

DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

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CONDUCTIVITY OF NICKEL SOLUTIONS

This investigation was conducted as a part of the general study of nickel deposition in progress at the Bureau of Standards. The conductivity of nickel solutions such as are used in electroplating and electrotyping is important because it may affect the power cost, the throwing power and the character of the deposits. The conductivities of nickel sulphate solutions containing such substances as are commonly added to nickel baths were therefore determined. The details of the methods used in the investigation have been described in a recently published article¹. The

¹L. D. Hammond - "Conductivity of Nickel Depositing Solutions", Trans. Am. Electrochem. Soc., Vol. 45, (preprint) April 1924.

results of interest to electroplaters may be summarized as follows:

To avoid confusion it is desirable to distinguish clearly between the following terms, viz. resistance, resistivity, conductance and conductivity. The resistance of any bath containing two electrodes is expressed in ohms, and (if we disregard polarization) it is equal to the applied voltage

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divided by the current in amperes. Thus if when a potential of 3 volts is applied to a certain bath, a current of 300 amperes flows, the resistance of the bath is equal to $3/300 = 1/100$ or 0.01 ohms.

The resistivity of the solution in the vessel is the resistance of a definite portion of that solution contained between two electrodes of a definite size and at a definite distance from each other. The customary unit of resistivity is that of a "centimeter cube" of solution having a resistance of one ohm between two electrodes each 1 cm square and one centimeter apart. This unit is called the ohm-centimeter, and the resistivities so expressed are often referred to as "ohms per centimeter cube". It is possible to express and compare the resistivities in terms of the "inch cube", the resistivity of which is equal to 0.39 times that of the "centimeter cube". As, however, we are usually concerned with relative and not actual values, there is no advantage in converting the metric to the English units.

The conductance is the reverse or reciprocal of resistance, and conductivity is the reciprocal of resistivity. Thus if the resistance of a certain bath is 0.01 ohm, its conductance is 100 "reciprocal ohms". Similarly if the resistivity of a certain solution is 25 ohm-centimeters, its conductivity is $1/25$ or 0.04 reciprocal ohm-centimeters.

In the usual determination of electrical conductivity, it is customary to measure the resistance, in ohms, of a

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vessel or "cell" filled with the solution. The electrodes are of platinum, coated with spongy platinum or "platinum black", and an alternating current is used in order to eliminate the effects of "polarization", such as may be caused by changes in the concentration of the solution near the electrodes during electrolysis with a direct current. The resistivity of the solution is calculated from the resistance of the cell when filled with a solution of known resistivity.

The numerical results in this paper are given in terms of resistivity in ohm-centimeters. In considering these data, it is important to remember that a decrease in resistivity corresponds to an increase in conductivity.

Table I

Resistivity of Nickel Sulphate Solutions
at 25°C (77°F)

Concentration of $\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$			Resistivity ohm-cm
N	g/L	oz/gal	
0.5	70	9	53.0
1	140	19	34.4
2	281	37	22.2
3	421	56	19.0
4	562	75	18.3

From Table 1, it may be seen that increasing the concentration of nickel sulphate from 9 to 37 oz/gal makes a decided increase in conductivity, but beyond that point the improvement is not sufficient to warrant the increased cost of stronger solutions and the consequently greater loss of material in the solution which adheres to the work.

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DEPARTMENT OF THE HISTORY OF ARTS

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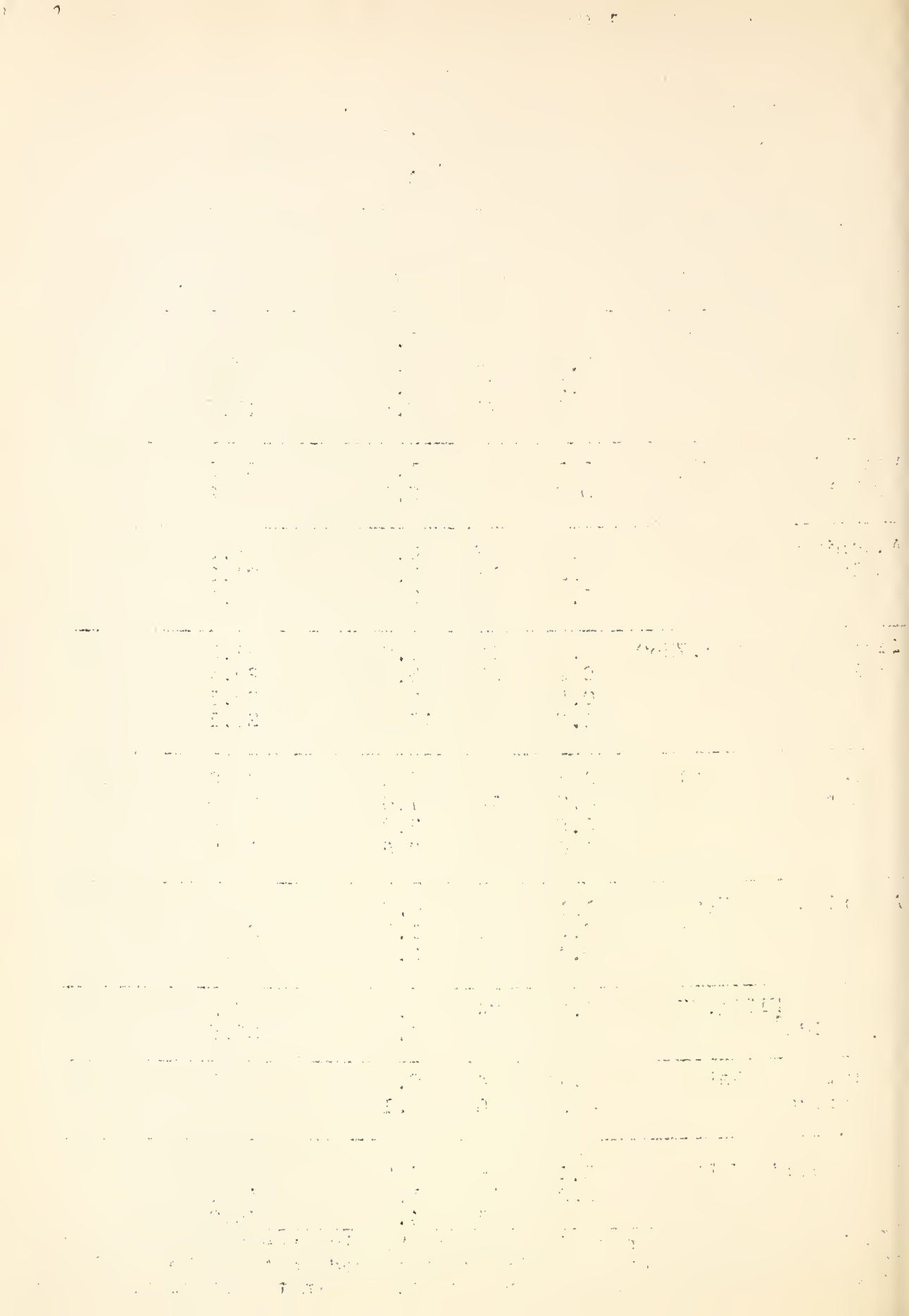
CHICAGO, ILLINOIS
JANUARY 10, 1911
TO THE PRESIDENT OF THE UNIVERSITY
FROM THE DEAN OF THE DEPARTMENT OF THE HISTORY OF ARTS
SUBJECT: REPORT ON THE PROGRESS OF THE DEPARTMENT DURING THE YEAR 1910-1911

Table 2

Resistivity of Normal Nickel Sulphate Solution
(140 g/L or 19 oz/gal) containing added
compounds.
At 25°C (77°F)

Added Compound Name	Formula	Concentration			Resistivity ohm-cm
		N	g/L	oz/gal	
Sodium sulphate	Na ₂ SO ₄	0.1	7	0.9	29.4
		0.2	14	1.9	26.2
		0.5	36	4.8	20.0
		1.0	71	9.5	15.0
Potassium sulphate	K ₂ SO ₄	0.1	9	1.2	28.1
		0.2	17	2.3	24.2
Ammonium sulphate	(NH ₄) ₂ SO ₄	0.1	7	0.9	28.0
		0.2	13	1.7	24.0
		0.4	26	3.5	18.8
Magnesium sulphate	MgSO ₄ .7H ₂ O	0.1	12	1.6	31.5
		0.2	25	3.3	29.4
		0.5	62	8.3	25.3
		1.0	123	16.5	21.1
Sodium chloride	NaCl	0.1	6	0.8	27.0
		0.2	12	1.6	22.5
		0.5	29	3.9	15.4
		1.0	58	7.8	10.5
Ammonium chloride	NH ₄ Cl	0.1	5	6.7	26.0
		0.2	11	1.5	21.1
		0.4	21	2.8	15.3
Nickel chloride ¹	NiCl ₂ .6H ₂ O	0.2	24	3.2	27.2
		0.5	59	7.9	20.5
Sodium fluoride	NaF	0.1	4	0.5	28.8
		0.2	8	1.1	25.5
Boric acid	H ₃ BO ₃	M			
		0.1	6	0.8	33.9
		0.2	12	1.6	34.1
		0.5	31	4.1	35.0

¹In the solutions containing nickel chloride the nickel sulphate concentration was correspondingly decreased so that the total nickel concentration was always normal, as in the other solutions.



From Table 2 and Fig. 1 (Insert Fig. 1) it may be seen that the resistivity of normal nickel sulphate solution (34.4 ohm-cm) is decreased by the addition of each of the compounds listed except boric acid, which has a practically negligible effect. Of the four sulphates tested, equivalent additions of the magnesium sulphate have the least effect, and in small concentrations ammonium sulphate has the largest effect. The possible concentration of ammonium sulphate is, however, limited by the low solubility of the nickel ammonium sulphate $(\text{NH}_4)_2\text{SO}_4 \cdot \text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ (the common "double nickel salt").

Similarly low concentrations of ammonium chloride produce a greater increase in conductivity than do equivalent amounts of sodium chloride. Owing to the limited solubility of the ammonium chloride in the nickel sulphate solution, a higher conductivity can be produced by the addition of sodium chloride than with any of the other salts tested. The indications are, however, that the ammonium chloride has a more beneficial effect upon the character of the deposit than has the sodium chloride.

The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \sum_{n=0}^{\infty} \frac{f_n(x)}{n!}$, where $f_n(x)$ is a polynomial of degree n . It is shown that $f(x)$ is a continuous function and that it satisfies the functional equation $f(x+y) = f(x)f(y)$. The second part of the paper is devoted to the study of the properties of the function $g(x)$ defined by the equation $g(x) = \sum_{n=0}^{\infty} \frac{g_n(x)}{n!}$, where $g_n(x)$ is a polynomial of degree n . It is shown that $g(x)$ is a continuous function and that it satisfies the functional equation $g(x+y) = g(x) + g(y)$. The third part of the paper is devoted to the study of the properties of the function $h(x)$ defined by the equation $h(x) = \sum_{n=0}^{\infty} \frac{h_n(x)}{n!}$, where $h_n(x)$ is a polynomial of degree n . It is shown that $h(x)$ is a continuous function and that it satisfies the functional equation $h(x+y) = h(x)h(y)$.

The fourth part of the paper is devoted to the study of the properties of the function $k(x)$ defined by the equation $k(x) = \sum_{n=0}^{\infty} \frac{k_n(x)}{n!}$, where $k_n(x)$ is a polynomial of degree n . It is shown that $k(x)$ is a continuous function and that it satisfies the functional equation $k(x+y) = k(x) + k(y)$. The fifth part of the paper is devoted to the study of the properties of the function $l(x)$ defined by the equation $l(x) = \sum_{n=0}^{\infty} \frac{l_n(x)}{n!}$, where $l_n(x)$ is a polynomial of degree n . It is shown that $l(x)$ is a continuous function and that it satisfies the functional equation $l(x+y) = l(x)l(y)$. The sixth part of the paper is devoted to the study of the properties of the function $m(x)$ defined by the equation $m(x) = \sum_{n=0}^{\infty} \frac{m_n(x)}{n!}$, where $m_n(x)$ is a polynomial of degree n . It is shown that $m(x)$ is a continuous function and that it satisfies the functional equation $m(x+y) = m(x) + m(y)$.

Table 3

RESISTIVITIES OF NORMAL SOLUTIONS AT 25°C (77°F)

Name	Formula	Concentration		Resistivity Ohm-cm
		g/L	oz/gal	
Hydrochloric acid	HCl	36.5	4.9	3.07
Sulphuric acid	H ₂ SO ₄	49	6.6	4.8
Acetic acid	HC ₂ H ₃ O ₂	60	8.0	670
Boric acid	H ₃ BO ₃ (M)	62	8.3	70000
Potassium hydroxide	KOH	56	7.5	5.7
Potassium chloride	KCl	74.5	10.0	8.9
Potassium cyanide	KCN	65	8.7	8.2
Sodium hydroxide	NaOH	40	5.4	5.7
Sodium chloride	NaCl	58.5	7.8	11.6
Sodium fluoride	NaF	42	5.6	18.5
Sodium sulphate	Na ₂ SO ₄	71	9.5	16.8
Sodium carbonate	Na ₂ CO ₃	53	7.1	18.7
Sodium phosphate	Na ₂ HPO ₄ ·12H ₂ O	119	16.0	31.5
Ammonium hydroxide	NH ₄ OH	35	4.7	970
Ammonium chloride	NH ₄ Cl	53.5	7.2	9.0
Ammonium sulphate	(NH ₄) ₂ SO ₄	61	8.2	12.9
Calcium chloride	CaCl ₂	56	7.5	13.2
Magnesium sulphate	MgSO ₄ ·7H ₂ O	123	16.5	29.9
Copper sulphate	CuSO ₄ ·5H ₂ O	125	16.7	34.1
Zinc sulphate	ZnSO ₄ ·7H ₂ O	144	19.3	32.1
Zinc chloride	ZnCl ₂	68	9.1	13.4
Cadmium sulphate	CdSO ₄	104	13.9	38.
Cadmium chloride	CdCl ₂	92	12.3	40
Ferrous chloride	FeCl ₂ ·4H ₂ O	99	13.2	14.5
Ferrous sulphate	FeSO ₄ ·7H ₂ O	139	18.6	31.6
Nickel sulphate	NiSO ₄ ·7H ₂ O	140	18.8	34.4
Nickel chloride	NiCl ₂ ·6H ₂ O	119	16.0	14.1
Cobalt sulphate	CoSO ₄ ·7H ₂ O	141	18.9	34.1
Cobalt chloride	CoCl ₂ ·6H ₂ O	119	16.0	14.5

INDEX

Page	Author	Title	Year	Notes
101	Smith	History of the State	1850	First edition
102	Johnson	Geography of the State	1855	Second edition
103	Williams	Political Economy of the State	1860	Third edition
104	Miller	Law and Equity of the State	1865	Fourth edition
105	Clark	Science and Art of the State	1870	Fifth edition
106	Green	History of the State	1875	Sixth edition
107	White	Geography of the State	1880	Seventh edition
108	Black	Political Economy of the State	1885	Eighth edition
109	Gray	Law and Equity of the State	1890	Ninth edition
110	Lee	Science and Art of the State	1895	Tenth edition
111	King	History of the State	1900	Eleventh edition
112	Wright	Geography of the State	1905	Twelfth edition
113	Scott	Political Economy of the State	1910	Thirteenth edition
114	Walker	Law and Equity of the State	1915	Fourteenth edition
115	Young	Science and Art of the State	1920	Fifteenth edition
116	Allen	History of the State	1925	Sixteenth edition
117	Kim	Geography of the State	1930	Seventeenth edition
118	Green	Political Economy of the State	1935	Eighteenth edition
119	Wright	Law and Equity of the State	1940	Nineteenth edition
120	Scott	Science and Art of the State	1945	Twentieth edition

In order to compare the resistivities of the nickel solutions with those of other solutions such as may be used in plating operations, Table 3 has been compiled. From this table it may be seen that in normal or chemically equivalent solutions, the strong acids and alkalis have the lowest resistivity or highest conductivity. The sulphates of the "heavy" metals, such as iron, nickel, cobalt and zinc have relatively high resistivities, which can be reduced by the addition of better conducting salts, such as the chlorides and sulphates of sodium, potassium and ammonium. When, as in copper sulphate solutions, a high concentration of sulphuric acid is permissible, the conductivity may be thereby greatly increased. With nickel solutions, however, which must be kept nearly neutral, it is not practicable to increase the conductivity to approach that of the acid copper bath.

Resistivity of Normal Nickel Sulfate Solutions Containing Added Compounds at 25°C
 $N-NiSO_4 = 34.4 \Omega\text{-cm.}$

