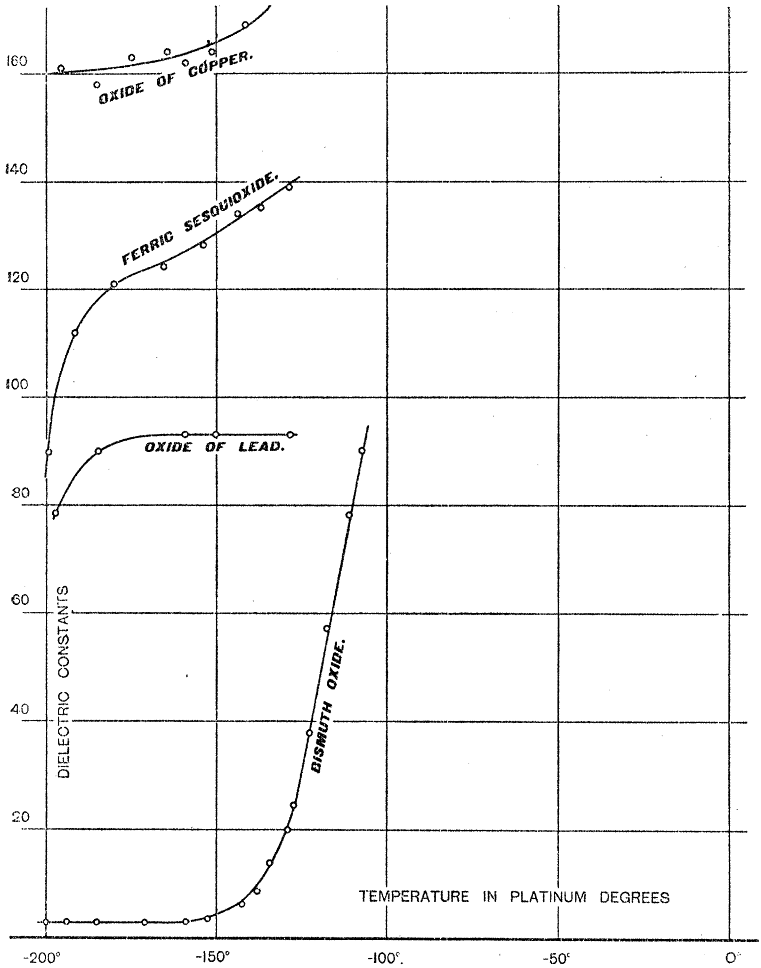

FIG. 3.—Curves showing the variation in Dielectric Constant with Temperature of various Oxides.

"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 ?	

* 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 for the first two readings, then 1000 ohms.
−200·0	9·74	2·62	92·20	
−192·0	10·20	2·90	99·20	
−177·0	12·85	3·68	99·20	
−165·2	16·45	4·73	99·20	The condenser was warmed up out of the vacuum tube.
−156·5	4·05	5·88	19·80	
−122·7	18·60	27·40	19·80	
−108·3	2·25	156·00 ?	1·43	

IX. *Dielectric Constant of Sodic Chlorate* ($NaClO_4$).

(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.
−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* (Na_2SO_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.
−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; no resistance in series with galvanometer.
−180·0	1·95	33·0	
−156·0	2·10	35·4	
−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 galvanometer.
−197·7	10·15	2·86	
−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	

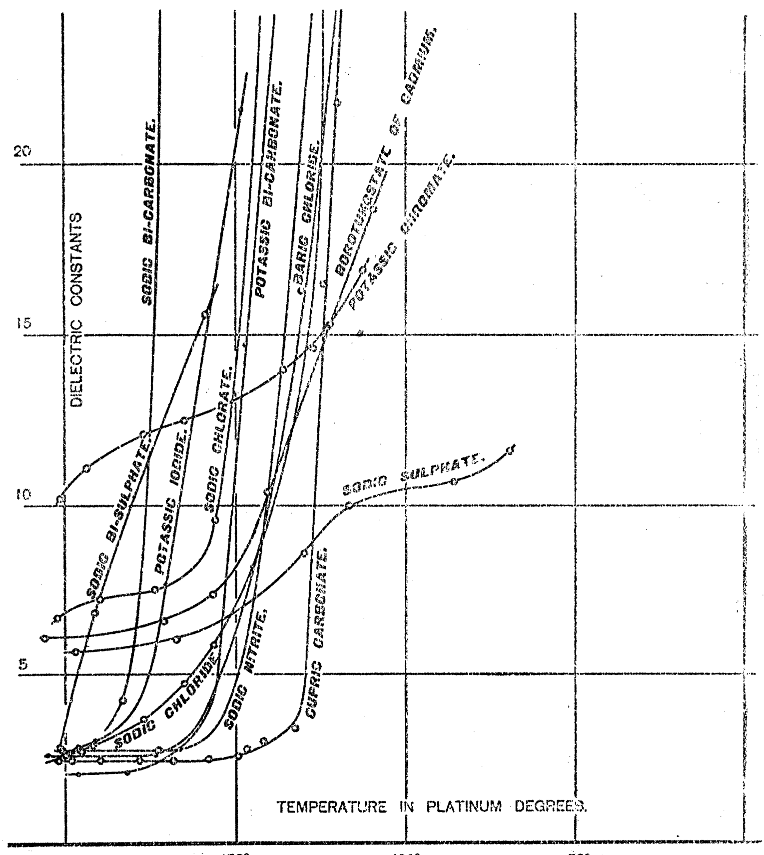

FIG. 1.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

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	

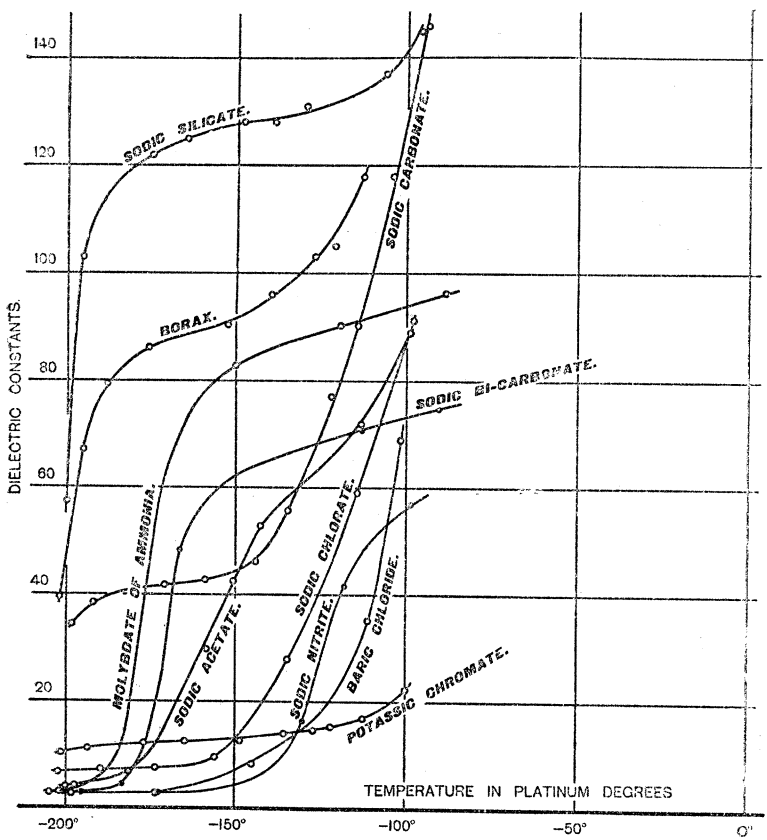

FIG. 2.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

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.

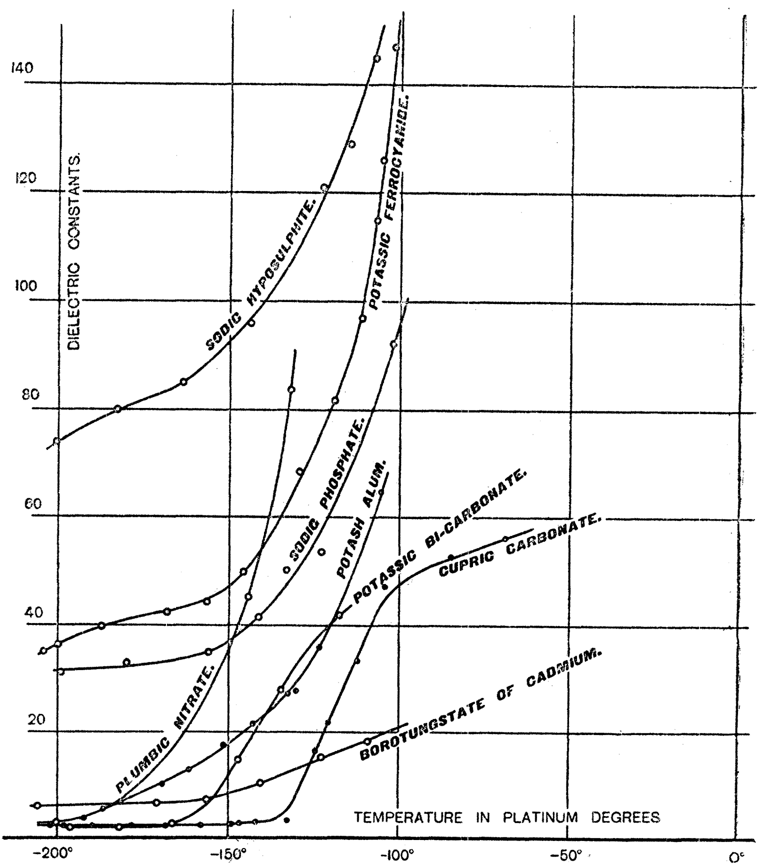

Fig. 3.—Curves showing the Variation in Dielectric Constant with Temperature of various Frozen Electrolytes.

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.