[CONTRIBUTION FROM THE DEPARTMENTS OF CHEMISTRY AND PHYSICS OF BOSTON UNIVERSITY]

A STUDY OF MAGNETO-ELECTROLYTIC POTENTIALS

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Introduction

It has been found that upon allowing solutions containing dissolved electrolytes to move through constant magnetic fields, a potential difference is obtained in a direction at right angles both to the direction of flow of the liquids and the field. It is thought that the term magneto-electrolytic potential adequately describes the above effect. The existence of magneto-electrolytic potentials in solutions containing certain dissolved electrolytes was believed by Scarpa[1] to prove the presence of free electrolytic ions.

Methods of two general types have been developed for proving the presence of ions in solutions of electrolytes in the absence of an electric field, one type using gravitational and centrifugal forces and the other magnetic fields of force. Those investigators using gravitational and centrifugal means were Colley,[2] DesCoudres[3] and Tolman,[4] while others using magnetic fields were Guthrie and Boys,[5] Ostwald,[6] Franklin and Freudenberger,[7] and Scarpa.[1]

As the work presented herewith enlarges upon that of Scarpa, it would not be out of place to outline briefly the essential features of his work. Scarpa believed that if a flowing solution containing dissolved electrolyte actually contained free ions they would be forced to opposite sides of the stream in a magnetic field, thereby causing a potential difference. He was able to measure this potential difference across electrodes inserted in side tubes placed at right angles to the direction of flow of liquid and of the magnetic field. Solutions of copper and of zinc sulfate with electrodes of copper and of zinc, respectively, were used. In conclusions based upon but six readings in which he varied the flow velocity and the field strength, he derived an equation, neglecting osmotic forces, which proves to be the law of the dynamo, e.m.f. = $HVL \times 10^{-8}$, where H is the field strength in Gauss, L the length of the conductor in cm. and V the linear velocity of the wire in cm./sec. On account of the dearth of data presented and

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[1] Scarpa, *Gazz. chim. ital.*, **54,** 860 (1924).

[2] Colley, *J. St. Petersburg Chem. Phys. Ges.*, **7,** 33 (1875); *Pogg. Ann.*, **157,** 370, 624 (1876); *Wied. Bei.*, **5,** 451 (1881); *Wied. Ann.*, **17,** 55 (1882).

[3] DesCoudres, *Wied. Ann.*, **49,** 284 (1893); *ibid.*, **59,** 232 (1896).

[4] Tolman, *Proc. Am. Acad. Arts Sci.*, **46,** 5 (1910).

[5] Guthrie and Boys, *Phil. Mag.*, **8,** 449 (1879); **10,** 328 (1880).

[6] Ostwald, *Z. physik. Chem.*, **2,** 270 (1888).

[7] Franklin and Freudenberger, *Phys. Rev.*, **25,** 294 (1907).

the interesting features not investigated by Scarpa, the effect seemed worthy of further study.

Present Work

The relations between the potential difference measured and the concentration of the electrolyte, the flow velocity of the electrolyte, the strength of the magnetic field, the position of the cell with respect to the center of the magnetic poles and the chemical nature of the solute were investigated in turn. The change of resistance of solutions of electrolytes while flowing in a magnetic field was determined.

Experimental Part

Procedure

The solutions of electrolytes under investigation ran under the influence of gravity through a vertical tube placed between the flat centers of the conical poles of a large Weiss electromagnet. To the opposite sides of this tube were attached horizontal side arms containing copper electrodes (sealed in with de Khotinsky cement). This cell was then centrally placed in the magnetic field. In the first series of determinations in which the effect of concentration on the generated potential difference was measured, a glass cell was used but in later runs this was replaced by one made of hard rubber sheet, drilled so that a uniform and easily measurable bore could be obtained. Into the top and bottom of this rubber matrix were sealed glass entrance and exit tubes and on each side the tubes containing

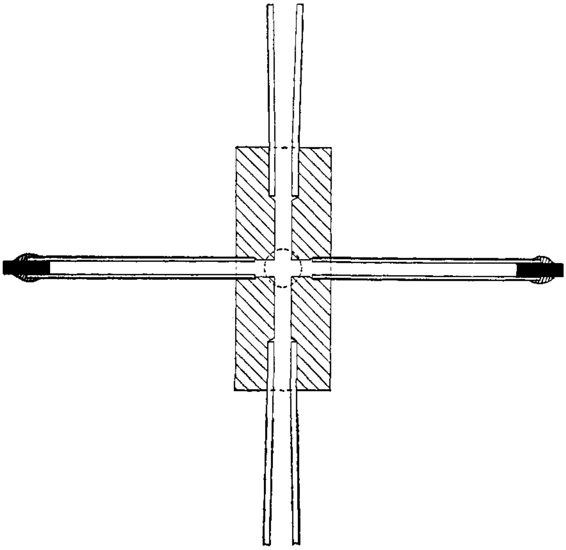

Fig. 1.

electrodes. Fig. 1 shows the construction in detail. It was necessary to place the electrodes several centimeters from the center of the vertical stream of the dissolved electrolyte so that no frictional electromotive force would be generated due to the turbulence of the flowing solution.

The rate of flow of the solution was determined by measuring with a stop watch the time for a definite quantity to pass through the cell. Knowing the diameter of the vertical hole through the cell, the linear velocity could be computed. Individual readings were taken on every run as a sufficiently reliable constant could not be obtained.

The potential difference was measured on a Wolf potentiometer connected to a sensitive d'Arsonval galvanometer. There was a residual electromotive force which could not be entirely eliminated even on long periods of short circuit. Its value had to be read before and after each run and subtracted from the maximum reading.

This residual electromotive force was usually constant but if it changed more than a few millivolts during the run the results were discarded. Scarpa[1] experienced this difficulty also. Readings for the maximum potential difference produced were always taken near the time of half flow, although on account of the large surface of the liquid in the upper container this precaution was hardly necessary. Fig. 2 shows the arrangement of the apparatus. The solutions used were analyzed for copper by electrolytic deposition, for zinc by precipitation with diammonium phosphate and for sulfate by precipitation with barium chloride.

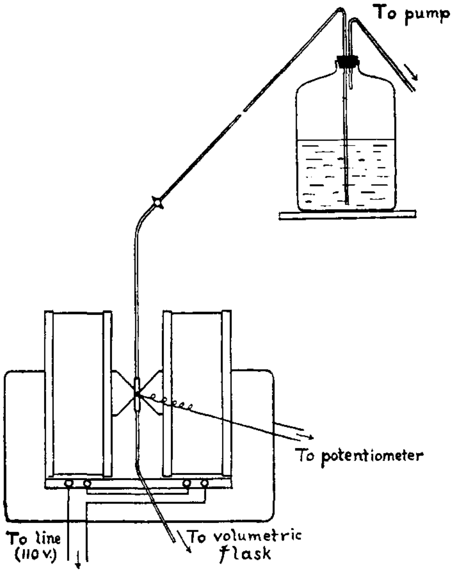

Fig. 2.

Effect of Concentration on Potential Difference

It was necessary before any other runs were made to see whether the potential difference produced was a function of the concentration of the electrolyte used, so that means might be found for keeping the concentration constant if necessary. The following results were obtained for constant field intensity corrected to constant flow.

Each of the above reported readings is a mean of several observations. It can be seen by inspection of the table that the potential difference is

TABLE I

CONCENTRATION *vs.* POTENTIAL DIFFERENCE

Molal concn., $Cu(NO_3)_2$	Vel. of soln. in liters per min.	Potential diff. in volts	Potential diff. corr. to 1.25 liters per min.
2.49	1.25	0.0045	0.0045
.259	1.25	.0043	.0043
.0326	1.23	.0042	.0043
.0033	1.15	.0041	.0044
		Mean	.0044

not a function of the concentration. Obviously this is not a concentration cell as might reasonably be expected on primary consideration.

Effect of Velocity of Solution on Potential Difference

If the solution of electrolyte affords metallic conduction, then according to the law for metallic conductors, e.m.f. = $HVL \times 10^{-8}$, the potential difference produced should be directly proportional to the linear velocity of the electrolyte and the potential difference divided by the velocity should be constant. In order to illustrate the accuracy of readings obtained, the latter are given in full in this case while subsequent data are the mean of two or more readings.

TABLE II

VELOCITY OF SOLUTION *vs.* POTENTIAL DIFFERENCE

H = 23,000 Gauss. Concn. $CuSO_4$ = 0.0967 molal. Pole separation = 1.00 cm.

Run	Linear vel. of soln., cm./sec.	Mean linear vel., cm./sec.	Pot. diff., volts	Mean pot. diff., volts	Constant obtained, (P. D./vel.) $\times 10^4$
1	150	150	0.0128	0.0128	0.85
2	144		.0121		
	144	144	.0123	.0122	.85
3	137		.0117		
	135	136	.0120	.0118	.87
4	107	107	.0094	.0094	.88
5	94.6		.0081		
	94.4	94.5	.0081	.0081	.86
6	59.0		.0051		
	59.0	59.0	.0051	.0051	.86
7	56.7		.0046		
	56.4	56.6	.0049	.0047	.84
8	28.2		.0023		
	28.2	28.2	.0024	.0024	.83
9	20.6		.0018		
	20.4	20.5	.0016	.0017	.83
10	17.5		.0015		
	17.5	17.5	.0015	.0015	.86
				Mean	.85

The above table consists of two series of runs made on different days; a fairly good constant is obtained for a nine-fold change in solution velocity.

It was impossible to prevent the magnet from heating on long runs and as the permeability of the core changes with temperature the field must necessarily have varied somewhat during the course of the runs in spite of the fact that the exciting current was kept constant.

Effect of Field Strength on Potential Difference

If this is a case of metallic conduction as suggested by Scarpa's results,[1] then the potential difference must be proportional to the field strength. The strength of the magnetic field was carefully measured by the usual method of determining the change in resistance of a calibrated bismuth spiral placed in the center of the field. Table III gives the results obtained and also includes the value for the electromotive force based on the law of the dynamo, and the difference between these values and those observed.

TABLE III

EFFECT OF FIELD STRENGTH ON POTENTIAL DIFFERENCE

Concn. $CuSO_4$ = 0.0967 molal. Bore of cell = 4.35 mm. Pole separation = 1.00 cm.

H, Gauss	P. D. corr. to 112.7 cm./sec.	(H/P. D.) $\times 10^{-6}$	E.m.f. calcd.	Diff. between calcd. and obs.	Diff., %
8,300	0.0033	25.1	0.0041	0.0008	19
12,900	.0052	24.8	.0063	.0011	17
16,400	.0067	24.5	.0080	.0013	17
19,200	.0079	24.3	.0094	.0015	16
21,200	.0087	24.4	.0104	.0017	16
22,200	.0091	24.4	.0109	.0018	16
22,800	.0093	24.5	.0112	.0019	17
	Mean	24.6		Mean	17

An examination of the table will show a constant value for the field strength divided by the potential difference observed. However, it should also be noticed that there is a constant difference between the observed and the calculated values for the electromotive force (to be explained in a later section).

Relation of Position of Cell to Potential Difference

In order to ascertain whether the time required to displace the ions by a magnetic field (that is, if they actually are displaced) was measurable, the position of the cell was varied from a point directly above the center of the magnetic poles and about even with the upper edge of the pole to one an equal distance below, taking care to move the cell along a vertical axis between these two points. The strength of the field was determined over this range with the same bismuth spiral used to calibrate the field strength at constant pole separation.

The two curves obtained for copper sulfate (0.0967 molar) are plotted in Fig. 3 to the same scale but are slightly displaced to indicate more clearly any difference in form. Were this a case of metallic conduction in liquids the two curves should coincide at all points upon being superimposed. On the other hand, if the ions are responsible for the potential difference and require an appreciable time element to be magnetically displaced then the ΔV curve should be shifted bodily to the left with respect to the H curve. The fact that no apparent shift occurs does not necessarily prove that the ions are not displaced as this process may be very rapid and follow the value for the field strength closely. That the two curves would not coincide if superimposed cannot be adequately explained in the light of our present knowledge but might be caused by the bismuth spiral being a flat disk while the portion of the cell between the side arms is cylindrical.

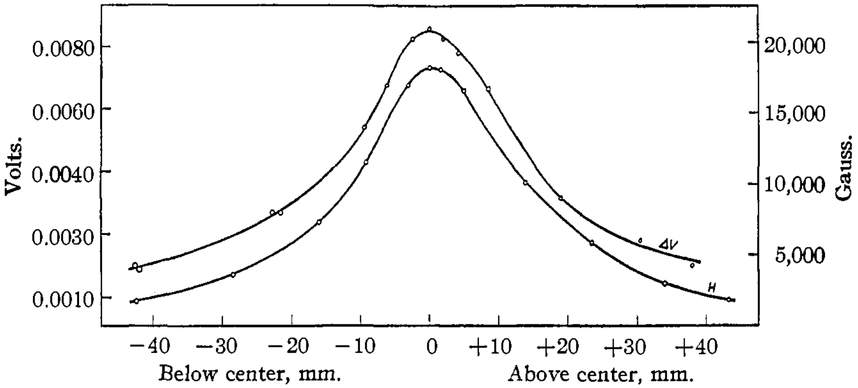

Fig. 3.

Effect of Chemical Nature of Electrolyte on Potential Difference

Up to this point all of the work with the hard rubber cell had been done with the same copper sulfate solution. The effect of the chemical nature of the solute on the potential difference generated was next studied. The results are given in Table IV.

The constants obtained in the above runs agree well with those for copper sulfate with the exception of those for potassium sulfate. In this case it is believed that they are near enough to the mean to suggest that the same phenomena are taking place as in the others.

It was believed that the constant difference between the observed and the calculated results was due to one of two causes, either the effective bore of the cell at the point where the side arms entered was greater than the value used (the side arms being of the same diameter as the central vertical tube) or the difference was due to osmotic forces set up by the displaced ions.

Consequently, a new cell was made on the same general plan as that used hitherto except that the bore of the side arms at the point of entrance into the main vertical tube was made much smaller (1.0 mm.), so as to

TABLE IV

EFFECT OF SOLUTE ON POTENTIAL DIFFERENCE

Solute	Molal concn.	*H*, Gauss	P. D., v.	Linear vel., cm./sec.	P. D., v. (at 112.7 cm./sec.)	Calcd., P. D., v.	% Diff. between calcd. and obs. P. D., %	(P.D./vel.) × 10^4	(*H*/P. D.) × 10^{-5}
$Cu(NO_3)_2$	0.107	23,200	0.0111	132	0.0095	0.0133	17	0.84	24
$Cu(NO_3)_2$	.107	19,400	.0096	135	.0080	.0114	18	..	24
$Cu(NO_3)_2$	.107	19,400	.0083	121	.0077	.0102	19	..	25
$Cu(NO_3)_2$	.107	19,200	.0047	69	.0078	.0058	19	..	25
$Cu(NO_3)_2$	.107	19,200	.0044	66	.0075	.0055	20	..	26
$Cu(NO_3)_2$	.107	19,200	.0026	34	.0086	.0028	7	..	22
$Cu(NO_3)_2$	.107	19,200	.0023	32	.0081	.0027	15	..	24
$Cu(NO_3)_2$ =	.106	23,200	.0109	134	.0091	.0135	18	.81	25
and									
$ZnSO_4$ =	.163	19,300	.0092	134	.0077	.0112	18	..	25
$ZnSO_4$	.1163	23,000	.0110	136	.0091	.0136	19	.81	25
$ZnSO_4$	.1163	19,600	.0056	81	.0078	.0069	19	..	25
$ZnSO_4$	.1163	19,300	.0097	134	.0082	.0114	15	..	25
K_2SO_4	.1156	23,200	.0106	134	.0089	.0135	21	.79	26
K_2SO_4	.1156	23,200	.0036	46	.0086	.0046	22	..	26
K_2SO_4	.1156	19,200	.0092	135	.0077	.0113	19	..	25

affect as little as possible the effective diameter of the vertical stream of solution at this point.

The results obtained with this new cell are presented in Table V.

TABLE V

RESULTS WITH NEW CELL

Concn. $CuSO_4$ = 0.0415 molal. Diam. vert. tube = 4.2 mm. Diam. side arm = 1.0 mm.

Time in secs. for one liter	*H*, Gauss	P. D. obs., v.	P. D. corr. to one liter per min.
61.2	23,000	0.0113	0.0115
62.4	23,000	.0108	.0112
66.6	23,000	.0100	.0111
59.4	23,000	.0114	.0113
61.8	23,000	.0113	.0116
64.8	23,000	.0107	.0116
61.0	23,000	.0118	.0120
59.8	23,000	.0115	.0115
66.4	23,000	.0102	.0113
59.8	23,000	.0114	.0114
59.6	23,000	.0116	.0115
		Mean	.0115 (theor. val. = .0116)
60.4	19,600	.0099	.0100
60.4	19,600	.0100	.0101
63.4	19,600	.0096	.0101
61.2	19,600	.0099	.0098
62.0	19,600	.0096	.0099
		Mean	.0100 (theor. val. = .0099)

TABLE V (*Concluded*)

Time in secs. for one liter	*H*, Gauss	P. D. obs., v.	Calcd. P. D.
271.6	23,500	.0025	.0026
93.0	22,900	.0072	.0074
93.2	22,900	.0074	.0074
94.6	22,900	.0074	.0073
98.0	22,800	.0072	.0069
102.6	22,800	.0066	.0066
99.0	22,800	.0070	.0070
99.2	22,800	.0070	.0070
100.6	22,800	.0070	.0069
99.2	22,800	.0070	.0070

From an examination of the table it is evident that our results check the theoretical value calculated on the rule of the dynamo within the limit of experimental error.

Limits of Detectability of Potential Difference

Concentration.—With a solution of copper sulfate so dilute that no color was apparent to the eye even after adding ammonia but still containing enough copper to give a red tinge with potassium ferrocyanide, results were obtained of the same order of magnitude as with more concentrated solutions. However, the sensitivity of the galvanometer was decreased markedly due to the extremely high resistance of the cell, which was about seven thousand ohms when filled with a tenth molal solution.

Minimum Velocity.—With the system containing an approximately tenth normal copper sulfate solution (0.0967 *M*) a detectable potential (0.0002 volt) was obtained with a linear velocity of solution of 0.75 cm./sec.

Resistance of Flowing Electrolyte in Magnetic Field

The resistance of the solution of electrolyte was measured in a stationary state with no field and then flowing with full field strength. As a source of alternating current an electron tube sine wave oscillator was used but as the bridge coils were of a poor quality the measurements were of an accuracy of about 1%. Within this range of error no difference in resistance could be detected.

Attempts to Detect Actual Magnetic Displacement of Ions

As another method of approach a water solution of phenolphthalein was passed through a glass cell (of similar construction to that first used) placed in the center of the field in order to determine whether the phenolphthalein would be caused to dissociate and the phthalate ions thereby formed be concentrated in one side arm—which ionization, if in excess of 6%, would be evidenced by coloration. Negative results were obtained.

Following this line of reasoning a saturated solution of sodium chloride replaced the phenolphthalein solution. If the sodium ion were concentrated in one side arm and the chlorine in the other a precipitation of undissociated sodium chloride should take place, at least temporarily, due to the common ion effect. No such precipitate was observed.

The three above described experiments offer no evidence that the solute while passing through a magnetic field is caused to dissociate or that the ions are actually displaced.

Theoretical Section

Although the results seem to indicate that the solution behaves like a metallic conductor (flowing electrons) a theoretical consideration of the phenomena will show that the displacement of the ions due to their motion in a magnetic field can as well account for the results obtained, even when osmotic forces are taken into consideration.

Let us consider an imaginary cell composed of a cube of liquid (Donnan[8] on the Hall Effect in liquids). This cube is moved through a magnetic field at right angles to the lines of force; the positive ion will be moved toward one vertical face of the cube and the negative ion toward the opposite face according to the right-hand rule of the dynamo. The ions would therefore pass through the opposite faces of the cube into the spaces beyond, which can be imagined to be adjacent cubes (or the side arms in an actual cell). This causes the formation of two electric layers, each on an opposite face of the central cube. The potential gradient due to the two layers of charged particles (ions) constitutes a force tending to oppose and partially annul the magnetic force displacing the ions. Consider one face of the cube. Inasmuch as a number of ions have been moved from the central cube to an adjoining cube the osmotic force due to this type of ion in the latter is now greater than the osmotic force due to the same kind of ion in the central cube, constituting an excess of osmotic force in a direction opposing the magnetic force.

Due to the increase of one type of ion in an adjacent cube, according to mass action the equilibrium must be displaced with the formation of a larger number of undissociated molecules and a subsequent decrease of ions of the opposite type. In the central cube, due to a loss of ions of the first type (let us say the positive ion), there will be an equilibrium shift in the opposite direction with the formation of more negative ions and a subsequent loss of undissociated molecules. This shift in equilibrium tends to decrease slightly the osmotic force due to the positive ions, to cause an increase in the negative ions in the central cube over that in the adjacent cube and thereby produce an osmotic force tending to move negative ions from the central cube into the adjacent cube. In the same way it creates an osmotic force due to the increase in the number of undissociated molecules in the adjacent cube over the number of the same in the central

[8] Donnan, *Phil. Mag.*, **46**, 465 (1898).

cube. When a stationary state is attained there must be an equilibrium among these several forces and the amount of matter transported through the face of the central cube in one direction into the adjacent cube must be exactly equal to that transported in the opposite direction.

It will be remembered that the above discussion concerns the relation between the central and one adjacent cube. The same reasoning applies to the relation between the central cube and that on the opposite side.

The phenomena discussed above may be expressed mathematically as follows. Let D = cell diameter; V = linear velocity of solution; ω = valence of ion; H = field strength in Gauss; N = Avogadro's number; α = fraction of total number of molecules ionized; C = concn. in gram moles per cc.; n = number of ions given on dissociation; ϵ = unit electrical charge; u_1 = vel. of Cu^{++} ion in cm. per sec. under unit force; u_2 = vel. of SO_4^{--} ion in cm. per sec. under unit force; u_3 = vel. of $CuSO_4$ ion in cm. per sec. under unit force; dE/dx = potential gradient due to magnetic separation of ions; z = excess concn. of $CuSO_4$ due to equilibrium shift.

In the following discussion any force acting from left to right (according to the ordinary geometrical convention) is considered as a positive force. Assume copper sulfate to form an "ideal" solution.

Let us consider the forces common to cubes 2 and 3 (see Fig. 4).

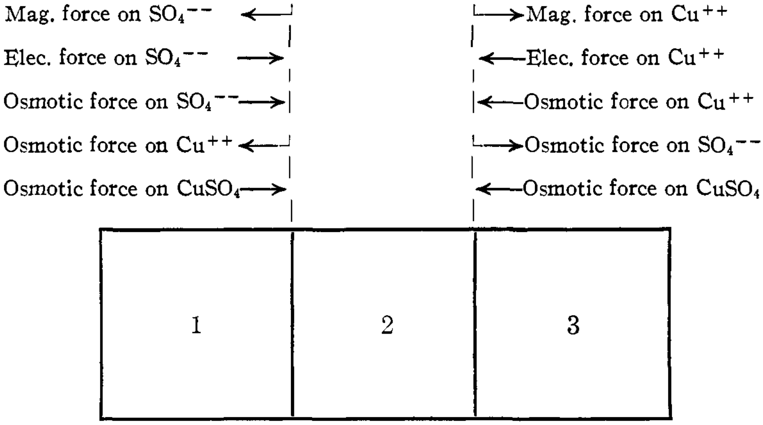

Fig. 4.

$$\text{Magnetic force on } Cu^{++} \text{ ion} = \omega\epsilon vH \tag{1}$$

$$\text{Electric force on } Cu^{++} \text{ ion} = -\omega\epsilon\frac{dE}{dx} \tag{2}$$

$$\text{Osmotic force on } Cu^{++} \text{ ion} = -\frac{RT}{\alpha C_1 n}\left(\frac{d\alpha C_1 n}{dx}\right) \tag{3}$$

$$\text{Osmotic force on } SO_4^{--} \text{ ion} = -\frac{RT}{\alpha C_2 n}\left(\frac{d\alpha C_2 n}{dx}\right) \tag{4}$$

$$\text{Osmotic force on } CuSO_4 \text{ molecule} = \frac{RT}{(1-\alpha)C_3}\left(\frac{d(1-\alpha)C_3}{dx}\right) \tag{5}$$

The above equations apply to conditions existing between the cubes 2 and 1 with appropriate changes in symbols. For example, the magnetic force acting upon the SO_4^{--} ion, which carries two negative charges, would cause the ion to move in a negative direction and would then be denoted as a positive force.

Imagine cubes 1 and 3 being brought into contact upon removal of cube 2 and consider the flux of matter across the common face. The two osmotic forces due to the same type of ion will be merged into one for the sake of simplicity, inasmuch as they act in the same direction.

Flux of Cu^{++} due to magnetic force $= \omega\epsilon vHu_1n\alpha CN$ (6)

Flux of SO_4^{--} due to magnetic force $= \omega\epsilon vHu_2n\alpha CN$ (7)

Flux of Cu^{++} due to electric force $= -\omega\epsilon \frac{\mathrm{d}E}{\mathrm{d}x} u_1n\alpha CN$ (8)

Flux of SO_4^{--} due to electric force $= -\omega\epsilon \frac{\mathrm{d}E}{\mathrm{d}x} u_2n\alpha CN$ (9)

Flux of Cu^{++} due to osmotic force $= -\frac{RT}{\alpha Cn}(u_1)\frac{\mathrm{d}(n\alpha C)}{\mathrm{d}x}$ (10)

Flux of SO_4^{--} due to osmotic force $= -\frac{RT}{\alpha Cn}(u_2)\frac{\mathrm{d}(n\alpha C)}{\mathrm{d}x}$ (11)

Flux of $CuSO_4$ due to osmotic force =

$$\frac{RT}{(1-\alpha)C}\left[\frac{\mathrm{d}[(1-\alpha)(C+z)]}{\mathrm{d}x} - \frac{\mathrm{d}[(1-\alpha)(C-z)]}{\mathrm{d}x}\right] \tag{12}$$

Due to osmotic diffusion forces the Cu^{++} ion tends to diffuse through the common face of cubes 1 and 3 and at the same time the SO_4^{--} tends to diffuse in the opposite direction. Although in the case of a binary electrolyte such as copper sulfate these forces are equal and opposite, due to the difference in mobility of the ions, more of one type will pass through this face than of the other. Hence, another double layer will be established due to the excess charges on one side of this common face (similar to an electrolytic diffusion potential where both ions are diffusing in the same direction). The direction of the potential gradient of the double layer resulting from diffusion will depend upon the relative mobilities of the ions. The osmotic forces due to the undissociated copper sulfate molecules are equal and opposite, as a study of the equilibrium conditions will show.

Combining the several equations into a general equilibrium equation, the sum of the fluxes equals zero. Inasmuch as equations (10), (11) and (12) represent electrically the double layer due to diffusion forces (mentioned above) the term $K\mathrm{d}E_1/\mathrm{d}x$ will be substituted.

$$\omega\epsilon vH(u_1+u_2)\alpha CN - \omega\epsilon\frac{\mathrm{d}E}{\mathrm{d}x}(u_1+u_2)n\alpha CN \pm \frac{\mathrm{d}E_1}{\mathrm{d}x}K = 0$$

or, simplifying

$$vH - \frac{\mathrm{d}E}{\mathrm{d}x} \pm \frac{1}{\omega\epsilon(u_1+u_2)n\alpha CN}\left(\frac{\mathrm{d}E_1}{\mathrm{d}x}\right)K = 0$$

Multiplying by D

$$DvH - D\frac{dE}{dx} \pm \frac{D}{\omega\epsilon(u_1 + u_2)n\alpha CN}\left(\frac{dE_1}{dx}\right)K = 0$$

However

$$D\frac{dE}{dx} = \text{e.m.f.}$$

Rearranging the above equation

$$\text{E.m.f.} = DvH \pm \frac{D}{\omega\epsilon(u_1 + u_2)n\alpha CN}\left(\frac{dE_1}{dx}\right)K = 0$$

This equation represents the rule of the dynamo plus or minus the last term, which must be extremely small owing to the fact that Avogadro's constant ($N = 6 \times 10^{23}$) appears in the denominator, which more than offsets the value of ϵ in coulombs.

On account of the minuteness of this last term, the effect can be used as the basis of a method for the continuous recording of flow velocities.

Summary

In solutions of electrolytes flowing through magnetic fields a potential difference is developed at right angles to the direction of flow and that of the field, for which the term magneto-electrolytic potential is suggested.

This potential difference is independent of the concentration and nature of the dissolved electrolyte but is proportional to its linear velocity and the field strength.

Although the above appears to be a case of metallic conduction in solutions of electrolytes and to obey the rule of the dynamo it may equally well be explained by assuming the ions to be displaced. An equation may be derived which is essentially the rule of the dynamo with an added term accounting for the osmotic forces, which is extremely small.

No conclusive evidence of the actual displacement of an ion could be found. No difference in conductivity of a solution flowing through a magnetic field from that of the same solution in a stationary state out of the field was found, showing that ions are not created by magnetic dissociation of the molecules.

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