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IONIC MASS TRANSPORT BY FREE CONVECTION TO HORIZONTAL ELECTRODES

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Eugene Joseph Fenech

(Thesis)

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ABSTRACT

Electrodeposition of copper from acid copper sulfate solutions onto horizontal electrodes facing upward is employed to investigate the mechanism and rate of mass transport under free-convection conditions. Mass-transfer rates are obtained by limiting-current measurements, and the distribution of current densities over the electrode surface is examined by the "sectioned-electrode" technique.

Solution properties (concentration, viscosity, and density) and geometry (shape and size) are varied between broad limits. A physical model involving two distinct types of free convection is postulated by which the effect of geometry on mass-transfer rates can be explained. In the absence of a suitable mathematical model the data are correlated by the equation:

$$Nu' = 0.122\ (Sc^{9/8}\ Gr)^{1/3} \cdot d_n ,$$

where Nu', Sc, Gr, and d_n are respectively the Nusselt number for mass transfer, the Schmidt number, the Grashof number, and the correction factor for electrode size.

In the range of $2{,}000 < Sc < 50{,}000$ and $4 \times 10^6 < (Sc^{9/8}\ Gr) < 4 \times 10^{13}$, 95% of the experimentally obtained mass-transfer rates are within ±6.7% of the values predicted by this correlation.

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INTRODUCTION

When an electric current is passed through an electrolytic cell, a complicated process of charge transfer occurs by means of ionic mass transport. In general, there are three separate and distinct mechanisms by which this transport takes place: migration, diffusion, and convection.

Migration is the movement of ions under the influence of an electric potential gradient. It is rather well understood, and a discussion of it can be found in a standard electrochemical textbook.[1] Diffusion is the movement of mass under the influence of concentration gradients. Many reports, both mathematical and experimental, are available on this phenomenon.[2]

Convection is the movement of fluid elements under the influence of external forces. Since in this work the only external force that will be considered is gravity, this definition can be modified. It becomes: natural convection (stirring due to gravity) is the movement of fluid elements under the influence of density gradients. This mode of mass transfer, then, is under consideration in this paper. The model to be studied is that of a horizontal cathode facing upwards in a copper sulfate-sulfuric acid solution. When current is passed through this cell, copper is plated on the cathode. This produces a density gradient and stirring by natural convection. This model has been experimentally studied by the author and is the subject of an earlier report[3] which presents the general correlation,*

$$Nu' = 0.129\ (Sc^{1.1} \cdot Gr)^{1/3}, \tag{1}$$

*All symbols are defined in Nomenclature, page 85 .

where $Nu' = k_L \, x \, / \, D_{Cu^{++}\,Av}$ (2)

$$Sc = \nu_{Av} \, / \, D_{Cu^{++}\,Av} \quad (3)$$

$$Gr = g \, \Delta \rho \, x^3 \, / \, \rho_i \, \nu^2_{Av} \quad (4)$$

This equation, while apparently yiedling acceptable results, suffers from certain limitations. First, upon closer inspection it is noted that the characteristic dimension, the unhindered height of fluid above the electrode (free height), which is a factor in both the Nusselt and Grashof numbers, cancels out of the correlation. Therefore, Eq. (1) cannot predict a dependence on that variable when, in fact, for small enough heights, convection and therefore mass transfer must be influenced by the free height. In 1935, Schmidt and Milverton experimentally showed that for heat transfer, at least for small distances (0.4 and 1.1 cm), there is a dependence on this dimension.[4] However, in the precious mass-transfer work,[3] no such response has been observed at distances as small as 1 cm.

The empirical power on the Schmidt number is another point that needs validation. The need for a different exponent on the Schmidt number has been suggested by Schmidt in order that broad ranges of viscosity and diffusion coefficients could be taken into account.[5] Until now, this constant has been determined by the author from experiments in which only two different viscosity solutions (1.4 and 8.0 centipoises) were used. Additional experiments using a wider range of viscosity must be made in order to obtain a better estimate of this constant.

An anomaly in the previous work[3] which was quite disturbing was the fact that experiments with solutions having extremely low mass-transfer and natural-convection driving forces (i.e., concentration and density gradients) resulted in abnormally high mass-transfer rates. This has also been observed by Ibl in work done on natural-convection mass transfer at vertical surfaces.[6] These high values have been explained previously by noting the possibility of an unsteady-state condition.[3]

It is also necessary to point out that Eq. (1) is valid only for large transferring surfaces. In earlier work it was found that the dimensions of the surface were important if they were less than approximately 10 cm in either direction, and a correction factor has been empirically determined by the author for the case of a rectangular surface less than 10 cm <u>in one dimension only</u>.[3] The experimental Nusselt number, when multiplied by the correction factor presented in Fig. 1, is reduced to the value predicted by Eq. (1).

This picture of size effect is completely confused by the addition of vertical end walls at the free edges of the electrode. In some cases, the presence of this barrier greatly reduces the rate of mass transfer, and in others is seems to have no effect. One thing can be said for certain, however; in the case of large surfaces, the presence of end walls causes no appreciable difference in the rate of transfer.

The postulated explanation for the variation of mass-transfer rate with surface dimensions and for "wall" effect is based on the existence of two modes of natural convection: an extremely turbulent boundary layer, and a secondary laminar convection.[3] The turbulent boundary layer is the primary mode of transfer immediately above the electrode surface and if not disturbed is of uniform intensity over the entire electrode. The intensity of this turbulence depends on the density difference between surface and bulk solution The secondary-convection currents are responsible for mass transfer between the solution and the boundary layer, their intensity depending on the density differences from point to point within the bulk solution. At the edges of the electrodes, where density differences are the greatest within the bulk solution, the secondary currents have the greatest velocity and, in turn, reduce the size of the boundary layer, increasing local current density.

In this paper, the author desires to present data and observations that will help to give a better physical understanding of the natural convection mechanism and, in the absence of a mathematically solvable theoretical model, to correlate the data.

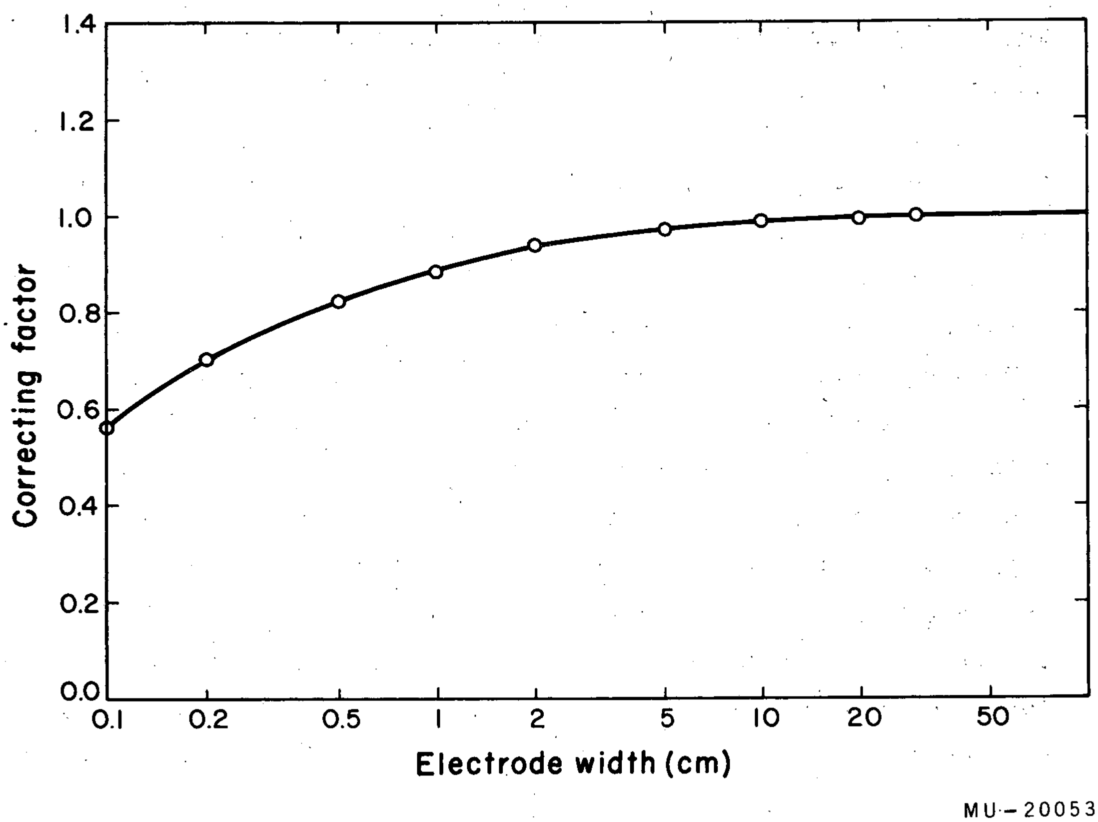

Fig. 1. Correction factor as a function of electrode width (from Reference 3).

DISCUSSION OF THE BASIC EXPERIMENT

Since the experimental techniques involved in the various sections of this work are basically the same, it seems advisable to describe the experiment and the theory underlying it.

The requirements of these experiments are: to cause mass transfer across the boundary; to know the mass transfer and natural convection driving forces; and to be able to measure the physical dimensions of the system. The use of an electrolytic cell in this work has many advantages. First, it is easy to find a system that will produce the required density gradient. Second, the mass-transfer rate is measured simply by recording the current flowing through the cell. Third, the driving forces can be measured by forcing the cell into limiting current, at which time the concentration of cupric ion at the electrode surface is zero, allowing calculation of the density of the electrolyte at the electrode surface. Fourth, electrodeposition can be continued for some time without appreciably changing the physical dimensions of the electrode. For this work, the choice of the copper sulfate-sulfuric acid-water system is made attractive by the very extensive data available on its physicochemical properties.*

Limiting current is the maximum rate of electrical-current passage that can by utilized for a particular electrode reaction. As has been stated previously, it occurs when the concentration of the reacting species at the electrode surface is zero.[3] Limiting current is measured by observing the emf of a concentration cell formed of the bulk and interface solutions. The equation for this emf (concentration polarization) is

$$\Delta E = (RT/nF) \ln (a_o/a_i) \approx (RT/nF) \ln (c_o/c_i). \qquad (5)$$

The limiting current is determined by plotting current as a function of concentration polarization and determining the point at which the rate of change of current with polarization is zero. Figure 2 is a typical limiting current curve. The solid line exemplifies the function in the presence of a subsequent electrode reaction, the decomposition of water, while the dotted extension shows the curve in the absence of all other possible reactions.

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*See Appendix I.

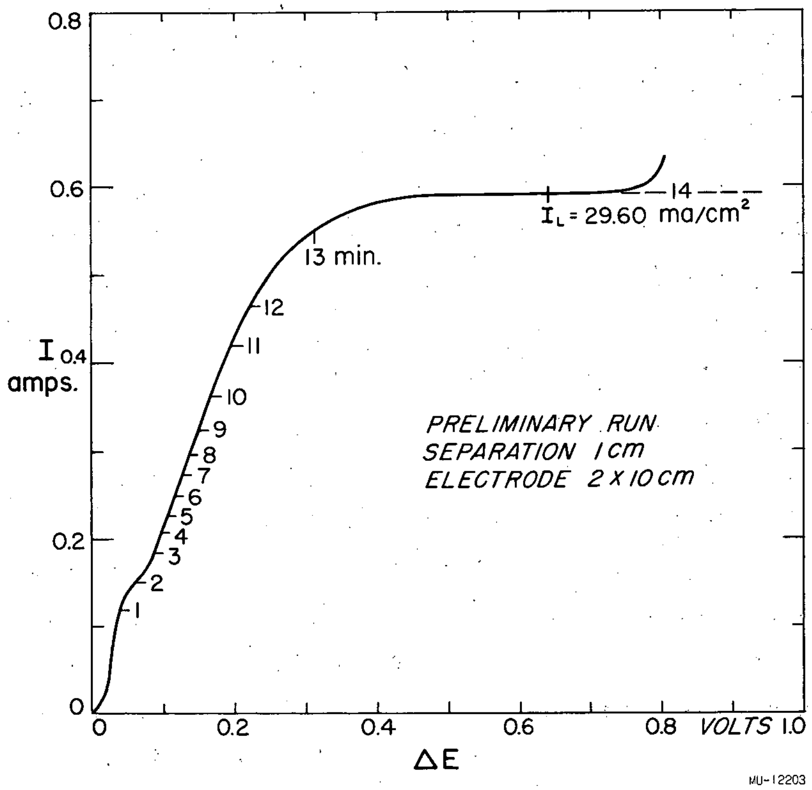

Fig. 2. A typical limiting-current curve, showing electrode current as a function of polarization voltage.

The experiments in this work are conducted by plating copper from a copper sulfate-sulfuric acid-water solution (with glycerol added to increase the viscosity, when necessary) to a horizontal cathode facing upwards. Figure 3 gives the circuit for the general experiment. The cathode is separated from the anode compartment by a porous ceramic diaphragm which serves to eliminate the influence of convection currents produced in the anode section. The construction of the three individual cells is presented in its appropriate section. Extended descriptions of these procedures and the associated phenomena are given elsewhere.[3,7]

Using the following equations, one can quantitatively evaluate the data:

$$\Delta C_{(H_2SO_4)} = \frac{t_{H^+ Av}\ C_{0\ CuSO_4}}{(1 - t_{Cu^{++}})} \left(\frac{D_{CuSO_4}}{D_{H_2SO_4}} \right)^{2/3}_{Av} \tag{6}$$

$$k_L = I_L \left(1 - t_{Cu^{++}Av}\right) / nF\ C_{0\ CuSO_4} . \tag{7}$$

The solution to Eq. (3) is a trial-and-error process made necessary by the fact that the concentration of sulfuric acid at the interface is higher than that in the bulk solution.[3,8] Appendix I contains a summary of the equation for the physical properties of the solutions as functions of concentration.

EFFECT OF FREE HEIGHT ABOVE THE TRANSFERRING SURFACE

In order to determine if the mass transfer rate does depend on the liquid height above the transferring surface, several series of experiments were made in which no variable, other than this height, was changed. It should be remembered that in previous work on this system, no change was noted at distances as small as 1 cm.[3]

The cross section of the electrolytic cell used in these experiments is shown in Fig. 4. The inside dimensions of the cell are 10 cm wide by 40 cm long by 20 cm high. Provisions were made to set the distance between the cathode and the diaphragm at 2, 1, 0.5, and 0.2 cm. A 2-by 10-cm

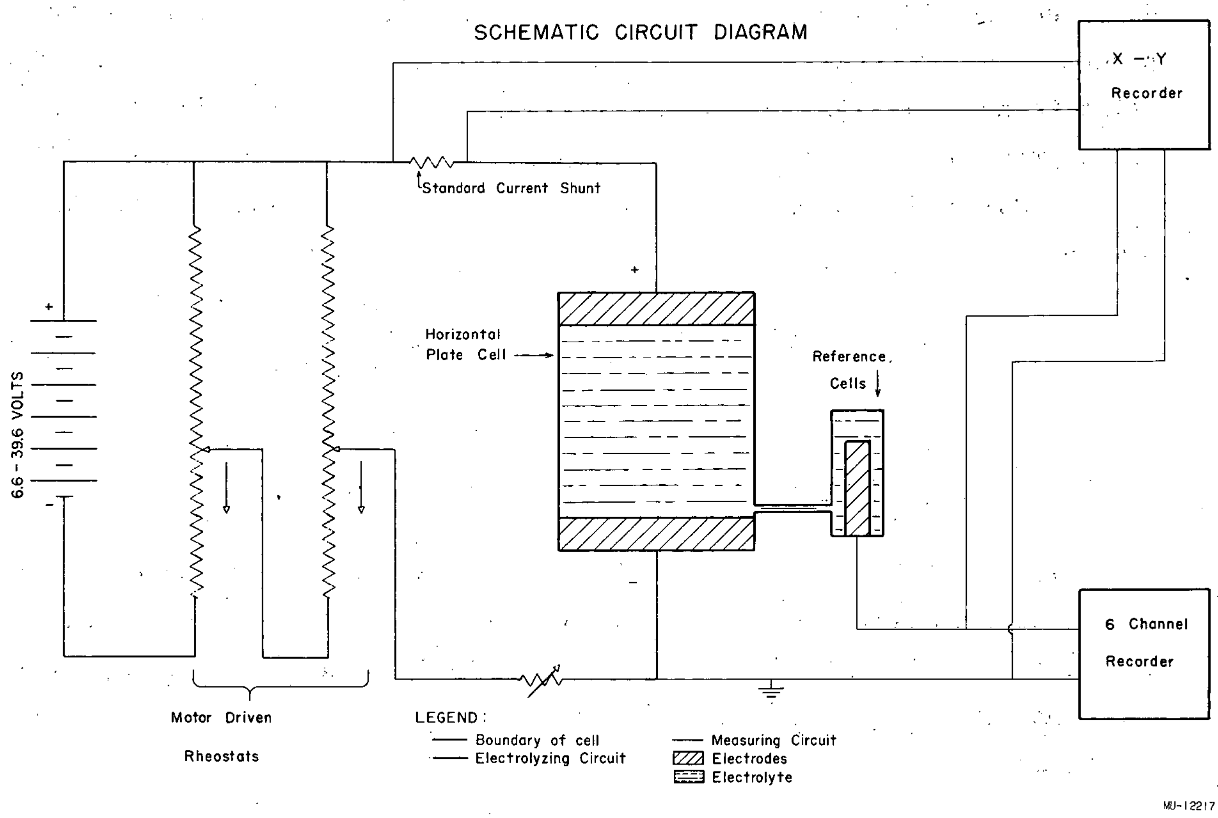

Fig. 3. Schematic diagram of experimental circuit.

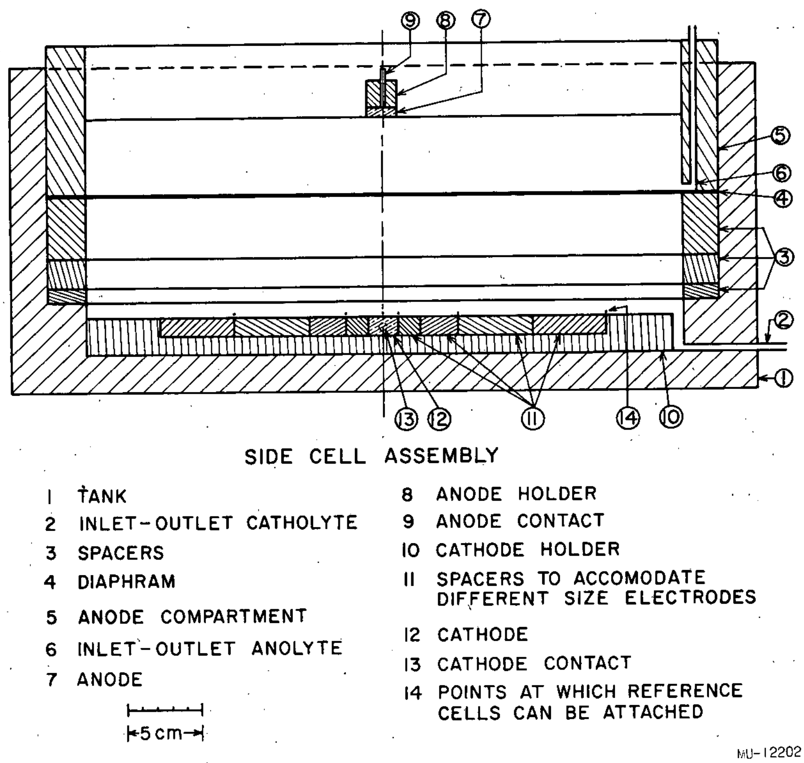

Fig. 4. Section drawing of experimental cell used for most measurements. This cell was modified for forced-convection experiments.

electrode was used in a solution of 1.472 M sulfuric acid and 0.1538 M cupric sulfate. In order to insure the reliability and reproducibility of the measurements, certain precautions were taken in the course of each run. Immediately before each run, the electrode to be used was washed, polished, and degreased. It was then assembled into its place in the cell, and the cell was filled carefully to avoid the possibility of bubbles on the surface of the cathode. Finally, the electrode was plated with a very thin layer of copper from the experimental solution. This procedure was necessary in order to provide a uniform surface quality for each experiment, and to assure uniform plating. Table I gives the results of the free-height experiments.

Table I

Limiting current density as a function of free height

Free height (cm)	Limiting current density (ma/cm^2)					Mean (ma/cm^2)	Standard deviation (ma/cm^2)
2.0	17.92	17.92	17.98	18.00	18.00	17.964	0.041
1.0	17.68	17.70	17.93	17.93	18.20	17.888	0.212
0.5	17.95	17.97	18.02	18.10	18.20	18.048	0.103
0.2	16.58	16.60	16.83	16.90	17.13	16.808	0.228

If it can be assumed that the error in these measurements is normally distributed and is the same in magnitude regardless of the true value of the limiting-current density, the standard deviation of the error can be calculated to be 0.165 ma/cm^2. If there were no difference between the limiting currents of the various free heights, then from the theory of statistics, two-thirds of all experimental results should lie between plus and minus one standard deviation of the true value. It is therefore concluded that, on the basis of these experiments, there is no difference in the limiting current densities of the three larger distances. Furthermore, it is concluded that the experiments show a definite difference in the value of the limiting current density for the smaller distance.

Further evidence supporting these conclusions comes from the fact that if there were no difference in any of the measurements, the best estimate of the standard deviation would be 0.540 ma/cm^2, which is completely inconsistent with the standard deviations calculated for the individual heights. If the experimental values of only the larger three heights are considered, then the standard deviation is 0.144 ma/cm^2, which is consistent with the conclusion that for heights greater than 0.5 cm there is no dependence on height.[9]

It is interesting to note that whenever an electrode had a free edge (one not bounded by a vertical wall), certain markings appeared within 1 cm of the edge. It has been hypothesised that these are caused by large convection currents sweeping in and upward across the free edge. It should be pointed out, however, that a difference in the markings on the electrodes has been observed in these experiments depending on the free height (see Fig. 5). Electrode A was used in an experiment with a 0.5-cm free height, while electrode B was used in a 0.2-cm run. Careful observation of electrode A shows straight markings, perpendicular to the edge, and about 0.5 cm long. On the other hand, electrode B has markings not quite perpendicular to the edge, still straight, and still approximately 0.5 cm long, but now with a small tail toward one end. It is as though the edge currents, instead of rising, are being forced to run up the center of the electrode. Evidently, this large convection current can be greatly compressed before it is distorted and loses its strength. More will be said concerning these markings in a subsequent section.

From this analysis, then, it appears quite reasonable to conclude that there is no effect due to free height above the transferring surface unless that dimension is very small (less than 0.5 cm). Even at 0.2 cm, the reduction in the LCD (limiting current density) is only on the order of 5%.

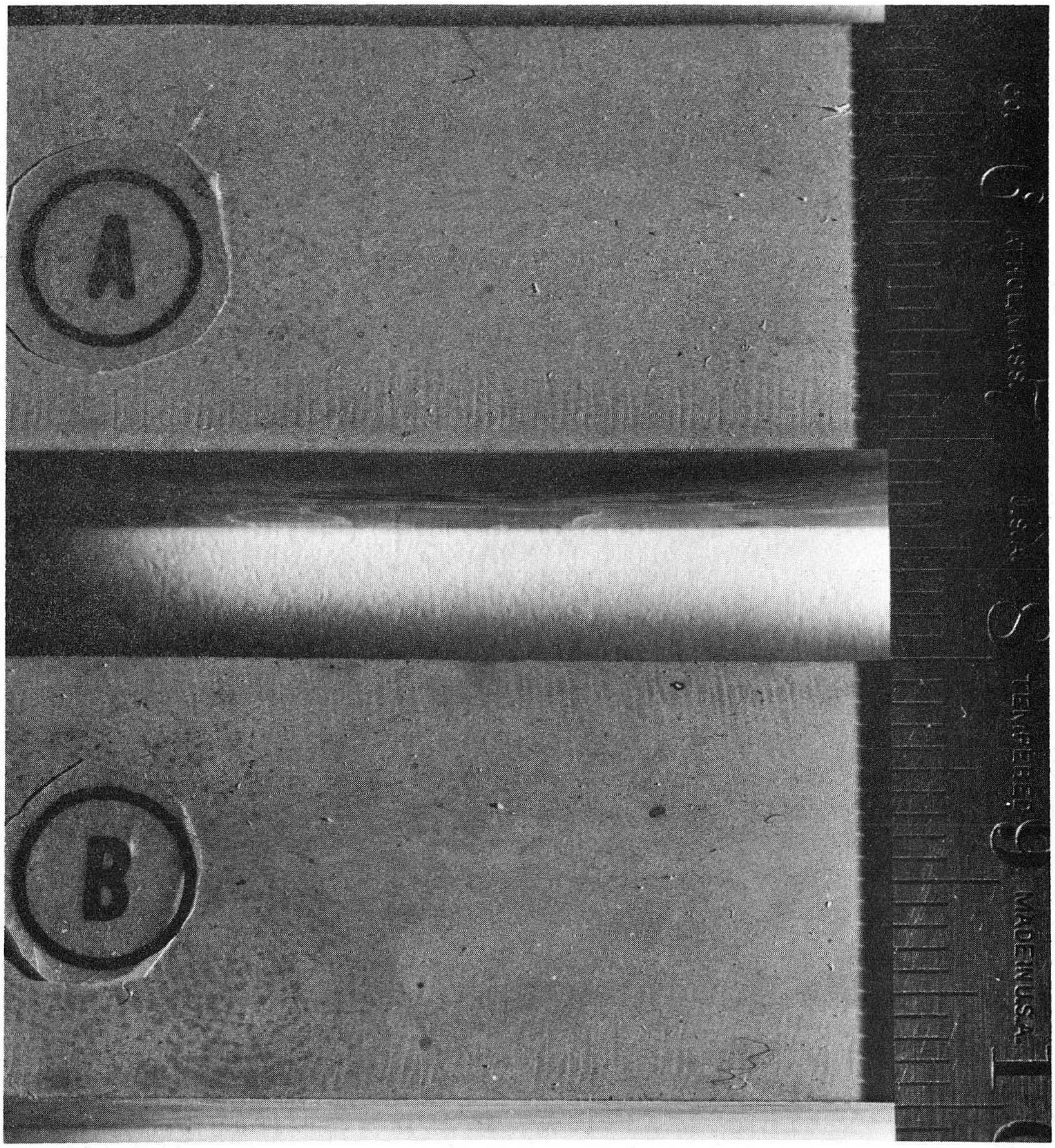

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Fig. 5. Two electrodes used in free-height experiments. Electrode A shows typical markings found after an experiment with free height greater or equal to 0.5 cm. Electrode B was used in an experiment with free height equal to 0.2 cm.

EFFECT OF VISCOSITY ON MASS TRANSFER RATE

As stated in the introduction, the power to which the Schmidt number is raised in Eq. (1) has been determined from essentially only two values of viscosity. In order to determine this power with greater accuracy, further work has been done using three new solutions. The physical dimensions, the concentrations of chemicals, and the limiting current densities are presented in Table II, while the rest of the properties are given in the Run Index, Appendix III. This data will be fitted into the general equation in the section entitled CORRELATION OF DATA.

THE PROBLEM OF LOW-CONCENTRATION EXPERIMENTS

As pointed out in the INTRODUCTION, low-concentration experiments consistently give high limiting currents, and, in the experience of the author, are quite unreproducible. A partial explanation for these high results may be found by a discussion of the s-shaped limiting-current curves recorded for all 0.01 M $CuSO_4$ experiments. Figure 6 is a typical example of such curves. The most obvious difficulty is determining exactly the LCD. This problem is "simplified" by the fact that even if one reads the lowest value possible, the resulting Nusselt number is much higher than predicted by Eq. (1).

The following is hypothesized to be an explanation of the peculiar limiting-current curves observed in the low-concentration experiments. It should be noted in preface that visual observations have confirmed the fact that in these low-concentration runs, natural convection is very slow to develop.* When voltage is first applied to the electrodes, the supply of ions at the surface is large, and by diffusion alone the electrical current is very high. Then as the supply of ions at the surface is reduced and since the uncompletely developed convection cannot supply the abnormally high demand for ions, the current begins to fall, forming the maximum in the

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*The procedure and equipment are described in the next section.

Table II

Results of glycerol experiments

Run No.	H_2SO_4 (M)	$CuSO_4$ (M)	Glycerol (M)	Electrode[a] width (cm)	Free Height (cm)	LCD (ma/cm^2)
411	1.573	0.256	5.38	30.0	2.0	7.99
412	1.573	0.256	5.38	30.0	4.0	8.02
413	1.573	0.256	5.38	10.0	2.0	8.10
414	1.573	0.256	5.38	10.0	4.0	8.07
415	1.573	0.256	5.38	2.0	2.0	8.48
416	1.573	0.256	5.38	2.0	4.0	8.39
417	1.573	0.256	5.38	1.0	2.0	8.73
418	1.573	0.256	5.38	1.0	4.0	8.71
419	1.573	0.256	5.38	0.5	2.0	9.20
420	1.573	0.256	5.38	0.5	4.0	9.43
421	1.526	0.230	4.01	30.0	1.0	9.83
422	1.526	0.230	4.01	30.0	8.0	9.79
423	1.526	0.230	4.01	10.0	1.0	9.81
424	1.526	0.230	4.01	10.0	8.0	9.93
425	1.526	0.230	4.01	2.0	1.0	10.73
426	1.526	0.230	4.01	2.0	8.0	10.14
427	1.526	0.230	4.01	1.0	1.0	10.76
428	1.526	0.230	4.01	1.0	8.0	10.71
429	1.526	0.230	4.01	0.5	1.0	11.23
430	1.526	0.230	4.01	0.5	8.0	11.56
431	1.537	0.318	2.26	30.0	1.0	25.5
432	1.537	0.318	2.26	30.0	4.0	25.5
433	1.537	0.318	2.26	10.0	1.0	26.1
434	1.537	0.318	2.26	10.0	4.0	26.4
435	1.537	0.318	2.26	2.0	1.0	27.0
436	1.537	0.318	2.26	2.0	4.0	27.1
437	1.537	0.318	2.26	1.0	1.0	28.0
438	1.537	0.318	2.26	1.0	4.0	27.7
439	1.537	0.318	2.26	0.5	1.0	29.5
440	1.537	0.318	2.26	0.5	4.0	29.6

[a]The length of all electrodes is 10 cm.

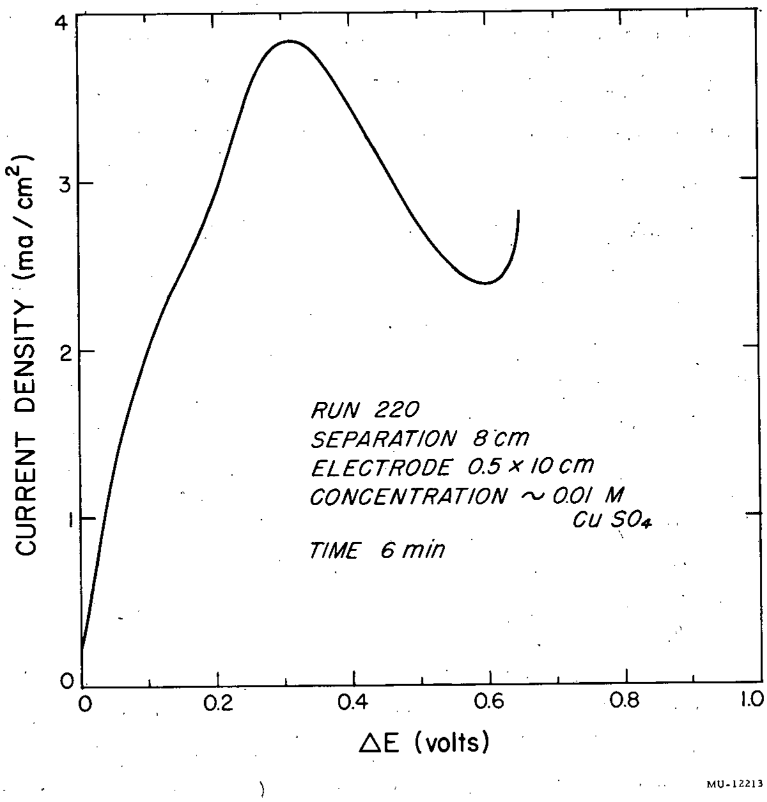

Fig. 6. Typical limiting-current curve for 0.01 M $CuSO_4$ concentration.

curve of Fig. 6. Simultaneously, however, the applied voltage has increased to such a value that the limiting current is exceeded, hydrogen is evolved, and the current begins again to rise, forming the minimum. The obvious answer, if these assumptions are correct, is to increase the length of the experiment so that there is essentially a steady-state condition at all times. Examination of data previously taken (presented in Table III) shows that this does help. Note particularly that the difference between maximum and minimum decreases with increasing time, and that the minimum approaches 0.77 ma/cm^2, the value predicted by Eq. (1). These experiments were made using 0.01355 M $CuSO_4$, 1.678 M H_2SO_4, an electrode 0.5 by 10 cm and a free height of 8 cm. There seems to be only one argument against increasing the length of a run until the hump disappears completely, i.e., as the length of the run increases, the solution is depleted in copper and the concentration in the vicinity of the electrode is unknown. While it is true that the amount of copper plated can be calculated from a knowledge of the current passed, the change in distribution of copper along the cell cannot be determined. Thus one has no alternative but to try to shorten the duration of the experiments as much as possible.

Table III

Low-concentration time dependence

Run	Current Density (ma/cm^2) Maximum	Minimum	Difference	Time (min)
211	4.43	2.98	1.45	1.76
212	2.52	1.48	1.04	3.04
215	2.09	1.17	0.92	4.97
213	1.73	1.01	0.72	8.42
214	1.53	0.89	0.64	14.91
216	1.49	0.86	0.63	20.04

It appears, then, that by lengthening the experimental runs, one can eventually cause the hump in the limiting-current curve to disappear. By doing so, however, the concentration of the copper in the solution region near the electrode becomes unknown. Since the plating process causes a depletion of copper ions near the cathode, it is expected that the LCD should also be reduced. In contrast to this expectation, however, the author has never obtained a low LCD in a run with 0.01 M $CuSO_4$ solution. Because experiments of this type have a time dependence which reduces their reliability, they have been eliminated from the general correlation.

EFFECT OF ELECTRODE SIZE ON MASS TRANSFER

In previous work,[3] the effect of changing one dimension of the cathode has been determined (see Fig. 1). In the determination of this dependence, however, only the results from the approximately 0.25 M $CuSO_4$ solutions were used, and very poor reproducibility was encountered in the case of the 0.1- and 0.2-cm electrodes. All of the electrodes used were 10 cm in length and bounded by walls at both ends in order to produce a situation in which the electrode could be considered infinite.

A possible explanation of the increase in LCD as the width* of the electrode decreases is the existence of an edge effect. Obviously, the availability of a more concentrated and dense solution is greater at the edge of the electrode than it is in the center of the electrode. In the center, the solution (less concentrated in cupric ion) is more buoyant than that at the edge and thus rises. Meanwhile, the more dense solution at the edge is flowing in to replace the lighter solution. If this hypothesis is true, a large convection current should be found rising over the center of the electrode and descending at the edges.

In order to observe this convection, it was decided to suspend fine particles of rosin** in the solution and examine their motion by the use of a photographic technique known as dark-field illumination. This

*The word "width" is used here because the electrodes are supposedly infinite in length.

**Rosin particles were used which passed through a No. 200 sieve and were retained by a No. 325 sieve.

technique consists of the very strong side lighting of objects in the foreground against as dark a background as possible. Perfectly done, the resulting photographs would consist of only brightly lit particles, much as the stars in the sky.

Figure 7 is a picture of the cell used to view these convection currents. It has provisions for experiments with different sizes of electrodes and any cathode-diaphragm distance wanted. Figures 8a and 8b are, respectively, viewing-side and cell-side photographs showing the placement of lights, sight shields, and camera. The glass containers placed in front of the lights are heat filters. Filled with copper sulfate solution, they absorb much of the heat from the lamps, thus cutting down on thermal convection currents within the cell.

As was expected, this cell showed that a large convection current ascended at the center of the electrode. Figures 9, 10, 11, and 12 are photographs showing the formation of this current. Figure 9 was taken just after voltage was applied to the electrodes; Fig. 10 was taken 2 minutes later; Fig. 11, at limiting current; and Fig. 12, just after the start of hydrogen evolution. The convection patterns at the edges of the cell were caused by heat from the spotlights. The electrode in these pictures is 1.5 by 10 cm, and the free height above the electrode is 6 cm. Other electrodes as small as 0.1 cm and other free heights as low as 2 cm were used in similar experiments, and the same convective pattern was noted in all cases. In this experimental setup, more quantitative data could not be taken because of the competing convection caused by the heat from the lights and the incomplete separation of the anode and cathode compartments. Although the diaphragm fit fairly well, some mixing was observed.

The existence of an edge effect is also inferred by the markings on the free edges of the electrodes. Figure 13 shows a section of a 5- by 10-cm electrode in which these markings can be clearly seen. It has been noted that the length and other characteristics of these markings remain constant under all conditions of concentration and physical dimensions, except for extremely small free heights as previously discussed. In cases where the distance across the electrode is shorter than

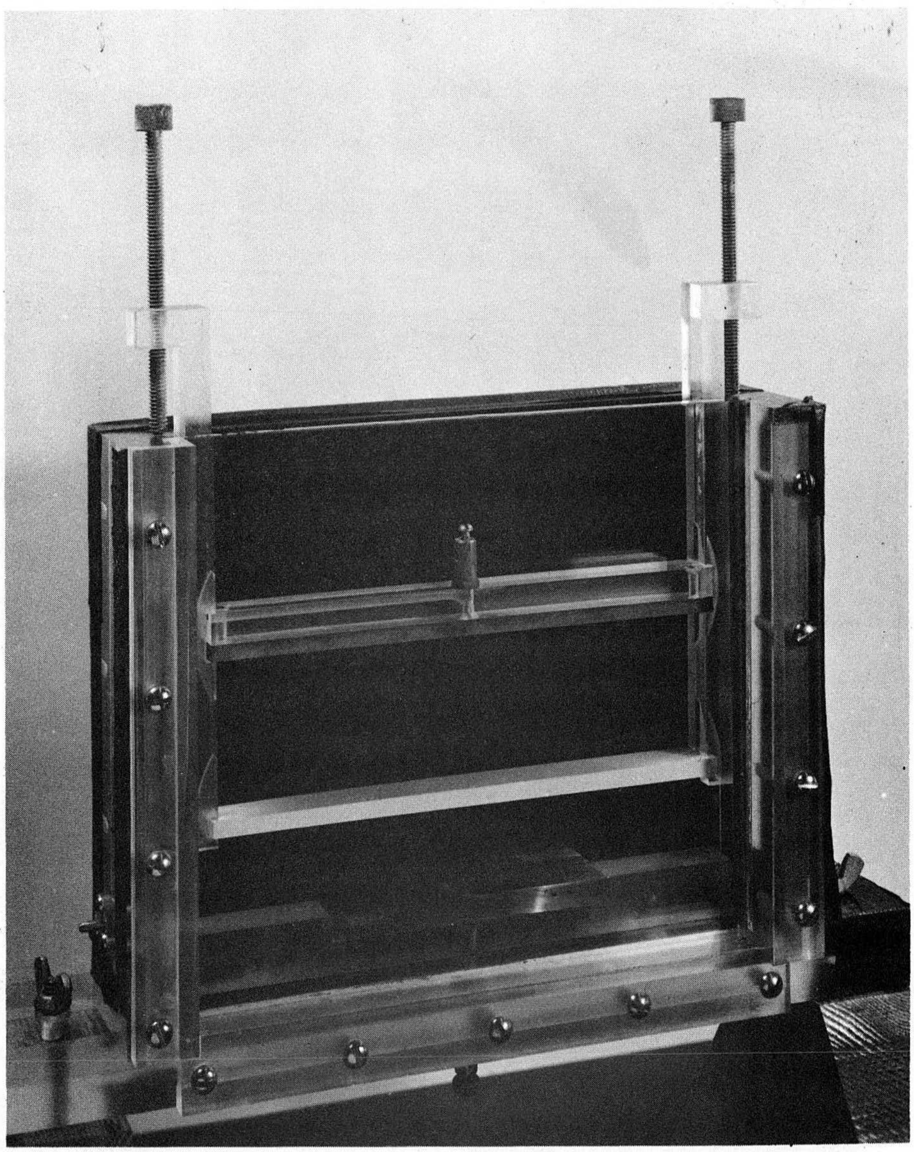

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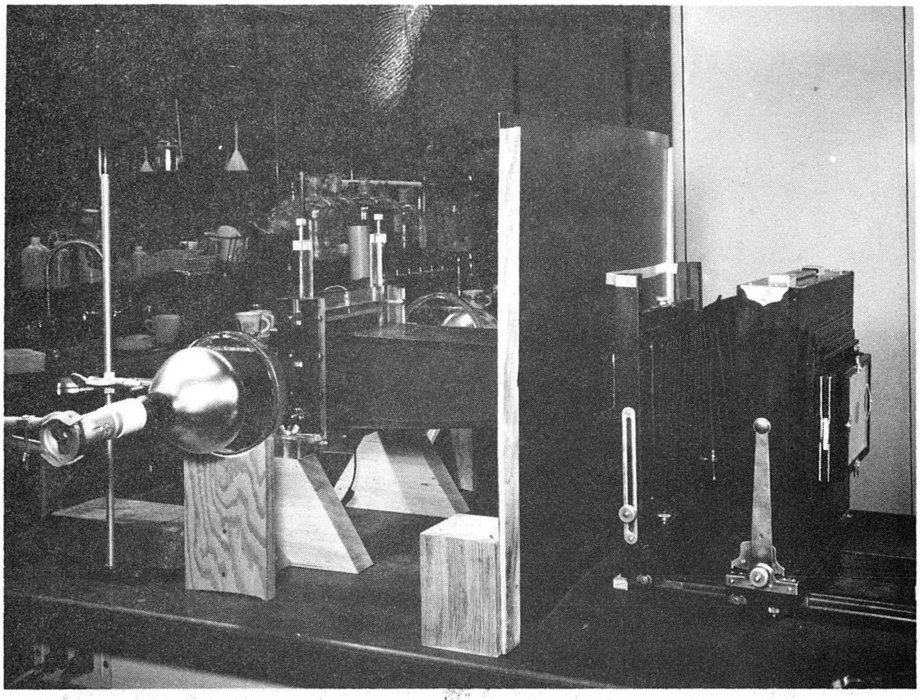
Fig. 7. Secondary-current observation cell.



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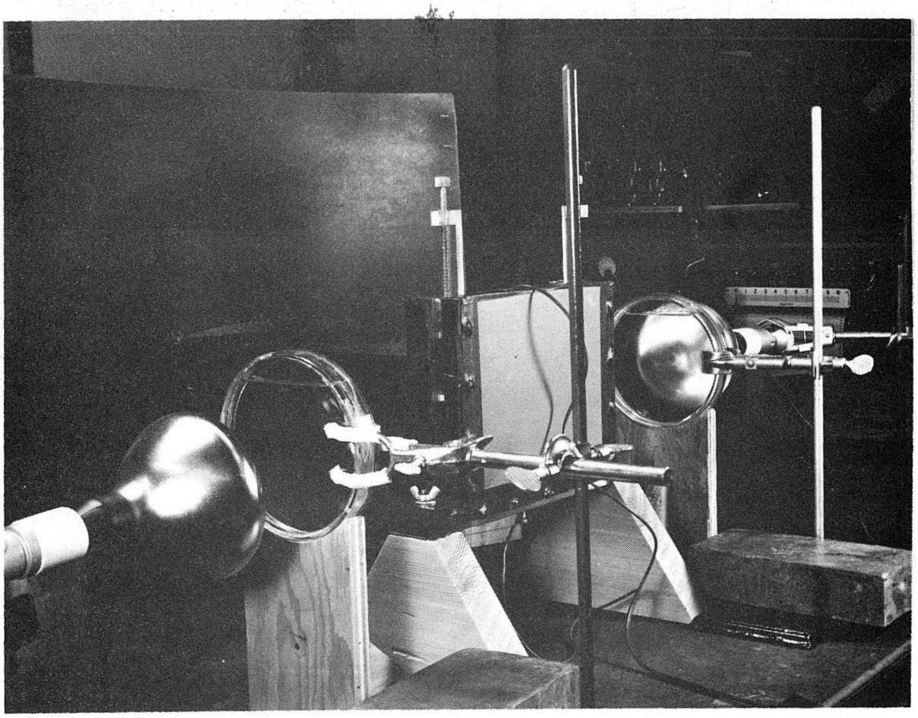

(b)

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Fig. 8. Experimental set-up for dark-field illumination: (a) viewing side; (b) cell side.

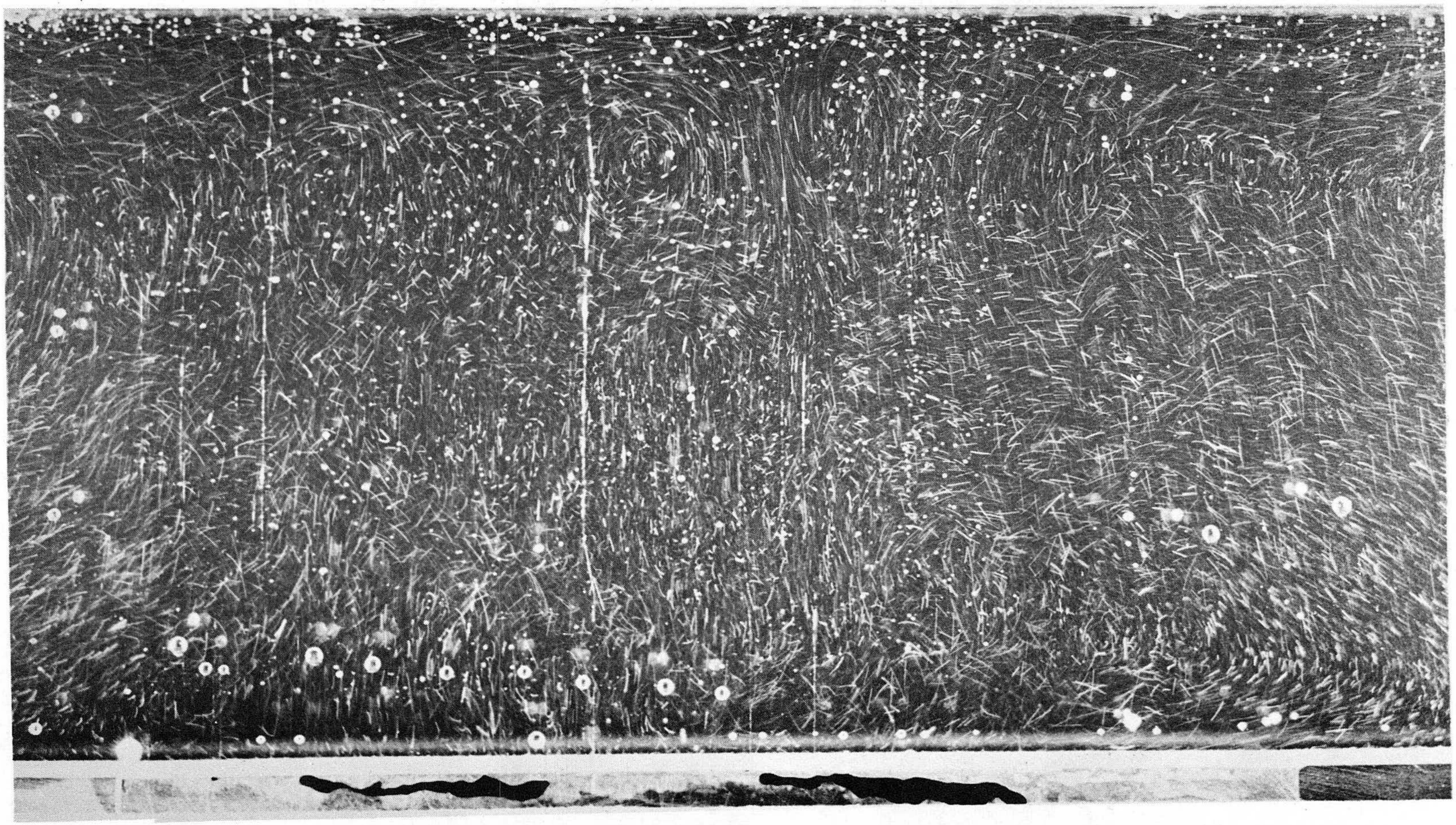

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Fig. 9. Secondary-convection pattern a few seconds after experiment started. Patterns at the sides of picture are caused by heat from lamps.

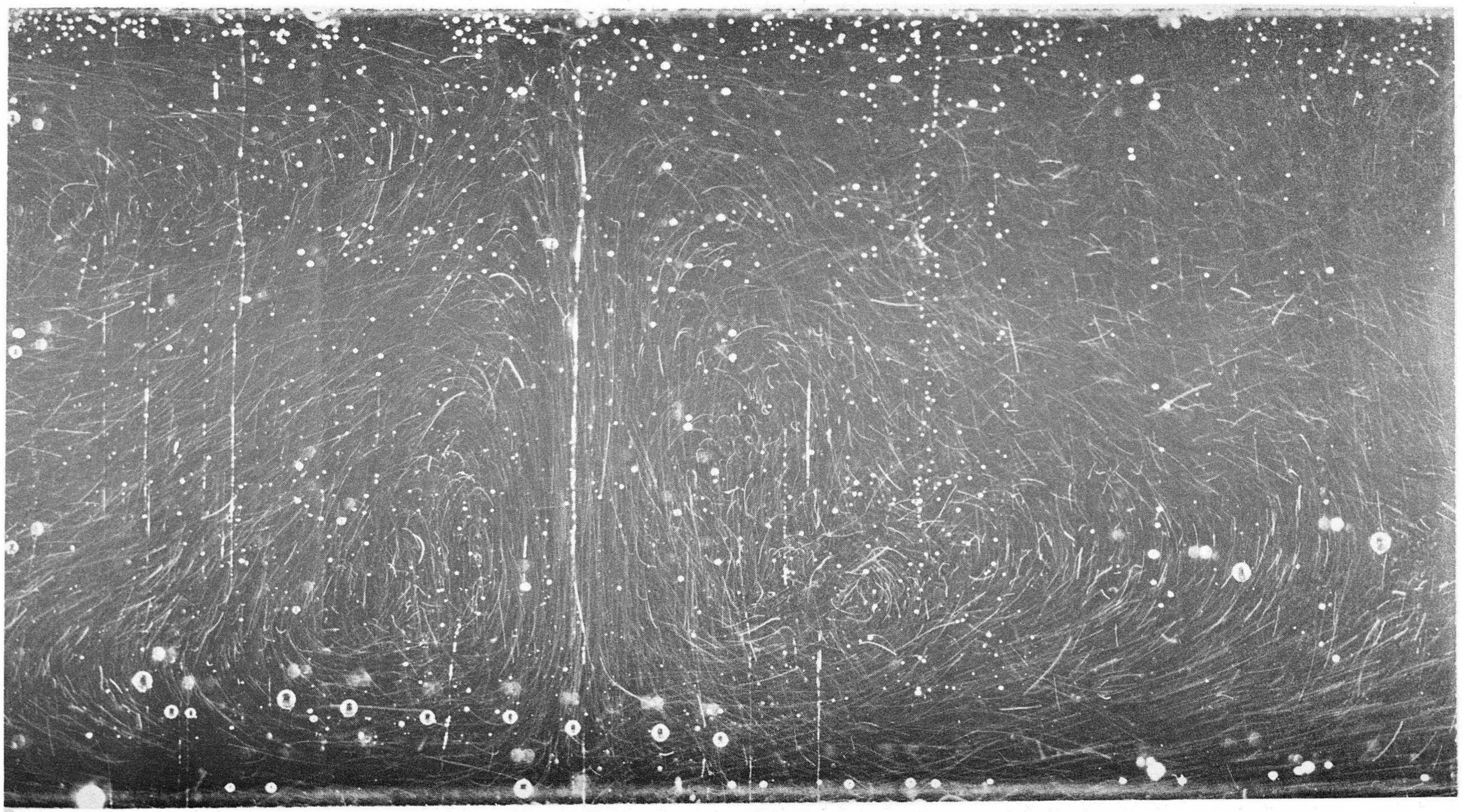

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Fig. 10. Secondary-convection pattern 2 min after experiment started.

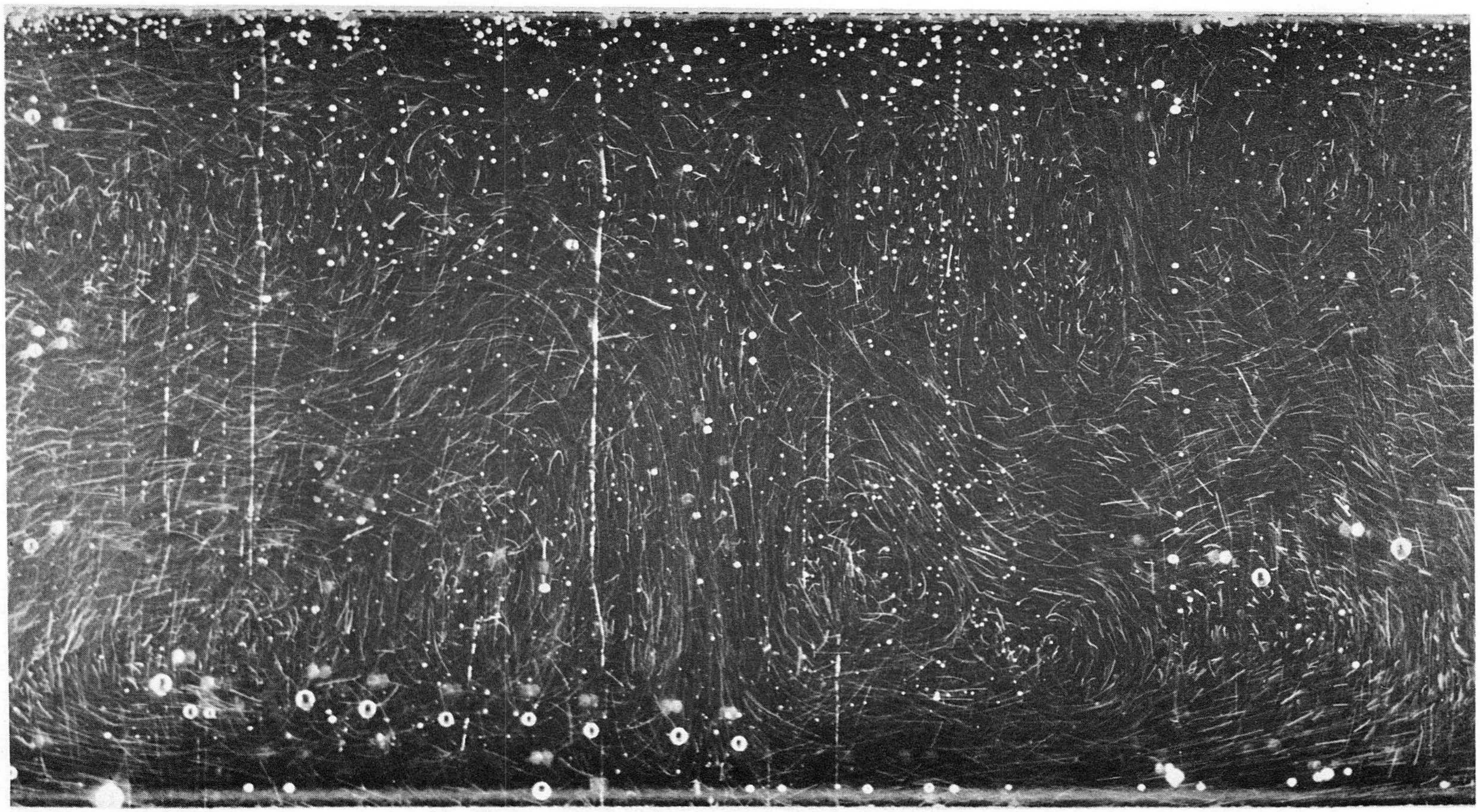

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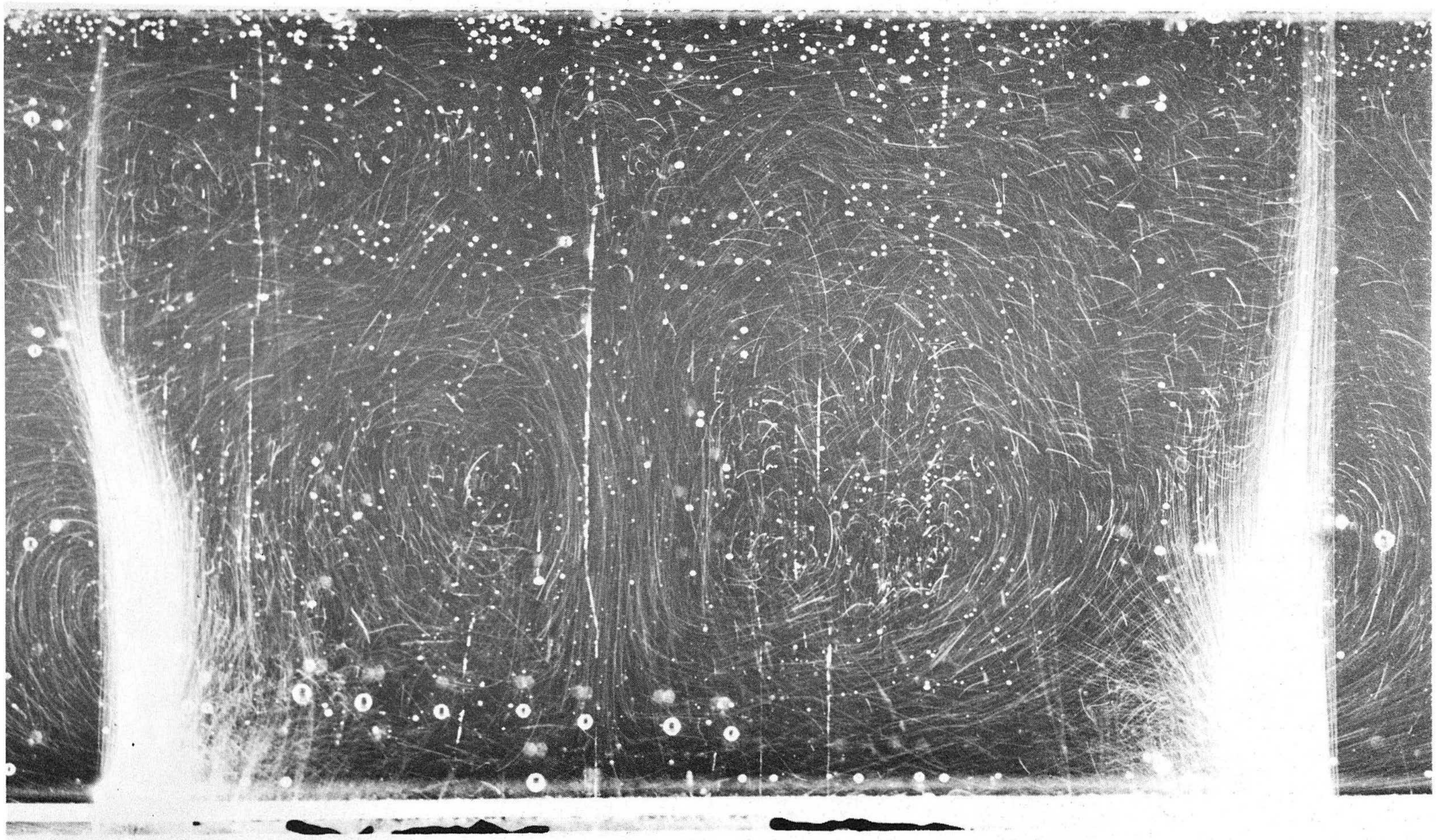
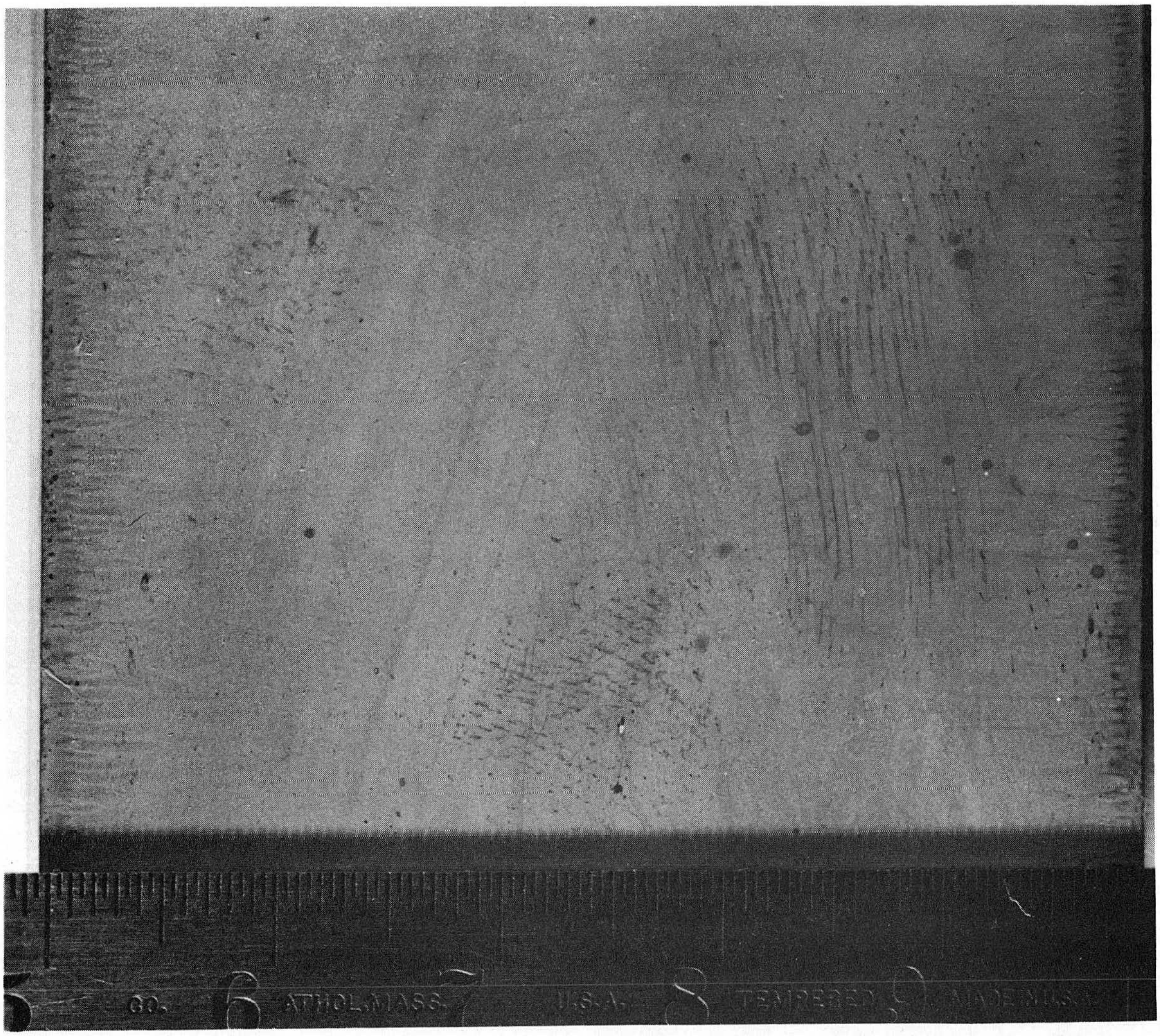
Fig. 11. Secondary-convection pattern at limiting current.



ZN-2404

Fig. 12. Secondary-convection pattern after limiting current with hydrogen being evolved at edges of electrode.



ZN-2401

Fig. 13. Markings on free edges of electrode. Note absence of markings on edge of electrode against wall.

the markings, the lines appear to be continuous across the electrode. As can be seen in Fig. 13, the markings do not appear where the electrode is against a wall.

In the experiments involving 0.2-cm free heights the existence of this convection current could be argued only from the relative size of the LCD and the fact that markings did occur on the electrodes. Visual observations were impossible because of limitations of the experimental equipment itself.

Having postulated an edge current, the next step is to prove its existence by measuring its effect. In order to accomplish this, a sectioned-electrode cell was designed and built. The purpose of this cell was to measure the current density as a function of distance from the edge of the electrode, since the postulated edge current would have a higher limiting current at the edge of the electrodes than in the center. A section drawing of the three component parts of this new cell is presented in Fig. 14, and a circuit diagram is given in Fig. 15. Figure 16 shows a possible arrangement of the electrode segments to measure current density as a function of distance on a 4.27-by 10-cm electrode. Complete design details for this sectioned-electrode cell are given in Appendix II. With this cell the total current and the current through each of five 0.1-inch segments could be measured at one time. For various arrangements of electrode segments, the current distribution across four differently dimensioned electrodes was measured. Figure 17 illustrates a typical set of measurements on the electrode shown in Fig. 16. These curves have been corrected for differences caused by a slight variation in the current shunt resistances. In order to check the measuring system, a run was made under very high forced convection from three stirrers directly over a 4.27- by 10-cm electrode, and the current distribution over several experiments was found uniform within 0.8%.

The current-density distributions and the electrode-segment arrangements used in these experiments are given in Figs. 18, 19, 20, and 21. It was not possible to obtain current-density distributions across

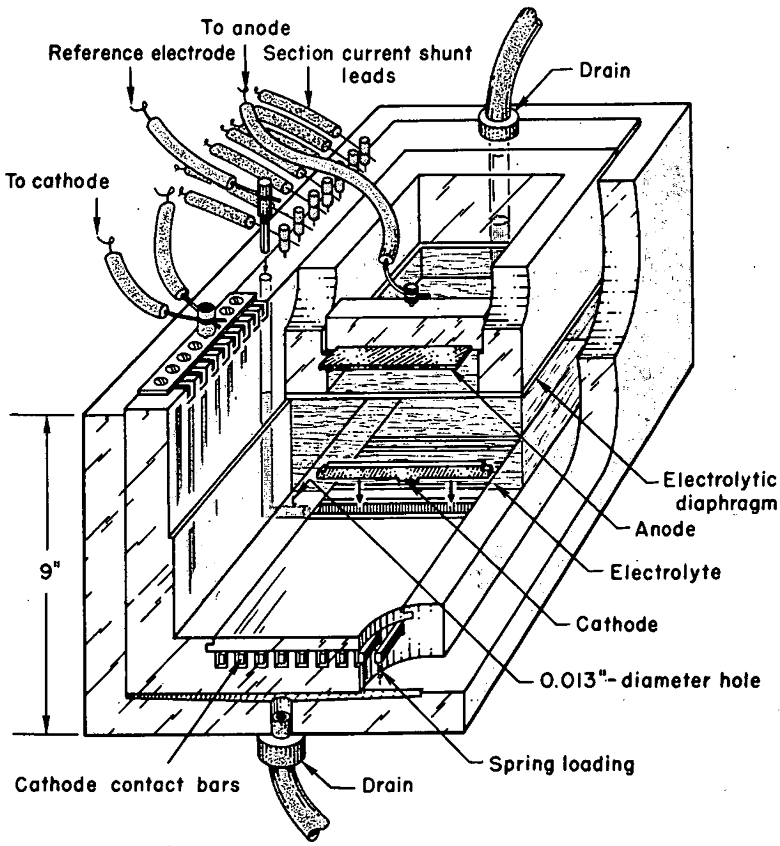


Fig. 14. Sectioned electrode cell.

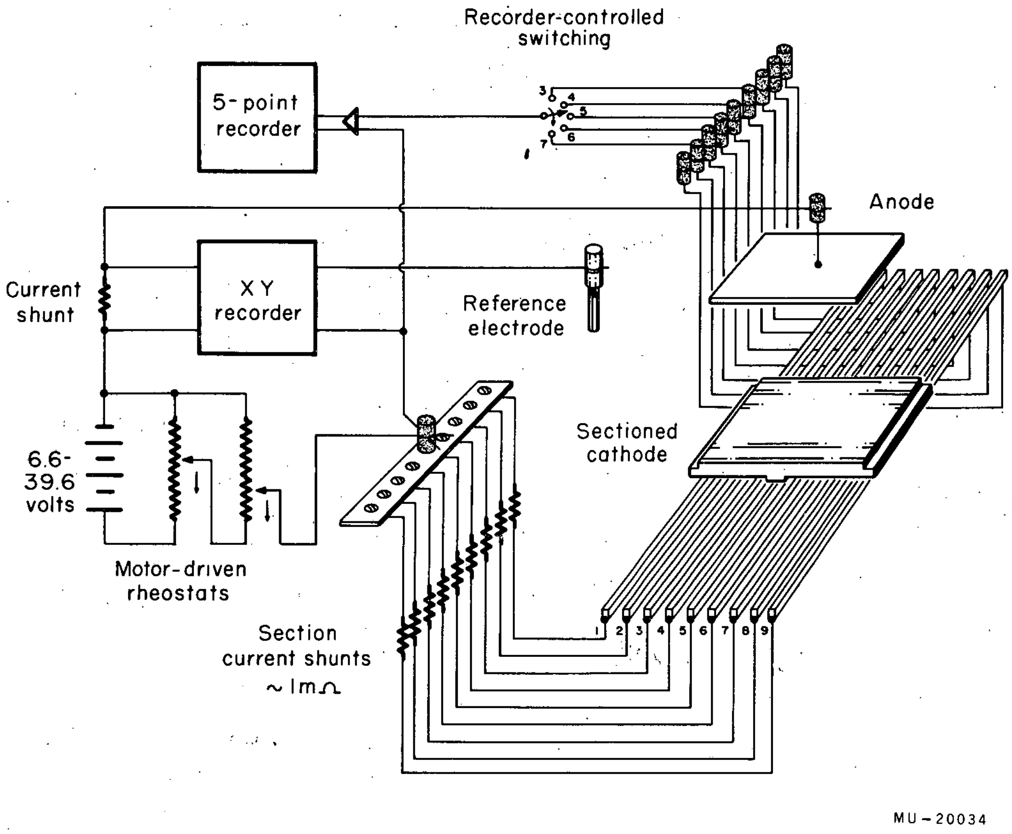


Fig. 15. Circuit diagram of sectioned electrode cell.

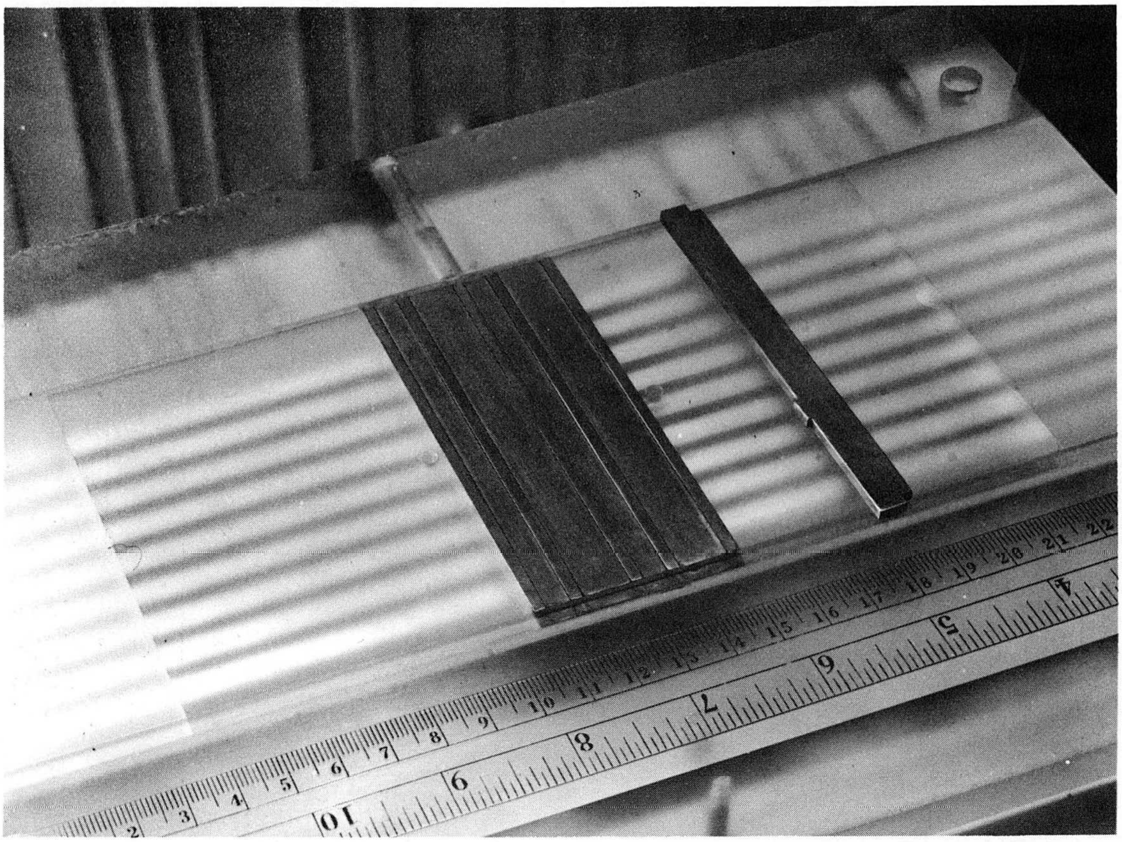


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Fig. 16. Possible arrangement of electrode segments in a 4.27- by 10-cm electrode.

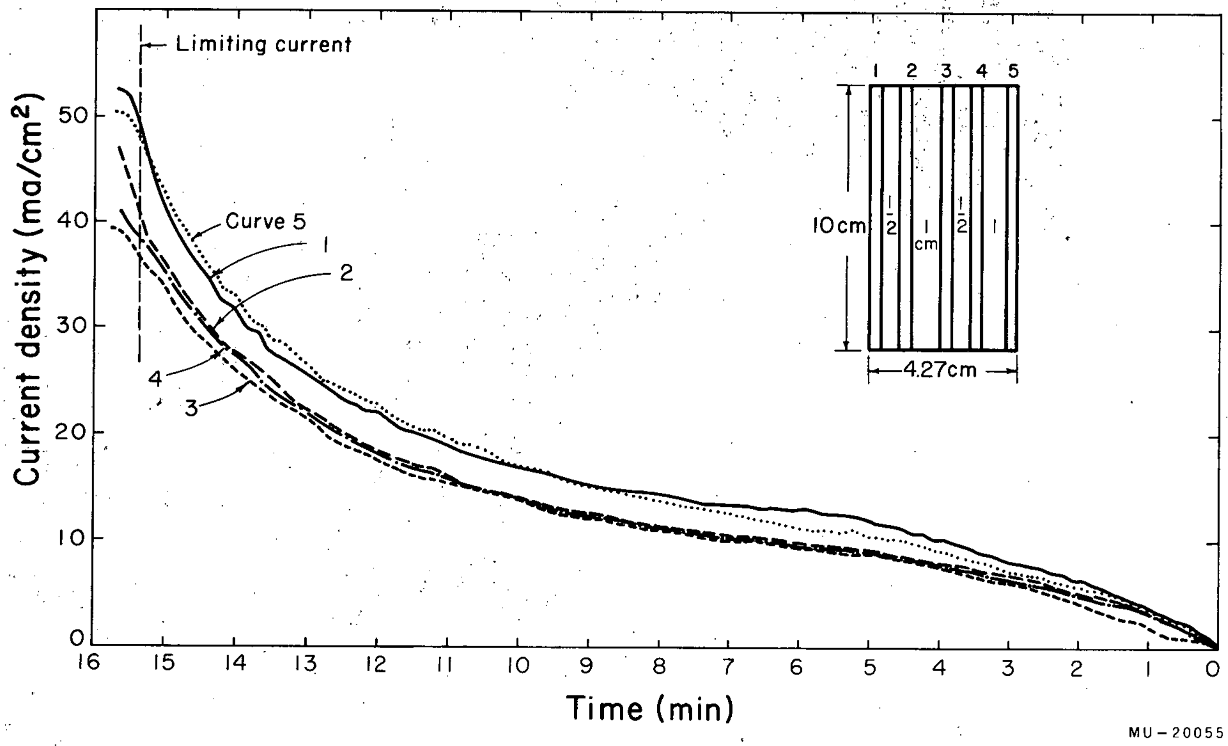


Fig. 17. Example of a set of measurements on a sectioned electrode.

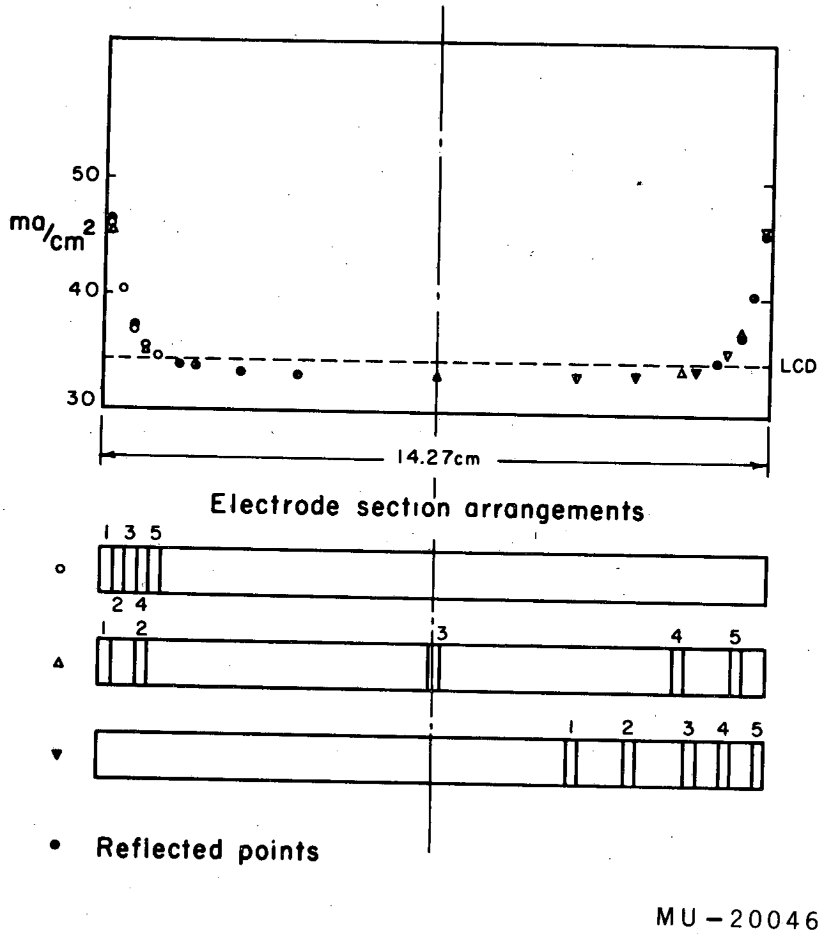


Fig. 18. Average values for current-density distribution on a 14.27-cm electrode for segment arrangements shown.

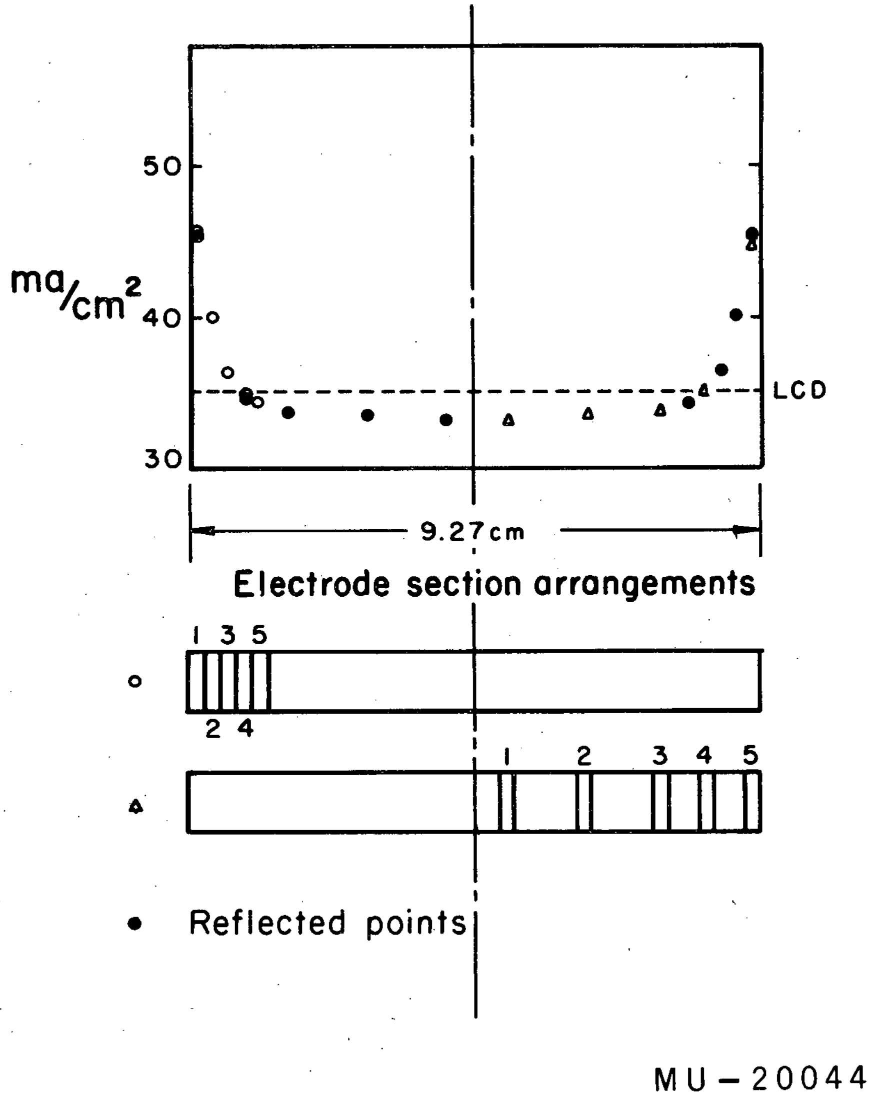


Fig. 19. Average values for current-density distribution on a 9.27-cm electrode for segment arrangements shown.

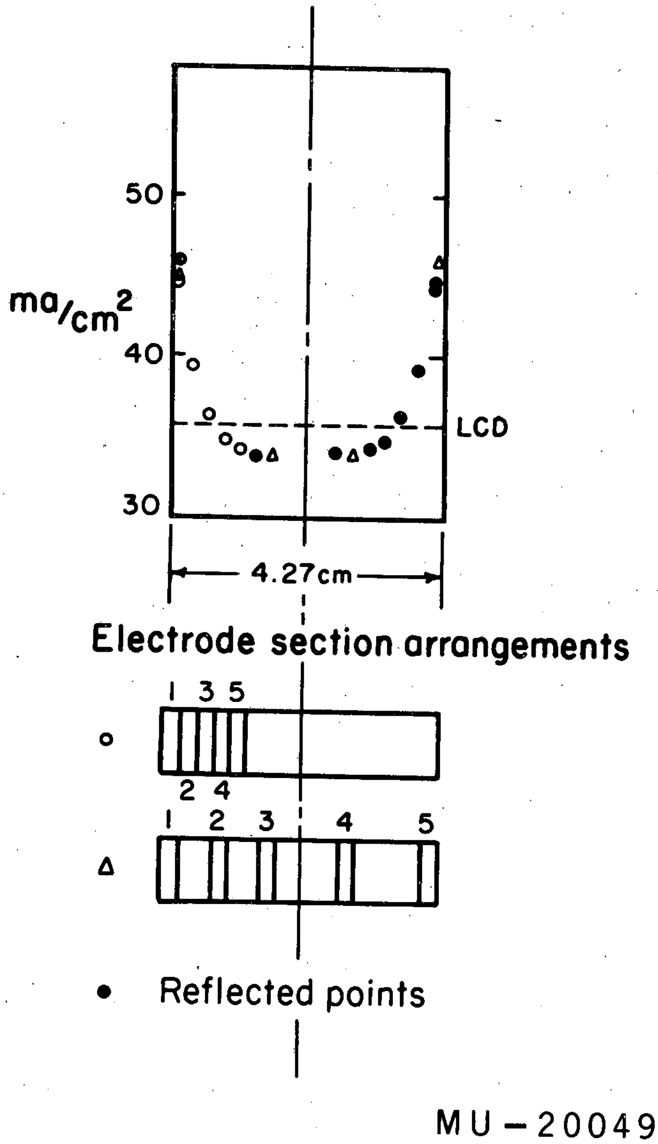
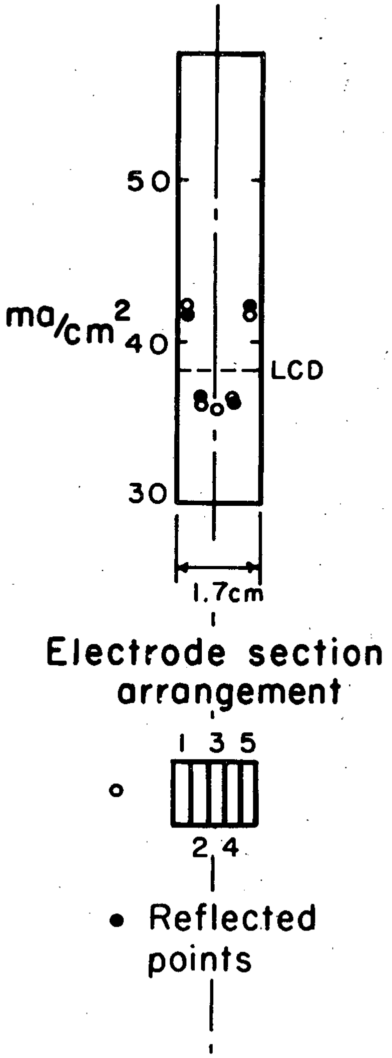


Fig. 20. Average values for current-density distribution on a 4.27-cm electrode for segment arrangements shown.



MU-20048

Fig. 21. Average values for current-density distribution on a 1.27-cm electrode for segment arrangement shown.

smaller electrodes because of the limitation on the smallness of the segments. From these graphs, it is seen that the current density distribution is practically uniform at distances greater than 1 cm from the edges. It is interesting to note that the patterns on the edge of the electrode were also very close to 1 cm in length.

It is noted that the current-density distributions presented here are not like those presented by Wagner for the same geometry,[10] but it must be remembered that the experimental conditions are different. In the present work, not only is free convection present, but the electrode is being driven at limiting-current density, where it is impossible to raise the current by an increase in voltage. Unequal current distribution across an electrode in limiting current definitely shows the effect of the secondary-convection current. Increasing the voltage until hydrogen is evolved from the cathode shows the tendency of the edge to conduct more current, as predicted by Wagner.

From the results of these experiments, it is seen that the current density is approximately equal in the edge segment of all the electrodes tested. The shapes of the distribution curves seem to be similar, except that as the dimension of the over-all electrode gets smaller, the flat center portion of the curve is left out. As a result, the average limiting-current density becomes higher.

The question that now arises is whether or not this effect would be noted if both of the linear dimensions of the electrode were changed. In order to test this, circular electrodes measuring 0.5, 1, 2, 5, and 10 cm in diameter were made and their limiting-current densities measured. Table IV gives the results of these experiments in which a 1.486 M H_2SO_4 - 0.2579 M $CuSO_4$ solution was used. These experiments plainly show that the effect of changing two dimensions of an electrode is much greater than shown in the experiments in which one dimension was fixed. Further discussion of these results will be given in the correlation section.

By these results, the existence of a secondary-convection current operating over free edges has been proven. As long as all dimensions of an electrode are greater than several centimeters, the average LCD can be calculated from a knowledge of the LCD for the infinite electrode by taking into consideration the higher current densities near the edge of the electrode.

Table IV

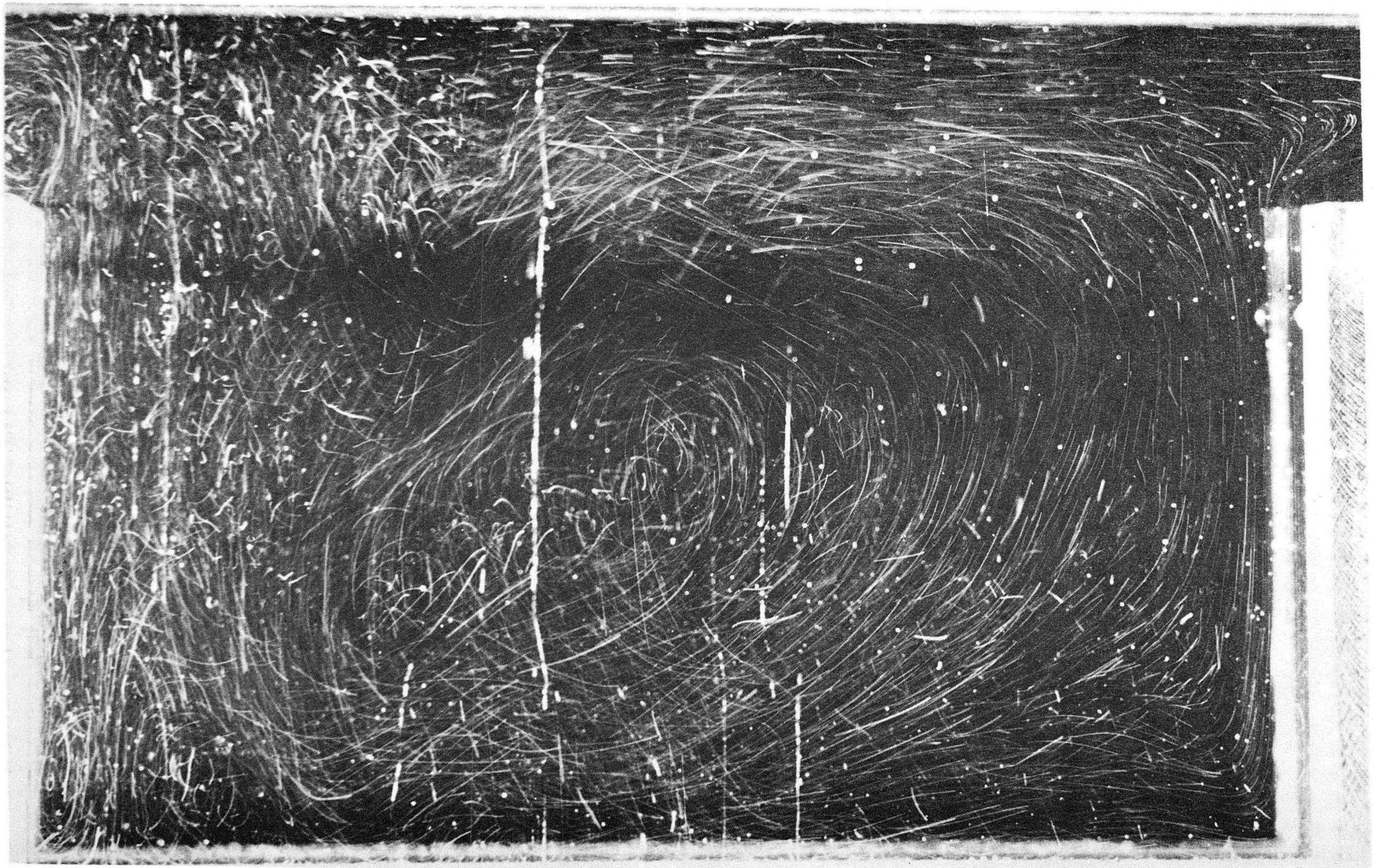
Limiting-current density as a function of diameter

Diameter (cm)	Current density (ma/cm^2)								mean (ma/cm^2)
10	31.36	31.40	31.09	31.71	31.44	31.44			31.409
5	32.97	32.40	32.83	33.00	32.03	32.34	32.60	32.93	32.625
2	33.80	33.93	33.24	33.90	33.60				33.694
1	36.82	38.21	36.64	37.90	37.69				37.457
0.5	48.78	46.43	47.02	48.21					47.828

EFFECT OF BOUNDARIES AT THE ELECTRODE EDGE

In the previous section it was postulated that a strong current was responsible for the change in LCD with electrode size. If boundaries are set up at the edge of the electrode, it would be expected that these strong currents would be suppressed and that the LCD would become independent of the size of the electrode. Figure 22 is a photograph of the convection pattern in a cell with side walls. Comparison of this picture with Fig. 9 shows the difference in the secondary-convection process. The strong secondary-convection currents at the edges have been replaced with a single current operating over the entire surface of the electrode. Using a heat-transfer model, Soberman has shown that in steady-state conditions the shape of the container does not affect the convection pattern.[11] He also shows that during the onset of convection, the patterns will take the shape of the container, damping out to the steady-state pattern as time goes on.

In the case of very small enclosed circular or rectangular electrodes, however, the secondary convection pattern does change. This change occurs when there is not sufficient distance between walls for the



ZN-2405

Fig. 22. Secondary-convection pattern over an electrode having no free edges.

normal convection to occur. In this case the boundary-layer convection depletes the solution close to the electrode of copper, creating a small "bubble" of buoyant fluid. When this fluid becomes so light that the buoyant forces can overcome inertia and friction, the element rises and is replaced with dense solution, at which time the process begins again. Since the boundary-layer convection depends on the density difference between the electrode surface and the solution immediately above the surface, one would also expect this region to be affected. Figure 23 presents a case in which just such action was observed. This type of limiting-current curve was obtained in every case in which a small (less than 1 cm), circular, enclosed electrode was used. Suprisingly enough, the mass-transfer rate for this process is as high as that expected for normal convection. This is shown in Table V in which data are given for experiments using a 0.2448 M $CuSO_4$ and 1.527 M H_2SO_4 solution.

Also found in Table V are data on several larger completely enclosed circular electrodes. The conditions of these measurements are very close to those of the experiments presented in Table IV, allowing a direct comparison. It should be noted that the limiting-current densities are approximately the same, regardless of the particular diameter.

Table V

Limiting-current density as a function of diameter (enclosed)

Diameter (cm)	Current density (ma/cm^2)						Mean (ma/cm^2)
5	30.53	29.87	31.26	30.26	31.01	30.87	30.63
2	31.77	30.84	30.60	31.02	31.88	32.12	31.37
1	31.78	32.48	31.77	32.00	31.32		31.87
0.5	31.35	32.54	31.70	31.28			31.72

As a final step toward determining whether the secondary convection plays a significcant role in the case of an enclosed electrode, the sectioned-electrode cell was used for electrodes of two different sizes,

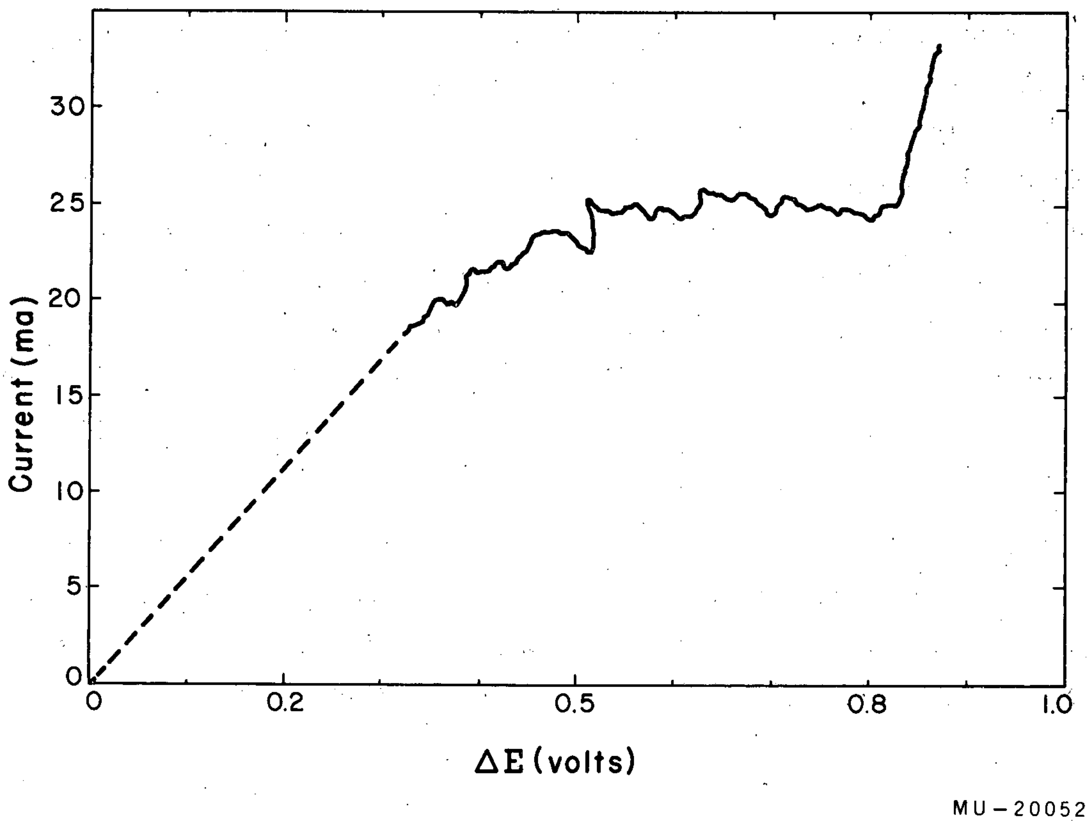


Fig. 23. Limiting-current curve for a very small (1-cm round) electrode with no free edge.

4.27 by 10 and 14.27 by 10 cm. The results of these experiments are given in Figs. 24 and 25. It is noted that the edge effect is completely gone, and in its place is a small increase in current density a short distance from one side, which may be due to the convection pattern shown in Fig. 22.

In general, the placement of a limiting wall at the edge of an electrode causes the convection current to behave as though the electrode were very long in that direction. This is true except where the presence of a wall actually orients the flow, as in the case of a completely enclosed 0.1- by 10-cm electrode. For this case we have a LCD almost as high as for the case without walls (45.36 to 53.46 mc/cm^2; "infinite" electrode, 24.80 ma/cm^2).

CORRELATION OF DATA

Now, with the completion of experiments designed to clarify points of uncertainty, it is possible to improve and extend the correlation given by Eq. (1). The equation to be used will again be of the form

$$Nu' = a\ Sc^{b}\ Gr^{c}\ d, \tag{8}$$

where d is a dimensionless number that is a function of the size of the electrode. In order to simultaneously obtain the best constants for Eq. (8), the method of least squares will be used.[12] The equation to be fitted is

$$\begin{aligned} \ln Nu' = \ln a + b \ln Sc + c \ln Gr + x \ln d_{0.1} + x \ln d_{0.2} \\ + x \ln d_{0.5} + x \ln d_{1} + x \ln d_{2} + x \ln d_{5} \\ + x \ln d_{10} + x \ln d_{20}, \end{aligned} \tag{9}$$

where d_n is the factor for the n cm electrode and x equals 1 if the nth-size electrode is used and 0 otherwise. The correlation was made using all experimental data from concentrations 0.08 M $CuSO_4$ and higher in which there were only two free edges and in which the distance between the two

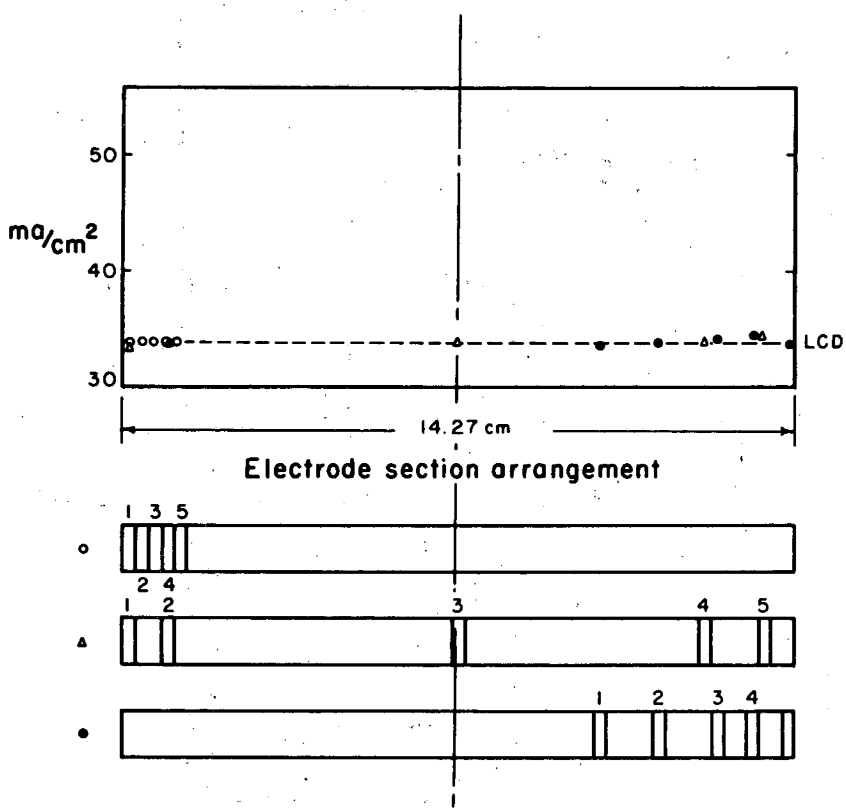


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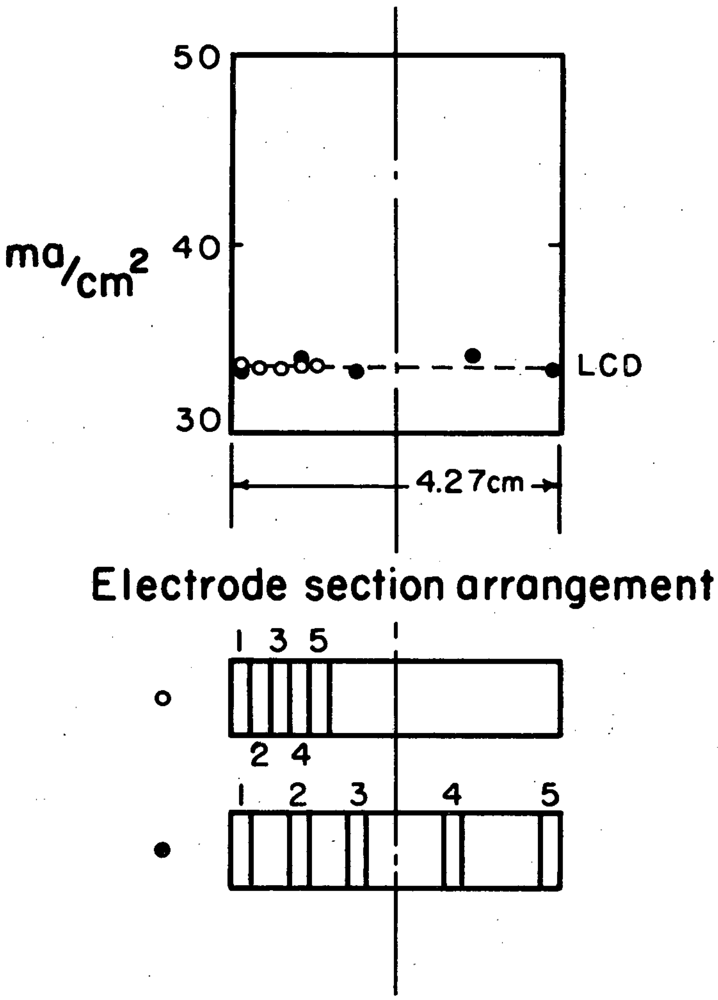
Fig. 24. Average values for current-density distribution on a 14.27-cm electrode for segment arrangements shown (no free edges).



MU-20045

Fig. 25. Average values for current-density distribution on a 4.27-cm electrode for segment arrangements shown (no free edges).

vertical walls was 10 cm. Table VI gives the values of the calculated constants and the 95% confidence limits. Although the 30-cm electrodes were used in the correlation, there is no term in the equation for these electrodes. The reason for this is that if such a term is included, the resulting system of equations becomes indeterminate. Equation (9) therefore has included in it d_{30} equals 1. This assumption is correct if the 30-cm electrode can be regarded as not having a size effect. Actually there appears to be a very small effect when the data are smoothed, and the curve will be made to approach $aSc^{b}Gr^{c}$ asymptotically as the electrode increases in length to infinity. Figure 26 presents the data, the 95% confidence limits, and the smoothed curve. The only reason for presenting this graph on semi-log graph paper is to spread out the points in the narrow-electrode region and to compress the points in the wide-electrode region where the change is only slight.

Table VI

Correlation constants

Constant	Value	95% confidence limits Upper	Lower	Value (smoothed)
a	0.1220	0.1293	0.1151	---
b	0.3731	0.3741	0.3661	0.3750
c	0.3333	0.3347	0.3319	0.3333
$d_{0.1}$	1.847	1.936	1.763	1.847
$d_{0.2}$	1.360	1.412	1.309	1.375
$d_{0.5}$	1.172	1.204	1.142	1.166
d_{1}	1.109	1.142	1.076	1.101
d_{2}	1.065	1.091	1.040	1.063
d_{5}	0.958	0.983	0.934	1.030
d_{10}	1.004	1.035	0.975	1.016
d_{20}	0.986	1.017	0.957	1.008
d_{30}	1.000	---	---	1.004

The data for the unwalled circular electrodes were subjected to this same type of treatment, and the values of d_n necessary to fit the

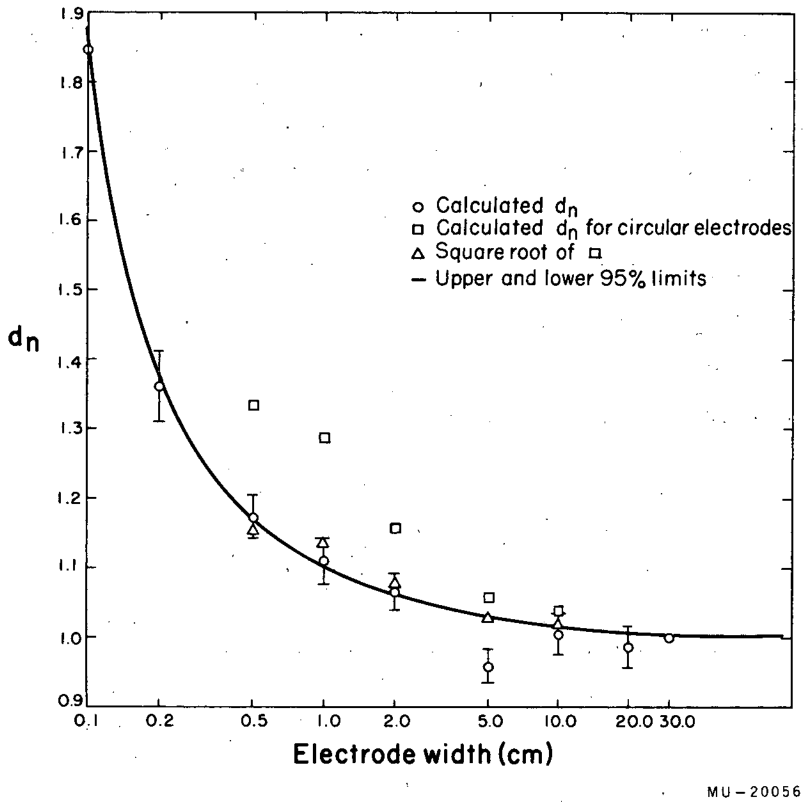


Fig. 26. Correction factor as a function of one dimension of electrode. Also given are correction factors and square roots for round electrodes.

general correlation are also plotted in Fig. 26. It is noticed that the square roots of these d_n values fall very close to the points for the single-dimension correlation, suggesting the possibility of treating each of the major dimensions of an electrode separately. To find $d_{effective}$ for a particular unwalled electrode, one determines d_n for each of the major dimensions and multiplies them together.

Figure 27 presents the general correlation and over 400 data points. The two lighter lines on the graph represent the correlation plus or minus one standard deviation. In terms of the logarithmic (base e) scale, the standard deviation is 0.0411; at Nu' = 300, this corresponds to ± 10 or ± 3.3%. Figure 27 contains approximately 225 data points for electrodes contained between two walls 10 cm apart; it also contains about 100 data points for completely enclosed electrodes, which are plotted using $d_n = 1$. Two types of unwalled-electrode data points are presented: about 50 for circular electrodes and about 25 for rectangular electrodes. These points were plotted as suggested in the foregoing by considering each dimension separately.

When the constants are fitted into Eq. (8), the general correlation becomes

$$Nu' = 0.122\ Sc^{3/8}\ Gr^{1/3}\ d_n \tag{10}$$

or

$$Nu' = 0.122\ (Sc\ Gr)^{1/3}\ Sc^{1/24}\ d_n\ . \tag{11}$$

IMPOSED FORCED CONVECTION

In order to determine the effect of imposing forced convection upon this natural convection system, the cell shown in Fig. 4 was fitted with a straightening section and an overflow weir so that laminar forced convection could be passed over the electrode. The modified cell is shown in Fig. 28. The flow through the cell was measured by calibrated rotameters; the total flow that could be handled in this system was approximately 6 gal/min, or, in terms of velocity through the 1 by 10 channel, 37.85 cm/sec. In these experiments two electrode sizes were used

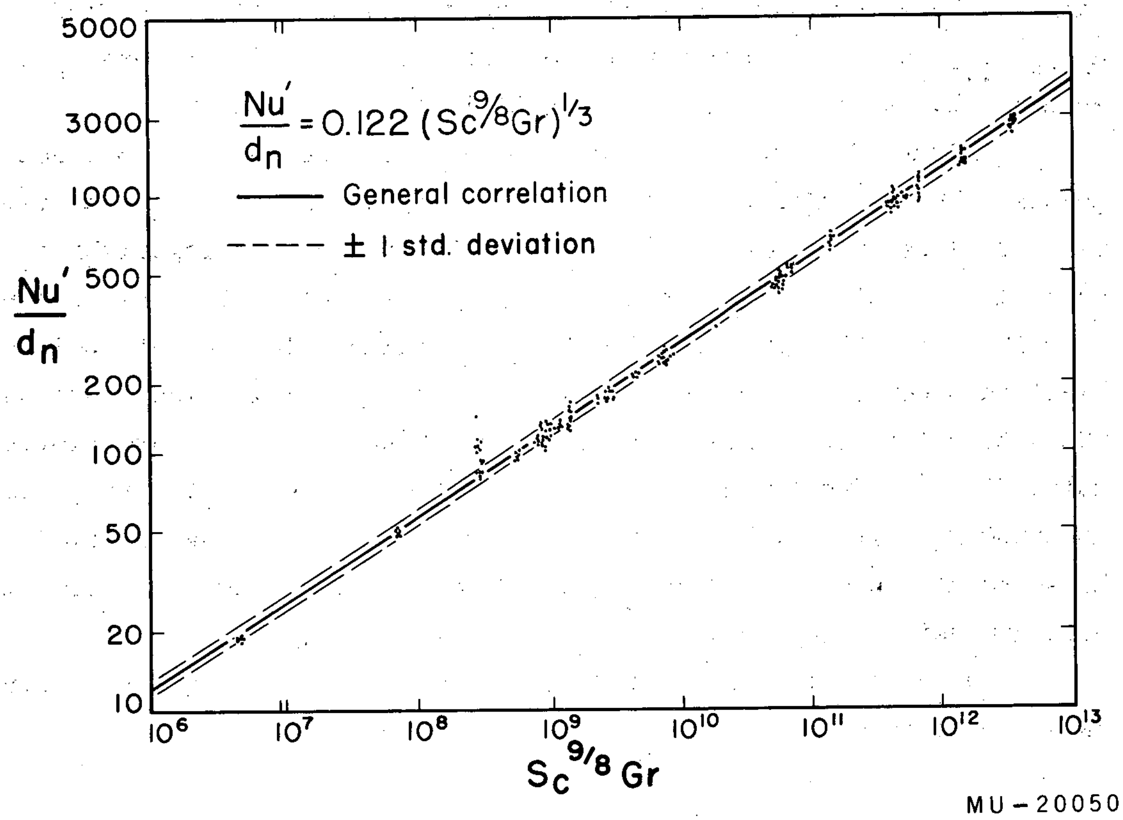
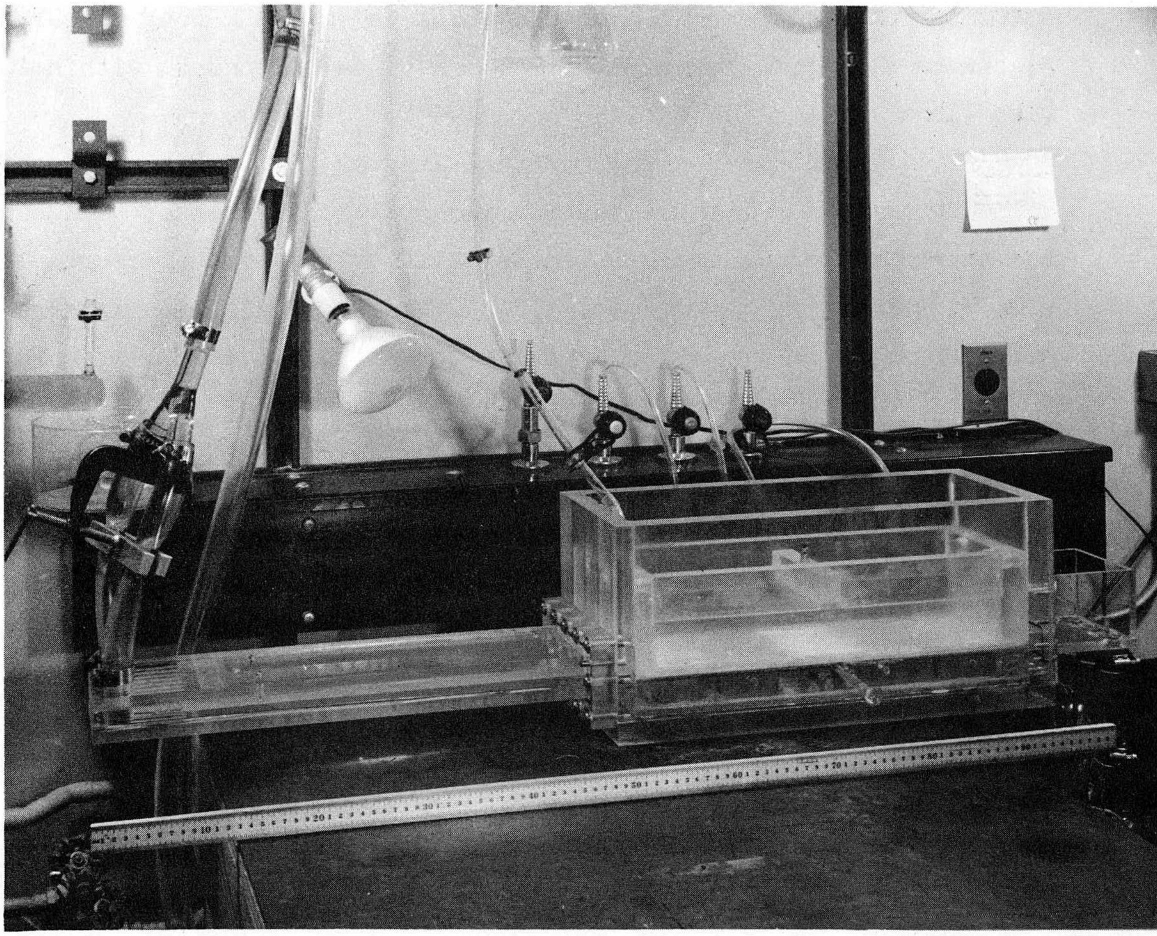


Fig. 27. Data and general correlation.



ZN-2400

Fig. 28. Cell modified for use in forced-convection experiments.

(2 by 10 and 10 by 10 cm) in a solution of 1.514 M H_2SO_4 and 0.1446 M $CuSO_4$. The results are given in Fig. 29. The average LCD for this solution without forced convection was 17.43 ma/cm^2 (four measurements). As can be seen from Fig. 29 the LCD can be calculated to within 20% even with flows up to 6.31 cm/sec.[13]

It should be pointed out that laminar forced convection of low velocity is not unlike the secondary-convection currents. Velocities in the secondary natural convection calculated from time exposures like Fig. 12 ranged up to 4 cm/sec. These velocities might be in error up to 20% because of an uncertain exposure time of 5 ± 1 sec.

CONCLUSIONS

As a result of this work, the following interesting comments can be made concerning the questions raised in the introduction:

(a) The free height above the electrode causes a difference in limiting-current densities, but only if this dimension is less than 0.5 cm. Even then, the effect seems to be very small. In almost all practical cases, the effect of this variable is insignificant.

(b) In the general correlation, the effect of a change in viscosity is taken into account by the three-eights power on the Schmidt number.

(c) Inaccurate experimental data taken in the very-low-concentration range are thought to be due to the slowness of achieving steady state with such small driving forces. No solution for this problem is known if present experimental techniques are used.

(d) The change of limiting-current density with size of electrode is due to strong secondary-convection currents at the free edges of the electrode.

(e) By appropriate considerations, the effect of electrode size and of the presence or absence of walls can be accounted for by the general correlation.

(f) The correlation can be used in a forced-convection case providing the linear velocity past the horizontal plate does not exceed 5 cm/sec.

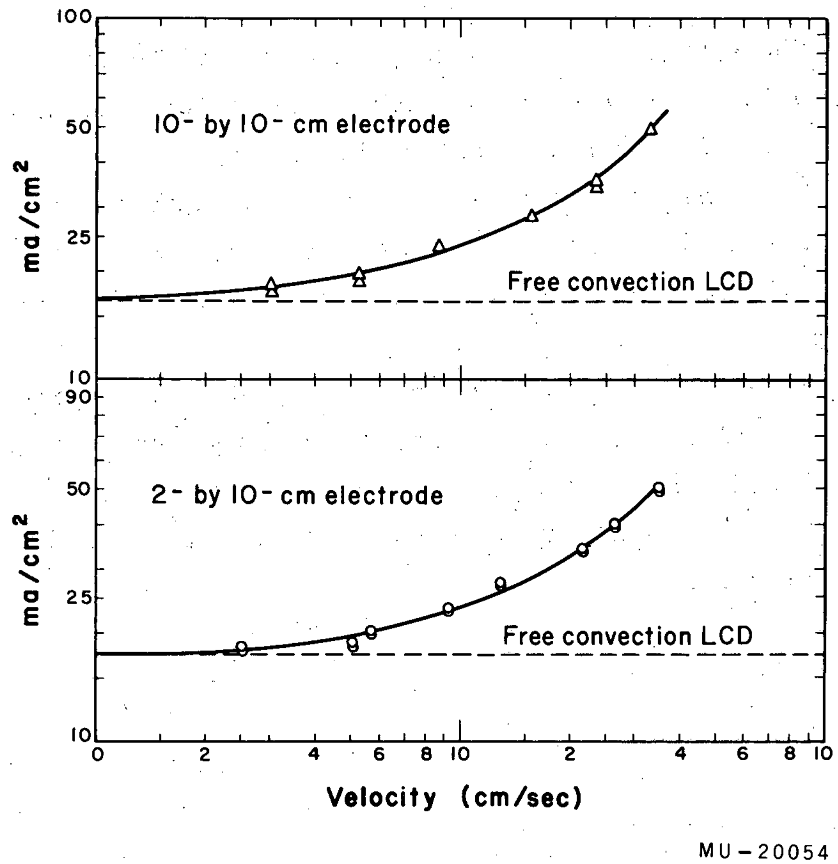


Fig. 29. Limiting-current density as a function of velocity in forced convection for two electrode sizes.

In conclusion, Fig. 30 shows the behavior of the secondary natural convection, as presented herein.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. Charles Tobias for his valued help and encouragement, and to Drs. H. A. Johnson and S. F. Ravitz for their critical review of this text.

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Finally, the author wishes to extend a very special thanks to his wife, Marilyn, for her continued encouragement especially during the conclusion of this work.

This work was performed under the auspices of the U. S. Atomic Energy Commission.

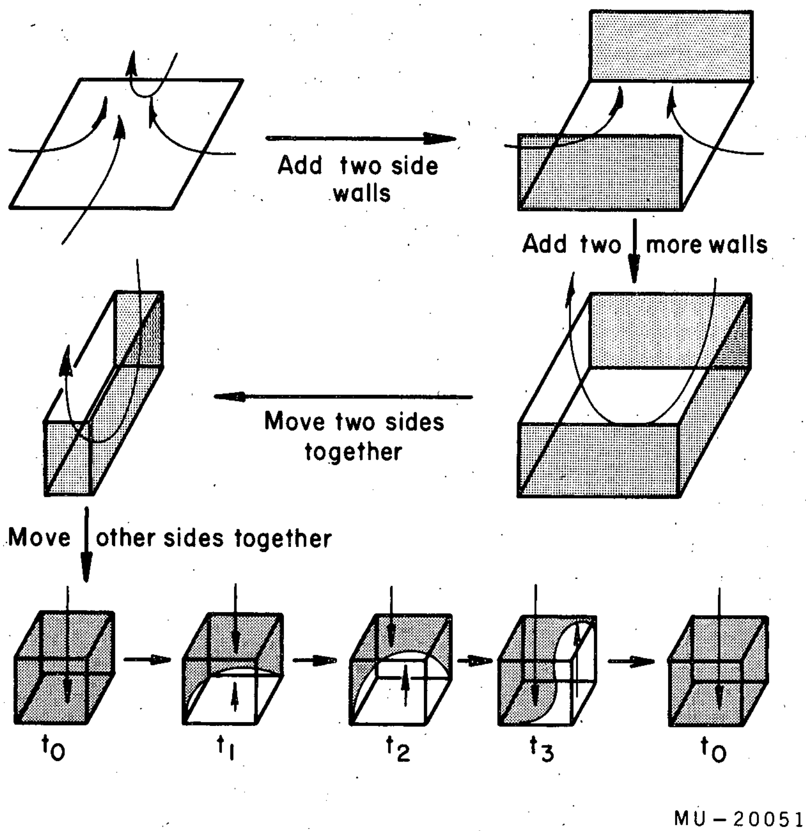

Fig. 30. Summary of hypothesized secondary natural convection.

APPENDIXES

Appendix I. Equations for Prediction of Physical Properties

In order to make the best use of the IBM-650 electronic calculator, it was necessary to set up equations relating the physical properties of the solutions to the concentration. The following set of equations was derived for this purpose:

$$\rho = 0.9978 + 0.06406\, C_{H_2SO_4} - 0.00167\, C^2_{H_2SO_4} + 0.12755\, C_{CuSO_4} + 0.01820\, C^2_{CuSO_4} - 0.00235\, C_{Glyc} + 0.00353\, C^2_{Glyc} \tag{12}$$

$$\mu = 0.974 + 0.1235\, C_{H_2SO_4} + 0.0556\, C^2_{H_2SO_4} + 0.5344\, C_{CuSO_4} + 0.5356\, C^2_{CuSO_4} + 0.1475\, C_{Glyc} + 0.2029\, C^2_{Glyc} \tag{13}$$

$$\mu\, D_{CuSO_4} = (0.7363 + 0.00511\, C_{H_2SO_4} + 0.02044\, C_{CuSO_4} + 0.06530\, C_{Glyc})\, 10^{-5} \tag{14}$$

$$\mu\, D_{H_2SO_4} = (1.6691 + 0.24519\, C_{H_2SO_4} + 0.96637\, C_{CuSO_4} + 0.06530\, C_{Glyc})\, 10^{-5} \tag{15}$$

$$t_{Cu^{++}} = (0.2633 - 0.1020\, C_{H_2SO_4})\, C_{Cu^{++}} \tag{16}$$

$$t_{H^+} = 0.8156 - 0.2599\, C_{Cu^{++}} - 0.1089\, C^2_{Cu^{++}} . \tag{17}$$

These equations were obtained by assuming power-series behavior. Maximum deviation of calculated points from experimental curves was within ± 0.5% in the concentration range used. The equations hold for 22°C.

The data for the density and viscosity equations were taken by Eisenberg, Tobias, and Wilke.[14] Data published by Gordon and Cole,[15] Gordon,[16] and Thovert[17] corrected for ionic strength,[8] were used in estimating diffusivities.

Transference numbers were estimated on the assumption that (a) sulfuric acid dissociated completely to hydrogen and bisulfate ions,[18] (b) bisulfate ion dissociated to hydrogen and sulfate ions with an equilibrium constant 2×10^{-2}, (c) copper sulfate dissociated completely to cupric and sulfate ions, and (d) ionic mobilities in concentrated solutions were equal to the ratio of ionic conductance in concentrated solution to ionic conductance at infinite dilution multiplied by the ionic mobility at infinite dilution. Ionization constants were obtained from the Handbook of Chemistry and Physics.[18] Ionic mobilities at infinite dilution were taken from Glasstone;[1] ionic conductances from Landolt-Boernstein.[19] Transference numbers were calculated from

$$t_i = C_i n_i u_i / C_1 n_1 u_1 + C_2 n_2 u_2 +, \text{ etc.} \tag{18}$$

Appendix II. Construction of the Sectioned-Electrode Cell

In the construction of a sectioned-electrode cell, the most important thing to be remembered is that all sections of the electrode must at all time be at the same potential.

This is no problem at all until it is remembered that the current in each section must be measured. The conventional method of doing this would be to place in each circuit a current shunt, and by means of a potentiometer measure the voltage drop across the shunt. Obviously, this will not work, since now the potential of that particular section is dependent on the current flowing into it.

An alternate solution would be to place galvanometers between every pair of electrode sections, and in addition to the current shunt place an adequate rheostat in each circuit. Now, by means of the rheostats, it would be possible to adjust the circuits so that no potential exists between the electrode sections. This method would be quite acceptable in a steady-state process, but even then with very many circuits it would take an extremely long time to achieve balance. When the condition is added that the system is continuously changing and more than three sections are being used, it becomes impossible. An analog computer could be built to accomplish this, but the complexity and cost of such a device would be very great.

If in addition to this, it is desired that the electrode sections should be replaceable and vary in number from experiment to experiment, the whole problem becomes unsolvable. If, however, the condition of equal potential can be relaxed to the slightest degree, the difficulty vanishes.

In the cell constructed for this work this specification was set up: The maximum allowable potential difference between electrode sections is 2 millivolts, and this shall be allowed only when there is a difference of 1 amp flowing in the two circuits.

The method of achieving the flexibility in electrode arrangement can be seen in Fig. 11. Note the contact rails for the different circuits and the shape of the electrode sections. These details can also be seen in Fig. 13. The resistance of the contact between the electrode section and the contact rail was made less than 1 milliohm by very careful machine work and by silver plating the mating surfaces.

With the relaxation of the requirements for perfect uniformity of potential at the metal surface, the normal method of current measurement can be used, except that special shunts whose resistance is less than 1 milliohm must be used. Now, with the use of a fine-quality dc amplifier, a stepping switch, and a multipoint recorded, the current can be quickly and accurately measured even in unsteady-state situations.

The only problem now remaining is the insulation of the electrode segments from one another. To do this, we used thin pieces of polyethylene. To best simulate one continuous electrode, these insulators had to be made as thin as possible, and yet to function properly they had to be thick enough to prevent bridging of the copper plate during an experimental run. By preliminary experiments, 0.006- to 0.008-inch material was found to be best. At the same time it was decided that more than 5% insulating material between the smallest segments was excessive and, therefore, the smallest segments were made 0.100 inch thick,

Appendix III. Run Index

The table included in this index contains complete information on every quantitative experiment on which this report is based. Part 1 of the table consists of every quantity measured during the course of an experiment; part 2 contains that information which is calculated based on the measured quantities and the equations presented. The information is printed directly from the cards used in the IBM-650 electronic calculator. This explains the presence of the extraordinarily large number of significant figures. The data and calculated quantities are written in a floating-decimal system used by the computer and are read as follows. A number, xxxxxxxxcc±, consists of three parts; the significant figures, xxxxxxxx; the characteristic, cc; and the sign, ±. Its equivalent in the common system is

$$\text{xxxxxxxxcc}\pm = \pm\ 0.\text{xxxxxxxx} \cdot 10^{\text{cc} - 50}.$$

For example, the number 1234567852 is read 12.345678 and -2468864249 is read -0.024688642.

The same experiment in each part of the index is identified by a run number printed at the beginning of each line. Further information is given in the second number of each line, a code word whose form is abcd±. The number, a, is the concentration code; its meaning is:

1 --- approximately 0.01 M $CuSO_4$
2 --- approximately 0.08 M $CuSO_4$
3 --- approximately 0.25 M $CuSO_4$
4 --- approximately 0.70 M $CuSO_4$
5 --- approximately 0.37 M $CuSO_4$ and 5.4 M glycerol
6 --- approximately 0.15 M $CuSO_4$
7 --- approximately 0.25 M $CuSO_4$ and 5.4 M glycerol
8 --- approximately 0.23 M $CuSO_4$ and 4.0 M glycerol
9 --- approximately 0.32 M $CuSO_4$ and 2.3 M glycerol.

The number, b, is the electrode code; its meaning is:

1 --- 0.1-cm-wide electrode
2 --- 0.2-cm-wide electrode
3 --- 0.5-cm-wide electrode
4 --- 1.0-cm-wide electrode
5 --- 2.0-cm-wide electrode
6 --- 5.0-cm-wide electrode
7 -- 10.0-cm-wide electrode
8 -- 20.0-cm-wide electrode
9 -- 30.0-cm-wide electrode.

The number, c, is the free-height code; its meaning is:

0 --- less than 1-cm free height
1 --- 1-cm free height
2 --- 2-cm free height
3 --- 4-cm free height
4 --- 8-cm free height
5 -- 16-cm free height.

The number, d, is the wall code; its meaning is:

1 --- no extra wall other than the cell itself
2 --- extra wall completely surrounding the electrode.

The meaning of the + or - sign is:

+ --- two walls always present
- --- there were no permanent walls.

The number 9999999999 indicates an electrode which completely fills the width of the cell.

This coding system is correct except for a few special cases for which a code did not exist.

Run Index: Measured Quantities

Run No.	Run Code	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
000	3311	1501000051	2444000050		3920000052	9999999999	5000000050	1000000051
001	3311	1501000051	2444000050		3920000052	9999999999	5000000050	1000000051
002	3311	1501000051	2444000050		3980000052	9999999999	5000000050	1000000051
003	3321	1501000051	2444000050		3520000052	9999999999	5000000050	2000000051
004	3321	1501000051	2444000050		3430000052	9999999999	5000000050	2000000051
005	3321	1501000051	2444000050		3660000052	9999999999	5000000050	2000000051
006	3321	1525000051	2438000050		3780000052	9999999999	5000000050	2000000051
007	3321	1525000051	2438000050		3590000052	9999999999	5000000050	2000000051
008	3321	1525000051	2438000050		3560000052	9999999999	5000000050	2000000051
009	3331	1516000051	2437000050		3660000052	9999999999	5000000050	4000000051
010	3331	1516000051	2437000050		3490000052	9999999999	5000000050	4000000051
011	3331	1516000051	2437000050		3440000052	9999999999	5000000050	4000000051
012	3341	1654000051	2256000050		3490000052	9999999999	5000000050	8000000051
013	3341	1654000051	2256000050		3220000052	9999999999	5000000050	8000000051
014	3351	1656000051	2251000050		3160000052	9999999999	5000000050	1600000052
015	3351	1656000051	2251000050		3040000052	9999999999	5000000050	1600000052
016	3411	1525000051	2433000050		3280000052	9999999999	1000000051	1000000051
017	3411	1525000051	2433000050		3280000052	9999999999	1000000051	1000000051
018	3411	1525000051	2433000050		3260000052	9999999999	1000000051	1000000051
019	3421	1523000051	2430000050		3400000052	9999999999	1000000051	2000000051
020	3421	1523000051	2430000050		3400000052	9999999999	1000000051	2000000051
021	3421	1523000051	2430000050		3400000052	9999999999	1000000051	2000000051
022	3431	1527000051	2423000050		3480000052	9999999999	1000000051	4000000051
023	3431	1527000051	2423000050		3450000052	9999999999	1000000051	4000000051
024	3431	1527000051	2423000050		3390000052	9999999999	1000000051	4000000051
025	3441	1540000051	2415000050		3180000052	9999999999	1000000051	8000000051
026	3441	1540000051	2415000050		3220000052	9999999999	1000000051	8000000051
027	3441	1540000051	2415000050		3220000052	9999999999	1000000051	8000000051
028	3451	1659000051	2240000050		2970000052	9999999999	1000000051	1600000052
029	3451	1659000051	2240000050		2910000052	9999999999	1000000051	1600000052
030	3511	1536000051	2408000050		3210000052	9999999999	2000000051	1000000051
031	3511	1536000051	2408000050		3240000052	9999999999	2000000051	1000000051
032	3511	1536000051	2408000050		3220000052	9999999999	2000000051	1000000051
033	3521	1543000051	2402000050		3220000052	9999999999	2000000051	2000000051
034	3521	1543000051	2402000050		3220000052	9999999999	2000000051	2000000051
035	3521	1543000051	2402000050		3220000052	9999999999	2000000051	2000000051
036	3531	1551000051	2397000050		3090000052	9999999999	2000000051	4000000051
037	3531	1551000051	2397000050		3090000052	9999999999	2000000051	4000000051
038	3531	1551000051	2397000050		3020000052	9999999999	2000000051	4000000051
039	3541	1559000051	2391000050		3150000052	9999999999	2000000051	8000000051
040	3541	1559000051	2391000050		3160000052	9999999999	2000000051	8000000051
041	3541	1559000051	2391000050		3110000052	9999999999	2000000051	8000000051
042	3551	1566000051	2385000050		3040000052	9999999999	2000000051	1600000052
043	3551	1566000051	2385000050		3050000052	9999999999	2000000051	1600000052
044	3551	1566000051	2385000050		3050000052	9999999999	2000000051	1600000052
045	3611	1566000051	2385000050		2730000052	9999999999	5000000051	1000000051
046	3611	1566000051	2385000050		2730000052	9999999999	5000000051	1000000051
047	3611	1566000051	2385000050		2630000052	9999999999	5000000051	1000000051
048	3621	1580000051	2369000050		2860000052	9999999999	5000000051	2000000051
049	3621	1580000051	2369000050		2790000052	9999999999	5000000051	2000000051
050	3621	1580000051	2369000050		2790000052	9999999999	5000000051	2000000051
051	3631	1587000051	2360000050		2720000052	9999999999	5000000051	4000000051
052	3631	1587000051	2360000050		2720000052	9999999999	5000000051	4000000051
053	3631	1587000051	2360000050		2720000052	9999999999	5000000051	4000000051
054	3641	1597000051	2347000050		2730000052	9999999999	5000000051	8000000051
055	3641	1597000051	2347000050		2730000052	9999999999	5000000051	8000000051
056	3641	1597000051	2347000050		2710000052	9999999999	5000000051	8000000051
057	3651	1605000051	2340000050		2670000052	9999999999	5000000051	1600000052
058	3651	1605000051	2340000050		2650000052	9999999999	5000000051	1600000052
059	3711	1608000051	2336000050		2850000052	9999999999	1000000052	1000000051
060	3711	1608000051	2336000050		2790000052	9999999999	1000000052	1000000051
061	3711	1608000051	2336000050		2790000052	9999999999	1000000052	1000000051
062	3721	1608000051	2336000050		2910000052	9999999999	1000000052	2000000051
063	3721	1608000051	2336000050		2880000052	9999999999	1000000052	2000000051
064	3731	1618000051	2320000050		2720000052	9999999999	1000000052	4000000051
065	3731	1618000051	2320000050		2750000052	9999999999	1000000052	4000000051
066	3741	1621000051	2316000050		2820000052	9999999999	1000000052	8000000051
067	3741	1621000051	2316000050		2810000052	9999999999	1000000052	8000000051
068	3751	1628000051	2307000050		2840000052	9999999999	1000000052	1600000052
069	3751	1628000051	2307000050		2830000052	9999999999	1000000052	1600000052
070	3811	1674000051	2196000050		2570000052	9999999999	2000000052	1000000051

Run No.	Run Code	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
071	3811	1674000051	2196000050		2500000052	9999999999	2000000052	1000000051
072	3821	1672000051	2200000050		2510000052	9999999999	2000000052	2000000051
073	3821	1672000051	2200000050		2550000052	9999999999	2000000052	2000000051
074	3831	1671000051	2202000050		2510000052	9999999999	2000000052	4000000051
075	3831	1671000051	2202000050		2490000052	9999999999	2000000052	4000000051
076	3841	1643000051	2270000050		2610000052	9999999999	2000000052	8000000051
077	3841	1643000051	2270000050		2620000052	9999999999	2000000052	8000000051
078	3841	1643000051	2270000050		2610000052	9999999999	2000000052	8000000051
079	3851	1636000051	2294000050		2900000052	9999999999	2000000052	1600000052
080	3851	1636000051	2294000050		2700000052	9999999999	2000000052	1600000052
081	3851	1636000051	2294000050		2700000052	9999999999	2000000052	1600000052
082	3911	1674000051	2196000050		2560000052	9999999999	3000000052	1000000051
083	3911	1674000051	2196000050		2580000052	9999999999	3000000052	1000000051
084	3911	1674000051	2196000050		2540000052	9999999999	3000000052	1000000051
085	3921	1680000051	2182000050		2510000052	9999999999	3000000052	2000000051
086	3921	1680000051	2182000050		2480000052	9999999999	3000000052	2000000051
087	3931	1680000051	2182000050		2470000052	9999999999	3000000052	4000000051
088	3931	1680000051	2182000050		2440000052	9999999999	3000000052	4000000051
089	3931	1667000051	2208000050		2670000052	9999999999	3000000052	4000000051
090	3931	1667000051	2208000050		2640000052	9999999999	3000000052	4000000051
091	3941	1665000051	2223000050		2650000052	9999999999	3000000052	8000000051
092	3941	1665000051	2223000050		2620000052	9999999999	3000000052	8000000051
093	3951	1662000051	2228000050		2750000052	9999999999	3000000052	1600000052
094	3951	1662000051	2228000050		2630000052	9999999999	3000000052	1600000052
095	3951	1662000051	2228000050		2590000052	9999999999	3000000052	1600000052
096	3951	1662000051	2228000050		2590000052	9999999999	3000000052	1600000052
097	3211	1647000051	2278000050		3520000052	9999999999	2000000050	1000000051
098	3211	1647000051	2278000050		3400000052	9999999999	2000000050	1000000051
099	3211	1647000051	2278000050		4180000052	9999999999	2000000050	1000000051
100	3211	1647000051	2278000050		3710000052	9999999999	2000000050	1000000051
101	3211	1647000051	2278000050		3620000052	9999999999	2000000050	1000000051
102	3312	1693000051	2136000050		3000000052	9999999999	5000000050	1000000051
103	3312	1693000051	2136000050		2960000052	9999999999	5000000050	1000000051
104	3342	1691000051	2144000050		2960000052	9999999999	5000000050	8000000051
105	3342	1691000051	2144000050		2920000052	9999999999	5000000050	8000000051
106	3512	1687000051	2156000050		2620000052	9999999999	2000000051	1000000051
107	3512	1687000051	2156000050		2610000052	9999999999	2000000051	1000000051
108	3542	1689000051	2150000050		2430000052	9999999999	2000000051	8000000051
109	3542	1689000051	2150000050		2430000052	9999999999	2000000051	8000000051
110	3812	1683000051	2168000050		2450000052	9999999999	2000000052	1000000051
111	3812	1683000051	2168000050		2450000052	9999999999	2000000052	1000000051
112	3842	1683000051	2168000050		2440000052	9999999999	2000000052	8000000051
113	3842	1683000051	2168000050		2440000052	9999999999	2000000052	8000000051
114	4311	1480000051	6921000050		1230000053	9999999999	5000000050	1000000051
115	4311	1480000051	6921000050		1230000053	9999999999	5000000050	1000000051
116	4311	1480000051	6921000050		1240000053	9999999999	5000000050	1000000051
117	4341	1490000051	6849000050		1240000053	9999999999	5000000050	8000000051
118	4341	1490000051	6849000050		1290000053	9999999999	5000000050	8000000051
119	4341	1490000051	6773000050		1260000053	9999999999	5000000050	8000000051
120	4341	1490000051	6773000050		1270000053	9999999999	5000000050	8000000051
121	4342	1490000051	6699000050		1220000053	9999999999	5000000050	8000000051
122	4342	1490000051	6699000050		1230000053	9999999999	5000000050	8000000051
123	4312	1500000051	6644000050		1210000053	9999999999	5000000050	1000000051
124	4312	1500000051	6644000050		1210000053	9999999999	5000000050	1000000051
125	4511	1500000051	6644000050		1180000053	9999999999	2000000051	1000000051
126	4511	1500000051	6644000050		1200000053	9999999999	2000000051	1000000051
127	4511	1500000051	6644000050		1210000053	9999999999	2000000051	1000000051
128	4512	1500000051	6644000050		1200000053	9999999999	2000000051	1000000051
129	4512	1500000051	6644000050		1200000053	9999999999	2000000051	1000000051
130	4541	1510000051	6620000050		1220000053	9999999999	2000000051	8000000051
131	4541	1510000051	6620000050		1220000053	9999999999	2000000051	8000000051
132	4542	1520000051	6593000050		1240000053	9999999999	2000000051	8000000051
133	4542	1520000051	6593000050		1250000053	9999999999	2000000051	8000000051
134	4712	1530000051	6570000050		1044000053	9999999999	1000000052	1000000051
135	4712	1530000051	6570000050		1044000053	9999999999	1000000052	1000000051
136	4712	1530000051	6570000050		1044000053	9999999999	1000000052	1000000051
137	4712	1530000051	6570000050		1032000053	9999999999	1000000052	1000000051
138	4742	1530000051	6565000050		1034000053	9999999999	1000000052	8000000051
139	4742	1530000051	6565000050		1023000053	9999999999	1000000052	8000000051
140	2311	1450000051	7820000049		1220000052	9999999999	5000000050	1000000051

Run No.	Run Code	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
141	2311	1450000051	7820000049		1280000052	9999999999	5000000050	1000000051
142	2311	1450000051	7820000049		1270000052	9999999999	5000000050	1000000051
143	2311	1450000051	7820000049		1210000052	9999999999	5000000050	1000000051
144	2311	1450000051	7820000049		1400000052	9999999999	5000000050	1000000051
145	2311	1450000051	7820000049		1350000052	9999999999	5000000050	1000000051
146	2311	1450000051	7820000049		1240000052	9999999999	5000000050	1000000051
147	2311	1450000051	7820000049		1170000052	9999999999	5000000050	1000000051
148	2312	1460000051	7900000049		8600000051	9999999999	5000000050	1000000051
149	2312	1460000051	7900000049		1070000052	9999999999	5000000050	1000000051
150	2341	1460000051	7900000049		1440000052	9999999999	5000000050	8000000051
151	2341	1460000051	7900000049		1526000052	9999999999	5000000050	8000000051
152	2741	1470000051	8000000049		7220000051	9999999999	1000000052	8000000051
153	2741	1470000051	8000000049		6880000051	9999999999	1000000052	8000000051
154	2731	1470000051	8000000049		6900000051	9999999999	1000000052	4000000051
155	2721	1470000051	8000000049		7460000051	9999999999	1000000052	2000000051
156	2721	1470000051	8100000049		6980000051	9999999999	1000000052	2000000051
157	2711	1470000051	8100000049		7380000051	9999999999	1000000052	1000000051
158	2711	1470000051	8100000049		7210000051	9999999999	1000000052	1000000051
159	2721	1470000051	8100000049		7100000051	9999999999	1000000052	2000000051
160	2811	1470000051	8100000049		7560000051	9999999999	2000000052	1000000051
161	2511	1490000051	8200000049		8990000051	9999999999	2000000051	1000000051
162	2541	1490000051	8200000049		8500000051	9999999999	2000000051	8000000051
163	2542	1510000051	8300000049		8760000051	9999999999	2000000051	8000000051
164	2512	1510000051	8300000049		9030000051	9999999999	2000000051	1000000051
165	2712	1510000051	8300000049		7810000051	9999999999	1000000052	1000000051
166	2742	1540000051	8300000049		8000000051	9999999999	1000000052	8000000051
167	2311	1540000051	8300000049		1040000052	9999999999	5000000050	1000000051
168	2311	1540000051	8300000049		1000000052	9999999999	5000000050	1000000051
169	2311	1560000051	8400000049		1450000052	9999999999	5000000050	1000000051
170	2311	1560000051	8400000049		1210000052	9999999999	5000000050	1000000051
171	2311	1560000051	8400000049		1370000052	9999999999	5000000050	1000000051
172	2311	1560000051	8400000049		1050000052	9999999999	5000000050	1000000051
173	2312	1560000051	8400000049		1340000052	9999999999	5000000050	1000000051
174	2312	1560000051	8400000049		1340000052	9999999999	5000000050	1000000051
175	2211	1580000051	8600000049		1250000052	9999999999	2000000050	1000000051
176	2111	1580000051	8600000049		2250000052	9999999999	1000000050	1000000051
177	2341	1580000051	8600000049		1160000052	9999999999	5000000050	8000000051
178	2342	1580000051	8600000049		1260000052	9999999999	5000000050	8000000051
179	2211	1580000051	8600000049		1840000052	9999999999	2000000050	1000000051
180	2111	1580000051	8600000049		2200000052	9999999999	1000000050	1000000051
181	1711	1570000051	1100000049		7200000050	9999999999	1000000052	1000000051
182	1711	1570000051	1100000049		8000000050	9999999999	1000000052	1000000051
183	1711	1570000051	1100000049		8200000050	9999999999	1000000052	1000000051
184	1711	1570000051	1100000049		8100000050	9999999999	1000000052	1000000051
185	1711	1570000051	1100000049		7200000050	9999999999	1000000052	1000000051
186	1711	1570000051	1100000049		7800000050	9999999999	1000000052	1000000051
187	1712	1570000051	1100000049		8000000050	9999999999	1000000052	1000000051
188	1742	1580000051	1130000049		7900000050	9999999999	1000000052	8000000051
189	1741	1580000051	1130000049		8200000050	9999999999	1000000052	8000000051
190	1542	1580000051	1130000049		1150000051	9999999999	2000000051	8000000051
191	1542	1601000051	1209000049		2000000051	9999999999	2000000051	8000000051
192	1541	1605000051	1220000049		1380000051	9999999999	2000000051	8000000051
193	1541	1610000051	1232000049		1300000051	9999999999	2000000051	8000000051
194	1541	1614000051	1243000049		1880000051	9999999999	2000000051	8000000051
195	1541	1623000051	1266000049		2420000051	9999999999	2000000051	8000000051
196	1341	1627000051	1277000049		2900000051	9999999999	5000000050	8000000051
197	1341	1632000051	1289000049		2630000051	9999999999	5000000050	8000000051
198	1341	1637000051	1300000049		1710000051	9999999999	5000000050	8000000051
199	1341	1641000051	1312000049		1610000051	9999999999	5000000050	8000000051
200	1511	1645000051	1323000049		1430000051	9999999999	2000000051	1000000051
201	1511	1645000051	1323000049		1560000051	9999999999	2000000051	1000000051
202	1511	1645000051	1323000049		1230000051	9999999999	2000000051	1000000051
203	1511	1645000051	1323000049		1350000051	9999999999	2000000051	1000000051
204	1512	1645000051	1323000049		1090000051	9999999999	2000000051	1000000051
205	1512	1645000051	1323000049		1250000051	9999999999	2000000051	1000000051
206	1312	1662000051	1337000049		6800000050	9999999999	5000000050	1000000051
207	1312	1662000051	1337000049		9000000050	9999999999	5000000050	1000000051
208	1312	1662000051	1337000049		3000000051	9999999999	5000000050	1000000051
209	1312	1662000051	1337000049		1000000051	9999999999	5000000050	1000000051
210	1312	1662000051	1337000049		9400000050	9999999999	5000000050	1000000051

Run No.	Run Code	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
211	1311	1678000051	1355000049		2980000051	9999999999	5000000050	1000000051
212	1311	1678000051	1355000049		1480000051	9999999999	5000000050	1000000051
213	1311	1678000051	1355000049		1010000051	9999999999	5000000050	1000000051
214	1311	1678000051	1355000049		8900000050	9999999999	5000000050	1000000051
215	1311	1678000051	1355000049		1170000051	9999999999	5000000050	1000000051
216	1311	1678000051	1355000049		8600000050	9999999999	5000000050	1000000051
217	1341	1684000051	1362000049		2140000051	9999999999	5000000050	8000000051
218	1341	1691000051	1369000049		2040000051	9999999999	5000000050	8000000051
219	1342	1698000051	1376000049		1600000051	9999999999	5000000050	8000000051
220	1342	1704000051	1383000049		3840000051	9999999999	5000000050	8000000051
221	1342	1711000051	1390000049		1980000051	9999999999	5000000050	8000000051
222	1342	1718000051	1397000049		1640000051	9999999999	5000000050	8000000051
223	1211	1724000051	1405000049		7970000051	9999999999	2000000050	1000000051
224	1211	1724000051	1405000049		4270000051	9999999999	2000000050	1000000051
225	1211	1724000051	1405000049		4090000051	9999999999	2000000050	1000000051
226	1111	1724000051	1405000049		1180000052	9999999999	1000000050	1000000051
227	1111	1724000051	1405000049		9600000051	9999999999	1000000050	1000000051
228	1111	1724000051	1405000049		8000000051	9999999999	1000000050	1000000051
229	1111	1724000051	1405000049		5350000051	9999999999	1000000050	1000000051
230	1111	1724000051	1405000049		1175000052	9999999999	1000000050	1000000051
231	5711	7530000050	3732000050	5410000051	1320000052	9999999999	1000000052	1000000051
232	5711	7530000050	3732000050	5410000051	1530000052	9999999999	1000000052	1000000051
233	5711	7530000050	3732000050	5410000051	1450000052	9999999999	1000000052	1000000051
234	5712	7530000050	3732000050	5410000051	1430000052	9999999999	1000000052	1000000051
235	5712	7530000050	3732000050	5410000051	1600000052	9999999999	1000000052	1000000051
236	5712	7530000050	3732000050	5410000051	1430000052	9999999999	1000000052	1000000051
237	5511	7530000050	3732000050	5410000051	1360000052	9999999999	2000000051	1000000051
238	5511	7530000050	3732000050	5410000051	1540000052	9999999999	2000000051	1000000051
239	5511	7597000050	3700000050	5330000051	1430000052	9999999999	2000000051	1000000051
240	5512	7597000050	3700000050	5330000051	1450000052	9999999999	2000000051	1000000051
241	5512	7597000050	3700000050	5330000051	1450000052	9999999999	2000000051	1000000051
242	5311	7597000050	3700000050	5330000051	1560000052	9999999999	5000000050	1000000051
243	5311	7597000050	3700000050	5330000051	1430000052	9999999999	5000000050	1000000051
244	5312	7597000050	3700000050	5330000051	1610000052	9999999999	5000000050	1000000051
245	5312	7597000050	3700000050	5330000051	1870000052	9999999999	5000000050	1000000051
246	5312	7597000050	3700000050	5330000051	1850000052	9999999999	5000000050	1000000051
247	5311	7708000050	3709000050	5432000051	1670000052	9999999999	5000000050	1000000051
248	5211	7708000050	3709000050	5432000051	1830000052	9999999999	2000000050	1000000051
249	5211	7708000050	3709000050	5432000051	1830000052	9999999999	2000000050	1000000051
250	5111	7708000050	3709000050	5432000051	2378000052	9999999999	1000000050	1000000051
251	5111	7708000050	3709000050	5432000051	2395000052	9999999999	1000000050	1000000051
252	5312	7708000050	3709000050	5432000051	1600000052	9999999999	5000000050	1000000051
253	5741	7719000050	3706000050	5430000051	1256000052	9999999999	1000000052	8000000051
254	5741	7719000050	3706000050	5430000051	1224000052	9999999999	1000000052	8000000051
255	5742	7730000050	3703000050	5420000051	1280000052	9999999999	1000000052	8000000051
256	5742	7730000050	3703000050	5420000051	1330000052	9999999999	1000000052	8000000051
257	5541	7741000050	3700000050	5420000051	1390000052	9999999999	2000000051	8000000051
258	5541	7741000050	3700000050	5420000051	1420000052	9999999999	2000000051	8000000051
259	5542	7752000050	3696000050	5410000051	1380000052	9999999999	2000000051	8000000051
260	5542	7752000050	3696000050	5410000051	1460000052	9999999999	2000000051	8000000051
261	5542	7763000050	3693000050	5410000051	1350000052	9999999999	2000000051	8000000051
262	5341	7763000050	3693000050	5410000051	1680000052	9999999999	5000000050	8000000051
263	5341	7744000050	3690000050	5400000051	1720000052	9999999999	5000000050	8000000051
264	5342	7744000050	3690000050	5400000051	1680000052	9999999999	5000000050	8000000051
265	5342	7785000050	3687000050	5390000051	1690000052	9999999999	5000000050	8000000051
266	3131	1405000051	2368000050		4889000052	9999999999	1000000050	4000000051
267	3131	1405000051	2368000050		4724000052	9999999999	1000000050	4000000051
268	3132	1405000051	2368000050		4536000052	9999999999	1000000050	4000000051
269	3132	1405000051	2368000050		5800000052	9999999999	1000000050	4000000051
270	3132	1405000051	2368000050		4800000052	9999999999	1000000050	4000000051
271	3631-	1405000051	2370000050		2924000052	5000000051	5000000051	4000000051
272	3631-	1405000051	2370000050		2932000052	5000000051	5000000051	4000000051
273	3631-	1405000051	2370000050		3035000052	5000000051	5000000051	4000000051
274	3631-	1405000051	2370000050		3035000052	5000000051	5000000051	4000000051
275	3632-	1405000051	2405000050		3064000052	5000000051	5000000051	4000000051
276	3632-	1405000051	2405000050		2898000052	5000000051	5000000051	4000000051
300	3531	1425000051	2539000050		3416000052	9999999999	2000000051	4000000051
301	3631-	1425000051	2539000050		3297000052	5000000051	5000000051	4000000051
302	3631-	1425000051	2539000050		3240000052	5000000051	5000000051	4000000051
303	3631-	1425000051	2539000050		3283000052	5000000051	5000000051	4000000051

Run No.	Run Code	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
304	3631-	1425000051	2539000050		3300000052	5000000051	5000000051	4000000051
305	3731-	1425000051	2539000050		3136000052	1000000052	1000000052	4000000051
306	3731-	1425000051	2539000050		3140000052	1000000052	1000000052	4000000051
307	3731-	1425000051	2539000050		3109000052	1000000052	1000000052	4000000051
308	3731-	1490000051	2526000050		3171000052	1000000052	1000000052	4000000051
309	3711-	1507000051	2617000050		3144000052	1000000052	1000000052	1000000051
310	3711-	1507000051	2617000050		3144000052	1000000052	1000000052	1000000051
311	3611-	1507000051	2617000050		3203000052	5000000051	5000000051	1000000051
312	3611-	1507000051	2617000050		3224000052	5000000051	5000000051	1000000051
313	3311-	1507000051	2617000050		4878000052	5000000050	5000000050	1000000051
314	3311-	1507000051	2617000050		4643000052	5000000050	5000000050	1000000051
315	3321-	1507000051	2617000050		4702000052	5000000050	5000000050	2000000051
316	3331-	1507000051	2617000050		4821000052	5000000050	5000000050	4000000051
317	3331-	1507000051	2617000050		4870000052	5000000050	5000000050	4000000051
318	3411-	1506000051	2578000050		3682000052	1000000051	1000000051	1000000051
319	3411-	1506000051	2578000050		3821000052	1000000051	1000000051	1000000051
320	3421-	1506000051	2578000050		3664000052	1000000051	1000000051	2000000051
321	3421-	1506000051	2578000050		3790000052	1000000051	1000000051	2000000051
322	3431-	1506000051	2578000050		3769000052	1000000051	1000000051	4000000051
323	3511-	1506000051	2578000050		3380000052	2000000051	2000000051	1000000051
324	3511-	1506000051	2578000050		3393000052	2000000051	2000000051	1000000051
325	3521-	1506000051	2578000050		3324000052	2000000051	2000000051	2000000051
326	3521-	1506000051	2578000050		3390000052	2000000051	2000000051	2000000051
327	3531-	1506000051	2578000050		3360000052	2000000051	2000000051	4000000051
328	3611-	1506000051	2578000050		3260000052	5000000051	5000000051	1000000051
329	3611-	1506000051	2578000050		3293000052	5000000051	5000000051	1000000051
330	3632-	1531000051	2556000050		3053000052	5000000051	5000000051	4000000051
331	3632-	1531000051	2556000050		2987000052	5000000051	5000000051	4000000051
332	3632-	1531000051	2556000050		3026000052	5000000051	5000000051	4000000051
333	3532-	1531000051	2556000050		3177000052	2000000051	2000000051	4000000051
334	3532-	1531000051	2556000050		3060000052	2000000051	2000000051	4000000051
335	3532-	1531000051	2556000050		3102000052	2000000051	2000000051	4000000051
336	3432-	1531000051	2556000050		3178000052	1000000051	1000000051	4000000051
337	3432-	1531000051	2556000050		3200000052	1000000051	1000000051	4000000051
338	3332-	1531000051	2556000050		3135000052	5000000050	5000000050	4000000051
339	3332-	1531000051	2556000050		3254000052	5000000050	5000000050	4000000051
340	3632-	1531000051	2556000050		3126000052	5000000051	5000000051	4000000051
341	3632-	1531000051	2556000050		3101000052	5000000051	5000000051	4000000051
342	3632-	1531000051	2556000050		3087000052	5000000051	5000000051	4000000051
343	3532-	1523000051	2340000050		3084000052	2000000051	2000000051	4000000051
344	3532-	1523000051	2340000050		3188000052	2000000051	2000000051	4000000051
345	3532-	1523000051	2340000050		3212000052	2000000051	2000000051	4000000051
346	3432-	1523000051	2340000050		3178000052	1000000051	1000000051	4000000051
347	3432-	1523000051	2340000050		3248000052	1000000051	1000000051	4000000051
348	3432-	1523000051	2340000050		3132000052	1000000051	1000000051	4000000051
349	3332-	1523000051	2340000050		3170000052	5000000050	5000000050	4000000051
350	3332-	1523000051	2340000050		3128000052	5000000050	5000000050	4000000051
351	3741	1547000051	2610000050		3377000052	1000000052	1427000052	7620000051
352	3741	1548000051	2610000050		3382000052	1000000052	1427000052	7620000051
353	3741	1548000051	2610000050		3369000052	1000000052	1427000052	7620000051
354	3741	1548000051	2610000050		3351000052	1000000052	1427000052	7620000051
355	3741	1548000051	2610000050		3390000052	1000000052	1427000052	7620000051
356	3741	1550000051	2680000050		3495000052	1000000052	1427000052	7620000051
357	3741	1550000051	2680000050		3490000052	1000000052	1427000052	7620000051
358	3441	1550000051	2680000050		3740000052	1000000052	1270000051	7620000051
359	3441	1550000051	2680000050		3720000052	1000000052	1270000051	7620000051
360	3641	1550000051	2680000050		3571000052	1000000052	4270000051	7620000051
361	3641	1550000051	2680000050		3575000052	1000000052	4270000051	7620000051
362	3642	1558000051	2775000050		3581000052	1000000052	4270000051	7620000051
363	3642	1558000051	2775000050		3550000052	1000000052	4270000051	7620000051
364	3641	1558000051	2775000050		3732000052	1000000052	4270000051	7620000051
365	3641	1558000051	2775000050		3732000052	1000000052	4270000051	7620000051
366	6521	1472000051	1538000050		1800000052	9999999999	2000000051	2000000051
367	6521	1472000051	1538000050		1800000052	9999999999	2000000051	2000000051
368	6521	1472000051	1538000050		1798000052	9999999999	2000000051	2000000051
369	6521	1472000051	1538000050		1792000052	9999999999	2000000051	2000000051
370	6521	1472000051	1538000050		1792000052	9999999999	2000000051	2000000051
371	6511	1472000051	1538000050		1820000052	9999999999	2000000051	1000000051
372	6511	1472000051	1538000050		1793000052	9999999999	2000000051	1000000051
373	6511	1472000051	1538000050		1793000052	9999999999	2000000051	1000000051

Run No.	Run Code.	Conc. of H_2SO_4 (M)	Conc. of $CuSO_4$ (M)	Conc. of glycerol (M)	Limiting-current density (ma/cm^2)	Electrode length (cm)	Electrode width (cm)	Free height (cm)
374	6511	1472000051	1538000050		1770000052	9999999999	2000000051	1000000051
375	6511	1472000051	1538000050		1768000052	9999999999	2000000051	1000000051
376	6501	1472000051	1538000050		1820000052	9999999999	2000000051	5000000050
377	6501	1472000051	1538000050		1810000052	9999999999	2000000051	5000000050
378	6501	1472000051	1538000050		1802000052	9999999999	2000000051	5000000050
379	6501	1472000051	1538000050		1797000052	9999999999	2000000051	5000000050
380	6501	1472000051	1538000050		1795000052	9999999999	2000000051	5000000050
381	6501	1472000051	1538000050		1713000052	9999999999	2000000051	2000000050
382	6501	1472000051	1538000050		1690000052	9999999999	2000000051	2000000050
383	6501	1472000051	1538000050		1683000052	9999999999	2000000051	2000000050
384	6501	1472000051	1538000050		1660000052	9999999999	2000000051	2000000050
385	6501	1472000051	1538000050		1658000052	9999999999	2000000051	2000000050
386	6611	1472000051	1538000050		1604000052	9999999999	5000000051	1000000051
387	6611	1472000051	1538000050		1600000052	9999999999	5000000051	1000000051
388	6611	1472000051	1538000050		1594000052	9999999999	5000000051	1000000051
389	6611	1472000051	1538000050		1594000052	9999999999	5000000051	1000000051
390	6611	1472000051	1538000050		1594000052	9999999999	5000000051	1000000051
391	6601	1472000051	1538000050		1608000052	9999999999	5000000051	5000000050
392	6601	1472000051	1538000050		1603000052	9999999999	5000000051	5000000050
393	6601	1472000051	1538000050		1600000052	9999999999	5000000051	5000000050
394	6601	1472000051	1538000050		1597000052	9999999999	5000000051	5000000050
395	6601	1472000051	1538000050		1597000052	9999999999	5000000051	5000000050
396	6601	1472000051	1538000050		1600000052	9999999999	5000000051	2000000050
397	6601	1472000051	1538000050		1600000052	9999999999	5000000051	2000000050
398	6601	1472000051	1538000050		1606000052	9999999999	5000000051	2000000050
399	6601	1472000051	1538000050		1606000052	9999999999	5000000051	2000000050
400	6601	1472000051	1538000050		1608000052	9999999999	5000000051	2000000050
401	3441-	1550000051	2680000050		3713000052	1000000052	1270000051	8000000051
402	3441-	1550000051	2680000050		3764000052	1000000052	1270000051	8000000051
403	3641-	1550000051	2680000050		3564000052	1000000052	4270000051	8000000051
404	3641-	1550000051	2680000050		3558000052	1000000052	4270000051	8000000051
405	3741-	1550000051	2680000050		3520000052	1000000052	9270000051	8000000051
406	3741-	1550000051	2680000050		3533000052	1000000052	9270000051	8000000051
407	3741-	1550000051	2680000050		3516000052	1000000052	9270000051	8000000051
408	3741-	1550000051	2680000050		3507000052	1000000052	9270000051	8000000051
409	3741-	1550000051	2680000050		3525000052	1000000052	9270000051	8000000051
410	3741-	1550000051	2680000050		3540000052	1000000052	9270000051	8000000051
411	7921	1573000051	2560000050	5380000051	7990000051	9999999999	3000000052	2000000051
412	7931	1573000051	2560000050	5380000051	8020000051	9999999999	3000000052	4000000051
413	7721	1573000051	2560000050	5380000051	8100000051	9999999999	1000000052	2000000051
414	7731	1573000051	2560000050	5380000051	8070000051	9999999999	1000000052	4000000051
415	7521	1573000051	2560000050	5380000051	8480000051	9999999999	2000000051	2000000051
416	7531	1573000051	2560000050	5380000051	8390000051	9999999999	2000000051	4000000051
417	7421	1573000051	2560000050	5380000051	8730000051	9999999999	1000000051	2000000051
418	7431	1573000051	2560000050	5380000051	8710000051	9999999999	1000000051	4000000051
419	7321	1573000051	2560000050	5380000051	9200000051	9999999999	5000000050	2000000051
420	7331	1573000051	2560000050	5380000051	9430000051	9999999999	5000000050	4000000051
421	8911	1526000051	2300000050	4010000051	9830000051	9999999999	3000000052	1000000051
422	8941	1526000051	2300000050	4010000051	9790000051	9999999999	3000000052	8000000051
423	8711	1526000051	2300000050	4010000051	9810000051	9999999999	1000000052	1000000051
424	8741	1526000051	2300000050	4010000051	9930000051	9999999999	1000000052	8000000051
425	8511	1526000051	2300000050	4010000051	1073000052	9999999999	2000000051	1000000051
426	8541	1526000051	2300000050	4010000051	1014000052	9999999999	2000000051	8000000051
427	8411	1526000051	2300000050	4010000051	1076000052	9999999999	1000000051	1000000051
428	8441	1526000051	2300000050	4010000051	1071000052	9999999999	1000000051	8000000051
429	8311	1526000051	2300000050	4010000051	1123000052	9999999999	5000000050	1000000051
430	8341	1526000051	2300000050	4010000051	1156000052	9999999999	5000000050	8000000051
431	9911	1537000051	3180000050	2260000051	2550000052	9999999999	3000000052	1000000051
432	9931	1537000051	3180000050	2260000051	2550000052	9999999999	3000000052	4000000051
433	9711	1537000051	3180000050	2260000051	2610000052	9999999999	1000000052	1000000051
434	9731	1537000051	3180000050	2260000051	2640000052	9999999999	1000000052	4000000051
435	9511	1537000051	3180000050	2260000051	2700000052	9999999999	2000000051	1000000051
436	9531	1537000051	3180000050	2260000051	2710000052	9999999999	2000000051	4000000051
437	9411	1537000051	3180000050	2260000051	2800000052	9999999999	1000000051	1000000051
438	9431	1537000051	3180000050	2260000051	2770000052	9999999999	1000000051	4000000051
439	9311	1537000051	3180000050	2260000051	2950000052	9999999999	5000000050	1000000051
440	9331	1537000051	3180000050	2260000051	2960000052	9999999999	5000000050	4000000051

Run Index: Calculated Quantities

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
000	3311	9557140049	8203546 47	1371946549	1122451951	2663240049	5442720045	1287057649	1507251353	2273219854	1557490556
001	3311	9557140049	8203546 47	1371946549	1122451951	2663240049	5442720045	1287057649	1507251353	2273219854	1557490556
002	3311	9557140049	8329111 47	1371946549	1122451951	2663240049	5442720045	1287057649	1530321453	2273219854	1557490556
003	3321	9557140049	7366449 47	1371946549	1122451951	2663240049	5442720045	1287057649	2706900253	2273219854	1245992557
004	3321	9557140049	7178103 47	1371946549	1122451951	2663240049	5442720045	1287057649	2637689853	2273219854	1245992557
005	3321	9557140049	7659433 47	1371946549	1122451951	2663240049	5442720045	1287057649	2814561153	2273219854	1245992557
006	3321	9516050049	7932661 47	1378815249	1123786251	2658230049	5416444045	1254312149	2929103153	2292870254	1232755057
007	3321	9516050049	7533930 47	1378815249	1123786251	2658230049	5416444045	1254312149	2781873153	2292870254	1232755057
008	3321	9516050049	7470972 47	1378815249	1123786251	2658230049	5416444045	1254312149	2758626353	2292870254	1232755057
009	3331	9519570049	7683154 47	1376106349	1123241751	2656370049	5426765445	1264961549	5663155853	2285114354	9889184457
010	3331	9519570049	7326286 47	1376106349	1123241751	2656370049	5426765445	1264961549	5400112953	2285114354	9889184457
011	3331	9519570049	7221325 47	1376106349	1123241751	2656370049	5426765445	1264961549	5322747353	2285114354	9889184457
012	3341	8755040049	7933983 47	1411034149	1128888251	2458960049	5295983045	1016631849	1198490754	2386627954	7000697458
013	3341	8755040049	7320179 47	1411034149	1128888251	2458960049	5295983045	1016631849	1105770854	2386627954	7000697458
014	3351	8735390049	7200057 47	1411464549	1128937451	2453370049	5294400745	1012195449	2175901054	2387902454	5584668659
015	3351	8735390049	6926637 47	1411464549	1128937451	2453370049	5294400745	1012195449	2093271954	2387902454	5584668659
016	3411	9497810049	6897685 47	1378621749	1123718051	2652480049	5417163845	1251852849	1273302153	2292323254	1537950756
017	3411	9497810049	6897685 47	1378621749	1123718051	2652480049	5417163845	1251852849	1273302153	2292323254	1537950756
018	3411	9497810049	6855626 47	1378621749	1123718051	2652480049	5417163845	1251852849	1265538053	2292323254	1537950756
019	3421	9488450049	7158794 47	1377911649	1123559151	2648870049	5419857345	1252845949	2641691153	2290293054	1229779857
020	3421	9488450049	7158794 47	1377911649	1123559151	2648870049	5419857345	1252845949	2641691153	2290293054	1229779857
021	3421	9488450049	7158794 47	1377911649	1123559151	2648870049	5419857345	1252845949	2641691153	2290293054	1229779857
022	3431	9459730049	7349028 47	1378829549	1123699551	2641140049	5416340345	1244471349	5427302153	2292933854	9797715057
023	3431	9459730049	7285675 47	1378829549	1123699551	2641140049	5416340345	1244471349	5380515153	2292933854	9797715057
024	3431	9459730049	7158967 47	1378829549	1123699551	2641140049	5416340345	1244471349	5286940953	2292933854	9797715057
025	3441	9420280049	6739094 47	1382395549	1124356651	2632950049	5402782545	1224594149	9978701353	2303181054	7778170158
026	3441	9420280049	6823862 47	1382395549	1124356651	2632950049	5402782545	1224594149	1010422054	2303181054	7778170158
027	3441	9420280049	6823862 47	1382395549	1124356651	2632950049	5402782545	1224594149	1010422054	2303181054	7778170158
028	3451	8693170049	6800933 47	1411976449	1128963651	2440980049	5292502645	1004063049	2056020354	2389431454	5552582359
029	3451	8693170049	6663540 47	1411976449	1128963651	2440980049	5292502645	1004063049	2014484654	2389431454	5552582359
030	3511	9397880049	6822341 47	1380930749	1124025551	2624600049	5408309545	1226094449	1261455553	2298984754	1517126456
031	3511	9397880049	6886102 47	1380930749	1124025551	2624600049	5408309545	1226094449	1273244953	2298984754	1517126456
032	3511	9397880049	6843595 47	1380930749	1124025551	2624600049	5408309545	1226094449	1265385353	2298984754	1517126456
033	3521	9370500049	6861486 47	1382790049	1124356151	2618240049	5401246745	1214631849	2540704553	2304335854	1207863557
034	3521	9370500049	6861486 47	1382790049	1124356151	2618240049	5401246745	1214631849	2540704553	2304335854	1207863557

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
035	3521	9370500049	6861486 47	1382790049	1124356151	2618240049	5401246745	1214631849	2540704553	2304335854	1207863557
036	3531	9346020049	6599016 47	1384993349	1124759151	2613110049	5392907945	1202473449	4894588953	2310682554	9616775157
037	3531	9346020049	6599016 47	1384993349	1124759151	2613110049	5392907945	1202473449	4894588953	2310682554	9616775157
038	3531	9346020049	6449524 47	1384993349	1124759151	2613110049	5392907945	1202473449	4783708153	2310682554	9616775157
039	3541	9317920049	6744893 47	1387165049	1125148351	2606830049	5384710345	1189879549	1002080854	2316949554	7653578758
040	3541	9317920049	6766305 47	1387165049	1125148351	2606830049	5384710345	1189879549	1005262054	2316949554	7653578758
041	3541	9317920049	6659244 47	1387165049	1125148351	2606830049	5384710345	1189879549	9893559953	2316949554	7653578758
042	3551	9290630049	6526482 47	1389042049	1125478551	2600470049	5377642445	1178545049	1941812154	2322375354	6093225659
043	3551	9290630049	6547951 47	1389042049	1125478551	2600470049	5377642445	1178545049	1948199854	2322375354	6093225659
044	3551	9290630049	6547951 47	1389042049	1125478551	2600470049	5377642445	1178545049	1948199854	2322375354	6093225659
045	3611	9290630049	5860952 47	1389042049	1125478551	2600470049	5377642445	1178545049	1089874053	2322375354	1487604056
046	3611	9290630049	5860952 47	1389042049	1125478551	2600470049	5377642445	1178545049	1089874053	2322375354	1487604056
047	3611	9290630049	5646265 47	1389042049	1125478551	2600470049	5377642445	1178545049	1049951953	2322375354	1487604056
048	3621	9221560049	6183041 47	1392657749	1126083851	2583150049	5364064245	1154141349	2305357053	2332855954	1176664357
049	3621	9221560049	6031708 47	1392657749	1126083851	2583150049	5364064245	1154141349	2248932353	2332855954	1176664357
050	3621	9221560049	6031708 47	1392657749	1126083851	2583150049	5364064245	1154141349	2248932353	2332855954	1176664357
051	3631	9183430049	5903551 47	1394435149	1126372751	2573340049	5357410545	1141560949	4407764753	2338020454	9356096957
052	3631	9183430049	5903551 47	1394435149	1126372751	2573340049	5357410545	1141560949	4407764753	2338020454	9356096957
053	3631	9183430049	5903551 47	1394435149	1126372751	2573340049	5357410545	1141560949	4407764753	2338020454	9356096957
054	3641	9128490049	5959156 47	1396978049	1126783251	2559170049	5347919145	1123631649	8914355153	2345421254	7419316058
055	3641	9128490049	5959156 47	1396978049	1126783251	2559170049	5347919145	1123631649	8914355153	2345421254	7419316058
056	3641	9128490049	5915499 47	1396978049	1126783251	2559170049	5347919145	1123631649	8849048453	2345421254	7419316058
057	3651	9096970049	5846371 47	1399151549	1127157651	2551720049	5339846845	1110921349	1751772254	2351749154	5901773559
058	3651	9096970049	5802578 47	1399151549	1127157651	2551720049	5339846845	1110921349	1738650354	2351749154	5901773559
059	3711	9080150049	6251534 47	1399915349	1127279351	2547360049	5337010545	1105548449	1171355153	2353978354	1436988556
060	3711	9080150049	6119923 47	1399915349	1127279351	2547360049	5337010545	1105548449	1146695053	2353978354	1436988556
061	3711	9080150049	6119923 47	1399915349	1127279351	2547360049	5337010545	1105548449	1146695053	2353978354	1436988556
062	3721	9080150049	6383145 47	1399915349	1127279351	2547360049	5337010545	1105548449	2392030353	2353978354	1149590757
063	3721	9080150049	6317340 47	1399915349	1127279351	2547360049	5337010545	1105548449	2367370353	2353978354	1149590757
064	3731	9014420049	6008679 47	1402365849	1127648351	2529720049	5327920445	1086533149	4511088053	2361146454	9104166957
065	3731	9014420049	6074952 47	1402365849	1127648351	2529720049	5327920445	1086533149	4560842953	2361146454	9104166957
066	3741	8997630049	6240681 47	1403134049	1127769951	2525360049	5325080545	1081215349	9375529653	2363393954	7263611958
067	3741	8997630049	6218550 47	1403134049	1127769951	2525360049	5325080545	1081215349	9342282653	2363393954	7263611958
068	3751	8959680049	6310239 47	1404943149	1128058051	2515550049	5318405845	1069001049	1898385254	2368690854	5774908559
069	3751	8959680049	6288020 47	1404943149	1128058051	2515550049	5318405845	1069001049	1891700754	2368690854	5774908559

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta\rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
070	3811	8522170049	6005052 47	1414975249	1129244351	2391700049	5281479145	9684984848	1137002153	2398353054	1322962456
071	3811	8522170049	5841491 47	1414975249	1129244351	2391700049	5281479145	9684984848	1106033253	2398353054	1322962456
072	3821	8538160049	5853961 47	1414502349	1129181651	2396130049	5283204345	9724169448	2216065053	2396952454	1060979357
073	3821	8538160049	5947252 47	1414502349	1129181651	2396130049	5283204345	9724169448	2251380753	2396952454	1060979357
074	3831	8546150049	5848529 47	1414265949	1129150251	2398350049	5284067245	9743790548	4427293453	2396252354	8498299457
075	3831	8546150049	5801927 47	1414265949	1129150251	2398350049	5284067245	9743790548	4392016253	2396252354	8498299457
076	3841	8813970049	5895729 47	1408156249	1128434251	2474210049	5306519845	1035334249	8888279853	2378166654	7070066158
077	3841	8813970049	5918318 47	1408156249	1128434251	2474210049	5306519845	1035334249	8922334753	2378166654	7070066158
078	3841	8813970049	5895729 47	1408156249	1128434251	2474210049	5306519845	1035334249	8888279853	2378166654	7070066158
079	3851	8906470049	6481056 47	1406912849	1128350151	2501210049	5311146445	1053929049	1952439354	2374473454	5727424459
080	3851	8906480049	6034087 47	1406912849	1128350151	2501210049	5311146445	1053929049	1817788254	2374473454	5727424459
081	3851	8906480049	6034087 47	1406912849	1128350151	2501210049	5311146445	1053929049	1817788254	2374473454	5727424459
082	3911	8522170049	5981687 47	1414975249	1129244351	2391700049	5281479145	9684984848	1132578053	2398353054	1322962456
083	3911	8522170049	6028419 47	1414975249	1129244351	2391700049	5281479145	9684984848	1141426353	2398353054	1322962456
084	3911	8522170049	5934955 47	1414975249	1129244351	2391700049	5281479145	9684984848	1123729753	2398353054	1322962456
085	3921	8466930049	5903234 47	1416320449	1129405351	2376110049	5276568345	9559544948	2237527953	2402347454	1049628057
086	3921	8466920049	5832678 47	1416320449	1129405351	2376110049	5276568345	9559546048	2210784853	2402347454	1049628057
087	3931	8466930049	5809159 47	1416320449	1129405351	2376110049	5276568345	9559544948	4403740453	2402347454	8397023557
088	3931	8466930049	5738602 47	1416320449	1129405351	2376110049	5276568345	9559544948	4350253753	2402347454	8397023557
089	3931	8570840049	6203998 47	1413244949	1128997651	2404930049	5287788045	9813993648	4693076453	2393237454	8532766557
090	3931	8570840049	6134290 47	1413244949	1128997651	2404930049	5287788045	9813993648	4640345153	2393237454	8532766557
091	3941	8626950049	6115445 47	1413195649	1129084051	2421950049	5288018745	9900158348	9251775553	2393053054	6875503958
092	3941	8626950049	6046213 47	1413195649	1129084051	2421950049	5288018745	9900158348	9147038653	2393053054	6875503958
093	3951	8647300049	6331621 47	1412451049	1128976451	2427470049	5290737745	9955359048	1914779354	2390854754	5518219659
094	3951	8647300049	6055332 47	1412451049	1128976451	2427470049	5290737745	9955359048	1831225354	2390854754	5518219659
095	3951	8647300049	5963236 47	1412451049	1128976451	2427470049	5290737745	9955359048	1803373954	2390854754	5518219659
096	3951	8647300049	5963236 47	1412451049	1128976451	2427470049	5290737745	9955359048	1803373954	2390854754	5518219659
097	3211	8840210049	7923496 47	1409704949	1128777151	2483660049	5300897845	1034183449	1494746153	2382679254	1383520156
098	3211	8840210049	7653377 47	1409704949	1128777151	2483660049	5300897845	1034183449	1443788853	2382679254	1383520156
099	3211	8840210049	9409151 47	1409704949	1128777151	2483660049	5300897845	1034183449	1775011053	2382679254	1383520156
100	3211	8840210049	8351185 47	1409704949	1128777151	2483660049	5300897845	1034183449	1575428453	2382679254	1383520156
101	3211	8840210049	8148595 47	1409704949	1128777151	2483660049	5300897845	1034183449	1537210553	2382679254	1383520156
102	3312	8290050049	7210033 47	1418650249	1129542051	2324470049	5268007845	9226032348	1368645253	2409338954	1279477156
103	3312	8290050049	7113900 47	1418650249	1129542051	2324470049	5268007845	9226032348	1350396753	2409338954	1279477156
104	3342	8320640049	7086963 47	1418325649	1129533551	2333470049	5269204545	9280783248	1075982354	2408359054	6579235958

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
105	3342	8320640049	6991193 47	1418325649	1129533551	2333470049	5269204545	9280783248	1061442054	2408359054	6579235958
106	3512	8367190049	6237418 47	1417525049	1129462251	2346890049	5272131245	9374151148	1183092453	2405966354	1293772056
107	3512	8367190049	6213611 47	1417525049	1129462251	2346890049	5272131245	9374151148	1178576753	2405966354	1293772056
108	3542	8343920049	5801505 47	1417925149	1129497951	2340180049	5270668245	9327409548	8805722253	2407161854	6601664458
109	3542	8343920049	5801505 47	1417925149	1129497951	2340180049	5270668245	9327409548	8805722253	2407161854	6601664458
110	3812	8413750049	5799866 47	1416726649	1129391051	2360320049	5275053145	9467979048	1099489853	2403581754	1302556756
111	3812	8413750049	5799866 47	1416726649	1129391051	2360320049	5275053145	9467979048	1099489853	2403581754	1302556756
112	3842	8413750049	5776193 47	1416726649	1129391051	2360320049	5275053145	9467979048	8760016153	2403581754	6669090558
113	3842	8413750049	5776193 47	1416726649	1129391051	2360320049	5275053145	9467979048	8760016153	2403581754	6669090558
114	4311	2358855050	8888649 47	1562383749	1185946051	8314330049	4810206045	3471221749	1847872953	2843642554	3952948156
115	4311	2358855050	8888649 47	1562383749	1185946051	8314330049	4810206045	3471221749	1847872953	2843642554	3952948156
116	4311	2358855050	8960914 47	1562383749	1185946051	8314330049	4810206045	3471221749	1862896253	2843642554	3952948156
117	4341	2337425050	9061429 47	1561826049	1185438251	8217730049	4811744745	3403923249	1506552054	2841668854	2001061959
118	4341	2337425050	9426809 47	1561826049	1185438251	8217730049	4811744745	3403923249	1567300054	2841668854	2001061959
119	4341	2317146050	9314203 47	1558102649	1184280451	8113770049	4822711545	3369654249	1545056754	2829912854	1983358859
120	4341	2317146050	9388125 47	1558102649	1184280451	8113770049	4822711545	3369654249	1557319154	2829912854	1983358859
121	4342	2297278050	9121290 47	1554490549	1183155151	8012830049	4833398745	3336232049	1509710454	2818530654	1966020759
122	4342	2297278050	9196054 47	1554490549	1183155151	8012830049	4833398745	3336232049	1522085054	2818530654	1966020759
123	4312	2280200050	9126922 47	1554804649	1182910751	7940040049	4832361345	3277850049	1888708753	2819328354	3802815156
124	4312	2280200050	9126922 47	1554804649	1182910751	7940040049	4832361345	3277850049	1888708753	2819328354	3802815156
125	4511	2280200050	8900635 47	1554804649	1182910751	7940040049	4832361345	3277850049	1841881253	2819328354	3802815156
126	4511	2280200050	9051493 47	1554804649	1182910751	7940040049	4832361345	3277850049	1873099553	2819328354	3802815156
127	4511	2280200050	9126922 47	1554804649	1182910751	7940040049	4832361345	3277850049	1888708753	2819328354	3802815156
128	4512	2280200050	9051493 47	1554804649	1182910751	7940040049	4832361345	3277850049	1873099553	2819328354	3802815156
129	4512	2280200050	9051493 47	1554804649	1182910751	7940040049	4832361345	3277850049	1873099553	2819328354	3802815156
130	4541	2271489050	9239927 47	1556640049	1183137051	7909480049	4826820045	3233717749	1531431154	2824923054	1935377959
131	4541	2271489050	9239927 47	1556640049	1183137051	7909480049	4826820045	3233717749	1531431154	2824923054	1935377959
132	4542	2261975050	9434269 47	1558341749	1183317751	7874850049	4821684445	3188504049	1565306854	2830106454	1923026459
133	4542	2261975050	9510351 47	1558341749	1183317751	7874850049	4821684445	3188504049	1577930254	2830106454	1923026459
134	4712	2253550050	7974410 47	1560249349	1183558951	7845660049	4815952345	3145285349	1655832453	2835947954	3733663356
135	4712	2253550050	7974410 47	1560249349	1183558951	7845660049	4815952345	3145285349	1655832453	2835947954	3733663356
136	4712	2253550050	7974410 47	1560249349	1183558951	7845660049	4815952345	3145285349	1655832453	2835947954	3733663356
137	4712	2253550050	7882750 47	1560249349	1183558951	7845660049	4815952345	3145285349	1636799953	2835947954	3733663356
138	4742	2252196050	7904219 47	1560007149	1183483151	7838870049	4816665145	3143118549	1312811954	2835184554	1910458159
139	4742	2252196050	7820131 47	1560007149	1183483151	7838870049	4816665145	3143118549	1298845854	2835184554	1910458159

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
140	2311	3207080049	8047474 47	1296268149	1097261551	8188300048	5744109945	4448187648	1400996053	2064411854	5245266455
141	2311	3207080049	8443252 47	1296268149	1097261551	8188300048	5744109945	4448187648	1469897453	2064411854	5245266455
142	2311	3207080049	8377289 47	1296268149	1097261551	8188300048	5744109945	4448187648	1458413853	2064411854	5245266455
143	2311	3207080049	7981512 47	1296268149	1097261551	8188300048	5744109945	4448187648	1389512453	2064411854	5245266455
144	2311	3207080049	9234807 47	1296268149	1097261551	8188300048	5744109945	4448187648	1607700353	2064411854	5245266455
145	2311	3207080049	8904992 47	1296268149	1097261551	8188300048	5744109945	4448187648	1550282453	2064411854	5245266455
146	2311	3207080049	8179400 47	1296268149	1097261551	8188300048	5744109945	4448187648	1423963153	2064411854	5245266455
147	2311	3207080049	7717660 47	1296268149	1097261551	8188300048	5744109945	4448187648	1343578153	2064411854	5245266455
148	2312	3236680049	5615338 47	1299412149	1097957951	8276200048	5730673745	4452807048	9798739752	2073034654	5279294155
149	2312	3236680049	6986525 47	1299412149	1097957951	8276200048	5730673745	4452807048	1219145653	2073034654	5279294155
150	2341	3236680049	9402426 47	1299412149	1097957951	8276200048	5730673745	4452807048	1312575454	2073034654	2702998658
151	2341	3236680049	9963960 47	1299412149	1097957951	8276200048	5730673745	4452807048	1390965354	2073034654	2702998658
152	2741	3274230049	4655274 47	1302636949	1098680051	8385600048	5716965045	4467605648	6514330153	2081893654	2726975258
153	2741	3274230049	4436051 47	1302636949	1098680051	8385600048	5716965045	4467605648	6207561053	2081893654	2726975258
154	2731	3274230049	4448946 47	1302636949	1098680051	8385600048	5716965045	4467605648	3112803053	2081893654	3408719057
155	2721	3274230049	4810020 47	1302636949	1098680051	8385600048	5716965045	4467605648	1682718253	2081893654	4260898756
156	2721	3314310049	4444721 47	1302983549	1098810551	8492400048	5715530545	4522622948	1555313553	2082824954	4313379056
157	2711	3314310049	4699432 47	1302983549	1098810551	8492400048	5715530545	4522622948	8222216352	2082824954	5391723755
158	2711	3314310049	4591180 47	1302983549	1098810551	8492400048	5715530545	4522622948	8032815552	2082824954	5391723755
159	2721	3314310049	4521134 47	1302983549	1098810551	8492400048	5715530545	4522622948	1582052453	2082824954	4313379056
160	2811	3314310049	4814053 47	1302983549	1098810551	8492400048	5715530545	4522622948	8422758152	2082824954	5391723755
161	2511	3349100049	5654996 47	1309121549	1100123351	8604600048	5689598045	4494090448	9939185252	2099765054	5418311255
162	2541	3349100049	5346771 47	1309121549	1100123351	8604600048	5689598045	4494090448	7517960053	2099765054	2774175458
163	2542	3383770049	5444097 47	1315304849	1101434951	8717000048	5663712545	4463502248	7689793453	2116901154	2787368858
164	2512	3383770049	5611895 47	1315304849	1101434951	8717000048	5663712545	4463502248	9908509752	2116901154	5444079755
165	2712	3383770049	4853698 47	1315304849	1101434951	8717000048	5663712545	4463502248	8569818552	2116901154	5444079755
166	2742	3375840049	4972411 47	1324141949	1103203951	8725100048	5627070045	4336680348	7069273053	2141555954	2757265358
167	2311	3375840049	6464135 47	1324141949	1103203951	8725100048	5627070045	4336680348	1148756953	2141555954	5385283855
168	2311	3375840049	6215514 47	1324141949	1103203951	8725100048	5627070045	4336680348	1104573953	2141555954	5385283855
169	2311	3410310049	8905510 47	1330437849	1104512151	8837600048	5601293145	4302511148	1589902653	2159182054	5409619455
170	2311	3410310049	7431495 47	1330437849	1104512151	8837600048	5601293145	4302511148	1326746353	2159182054	5409619455
171	2311	3410310049	8414172 47	1330437849	1104512151	8837600048	5601293145	4302511148	1502183953	2159182054	5409619455
172	2311	3410310049	6448818 47	1330437849	1104512151	8837600048	5601293145	4302511148	1151308853	2159182054	5409619455
173	2312	3410310049	8229920 47	1330437849	1104512151	8837600048	5601293145	4302511148	1469289353	2159182054	5409619455
174	2312	3410310049	8229920 47	1330437849	1104512151	8837600048	5601293145	4302511148	1469289353	2159182054	5409619455

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
175	2211	3484260049	7498526 47	1337128649	1105949751	9057800048	5574196445	4315610348	1345221253	2177964054	5496193155
176	2111	3484260049	1349734 48	1337128649	1105949751	9057800048	5574196445	4315610348	2421398053	2177964054	5496193155
177	2341	3484260049	6958633 47	1337128649	1105949751	9057800048	5574196445	4315610348	9986921953	2177964054	2814050858
178	2342	3484260049	7558515 47	1337128649	1105949751	9057800048	5574196445	4315610348	1084786354	2177964054	2814050858
179	2211	3484260049	1103783 48	1337128649	1105949751	9057800048	5574196445	4315610348	1980165653	2177964054	5496193155
180	2111	3484260049	1319740 48	1337128649	1105949751	9057800048	5574196445	4315610348	2367589253	2177964054	5496193155
181	1711	4547200048	3389507 47	1308576949	1095663151	1137900048	5688979745	5661045047	5958023252	2100456354	7142516954
182	1711	4547200048	3766119 47	1308576949	1095663151	1137900048	5688979745	5661045047	6620025952	2100456354	7142516954
183	1711	4547200048	3860272 47	1308576949	1095663151	1137900048	5688979745	5661045047	6785526652	2100456354	7142516954
184	1711	4547200048	3813195 47	1308576949	1095663151	1137900048	5688979745	5661045047	6702776152	2100456354	7142516954
185	1711	4547200048	3389507 47	1308576949	1095663151	1137900048	5688979745	5661045047	5958023252	2100456354	7142516954
186	1711	4547200048	3671966 47	1308576949	1095663151	1137900048	5688979745	5661045047	6454525252	2100456354	7142516954
187	1712	4547200048	3766119 47	1308576949	1095663151	1137900048	5688979745	5661045047	6620025952	2100456354	7142516954
188	1742	4667400048	3620272 47	1311664949	1096289551	1169400048	5676001745	5757460747	5102566853	2109050854	3742667057
189	1741	4667400048	3757751 47	1311664949	1096289551	1169400048	5676001745	5757460747	5296335453	2109050854	3742667057
190	1542	4667400048	5270016 47	1311664949	1096289551	1169400048	5676001745	5757460747	7427787453	2109050854	3742667057
191	1542	4984800048	8566125 47	1318239449	1097624351	1252200048	5648575045	6029511547	1213208754	2127402954	3972623457
192	1541	5028500048	5857317 47	1319483949	1097873251	1263700048	5643411645	6059345947	8303228553	2130887554	4002455157
193	1541	5075900048	5464002 47	1321036149	1098182051	1276400048	5636984345	6087381047	7754504753	2135238054	4034319557
194	1541	5119500048	7831838 47	1322284749	1098430851	1288000048	5631825445	6116237447	1112511554	2138740354	4064219957
195	1541	5210400048	9898200 47	1325094649	1098988151	1312200048	5620249545	6171007547	1408934054	2146633754	4125131457
196	1341	5254000048	1175927 48	1326349049	1099236751	1323800048	5615097545	6198433547	1675379654	2150162054	4154669857
197	1341	5301200048	1056513 48	1327913649	1099545151	1336400048	5608684245	6223655547	1506968454	2154567454	4185510457
198	1341	5344300048	6811209 47	1329477749	1099852251	1348100048	5602287145	6243473647	9726326853	2158976554	4213401657
199	1341	5391900048	6354218 47	1330741749	1100101951	1360700048	5597129645	6274181547	9082110853	2162541554	4245670857
200	1511	5435300048	5596869 47	1332004249	1100350351	1372400048	5591987245	6299649147	1000873153	2166106054	8349664154
201	1511	5435300048	6105676 47	1332004249	1100350351	1372400048	5591987245	6299649147	1091861653	2166106054	8349664154
202	1511	5435300048	4814090 47	1332004249	1100350351	1372400048	5591987245	6299649147	8608908752	2166106054	8349664154
203	1511	5435300048	5283758 47	1332004249	1100350351	1372400048	5591987245	6299649147	9448802252	2166106054	8349664154
204	1512	5435300048	4266145 47	1332004249	1100350351	1372400048	5591987245	6299649147	7629032852	2166106054	8349664154
205	1512	5435300048	4892368 47	1332004249	1100350351	1372400048	5591987245	6299649147	8748890952	2166106054	8349664154
206	1312	5485600048	2633593 47	1337280249	1101363451	1387700048	5570586345	6250223047	4727676952	2181046454	8383973454
207	1312	5485600048	3485637 47	1337280249	1101363451	1387700048	5570586345	6250223047	6257219152	2181046454	8383973454
208	1312	5485600048	1161879 48	1337280249	1101363451	1387700048	5570586345	6250223047	2085739753	2181046454	8383973454
209	1312	5485600048	3872931 47	1337280249	1101363451	1387700048	5570586345	6250223047	6952465852	2181046454	8383973454

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
210	1312	5485600048	3640555 47	1337280249	1101363451	1387700048	5570586345	6250223047	6535317752	2181046454	8383973454
211	1311	5552600048	1138804 48	1342291549	1102322151	1407100048	5550413245	6223570647	2051747853	2195283454	8445169554
212	1311	5552600048	5655808 47	1342291549	1102322151	1407100048	5550413245	6223570647	1018988853	2195283454	8445169554
213	1311	5552600048	3859707 47	1342291549	1102322151	1407100048	5550413245	6223570647	6953909852	2195283454	8445169554
214	1311	5552600048	3401128 47	1342291549	1102322151	1407100048	5550413245	6223570647	6127702952	2195283454	8445169554
215	1311	5552600048	4471146 47	1342291549	1102322151	1407100048	5550413245	6223570647	8055519552	2195283454	8445169554
216	1311	5552600048	3286483 47	1342291549	1102322151	1407100048	5550413245	6223570647	5921151152	2195283454	8445169554
217	1341	5578700048	8135971 47	1344179049	1102681851	1414700048	5542853245	6213953447	1174264754	2200658054	4336494657
218	1341	5604300048	7716141 47	1346382249	1103099751	1422300048	5534054445	6196927747	1115441454	2206940254	4347181557
219	1342	5630000048	6021099 47	1348590849	1103517551	1429900048	5525262345	6179400747	8717920253	2213247054	4357756557
220	1342	5656000048	1437751 48	1350491649	1103876751	1437400048	5517718445	6168424847	2084559154	2218681754	4369712357
221	1342	5681600048	7376084 47	1352710549	1104294251	1445100048	5508937745	6149932747	1071144454	2225034854	4380376657
222	1342	5707100048	6078883 47	1354934749	1104711551	1452700048	5500164245	6130939247	8841747753	2231412354	4390627157
223	1211	5737100048	2937370 48	1356852249	1105071651	1461300048	5492624045	6122947947	5347845053	2236916854	8604650654
224	1211	5737100048	1573722 48	1356852249	1105071651	1461300048	5492624045	6122947947	2865156653	2236916854	8604650654
225	1211	5737100048	1507383 48	1356852249	1105071651	1461300048	5492624045	6122947947	2744377453	2236916854	8604650654
226	1111	5737100048	4348929 48	1356852249	1105071651	1461300048	5492624045	6122947947	7917763053	2236916854	8604650654
227	1111	5737100048	3538112 48	1356852249	1105071651	1461300048	5492624045	6122947947	6441570053	2236916854	8604650654
228	1111	5737100048	2948426 48	1356852249	1105071651	1461300048	5492624045	6122947947	5367974953	2236916854	8604650654
229	1111	5737100048	1971760 48	1356852249	1105071651	1461300048	5492624045	6122947947	3589833453	2236916854	8604650654
230	1111	5737100048	4330501 48	1356852249	1105071651	1461300048	5492624045	6122947947	7884213353	2236916854	8604650654
231	5711	1744679950	1771898 47	7971863049	1185829751	3944970049	1376943845	3313943849	1286834353	4967494255	7215674754
232	5711	1744679850	2053791 47	7971863049	1185829751	3944970049	1376943845	3313943849	1491558053	4967494255	7215674754
233	5711	1744679850	1946403 47	7971863049	1185829751	3944970049	1376943845	3313943849	1413568053	4967494255	7215674754
234	5712	1744679950	1919556 47	7971863049	1185829751	3944970049	1376943845	3313943849	1394070553	4967494255	7215674754
235	5712	1744679850	2147755 47	7971863049	1185829751	3944970049	1376943845	3313943849	1559799253	4967494255	7215674754
236	5712	1744679950	1919556 47	7971863049	1185829751	3944970049	1376943845	3313943849	1394070553	4967494255	7215674754
237	5511	1744679850	1825592 47	7971863049	1185829751	3944970049	137 943845	3313943849	1325829353	4967494255	7215674754
238	5511	1744679750	2067215 47	7971863049	1185829751	3944970049	1376943845	3313943849	1501306753	4967494255	7215674754
239	5511	1727163950	1936947 47	7785823249	1182945551	3910890049	1403132045	3274538149	1380445553	4772085755	7481128254
240	5512	1727163950	1964037 47	7785823249	1182945551	3910890049	1403132045	3274538149	1399752553	4772085755	7481128254
241	5512	1727163950	1964037 47	7785823249	1182945551	3910890049	1403132045	3274538149	1399752553	4772085755	7481128254
242	5311	1727163950	2113033 47	7785823249	1182945551	3910890049	1403132045	3274538149	1505940653	4772085755	7481128254
243	5311	1727163950	1936947 47	7785823249	1182945551	3910890049	1403132045	3274538149	1380445553	4772085755	7481128254
244	5312	1727163950	2180758 47	7785823249	1182945551	3910890049	1403132045	3274538149	1554207953	4772085755	7481128254

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
245	5312	1727163950	2532931 47	7785823249	1182945551	3910890049	1403132045	3274538149	1805198053	4772085755	7481128254
246	5312	1727163950	2505841 47	7785823249	1182945551	3910890049	1403132045	3274538149	1785891153	4772085755	7481128254
247	5311	1733162950	2256857 47	8026413849	1187390551	3920580049	1369455745	3260939349	1647996153	5021551055	7083303354
248	5211	1733162850	2473083 47	8026413849	1187390551	3920580049	1369455745	3260939349	1805888153	5021551055	7083303354
249	5211	1733162850	2473083 47	8026413849	1187390551	3920580049	1369455745	3260939349	1805888153	5021551055	7083303354
250	5111	1733162950	3213657 47	8026413849	1187390551	3920580049	1369455745	3260939349	2346667753	5021551055	7083303354
251	5111	1733163050	3236631 47	8026413849	1187390551	3920580049	1369455745	3260939349	2363443553	5021551055	7083303354
252	5312	1733162950	2162258 47	8026413849	1187390551	3920580049	1369455745	3260939349	1578918553	5021551055	7083303354
253	5741	1731658050	1698827 47	8021825349	1187343851	3917320049	1370079045	3256364749	9919590053	5016523555	3627644357
254	5741	1731658050	1655545 47	8021825349	1187343851	3917320049	1370079045	3256364749	9666861553	5016523555	3627644357
255	5742	1729857050	1732773 47	7998447049	1187009651	3914250049	1373269745	3251821549	1009429354	4991641655	3644999457
256	5742	1729857050	1800459 47	7998447049	1187009651	3914250049	1373269745	3251821549	1048860154	4991641655	3644999457
257	5541	1728427050	1883298 47	7998562549	1187034951	3910950049	1373252645	3247246249	1097131454	4991592855	3641903457
258	5541	1728427150	1923944 47	7998562549	1187034951	3910950049	1373252645	3247246249	1120810554	4991592855	3641903457
259	5542	1726203250	1871876 47	7975183749	1186687351	3906730049	1376460645	3241871949	1087936354	4966787355	3658268457
260	5542	1726203150	1980391 47	7975183749	1186687351	3906730049	1376460645	3241871949	1151005154	4966787355	3658268457
261	5542	1724773750	1832758 47	7975299549	1186712651	3903430049	1376443445	3237303249	1065213754	4966739755	3655153957
262	5341	1724773850	2280765 47	7975299549	1186712651	3903430049	1376443445	3237303249	1325599354	4966739755	3655153957
263	5341	1723405950	2336941 47	7951349649	1186195551	3899930049	1379751645	3238377849	1354992754	4942063955	3672311757
264	5342	1723406050	2282594 47	7951349649	1186195551	3899930049	1379751645	3238377849	1323481354	4942063955	3672311757
265	5342	1721175550	2298290 47	7928747049	1186047851	3897300049	1382883145	3228245049	1329564554	4917419655	3690333457
266	3131	9353970049	1055153 48	1341259449	1115732151	2568580049	5562970445	1364198549	7586978453	2186619454	9998555657
267	3131	9353970049	1019542 48	1341259449	1115732151	2568580049	5562970445	1364198549	7330923853	2186619454	9998555657
268	3132	9353970049	9789682 47	1341259449	1115732151	2568580049	5562970445	1364198549	7039176653	2186619454	9998555657
269	3132	9353970049	1251767 48	1341259449	1115732151	2568580049	5562970445	1364198549	9000710153	2186619454	9998555657
270	3132	9353970049	1035945 48	1341259449	1115732151	2568580049	5562970445	1364198549	7448864453	2186619454	9998555657
271	3631-	9361370049	6305236 47	1341336149	1115759351	2570870049	5562669045	1365306049	4533965153	2186832454	1000656458
272	3631-	9361370049	6322487 47	1341336149	1115759351	2570870049	5562669045	1365306049	4546369953	2186832454	1000656458
273	3631-	9361370049	6544594 47	1341336149	1115759351	2570870049	5562669045	1365306049	4706082353	2186832454	1000656458
274	3631-	9361370049	6544594 47	1341336149	1115759351	2570870049	5562669045	1365306049	4706082353	2186832454	1000656458
275	3632-	9490850049	6509697 47	1342679649	1116236251	2610910049	5557394045	1384674749	4685431753	2190565954	1014632458
276	3632-	9490850049	6157018 47	1342679649	1116236251	2610910049	5557394045	1384674749	4431586553	2190565954	1014632458
300	3531	9967260049	6871160 47	1353554249	1119252651	2766420049	5514602045	1432842849	4983975653	2220995154	1060680658
301	3631-	9967260049	6631796 47	1353554249	1119252651	2766420049	5514602045	1432842849	4810353753	2220995154	1060680658
302	3631-	9967260049	6517143 47	1353554249	1119252651	2766420049	5514602045	1432842849	4727190153	2220995154	1060680658

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
303	3631-	9967260049	6603636 47	1353554249	1119252651	2766420049	5514602045	1432842849	4789927553	2220995154	1060680658
304	3631-	9967260049	6637830 47	1353554249	1119252651	2766420049	5514602045	1432842849	4814730853	2220995154	1060680658
305	3731-	9967260049	6307950 47	1353554249	1119252651	2766420049	5514602045	1432842849	4575453153	2220995154	1060680658
306	3731-	9967260049	6315996 47	1353554249	1119252651	2766420049	5514602045	1432842849	4581289153	2220995154	1060680658
307	3731-	9967260049	6253641 47	1353554249	1119252651	2766420049	5514602045	1432842849	4536059753	2220995154	1060680658
308	3731-	9865260049	6417058 47	1371890849	1122922351	2756800049	5443199545	1342426549	4715651953	2272959554	1032304358
309	3711-	1018111050	6139714 47	1380443049	1125172151	2863410049	5410838945	1365990649	1134706653	2297294254	1657930856
310	3711-	1018111050	6139714 47	1380443049	1125172151	2863410049	5410838945	1365990649	1134706653	2297294254	1657930856
311	3611-	1018111050	6254932 47	1380443049	1125172151	2863410049	5410838945	1365990649	1156000453	2297294254	1657930856
312	3611-	1018111050	6295941 47	1380443049	1125172151	2863410049	5410838945	1365990649	1163579653	2297294254	1657930856
313	3311-	1018111050	9525931 47	1380443049	1125172151	2863410049	5410838945	1365990649	1760527653	2297294254	1657930856
314	3311-	1018111050	9067015 47	1380443049	1125172151	2863410049	5410838945	1365990649	1675713453	2297294254	1657930856
315	3321-	1018111050	9182232 47	1380443049	1125172151	2863410049	5410838945	1365990649	3394014453	2297294254	1326344757
316	3331-	1018111050	9414620 47	1380443049	1125172151	2863410049	5410838945	1365990649	6959822853	2297294254	1061075758
317	3331-	1018111050	9510309 47	1380443049	1125172151	2863410049	5410838945	1365990649	7030561653	2297294254	1061075758
318	3411-	1004075050	7300456 47	1378624949	1124578751	2818170049	5417622445	1347871349	1347538853	2292135054	1635198656
319	3411-	1004075050	7576057 47	1378624949	1124578751	2818170049	5417622445	1347871349	1398410153	2292135054	1635198656
320	3421-	1004075050	7264767 47	1378624949	1124578751	2818170049	5417622445	1347871349	2681902553	2292135054	1308158957
321	3421-	1004075050	7514593 47	1378624949	1124578751	2818170049	5417622445	1347871349	2774129553	2292135054	1308158957
322	3431-	1004075050	7472955 47	1378624949	1124578751	2818170049	5417622445	1347871349	5517516353	2292135054	1046527158
323	3511-	1004075050	6701668 47	1378624949	1124578751	2818170049	5417622445	1347871349	1237012853	2292135054	1635198656
324	3511-	1004075050	6727444 47	1378624949	1124578751	2818170049	5417622445	1347871349	1241770653	2292135054	1635198656
325	3521-	1004075050	6590635 47	1378624949	1124578751	2818170049	5417622445	1347871349	2433035953	2292135054	1308158957
326	3521-	1004075050	6721496 47	1378624949	1124578751	2818170049	5417622445	1347871349	2481345353	2292135054	1308158957
327	3531-	1004075050	6662013 47	1378624949	1124578751	2818170049	5417622445	1347871349	4918772953	2292135054	1046527158
328	3611-	1004075050	6463739 47	1378624949	1124578751	2818170049	5417622445	1347871349	1193095353	2292135054	1635198656
329	3611-	1004075050	6529169 47	1378624949	1124578751	2818170049	5417622445	1347871349	1205172653	2292135054	1635198656
330	3632-	9940010049	6108101 47	1385183549	1125752351	2794810049	5392712345	1304436649	4530634253	2310981254	1029127158
331	3632-	9940010049	5976056 47	1385183549	1125752351	2794810049	5392712345	1304436649	4432690653	2310981254	1029127158
332	3632-	9940010049	6054083 47	1385183549	1125752351	2794810049	5392712345	1304436649	4490566353	2310981254	1029127158
333	3532-	9940010049	6356187 47	1385183549	1125752351	2794810049	5392712345	1304436649	4714649453	2310981254	1029127158
334	3532-	9940020049	6122106 47	1385183549	1125752351	2794810049	5392712345	1304436649	4541022153	2310981254	1029127158
335	3532-	9940010049	6206135 47	1385183549	1125752351	2794810049	5392712345	1304436649	4603350053	2310981254	1029127158
336	3432-	9940010049	6358187 47	1385183549	1125752351	2794810049	5392712345	1304436649	4716133553	2310981254	1029127158
337	3432-	9940010049	6402202 47	1385183549	1125752351	2794810049	5392712345	1304436649	4748781453	2310981254	1029127158

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
338	3332-	9940010049	6272158 47	1385183549	1125752351	2794810049	5392712345	1304436649	4652321653	2310981254	1029127158
339	3332-	9940010049	6510240 47	1385183549	1125752351	2794810049	5392712345	1304436649	4828917253	2310981254	1029127158
340	3632-	9940020049	6254151 47	1385183549	1125752351	2794810049	5392712345	1304436649	4638965853	2310981254	1029127158
341	3632-	9940010049	6204135 47	1385183549	1125752351	2794810049	5392712345	1304436649	4601866153	2310981254	1029127158
342	3632-	9940010049	6176125 47	1385183549	1125752351	2794810049	5392712345	1304436649	4581090153	2310981254	1029127158
343	3532-	9159090049	6746230 47	1374441149	1122333051	2545580049	5432812145	1208409549	4967026753	2280495054	9492270157
344	3532-	9159090049	6973730 47	1374441149	1122333051	2545580049	5432812145	1208409549	5134526953	2280495054	9492270157
345	3532-	9159090049	7026229 47	1374441149	1122333051	2545580049	5432812145	1208409549	5173180853	2280495054	9492270157
346	3432-	9159090049	6951854 47	1374441149	1122333051	2545580049	5432812145	1208409549	5118420953	2280495054	9492270157
347	3432-	9159090049	7104979 47	1374441149	1122333051	2545580049	5432812145	1208409549	5231161853	2280495054	9492270157
348	3432-	9159090049	6851230 47	1374441149	1122333051	2545580049	5432812145	1208409549	5044334453	2280495054	9492270157
349	3332-	9159090049	6934354 47	1374441149	1122333051	2545580049	5432812145	1208409549	5105536253	2280495054	9492270157
350	3332-	9159090049	6842480 47	1374441149	1122333051	2545580049	5432812145	1208409549	5037892153	2280495054	9492270157
351	3741	1012161050	6616200 47	1392076049	1127434551	2858650049	5367028845	1309488849	9393548353	2330762454	7215948658
352	3741	1012076050	6626085 47	1392375949	1127493451	2858740049	5365909445	1308163549	9409546153	2331628454	7213444058
353	3741	1012076050	6600615 47	1392375949	1127493451	2858740049	5365909445	1308163549	9373377053	2331628454	7213444058
354	3741	1012076050	6565349 47	1392375949	1127493451	2858740049	5365909445	1308163549	9323296353	2331628454	7213444058
355	3741	1012076050	6641759 47	1392375949	1127493451	2858740049	5365909445	1308163549	9431804053	2331628454	7213444058
356	3741	1037077050	6666554 47	1395721849	1128571451	2940190049	5353677445	1338806149	9488644953	2341195254	7390349658
357	3741	1037077050	6657017 47	1395721849	1128571451	2940190049	5353677445	1338806149	9475070753	2341195254	7390349658
358	3441	1037077050	7133880 47	1395721849	1128571451	2940190049	5353677445	1338806149	1015380054	2341195254	7390349658
359	3441	1037077050	7095731 47	1395721849	1128571451	2940190049	5353677445	1338806149	1009950254	2341195254	7390349658
360	3641	1037077050	6811521 47	1395721849	1128571451	2940190049	5353677445	1338806149	9694979253	2341195254	7390349658
361	3641	1037077050	6819150 47	1395721849	1128571451	2940190049	5353677445	1338806149	9705838653	2341195254	7390349658
362	3642	1070350050	6594496 47	1401874149	1130348451	3051610049	5331227045	1372587349	9425609553	2358882954	7614990958
363	3642	1070350050	6537409 47	1401874149	1130348451	3051610049	5331227045	1372587349	9344013953	2358882954	7614990958
364	3641	1070350050	6872566 47	1401874149	1130348451	3051610049	5331227045	1372587349	9823059553	2358882954	7614990958
365	3641	1070350050	6872566 47	1401874149	1130348451	3051610049	5331227045	1372587349	9823059553	2358882954	7614990958
366	6521	6174710049	6012697 47	1329447449	1108525551	1640210049	5607980645	8459529848	2144335953	2154694754	8072392256
367	6521	6174710049	6012697 47	1329447449	1108525551	1640210049	5607980645	8459529848	2144335953	2154694754	8072392256
368	6521	6174710049	6006016 47	1329447449	1108525551	1640210049	5607980645	8459529848	2141953253	2154694754	8072392256
369	6521	6174710049	5985973 47	1329447449	1108525551	1640210049	5607980645	8459529848	2134805553	2154694754	8072392256
370	6521	6174710049	5985973 47	1329447449	1108525551	1640210049	5607980645	8459529848	2134805553	2154694754	8072392256
371	6511	6174710049	6079504 47	1329447449	1108525551	1640210049	5607980645	8459529848	1084080953	2154694754	1009049056
372	6511	6174710049	5989314 47	1329447449	1108525551	1640210049	5607980645	8459529848	1067998453	2154694754	1009049056

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
373	6511	6174710049	5989314 47	1329447449	1108525551	1640210049	5607980645	8459529848	1067998453	2154694754	1009049056
374	6511	6174710049	5912485 47	1329447449	1108525551	1640210049	5607980645	8459529848	1054298553	2154694754	1009049056
375	6511	6174710049	5905804 47	1329447449	1108525551	1640210049	5607980645	8459529848	1053107253	2154694754	1009049056
376	6501	6174710049	6079504 47	1329447449	1108525551	1640210049	5607980645	8459529848	5420404652	2154694754	1261311355
377	6501	6174710049	6046100 47	1329447449	1108525551	1640210049	5607980645	8459529848	5390622152	2154694754	1261311355
378	6501	6174710049	6019377 47	1329447449	1108525551	1640210049	5607980645	8459529848	5366796252	2154694754	1261311355
379	6501	6174710049	6002675 47	1329447449	1108525551	1640210049	5607980645	8459529848	5351904952	2154694754	1261311355
380	6501	6174710049	5995995 47	1329447449	1108525551	1640210049	5607980645	8459529848	5345948452	2154694754	1261311355
381	6501	6174710049	5722083 47	1329447449	1108525551	1640210049	5607980645	8459529848	2040693052	2154694754	8072392253
382	6501	6174710049	5645254 47	1329447449	1108525551	1640210049	5607980645	8459529848	2013293252	2154694754	8072392253
383	6501	6174710049	5621871 47	1329447449	1108525551	1640210049	5607980645	8459529848	2004954052	2154694754	8072392253
384	6501	6174710049	5545042 47	1329447449	1108525551	1640210049	5607980645	8459529848	1977554352	2154694754	8072392253
385	6501	6174710049	5538362 47	1329447449	1108525551	1640210049	5607980645	8459529848	1975171652	2154694754	8072392253
386	6611	6174710049	5357981 47	1329447449	1108525551	1640210049	5607980645	8459529848	9554207652	2154694754	1009049056
387	6611	6174710049	5344619 47	1329447449	1108525551	1640210049	5607980645	8459529848	9530381652	2154694754	1009049056
388	6611	6174710049	5324577 47	1329447449	1108525551	1640210049	5607980645	8459529848	9494642752	2154694754	1009049056
389	6611	6174710049	5324577 47	1329447449	1108525551	1640210049	5607980645	8459529848	9494642752	2154694754	1009049056
390	6611	6174710049	5324577 47	1329447449	1108525551	1640210049	5607980645	8459529848	9494642752	2154694754	1009049056
391	6601	6174710049	5371342 47	1329447449	1108525551	1640210049	5607980645	8459529848	4789016952	2154694754	1261311355
392	6601	6174710049	5354640 47	1329447449	1108525551	1640210049	5607980645	8459529848	4774125652	2154694754	1261311355
393	6601	6174710049	5344619 47	1329447449	1108525551	1640210049	5607980645	8459529848	4765190952	2154694754	1261311355
394	6601	6174710049	5334598 47	1329447449	1108525551	1640210049	5607980645	8459529848	4756256152	2154694754	1261311355
395	6601	6174710049	5334598 47	1329447449	1108525551	1640210049	5607980645	8459529848	4756256152	2154694754	1261311355
396	6601	6174710049	5344619 47	1329447449	1108525551	1640210049	5607980645	8459529848	1906076352	2154694754	8072392253
397	6601	6174710049	5344619 47	1329447449	1108525551	1640210049	5607980645	8459529848	1906076352	2154694754	8072392253
398	6601	6174710049	5364661 47	1329447449	1108525551	1640210049	5607980645	8459529848	1913224252	2154694754	8072392253
399	6601	6174710049	5364661 47	1329447449	1108525551	1640210049	5607980645	8459529848	1913224252	2154694754	8072392253
400	6601	6174710049	5371342 47	1329447449	1108525551	1640210049	5607980645	8459529848	1915606752	2154694754	8072392253
401	3441-	1037077050	7082379 47	1395721849	1128571451	2940190049	5353677445	1338806149	1058320054	2341195254	8552046158
402	3441-	1037077050	7179659 47	1395721849	1128571451	2940190049	5353677445	1338806149	1072856554	2341195254	8552046158
403	3641-	1037077050	6798168 47	1395721849	1128571451	2940190049	5353677445	1338806149	1015850354	2341195254	8552046158
404	3641-	1037077050	6786724 47	1395721849	1128571451	2940190049	5353677445	1338806149	1014140154	2341195254	8552046158
405	3741-	1037077050	6714240 47	1395721849	1128571451	2940190049	5353677445	1338806149	1003309054	2341195254	8552046158
406	3741-	1037077050	6739037 47	1395721849	1128571451	2940190049	5353677445	1338806149	1007014454	2341195254	8552046158
407	3741-	1037077050	6706611 47	1395721849	1128571451	2940190049	5353677445	1338806149	1002168954	2341195254	8552046158

Run No.	Run Code	$\Delta C_{H_2SO_4}$ (M)	k_L (cm/sec)	$\mu_{Av.}$ (poise)	ρ_o (gm/cm^3)	$\Delta \rho_D$ (gm/cm^3)	$D_{Cu^{++}Av.}$ (cm^2/sec)	$t_{Cu^{++}Av.}$	Nu'	Sc	Gr
408	3741-	1037077050	6689443 47	1395721849	1128571451	2940190049	5353677445	1338806149	9996035653	2341195254	8552046158
409	3741-	1037077050	6723778 47	1395721849	1128571451	2940190049	5353677445	1338806149	1004734254	2341195254	8552046158
410	3741-	1037077050	6752389 47	1395721849	1128571451	2940190049	5353677445	1338806149	1009009654	2341195254	8552046158
411	7921	1160944050	1597082 47	8066895149	1217810551	2704100049	1361818945	1240744849	2345513653	4919958855	3970017355
412	7931	1160944050	1603079 47	8066895149	1217810551	2704100049	1361818945	1240744849	4708640853	4919958855	3176013756
413	7721	1160944050	1619069 47	8066895149	1217810551	2704100049	1361818945	1240744849	2377804953	4919958855	3970017355
414	7731	1160944050	1613073 47	8066895149	1217810551	2704100049	1361818945	1240744849	4737996553	4919958855	3176013756
415	7521	1160944050	1695026 47	8066895149	1217810551	2704100049	1361818945	1240744849	2489356353	4919958855	3970017355
416	7531	1160944050	1677036 47	8066895149	1217810551	2704100049	1361818945	1240744849	4925872353	4919958855	3176013756
417	7421	1160944050	1744997 47	8066895149	1217810551	2704100049	1361818945	1240744849	2562745353	4919958855	3970017355
418	7431	1160944050	1740999 47	8066895149	1217810551	2704100049	1361818945	1240744849	5113748153	4919958855	3176013756
419	7321	1160944050	1838943 47	8066895149	1217810551	2704100049	1361818945	1240744849	2700716553	4919958855	3970017355
420	7331	1160944050	1884917 47	8066895149	1217810551	2704100049	1361818945	1240744849	5536469253	4919958855	3176013756
421	8911	1019930050	2188373 47	5229698349	1169305351	2430290049	1928528345	1178133149	1134737653	2343949455	1018995455
422	8941	1019930050	2179468 47	5229698349	1169305351	2430290049	1928528345	1178133149	9040960953	2343949455	5217256357
423	8711	1019930050	2183921 47	5229698349	1169305351	2430290049	1928528345	1178133149	1132428853	2343949455	1018995455
424	8741	1019930050	2210635 47	5229698349	1169305351	2430290049	1928528345	1178133149	9170249153	2343949455	5217256357
425	8511	1019930050	2388733 47	5229698349	1169305351	2430290049	1928528345	1178133149	1238630153	2343949455	1018995455
426	8541	1019930050	2257386 47	5229698349	1169305351	2430290049	1928528345	1178133149	9364182053	2343949455	5217256357
427	8411	1019930050	2395411 47	5229698349	1169305351	2430290049	1928528345	1178133149	1242093253	2343949455	1018995455
428	8441	1019930050	2384280 47	5229698349	1169305351	2430290049	1928528345	1178133149	9890571053	2343949455	5217256357
429	8311	1019930050	2500044 47	5229698349	1169305351	2430290049	1928528345	1178133149	1296348253	2343949455	1018995455
430	8341	1019930050	2573509 47	5229698349	1169305351	2430290049	1928528345	1178133149	1067553754	2343949455	5217256357
431	9911	1312318050	4088901 47	2782917049	1147435251	3469710049	3217190245	1587347649	1270954353	7657479554	5040157055
432	9931	1312318050	4088901 47	2782917049	1147435251	3469710049	3217190245	1587347649	5083817253	7657479554	3225700557
433	9711	1312318050	4185111 47	2782917049	1147435251	3469710049	3217190245	1587347649	1300859153	7657479554	5040157055
434	9731	1312318050	4233215 47	2782917049	1147435251	3469710049	3217190245	1587347649	5263245953	7657479554	3225700557
435	9511	1312318050	4329425 47	2782917049	1147435251	3469710049	3217190245	1587347649	1345716353	7657479554	5040157055
436	9531	1312318050	4345460 47	2782917049	1147435251	3469710049	3217190245	1587347649	5402802153	7657479554	3225700557
437	9411	1312318050	4489774 47	2782917049	1147435251	3469710049	3217190245	1587347649	1395557753	7657479554	5040157055
438	9431	1312318050	4441669 47	2782917049	1147435251	3469710049	3217190245	1587347649	5522421153	7657479554	3225700557
439	9311	1312318050	4730298 47	2782917049	1147435251	3469710049	3217190245	1587347649	1470319753	7657479554	5040157055
440	9331	1312318050	4746333 47	2782917049	1147435251	3469710049	3217190245	1587347649	5901215653	7657479554	3225700557

Appendix IV. Nomenclature

Symbol	Definition	Dimensions
a	Constant in correlation equation	---
a	Activity	---
b	Constant in correlation equation	---
c	Constant in correlation equation	---
C	Concentration	moles/liter; M
d	Electrode-size factor	---
D	Diffusion coefficient	cm^2/sec
E	Polarization voltage	volts
F	Faraday's constant	96,500 coulombs/equiv
g	Acceleration of gravity	981 cm/sec^2
I_L	Limiting current density	$amps/cm^2$
k_L	Over-all mass-transfer coefficient	cm/sec
n	Number of electrons transferred in electrode reaction	---
R	Universal gas constant	1.987 cal/gm-mole-^oC
t	Transference number	---
T	Temperature	^oK
u	Mobility	cm/sec
x	Characteristic dimension	cm
Greek letters		
Δ	Difference	---
μ	Viscosity	gm/cm-sec
$\nu = \frac{\mu}{\rho}$	Kinematic viscosity	cm^2/sec
ρ	Density	gm/cm^3
Subscripts		
o	Bulk property	
i	Interface property	
Av.	Average property	
n	Major-electrode dimension	

Dimensionless groups

Nu'	$= k_L\, x / D$	Nusselt number for mass transfer
Gr	$= g\,(\rho_o - \rho_i)\, x^3 / \rho_i\, \nu_{Av.}^2$	Grashof number
Sc	$= \nu_{Av.} / D_{Av.}$	Schmidt number.

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