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William W. Hintalla

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A Thesis
Submitted to the Department of Metallurgy
in Partial Fulfillment of the
Requirements for the Degree of
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COPPER-ALUMINUM ALLOYS

Among the many aluminum alloys which have been studied are the binary copper-aluminum alloys. These have proven to be among the most useful of the aluminum alloys thus far worked upon. At first nickel-aluminum alloys were approved as the standard castings. Now, however, the copper-aluminum series (especially No. 12 alloy: 92%Al, 8%Cu) are the standard. These may contain varying amounts of other metals such as iron, manganese, magnesium or nickel.

The copper-aluminum alloys series may be divided into three parts: light casting alloys, intermediate alloys, and aluminum bronzes. Of these three groups the useful ones are the light metal alloys (those containing less than 15% Cu) and the aluminum bronzes (those containing less than 11% Al).

The first class embraces those alloys most applicable to general casting purposes in the aluminum industry. The addition of copper has the effect of increasing the tensile strength and hardness, reducing the shrinkage, and improving the machining qualities of the pure aluminum. The alloying also has the effect of decreasing the elongation thereby detracting from the toughness of the metal. A limiting factor in the amount of copper to be added is the specific gravity of the alloy, which should be kept as low as possible. It has been found that an alloy containing more than about 15% copper is not of practical use. However, if the copper content is kept well within this limit, the material is sufficiently tough for most uses.

Alloys of this class cast well. Because of the nature of their constituents they are not so liable to be "burned" in the foundry as are alloys containing more volatile metals.

The aluminum bronzes are those alloys containing less than 11% aluminum. A large amount of aluminum makes the material hard and brittle (just as an increasing amount of copper makes the light metal alloys brittle). The tensile strength of the aluminum bronzes is quite high (80,000 to 110,000 lbs/sq. in.). They are also ductile, have a high resistance to corrosion, and have good working properties (hot or cold).

The disadvantages of the high copper alloys are the high cost, difficulty of melting and pouring (melting point copper 1083 deg. C.), excessive shrinkage, piping and tearing, and season cracking. Another great disadvantage is the difficulty of disposing of the scrap metal.

Intermediate alloys of the copper-aluminum series (from 15% to 90% Cu) give crystalline, brittle, grayish-white alloys which are of no use in the arts. However, the intermediate alloys are ordinarily used as a vehicle in foundry practice to introduce the minor metal into the alloy. The red color of the copper does not begin to show until the copper content reaches about 80%.

The equilibrium diagram of the copper-aluminum series (Figure 1) has been studied by many authorities.1) The diagram as presented here must be regarded in parts as tentative. This explanation will cover only that portion of the field containing less than 15% aluminum and that containing less than 10% copper.

At room temperature copper holds 10% aluminum in solid solution. With an increase in temperature the solubility decreases being 7% at the eutectic point (1083 deg. C.). A distinguishing feature here is the narrow freezing range for the α phase--the solidus and liquidus are practically one line. The range for pure α alloys corresponds to the first branch of the liquidus

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1) Bradley-Jones: Inst. of Metals Journal 625
Stockdale: J. Inst. Metals <u>28</u>, 273
Curry: J. Phys. Chem. <u>11</u>, 425
Gwyer: Z. anorg. Chem. <u>57</u>, 117

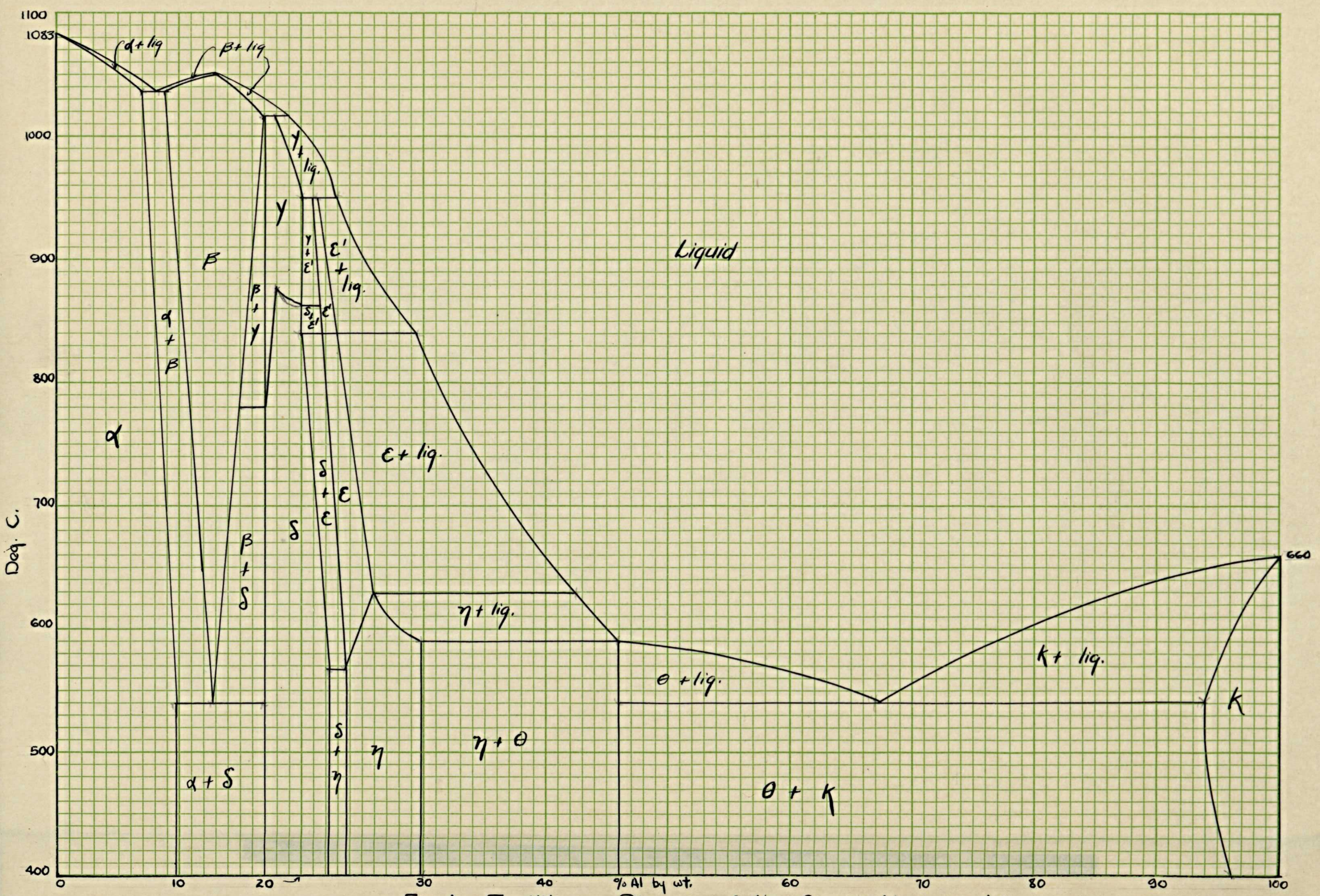

FIG. 1. Equilibrium Diagram of the Copper-Aluminum Alloys

curve. This ends at the $\alpha + \beta$ eutectic point, the eutectic range being only about 2%.

From the minimum the liquidus curve rises to a maximum which corresponds to the compound Cu_3Al. This compound forms solid solutions with the neighbouring phases and undergoes a eutectoid inversion at about 520 deg. C. Alloys containing much of the compound lose their ductility. This is an illustration of the fact that, in general, only alloys near the ends of a binary series are useful materials for practical purposes where strength and toughness are required.

On the aluminum end the diagram is comparatively simple. The limit of solid solubility of copper in aluminum is about 5% at the eutectic temperature and 1.5% at 300 deg. C. The compound $CuAl_2$ is found at 46% aluminum. Alloys containing any of the eutectic of $CuAl_2$ with aluminum are weak and brittle.

ELECTRICAL RESISTIVITY OF METALS AND ALLOYS

The investigation of the electrical resistivity of alloys is now considered a most important phase in the research concerning alloy systems. In regard to electrical conductivity it has been found that pure metals are the best conductors,1) and the presence of any foreign element decreases the conductivity. This reduction is particularly true in cases where a solid solution is formed. Even when the added metal is a better conductor, this decrease generally occurs.

Reduced conductivity in solid solutions is explained as follows. Atoms of the two metals concerned, having a certain resemblance, enter side by side into the same crystal lattice. Hence, a mixed crystal is formed. In this now distorted structure the electrons find difficulty in moving from atom to atom. Thus the resistance of the alloy becomes greater. The curve for a binary system in which there is complete solid solubility.is generally a U-shaped curve such as is shown in Figure 2, page 7.

In alloys where no solid solutions are formed, the two metals are in a state of simple mechanical mixture. There is no intermingling of molecules, and thus each metal retains its original electrical conductivity.

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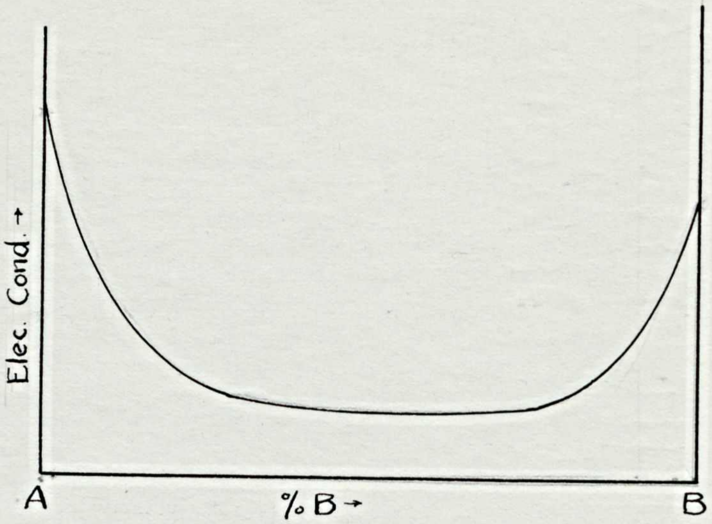
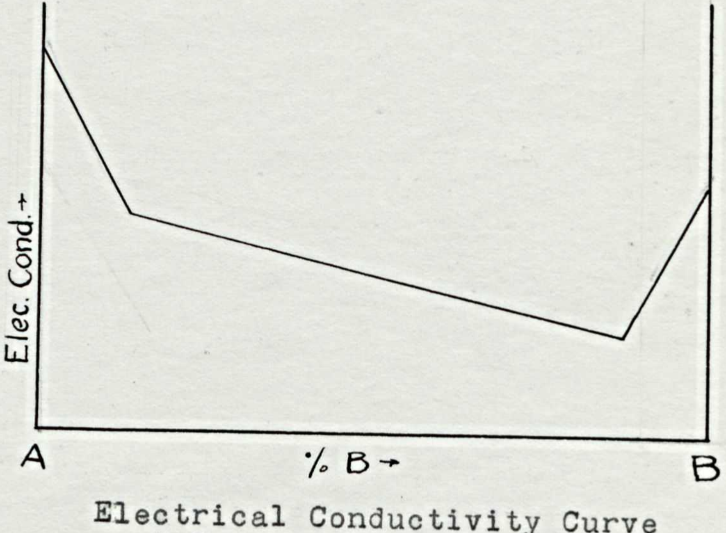
1) Rosenhain: "Introduction to Physical Metallurgy"

Fig. 2



Electrical Conductivity Curve
A-B mutually soluble in
solid state

Fig. 3



Electrical Conductivity Curve
A-B partially soluble in
solid state

The conductivity of the alloy is then the arithmetic mean of that of its two constituents. The curve of concuctivities should be a straight line joining the conductivities of the two metals. However, in any case there must be a slight degree of mutual solid solubility between any two metals.[1] Therefore in the majority of binary alloys of the eutectiferous type the curve of conductivity drops sharply at either end for a short distance. A typical curve is shown in Figure 3, page 7.

In the case of more complex alloys, containing either compounds or series of solid solutions which are based upon definite compounds, the conductivity curve assumes more complex shapes. If there is any sudden change in structure and constiturion, there is a corresponding change in the conductivity curve. However, it is not to be concluded that because the conductivity curve shows no deflection no line of the diagram can have been crossed. As a rule the existence of a definite break in a binary system is indicated by a break in the conductivity curve.

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1) Rosenhain: "Introduction to Physical Metallurgy"

EXPERIMENTATION

A master alloy was prepared containing 50% aluminum and 50% copper, from which were made all the test specimens containing various percentages of copper and aluminum. The metals were charged into graphite crucibles, covered with borax or carbon to prevent oxidation, and melted in an electric resistance furnace. The test specimens were made by melting first the pure metal and then bringing it to the desired compostion by the addition of the proper amount of master alloy.

The melts were cast into graphite molds, which produced ingots about ½" x ¼" x2". These were then rolled or hammered out to as small a cross-section as possible.

The high aluminum alloys proved quite difficult to cast and to hammer out. They are not amenable to cold work, and if heated to high temperatures will disintegrate upon hammering. Therefore a careful temperature control must be maintained during hammering.

The high copper alloys were more amenable to hammering. The addition of aluminum has a hardening effect on the copper, and in case of a 15% aluminum alloy it was impossible to draw a wire.

The ingots, after having been hammered out to as small a cross-section as possible, were then drawn by hand through a Le Joubert die into wires having a diameter of 0.0336 inches. In order to facilitate drawing the wires were heated and quenched after several passes through the die.

The wires were then annealed under the same conditions in a tube furnace. A reducing atmosphere was maintained by passing natural gas through the tube. The wires were kept at a temperature of 500 deg. C. for one hour. They were all slowly cooled intthe furnace in the reducing atmosphere.

Resistances were measured with a semi-precision Wheatstone bridge to 0.00001 ohm. All wires were measured at the same temperature (1 deg. C.) in a beaker of ice and water.

In Figure 4, page 11, are plotted the calculated specific conductances against the volume percentage of the metals. The obtained curve is rather short but follows the curve obtained from plotting data from volume 6 of the International Critical Tables. That the curves do not coincide is explained by the fact that resistances were measured at different temperatures. The curve obtained from data from the International Critical Tables shows lower specific conductances at a higher temperatures. This is in accordance with the fact that metallic conductors,

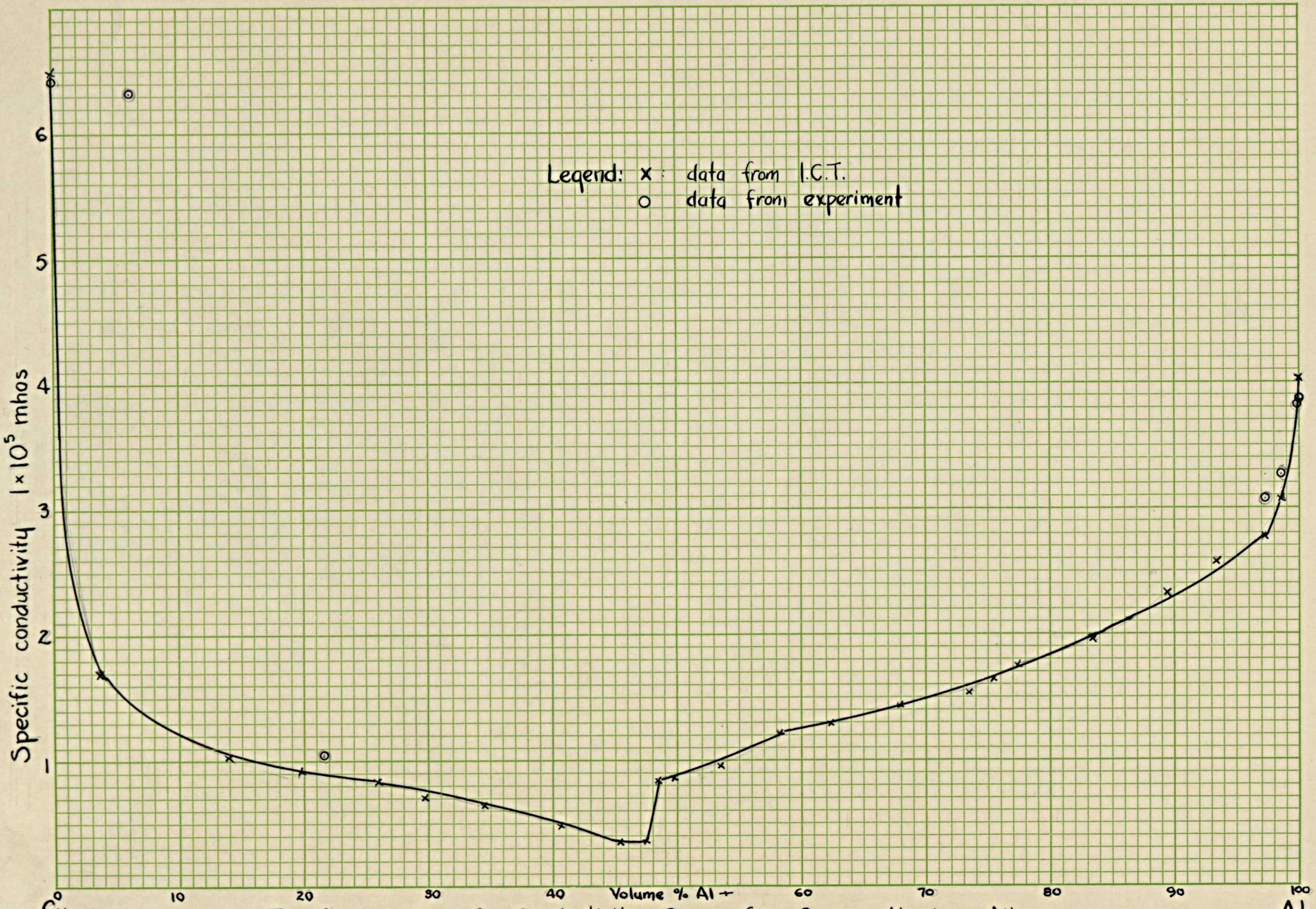

Fig. 4. Specific Conductivity Curve for Copper~Aluminum Alloys

as a general rule, have a higher resistance at high temperatures.[1] The units of the crystal lattice are in thermal agitation thus making it more difficult for the electrons to pass through. There is a distinct break in the curve at about 48% of aluminum by volume or about 78% copper by weight, where according to the diagram, there is a compound. No distinct breaks are shown for the other compounds present.

SUMMARY

The conductivity of the aluminum wire was found to be about 60% of the copper value. The addition of copper lowers the conductivity. With 4.35% copper the conductivity was about 86% of the aluminum value, and with 8.60% copper it dropped to 80%.

The addition of aluminum likewise lowered the conductivity of the copper. With 7.79% aluminum the conductivity value drops to only 16%.

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1) Getman: "Outline of Theoretical Chemistry"

TABLE I.

RESISTIVITIES

Length of wire	36 inches
Diameter of wire	0.0336 inches
Temperature	1 deg. C.

WIRE	RESISTIVITY--OHMS
Cu	0.02490
Al	0.04144
Cu - Al (97.52) (2.48)	0.02526
Cu - Al (92.21) (7.79)	0.15670
Al - Cu (99.83) (0.17)	0.04151
Al- Cu (95.65) (4.35)	0.04885
Al - Cu (91.40) (8.60)	0.05187

Percentages of metals are given in parentheses.

TABLE II.

SPECIFIC CONDUCTANCES

If R is resistance of wire in ohms

l is length of wire in centimeters

a is area in square centimeters

ρ is specific resistance

$\Lambda = \frac{1}{\rho} =$ specific conductance

$\rho = R\frac{l}{a}$

$\Lambda = \frac{1}{\rho} = \frac{l}{aR}$

Example of calculations:

Cu wire:

$$\Lambda = \frac{36 \times 2.54}{(0.0336)^2 \times \quad \times 2.54^2 \times 0.02490}$$

$$\Lambda = 6.41 \times 10^5$$

WIRE	SP. COND.	WT. ANALYSIS	VOL. ANAL.
Cu	6.41×10^5	100%	100%
Al	3.86	100	100
Cu-Al	6.32	Cu 97.52 Al 2.48	Cu 92.2 Al 87.8
Cu-Al	1.025	Cu 92.21 Al 7.79	Cu 78.1 Al 21.9
Cu-Al	3.84	Cu 0.17 Al 99.83	Cu 0.01 Al 99.99
Cu-Al	3.27	Cu 4.35 Al 95.65	Cu 1.5 Al 98.5
Cu-Al	3.08	Cu 8.60 Al 91.40	Cu 2.8 Al 97.2

TABLE III.

SPECIFIC CONDUCTANCES AT ROOM TEMPERATURE[1)]

SP. COND.	%Cu(wt.)	%Cu(vol.)
4.02×10^5	0.0%	0.0%
3.09	3.8	1.2
2.79	8.7	2.8
2.54	18.5	6.5
2.32	28.2	11.7
1.967	39.2	16.3
1.740	48.4	22.8
1.652	51.3	24.3
1.517	54.0	26.5
1.410	60.5	32.0
1.300	66.9	37.9
1.210	70.3	41.8
0.980	74.4	46.9
0.862	77.1	50.7
0.885	78.0	51.9
0.355	78.6	52.7
0.346	79.8	54.7
0.482	82.6	59.2
0.633	86.1	65.14
0.730	89.0	71.1
0.847	90.5	74.3
0.922	93.1	80.5
1.006	95.3	86.0
1.710	98.8	96.2
6.500	100.0	100.0

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1) International Critical Tables, Volume 6, page 167

ACKNOWLEDGEMENTS

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