·90	Condenser charged to 1·43 volts.
—117·8	2·60	41·70	

XVII. *Dielectric Constant of Potassic Iodide* (KI).

(52·17 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·44 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—199·0	9·65	2·72	Condenser charged with 100 volts.
—196·0	9·90	2·80	1000 ohms in series with galvano-
—196·7	10·17	2·87	meter.
—191·6	12·85	3·04	Charging volts = 99·8.
—170·6	5·30	7·67	Charging volts = 19·8.
—148·0	14·75	21·60	Charging volts = 19·8.

XVIII. *Dielectric Constant of Potassium Alum.*

(9 per cent. solution.)

Corrected galvanometer deflection when condenser had air as dielectric = 3·12 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—192·2	12·35	3·86	
—186·8	17·50	5·52	
—181·8	4·25	7·00	
—169·5	6·15	10·20	
—161·7	7·80	12·90	
—151·7	10·40	17·60	
—142·8	13·10	21·70	
—132·7	16·30	27·10	
—130·3	1·25	27·80	
—123·5	1·62	36·00	
—105·7	2·90	64·70 ?	
—66·8	3·23	72·20 ?	

XIX. *Dielectric Constant of Hydropotassic Sulphide* (KHS).

(5 per cent. solution.)

Corrected galvanometer deflection when condenser had air as dielectric = 3·44 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—199·8	10·14	2·86	Condenser charged with 100 volts.
—199·9	10·15	2·86	1,000 ohms in series with galvano-
—197·7	10·15	2·86	meter.
—197·2	10·47	2·95	

XX. *Dielectric Constant of Molybdate of Ammonia.*

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
—202·0	12·55	2·94	Condenser charged to 98·7 volts.
—150·2	4·95	82·80	Condenser charged to 1·434 volts.
—119·4	5·50	90·40	
—88·5	5·80	96·40	

XXI. *Dielectric Constant of Barium Chloride* ($BaCl_2$).

(23 per cent. (cryohydrate) solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·15 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−205·0	11·05	2·62	Condenser charged to 98·8 volts.
−198·2	2·15	2·52	Condenser charged to 19·8 volts.
−173·7	2·25	2·64	
−145·0	6·80	8·20	
−111·0	2·10	35·20	Condenser charged to 1·434 volts.
−101·7	4·05	69·00	
−84·8	9·75	164·20 ?	

XXII. *Dielectric Constant of Cupric Carbonate* ($CuCO_3$).

(10 per cent. in suspension in water.)

Corrected galvanometer deflection when the condenser had air as dielectric = 3·97 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−201·6	10·15	2·48	Condenser charged at 99·0 volts.
−202·0	10·10	2·47	
−198·0	10·10	2·47	
−189·8	10·08	2·46	
−178·3	10·08	2·46	
−168·3	10·15	2·48	
−158·0	10·23	2·50	
−149·2	10·55	2·58	
−146·7	11·40	2·80	
−142·0	2·25	3·02	Condenser charged at 18·2 volts.
−132·7	2·55	3·42	
−124·7	12·00	16·50	
−120·8	1·25	21·80	Condenser charged at 1·434 volts.
−112·9	1·90	33·30	
−104·3	2·70	47·00	
−85·0	3·00	52·60	
−78·5	2·90	50·80	
−69·0	3·20	56·20	

XXIII. *Dielectric Constant of Plumbic Nitrate,* $Pb(NO_3)_2$.

(10 per cent. solution.)

Corrected galvanometer deflection when the condenser had air as dielectric = 4·24 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−200·2	13·12	3·03	Charged to 98·7 volts.
−144·4	2·75	45·20	Charged to 1·434 volts.
−132·0	5·10	83·70	
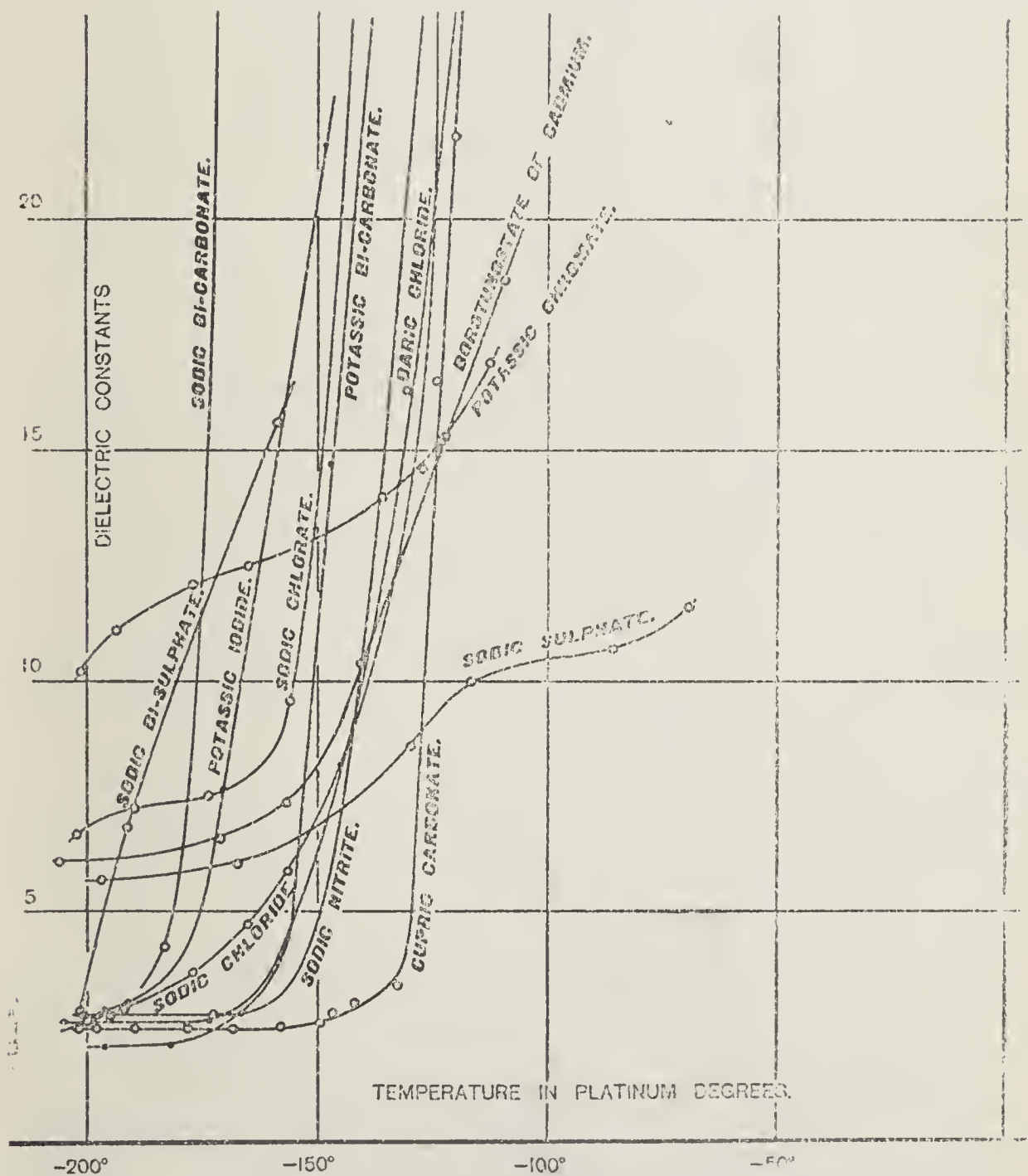
FIG. 1.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

XXIV. *Dielectric Constant of Borotungstate of Cadmium.*

Corrected galvanometer deflection when the condenser had air as dielectric = 4·13 cm. for 100 volts.

Temperature in platinum degrees.	Mean galvanometer deflection in centimetres.	Dielectric constant.	Observations.
−206·0	5·07	6·07	
−171·0	5·50	6·58	
−156·5	6·15	7·37	
−140·5	8·70	10·40	
−122·7	12·65	15·20	
−109·2	15·50	18·70	
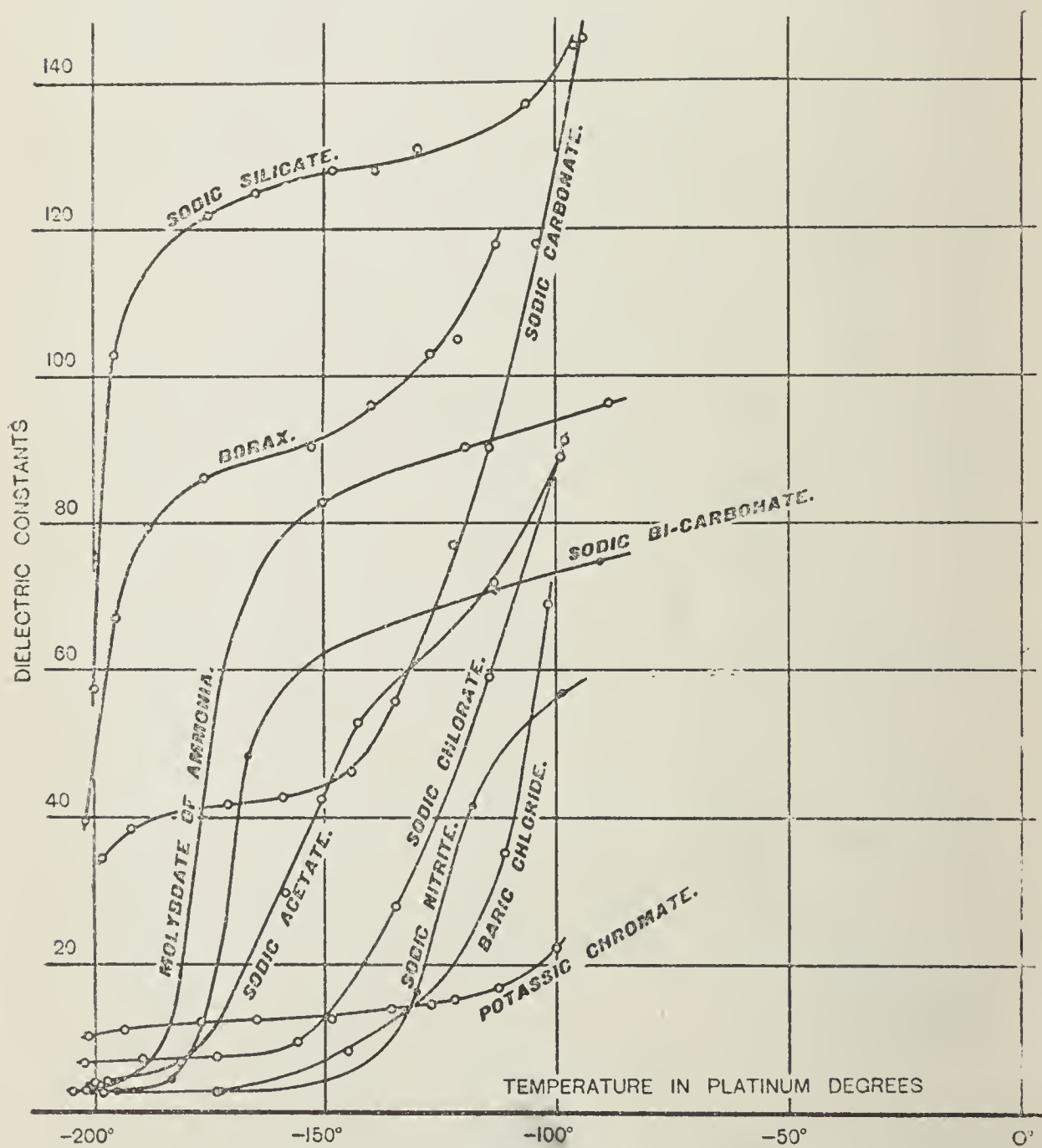
FIG. 2.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

The whole of the observations in the foregoing tables are delineated graphically in the charts in figs. 1, 2, and 3.

In the case of each dielectric measurement a preliminary resistance measurement was generally made to determine the electrical resistance of the frozen electrolyte. It was invariably found that in the case of all the true electrolytic solutions, the electrical resistance of the dielectric at the temperature of liquid air was exceedingly large, generally exceeding many thousands of megohms.

As the temperature of the dielectric rose the electrical resistance fell down, often very quickly, to a fraction of a megohm, and, long before the melting point of the electrolyte was reached, quite considerable conductive power always made its appearance in the frozen electrolytic solution.
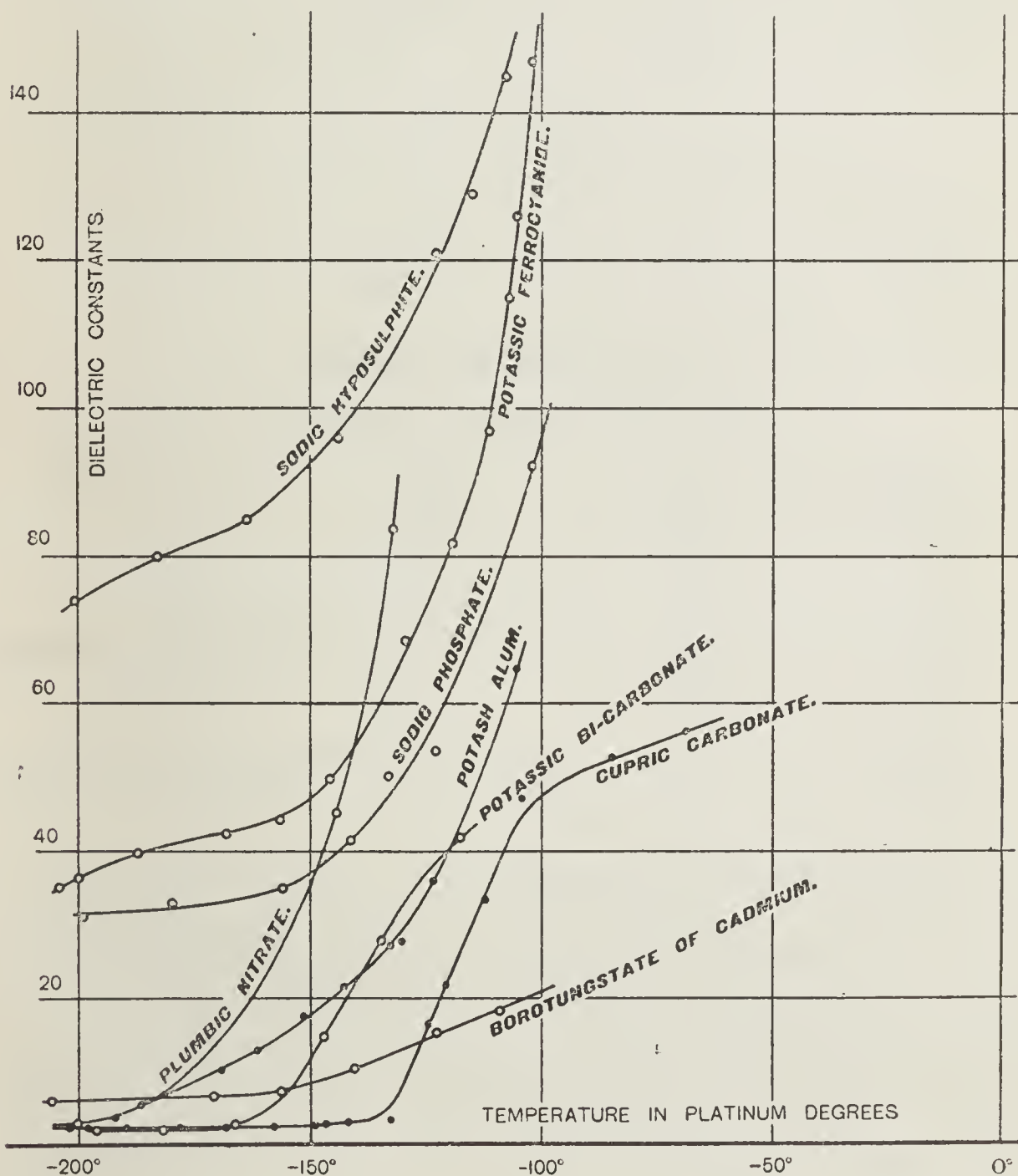

FIG. 3.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

The following tables illustrate the immense change in conductivity taking place in one or two cases within a range of from 10° to 100° :—

Resistance Measurements of Dielectrics at Low Temperatures.

Temperature of condenser in platinum degrees.	Galvanometer deflection in centimetres.	Approximate resistance of the condenser dielectric in megohms.	
Sodic Chloride			
(23·6 per cent. solution in water).			
—203·0	0·2	2500·0	
—125·0	0·4	1250·0	
— 90·5	26·0	02	
Potassium Iodide			
(52 per cent. solution in water).			
—200·0	0·1	5000·0	
—120·0	4·0	1·0	
Potassium Hydrate (KHO)			
(5 per cent. solution in alcohol).			
—187·0	0·1	5000·0	
—185·7	0·5	1000·0	
—183·9	5·0	100·0	
—182·1	10·0	50·0	
—181·5	4·5	11·0	Charging volts changed.
—179·1	12·0	4·0	
—178·5	20·0	3·0	
—176·1	4·0	0·9	Charging volts reduced.
—175·2	7·0	0·5	

The observations in the last table show the rapid rate at which a frozen alcoholic solution of potash increases in conductivity between very narrow limits of temperature, whilst the experiments with the frozen solutions of sodic chloride and potassic iodide show the same kind of change, but less rapid, in the case of aqueous electrolytes.

In each case we have very considerable conductivity in a solid condition far below the melting point of the electrolyte, but, at the same time, exceedingly high resistance at the temperature of liquid air.

On looking at the chart of curves it will be seen that the general

form of the dielectric temperature curve is not unlike the magnetisation curve of a ferro-magnetic body or a vapour tension curve.

In most of the curves there is within a certain range of temperature a fall more or less sudden *from* a high value of the dielectric constant *to* a low value.

As regards the value of the dielectric constants of frozen electrolytes at the temperature of liquid air, the salts employed by us may be divided into three broad classes:—

I. Those which, when added to water in percentages from 5 to 50, *do not much affect the dielectric constant* of the water when it is frozen ; and which, at the temperature of liquid air, have dielectric constants not far from 2·5, or lying between 2 and 3. Such salts are *sodic bicarbonate, sodic bisulphate, potassic bichromate, potassic bicarbonate, sodic chloride, baric chloride, potassic iodide, sodic nitrite, hydropotassic sulphide, cupric carbonate.* These include the acid salts and halogen salts.

II. Those salts which, when added to water in percentages from 5 to 50, *raise the dielectric constant of the water* somewhat and which yield frozen electrolytes, having, at the temperature of liquid air, dielectric constants lying between 3 and 10, that of pure ice at the same temperature being 2·5. Such salts are *potassic chromate, sodic sulphate, sodic chlorate, cadmic borotungstate, sodic acetate, potassium aluminic sulphate, plumbic nitrate.* These are all highly oxygenated salts.

III. Salts which, when added to water in percentages from 5 to 50, yield electrolytes which, if frozen, have *immensely greater dielectric constants*, than pure ice at the temperature of liquid air, viz., values from 30 to 70.

Such salts are *sodic carbonate, sodic biborate, sodic hyposulphite, sodic silicate, hydrodisodic phosphate, potassium ferrocyanide.*

It will be noticed that whenever we have tested a normal salt and an acid salt of the same base, such as a carbonate and a bicarbonate, a chromate and a bichromate, a sulphate and a bisulphate, the acid salt always has the lower dielectric constant of the two at the temperature of liquid air.

With the exception of sodium carbonate, potassium ferrocyanide, and hydrodisodic phosphate, the whole of the dielectric curves seem to be tending downwards in such a way as to show that at somewhat lower temperatures than we have at command, the whole of these frozen electrolytes would have dielectric constants not far from that of pure ice. In other words, would be reduced to values probably near 2 or 3.

There seems now a fair amount of evidence to show that with a

few exceptions all frozen electrolytes would, in all probability, if reduced to temperatures not far above the absolute zero, have their dielectric constants approximately equal, and reduce to a value not far from 2 or 3. At the same time the electric resistivity of such frozen electrolytes would tend to become infinite as the temperature is continuously reduced.

In the very great labour of taking and reducing the above numerous observations, Mr. J. E. Petavel has rendered us much valuable service.

June 17, 1897.

The LORD LISTER, F.R.C.S., D.C.L., President, in the Chair.

Sir W. H. Broadbent, Mr. Charles Chree, Mr. H. J. Elwes, Professor G. B. Howes, Mr. F. S. Kipping, Professor G. B. Mathews, Mr. F. H. Neville, Professor J. M. Thomson, and Professor F. T. Trouton were admitted into the Society.

A List of the Presents received was laid on the table, and thanks ordered for them.

The following Papers were read :—

> I. "An Experimental Research upon Cerebro-cortical Afferent and Efferent Tracts." By DAVID FERRIER, M.D., F.R.S., Professor of Neuropathology, and WILLIAM ALDREN TURNER, M.D.., F.R.C.P., Demonstrator of Neuropathology, King's College, London.

> II. "On the Relative Behaviour of the H and K Lines of the Spectrum of Calcium." By WILLIAM HUGGINS, D.C.L., LL.D., F.R.S., and Mrs. HUGGINS.

> III. "Further Observations of Enhanced Lines." By J. NORMAN LOCKYER, C.B., F.R.S.

> IV. "The Total Solar Eclipse of August 9, 1896. Report on the Expedition to Kiö Island." By J. NORMAN LOCKYER, C.B., F.R.S.

> V. "On the Classification of Stars of the δ Cephei Class." By J. NORMAN LOCKYER, C.B., F.R.S.

> VI. "On the Appearance of the Cleveite and other New Gas Lines in the Hottest Stars." By J. NORMAN LOCKYER, C.B., F.R.S.

VII. "On the Action exerted by certain Metals and other Substances on a Photographic Plate." By W. J. Russell, Ph.D., F.R.S., Lecturer on Chemistry at St. Bartholomew's Hospital.

VIII. "Stress and other Effects produced in Resin and in a Viscid Compound of Resin and Oil by Electrification." By J. W. Swan, F.R.S.

IX. "On Lunar and Solar Periodicities of Earthquakes." By Arthur Schuster, F.R.S.

X. "Cathode Rays and some analogous Rays." By Silvanus P. Thompson, D.Sc., F.R.S.

XI. "Micro-physical Structure of pure Gold and Micro-segregation in Gold Alloys." By Thomas Andrews, F.R.S.

XII. "A Maya Calendar Inscription, interpreted by Goodman's Tables." By Alfred P. Maudslay. Communicated by F. Ducane Godman, F.R.S.

XIII. "Studies in the Morphology of Spore-producing Members. Part III. Marattiaceæ." By F. O. Bower, Sc.D., F.R.S., Regius Professor of Botany in the University of Glasgow.

XIV. "The Vector Properties of Alternating Currents and other Periodic Quantities." By W. E. Sumpner, D.Sc. Communicated by O. Henrici, F.R.S.

XV. "On the Theory of the Magneto-Optic Phenomena of Iron, Nickel, and Cobalt." By J. G. Leathem, B.A., Fellow of St. John's College, Cambridge. Communicated by Sir Robert S. Ball, F.R.S.

XVI. "Some Observations on the Chemistry of the Contents of the Alimentary Tract under various conditions; and on the Influence of the Bacteria present in them." By A. Lockhart Gillespie, M.D., F.R.C.P.(Ed.), F.R.S.E. Communicated by Professor J. G. McKendrick, F.R.S.

XVII. "On a Discontinuous Variation occurring in *Biscutella lævigata*." By Miss E. R. Saunders, Lecturer at Newnham College, Cambridge. Communicated by W. Bateson, F.R.S.

XVIII. "Magnetic Properties of Iron at High Temperatures." By J. Hopkinson, D.Sc., F.R.S.

XIX. "On the Change of Absorption produced by Fluorescence." By John Burke, B.A.(Dub.), Berkeley Fellow of the Owens College, Manchester. Communicated by Professor Arthur Schuster, F.R.S.

XX. "Influence of Acids and Alkalis upon the Electrotonic Currents of Medullated Nerve." By Augustus W. Waller, M.D., F.R.S.

XXI. "On the Distribution of Frequency (Variation and Correlation) of the Barometric Height at diverse Stations." By Karl Pearson, M.A., F.R.S., University College, London, and Miss Alice Lee, Bedford College.

XXII. "On the Openings in the Wall of the Body-cavity of Vertebrates." By E. J. Bles. Communicated by Dr. Hans Gadow, F.R.S.

XXIII. "Electrification of Air, of Vapour of Water, and of other Gases." By Lord Kelvin, G.C.V.O., F.R.S., Magnus Maclean, D.Sc., F.R.S.E., and Alexander Galt, B.Sc., F.R.S.E.

XXIV. "Note on recent Investigations on the Mechanical Equivalent of Heat." By E. H. Griffiths, M.A., F.R.S.

The Society adjourned over the Long Vacation to Thursday, November 18.

"An Investigation on the Variability of the Human Skeleton with especial Reference to the Naqada Race, discovered by Professor Flinders Petrie in his Explorations in Egypt." By Ernest Warren, B.Sc. Communicated by Professor W. F. R. Weldon, F.R.S. Received April 2,—Read June 3, 1897.

(Abstract.)

Charles Darwin was the first to point out the great importance of the study of the nature and causes of variation. Since his time, two methods of investigation have been adopted; in the one the obvious and strongly pronounced variations are selected and the probability of species having been derived from such " sports " is analysed and discussed. According to the second method a population of a species is taken, and the condition of the organs in each individual is determined. It is believed that this latter statistical method will lead to more accurate ideas as to the causes of variation and as to the part which variation has played in the origin of species.

As in all other scientific investigations, the course pursued by statistical inquiry is, firstly, to record facts, and, secondly, to generalise from the facts. The facts consist of the nature of the

variation and the relationships which obtain between one variation and another; these may be expressed by diagrams or by means of a few numerical constants. After the data have thus been expressed in a convenient form, they are examined to see if any legitimate theory or generalisation can be drawn from them. If not, the facts nevertheless possess a value, for light is sure to be shed on them by future investigations, since the subject of variation is still in its infancy.

To obtain an accurate knowledge of the variability displayed by man and the mutual relationships of the different organs is surely a subject of great interest and of both practical and theoretical import-ance. An exceptionally favourable opportunity for studying the variation exhibited by the human skeleton in a fairly homogeneous race was presented by the kindness of Professor Petrie in placing at my disposal the skeletons of the " New Race " which he has recently brought over from Egypt. There were remains of about 400 skeletons.

Although numerous bone-measurements have been made, yet generally the number in each race has been too small to be of any statistical use, and even when fairly numerous measurements have been made on a single race, the results have been dealt with in a very inadequate manner. So far as I am aware, the present investi-gation is the first where the limb-bones have been measured for statistical purposes, and it is also, I believe, the largest series of measurements that have been made on the human skeleton.

The paper deals primarily with the nature of the variation in the length of the limb-bones and of the correlation between the bones. The sacrum and pectoral girdle have also been studied as far as the material would allow. Besides this I have made some observations on the more important ethnological characters which the material exhibited.

The measurements of each bone are recorded in the tables, and these constitute the foundation for all theory, and in the future will be of use for discovering fresh relationships and for correcting any erroneous ideas.

In the following paragraphs some of the more important conclu-sions are briefly recapitulated :—

(1) The variability of the limb-bones is roughly proportional to their absolute length, and hence expressing the variability in terms of the mean we tend to get a constant ratio.

The ratio $\dfrac{\text{standard deviation} \times 100}{\text{mean}}$ fluctuates about 5. We do not admit that this ratio (called the " coefficient of variation ") always expresses the variability of an organ as it concerns the indi-vidual.

(2) The mode of dispersion of the variations about the mean would appear to be distinctly skew, and the range given by the theoretical curves would seem to be generally limited. The frequency curves are steeper on the negative side than on the positive side of the origin, hence there is greater variability towards long bones than towards short bones, that is, abnormality in the direction of giants is greater than in the direction of dwarfs.

(3) The femora of the New Race were strongly pilastric, occasionally they were platymeric, but then the pilastric index[*] was generally low. This observation is in accordance with Professor Manouvrier's statement that platymerism is more frequently exhibited in femora with low than with high pilastric indices.

(4) The length of the head + neck of the femur in proportion to the total length of the bone is greater in man than in woman. I find that in the New Race the angle of the neck with the shaft is larger in woman than in man, though on somewhat scant data the reverse is stated to be the case in Europeans.

(5) In the New Race the angle of torsion of the femur is much greater than in Europeans; it is suggested that this angle may be found to be a race character.

(6) The angle which the condyles of the femur make with the horizontal plane, when the bone is held upright in the maximum position, is greater in woman than in man. This would appear to be due to the greater width of the pelvis. It is suggested that this angle might yield valuable information as to the width of the pelvis in prehistoric peoples.

(7) The tibiæ exhibited platycnemia to a marked degree. A correlation is believed to exist between the flattening of the tibia and the condition of the pilastre of the femur; hence as the pilastric condition would seem to be produced by a vigorous musculature platycnemia may probably be referred to a similar cause, and so it is not an atavistic character.

(8) Perforation of the septum between the olecranon and coronoid fossæ of the humerus was very frequent. Also it occurred more often in the female than in the male, and on the left side than on the right. It is suggested that in man this perforation is frequently incidental, and is due to the impact of the beak of the olecranon against the septum in extension of the arm.

(9) Many of the ulnæ were conspicuously incurved. The olecranon was remarkable for its variation in size.

(10) The femur + tibia is longer on the left side than on the right, while the right humerus + radius is very considerably greater

[*] Pilastric index $= \dfrac{\text{antero-posterior diameter} \times 100}{\text{diameter from right to left}}$. The measurements are taken at the middle of the shaft.

than the left. The difference between the means of the two sides would appear to vary in different races ; also it is distinctly greater in woman than in man.

(11) The absolute correlation between the lengths of the long bones is high, while, on the other hand, the correlation between length and breadth would appear to be weak.

(12) On comparing with the Aino it would seem that serially homologous bones are more strongly correlated with one another than are non-homologous bones. Also the femur and tibia are more closely correlated than the humerus and radius. Distal bones would appear to be somewhat less correlated with one another than are proximal bones, *e.g.*, there is slightly less correlation between the tibia and radius than between the femur and humerus.

In the New Race woman was distinctly less correlated than man.

(13) Sometimes it is desirable to refer the variations to some standard, such as stature. The index-correlations tend to be lower than the absolute correlations. From the results we have obtained it appears doubtful as to what meaning we can attach to the difference between the observed correlation of ratios and Professor Pearson's "spurious correlation."

(14) The New Race approached the Negro in the proportional lengths of the limb-bones to one another, but the sacral and scapular indices were nearly identical with those of Europeans.

"The average Contribution of each several Ancestor to the total Heritage of the Offspring." By Francis Galton, D.C.L., Sc.D., F.R.S. Received and Read June 3, 1897.

In the following memoir the truth will be verified in a particular instance, of a statistical law of heredity that appears to be universally applicable to bisexual descent. I stated it briefly and with hesitation in my book 'Natural Inheritance' (Macmillan, 1889; page 134), because it was then unsupported by sufficient evidence. Its existence was originally suggested by general considerations, and it might, as will be shown, have been inferred from them with considerable assurance. Consequently, as it is now found to hold good in a special case, there are strong grounds for believing it to be a general law of heredity.

I have had great difficulty in obtaining a sufficient amount of suitable evidence for the purpose of verification. A somewhat extensive series of experiments with moths were carried on, in order to supply it, but they unfortunately failed, partly owing to the diminishing fertility of successive broods and partly to the large disturbing effects of differences in food and environment on different

broods and in different places and years.   No statistical results of any consistence or value could be obtained from them.   Latterly, while engaged in planning another extensive experiment with small, fast-breeding mammals, I became acquainted with the existence of a long series of records, preserved by Sir Everett Millais, of the colours during many successive generations of a large pedigree stock of Basset hounds, that he originated some twenty years ago, having purchased ninety-three of them on the Continent, for the purpose. These records afford the foundation upon which this memoir rests.

The law to be verified may seem at first sight too artificial to be true, but a closer examination shows that prejudice arising from the cursory impression is unfounded.   This subject will be alluded to again, in the meantime the law shall be stated.   It is that the two parents contribute between them on the average one-half, or ($0 \cdot 5$) of the total heritage of the offspring; the four grand-parents, one-quarter, or ($0 \cdot 5$)^2; the eight great-grandparents, one-eighth, or ($0 \cdot 5$)^3, and so on.   Thus the sum of the ancestral contributions is expressed by the series $\{(0 \cdot 5) + (0 \cdot 5)^2 + (0 \cdot 5)^3, \&c.\}$, which, being equal to 1, accounts for the whole heritage.

The same statement may be put into a different form, in which a parent, grandparent, &c., is spoken of without reference to sex, by saying that each parent contributes on an average one-quarter, or ($0 \cdot 5$)^2, each grandparent one-sixteenth, or ($0 \cdot 5$)^4, and so on, and that generally the occupier of each ancestral place in the nth degree, whatever be the value of n, contributes ($0 \cdot 5$)^{2n} of the heritage.

In interbred stock there are always fewer, and usually far fewer, different individuals among the ancestry than ancestral places for them to fill.   A pedigree stock descended from a single couple, m generations back, will have 2^m ancestral places of the mth order, but only two individuals to fill them; therefore if $m = 10$ there are 1024 such places; if $m = 20$ there are more than a million.   Whenever the same individual occupies many places he will be separately rated for each of them.

The neglect of individual prepotencies is justified in a law that avowedly relates to average results; they must of course be taken into account when applying the general law to individual cases.   No difficulty arises in dealing with characters that are limited by sex, when their equivalents in the opposite sex are known, for instance in the statures of men and women.

The law may be applied *either* to total values or to deviations, as will be gathered from the following equation.   Let M be the mean value from which all deviations are reckoned, and let D_1, D_2, &c., be the means of all the deviations, including their signs, of the ancestors in the 1st, 2nd, &c., degrees respectively; then

$$\tfrac{1}{2}(M + D_1) + \tfrac{1}{4}(M + D_2) + \&c. = M + (\tfrac{1}{2}D_1 + \tfrac{1}{4}D_2 + \&c.)$$

It should noted that nothing in this statistical law contradicts the generally accepted view that the chief, if not the sole, line of descent runs from germ to germ and not from person to person. The person may be accepted on the whole as a fair representative of the germ, and, being so, the statistical laws which apply to the persons would apply to the germs also, though with less precision in individual cases. Now this law is strictly consonant with the observed binary sub-divisions of the germ cells, and the concomitant extrusion and loss of one-half of the several contributions from each of the two parents to the germ-cell of the offspring. The apparent artificiality of the law ceases on these grounds to afford cause for doubt; its close agreement with physiological phenomena ought to give a prejudice in *favour* of its truth rather than the contrary.

Again, a wide though limited range of observation assures us that the occupier of each ancestral place *may* contribute something of his own personal peculiarity, apart from all others, to the heritage of the offspring. Therefore there is such a thing as an average contribution appropriate to each ancestral place, which admits of statistical valuation, however minute it may be. It is also well known that the more remote stages of ancestry contribute considerably less than the nearer ones. Further, it is reasonable to believe that the contributions of parents to children are in the same proportion as those of the grandparents to the parents, of the great-grand-parents to the grandparents, and so on; in short, that their total amount is to be expressed by the sum of the terms in an infinite geometric series diminishing to zero. Lastly, it is an essential condition that their total amount should be equal to 1, in order to account for the whole of the heritage. All these conditions are fulfilled by the series of $\frac{1}{2} + \frac{1}{2}^2 + \frac{1}{2}^3 +$ &c., and by no other. These and the foregoing considerations were referred to when saying that the law might be inferred with considerable assurance *à priori*; consequently, being found true in the particular case about to be stated, there is good reason to accept the law in a general sense.

The Bassets are dwarf blood-hounds, of two, and only two, recognised varieties of colour. Excluding, as I have done, a solitary exception of black and tan, they are either white, with large blotches ranging between red and yellow, or they may in addition be marked with more or less black. In the former case they are technically known and registered as "lemon and white," in the latter case as "tricolour." Tricolour is, in fact, the introduction of melanism, so I shall treat the colours simply as being "tricolour" or "non-tri-colour;" more briefly, as T. or N. I am assured that transitional cases between T. and N. are very rare, and that experts would hardly ever disagree about the class to which any particular hound should be assigned. A stud-book is published from time to time

containing the pedigrees, dates of birth, and the names of the breeders of these valuable animals.   The one I have used bears the title 'The Basset Hound Club Rules and Stud-Book,' compiled by Everett Millais, 1874–1896.   It contains the names of nearly 1000 hounds, to which Sir Everett Millais has very obligingly, at my request, appended their colours so far as they have been registered, which during later years has almost invariably been done.   The upshot is that I have had the good fortune to discuss a total of 817 hounds of known colour, all descended from parents of known colour. In 567 out of these 817, the colours of all four grandparents were also known.   These two sets are summarised in Table I and discussed in Table V, and they afford the data for Tables II, III, and IV.   In 188 of the above cases the colours of all the eight great-grandparents were known as well; this third set is discussed in Table VI.

Partly owing to inequality in the numbers of the tricolours and non-tricolours, and partly owing to a selective mating in favour of the former, the different possible combinations of T. and N. ancestry are by no means equally common.   The effect of this is conspicuous in Table I, where the entries are huddled together in some parts and absent in others.   Still, though the data are not distributed as evenly as could be wished, they will serve our purpose if we are justified in grouping them without regard to sex; or, more generally, if we treat the 2^n components of each several A_n, whatever be the value of n, as equally efficient contributors.

Our first inquiry then must be, "Is or is not one sex so markedly prepotent over the other, in transmitting colour, that a disregard of sex would introduce statistical error?"   In answering this, we should bear in mind a common experience, that statistical questions relating to sex are very difficult to deal with.   Large and unknown disturbing causes appear commonly to exist, that make data which are seemingly homogeneous, very heterogeneous in reality.   Some of these are undoubtedly present here, especially such as may be due to individual prepotencies combined with close interbreeding.   For although this pedigree stock originated in as many as ninety-three different hounds, presumably more or less distant relations to one another, some of them proved of so much greater value than the rest that very close interbreeding has subsequently been resorted to in numerous instances.   In order to show the danger of trusting blindly to averages of sex, even when the numbers are large, I have compared the results derived from different sets of data, namely from those contained in the last two columns of Table I, where they are distinguished by the letters A and B, and have treated them both separately and together in Table II.   They will be seen to disagree widely, concurring only in showing that the dam is prepotent over the sire in transmitting colour.   According to the A data, their

relative efficacy in this respect is as 58 to 51, say 114 to 100 ; according to the B data, it is as 47 to 32, say 147 to 100. Taking all the data together, it is as 54 to 45, say 120 to 100, or as 6 to 5.

It does not seem to me that this ratio of efficacy of 6 to 5 is sufficient to overbear the statistical advantages of grouping the sexes as if they were equally efficient, the error in one case being more or less balanced by an opposite error in the other. It is true that the reciprocal forms of mating are by no means equally numerous, the prevailing tendency to use tricolours as sires being conspicuous. Still, as will be found later, on the application of a general test, the error feared is too insignificant to be observed. Should, however, a much larger collection of these data be obtained hereafter, minutiæ ought to be taken into account which may now be disregarded, and the neglect of female prepotency would cease to be justified.

The law to be verified supposes all the ancestors to be known, or to be known for so many generations back that the effects of the unknown residue are too small for consideration. The amount of the residual effect, beyond any given generation, is easily determined by the fact that in the series $\frac{1}{2} + \frac{1}{4} + \frac{1}{8}$, &c., each term is equal to the sum of all its successors. Now in the two sets of cases to be dealt with the larger refers to only two generations, therefore as the effect of the second generation is $\frac{1}{4}$, that of the unknown residue is $\frac{1}{4}$ also. The smaller set refers to three generations, leaving an unknown residual effect of $\frac{1}{8}$. These large residues cannot be ignored, amounting, as they do, to 25 and 12·5 per cent. respectively. We have, therefore, to determine fixed and reasonable rules by which they should be apportioned.

The requisite data for doing this are given in Table III, which shows that 79 per cent. of the parents of tricolour hounds are tricolour also, and that 56 per cent. of the parents of non-tricolour hounds are tricolour. It is not to be supposed that the trustworthiness of these results reaches to 1 per cent., but they are the best available data, so I adopt them.

It will be convenient to use the following nomenclature in calculation :—

a_0 stands for a single member of the offspring.

a_1 for a single parent; a_2 for a single grandparent, and so on, the suffix denoting the number of the generation. A parallel nomenclature, using capital letters, is :—

A_0 stands for all the offspring of the same ancestry.

A_1 for the two parents ; A_2 for all the four grandparents, and so on. Consequently A_n contains 2^n individuals, each of the form a_n, and A_n contributes $(0.5)^n$ to the heritage of each a_0; while each a_n contributes $(0.5)^{2n}$ to it.

In the upper part of Table IV the ratios are entered of the average

contributions of T. supplied by *known* ancestors. Nothing further need be said about these, except that they are styled coefficients because they must be multiplied into the total number of offspring, in order to calculate the number of them that will, on their separate and independent accounts, be probably tricolours.

We have next to explain how the coefficients for the *unknown* ancestry have been calculated, namely, those which are entered in the lower part of Table IV. Suppose all the four grandparents, A_2, to be tricolour, then only 0.79 of A_3 will be tricolour also, $(0.79)^2$ of A_4, and so on. These several orders of ancestry will respectively contribute an average of tricolour to each a_0 of the amounts of $(0.5)^3 \times (0.79)$, $(0.5)^4 \times (0.79)^2$, &c. Consequently the sum of their tricolour contributions is

$$(0.5)^3 \times (0.79) \{1 + (0.5) \times (0.79) + (0.5)^2 \times (0.79)^2 + \&c.\},$$

which equals 0.1632. The average tricolour contribution from the ancestry of *each* of the four tricolour grandparents must be reckoned as the quarter of this, namely, 0.0408.

By a similar process, the average tricolour contribution from the ancestry of *each* non-tricolour grandparent is found to be 0.0243.

When the furthest known generation is that of the great-grandparents, the formula differs from the foregoing only by substituting $(0.5)^4 \times (0.79)$ for $(0.5)^3 \times (0.79)$. This makes the average tricolour contribution from the ancestry of the whole eight tricolour great-grandparents equal to 0.08160, and that from the ancestry of *each* of them to be one-eighth of this, or 0.0102.

In a similar way the tricolour contribution from the ancestry of *each* non-tricolour great-grandparent is found to be 0.0061.

The following example shows how the coefficients in Table IV were utilised in calculating the general coefficients entered in Table V.

2 Parents, T_1 (personal)	0.5000
3 Grandparents, T_2 (personal)	0.1875
1 Grandparent, N_2 (personal)	—
3 Grandparents, T_2 (ancestral).......	0.1224
1 Grandparent, N_2 (ancestral)	0.0243
Total tricolour contribution ..	0.8342

The coefficient 0.83 will consequently be found under the appropriate head in Table V, where the total number of offspring ("all cases") is recorded as 119. By multiplying these together, viz., 0.83×119, the "calculated" number of 99 is obtained. It will be seen that the observed number was 101, a difference of only 2 per cent.

The extraordinarily close coincidence throughout the two tables,

V and VI, between calculation and observation, proves that the law is correct in the present instance, and that the principle by which the unknown ancestry was apportioned, is practically exact also. It is not so strictly exact as it might have been, because the whole of the available knowledge has not been utilised. The 0·79 applied to A_4, &c., requires some small correction according to the known colours of the *offspring* of A_3. If they had been all tricolour the 0·79 would have to be increased; if all non-tricolour, it would have to be diminished. Having insufficient data to check a theoretical emendation, I note its omission, but shall not discuss the matter further.

It will be easily understood from these remarks how *collateral* data are to be brought into calculation, for if the collaterals were more tricolour than the average of hounds, the 0·79 would have to be somewhat increased (but not beyond the limiting value of 1·00); if less tricolour than the average, the 0·79 would have to be diminished. The knowledge of collaterals would be superfluous, if that of the direct ancestry were complete, but this important prolongation of the present subject must not be considered further on this occasion.

There are three stages in Tables V and VI at which comparisons may be made between calculated results and observed facts.

(1) *The Grand Totals.*—In Table V the sum of all the calculated values amounts to 391; that of all the observed ones to 387, which are closely alike. In Table VI they amount to 180 and 181 respectively, which is a still closer resemblance. Consequently the calculations are practically exact *on the whole,* and the error occasioned by neglect of sex, &c., is insignificant.

(2) *The Subordinate Pairs of Totals.*—These are entered at the sides of the tables, and are nine in number, namely, 236, 239; 149, 139; 6, 9; 53, 56; 52, 56: 9, 9; 8, 6; 49, 46; 9, 8. The coincidences are striking, in comparison with such results as statisticians have usually to be contented with; the second pair, 149, 139, is the least good, and will be considered in the next paragraph.

(3) *Individual Pairs of Entries.*—There are 32 of these; here also calculation compares excellently well with observation, excepting in the line that furnishes the " subordinate totals " of 149, 139, where the " all cases " of 37, 158, 60 yield the tricolour contingents of 20, 79, 36. Dividing each tricolour by the corresponding "all cases," we obtain what may be called " Coefficients from Observation," to compare with the calculated coefficients. They are as follows :—

			Diff.		Diff.	
Coefficients from observation	54	(−4)	50	(+10)	60
,, ,, calculation	66	(−8)	58	(−7)	51

The great irregularity of the entries in the upper line shows that the observed values cannot be accepted as true representa-

tives of the normal condition. I have not unravelled the causes of this error, and it is not urgent to do so, since its ill effects are swamped by the large number of successes elsewhere.

In order to satisfy myself that the correspondence between calculated and observed values was a sharp test of the correctness of the coefficients, I made many experiments by altering them slightly, and recalculating. In every case there was a notable diminution in the accuracy of the results. The test that the theory has successfully undergone appeared on that account, to be even more searching and severe than I had anticipated.

It is hardly necessary to insist on the importance of possessing a correct law of heredity. Vast sums of money are spent in rearing pedigree stock of the most varied kinds, as horses, cattle, sheep, pigs, dogs, and other animals, besides flowers and fruits. The current views of breeders and horticulturists on heredity are contradictory in important respects, and therefore *must* be more or less erroneous. Certainly no popular view at all resembles that which is justified by the present memoir. A correct law of heredity would also be of service in discussing actuarial problems relating to hereditary longevity and disease, and it might throw light on many questions connected with the theory of evolution.

Table I.—Pedigrees of Parental and Grand Parental Colours (Tricolour (T) or Non-Tricolour (N)).

The Sex of the Ancestors is taken into Account, but not that of the Offspring.

Sire	Dam	Offspring	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	Totals A	Others of which all G.P.'s are not known. B
Sire's sire			T	T	T	T	T	T	T	T	N	N	N	N	N	N	N	N		
Sire's dam			T	T	N	N	T	T	N	N	T	T	N	N	T	T	N	N		
Dam's sire			T	T	T	T	N	N	N	N	T	T	T	T	N	N	N	N		
Dam's dam			T	N	T	N	T	N	T	N	T	N	T	N	T	N	T	N		
Tric.	Tric.	Tric.	106	38	47	12	12	7	2	4	3	.	3	4	.	.	.	.	239	87
		Non-T.	13	4	12	2	2	1	1	.	.	.	.	3	.	.	.	.	38	20
Tric.	Non-T.	Tric.	.	.	16	3	.	.	1	.	3	.	.	.	1	1	.	.	25	15
		Non-T.	.	.	6	1	.	.	3	.	2	.	.	4	1	1	.	.	18	17
Non-T.	Tric.	Tric.	20	45	4	20	11	4	4	.	.	2	.	3	1	.	.	.	114	30
		Non-T.	17	50	16	9	5	.	1	1	.	8	.	1	1	.	.	.	109	64
Non-T.	Non-T.	Tric.	.	.	.	2	.	.	.	.	.	5	.	1	.	1	.	.	9	11
		Non-T.	.	.	.	8	.	.	.	4	.	3	.	.	.	.	.	.	15	6
Totals			156	138	101	57	30	12	12	9	8	18	3	16	4	3	.	.	567	250

Table II.—Offspring of one parent Tricolour (T) and of one Non-tricolour (N).   The sex of the parents is not regarded.

From Table I.		Observed.			Per cents.	
		Tricolour.	Non-tricolour.		Tricolour.	Non-tricolour.
Sire T, dam N	A	114	109	223	51	49
	B	30	64	94	32	68
	Sum	144	173	317	45	55
Dam T, sire N	A	25	18	43	58	42
	B	15	17	32	47	53
	Sum	40	35	75	54	46

Table III.—Distribution of T and N colour in Parents, when the Offspring are T and N respectively.

From Table I.		No. of T offspring.			Parents* of T offspring.	
Sires.	Dams.	A.	B.	Total.	T.	N.
T	T	239	87	326	652	0
T	N	25	15	40	40	40
N	T	114	30	144	144	144
N	N	9	11	20	0	40
Totals				530	836	224
Per cent. of parents*				50	79	21

From Table I.		No. of N offspring.			Parents* of N offspring.	
Sires.	Dams.	A.	B.	Total.	T.	N.
T	T	38	20	58	116	0
T	N	18	17	35	35	35
N	T	109	64	173	173	173
N	N	15	6	21	0	42
Totals				287	324	250
Per cent. of Parents*				50	56	44

*   More properly "Parental Places"; the number of these, though not that of the individual parents, being always double the number of any group of offspring.

Table IV.—Tricolour coefficients.

	Ancestry known up to and inclusive of	
	Grandparents.	Great-grandparents.
Personal allowance of T for each		
Tricolour parent	0·2500	0·2500
„ grandparent	0·0625	0·0625
„ great-grandparent	—	0·0156
(No allowance for Non-tricolours.)	—	—
Ancestral allowance of T for each		
Tricolour grandparent	0·0408	—
Non-tricolour „	0·0243	—
Tricolour great-grandparent	—	0·0102
Non-tricolour „ „	—	0·0061

Table V.—Calculation and Observation Compared.

The pedigrees are utilised up to the second ascending generation. Sex not taken into account.

No. of tricolours in parents.		Number of tricolours in grandparents.				Total tricolour offspring.	
		4	3	2	1	Calculated.	Observed.
		a	*bcei*	*dfgjkm*	*hlno*		
2	All cases	119	119	28	11		
	Coefficient	0·91	0·83	0·76	0·68		
	Tricolour calc'd.	*108*	*99*	*21*	*8*	*236*	
	„ observed	106	101	24	8		239
1	All cases	37	158	60	6		
	Coefficient	0·66	0·58	0·51	0·43		
	Tricolour calc'd.	*24*	*92*	*30*	*3*	*149*	
	„ observed	20	79	36	4		139
0	All cases	..	..	18	6		
	Coefficient	..	..	0·26	0·18		
	Tricolour calc'd.	..	..	*5*	*1*	*6*	
	„ observed	..	..	7	2		9
	Grand totals					*391*	387

Table VI.—Calculation and Observation Compared.

The pedigrees are utilised up to the third ascending generation.
Sex not taken into account.

No. of tricolours in parents.	in grand-parents.		Number of tricolours in great-grandparents.					Total tricolour offspring. Calculated.	Observed
			8	7	6	5	4		
2	4	All cases	2	25	14	16			
		Coefficient	0·96	0·94	0·92	0·90			
		Tricolours calc'd.	2	24	13	14	..	53	
		,, observed	2	25	14	15	..		56
	3	All cases	..	18	21	16	6		
		Coefficient	..	0·87	0·85	0·83	0·81		
		Tricolours calc'd.	..	16	18	13	5	52	
		,, observed	..	17	19	14	6		56
	2	All cases	..	3	2	3	3		
		Coefficient	..	0·81	0·79	0·77	0·75		
		Tricolours calc'd.	..	2	3	2	2	9	
		,, observed	..	2	2	3	2		9
1	4	All cases	..	2	1	9			
		Coefficient	..	0·69	0·67	0·65			
		Tricolours calc'd.	..	1	1	6	..	8	
		,, observed	..	1	..	5	..		6
	3	All cases	1	28	14	31	9		
		Coefficient	0·64	0·62	0·60	0·58	0·56		
		Tricolours calc'd.	1	17	8	18	5	49	
		,, observed.	1	16	12	8	9		46
	2	All cases	..	..	4	13			
		Coefficient	..	..	0·54	0·52			
		Tricolours calc'd.	..	..	2	7	..	9	
		,, observed	..	..	1	7	..		8
		Grand totals ..						180	181

The summed data derived from Table IV, form the coefficients entered in Tables V and VI. These are multiplied into the corresponding number of " all cases," and the result gives the " calculated " number of tricolour hounds among them.

The entries of "all cases" and of "tricolours observed" in Table V are deduced from Table I, by combining the appropriate columns. The letters at the top show which columns are combined.

Seven other observed cases, disposed in three groups, are scattered beyond the limits of Table VI; two of these seven cases are tricolour.

"Further Note on the Influence of a Magnetic Field on Radiation Frequency." By OLIVER LODGE, F.R.S., assisted by Mr. BENJAMIN DAVIES. Received May 19,—Read June 3, 1897.

Referring to a former communication of mine, on the subject of Zeeman's discovery, printed on page 513 of the 'Proceedings of the Royal Society' for February 11 this year, vol. 60, No. 367, I wish to add an observation to those previously recorded, as I have recently acquired a concave Rowland grating ($3\frac{1}{2} \times 1\frac{1}{2}$-inch ruled surface, 14,438 lines to inch, 10 feet radius of curvature, being the one used by Mr. George Higgs), of which the spectra of the first and third orders on one side are very satisfactory.

It is said on page 513, "If the focussing is sharp enough to show a narrow, dark reversal line down the middle of each sodium line, that dark line completely disappears when the magnet is excited." With the greater optical power now available the dark reversal line is often by no means narrow, and though in some positions of the flame it does still tend to disappear or become less manifest when the flame is subjected to a concentrated magnetic field, the reason of its partial disappearance is that it is partially reversed again—*i.e.*, that a third bright line, as it were, makes its appearance in the midst of the dark line, giving a triple appearance to each sodium line.

More completely stated the phenomena are as follows:—After obtaining each sodium line with a prominently double aspect by manipulating the flame, the magnet is excited, and the dark band in the midst of each sodium line is then seen to widen out considerably in the region of most intense magnetisation, while a bright intrusion line makes its appearance. On closer examination this new line is seen to be double, by reason of a dark division down its middle; and I apprehend that with still more magnetic power this dark band might itself open out into two; but this last phenomenon I have not yet observed.

The whole sodium group is thus seen as if it were octuple. The effect is not due to a mere mechanical disturbance or rearrangement of the gases of the flame by the agency of magnetism; because a

nicol, placed in the rays emanating transversely to the magnetic lines of force, cuts off nearly all the visible magnetic effect when oriented so as to get rid of light whose plane of polarisation contains the lines of force—that is, of oscillations or revolutions whose electrical components are across or around the magnetic lines. That it does not cut off every trace of the effect appears to be due to the fact that the field of force is not strictly uniform, and so its lines are not strictly parallel.

. The following is a summary of the different appearances that may be seen according to the state of the flame and the strength of the field :—

At low temperature, and with the flame forward in the field, when each sodium line is sharp and single, magnetism widens it, and with a little more power doubles it, causing a distinct dark line down its middle. The same effect occurs with lithium and thallium lines.

At higher temperature, and with the flame partially behind the field, when each sodium line appears as a broad hazy-edged double, magnetisation greatly widens the doubling, pushing asunder the bright components very markedly; stronger magnetisation reverses the middle of the widened dark band, giving a triple appearance; stronger magnetisation still reverses the middle once more, giving a quadruple appearance to the line. In every case a nicol, suitably placed, cuts off all the magnetic effect and restores the original appearance of the line.

A curious circumstance is that although both lines, D_1 and D_2, show the effect, D_1, *i.e.*, the less refrangible line, shows it best and most sharply. I should describe the effect on D_2 as a coarse widening of considerable amount, but without very clear definition; whereas the widening of D_1, though perhaps no greater in amount, is decidedly better defined. There is no doubt but that, with my grating, D_1 is the line at which one finds oneself usually looking in order to see the details of the change best; and I can hardly suppose this to be subjective to the grating. I hope to show the effects at the soirée next Wednesday.

[The same thing is seen when salts of lithium or of thallium are introduced into the flame; and the components of the doubled red lines are more widely separated than the components of the doubled green lines, the effect being proportional to wave-length. The most interesting line to try was the red cadmium line, since this has been proved to be of specially simple constitution by Michelson. We have recently been able to get the cadmium spectrum well developed by means of a sort of spark arc between the magnet poles, maintained by an induction coil excited by an alternating machine; and we find that the magnetic doubling of the chief lines occurs in

precisely the same way with the spark spectrum as with the flame spectrum, and that the red cadmium line behaves in the same way as the others. The magnetic effect is better seen, from a direction perpendicular to the line of force, when a nicol is interposed in the path of the light, but rotation of the nicol through 90° cuts it entirely off, accurately so when a small spark is the source of light.—May 31.]

Fifth Report to the Royal Society Water Research Committee.

By H. Marshall Ward, Sc.D., F.R.S., F.L.S., Professor of Botany in the University of Cambridge. Presented to the President and Council, December 10, 1896.

(Abstract.)

The following is a short *résumé* of the principal points resulting from three years' study of the Bacterial Flora of the Thames.

All the forms have been grown on gelatine, agar, and potato, as well as in broth, milk, and sugar-solutions, and some of them in special media in addition. Moreover, most of them have been cultivated in hanging drops under the microscope, sometimes isolated and under high powers, for long periods, and the course of development of the colonies traced in detail in several cases, and even when this could not be successfully carried to a conclusion, information as to the changes and growth of the organisms has been obtained, which helps to throw light on their behaviour and relationships.

This work has occupied a long time, and these water bacteria do little beyond growing and dividing, so that in many respects this part of the work only starts problems for the future. In some cases, however, the morphological changes observed are helpful in explaining the macroscopic appearances of the colonies, and in any case it is clear that no examination of a bacterium can be considered complete until its life-history has been traced under the microscope.

The number of forms isolated and cultivated amount to eighty, not counting the large number which were either rejected at an early stage as certainly duplicates, or lost during cultivation.

Of these eighty forms some have been distinctly recognised as well known types, *e.g.*, *Bacillus membranaceus amethystinus* (Eis.), *B. fluorescens liquefaciens* (Fl.), *B. fluorescens non-liquefaciens* (Fl.), *B. coli commune*, *Proteus vulgaris* (Haus.), *Bacillus arborescens* (Fr.), *B. prodigiosus* (Ehr), *B. termo* (Cohn), *B. subtilis*, and *Sarcina lutea*.

Others have been referred with less certainty to less well known forms, such as *Bacterium ureæ* (Jaksch), *B. fulvus* (Zimm.), *B. aureus* (Adam.), *Ascococcus* (Cohn), *Micrococcus carneus* (Zimm.), and *M. candicans* (Fl.).

The remainder are either new, or only doubtfully identified as already described forms, or evidently varieties of some of the foregoing.

During the progress of the cultures, large numbers of coloured drawings were made, with the intention of affording means of identification, but it was found that variations are so numerous and so large, that some study of these variations had to be undertaken.

This led to an investigation of the growth of the colonies in gelatine and other media, and an attempt to explain why, and how far, the colonies vary in culture. This necessitated a careful examination of the factors concerned in the development of the shapes, markings, movements, and so forth of the colonies themselves, and to a classification of the characters furnished by these colonies.

One outcome of the above studies was the conviction that two sets of factors are at work in causing the variations found in the colonies. First, the slight variations in the food-materials, temperature, moisture, &c., which cannot be avoided, however carefully the work is done; and, second, variations in the bacterium cell itself as it comes from the river, owing to the exigencies it has been subjected to during its sojourn there. The water of the river is, in fact, a very dilute and indefinite food-solution, and just as changes occur when we remove a bacterium from broth to milk or to gelatine, so do such result when we transfer from the river to these media, and the changes induced in all cases depend on how long the bacterium has been in the one medium or the other, as well as upon other factors.

The river water is a very poor food medium, and so we cannot be surprised that in many cases the recently isolated bacteria behave as weakened forms; the recognition of these enfeebled varieties suggests explanations of many of the bad "species" in the literature of water bacteria. My work goes to show, not that species cannot be made out, but that the limits of the species are, in most cases, far wider than is assumed in descriptions—in other words, that many so-called species in the books are merely varietal forms, whose characters, as given, are not constant, but depend on treatment. How far this is true for any given case will have to be tested on the particular form in question.

Very slight variations in rapidity of growth of the individual bacterium, its power of liquefaction, pigment production, capacity of fermenting, and so on, lead to comparatively very great differences in the appearance of the colonies formed in a given time on, or in, a medium like gelatine, the composition, aëration, hygroscopicity,

density, &c., of which is changing all the time, and since every variation in temperature, light, air-supply, &c., affects the matter also, I find abundant causes for the variations which otherwise appear so astonishing. It results, therefore, that the attempt to determine species of bacteria by ordinary macroscopic methods leads to difficulties of the same kind as would be met if we tried to differentiate species from the marks presented by masses of trees in forests from a distance—say in a balloon. A forest of a given species of tree would appear very different at different seasons, and according to its age, the kind of soil, climate, and so on, and the treatment it had received previous to planting.

In order to emphasise my own impressions of the specific value of the forms isolated, and at the same time leave it clear what are the differences between the various forms or varieties themselves, I have grouped them into types. Each group contains a type which I regard as probably a species, of which the other forms included are varieties. These varieties are fully described and figured, and would certainly be regarded as species in most books consulted. The reasons for grouping them as I have done are fully discussed with the literature under each. Here, of course, I can only give a very brief summary of the groups as follows :—

Group I is made to contain a form which appears to be identical with the *Bacterium ureæ* of Jaksch, and forming curiously character- istic dull stearine-like plate colonies. It was not uncommon in the river, but the want of salient features rendered it comparatively uninteresting, and no prolonged study of other varieties of it was undertaken.

Group II was constituted for a type which in certain cultures develops an intense violet colour exactly like that of a strong solution of gentian violet. It was not common—at any rate in the typical form—but it was easily cultivated, and two varieties were isolated and kept under observation for many months.

The type accords best with Jolles and Eisenberg's *B. membrana- ceus amethystinus*, and forms the deep blue violet zooglœa-membrane described for that species, but three years' study of the variations in culture convinces me that several violet bacilli described in the literature are identical with this, or at least cannot be separated by the characters given.

A marked tendency to lose its power of forming pigment, and to grow as a pure white form, characterises this bacillus. It is the species with which I obtained the bacterial photographs exhibited in 1894, and is very sensitive to light. The spectroscopic characters of the pigment were determined, and the bacillus itself cultivated under high powers.

Group III comprises the common *B. fluorescens liquefaciens*, very

abundant in the river. Four varieties were isolated and cultivated. It is the same as that previously described by P. Frankland as *B. viscosus*, and by Sehmolck as *B. fluorescens nivalis*. Some of the varieties liquefied very feebly or not at all, suggesting that *B. fluorescens non-liquefaciens* may be only a form of the present species, a conclusion borne out by comparing the two side by side, on, and in, various media.

Group IV comprises the non-liquefying forms of the type *B. fluorescens non-liquefaciens*, extremely common in the river, and of which eight were isolated and kept in culture.

These eight varieties differ in details, but the differences are not constant, and their behaviour suggests the identity of several so-called species of green fluorescing bacteria, hitherto regarded as distinct, *e.g.*, the Bacillus of Lesage, that of Adametz, Lustig's *B. aquatilis fluorescens*, Flugge's *B. fluorescens putidus*, and certain forms described by Frick and Zimmermann.

The fact that some of these varieties were pathogenic and some not, points to the possibility of there being two species, but as experience shows that pathogenicity varies as well as other characters, this could not be relied on, any more than the differences in size, colour, &c.

Group V embraces a large series of forms comprising the typical *B. coli communis* and a number of varietal and allied forms. In all sixteen varieties were studied in detail, some of them very closely and for long periods. They are common in the river, especially in summer, though some of the forms show variations so marked that few observers would be likely to suspect their close relationships. For instance, varieties occurred incapable of coagulating milk; others which formed no gas-bubbles in gelatine; others not pathogenic for guinea-pigs. Some other forms, suspiciously like *B. coli* in other respects, but forming capsules, or liquefying gelatine to a greater or less extent, are placed in different groups in deference to usually received opinion, though I am convinced of their close relationship.

High-power cultures show considerable differences in size of rodlets, and facts were obtained of value in understanding the very great differences observed in the macroscopic characters.

Group VI comprises a series of forms centering around the type of Hauser's *Proteus vulgaris*, and of which eleven forms were isolated and cultivated.

One of the most striking features of this type is its variability as to liquefying power; another is the concurrent variations in motile power of the plate-colonies. I recognised the types named *P. mirabilis* and *P. proteus* by Hauser, and during cultures extending over three years have convinced myself that not only are these and his *P. Zenkeri* merely varieties of the same form differing in liquefying

power, but that they vary in several directions towards powerfully liquefying forms of the *B. termo* type, on the one hand, and yellow chromogenic forms, like Zimmermann's *B. ochraceus* and P. Frankland's *B. arborescens*, on the other.

A careful and prolonged study of the plate-colonies and " wandering islets " was made under high powers, throwing light not only on the movements of these colonies over the surface of the gelatine, but also on the structure of all such colonies as are composed of tresses, zoogloea-clumps, and contoured groups of filaments, motile or not.

Drawings were made illustrating the movements and changes in form of the " wandering islets " at intervals, and showing the individual movements of the bacilli on which these depend. Evidence is also given showing that the differences in size, vigour of movement, and liquefaction, and chromogenic power, depend on the vigour of the organism as it comes from the river, as well as on variations in conditions of culture.

Group VII includes seven forms evidently closely allied to the last group, if really distinct. They are remarkable for their more or less pronounced yellow pigment formation, and are termed the yellow Proteus type.

I have identified some of the varieties here collected together as Zimmermann's *B. radiatus* and *B. ochraceus* and P. Frankland's *B. arborescens*, and there can be little doubt that other yellow chromogenic forms described will have to be included. Among these, a number of "non-liquefying" yellow forms may also have to be counted when they have been sufficiently studied in detail.

Group VIII includes a form which varied so much that I had to make numerous separation cultures at various periods during the two years it was kept in culture, to satisfy myself there was no admixture. Its most characteristic features were the star-like character of the plate-colonies and the presence of a bluish iridescence when held up, but a yellow pigment was also formed in varying degrees of intensity. In other characters it comes near Group IX, on the one hand, and the yellow Proteus type of Group VII on the other, but its peculiarities were so puzzling that I kept it apart.

Group IX comprises a series of golden-yellow liquefying forms, of which five varieties were studied. The type is that of Zimmermann's *B. fulvus* and *B. subflavus*, and, while they differ in liquefying power, all form deep chrome-yellow pigment, like yolk of egg. The group is clearly allied to the yellow Proteus group, and seems to connect P. Frankland's *B. aquatilis* and the true Proteus type with *B. arborescens* and *B. ochraceus*, the differences depending largely on the formation of zoogloea or not.

Group X consists of a series of very common non-liquefying forms, of which three varieties were studied in detail. The type appears

nearest to Adametz's *B. aureus* and P. Frankland's *B. aurantiacus*. They grow very slowly, and seem to be feeble forms. From their behaviour during culture and comparison with the last group, I am compelled to regard these non-liquefying yellow forms as merely weakened varieties of the last group; this is borne out by the tendency to liquefaction shown by some of them after being cultivated for some time, as well as by the enfeeblement of liquefying power shown by some of the older cultures of the yellow Proteus group. It is probable that they are simply species of the Proteus group, so weakened by their prolonged sojourn in the river that they can only be cultivated with difficulty in the new environment of the gelatine media, &c. This being so, the whole of the series included in Groups VI to X inclusive may be varieties of one or two species, since I find that, great as the differences seem between the extreme forms, the varieties studied present characters passing imperceptibly into one another. This result is also in accordance with the fact that so many yellow varieties, impossible to separate satisfactorily, have been isolated from water and described by other observers.

Group XI is made to include a colourless capsuled form, not very common in the river, and reminding one of Cohn's *Ascococcus*. Two sets of cultures of it were carried out in detail, and a very characteristic feature was discovered in the plate-colonies, viz., the presence of curious vermiform zoogloea masses imbedded in the colonies; these are not intruded forms, but merely growth-phases of the same species. So far as can be judged, the " species " seems new.

Group XII comprises a series of yellow capsuled bacilli, not uncommon in the river, and morphologically conforming to the type of Friedländer's bacillus. I cultivated five varieties of it. The most characteristic feature is the formation of extremely tough zoogloea-colonies, often looking like the roe of a fish. There is some variation in the degree of liquefying power, and much difference in consistency and other characters, but the sum of all the diagnoses leaves no doubt that all the forms belong to one species.

Group XIII comprises a series of forms which produce a crimson pigment. The type is that of *B. prodigiosus*, and five varieties were isolated and very closely investigated. Colourless varieties were developed in cultivation, and the pigment again restored by suitable treatment. Weakened forms, and considerable differences in liquefying power were also found. Koch's *B. indicus*, Breunig's *Kieler bacillus*, Frank's *B. ruber*, Dowdeswell's *B. rosaceum metalloides*, and Zimmermann's *B. miniaceus* are all identical with this form, or, at least, can be matched by the varieties arising in culture.

Group XIV comprises a series of rapidly liquefying, colourless forms, very common in the river at all times, and conforming to the type of *B. termo* as amended by Macé. I made a prolonged study of

five varieties, and found considerable differences as regards rapidity of liquefaction, anaërobism, and other characters. The series includes Eisenberg's *B. liquefaciens*, Frankland's *B. liquidus*, and Zimmermann's *B. punctatus* and *B. devorans*, and brings together a large series of incompletely described forms with more or less probability. The type is one of the commonest in the Thames, and a pronounced putrefactive bacterium.

Group XV includes three varieties not uncommon in the river in the summer, and conforming to the type of *B. subtilis* in general behaviour and in the characters of their highly resistant spores, the germination of which was carefully traced. The total behaviour of these varieties points to confusion between the hay bacillus (*B. subtilis*) and the potato bacillus (*B. mesentericus*), and I am driven to the conclusion that these two " species " are either identical or more similar than is usually assumed. In any case both these forms are matched by the varieties in this group, which my examination suggests are varieties of one species. The wrinkled growth on potato cannot be relied upon to separate them.

Group XVI comprises a series of varieties of a yellow *Sarcina* of the type *S. lutea*. I obtained five varieties, showing considerable differences in liquefying power, and it was interesting to find that the *Sarcina* form—" packet form "—is not always maintained. My cultures unite Frankland's *S. liquefaciens*, Lindner's *S. flava*, and Schroeter's *S. lutea* as mere varieties of one and the same species.

Group XVII was made for a rose-pink or cerise-coloured micrococcus of the type of Zimmermann's *M. carneus*, not common, but isolated several times in the winter of 1894—1895. The most interesting point was the discovery that in early stages of division, followed under high powers, it develops as a *Sarcina*, and several facts point to the conclusion that the *Sarcina* form is a mere result of slow development—*e.g.*, in acid media—of *Staphylococcus* forms of *Micrococcus*. My cultures unite *M. carneus* with Maschek's *Coccus ruber*, Flügge's *Micrococcus cinnabareus*, Zimmermann's *M. cinnabarinus*, and certain forms often termed *M. roseus*, as well as Schröter's *Sarcina rosea*, as mere varieties of one form.

Group XVIII is made for a curious form which serial cultures under the high power shows to be no schizomycete at all, but a truly branching micro-organism with acropetal growth and other characters which place it in the category of true fungi. Nevertheless it breaks up into minute coccus-like oidial joints, so similar to a short bacterium or oval coccus that it would inevitably be taken for such if examined by ordinary methods only. I referred to it in 1895 as a " false bacterium," and its history affords an excellent proof of the necessity of microscopic cultures in these investigations. It presents

undoubted resemblances to Löffler's *B. diphtheriæ.* It was not found
to be pathogenic to guinea-pigs by Dr. Kanthack.

Group XIX was made to contain a white micrococcus of the type
M. candicans of Flügge. It is very common in the river, and was
kept under observation a long time, with interesting results; for
although typically a non-liquefying form, it becomes capable of lique-
fying gelatine in time, and the plate-colonies and other cultures show
variations which lead me to connect *M. candicans* with Zimmermann's
M. concentricus, Tataroff's " schminkeweisser *Streptococcus,*" and some
other forms, as mere varieties of one and the same species.

Group XX contains a form only isolated once from the Thames,
but studied very thoroughly in 1894. It develops lemon-yellow
liquefying colonies on gelatine, and presents close resemblances to
Sarcina lutea, but it is a fairly large bacillus, and no attempt to
convert is into a *Sarcina* form succeeded. All efforts to match this
form among those described have failed, though incompletely
examined forms by Maschek, Unna and Tommasoli, and Adametz
present resemblances, so far as their imperfect diagnoses go. It
may be necessary to name it as a new species.

Group XXI contains two varieties of a short oval form, or coccus,
principally characterised by the development of a red pigment, vary-
ing from pale salmon-pink to deep rosy-scarlet, but also differing in
details of shape and adaptation to temperature, and a few other
points. Nevertheless it was difficult to give the varieties specific
rank on the evidence. I have been unable to identify this
form.

Group XXII comprises two forms, not completely investigated,
and nearer the type of Group XIV than any others of my groups.
Both seem common in the river.

The question of the pathogenicity or otherwise of these forms
was naturally raised, and was kindly tested for me in several cases
by Dr. Lazarus Barlow, and at much greater length by Dr. Kanthack,
through whose hands nearly all the forms have passed. In the
following summary pathogenic means pathogenic to guinea-pigs.
Pathogenic varieties occurred in Groups IV, V, VI, VIII, XI, XIII,
XIV, and XVII, with considerable variation in detail, while the other
groups seem to be harmless. The most markedly pathogenic forms
were in Group V (type of *B. coli commune*). Those in Group IV
aroused the suspicion that *B. pyocyaneus* comes here; and it is inter-
esting to note that *B. prodigiosus* (Group XIII) was pathogenic in
some cases.

Of course no full test of pathogenicity is afforded by the few
trials made in this way, but the positive results obtained at least
show that a not inconsiderable number of the river bacteria are
pathogenic, or can become so in culture. Not less important is the

fact that pathogenicity, like the other characters, is variable, as is abundantly shown by Dr. Kanthack's experiments.

In conclusion, the results show that—

1. Very many forms occur in the Thames, some of which are pathogenic under certain conditions.

2. The "species" of the descriptive hand-books—principally medical—are frequently not species at all, in the botanical sense, but varieties, or growth-forms, the distinctive characters of which are not constant. These so-called species need revision and grouping around types, which may turn out to be the true species.

3. The characters derived from the behaviour of colonies are not sufficient for the determination of species, and how far they may be employed in conjunction with other characters will only be eluci-dated by advances in our knowledge of the way the colonies are built up by the growing bacteria on the given media.

4. The effects of definite changes in the environment on the media are of great importance, but have hardly been noticed as yet. Plate-colonies on gelatine, for instance, develop quite differently, according to the condition of the gelatine ; so that a feeble and slow-growing bacterium produces colonies quite unlike those developed by the same species when vigorous and quickly growing, not only owing to its peculiarities of growth as a feeble form, but also because the gelatine has altered during the intervening period.

5. The effect of changes of the environment on the growing organism itself is recognised as important.

6. With especial reference to the Thames bacteria, the past history of the organism isolated from the river implies causes of variation. The river water is a poor nutritive medium, and the organism is exposed to great changes of temperature, light, movement, &c., during its sojourn therein. Consequently the time it has been in the river affects the behaviour of the organism when isolated, just as we know that a bacterium is affected by the previous conditions of its culture in other media. Hence two colonies on a plate may look very differ-ent, and yet belong to the same species, one being developed from a cell that had been many days or weeks in the water, the other from one that had only been there a few hours. It may need weeks or months of cultivation under constant conditions to establish the identity of the two.

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