THE CONDUCTIVITY AND VISCOSITY OF SOLUTIONS OF ELECTROLYTES IN FORMAMID.*

BY

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THE work of Jones and his collaborators in the field of non-aqueous solvents, and in mixtures of these solvents with one another, thus far included a comprehensive study of both the conductivity and viscosity of typical salts in methyl and ethyl alcohols, in acetone and in glycerol; as well as in binary and ternary mixtures of these solvents with one another and with water. A review of all this work is to be found in Publication of the Carnegie Institution of Washington No. 210, Chapter 7.

Because of the somewhat limited solubility of electrolytes in most organic solvents, the scope of this work has necessarily been somewhat limited in the case of the pure liquids themselves. This is especially true with acetone and the alcohols. Glycerol, however, notwithstanding its high viscosity, proved to be a remarkably good solvent.

Among the few remaining liquids suitable for such work, the one used in this investigation—formamid—is, perhaps, the most important.

The fact that it has been studied so little in the past must be attributed to the difficulties encountered in obtaining a product pure enough for conductivity purposes, and to its relatively high price.

PREVIOUS WORK IN FORMAMID.

Until quite recently no investigation of the physical chemical properties of this remarkable liquid had been made. A brief sketch of the recent work is given below.

In his preliminary paper on organic solvents, Walden mentions the marked similarity of formamid to water as compared with other liquids in its solvent action on inorganic salts, and in

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later papers he records some of its physical constants in comparison with other amids and with water, viz., the dielectric constant and association factors,¹ specific conductivity and molecular conductivity of the normal electrolyte $N(C_2H_5)_4I^2$ and the viscosity.³ All of these constants were obtained with a product which, as will be shown later, was far from pure; although it may be pointed out that the first two constants are not appreciably affected by small changes in the purity of the solvent.

Turner and Merry,⁴ in their work on the molecular composition of trivalent nitrogen compounds, pointed out that the high association factor of formamid is one of its most striking characteristics, and they observed its similarity to water. They noted also that the association of formamid diminishes more rapidly with rise in temperature than that of water, and suggested that the solvent power for salts was largely due to its high molecular complexity. Somewhat later, Walden,⁵ in a study of the temperature coefficient K , for organic liquids in the Ramsay and Shields equation for molecular surface-tension, found that in the case of formamid the value was far below that for non-associated liquids (2.12), having only the value 0.594–0.710, and from these data obtained an association factor in close agreement with that as determined by Turner and Merry.⁶

Dunstan and Kassel,⁷ while determining the fluidity of various binary mixtures, measured the viscosity of mixtures of formamid and *i*-amyl alcohol at both low and somewhat elevated temperatures, and noted a pronounced minimum in the fluidity curves at about 60 to 70 per cent. of formamid at both temperatures; and also a slight maximum at about 10 to 20 per cent. formamid for the lower temperature.

Rohler⁸ studied the solvent properties of formamid for organic salts, and also the electrolysis of its solutions. He compared the density with that of water above the freezing-point

¹ *Zeit. phys. Chem.*, **46**, 143, 175 (1906).

² *Ibid.*, **54**, 179 (1905).

³ *Ibid.*, **55**, 230 (1906).

⁴ *Journ. Chem. Soc.*, **97**, 2076 (1910).

⁵ *Zeit. phys. Chem.*, **75**, 555 (1910).

⁶ *Loc cit.*

⁷ *Zeit. phys. Chem.*, **76**, 367 (1911).

⁸ *Zeit. Elektrochem.*, **16**, 420, (1910).

and found no minimum, as in the case of the latter, but that the solvent expanded linearly with rise in temperature; the variation of the specific volume being represented by $V = 0.8674 \times (t + .000742t)$.

Rohler also found that, according to Faraday's law, copper dissolves in formamid at all dilutions, half as univalent and half as bivalent ions at the anode, and obtained a good separation of copper with a weak current; but with a stronger current the metal separated as a dark slime.

Similar results were obtained with lead, zinc, and tin. With all of these metals in air more metal dissolved at the anode than separated at the cathode. The electrolysis of nickel, cobalt, iron, aluminum, and magnesium salts yielded no appreciable amount of metal at the cathode.

Rohler also noted the formation of metallic formamides, and also of crystalline double compounds, which will be considered in discussing the properties of formamid as compared with those of water.

In a quite recent paper Walden⁹ gives an account of his cryoscopic work in this solvent. In his preliminary discussion he states as his reason for adopting the freezing-point rather than the conductivity method for measuring dissociations, that the high specific conductivity of the solvent (as measured by him) rendered it impossible to obtain accurate data by the latter method. However, as will be pointed out later, by our method of preparation, formamid with a specific conductivity comparable with that of water, may be obtained with a loss of material only one-third that experienced by Walden.

Walden determined the freezing-point constant of formamid, and gives the value 35.0 as the mean of six determinations using urea, acetic ester, diethylsulphite, ethyl acetate, mesityl oxide, and nitraniline respectively as the solute.

He also studied the dissociation of a number of electrolytes, including salts and both strong and weak acids, and pointed out that all binary salts are strongly ionized at relatively high concentrations; the ionization increasing slowly to the limit $\alpha = 100$ as in water; the limit, however, being reached at a smaller dilution in formamid.

⁹ *Bull. Imp. Acad. Sci., St. Petersburg* (1911).

The same was found to hold for acids, except in the case of those where combination took place between solvent and solute, as in the case of some of the strong acids; the values found being smaller than those for water.

FORMAMID AS A SOLVENT.

Formamid is a clear, colorless, and somewhat viscous liquid, melting at about 18° , and boiling under atmospheric pressure with partial decomposition at 200° to 212° . It reacts neutral to litmus and is quite hygroscopic, undergoing a slow hydrolysis at ordinary temperature into ammonium formate.

This solvent is the most closely allied to water in its properties of all the organic solvents. The two are miscible in all proportions, neither being soluble to any extent in absolute ether, chloroform, benzol, hexane, etc.; nor do they dissolve appreciably the aromatic hydrocarbons, nitrobenzol, fats, oils, etc.

Further similarity may be traced in their solvent action on metallic salts, thus: in the cold, cobalt and nickel salts yield solutions in formamid, similarly colored with those in water; although in some instances the formamid solutions undergo change in color on warming, which is probably due to a predominance of the unionized salt, since formamid undergoes a much sharper decrease in association with rise in temperature than water.

As Walden has pointed out, the similarity between water and formamid is still more wide-reaching. Phosphorus and sulphur are practically equally insoluble in both, while iodine gives a brownish-yellow solution. Starch is also soluble in formamid with formation in concentrated solution of a jelly; and on addition of formamid solution of iodine the starch solution turns intensely blue. The color, however, is less permanent than in water, owing to the slow action of the iodine on the solvent. The fluorescent dyes also exhibit like phenomena in formamid and in water, this being particularly marked in the case of eosin.

Bruni and Manuelli¹⁰ further show that just as water hydrolyzes the salts of weak bases, such as those of bismuth and antimony, forming unstable basic salts, formamid, by a process of amidolysis, may form basic salts of these same metals; and Rohler,¹¹ in extending this work, has isolated characteristic basic

¹⁰ *Zeit. Elektrochem.*, **11**, 551 (1905).

¹¹ *Ibid.*, **16**, 418 (1910).

salts of copper, cobalt, nickel, and zinc. He also obtained amidates similar to hydrates, of which $\text{PbCl}_2 \cdot \text{HCONH}_2$ is an example; as well as metal formamidates having the general composition $\text{Me}(\text{HINCOH})_2 \cdot \text{HCONH}_2$, where Me may be either copper, nickel, cobalt, or zinc.

In addition to the above, Rohler has noticed the formation of well-defined crystalline compounds of formamid with the halogen acids corresponding to the well-known mono-, di- and tri-hydrates.

As is now a well-established fact, the dielectric constant of the solvent is a measure of its own association, and therefore a measure of its dissociation power for electrolytes. Of the common solvents water has the highest dielectric constant, and is the best dissociant. Formamid, however, has a higher dielectric constant than water, as will be shown by referring to the following table of physical constants of the two solvents, and should therefore be a better dissociant, which will be pointed out in our discussion.

TABLE I.

Molecular weight	Water 18	Formamid 45
Melting-point	0°	1.5-2.1 (Walden)
Boiling-point 760 mm.	100°	200-212
Density 0°/4°	.9999	1.151 (Walden, Davis)
Dielectric constant	81 (Drude) ^{25°}	84 (Walden)
Association factor 30°	3.81 (Ramsay-Shield)	6.18 (Turner and Merry)
K—surface tension 20°-30°		0.65 (Turner and Merry)
Minimum specific conductivity $4. \times 10^{-8}$		2.8×10^{-6} (Davis and Putnam)
Average specific conductivity working values 1.5×10^{-6}		2.7×10^{-6} (Davis and Putnam)
Viscosity 25°	0.00891 (Thorpe and Roger)	0.0324 (Davis)
Dissociation of $\text{N}(\text{C}_2\text{H}_5)_4\text{I}$ at $V=100$	91%	93% (Walden) 98% (Davis and Putman)

PURIFICATION OF THE SOLVENT.

It might be well to note at the outset that neither a clean melting-point nor a constant boiling-point is a sufficient criterion for the purity of the solvent for conductivity purposes; since it has been found by ourselves and others that a constant boiling liquid such as formamid may be separated into fractions of widely different specific conductivities. That this is true is due no doubt

in this particular case to the fact that minute quantities of the products of hydrolysis, such as would have no measurable effect on the apparent boiling-point of the liquid, on account of the high dissociating power of the formamid, produce a marked increase in its conductivity.

The chief criterion, therefore, in judging of the purity of the solvent used in this investigation was its specific conductivity. The material with which we started was obtained from Kahlbaum, and had a specific conductivity of about 674×10^{-5} , or about that of tap-water. Samples obtained from Bender and Hobein, Schuchardt, and from Hoffman and Kropff proved, from the conductivity standpoint, to be little or no better than the above.

As has already been pointed out, formamid is hygroscopic, forms a true solution with water, and subsequently undergoes slow hydrolysis into ammonium formate. The first problem, therefore, that presented itself, was the removal of any dissolved water not already acted on; and, second, the removal of the products of hydrolysis already present. The method of purification finally adopted made it necessary to design and construct suitable apparatus for distillation in comparatively high vacua.

A third problem presented itself in connection with the preservation and subsequent manipulation of the solvent and of solutions in it, in such a manner as to incur minimum exposure to moisture. In addition, the expense of the solvent made necessary the recovery of it with the least possible loss by decomposition from solutions of salts in this solvent.

The removal of dissolved water was finally effected by the use of carefully dehydrated sodium sulphate. After testing a number of other dehydrating agents, such as magnesium sulphate, calcium chloride, sulphuric acid, *in vacuo*, etc., it was found that sodium sulphate produced a smaller loss of materials from combination with it than any of the other dehydrating agents studied.

Formamid was therefore allowed to stand for several weeks over anhydrous sodium sulphate, in carefully sealed, glass-stoppered bottles placed in a cool, dark room. An attempt was made to effect a preliminary purification of formamid by fractional crystallization, but the end product, after several fractionations, invariably showed a higher conductivity than the original

substance. We were therefore forced to conclude, as were Freer and Sherman in preparing formamid, to study its sodium salts, that a properly conducted distillation process was the best one available.

The apparatus finally adopted for distillation is shown diagrammatically in Fig. 1; although by placing the various parts in parallel rows it was possible to mount the whole apparatus upon a desk space of only $2\frac{1}{2}$ feet square, as is shown in the photograph Fig. 2.

In this apparatus, with all the stop-cocks closed, a vacuum of 0.5 mm. was easily maintained by the Gaede pump (Fig. 1, K). This pump was mounted, together with a $\frac{1}{12}$ -horse-power motor (Fig. 1, L), connecting rheostat (not shown), idler (Fig. 1, M).

FIG. 1.

and switch, on a heavy maple-wood base, provided with carrying handles and rubber feet.

During the actual process of distillation, the vacuum rose to from 1.5 to 2.5 mm.; since, on account of the high viscosity of the liquid, it was necessary to keep a fairly rapid current of air flowing in through the stop-cock and drawn-out portion of the distillation head (Fig. 1, E), in order to keep the liquid agitated and prevent the violent bumping which usually attended distillation in a high vacuum. The drying of this current of air sufficiently, and the proper method of introducing it, proved to be one of the most serious difficulties encountered. The method finally adopted is shown in the figure. The air, before entering the distillation flask, passed through a soda line tower (not shown in the drawing, but appears on the left in Fig. 2), then

through the two wash bottles (Fig. 1, *A*), and finally over phosphorus pentoxide contained in the long tube *B*, which was protected by two glass stop-cocks, the one sealed permanently into the tube and the other securely fastened with sealing wax in the left-hand tapered end of *B*. This joint made it possible to open *B*, in renewing the phosphorus pentoxide. From *B* the current of air passed into *C*, through a short rubber connection and a right-angle glass bend; the open end of which is connected with *C* by a rubber joint made air tight with rubber cement.

FIG. 2.

The distillation head *C* consisted of a short projecting tube, a well-ground stop-cock of large bore; the ground connection with the 750-cubic centimetre distilling flask *D*, and the long inner tube reaching to the bottom of the flask and drawn down to a capillary at the end, so as to cause the air to bubble in a fine stream through the liquid. Connection between the flask and the condenser was effected by a ground joint designed to prevent the liquid distilling over, from coming in contact with the stop-

cock grease used in making the joint air-tight. The condenser was also ground into the Axtell receiver *F*, which is too well known to require further description, other than to state that the capacity of the barrel was about 100 cubic centimetres, and that of the small bulb 250 centimetres. The receiver allowed the removal of different fractions without interrupting the vacuum.

The receiver was connected with the pump *K*, through the gas wash bottles *A*¹, the soda lime tower *I*, and the three-way stop-cock *J*. One of the wash bottles was filled just to the upper level of the holes in the inner cylinder with sulphuric acid; the other being empty and serving as a trap in the case of back pressure. The construction of the wash bottles secured a maximum exposure of acid to the possible alkaline vapors (NH_3) without appreciable back pressure.

Liquid formamid was introduced into the flask at any time during the distillation without destroying the vacuum, by closing the stop-cock on *C*, temporarily disconnecting the air inlet, and attaching at the same point the flask and syphon *N*. On opening the stop-cock the diminished pressure in the flask drew in any liquid in *N*.

During the distillation the flask was immersed in a bath of hardened cottonseed oil ("Crisco"), into which the thermometer dipped. Ordinary rectified cottonseed oil was first used, but this was soon discontinued, since the oil quickly became rancid and offensive when heated. The "Crisco," however, remains sweet and untainted even after continued use. The temperature in the outer bath was maintained at from 10° to 15° higher than the boiling-point of the liquid at a given pressure; the usual temperature being 100° to 115° . In the apparatus used in the preliminary work a thermometer was scaled into the air inlet tube of *C*, with its bulb well down in the flask, and the boiling-point of the liquid observed; but this thermometer was subsequently discarded and the temperature controlled solely by the thermometer in the outer bath, so as to obtain about 100 cubic centimetres of distillate every 15 minutes.

As a rule, starting with Kahlbaum's so-called c.p. formamid, from three to four distillations yielded a product sufficiently pure for our purpose. The decrease in the conductivity with successive distillation is shown in the following table:

<i>Specific Conductivity.</i>		
Original Material	674.0×10^{-5}	
First distillation	First fraction	785.8×10^{-5}
	Second fraction	435.0×10^{-5}
	Third fraction	112.3×10^{-5}
Second distillation	First fraction	204.2×10^{-5}
	Second fraction	153.8×10^{-5}
	Third fraction	67.4×10^{-5}
		<hr/>
Third distillation—first fraction		24.6×10^{-5}
		10.3×10^{-5}
		4.8×10^{-5}

While the end fraction in this case was sufficiently pure for use, a fourth distillation yielded a product with the conductivity of about 3.4×10^{-5} ; although the exact minimum conductivity of this solvent has thus far not been ascertained, we have obtained small lots with a specific conductivity of 2.8×10^{-5} or from two to three times the value for the conductivity water used in this laboratory. Walden used in his work a product with a conductivity of 7.5×10^{-4} , but obtained a small fraction of about 10 per cent. of the original material, with a conductivity of 4.7×10^{-5} . Our solvent was from 35 to 40 per cent. of the original volume with a maximum specific conductivity of 4.8×10^{-5} , with a minimum of 1.37×10^{-5} and an average of 2.7×10^{-5} .

SALTS.

On account of the instability of the solvent formamid in the presence of moisture, the salts used in this investigation were all dehydrated with special care at the highest temperature which it was possible to use for these substances.

SOLUTIONS.

The more concentrated solutions in formamid were made up by direct weighing; the more dilute by diluting the more concentrated. This operation was much facilitated by the use of two burettes holding 50 and 10 centimetres respectively; the one being employed for the solvent, the other for the one-tenth normal solution. Each burette was connected with the reservoir containing the solvent or the solution by a siphon provided with a glass stop-cock; and access of moisture being prevented by calcium chloride tubes connected with both the burettes and the reservoirs.

The solvent was kept until required in half-litre glass-stoppered Erlenmeyer flasks, and the solutions when made up were

preserved in 35 c.c. flasks of similar design, which were sealed with rubber cement.

On account of the high price of the solvent, only 25 cubic centimetres of each solution was prepared; this amount serving both for conductivity and viscosity measurements. All operations in preparing the solutions were carried out at 20°.

CONDUCTIVITY APPARATUS.

The conductivity apparatus used in this investigation was identical with that employed in our earlier work on binary and ternary mixtures of water, acetone, and glycerol; the method of obtaining duplicate readings and other details being exactly the same as in the earlier work, with the exception of the use of a rocking commutator with mercury contact, instead of the two-blade, double-throw switch used in reading both ends of the bridge; the object being to eliminate as nearly as possible all external resistance.

The conductivity cells were also of the type recently employed in this laboratory for work with non-aqueous solvents, and were carefully standardized at regular intervals.

VISCOSITY APPARATUS.

The apparatus used in this work was essentially the same as in our earlier investigations. We have designed and used an improved support for the viscometers, which is particularly well adapted to our new thermostat. A new pycnometer * has also been devised, which has proved to have advantages over the older form.

THERMOSTATS.

The new form of constant temperature bath for conductivity and viscosity investigations, which has already been fully described in Chapter 6 of the Publication of the Carnegie Institution of Washington, No. 210, has already met with such approval that by request it is here described in some detail.

These thermostats are substantially constructed of copper and use gas for maintaining constant temperature; the heat being applied directly to a heavy galvanized iron pipe (Fig. 3, *A-H*), outside the bath, through which a part of the water is kept circulating by means of the propellers (*FF*). This mixes with the remainder of the water in the space enclosed by the cooling coils (*NN*), and the diaphragm *I*. By this means a very even distribu-

* *Jour. Am. Chem. Soc.*, 37, 1199 (1915).

FIG. 3.

Constant temperature apparatus used in conductivity and viscosity investigation.

A. Sixty-five Bath of 20-ounce Copper:

(A) Asbestos insulation; (B) sheet-brass cover; (C) woven wire grid; (D) semicircular diaphragm; (E) deflector to divert part of the water into the heater pipes; (F) thermometer; (G) tripod; (H) galvanized iron heater pipes attached to bath with $1\frac{1}{2}$ -inch brass nipples; (I) brass bands supporting insulation; (J) outline of windows shown also in F.

B. Thermostat:

(K) Holder; (L) toluol reservoir tubes with $\frac{1}{8}$ -mm. walls. (M) expansion chamber partially filled with mercury; (N) 1.5-mm. capillary; (O) side arm with sealed-in platinum contact.

C. Gas Flow Regulator:

(Based on "steel block" devised by E. E. Reid, *Amer. Chem. Journ.*, 47, 157, and improved by others.)

(Q) Binding posts to coils; (R) magnet coils; (S) armature; (T) steel valve-chamber; (U) plunger, with rubber washer and mercury seal, working against end of gas-supply pipe (V) and wire to armature (S); (W) needle valve to regulate size of pilot flame (shown as dotted circle); (X) microburner with needle valve; (Y) gas-cocks regulating supply to relay and rough heater; (Z) high-voltage lamp spanning spark-gap of thermostat.

D. Stirring Mechanism:

(AA) Shaft; (BB)-shaped bracket supporting (CC) oil cups and journals; (DD) pulley with oil trap filled with waste; (EE) oil trap; (FF) six-bladed $3\frac{1}{2}$ -inch propeller.

E. Cooling System:

(GG) Standpipe; (HH) supply; (II) overflow; (JJ) pet-cock in cap; (KK) regulating valve to coils; (LL) inlet pipe to coils; (MM) interchangeable unions (here ice- or hot-water coils may be inserted for very low or high temperatures); (NN) cooling coils; (OO) waste pipe.

F. Diagram of Top (smaller scale):

(B), (D), (F), (H), (J), and (K) the same as in A; (MM) same as in E; (PP) apertures in cover for conductivity cells; (QQ) lugs supporting cover; (RR) handle to removable section of cover.

tion of heat is obtained, and because of the large heat capacity of the bath itself, these thermostats are insensible to other than marked changes in room temperature. The improved toluol regulator (Fig. 1, *B*), mentioned in our publication on conductivity and viscosity in ternary mixtures, and described in detail elsewhere,¹² was used to operate the relays controlling the gas-supply to the micro-burners of the thermostats. The gas valve shown in the illustration is an improvement made by others on the steel

FIG. 4.

block devised by E. E. Reid, and was used throughout the greater part of this work. Subsequently, however, a new type of valve was devised here for eliminating the expensive telegraph relay and the mercury seal of the plunger *U*. Preliminary tests have shown this valve to have decided advantages over the former thermostats; and should it prove satisfactory a complete discussion will appear later. There are at present in this laboratory seven

¹² *Journ. Amer. Chem. Soc.*, 37, 1198 (1915).

such thermostats in use, and they are capable of maintaining temperature uniform to within 0.01° at 15° and 35° , and to within 0.003 to 0.005 at 25° . The thermostats used in this laboratory are all driven by a single $\frac{1}{12}$ -horse-power, direct-current motor. The complete baths are shown in Fig. 4.

Both conductivity and viscosity measurements were made at 15° , 25° , and 35° ; the data are tabulated in the usual manner, tables of constants and the use of a calculating machine greatly facilitating the calculations.

TABLE II.
Comparison of the Various Solvents.

Solvent	Dielectric constant	Association factor	Viscosity at 25°
HCN	95		
HCONH ₂	94	6.18	0.0326
H ₂ O	81.7	3.81	0.0089
CH ₃ OH	32.5	3.43	0.0056
C ₂ H ₅ OH	21.7	2.74	0.0111
C ₃ H ₇ (OH) ₂	16.5	1.80	5.854
CH ₃ -CO-CH ₃	20.7	1.26	0.0035

TABLE III.
Sodium Bromide in Formamid.
MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	11.83	15.53	19.76	62.1	63.1	63.4
4	13.80	18.01	22.82	72.4	73.2	73.6
10	16.20	21.09	26.64	85.0	85.7	86.0
50	17.46	22.62	28.55	91.6	91.9	92.1
200	18.79	24.36	30.59	98.6	98.9	98.7
400	19.06	24.62	30.99	100.0	100.0	100.0
* $K 1.53 \times 10^{-5}$ 1.99×10^{-5} 2.46×10^{-5}						

*K is the specific conductivity of the solvent

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15° - 25°	25° - 35°	15° - 25°	25° - 35°
2	0.0313	0.0272	0.370	0.423
4	0.0305	0.0267	0.421	0.481
10	0.0302	0.0263	0.489	0.555
50	0.0296	0.0262	0.516	0.593
200	0.0296	0.0256	0.557	0.623
400	0.0292	0.0259	0.0556	0.637

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.05578	0.04081	0.03120	17.93	24.50	32.05
4	0.04883	0.03678	0.02837	20.48	27.19	35.25
10	0.04523	0.03413	0.02666	22.11	29.30	37.51
Solv.	0.04274	0.03194	0.02511	23.40	31.31	39.83

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0367	0.0308
4	0.0328	0.0296
10	0.0325	0.0280
Solv.	0.0338	0.0272

TABLE IV.

Sodium Iodide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	11.92	15.71	20.01	64.7	65.6	66.1
4	14.17	18.57	23.59	76.9	77.5	78.0
10	15.91	20.67	26.05	86.3	86.3	86.1
50	17.17	22.33	28.17	93.2	93.2	93.1
200	18.27	23.80	29.98	99.1	99.3	99.1
400	18.43	23.96	30.25	100.0	100.0	100.0
K	2.23×10^{-5}	2.83×10^{-5}	3.48×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0318	0.0274	0.379	0.430
4	0.0311	0.0270	0.440	0.502
10	0.0299	0.0260	0.476	0.538
50	0.0301	0.0262	0.516	0.584
200	0.0303	0.0260	0.553	0.618
400	0.0300	0.0263	0.553	0.629

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.05425	0.03997	0.03065	18.43	25.02	32.63
4	0.04822	0.03640	0.02800	20.74	27.47	35.71
10	0.04532	0.03381	0.02653	22.07	29.58	37.69
Solv.	0.04307	0.03302	0.02570	23.22	30.29	38.91

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0357	0.0304
4	0.0325	0.0300
10	0.0340	0.0274
Solv.	0.0304	0.0285

TABLE V.
Sodium Chromate in Formamid.
MOLECULAR CONDUCTIVITY.

V	Molecular conductivity		
	15°	25°	35°
10	24.57	33.66	42.66
50	31.46	41.48	52.18
200	34.34	44.82	56.38
400	39.00	50.79	.....
800	42.64	55.07	69.16
1600	72.06	93.51	116.44
K	1.30×10^{-5}	1.65×10^{-5}	2.03×10^{-5}

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
10	0.0316	0.0267	0.809	0.900
50	0.0319	0.0258	1.002	1.070
200	0.0305	0.0258	1.048	1.156
400	0.0302	.....	1.179	.....
800	0.0292	0.0256	1.243	1.409
1600	0.0298	0.0245	2.145	2.293

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
10	0.04966	0.03633		20.14	27.30	
Solv.	0.04301	0.03221		23.25	31.05	

TABLE VI.
Potassium Chloride in Formamid.
MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	14.12	18.25	22.94	67.9	68.3	68.7
4	16.15	20.84	26.13	77.6	78.0	78.3
10	18.06	23.27	28.99	86.8	87.1	86.8
50	19.27	24.94	31.12	92.6	93.3	93.2
200	20.66	26.60	33.10	99.3	99.5	99.1
400	20.80	26.73	33.39	100.0	100.0	100.0
K	2.94×10^{-5}	3.75×10^{-5}	4.69×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0292	0.0257	0.413	0.469
4	0.0290	0.0252	0.469	0.529
10	0.0288	0.0246	0.521	0.572
50	0.0294	0.0248	0.567	0.618
200	0.0288	0.0244	0.594	0.650
400	0.0285	0.0249	0.593	0.666

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
2	0.05251	0.03922	0.03000	19.04	25.50	33.33
4	0.04724	0.03572	0.02794	21.17	28.00	35.79
10	0.04457	0.03386	0.02642	21.94	29.53	37.85
Solv.	0.04304	0.03256	0.02542	23.23	30.71	39.34

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0339	0.0307
4	0.0323	0.0278
10	0.0338	0.0282
Solv.	0.0322	0.0281

TABLE VII.

Potassium Iodide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	36°	15°	25°	35°
2	14.42	18.67	23.29	70.7	71.0	71.0
4	16.32	21.05	26.34	80.0	80.1	80.3
10	18.23	23.45	29.21	89.4	89.2	89.0
50	19.25	24.87	31.03	94.4	94.6	94.5
200	20.39	26.28	32.81	100.0	100.0	100.0
400	20.26	26.29	32.82			
K	2.23×10^{-5}	2.83×10^{-5}	3.48×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0295	0.0247	0.425	0.462
4	0.0290	0.0251	0.473	0.529
10	0.0286	0.0246	0.522	0.576
50	0.0292	0.0248	0.562	0.616
200	0.0289	0.0248	0.589	0.653

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
2	0.04982	0.03710	0.02884	20.07	...	34.67
4	0.04631	0.03525	0.02716	21.59	28.37	36.81
10	0.04418	0.03353	0.02629	22.64	29.82	38.04
Solv.	0.04307	0.03302	0.02570	23.22	30.29	38.91

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0343	0.0286
4	0.0314	0.0298
10	0.0318	0.0274
Solv.	0.0304	0.272

TABLE VIII.
Potassium Sulphocyanate in Formamid.
 MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	15.15	19.10	24.28	70.0	69.2	70.4
4	17.42	22.31	27.87	80.6	80.8	80.8
10	19.04	24.38	30.35	88.0	88.3	88.0
50	20.02	25.61	32.16	92.6	92.8	93.3
200	21.21	27.19	33.89	98.1	98.5	98.3
400	21.62	27.60	34.47	100.0	100.0	100.0
K	1.07×10^{-5}	1.37×10^{-5}	1.69×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0261	0.0271	0.395	0.518
4	0.0281	0.0249	0.489	0.556
10	0.0280	0.0245	0.534	0.597
50	0.0279	0.0256	0.558	0.655
200	0.0282	0.0246	0.598	0.670
400	0.0277	0.0249	0.598	0.687

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.04891	0.03657	0.02838	20.45	27.35	35.24
4	0.04585	0.03473	0.02713	21.81	28.79	36.86
10	0.04369	0.03280	0.02574	22.89	30.49	38.85
Solv.	0.04294	0.03258	0.02554	23.29	30.69	39.15

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0337	0.0287
4	0.0320	0.0280
10	0.0332	0.0274
Solv.	0.0314	0.0276

TABLE IX.
Ammonium Bromide in Formamid.
 MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	16.31	20.85	25.79	70.6	70.6	70.0
4	18.21	23.31	28.88	78.8	78.9	78.3
10	20.57	26.21	32.53	89.0	88.7	88.3
50	21.82	27.94	34.82	94.4	94.6	94.5
200	22.63	28.83	35.93	97.9	97.6	97.5
400	23.11	29.54	36.86	100.0	100.0	100.0
K	2.94×10^{-5}	3.76×10^{-5}	4.67×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0278	0.0237	0.454	0.494
4	0.0280	0.0247	0.510	0.557
10	0.0274	0.0241	0.564	0.632
50	0.0280	0.0246	0.612	0.688
200	0.0274	0.0246	0.620	0.710
400	0.0278	0.0248	0.643	0.732

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.04795	0.03607	0.02776	20.86	27.73	36.02
4	0.04550	0.03455	0.02680	21.98	28.94	37.31
10	0.04399	0.03273	0.02635	22.73	30.55	37.95
S.	0.04304	0.03256	0.02542	23.23	30.71	39.34

TEMPERATURE COEFFICIENTS.

V	15°-25°	25°-35°
2	0.0330	0.0299
4	0.0317	0.0289
10	.....	.....
S.	0.0322	0.0281

TABLE X.

Ammonium Iodide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	16.90	21.70	26.80	73.6	73.1	72.5
4	18.78	24.06	29.88	81.8	81.0	80.8
10	20.48	26.32	32.44	89.2	88.6	87.7
50	21.31	27.39	33.92	92.8	92.3	91.2
100	22.20	28.40	35.40	96.7	95.7	95.8
400	22.96	29.69	36.97	100.0	100.0	100.0
K	3.68×10^{-5}	4.71×10^{-5}	5.87×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0284	0.0281	0.480	0.610
4	0.0281	0.0240	0.528	0.582
10	0.0285	0.0233	0.584	0.612
50	0.0285	0.0238	0.608	0.653
100	0.0279	0.0246	0.620	0.700
400	0.0293	0.0245	0.673	0.728

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.05091	0.03856	0.03007	19.64	25.93	33.26
4	0.04571	0.03417	0.02669	21.88	29.27	37.47
10	0.04367	0.03311	0.02607	22.90	30.20	38.36
Solv.	0.04201	0.03207	0.02496	23.80	31.18	40.06

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0320	0.0282
4	0.0292	0.0280
10	0.0319	0.0270
S.	0.0310	0.0285

TABLE XI.

Tetramethyl Ammonium Chloride in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	14.62	18.72	23.38	68.6	68.5	68.1
4	16.92	21.80	27.27	79.4	79.7	79.4
10	18.37	23.65	29.32	86.2	86.5	85.4
50	19.64	25.32	31.65	92.1	92.6	92.1
200	21.19	27.34	34.11	99.5	100.0	99.3
400	21.30	27.34	34.35	100.0	100.0	100.0
K	1.53×10^{-5}	1.99×10^{-5}	2.46×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25	25°-35	15°-25-	25°-35
2	0.0280	0.0249	0.410	0.466
4	0.0288	0.0251	0.488	0.547
10	0.0287	0.0240	0.528	0.567
50	0.0289	0.0250	0.568	0.633
200	0.0290	0.0248	0.615	0.677
400	0.0283	0.0256	0.604	0.701

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.04775	0.03578	0.02791	20.94	27.95	35.83
4	0.04503	0.03427	0.02679	22.21	29.18	37.33
10	0.04394	0.03313	0.02601	22.76	30.18	38.45
Solv.	0.04274	0.03194	0.02511	23.40	31.31	39.83

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0335	0.0282
4	0.0314	0.0279
10	0.0326	0.0274
Solv.	0.0338	0.0272

TABLE XII.

Tetraethylammonium Iodide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	11.78	15.42	19.47	62.6	63.5	64.0
4	13.86	18.10	22.78	73.7	74.5	74.0
10	15.74	20.31	25.31	83.7	83.6	83.2
50	17.60	22.69	28.47	93.6	93.5	93.6
100	18.45	23.79	29.85	98.1	98.0	98.1
200	18.81	24.28	30.43	100.0	100.0	100.0
K	2.47×10^{-5}	3.17×10^{-5}	3.94×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0309	0.0262	0.364	0.405
4	0.0306	0.0259	0.424	0.468
10	0.0290	0.0246	0.457	0.500
50	0.0298	0.0255	0.509	0.578
100	0.0289	0.0255	0.534	0.606
200	0.0291	0.0253	0.547	0.615

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
2	0.04879	0.03618	0.02802	20.50	27.64	35.68
4	0.04573	0.03486	0.02687	21.87	28.69	37.22
10	0.04431	0.03336	0.02607	22.57	29.98	38.36
Solv.	0.04284	0.03256	0.02561	23.34	30.71	39.05

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0349	0.0291
4	0.0312	0.0297
10	0.0328	0.0280
Solv.	0.0316	0.0271

TABLE XIII.

Rubidium Chloride in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	14.28	18.46	23.10	67.7	68.1	68.6
4	16.31	21.00	26.17	77.3	77.5	78.0
10	18.77	24.09	30.10	89.0	88.9	89.3
50	19.84	25.54	31.82	94.1	94.3	94.4
100	20.59	26.49	33.03	97.6	97.8	98.0
200	21.09	27.08	33.69	100.0	100.0	100.0
K	2.47×10^{-5}	3.17×10^{-5}	3.94×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0292	0.0251	0.418	0.464
4	0.0288	0.0251	0.469	0.527
10	0.0283	0.0249	0.532	0.601
50	0.0287	0.0246	0.570	0.628
100	0.0287	0.0247	0.590	0.654
200	0.0284	0.0244	0.599	0.661

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	0.05246	0.03869	0.02961	19.06	25.85	33.77
4	0.04773	0.03606	0.02778	20.95	27.73	36.00
10	0.04486	0.03396	0.2623	22.29	29.45	38.12
Solv.	0.04284	0.03256	0.2561	23.34	30.71	39.05

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0356	0.0308
4	0.0324	0.0298
10	0.0321	0.0295
S.	0.0316	0.0271

TABLE XIV.

Rubidium Bromide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
4	16.36	21.26	26.52	79.8	81.1	81.2
10	18.47	23.79	29.63	90.1	90.8	90.7
50	20.49	26.21	32.68	100.0	100.0	100.0
100	20.36	26.27	32.71			
K	4.79×10^{-5}	6.07×10^{-5}	7.62×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
4	0.0300	0.0247	0.490	0.526
10	0.0286	0.0245	0.532	0.584
50	0.0279	0.0247	0.572	0.647

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
2	Solution supersaturated at 25°					
4	0.04661	0.03501	0.02717	21.46	28.56	36.81
10	0.04462	0.03394	0.02648	22.41	29.46	37.76
Solv.	0.04312	0.03260	0.02564	23.19	30.68	39.00

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
4	0.0331	0.0289
10	0.0315	0.0282
S.	0.0323	0.0271

TABLE XV.

Rubidium Iodide in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	14.73	19.01	23.78	72.4	72.0	72.2
4	16.87	21.71	27.21	82.9	82.2	82.6
10	18.60	24.00	29.83	91.4	90.9	90.5
50	19.59	25.27	31.49	96.3	95.7	95.6
100	20.23	26.06	32.62	99.5	98.7	98.7
200	20.34	26.41	32.95	100.0	100.0	100.0
K	3.68×10^{-5}	4.71×10^{-5}	5.87×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0290	0.0251	0.428	0.477
4	0.0287	0.0253	0.484	0.550
10	0.0290	0.0243	0.540	0.583
50	0.0290	0.0246	0.568	0.622
100	0.0288	0.0248	0.568	0.646
200	0.0298	0.0248	0.607	0.654

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
2	0.04945	0.03516	0.02865	20.22	27.66	34.90
4	0.04643	0.03503	0.02737	21.54	28.55	36.54
10	0.04432	0.03348	0.02634	22.56	29.87	37.97
S.	0.04201	0.03207	0.02496	23.80	31.18	40.06

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0368	0.0265
4	0.0325	0.0280
10	0.0324	0.0271
S.	0.0310	0.0285

TABLE XVI.

Rubidium Nitrate in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
4	16.20	20.79	25.85	77.7	77.6	77.6
10	18.85	24.07	30.00	90.4	89.8	90.1
50	20.22	25.97	32.23	97.0	96.9	96.8
100	20.85	26.80	33.31	100.0	100.0	100.0
200	20.76	26.68	33.02			
K	2.47×10^{-5}	3.17×10^{-5}	3.94×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25	25°-35	15°-25	25°-35
4	0.0283	0.0243	0.459	0.506
10	0.0277	0.0246	0.522	0.593
50	0.0284	0.0241	0.575	0.626
100	0.0285	0.0243	0.595	0.651

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
4	0.04586	0.03430	0.02673	21.81	29.16	37.41
10	0.04417	0.03346	0.02622	22.64	29.89	38.15
Solv.	0.04284	0.03256	0.02561	23.34	30.71	39.05

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
4	0.0337	0.0283
10	0.0320	0.0276
Solv.	0.0316	0.0271

TABLE XVII.

Cæsium Chloride in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
4	16.83	21.69	27.15	78.6	78.8	78.7
10	18.75	24.09	30.03	87.6	87.5	87.1
200	21.40	27.54	34.49	100.0	100.0	100.0
400	21.06	27.15	34.11			
K	1.34×10^{-5}	1.72×10^{-5}	2.10×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
4	0.0289	0.0252	0.486	0.546
10	0.0285	0.0247	0.534	0.594
200	0.0287	0.0252	0.614	0.695
400	0.0289	0.0256	0.609	0.696

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	ϕ 15°	ϕ 25°	ϕ 35°
4	0.04735	0.03578	0.02789	21.12	27.95	35.86
10	0.04481	0.03395	0.02654	22.32	29.46	37.68
Solv.	0.04317	0.03245	.....	23.16	30.18	.....

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
4	0.0323	0.0281
10	0.0320	0.0279
Solv.	.....	

TABLE XVIII.

Cesium Nitrate in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
4	17.00	21.79	27.10	78.2	78.1	78.3
10	18.90	24.23	29.92	86.9	86.8	86.4
100	21.36	27.42	33.99	98.2	98.3	98.2
200	21.75	27.90	34.61	100.0	100.0	100.0
400	21.59	27.64	34.43			
K	1.34×10^{-5}	1.72×10^{-5}	2.10×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
4	0.0282	0.0244	0.479	0.531
10	0.0282	0.0235	0.533	0.569
100	0.0284	0.0240	0.606	0.657
200	0.0283	0.0241	0.615	0.671
400	0.0280	0.0246	0.605	0.679

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
4	0.04614	0.03478	0.02725	21.67	28.75	36.70
10	0.04456	0.03362	0.02632	22.44	29.74	37.90
Solv.	0.04317	0.03245	.....	23.16	30.81	.....

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
4	0.0327	0.0276
10	0.0325	0.0277
Solv.	.....	.....

TABLE XIX.

Lithium Nitrate in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
2	12.16	15.57	.....	66.0	65.8	.....
4	14.10	18.07	.....	76.5	76.4	.....
10	16.11	20.58	25.54	87.5	87.0	86.9
50	17.38	22.29	27.68	94.4	94.2	94.1
200	18.42	23.66	29.34	100.0	100.0	99.8
400	18.23	23.63	29.40	.....	.....	100.0
K						

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
2	0.0280	.....	0.341	.....
4	0.0281	.....	0.397	.....
10	0.0277	0.0241	0.447	0.496
50	0.0283	0.0242	0.491	0.539
200	0.0284	0.0240	0.524	0.568
400	0.0296	0.0244	0.540	0.577

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
2	0.05191	0.03873	0.03019	19.26	25.82	33.12
4	0.04720	0.03571	0.02786	21.19	28.00	35.89
10	0.04460	0.03157	0.02646	22.42	31.68	37.79
Solv.	0.04272	0.03196	0.02503	23.41	31.29	39.95

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
2	0.0340	0.0283
4	0.0321	0.0282
10	.....	.....
Solv.	0.0337	0.0277

TABLE XX.

Barium Chloride in Formamid.

MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
10	30.58	40.00	50.12	70.3	71.6	70.1
50	38.06	49.43	61.90	87.5	88.5	86.6
200	40.38	52.48	65.93	92.9	93.9	92.2
800	43.45	55.82	70.38	99.9	99.9	98.5
1600	43.48	55.86	71.48	100.0	100.0	100.0
K	1.58×10^{-5}	2.02×10^{-5}	2.45×10^{-5}			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
10	0.0308	0.0253	0.942	1.012
50	0.0299	0.0234	1.137	1.157
200	0.0300	0.0256	1.210	1.345
800	0.0285	0.0261	1.237	1.456
1600	0.0285	0.0280	1.238	1.562

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
10	0.04941	0.03702	0.02878	20.24	27.01	34.75
Solv.	0.04301	0.03221	0.02510	23.25	31.05	39.84

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
10	0.0322	0.0280
Solv.	0.0335	0.0283

TABLE XXI.
Mercuric Chloride in Formamid.
MOLECULAR CONDUCTIVITY.

V	Molecular conductivity		
	15°	25°	35°
4	0.43	0.59	0.83
10	0.63	0.87	1.27
50	1.09	1.56	2.22
200	1.74	2.53	3.68
400	2.73	4.15	5.82
1000	....	134.49	....
1600	....	101.13	....
3200	....	75.35	....
K	1.30×10^{-5}	1.65×10^{-5}	2.03×10^{-5}

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
4	0.0372	0.0407	0.016	0.024
10	0.0381	0.0460	0.024	0.040
50	0.0431	0.0423	0.047	0.066
200	0.0437	0.0455	0.076	0.115
400	0.0520	0.0402	0.142	0.167

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
4	0.04688	0.03527	.....	21.33	28.35	.....
10	0.04496	0.03376	.....	22.25	29.62	.....
Solv.	0.04301	0.03221	0.02510	23.25	31.05	39.84

TABLE XXII.
Cobalt Bromide in Formamid.
MOLECULAR CONDUCTIVITY AND DISSOCIATION.

V	Molecular conductivity			Dissociation		
	15°	25°	35°	15°	25°	35°
10	27.11	35.35	44.30	60.9	61.4	60.7
50	34.70	45.01	56.56	78.0	78.1	77.5
200	39.00	50.34	.....	87.7	87.4	.....
800	44.48	57.60	72.95	100.0	100.0	100.0
1600	41.83	53.96	68.70			

TEMPERATURE COEFFICIENTS OF CONDUCTIVITY.

V	Per cent.		Conductivity units	
	15°-25°	25°-35°	15°-25°	25°-35°
10	0.0304	0.0253	0.825	0.895
50	0.0297	0.0257	1.031	1.155
200	0.0291	.....	1.134	.....
800	0.0295	0.0266	1.312	1.535
1600	0.0290	0.0273	1.213	1.474

VISCOSITY AND FLUIDITY.

V	η 15°	η 25°	η 35°	φ 15°	φ 25°	φ 35°
10	0.04892	0.03699	0.02867	20.44	27.03	34.88
Solv.	0.04301	0.03221	0.02510	23.25	31.05	39.84

TEMPERATURE COEFFICIENTS OF FLUIDITY.

V	15°-25°	25°-35°
10	0.0322	0.0290
Solv.	0.0335	0.0283

DISCUSSION OF RESULTS.

Tables III to XXII, inclusive, give the molecular conductivity, dissociation, viscosity and fluidity, as well as the temperature coefficients both of conductivity and fluidity for all the salts studied.

In this laboratory, during the past fifteen years, solutions in the following pure solvents have been investigated: Water, methyl and ethyl alcohols, acetone, and glycerol. Among the results of this work in pure solvents are the discovery or confirmation of many relations between the conductivity and viscosity of solutions, the dissociation of the solutes, and the dielectric constant, association factors and viscosities of the solvents.¹³ Reference to Table II shows that formamid is a solvent markedly different from any other pure solvent investigated, in regard to the three constants mentioned. The most important result of this investigation is that the evidence it has developed supports and confirms all the relations and conclusions that have been worked out by Jones and his co-workers, from their investigations with other pure solvents. These relations will be discussed in turn.

The Thomson¹⁴-Nernst¹⁵ theory is that the forces which hold

¹³ These results have been tabulated and discussed in Publications of the Carnegie Institute Nos. 170, 180, and 210.

¹⁴ *Phil. Mag.*, 36, 320 (1893).

¹⁵ *Zeit. phys. Chem.*, 13, 531 (1894).

the atoms together are electrical; hence the solvent having the highest dielectric constant has the greatest dissociating power. The dissociating power of solvents is shown in two ways: first, by comparing the percentage dissociation of solutions having the same normality; and, second, by comparing the dilutions at which complete dissociation is reached. Compare Table VII with the following:

Aqueous potassium iodide solution at 25

V		Temperature percentage coefficient, 25°-35°	
2	112.8	76.6	1.85
8	120.7	82.0	1.97
2048	147.2	100.0	2.04

Table VII shows that the dissociation of the N/2 solution of potassium iodide in formamid is only 71 per cent. at 25°. From the data we calculate that the viscosity of the N/2 solution is 12.4 per cent. greater than the solvent, while the viscosity of N/2 solution of potassium iodide in water is known to be less than that of the solvent. From a large mass of evidence we know that viscosity is by far the largest factor affecting conductivity in solutions in which dissociation is of the same order of magnitude. The conductivity of the N/2 solution in formamid at 25° is 18.67. We can assume without appreciable error that if the viscosity of the solvent and the N/2 solution were in the same ratio as in the case of the potassium iodide solution in water, the conductivity of the N/2 solution in formamid would be at least 12.4 per cent. larger than the figure given—18.67. Recalculating the dissociation of the potassium iodide-formamid solution on this basis gives 79.4 per cent., compared with 76.6 per cent. for the potassium iodide solution in water. This latter figure would be even less if corrections were made for the fact that the viscosity of an N/2 solution in water is less than that of the solvent, which would be a legitimate correction to make for the purpose of this comparison. Comparing in this way the dissociation of these two N/2 solutions, we find, as would be expected from the Thomson-Nernst theory, *that formamid has the greater dissociating power.*

Complete dissociation of potassium iodide in formamid is found in the N/200 solution, while in water it is not reached till the N/2048 solution. Therefore, in both respects, formamid falls

in line with the Thomson-Nernst theory. This relation is confirmed by every salt studied in this investigation for which data for comparison are available. The rubidium salts show the stronger dissociating power of formamid much more than some others that were studied.

The hypothesis of Dutoit and Aston¹⁶ states that the greater the association factor of the solvent, the greater its dissociating powers. Table I shows the relation of formamid to other pure solvents in regard to association factors. The correction and comparisons made above, with reference to the Thomson-Nernst theory, are equally applicable in connection with the Dutoit and Aston theory. Having these two theories in mind, it is of interest to give here the percentage dissociations of a few salts in ethyl alcohol, for comparison with the data given in Tables VII, VIII, and XIX.

Solutions in Ethyl Alcohol at 25°.

Salt	V for	α
KI	8192	76.7
KCNS	6400	93.8
LiNO ₃	6400	89.9

The above table was taken from the data of Jones and Kreider. Jones and Mahin showed that complete dissociation of lithium nitrate in acetone is not reached even when V is 100,000. The significance of these figures is apparent if one has in mind the association factors and dielectric constants of formamid, ethyl alcohol, and acetone, given in Table II.

Jones and Veazey's¹⁷ explanation of the decrease in viscosity produced to the greatest extent by cæsium and rubidium salts, and in a less degree by potassium, ammonium, and other salts, all having very large molecular and atomic volumes, has been of special interest in this investigation. They base their hypothesis on the theory of Thorpe and Roger, that viscosity is due to the friction between the surfaces of the molecules. If the particles of the solute are larger than those of the solvent, the frictional surfaces and, consequently, the viscosity will be decreased. If the added particles are smaller than those of the solvent, the vis-

¹⁶ *Compt. Rend.*, 126, 240 (1897).

¹⁷ *Amer. Chem. Journ.*, 37, 405 (1907).

Carnegie Institute of Washington, Publication No. 80, (1907).

cosity will be increased by the addition of the solute. The viscosity of all the concentrated solutions of salts having very large atomic or molecular volumes has been found to be less than the solvent in the case of all pure solvents, except acetone, which have previously been studied. The viscosity of formamid has, on the contrary, been *increased* by every salt used. The complex formamid molecule, HCONH_2 , and its very large association factor, 6.18, show that its actual molecule is *larger than that of any other pure solvent used in these investigations*, and the increase in viscosity by the salts named above confirms this conclusion. The following comparison strikingly illustrates this relation: A N/2 solution of rubidium iodide in glycerol *decreases* the viscosity of the solvent 13 per cent., while a N/2 solution of the same salt in formamid *increases* the viscosity of the solvent 12.7 per cent. This relation will be referred to again in discussing the results of the work with caesium nitrate and chloride.

That the percentage temperature coefficients of conductivity increase as the viscosity of the solution increases, is a relation that has been brought out by all the investigations in this laboratory. These coefficients for solution in formamid have the order of magnitude that would be expected from the relation of their viscosities to the viscosities of the same solutions in other solvents. For example, compare the coefficients for solutions of potassium iodide in water, given in the table on page 595, with those for the same salt in formamid in Table VII.

All salts containing water of crystallization were carefully dehydrated at suitable temperatures, just before the solutions were prepared. No thermal measurements were made of the heat of solution, but in the case of sodium iodide, which crystallizes with two molecules of water, a marked rise in temperature was noted when the salt dissolved in formamid, which indicated the formation of a solvate. It is well known that solvated salts give higher temperature percentage coefficients of conductivity than non-solvated, because complexes are usually simplified by rise in temperature. In the present investigation, salts crystallizing with water have given the larger coefficients, indicating the formation of solvates analogous to the formation of solvates by the same salts in water and other solvents. To illustrate this relation, let us compare these coefficients for sodium chromate, crystallizing with ten molecules of water (Table V), and cobalt bromide,

crystallizing with two molecules of water (Table XXII); also compare sodium iodide, crystallizing with two molecules of water (Table IV), with potassium iodide (Table VII). The coefficients for the dilute solutions of sodium chromate are probably not reliable for this comparison, as will be explained under the discussion of this salt.

SODIUM CHROMATE.

Table V gives the results for sodium chromate. They are of the usual order of magnitude, except for the N/1600 solution. At each temperature the increase in conductivity between the N/800 and N/1600 solutions is 59 per cent., which is probably due to chemical action or decomposition, instead of to an increase in ionization. Formic acid is a strong reducing agent. Formamid may be considered as formic acid in which a hydroxyl has been replaced by an amido group. Both the hydroxyl and amido group are basic; therefore, we might expect from this relationship that formamid would be a reducing agent. The reducing action of formamid will also be discussed with the results for mercuric chloride. Sodium chromate is a strong oxidizing agent; hence, it is not surprising that there should be chemical action between these two compounds when the chromate is in a highly ionized condition, as in a dilute solution. The percentage dissociations have not been calculated, because the conditions just referred to introduce an uncertainty regarding them.

MERCURIC CHLORIDE.

The conductivity of aqueous solutions of mercuric chloride is too small to be measured, but in formamid, on account of its greater dissociating power, the conductivity is measurable, and increases as dilution increases in the usual way up to the N/400 solution. The conductivity values for the N/1000, N/1600, and N/3200 solutions clearly result from some decomposition, probably of the solvent. The conductivity of barium chloride at complete dissociation is 55.86 at 25°. The large value, 134.49, for the N/1000 mercuric chloride solution shows that it is not due to dissociation. Assuming that at complete dissociation the conductivity of mercuric chloride would be of the same order of magnitude as of barium chloride, the dissociation of the N/4 solution would be about 1.0 per cent., increasing to about 7.0 per cent. for

the N/400 solution. Silver chloride is precipitated in the N/400 solution by silver nitrate. By standing in the sunlight for a short time, a heavy precipitate of metallic silver is formed, showing again the reducing action of formamid.

To recover the solvent from the mercuric chloride by vacuum distillation required several more distillations than usual. Metallic mercury was found in the receiver after the first distillation, showing again the reducing action of formamid. It is possible that the liberated chlorine formed a salt with the formamid which was easily dissociated, since the conductivity of the first fraction of the distillate was very high, and was lowered only a small amount by successive distillations. Repeated distillation, however, gave the solvent used for the solutions of the caesium salts.

COBALT BROMIDE.

The green, anhydrous cobalt bromide gives a pink solution in formamid as in water. After the determinations were made, a mixture of solutions was distilled to recover the formamid. The mixture contained mercuric chloride and cobalt bromide. As already stated, the mercuric chloride was reduced to metallic mercury. The dry residue in the distillation flask had the brilliant blue color of anhydrous cobalt chloride, showing that the free chlorine from the mercuric chloride had replaced the bromine in the cobalt bromide.

CÆSIUM NITRATE AND CHLORIDE.

For several years past this laboratory has been unable to obtain any caesium salts for its investigations in conductivity and viscosity. Recently, some caesium sulphate was obtained through the coöperation and courtesy of Prof. James Lewis Howe, of Washington and Lee University. The sulphate was converted into the nitrate and chloride, and the conductivity and viscosity of their solutions were determined. The results are recorded in Tables XVII and XVIII.

A survey of the work on the salts of all the alkali metals shows that conductivity values for the caesium, rubidium, and potassium salts used are approximately the same, and for sodium and lithium are less. The same relation is true of the results obtained in aqueous solutions. Dissociation percentage is of the same order of magnitude for all the salts named. The con-

ductivity results in connection with the dissociation percentage harmonize with the ionic velocities. For cæsium, rubidium, and potassium the relative ionic velocities are 73.6, 73.5, and 70.6, respectively, and for sodium and lithium they are 49.2 and 39.8.

The most striking difference between these metals is shown by the atomic volume curve of Lothar Meyer.¹⁸ This function increases by nearly regular steps from 12 for lithium to 72 for cæsium. In accordance with the theory of Jones and Veazey,¹⁹ to which reference has already been made, the percentage increases in the viscosity of the concentrated solutions over the viscosity of the solvent should be the smallest for cæsium salts, and should increase in the following order: Cæsium, rubidium, potassium, sodium, and lithium. This relation comes out clearly by comparing the viscosity data for cæsium and rubidium salts (Tables XIII to XVIII) with those for sodium and lithium. The salts of rubidium and cæsium increase the viscosity of formamid much less than sodium and lithium salts (Tables III, IV, and XIX). The difference in percentage increase is not as marked as the difference in the atomic volumes of the metal ions. The effect is partially suppressed by other factors. Consider the solution of a binary salt which is 80 per cent. dissociated. Every hundred molecules of the salt gives, in solution, eighty anions, eighty cations and twenty molecules. The eighty cations are only 44.5 per cent. of the number of particles in the solution. It is only this 44.5 per cent. of cations which have the atomic volume relations referred to above. The molecular volumes do not show this relation, and the atomic volumes of the anions are unknown.

SUMMARY OF RESULTS.

The first five of the conclusions drawn below have been developed or confirmed by the investigations in this laboratory with other pure solvents, and have been shown by this investigation to hold true for formamid.

1. The greater the dielectric constant of a solvent the greater its dissociating power.
2. The greater the association factor of a solvent the greater its dissociating power.

¹⁸ *Lieb. Ann. Suppl.*, 7, 354 (1870).

¹⁹ Carnegie Institute of Washington, Publication No. 80, (1907); *Amer. Chem. Journ.*, 37, 405 (1907).

3. The formation of *solvates* with formamid is indicated by those salts that form hydrates.

4. Solvated salts show larger percentage temperature coefficients of conductivity than non-solvated salts.

5. The order of magnitude of percentage temperature coefficients of conductivity is approximately proportional to the viscosity of the solutions.

6. Formamid is the first of the pure solvents studied with reference to the viscosity of solutions, in which none of the salts used produce negative viscosities. A satisfactory explanation of the above fact is apparent, if the very large association factor of the solvent is considered in connection with the theory of Jones and Veazey.

7. In regard to conductivity, dissociation, and effect on viscosity of solvent, caesium salts are very closely allied to rubidium salts.

8. Mercuric chloride is more dissociated in formamid than in water.

Johns Hopkins University,

May 15, 1915.

Metropolitan Needs and Sizes of Prime Movers. ANON. (*Electrical World*, vol. 66, No. 15, October 9, 1915.)—With the advent of the 20,000-kilowatt steam turbine many of the problems then confronting large modern generating stations were solved. However, the equipment soon proved to be too small to meet the rapidly advancing loads. The installation of 30,000-kilowatt and 35,000-kilowatt since has made another step forward in meeting pressing metropolitan needs, and now units of 50,000-kilowatt rating are being seriously considered. High economy and reliability are not the only desiderata in increasing the size of prime movers. Labor, real estate, and other considerations depending upon loads, design, and location of plant in a large city are factors almost as important. Recently many of the large lighting companies have acquired huge railway loads, it being generally recognized by railway officials that this is advantageous to them.

In New York City 30,000-kilowatt units are used to handle the elevated-railway and subway demand of the Interborough Rapid Transit Company. Units of 20,000 kilowatts are used by the central stations of New York, Cleveland, Detroit, and Chicago, and 30,000-kilowatt units in New York, Chicago, and Philadelphia. Philadelphia has the distinction of possessing the largest steam turbine thus far installed, a 35,000-kilowatt unit.