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### THE CONDUCTIVITY OF CHROMIC

ACID SOLUTIONS.

A Thesis

Submitted to the Faculty

of

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Department of Chemistry

By Edgar C. Hensen

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#### INTRODUCTION.

A great interest and activity in the new field of chromium plating has developed within the past few years. Although the electro deposition of chromium has been accomplished for many years, its successful commercial application has only recently been made. The unusual properties and advantages of chromium plating has resulted in numerous patents being granted on this process.

Bunsen (Poggendorff's Ann., <u>91</u>, . 619) was probably the first to accomplish the electro deposition of chromium but Guenther (Liebig's Ann., <u>99</u>, . 314) was the first to obtain it from solutions of chromic acid.

Carveth and Curry (Jor. of Phy. Chem.<u>9</u>, .353, (1905) proved that chromium could be deposited readily from solutions of chromic acid, provided that the bath contained some impurity such as a sulfate in an amount up to one per cent.

In 1915 the successful application of electrodeposited chromium to printing plates at the U.S. Bureau of Engraving was announced and the method used fully described. (H. E. Haring, Chem. and Met. Eng.,  $\frac{(U-\tau)}{22}$ , 692-756).

In the electroplating of metals the influence of conductivity upon the power used is of real importance. Good conductivity is useful in reducing power costs. The usual means of raising the conductivity of an electrolyte are; by using a more concentrated solution; adding highly ionised salts; heating; and preventing the accumulation in the electrolyte of materials which reduce the conductivity.

In electroplating from chromic acid solutions a certain amount of chromium dichromate is formed by reduction. For some time it was believed that this compound of trivalent and hexavalent chromium had a beneficial effect on the efficiency of the bath. It has now been shown as the result of experiments, (U. S. Bureau of Standards, Vol. 21, No. 346) that this compound serves no useful purpose in a plating bath and is in fact undesirable since its presence results in an increase of resistivity in the bath.

The resistivity of chromic acid baths is very low in comparison with other baths, but because of the relatively great current densities required it is still of real importance, and it seems unavoidable that chromium plating baths attain an increased resistance after use. To what extent this increased resistance is due to the formation of chromium dichromate within the bath, and to what extent it is due to common additions to the bath, is not known. No work seems to have been done along this particular line. Related work on nickel depositing solutions has been done by Hammond, (Trans.

Am. Electohem. Soc. Vol. 45,(1924) who studied effects on conductivity of different additions, and Kern and Chang (Trans. Am. Electrochem. Soc., Vol. 41,(1922) who did similar work on copper refining electrolytes. The conductivity of solutions of chromic acid at various concentrations was measured, and the effect upon the conductivity of common additions to and common formations in chromic acid plating baths was determined.

#### **EXPERIMENTAL**

As the primary object of this study was to obtain information in the interest of commercial chromium plating, no attempt at precision measurements was made.

All measurements were made at 25°C, using the slide wire of a feeds and Northrup student potentiometer as the conductivity bridge. A four dial resistance box with a range of (, 1 to 1000 ohms was used. The high frequency current was supplied by an electron tube arrangement as shown in the diagram. It was found by trial that this source of high frequency current was the most desirable.  $\blacktriangle$  high frequency generator, a michrophone hummer, and a buzzer were all tried out, but the electron tube proved the most suitable. Its greatest advantages are, its noislessness and the easy control of its frequency. The direct current for operating the tube was supplied by two 4-wolt lead storage batteries. The tube was type 216A. Western Electric. It was not necessary to use such a large tube, but as it was part of a setup at hand it was made use of.

As seen in the diagram, there are no condensers in the circuit. The capacity which is necessary for operation of the tube is in the form of distributive capacitance within or between the coils of the iron ring core. These coils were inclosed under an iron cover and the free space within filled with rosin which acted as the dielectric.

The B-battery had an E.M.F. of about 70 volts. The A-battery was at all times kept well charged, not varying more than one half volt. It was found that a change in the current from the A-battery would cause a change in frequency which resulted in a change in the resistance Washburn of the cell being measured. According to (Jor. of Am. Chem. Soc. 38, 515, 1916) there is no measurable change in the resistance of a solution when platinized electrodes one inch in diameter are used at a frequency of 500-1000 cycles. However, the electrodes used in this work were about one-half inch in diameter which may account for the error introduced, or it may be that Washburn's statement was not meant to hold with solutions of high concentration. By experiment it was found that the shange caused in the resistance of the cell, due to a change of one half volt in the A-battery, would cause an error of about 0.1 per cent.

It was necessary to attach a ground to each end of the bridge to eliminate harmonics. A very good end point could then be obtained.

Owing to the high concentrations of the solutions used in this work, ordinary types of conductivity cells could not be used. Several different kinds were tried eut preliminary to beginning the work, in order to determine which would be the most suitable. The first one tried was made from glass tubing 1/4 inch in diameter and bent into a U shape. Platinum wires for electrodes were sealed into the tube through the sides with a distance of about 20 centimeters between them. The leads from the electrodes were led up along the outsides of the tube and insulated by covering with rubber tubing. The electrodes were platinized before using. This type of cell proved unsatisfactory. The area of the electrodes was evidently too small. A change in frequency caused too great a change in the resistance of the cell.

An immersion type of cell was tried, but the resistance was altogether too small for measurements of solutions of high concentration.

The cell that was finally found to be satisfactory was a Leeds and Northrup, Students U type. The U tube was a little more thano.5 inches in diameter and 18 inches in length, (The sides being graduated so that the electrodes might be set at any desired point. The electrodes were platinum discs that just fitted inside the U tube, and were sealed to the ends of glass tubes, contact being made with mercury inside these tubes. They were fitted and adjustable through hard rubber caps which fitted over the ends of the U tube. Adjustment having once been made, the electrodes were tightly sealed into these caps to prevent any necessity of readjustment of them.

All measurements were made at 25°C by keeping the cell immersed in a water bath constant to  $(.1^\circ.)$  The bath was provided with a small electric stirting motor.

#### CHLL CONSTANT DETERMINATION

The cell constant was determined with a 0.1 normal solution of potassium chloride using Kohlranch's value of 0.01288 reciprocal ohms-cm. as the specific conductivity at 25°C.

Box Resistance ohms	Bridge Rdg.	Calc. Res. Cell ohms
1000	840	1146.4
1140	510	1144.5
1150	490	1145.4
	۲ <b>۵</b>	erage = 1145.4

1145.4 x .01288 = 14.76 = cell constant.



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The conductivity of chromic acid solutions at different concentrations was measured.

A solution of chromic acid containing 500 grams of Cr  $O_5$  per liter of solution, was prepared. The concentrations as listed in Table I below, were made by measuring out a certain volume of the chromic acid solution with a burrette, and then adding water from a second burrette until the required dilution was obtained.

Two checks on each measurement were made by varying the resistance in the box by a few tenths ohms, and thus obtaining other bridge readings. The average value of the calculated all resistance was used in determining the specific conductivity.

#### TABLE I

Effect of Concentration on the Conductivity of Chromic Acid Solutions

Cons. Gms. Cr0 <sub>3</sub> /L.	Box Res. Ohms	Bridge R <b>dg</b> .	R	es. (calc.) Ohm <b>s</b>
500	22.6	467		22.30
	22.4	489		22.30
Ħ	22.1	523		22.30
			Avg.	22.30
<b>45</b> 0	22.6	458		22.22
	22.4	480		22.22
	22.1	513		22.21
			Avg.	22.22
400	22.6	481		22.42

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Conc. Gms. Cr0 <sub>3</sub> /L.	Box Res. Ohms	Bridge Råg.	Res. (Calc. Ohms
400	22.4	503	22 .42
Ħ	22.1	535	22.41
		AV(	g. = 22.42
350	23.0	484	22.85
-	22.8	<b>5</b> 05 <sub>π</sub>	22.84
-	22.6	52 <b>6</b>	28.83
		AV	g. = 22.84
300	24.0	482	23,84
	23.8	502	23.82
-	23.6	52 <b>5</b>	23.85
		Av.	g. = 23.83
250	25.8	<b>4</b> 80	25.59
-	25.6	500	25.60
•	25 .4	520	25 <b>.6</b> 0
		AV	g <b>. = 25.60</b>
200	28.8	484	28.61
W	28.6	503	28.63
n	28 .4	520	28.63
		AV	g. = 28.63
150	34.4	490	34.26
•	34.1	512	34.26
•	34.0	520	34,28
		<b>▲</b> ▼	8. = 34.26
100	46.8	502	46.84
¥	46.2	535	46.86

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Cons. Gms. OrOz/L.	Box Res. Ohms	Bridg● Rdg•	Res. (Calc.) Ohms
100	<b>46.</b> 0	<b>54</b> 5	46.84
		4	Avg. = 46.84
50	85.0	504	85.13
	84.8	510	85.13
-	84.4	522	85.15
			Avg. = 85.13

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Summary
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Conc. Gms. CrO <sub>3</sub> /L	Res. (Calc.) Ohms	Sp. Cond. Mhos.
500	22.30	() .666
450	22.22	ı) <b>•66</b> 3
400	22.42	() <b>•657</b>
850	22.84	0.645
<b>3</b> 00	23.83	().618
250	25.60	0.575
200	28.63	() <b>.504</b>
150	34.27	6.431
100	46.85	6.516
50	85.13	0 <b>.173</b>

The effect of Na<sub>2</sub>SO<sub>4</sub> upon the conductivity of chromic acid solutions of different concentrations.

A solution containing 500 grams of  $\text{CrO}_3$  and 7.396 grams of anhydrous  $\text{Na}_2\text{SO}_4$  per liter was made. Dilutions as in Table I were then made. The amount of SO<sub>4</sub> then was always 1% of the amount of  $\text{CrO}_3$  present.

Conc. Gms. CrO <sub>3</sub> /L.	Box Res. Ohms	Bridg● Rdg•	Res. (calc.) Ohms
500	23.0	475	22 <b>.77</b>
	22.8	497	22 . 77
Π	22.6	520	22 .78
			Avg. = 22.77
<b>45</b> 0	23.0	465	22.68
	22 .8	<b>4</b> 85	22 <b>.66</b>
•	22.6	510	22.65
			Avg. = 22.66
360	23.4	<b>47</b> 5	23.16
•	23.2	497	23.17
	23.0	520	23.18
			Avg. = 23.17
262	26.2,	460	25.78
	26.0	479	25 <b>.7</b> 8
•	25.6	51 <b>7</b>	25.78
			Avg. = 25.78
157.20	34.6	477	34.28
•	34.4	491	34.28

TABLE II

Conc. Gms. Cr0 <sub>3</sub> /L.	Box Res. Ohms	Bridge Rdg.	Res. Calc. Ohms
157.20	34.2	505	34.27
			<b>▲vg. = 34.2</b> 8
<b>78.6</b> 0	58.4	505	58 <b>.52</b>
	58.2	115	58.55
	<b>5</b> 8 <b>.0</b>	523	58.54
			Avg. = 58.54

Summary

Conc. Gr. Cr0 <sub>5</sub> /L.	Res. (Calc.) Ohms	Sp. Cond. Mhos
<b>5</b> 00 <b>.00</b>	<b>2</b> 2 <b>. 77</b>	0.648
<b>450.00</b>	22.66	<b>∂</b> •651
360.00	23.17	<b>8.</b> 637
262.00	25.78	0.578
157.20	34.28	0.436
<b>78.6</b> 0	58.53	0.252

Effect of  $Ma_2SO_4$  on the conductivity of chromic acid solution.

To 100 cc. of a stock solution of chromic acid containing 250 gr. CrO<sub>3</sub>/L, was added 9.260 gr. of anhydrous Na<sub>2</sub>SO<sub>4</sub>. By heating a few minutes just below the poiling point, enough water vaporised to bring the volume down to 100 cc. The solution then contained 250 gr. CrO<sub>3</sub>/L and 30 gr. Na/L. By dilution with more of the stock solution of chromic acid the concentrations as given in Table III were obtained.

The same procedure was used for all the salts added in this work. Some of them required considerable heating before being brought into solution. This was especially true of  $Cr(OH)_3$ ; water then had to be added to bring it up to the required volume.

#### TABLE III

Conc. Gr. Na/L.	Box Res. Ohms	Bridge Rdg.	Res. Calc. Ohms
<b>3</b> 0	32.6	490	<b>32 .47</b>
•	32 •4	506	32.48
W	32 <b>.2</b>	522	32.48
		۲	vg. = 32.48
21	30 •4	470	30 -04
	30.2	487	<b>30.04</b>
	30.0	504	30.04

Avg. = 30.04

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Conc. Gms. Na/L.	Box Res. Onms	Bridge Rdg.	Res. (Calc.) Ohms
12.60	<b>2</b> 8 <b>.4</b>	473	28.09
	<b>2</b> 8 <b>. 2</b>	<b>49</b> 0	28.08
•	28.0	50 <b>7</b>	28.08
			<b>▲vg.</b> = 28.08
7.56	27.2	<b>4</b> 8 <b>2</b>	27.00
*	27.0	500	27.00
	26.8	518	27.00
			Avg. = 27.00
3.78	<b>26.6</b>	465	26.23
	26.4	485	26.24
	26.2	504	26.24
			Ama _ 96 94

Avg. = 26,24

## Summary

Conc. Gms. Na/L.	Res. (Calc.) Ohms	Sp. Cond. Mhos.
30.00	32.48	0.454
21.00	30.04	9.481
12.60	28.08	∩ <b>.526</b>
7.56	27.00	0.543
3.78	26.24	0.562

## TABLE IV

The Effect of Feg(SO4)3. 5 H20 on the Conductivity of Chromic Acid Solutions.

Conc. Gms. Fe/L.	Box Res. Ohms	Bridge Råg.	Res. (Calc.) Ohm <b>s</b>
35.00	39.2	490	39.04
₩	<b>39.</b> 0	503	39.05
	<b>38.8</b>	515	39.04
			Avg. = 39.04
30.00	37.0	<b>4</b> 8 <b>5</b>	56.78
	36.8	499	36.79
•	36.6	512	36.78
			Avg. = 36.78
19.20	32.6	475	52.27
	32 .4	<b>4</b> 90	32,27
-	<b>32.2</b>	505	32 <b>.26</b>
			Avg. = 32.27
15.00	31.0	480	<b>30.75</b>
	30.8	495	<b>30 . 74</b>
	30.6	510	30.72
			Avg. = 80.73
12.00	29.6	500	29.60
<b>17</b>	29.4	517	29.60
<b>11</b>	29 . 2	534	29.60
			Avg. = 29.60
9.60	29.0	475	28.71
	<b>2</b> 8.8	494	28.73
Ħ	28.6	512	28.74
			Avg. 28.73

Conc. Gms. Fe/L.	Box Res. Ohms	Bridge Rdg.	Res. (Calc.) Ohms.
6.72	27.8	495	27.73
-	27.6	512	27.73
π	27.4	530	27.73
			Avg. = 27.73
4.70	27.2	490	27.09
π	27.0	508	27.09
	26.8	525	27.07
			Avg. = 27.09
1.17	26.0	490	25.90
17	25.8	510	25.90
	25.6	528	25.89
			Avg. = 25.90

Summary

Conc. Gms. <b>Pe/L</b> .	Res. (Calc.)	Sp. Cond. Mhos.
35.00	0hm <b>s</b> 39 <b>.04</b>	J. 377
30.00	<b>36.1</b> 8	0.401
19.20	32 <b>.27</b>	0.457
15.00	30 .74	0.480
12.00	29.60	().498
9.60	28.73	0.514
6.72	27.73	0-582
4.70	27.09	().545
1.17	25.90	0.570

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# TABLE V

The Effect of Crg(SO4)3 on the Conductivity

## of Chromic Aoid Solutions.

Conc. Gms. Cr./L.	Box Res. Ohms	Bridge Råg.	Res. (Calc.) Ohms
30.00	50 •4	484	50.08
-	50.2	495	50.10
-	50.0	506	50.10
			Avg. = 50.10
24.00	43.4	<b>4</b> 86	43.16
•	43.2	498	43.17
<del>11</del>	43.0	510	43.17
			Avg. = 43.17
19.20	<b>38 .6</b>	493	38.49
	38.4	506	<b>38.49</b>
	38.2	519	<b>38.49</b>
			Avg. = 38.49
15.00	35 .4	490	86.25
•	35.2	504	35.25
	35.0	518	55.25
			Avg. = 35.25
12.00	33.0	495	82 <b>. 9</b> 8
*	32.9	510	32.93
	32.6	525	32.93
			Avg. = 32.93
9,60	31.2	500	31.20
	31.0	517	31.21
**	30 •8	53.4	31.22
			Avg. = 31.21

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Conc. Gma. Cr./L.	Box Res. Ohms	Bridge Råg.	Res. (Calc.) Ohms
6.72	29.6	490	29.48
-	29.4	507	29 <b>.48</b>
Ħ	29.2	524	29.48
			Avg. = 29.48
2.35	27 .2	473	26.91
	27.0	491	<b>26.91</b>
	26.8	510	<b>26.9</b> 0
			Avg. = 26.91
1.17	26.4	474	26.12
	26.2	492	26.11
<b>11</b>	26.0	510	<b>25.</b> 10
			Avg. = 26.11

Summary

Conc. Gms. Cr./L.	Res. (Calc.) Ohms	Sp. Cond. Mhos.
30.00	50.10	U-294
24.00	43.17	0.342
19.20	38.49	0.384
15.00	35 <b>.25</b>	0.419
12.00	32 <b>. 93</b>	<b>9.44</b> 8
9.60	31.21	( <b>). 47</b> 3
6.72	29.48	( <b>). 500</b>
2.35	26.91	0.548
1.17	26.11	<b>4.</b> 565

# TABLE VI

The Effect of FeSO4 on the Conductivity

## of Chromic Acid Solutions

Conc. Gms. Fe/L.	Box Res. Ohms	Bridge Råg.	Res. (Calc.) Ohms
30.00	71.0	485	70.58
-	70.6	500	70.59
	70.2	514	70.60
			Avg. = 70.59
24.00	55.8	485	55.47
	55.4	503	55.47
Ħ	55.0	520	55.45
			Avg. = 55.47
19.20	45.8	487	45.95
W	45.6	510	<b>45.9</b> 8
W	45.4	530	<b>4</b> 5 <b>.95</b>
			Avg. = 45.95
15.00	40.4	490	40.24
•	40.2	<b>5</b> 02	40.23
	40.0	515	40.24
			Avg. = 40.24
9.60	34.0	480	83.73
	33.8	495	33 <b>.75</b>
	<b>3</b> 3 <b>• 6</b>	510	<b>3</b> 3 <b>.73</b>
			Avg. = 33.73

Conc. <i>Fe</i> Gns. Or./L.	Box Res. Ohms	Bridge Rdg.	Res. (Calc.) Ohms
4.70	29.2	489	29.07
-	29.0	506	29.07
W	<b>28.8</b>	523	29.07
			Avg. = 29.07
2.35	27.4	482	27.20
-	27.2	500	27.20
	27.0	519	27.21
			Avg. = 27.20
1.17	26.6	476	26.33
W	26.4	495	26.34
	26.2	514	26.34
			Avg. = 26.34

Summary

Conc. Gms. Fe/L.	Res. (Calc.) Ohms	sp. Cond. Mhos.
<b>30</b> •00	70.59	0-209
24.00	55.47	<b>Q.266</b>
19.20	45.95	0.321
15.00	40.24	0.366
9.60	33.73	0.458
4.70	29.07	( <b>)</b> •508
2.35	27.20	<b>A.542</b>
1.17	26.34	<b>0.560</b>

## The Effect of Cr (OH) g on the Conductivity

of Chromic Acia Solutions.

The  $Cr(OH)_3$  was prepared by precipitating it from a hot solution of chromium sulfate with concentrated amonium hydroxide. The precipitate was filtered and washed free from sulfates. It was dried at room temperature for about two days and then finely powdered to make a uniform mixture. An analysis to determine its chromium content was made by igniting in a crucible to  $Cr_2O_3$ . It was found to contain 36.40% by weight of chromium. The hydroxide was then approximately of the formula  $Cr(OH)_3$ . 2H<sub>2</sub>O.

TABLE VII

Conc. Ems. Cr/L.	Box Res. Ohms	Bridge Råg.	Re	S. (Calc.) Ohms
34.12	82.6	472		81.68
	82.2	484		81.67
Ħ	81.6	503		81.70
			Avg. =	<b>81.</b> 68
27.30	59.6	472		59.19
Ħ	59.4	484		59.19
, <b>FT</b>	59.2	503		59.20
			<b>▲vg</b> • =	<b>5</b> 9 <b>.19</b>
21.84	59.6	472		47.60
	59.4	484		47.61
Ħ	59.2	503		47.63
			Avg. =	47.61

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Cons. Gms. Cr/L.	Box Res. Ohms	Bridge Råg.	Rea	3. (Calc.) Ohma
13.65	36.6	500		36.60
-	36.4	512		36.58
	36.0	540		36.58
			rg. =	36.58
8.73	32.0	<b>4</b> 76		<b>3</b> 3 <b>.75</b>
	31.8	492		<b>33.75</b>
77	31.6	507		83.75
			rg. =	83.75
2.51	27.0	491		26.90
<b>T</b>	26.8	510		26.91
-	26.6	530		26.92
		۲ <b>۵</b>	rg. =	26.91
1.25	26.4	480		26.18
1	26.2	<b>50</b> 0		26.20
	26.0	520		26.21
		۲ <b>ه</b>	√g. =	26.20

Summary

Conc. Gms. Cr/L.	Res. (Calc.) Ohms	Sp. Cond. Mhos.
34.12	81.68	0.180
27.84	59.19	0.249
21.84	47.61	0.310
<b>13.65</b>	36.58	0.403
8.73	31.69	()-466
2.51	26.91	<b>0.54</b> 8
1.25	26.20	0.563



Fig. I.





#### **DISCUSSION**

Fig. 1 shows the variation of the resistance and specific conductivity of chromic acid solution with changes in concentration. The resistivity of the solution becomes a minimum and the conductivity a maximum at a concentration of about 450 grams of  $CrO_g$  per liter of solution. This is the general effect of concentration of a solution upon specific conductivity.

From Table II it is seen that an addition of a salt such as  $Ma_2SO_4$  to chromic acid solutions of varying concentrations only increases its resentivity by a very small amount. The amount of  $SO_4$  added was always 1% of the  $CrO_3$  present, which is approximately the amount present in some plating baths.

Fig. 2 shows the effects of addition of varying amounts of several different salts to chromic acid solution of a concentration of 250 gms.  $CrO_3/L$  of solution. It is seen that  $FeSO_4$  and  $Cr(OH)_3$  have the greatest relative effect in increasing the resistivity of the solution. Both these compounds are basic or reducing substances and the increase in resistivity is probably due to a combination of two things: (1) The decrease in concentration of free chromic acid due to its reduction by the  $Cr(OH)_3$  and the  $FeSO_4$ . (2) The formation of a reduction product of chromic acid, chromium dichromate, a colloid, whose presence always increases the resistance

of the solution. In the case of both these compounds an equivalent amount of that component that carries practically all of the current. (the first hydrogen of chromic acid), is neutralised and as a result the resistivity is proportionally increased. The first factor mentioned is no doubt the one of greatest importance. A calculation of the amount of chromic acid reduced by 17.50 grams of chromium in the form of Cr(OH)3 shows that the resulting concentration of the original solution would be 151.60 grams of CrOg per liter. Referring to Fig. 1. the resistivity of chromic acid at that concentration is 32.00 ohms, while the actual measured resistance of the reduced solution was 40.70 ohms. The difference then must represent the resistivity due to the chromium dichromate formed, and in the case of  $\text{FeSO}_4$ , to  $\text{Fe}_2(SO_4)_{\pi}$  formed or any other compound.

The increasing slope of the  $FeSO_4$  and  $Cr(OH)_3$  curves as their concentration increases shows that the concentration of free chromic acid is approaching that point on the graph of Fig. 1, where the resistance begins to change rapidly with a small change in concentration.

Hon-reducing salts like  $Na_2SO_4$  and  $Pe_2(SO_4)_3$  have very little effect on the conductivity of chromic acid solutions. It is evident that a very great amount of either of these would have to be present in a plating bath to cause any serious effect, or change in its resistivity.

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Under ordinary plating conditions, it is practically impossible to prevent the formation of a limited amount of chromium dichromate as a by-product of chromium deposition but as all ready stated the change in resistivity of the bath is not due merely to its presence, but also to the result of its formation.

Fig. 3 represents resistances expressed as specific conductivity, or mhos (reciprocal ohm contimeters).

### CONCLUSIONS

1 - The conductivity of chromic acid solution becomes a maximum and the resistance a minimum at a concentration of approximately 450 grams of CrO<sub>3</sub> per liter of solution.

2 - Basic or reducing substances such as FeSO<sub>4</sub> and Cr(OH)<sub>3</sub> increase the resistance of chromic acid solutions due to the reduction of the free chromic acid present and also to the resultant formation of the colloid (chromium dichromate) and other compounds.

3 - Salts like  $Na_2SO_4$  and  $Fe_2(SO_4)_3$  which are nonreducing, unless present in large amounts, have very little effect on the resistance of chromic acid solutions.



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