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BUREAU OF STANDARDS

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May 7, 1924

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 article<sup>1</sup>. The

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

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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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THE UNIVERSITY OF CHICAGO

The University of Chicago is pleased to announce that it has received a grant from the National Endowment for the Humanities for the year 1918. This grant is for the purpose of supporting the work of the Department of the History of Ideas, which is now in its second year. The Department is directed by Professor James H. Muirhead, and its members are Professor Muirhead, Professor Charles A. Beard, Professor John D. P. Moore, Professor George S.arton, and Professor William D. Howells. The Department is engaged in a study of the history of ideas in the United States, and its work is being published in the *Journal of the History of Ideas*. The grant is for the purpose of supporting the work of the Department, and it is hoped that it will enable the Department to continue its work for many years to come.

James H. Muirhead, Director

Department of the History of Ideas

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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

The first part of the report deals with the general situation in the country during the year. It is noted that the economy has been generally stable, with a slight increase in production and a corresponding increase in the standard of living. The government has been successful in maintaining a balanced budget and in reducing the national debt. The report also mentions that the country has been able to maintain its independence and to resist the attempts of foreign powers to interfere in its internal affairs.

The second part of the report deals with the financial situation of the country. It is noted that the government has been successful in maintaining a balanced budget and in reducing the national debt. The report also mentions that the country has been able to maintain its independence and to resist the attempts of foreign powers to interfere in its internal affairs.

The third part of the report deals with the social situation in the country. It is noted that the government has been successful in maintaining a balanced budget and in reducing the national debt. The report also mentions that the country has been able to maintain its independence and to resist the attempts of foreign powers to interfere in its internal affairs.

The fourth part of the report deals with the political situation in the country. It is noted that the government has been successful in maintaining a balanced budget and in reducing the national debt. The report also mentions that the country has been able to maintain its independence and to resist the attempts of foreign powers to interfere in its internal affairs.

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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)

N	Concentration of NiSO <sub>4</sub> ·7H <sub>2</sub> O		Resistivity ohm-cm
	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.





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 <sub>2</sub> SO <sub>4</sub>	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 <sub>2</sub> SO <sub>4</sub>	0.1	9	1.2	28.1
		0.2	17	2.3	24.2
Ammonium sulphate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	0.1	7	0.9	28.0
		0.2	13	1.7	24.0
		0.4	26	3.5	18.8
Magnesium sulphate	MgSO <sub>4</sub> .7H <sub>2</sub> 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 <sub>4</sub> Cl	0.1	5	6.7	26.0
		0.2	11	1.5	21.1
		0.4	21	2.8	15.3
Nickel chloride <sup>1</sup>	NiCl <sub>2</sub> .6H <sub>2</sub> 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 <sub>3</sub> BO <sub>3</sub>	M			
		0.1	6	0.8	33.9
		0.2	12	1.6	34.1
		0.5	31	4.1	35.0

<sup>1</sup>In 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.



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 <sub>2</sub> SO <sub>4</sub>	49	6.6	4.8
Acetic acid	HC <sub>2</sub> H <sub>3</sub> O <sub>2</sub>	60	8.0	670
Boric acid	H <sub>3</sub> BO <sub>3</sub> (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 <sub>2</sub> SO <sub>4</sub>	71	9.5	16.8
Sodium carbonate	Na <sub>2</sub> CO <sub>3</sub>	53	7.1	18.7
Sodium phosphate	Na <sub>2</sub> HPO <sub>4</sub> .12H <sub>2</sub> O	119	16.0	31.5
Ammonium hydroxide	NH <sub>4</sub> OH	35	4.7	970
Ammonium chloride	NH <sub>4</sub> Cl	53.5	7.2	9.0
Ammonium sulphate	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	61	8.2	12.9
Calcium chloride	CaCl <sub>2</sub>	56	7.5	13.2
Magnesium sulphate	MgSO <sub>4</sub> .7H <sub>2</sub> O	123	16.5	29.9
Copper sulphate	CuSO <sub>4</sub> .5H <sub>2</sub> O	125	16.7	34.1
Zinc sulphate	ZnSO <sub>4</sub> .7H <sub>2</sub> O	144	19.3	32.1
Zinc chloride	ZnCl <sub>2</sub>	68	9.1	13.4
Cadmium sulphate	CdSO <sub>4</sub>	104	13.9	38.
Cadmium chloride	CdCl <sub>2</sub>	92	12.3	40
Ferrous chloride	FeCl <sub>2</sub> .4H <sub>2</sub> O	99	13.2	14.5
Ferrous sulphate	FeSO <sub>4</sub> .7H <sub>2</sub> O	139	18.6	31.6
Nickel sulphate	NiSO <sub>4</sub> .7H <sub>2</sub> O	140	18.8	34.4
Nickel chloride	NiCl <sub>2</sub> .6H <sub>2</sub> O	119	16.0	14.1
Cobalt sulphate	CoSO <sub>4</sub> .7H <sub>2</sub> O	141	18.9	34.1
Cobalt chloride	CoCl <sub>2</sub> .6H <sub>2</sub> O	119	16.0	14.5

INDEX

Year	Month	Day	Event	Location
1940	Jan	1	...	...
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1940	Jan	3	...	...
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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.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be clearly documented, including the date, amount, and purpose of the transaction. This ensures transparency and allows for easy reconciliation of accounts.

In addition, the document highlights the need for regular audits. By conducting periodic reviews of the financial records, any discrepancies or errors can be identified and corrected promptly. This proactive approach helps in maintaining the integrity of the financial data and prevents potential issues from escalating.

Furthermore, the document stresses the importance of keeping all supporting documents, such as receipts and invoices, organized and accessible. These documents serve as evidence for the transactions recorded in the accounts and are essential for resolving any disputes or queries that may arise.

Finally, the document concludes by stating that consistent and accurate record-keeping is the foundation of sound financial management. It encourages the user to adhere to these principles to ensure the reliability and accuracy of their financial records.

Date: \_\_\_\_\_  
 Signature: \_\_\_\_\_



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



