# The Diffusion of Zinc in Copper and its Alloys[1]

By

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Iron or steel coated with brass stands comparison with brass in the properties relating to its surface such as resistance against corrosion, while in mechanical properties it is superior owing to the iron or steel inside. Brass coating can be done by the following methods: 1. Electro-plating; 2. metal spraying; 3. the dip process, and 4. the method in which iron or steel is first coated with copper and then the latter is converted into brass by zinc diffusion brought about by heating it in contact with zinc vapour.

The diffusion of zinc in copper is an important problem to the author, who has studied the last two methods.

A number of investigations[2] have been carried out in connection with this problem, but all of them except that of Elam[3], who heated copper in contact with zinc vapour and examined the microstructure, were made with specimens in which these two metals came in contact with each other.

Dunn[4] studied the rate of diffusion in solid brass by measuring the loss of zinc observed on weighing after heating at different temperatures for different periods of time in vacuo. He found the relation between the amount of zinc lost and the composition of brass, as well as the temperature and the duration of heating, but his study is

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1. This was read in part at the Meeting of the Chemical Society of Japan, April. 1930.

2. O. F. Hudson: Journ. Inst. Metals, **12**, 94 (1914); J. H. Andrew and R. Higgin: Ibid., **28**, 185 (1922); O. Bauer and E. Piwowarsky: Metal u. Erz, **20**, 416 (1923); S. L. Hoyt: Amer. Inst. Min. Met. Eng. Tech. Publ., No. 128 (1928); W. Kohler: Journ. Inst. Metals, **39**, 493 (1928) (Abstract).

3. C. F. Elam: The Inst. of Metals, Advanced Copy, No. 158 (1930).

4. J. S. Dunn: Journ. Chem. Soc., 2973 (1926).

restricted within the $\alpha$ range. The author therefore studied this problem in connection with his coating practice, as described below.

## I. Experiments with Copper and Zinc

### 1. Specimen

Cast Copper :—Pure electrolytic copper was melted in a graphite crucible in a coke fired oven, molten sodium chloride being used as a cover, and cast in a preheated iron mould with a hole 12 mm. square in section and 170 mm. in length. Specimens of 5 mm. in thickness were prepared by cutting these bars.

Rolled Copper Plate :—Rectangular specimens, 14 mm. in width and 26 mm. in length, were prepared from rolled pure electrolytic copper plate of about 0.9 mm. thickness.

### 2. Experimental Procedure

After being weighed and its surface area measured, a cast copper specimen was placed on a support in the centre of a porcelain boat. Pure granular zinc was placed on both sides of this support so that it was not in contact with the specimen. Then the boat was placed in the centre of a glazed porcelain tube which was put into a nichrome furnace.

A slow current of purified dry hydrogen was first passed through the tube for 15—20 minutes in order to replace the air, whereupon the cork provided at the end of apparatus was closed so as to cut off the flow of hydrogen, but the whole apparatus was thus protected from air by hydrogen under pressure. Now it was heated to the desired temperature[1] and kept at that temperature, with variations within $\pm 3^{\circ}$C., for the desired period and then cooled. The specimen was then weighed. The amount of zinc[2] diffused in the copper per unit surface was calculated by dividing the total weight increase by the surface area of the specimen.

In the experiments with copper plate specimen, the porcelain boat, 13.8 mm. in width and 25.7 mm. in length and containing pure granular zinc at the bottom, was covered with the specimen.

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1. It reaches 900°C. within 10 minutes.
2. This was checked by analysis in a few cases.

## 3. The Influence of Temperature

The experimental values obtained by keeping the specimen for half an hour at temperatures ranging from 400° to 650°C. are given in Tables I and II.

Table I

Cast Copper: Duration of Heating=30 minutes

| Temp. °C | $1/T \times 10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-increase | | $\log \Delta W$ |
|---|---|---|---|---|---|---|
| | | | | in gms. | in gms./sq. cm. $\Delta W$ | |
| 405 | 1.4749 | 5.7634 | 4.87 | 0.0045 | 0.0009 | $\bar{4}.9657$ |
| 434 | 1.4144 | 5.9904 | 4.75 | 0.0104 | 0.0022 | $\bar{3}.3403$ |
| 450 | 1.3834 | 6.7194 | 5.09 | 0.0173 | 0.0034 | $\bar{3}.5313$ |
| 457 | 1.3699 | 5.3337 | 4.67 | 0.0198 | 0.0042 | $\bar{3}.6274$ |
| 478 | 1.3316 | 5.8217 | 4.60 | 0.0307 | 0.0067 | $\bar{3}.8244$ |
| 501 | 1.292 | 5.9481 | 5.01 | 0.0599 | 0.0120 | $\bar{2}.0776$ |
| 506 | 1.2837 | 6.8571 | 5.07 | 0.0623 | 0.0123 | $\bar{2}.0895$ |
| 550 | 1.215 | 5.3627 | 4.73 | 0.1602 | 0.0339 | $\bar{2}.5298$ |
| 554 | 1.2092 | 5.8396 | 4.94 | 0.1664 | 0.0337 | $\bar{2}.5274$ |
| 590 | 1.1588 | 5.2748 | 4.29 | 0.2764 | 0.0644 | $\bar{2}.8091$ |
| 601 | 1.1442 | 5.6571 | 4.87 | 0.3797 | 0.0780 | $\bar{2}.8919$ |
| 602 | 1.1428 | 4.8060 | 4.37 | 0.3370 | 0.0771 | $\bar{2}.8872$ |

Fig. 1

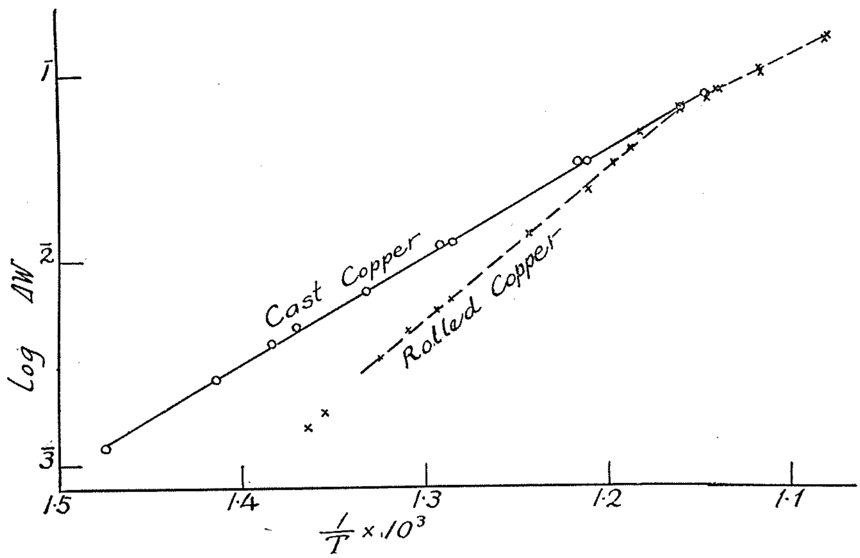


Table II

Rolled Copper: Duration of Heating=30 minutes

| Temp. °C | $1/T\times10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-increase | | log$\Delta$W |
|---|---|---|---|---|---|---|
| | | | | in gms. | in gms./sq. cm. $\Delta$W | |
| 460 | 1.3643 | 2.9198 | 3.72 | 0.0044 | 0.0012 | 3.073 |
| 465 | 1.355 | 2.8308 | 3.66 | 0.0052 | 0.0014 | 3.1525 |
| 480 | 1.328 | 2.8248 | 3.64 | 0.0102 | 0.0028 | 3.4475 |
| 491 | 1.309 | 2.7575 | 3.50 | 0.0141 | 0.0040 | 3.605 |
| 500 | 1.2937 | 2.9234 | 3.74 | 0.0196 | 0.0052 | 3.7194 |
| 505 | 1.2854 | 2.8100 | 3.62 | 0.0217 | 0.0060 | 3.7778 |
| 532 | 1.2422 | 2.9094 | 3.76 | 0.0509 | 0.0135 | $\bar{2}$.1315 |
| 554 | 1.2091 | 2.8898 | 3.70 | 0.0867 | 0.0234 | $\bar{2}$.3698 |
| 563 | 1.1962 | 2.9204 | 3.76 | 0.1231 | 0.0328 | $\bar{2}$.515 |
| 571 | 1.1862 | 2.9213 | 3.71 | 0.1458 | 0.0393 | $\bar{2}$.5943 |
| 583 | 1.1683 | 2.8700 | 3.66 | 0.1776 | 0.0485 | $\bar{2}$.686 |
| 590 | 1.1588 | 2.8372 | 3.68 | 0.2316 | 0.0629 | $\bar{2}$.799 |
| 590 | 1.1588 | 2.8478 | 3.64 | 0.2346 | 0.0645 | $\bar{2}$.8092 |
| 601 | 1.1442 | 2.8630 | 3.64 | 0.2668 | 0.0733 | $\bar{2}$.865 |
| 605 | 1.1392 | 2.8892 | 3.67 | 0.3002 | 0.0818 | $\bar{2}$.9127 |
| 607 | 1.1364 | 2.9284 | 3.67 | 0.3046 | 0.0830 | $\bar{2}$.919 |
| 624 | 1.1148 | 2.8553 | 3.68 | 0.3939 | 0.1070 | $\bar{1}$.0295 |
| 625 | 1.1136 | 2.9210 | 3.75 | 0.3784 | 0.1009 | $\bar{1}$.0039 |
| 625 | 1.1136 | 2.9081 | 3.71 | 0.3799 | 0.1024 | $\bar{1}$.0103 |
| 654 | 1.0788 | 2.9308 | 3.74 | 0.5703 | 0.1525 | $\bar{1}$.1832 |
| 655 | 1.0776 | 2.8407 | 3.63 | 0.5901 | 0.1626 | $\bar{1}$.211 |
| 655 | 1.0776 | 2.8431 | 3.70 | 0.6049 | 0.1635 | $\bar{1}$.2135 |

In Fig. 1, the logarithm of the amount of zinc diffused into copper per unit area (log $\Delta W$) is plotted against the reciprocal of the absolute temperature ($1/T$).

As straight lines are obtained for both cast copper and rolled copper, the relation between $\Delta W$ and $T$ will be expressed by the following equation

$$\Delta W = A e^{-\frac{B}{T}}$$

where $A$ and $B$ are constant.

At low temperatures, the amount of zinc diffused per unit area gives lower values for rolled copper than for cast copper. As the temperature rises, however, the former gradually approaches the latter, with the removal of its deformation owing to the recrystallisation, so that both give the same value at about 600°C.

## 4. The Influence of Time

To study how the diffusion is related to time, the both cast and rolled specimens were heated in contact with zinc vapour at certain

Table III

Cast Copper

| Temp. °C | Weight of Specimen in gms. | Surface Area. of Specimen in sq. cms. | Time in hrs. | Weight-increase | |
|---|---|---|---|---|---|
| | | | | in gms. | in gms./sq. cm. |
| 435 | 5.3640 | 4.34 | 0.5 | 0.0071 | 0.0016 |
| | 5.9904 | 4.75 | 0.5 | 0.0104 | 0.0022 |
| | 5.8050 | 4.60 | 1.0 | 0.0135 | 0.0029 |
| | 5.5650 | 4.53 | 1.5 | 0.0192 | 0.0042 |
| | 6.1595 | 4.75 | 2.0 | 0.0240 | 0.0051 |
| | 5.5413 | 4.56 | 2.5 | 0.0277 | 0.0061 |
| | 6.0257 | 4.70 | 3.0 | 0.0312 | 0.0066 |
| 478 | 5.8217 | 4.60 | 0.5 | 0.0307 | 0.0067 |
| | 5.7122 | 4.55 | 1.0 | 0.0455 | 0.0100 |
| | 5.6600 | 4.48 | 1.0 | 0.0455 | 0.0102 |
| | 6.0211 | 4.68 | 1.5 | 0.0630 | 0.0135 |
| | 6.4200 | 4.93 | 1.5 | 0.0691 | 0.0140 |
| | 5.7632 | 4.55 | 2.0 | 0.0716 | 0.0157 |
| | 6.3824 | 4.92 | 2.0 | 0.0846 | 0.0172 |
| | 5.3568 | 4.45 | 2.5 | 0.0880 | 0.0198 |
| | 5.4836 | 4.39 | 3.0 | 0.0989 | 0.0225 |

Table IV

Rolled Copper: Temperature = 550°C

| Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Time of Heating in hrs. | Weight-increase | |
|---|---|---|---|---|
| | | | in gms. | in gms./sq. cm. |
| 2.8932 | 3.68 | 0.5 | 0.1120 | 0.0304 |
| 2.8753 | 3.70 | 1.0 | 0.2165 | 0.0585 |
| 2.8550 | 3.66 | 1.0 | 0.2124 | 0.0580 |
| 2.8957 | 3.65 | 1.5 | 0.2837 | 0.0777 |
| 2.8948 | 3.69 | 2.0 | 0.3552 | 0.0963 |
| 2.9141 | 3.72 | 2.0 | 0.3636 | 0.0977 |
| 2.8760 | 3.70 | 2.5 | 0.4254 | 0.1150 |
| 2.8790 | 3.68 | 2.5 | 0.4110 | 0.1117 |
| 2.8335 | 3.68 | 3.0 | 0.4597 | 0.1249 |

definite temperatures for 1/2—3 hours. The results are given in Tables III and IV and are plotted in Fig. 2 and Fig. 3.

Fig. 2

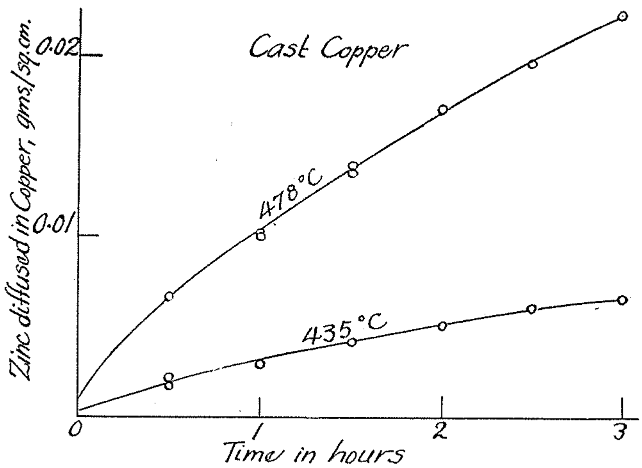
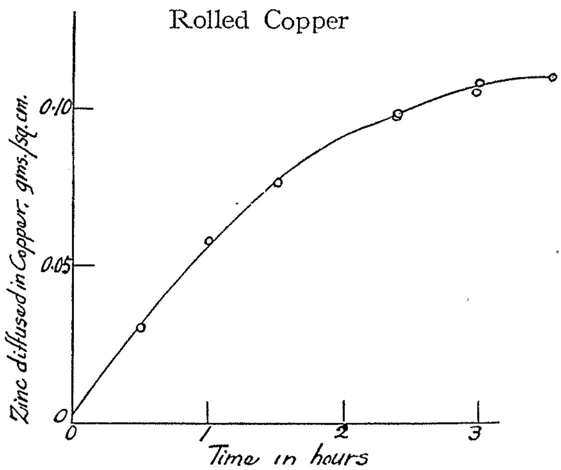



Fig. 3

Rolled Copper




## 5. Appearance and Microstructure

Copper heated in contact with zinc vapour became coated with brass, and its colour turned light yellow or white according to the temperature and the time of heating: these changes were accompanied by expansion. The copper plate specimens, which were placed over the boat, so that the diffusion occurred only from the surface facing the boat, bent upwards owing to the expansion of this surface. If the specimen was cubic in form, only its corners and their vicinity became white, these being the places where the penetration of zinc took place from the adjacent surfaces and was greatest in its amount, while the middle parts of the surfaces were yellow and there were very sharp lines of demarcation between the yellow and the white parts.

After the layer that looked yellow with the naked eye had been removed by grinding, the polished sections were examined under the microscope. Photo No. 1 shows the structure of a specimen heated three times for 30 minutes at 500°C, in which 0.0328 gm. of zinc was absorbed per unit surface, and No. 2 that of one heated for 30 minutes at 600°C with a gain of 0.0780 gm. per unit surface of the specimen. Both consist of homogeneous $\alpha$ solid solution in the outer layer, while in the inner area, the diffusion proceeds along grain boundaries, leaving in places a grain wholly converted into $\alpha$ brass.

## II. Experiments with Brass

### 1. Specimen

For the preparation of the specimens, pure zinc and pure electrolytic copper were taken in the required proportions and melted in a graphite crucible in a coke fired oven under molten sodium chloride in order to avoid changes in composition by volatilisation of zinc and oxidation. After the melt had been thoroughly stirred, it was cast in a preheated iron mould with a hole 10 mm. in diameter and 150 mm. in length. These rods were then turned and cut.

The copper content was determined with their turnings by duplicate volumetric analysis.

### 2. Experimental Procedure

The weighed specimen, of which the surface area was measured, was heated in a hydrogen atmosphere, in the same manner as described in the experiments with copper and zinc.

### 3. The Influence of Composition

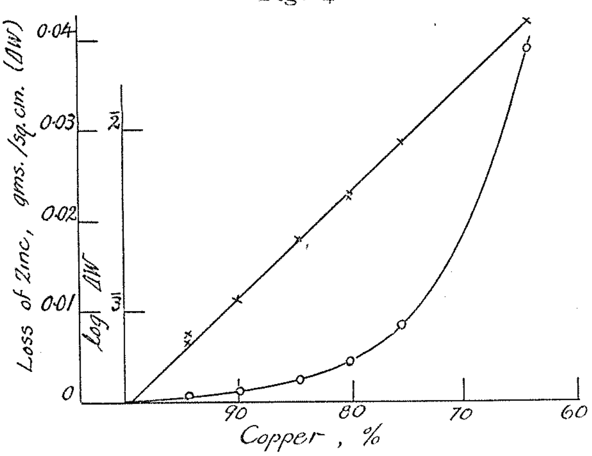
The amount of zinc lost per unit surface in half an hour at 850°C was estimated with brasses[1] of various zinc contents, up to about 36%. The experimental data are given in Table V and are shown in Fig. 4 where the circles denote the actual amounts of zinc lost and the crosses the logarithms of these numbers.

Table V

Temperature=850°C. : Time=30 minutes

| Copper Content in % | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-decrease | | log ΔW |
|---|---|---|---|---|---|
| | | | in gms. | in gms./sq. cm. ΔW | |
| 94.4 | 4.0218 | 3.27 | 0.0022 | 0.0007 | $\bar{4}.8279$ |
| | 3.8671 | 3.21 | 0.0023 | 0.0007 | $\bar{4}.8552$ |
| 89.8 | 3.8256 | 3.18 | 0.0037 | 0.0012 | $\bar{3}.0658$ |
| | 3.8516 | 3.22 | 0.0038 | 0.0012 | $\bar{3}.0719$ |
| 84.6 | 3.8176 | 3.19 | 0.0076 | 0.0024 | $\bar{3}.3770$ |
| | 3.8048 | 3.19 | 0.0076 | 0.0024 | $\bar{3}.3770$ |
| 80.3 | 3.6458 | 3.13 | 0.0138 | 0.0044 | $\bar{3}.6443$ |
| | 3.9350 | 3.29 | 0.0138 | 0.0042 | $\bar{3}.6272$ |
| 75.5 | 3.6510 | 3.13 | 0.0260 | 0.0083 | $\bar{3}.9194$ |
| | 3.6840 | 3.16 | 0.0265 | 0.0084 | $\bar{3}.9236$ |
| 64.2 | 3.8910 | 3.32 | 0.1290 | 0.0389 | $\bar{2}.5895$ |
| | 4.0079 | 3.37 | 0.1290 | 0.0383 | $\bar{2}.5830$ |

Fig. 4




1. These specimens were prepared from alloys melted in a Tammann tube.

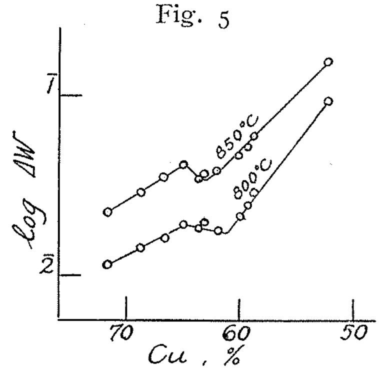
As is evident from these results, the amount of zinc lost ($\Delta W$) varies exponentially with the zinc content ($C$) in the $\alpha$ range, establishing the following equation :—

$$\Delta W = ae^{bC}$$

where $a$ and $b$ are constants. Dunn's results[1] agree with this.

From the results obtained in experiments II–4, some of which were calculated by interpolation, the logarithms of the amounts of zinc lost from unit surface at 850° and 800°C. with brasses containing 70—50 % copper were plotted against their composition and are shown in Fig. 5.

Fig. 5




In the case of the brasses ranging over the $\alpha$, $\alpha+\beta$, and $\beta$ fields, however, they are not continuous straight lines but show breaks at those points corresponding to the composition near the boundary between different fields.

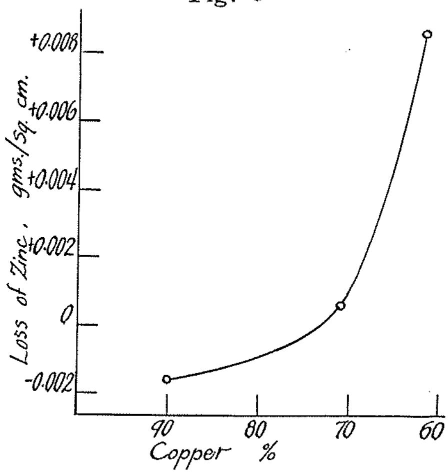
In connection with the above experiments, three specimens of different compositions put side by side were heated for 30 minutes at 670°C. with the results given in Table VI and Fig. 6.

Table VI

| Copper Content in % | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-change | |
|---|---|---|---|---|
| | | | in gms. | in gms./sq. cm. |
| 89.97 | 4.3374 | 3.48 | +0.0056 | +0.0016 |
| 70.62 | 3.7115 | 3.22 | −0.0027 | −0.00084 |
| 61.34 | 3.9800 | 3.36 | −0.0288 | −0.0086 |

1. J. S. Dunn: loc. cit.

Fig. 6




This experiment shows that zinc diffuses in or out of brass according to the vapour pressure of zinc in the surrounding medium, so the values given in Table VI and Fig. 6 will vary according to the temperature and duration of heating.

Table VII

| Copper Content in % | Temp. °C. | $1/T \times 10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-decrease | | log ΔW |
|---|---|---|---|---|---|---|---|
| | | | | | in gms. | in gms./sq. cm. ΔW | |
| 71.6 | 905 | .8489 | 3.4996 | 3.04 | 0.0796 | 0.0262 | $\bar{2}$.4180 |
| | 900 | .8525 | 3.5380 | 3.07 | 0.0847 | 0.0276 | $\bar{2}$.4407 |
| | 850 | .8905 | 3.9490 | 3.29 | 0.0730 | 0.0222 | $\bar{2}$.3461 |
| | 822 | .9132 | 3.5028 | 3.04 | 0.0524 | 0.0172 | $\bar{2}$.2365 |
| | 787 | .9434 | 3.5956 | 3.09 | 0.0292 | 0.0094 | $\bar{3}$.9754 |
| | 750 | .9775 | 3.6114 | 3.11 | 0.0174 | 0.0056 | $\bar{3}$.7478 |
| | 715 | 1.0121 | 3.0313 | 2.80 | 0.0082 | 0.0029 | $\bar{3}$.4667 |
| | 714 | 1.0132 | 3.4151 | 3.02 | 0.0086 | 0.0028 | $\bar{3}$.4545 |
| | 667 | 1.0638 | 3.3951 | 3.03 | 0.0044 | 0.0015 | $\bar{3}$.1620 |
| | 640 | 1.0953 | 3.8602 | 3.25 | 0.0028 | 0.0009 | $\bar{4}$.9353 |
| 68.6 | 891 | .8591 | 3.9679 | 3.36 | 0.1049 | 0.0312 | $\bar{2}$.4944 |
| | 850 | .8905 | 3.7576 | 3.25 | 0.0934 | 0.0287 | $\bar{2}$.4585 |
| | 812 | .9217 | 3.7832 | 3.24 | 0.0555 | 0.0171 | $\bar{2}$.2337 |
| | 773 | .9579 | 3.1958 | 2.90 | 0.0256 | 0.0088 | $\bar{3}$.9458 |
| | 735 | .9921 | 3.4226 | 3.04 | 0.0138 | 0.0045 | $\bar{3}$.6570 |
| | 699 | 1.0288 | 3.5674 | 3.14 | 0.0091 | 0.0029 | $\bar{3}$.4621 |
| | 664 | 1.0673 | 3.7900 | 3.24 | 0.0050 | 0.0015 | $\bar{3}$.1884 |

Table VII Continued

| Copper Content in % | Temp. °C | $1/T \times 10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-decrease in gms. | Weight-decrease in gms./sq. cm. ΔW | log ΔW |
|---|---|---|---|---|---|---|---|
| 66.7 | 841 | .8977 | 3.6095 | 3.24 | 0.1019 | 0.0315 | $\bar{2}.4976$ |
| | 790 | .9407 | 3.3202 | 3.00 | 0.0403 | 0.0134 | $\bar{2}.1282$ |
| | 740 | .9872 | 3.5324 | 3.14 | 0.0176 | 0.0056 | $\bar{3}.7486$ |
| | 690 | 1.0384 | 3.4711 | 3.10 | 0.0097 | 0.0031 | $\bar{3}.4954$ |
| | 650 | 1.0834 | 3.2308 | 3.01 | 0.0053 | 0.0018 | $\bar{3}.2457$ |
| 65.0 | 841 | .8977 | 3.6276 | 3.24 | 0.1158 | 0.0357 | $\bar{2}.5532$ |
| | 795 | .9363 | 3.6256 | 3.22 | 0.0560 | 0.0174 | $\bar{2}.2403$ |
| | 768 | .9606 | 3.6655 | 3.19 | 0.0346 | 0.0108 | $\bar{2}.0353$ |
| | 741 | .9862 | 3.5306 | 3.12 | 0.0225 | 0.0072 | $\bar{3}.8580$ |
| | 713 | 1.0142 | 3.3962 | 3.11 | 0.0172 | 0.0055 | $\bar{3}.7428$ |
| | 693 | 1.0352 | 3.5388 | 3.12 | 0.0134 | 0.0043 | $\bar{3}.6330$ |
| | 657 | 1.0753 | 3.2024 | 2.94 | 0.0072 | 0.0024 | $\bar{3}.3890$ |
| 63.6 | 847 | .8929 | 3.7078 | 3.21 | 0.1056 | 0.0329 | $\bar{2}.5172$ |
| | 797 | .9346 | 3.4930 | 3.09 | 0.0564 | 0.0183 | $\bar{2}.2613$ |
| | 750 | .9775 | 3.1046 | 2.86 | 0.0267 | 0.0093 | $\bar{3}.9701$ |
| | 704 | 1.0236 | 3.3050 | 2.99 | 0.0155 | 0.0052 | $\bar{3}.7147$ |
| | 654 | 1.0787 | 3.4118 | 3.05 | 0.0070 | 0.0023 | $\bar{3}.3608$ |
| 63.2 | 862 | .881 | 3.8606 | 3.30 | 0.1050 | 0.0318 | $\bar{2}.5027$ |
| | 807 | .926 | 3.5965 | 3.22 | 0.0695 | 0.0216 | $\bar{2}.3341$ |
| | 791 | .9399 | 3.3012 | 2.97 | 0.0530 | 0.0178 | $\bar{2}.2515$ |
| | 740 | .9872 | 3.5711 | 3.13 | 0.0269 | 0.0086 | $\bar{3}.9342$ |
| | 697 | 1.0309 | 3.1688 | 2.90 | 0.0138 | 0.0048 | $\bar{3}.6775$ |
| | 661 | 1.0707 | 3.4845 | 3.09 | 0.0085 | 0.0028 | $\bar{3}.4395$ |
| 59.9 | 850 | .8905 | 3.6454 | 3.18 | 0.1426 | 0.0448 | $\bar{2}.6517$ |
| | 800 | .932 | 3.8533 | 3.30 | 0.0659 | 0.0200 | $\bar{2}.3004$ |
| | 763 | .9652 | 4.0782 | 3.43 | 0.0385 | 0.0112 | $\bar{2}.0502$ |
| | 725 | 1.002 | 4.0666 | 3.43 | 0.0236 | 0.0069 | $\bar{3}.8376$ |
| | 691 | 1.0373 | 3.7767 | 3.26 | 0.0151 | 0.0046 | $\bar{3}.6658$ |
| | 653 | 1.0799 | 3.5616 | 3.14 | 0.0088 | 0.0028 | $\bar{3}.4476$ |
| 59.2 | 851 | .8897 | 3.6380 | 3.17 | 0.1644 | 0.0519 | $\bar{2}.7148$ |
| | 816 | .9191 | 3.6048 | 3.16 | 0.0935 | 0.0296 | $\bar{2}.4711$ |
| | 775 | .9542 | 3.2668 | 2.98 | 0.0492 | 0.0165 | $\bar{2}.2178$ |
| | 739 | .9881 | 3.4768 | 3.08 | 0.0264 | 0.0086 | $\bar{3}.9331$ |
| | 711 | 1.0162 | 3.4089 | 3.04 | 0.0189 | 0.0062 | $\bar{3}.7936$ |
| | 691 | 1.0373 | 3.5768 | 3.15 | 0.0157 | 0.0050 | $\bar{3}.6976$ |
| | 665 | 1.066 | 3.2052 | 2.96 | 0.0103 | 0.0035 | $\bar{3}.5406$ |
| 58.8 | 850 | .8905 | 3.6023 | 3.17 | 0.1819 | 0.0521 | $\bar{2}.7599$ |
| | 814 | .9178 | 3.6740 | 3.20 | 0.1162 | 0.0363 | $\bar{2}.5601$ |
| | 774 | .9551 | 3.6445 | 3.19 | 0.0629 | 0.0197 | $\bar{2}.2949$ |

Table VII Continued

| Copper Content in % | Temp. °C | $1/T \times 10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-decrease | | log ΔW |
|---|---|---|---|---|---|---|---|
| | | | | | in gms. | in gms./sq. cm. ΔW | |
| | 751 | .9716 | 3.3307 | 3.01 | 0.0380 | 0.0126 | $\bar{2}.1012$ |
| | 730 | .997 | 3.1477 | 2.92 | 0.0261 | 0.0089 | $\bar{3}.9513$ |
| 5.88 | 724 | 1.003 | 3.3896 | 3.03 | 0.0245 | 0.0081 | $\bar{3}.9077$ |
| | 699 | 1.0289 | 3.1766 | 2.93 | 0.0172 | 0.0059 | $\bar{3}.7687$ |
| | 668 | 1.0627 | 3.2564 | 3.04 | 0.0126 | 0.0041 | $\bar{3}.6175$ |
| | 839 | .8993 | 3.5783 | 3.17 | 0.4225 | 0.1333 | $\bar{1}.1248$ |
| | 801 | .9311 | 3.9392 | 3.37 | 0.3033 | 0.0900 | $\bar{2}.9542$ |
| | 773 | .956 | 3.8321 | 3.34 | 0.2271 | 0.0680 | $\bar{2}.8325$ |
| | 738 | .9891 | 3.8707 | 3.34 | 0.1476 | 0.0442 | $\bar{2}.6453$ |
| 50.6 | 708 | 1.0194 | 3.7189 | 3.25 | 0.0960 | 0.0295 | $\bar{2}.4704$ |
| | 704 | 1.0236 | 3.5948 | 3.18 | 0.0909 | 0.0286 | $\bar{2}.4561$ |
| | 670 | 1.0605 | 3.6202 | 3.20 | 0.0506 | 0.0158 | $\bar{2}.1990$ |
| | 665 | 1.0661 | 3.4971 | 3.12 | 0.0461 | 0.0148 | $\bar{2}.1696$ |
| | 633 | 1.1037 | 3.6644 | 3.21 | 0.0289 | 0.0090 | $\bar{3}.9544$ |
| | 840 | .8985 | 3.6858 | 3.25 | 0.4413 | 0.1358 | $\bar{1}.1329$ |
| | 801 | .9311 | 3.6460 | 3.23 | 0.2991 | 0.0926 | $\bar{2}.9666$ |
| | 766 | .9625 | 3.7650 | 3.26 | 0.2084 | 0.0639 | $\bar{2}.8057$ |
| 50.1 | 732 | .995 | 3.6112 | 3.20 | 0.1312 | 0.0410 | $\bar{2}.6128$ |
| | 693 | 1.0352 | 3.6304 | 3.23 | 0.0750 | 0.0232 | $\bar{2}.3659$ |
| | 661 | 1.0707 | 3.5103 | 3.15 | 0.0495 | 0.0157 | $\bar{2}.1963$ |
| | 660 | 1.0718 | 3.4826 | 3.13 | 0.0471 | 0.0150 | $\bar{2}.1775$ |
| | 635 | 1.1013 | 3.5427 | 3.14 | 0.0259 | 0.0082 | $\bar{3}.9164$ |

## 4. The Influence of Temperature

Specimens prepared from rods each of different composition were heated to 650—900°C. in a hydrogen atmosphere for 30 minutes; the results are shown summarised in Table VII.

Next, the specimen with 60.2 % Cu was annealed for 1.5 hours at 650°—670°C., its surface being covered with carbon to prevent change in the composition by volatilisation of zinc and oxidation. After being cooled in the furnace, it was machined and cut.

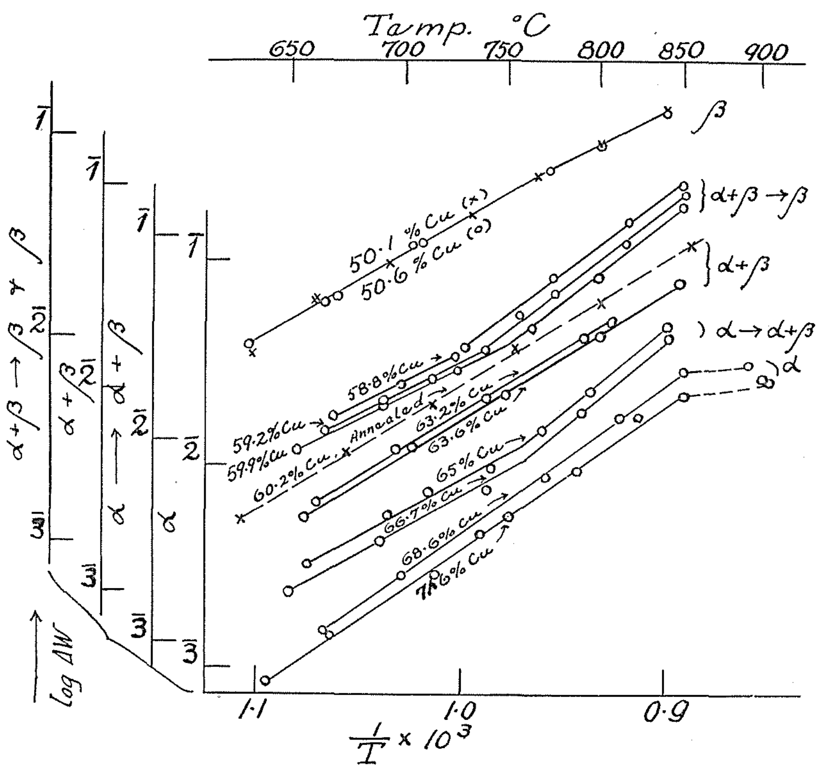
The results obtained with this specimen are given in Table VIII.

By plotting the logarithms of the amount of zinc lost, given in the last column of Tables VII and VIII, against the reciprocal of absolute temperature, two kinds of curves are obtained as shown in Fig. 7. The one kind consists of straight lines and the other shows break.

Table VIII

| Temp. °C. | $1/T \times 10^3$ | Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Weight-decrease in gms. | Weight-decrease in gms./sq. cm. $\Delta W$ | $\log \Delta W$ |
|---|---|---|---|---|---|---|
| 855 | 0.8865 | 3.6755 | 3.20 | 0.1667 | 0.0521 | $\bar{2}.7168$ |
| 801 | 0.9311 | 3.6110 | 3.17 | 0.0853 | 0.0269 | $\bar{2}.4299$ |
| 755 | 0.9728 | 3.2326 | 3.05 | 0.0486 | 0.0159 | $\bar{2}.2023$ |
| 714 | 1.0132 | 3.1680 | 2.96 | 0.0252 | 0.0085 | $\bar{3}.9301$ |
| 673 | 1.0571 | 3.4162 | 3.04 | 0.0149 | 0.0049 | $\bar{3}.6903$ |
| 630 | 1.1074 | 3.2917 | 3.00 | 0.0068 | 0.0023 | $\bar{3}.3554$ |

Fig. 7

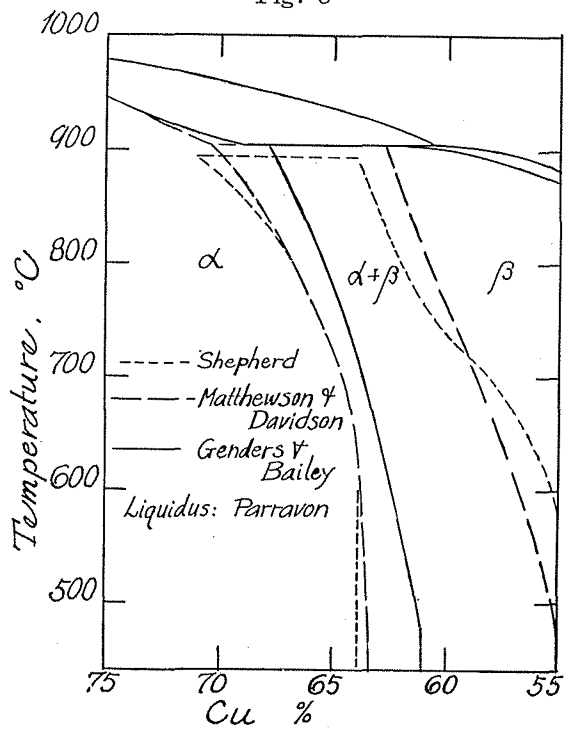



Comparing the above results with the equilibrium diagram of the Cu.–Zn system[1] lying between 70 % and 50 % Cu, Fig. 8, though

1. R. Genders and G. L. Bailey: Journ. Inst. Metals, **33**, 213 (1925).

the boundary lines between the $\alpha$ and $\alpha+\beta$ fields and the $\alpha+\beta$ and $\beta$ fields vary to some extent according to the previous treatment of the alloys examined, the following facts are noticeable :—

Fig. 8




(1) Brasses whose composition corresponds to those which does not change their structural constituent within the experimental temperature range, show a relation represented by a straight line.

(2) The angle of inclination to the abscissa does not depend on the chemical composition but on the structural constituent; $\alpha$ brass being the largest, followed by $\alpha+\beta$ and $\beta$ brass.

(3) With $\alpha$ brasses whose copper content is respectively 71.6 % and 68.7 %, the amount of zinc lost at 850° and 900°C. differs only a little. This could be explained if we were to find how the curve runs between these two temperatures by more experiments, but the present author could not do this owing to a lack of available specimens.

(4) In the case of brasses which change their structural constituent at some temperature within the experimental range, the line has a break at

the point approximately corresponding to the temperature at which this change occurs.

(5) In the case of brass which has $\alpha$ constituent at low temperatures, and $\alpha+\beta$ at high temperatures, both the parts corresponding to the $\alpha$ constituent stable at low temperatures and to the $\alpha+\beta$ stable at high temperatures do not run parallel respectively to that for brass of $\alpha$ constituent and that for brass of $\alpha+\beta$ constitusnt throughout the experimental range.

This phenomenon is probably due to the fact that the specimen retains to some extent the constituent stable at high temperatures because it is cast in an iron mould and subjected to relatively rapid cooling; it is also due to the fact that diffusion is aided by the distortion which occurs during the change of structural constituent

(6) The same relation holds in the case of the brasses which show $\alpha+\beta$ constituant at low temperatures and $\beta$ at high temperatures.

In general, the relation between the amount of zinc lost per unit surface ($\Delta W$) and the absolute temperature ($T$) may be expressed by the equation

$$\Delta W = A\, e^{-B/T}$$

where the constants $A$ and $B$ have a characteristic value depending on the structural constituents.

## 5. The Influence of Time

In order to study how the amount of zinc lost varies with the time, the following experiments were carried out:—

(1) Specimens of the same composition were heated at a definite temperature for period varying from 0.5 to 7.0 hours.

(2) A specimen was heated at a definite temperature for 45 minutes and the same operation was repeated ten times, the amount of zinc lost after each heating being measured.

Tables IX—XII and figs. 9 and 10 show the results.

Dunn[1] found that the amounts of zinc lost varied as the square root of the time with $\alpha$ brasses, in the form of a helical coil of wire, containing 9.58 % and 29.08 % Zn heated at 842°C. in vacuo. The above results, even those obtained with $\alpha$ brasses containing about 71 % Cu, do not agree with Dunn's.

1. J. S. Dunn: loc. cit.

Table IX

| Weight of Specimen in gms. | Surface Area of Specimen in sq. cms. | Time of Heating in hrs. | Weight-decrease | |
|---|---|---|---|---|
| | | | in gms. | in gms./sq. cm. |
| Copper Content=61.1%: Temperature=850°C. | | | | |
| 3.7033 | 3.20 | 0.5 | 0.1683 | 0.0526 |
| 3.9576 | 3.35 | 0.5 | 0.1761 | 0.0526 |
| 3.7611 | 3.24 | 1.0 | 0.2913 | 0.0899 |
| 3.7700 | 3.25 | 1.5 | 0.4045 | 0.1245 |
| 3.5244 | 3.10 | 2.0 | 0.4676 | 0.1508 |
| 4.0058 | 3.38 | 2.5 | 0.5869 | 0.1736 |
| 3.5400 | 3.11 | 3.0 | 0.6128 | 0.1970 |
| 3.5449 | 3.12 | 3.0 | 0.6049 | 0.1939 |
| 3.3892 | 3.02 | 4.0 | 0.6754 | 0.2236 |
| 3.7956 | 3.27 | 5.0 | 0.8226 | 0.2516 |
| 3.3586 | 3.06 | 6.0 | 0.8050 | 0.2689 |
| 3.4256 | 3.11 | 7.0 | 0.8835 | 0.2841 |
| Copper Content=62%: Temperature=794°C. | | | | |
| 3.7776 | 3.25 | 0.5 | 0.0560 | 0.0172 |
| 3.7937 | 3.25 | 1.0 | 0.1063 | 0.0327 |
| 3.6766 | 3.21 | 1.5 | 0.1516 | 0.0472 |
| 3.7086 | 3.21 | 2.0 | 0.1890 | 0.0589 |
| 3.6406 | 3.17 | 2.5 | 0.2362 | 0.0745 |
| 3.7652 | 3.23 | 3.0 | 0.2808 | 0.0889 |
| 3.5761 | 3.14 | 4.0 | 0.3365 | 0.1072 |
| 3.4844 | 3.09 | 5.0 | 0.3925 | 0.1270 |
| 3.4766 | 3.07 | 6.0 | 0.4288 | 0.1397 |
| 3.6110 | 3.16 | 6.0 | 0.4380 | 0.1386 |
| 3.7437 | 3.23 | 7.0 | 0.5094 | 0.1577 |
| 3.4607 | 3.06 | 7.0 | 0.4732 | 0.1546 |

Table X

Copper Content=61.1 %
Temperature=850°C.
Duration of each Heating=45 mins.

| Times of Heating | Weight-decrease after each Heating | | Total Weight-decrease in gms./sq. cm. |
|---|---|---|---|
| | in gms. | in gms./sq. cm. | |
| Weight of Specimen=3.7818gms.: Surface Area=3.25 sq. cms. | | | |
| 1 | 0.2384 | 0.0734 | 0.0734 |
| 2 | 0.1770 | 0.0558 | 0.1292 |
| 3 | 0.1367 | 0.0442 | 0.1734 |
| 4 | 0.1107 | 0.0363 | 0.2097 |
| 5 | 0.0817 | 0.0271 | 0.2368 |
| 6 | 0.0723 | 0.0245 | 0.2613 |
| 7 | 0.0682 | 0.0230 | 0.2843 |
| 8 | 0.0541 | 0.0185 | 0.3028 |
| 9 | 0.0481 | 0.0164 | 0.3192 |
| 10 | 0.0455 | 0.0159 | 0.3351 |
| Surface Area after being treated=2.878 sq. cms. | | | |
| Weight of Specimen=3.4978 gms.: Surface Area=3.086 sq. cms. | | | |
| 1 | 0.2250 | 0.0729 | 0.0729 |
| 2 | 0.1732 | 0.0577 | 0.1306 |
| 3 | 0.1351 | 0.0459 | 0.1765 |
| 4 | 0.1065 | 0.0369 | 0.2134 |
| 5 | 0.0845 | 0.0296 | 0.2430 |
| 6 | 0.0713 | 0.0253 | 0.2683 |
| 7 | 0.0557 | 0.0200 | 0.2883 |
| 8 | 0.0481 | 0 0173 | 0.3056 |
| 9 | 0.0414 | 0.0151 | 0.3207 |
| 10 | 0.0363 | 0.0132 | 0.3339 |
| Surface Area after being treated=2.726 sq. cms. | | | |

### Table XI

Copper Content=71.2 %
Temperature=850°C.
Duration of each Heating=45 mins.
Weight of Specimen=3.6198 gms.
Surface Area=3.17 sq. cms.

| Times of Heating | Weight-decrease after each Heating | | Total Weight-decrease in gms./sq. cm. |
|---|---|---|---|
| | in gms. | in gms./sq. cm. | |
| 1 | 0.1147 | 0.0362 | 0.0362 |
| 2 | 0.0817 | 0.0259 | 0.0621 |
| 3 | 0.0666 | 0.0213 | 0.0834 |
| 4 | 0.0582 | 0.0186 | 0.1020 |
| 5 | 0.0510 | 0.0164 | 0.1184 |
| 6 | 0.0459 | 0.0148 | 0.1332 |
| 7 | 0.0393 | 0.0137 | 0.1459 |
| 8 | 0.0351 | 0.0114 | 0.1573 |
| 9 | 0.0323 | 0.0105 | 0.1678 |
| 10 | 0.0282 | 0.0091 | 0.1769 |

Surface Area after being treated=3.07 sq. cms.

### Table XII

Copper Content=71.6 %
Temperature=850°C.
Duration of each Heating=45 mins.
Weight of Specimen=3.5214 gms.
Surface Area=3.04 sq. cms.

| Times of Heating | Weight-decrease after each Heating | | Total Weight-decrease in gms./sq. cm. |
|---|---|---|---|
| | in gms. | in gms./sq. cm. | |
| 1 | 0.1010 | 0.0332 | 0.0332 |
| 2 | 0.0728 | 0.0241 | 0.0573 |
| 3 | 0.0638 | 0.0212 | 0.0785 |
| 4 | 0.0502 | 0.0167 | 0.0952 |
| 5 | 0.0426 | 0.0143 | 0.1095 |
| 6 | 0.0420 | 0.0141 | 0.1236 |
| 7 | 0.0327 | 0.0110 | 0.1346 |
| 8 | 0.0302 | 0.0102 | 0.1448 |
| 9 | 0.0277 | 0.0093 | 0.1541 |
| 10 | 0.0264 | 0.0089 | 0.1630 |

Surface Area after being treated=2.954 sq. cms.

Fig. 9

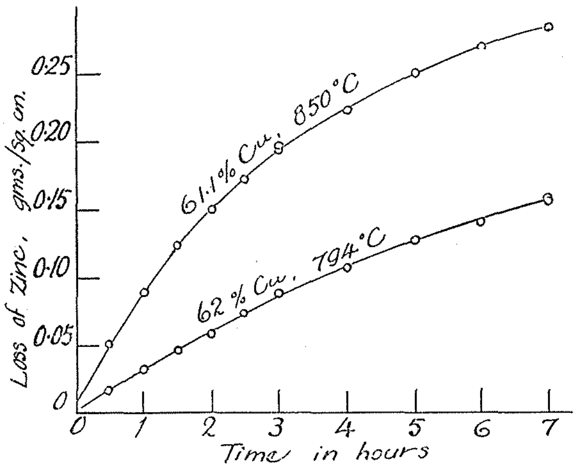
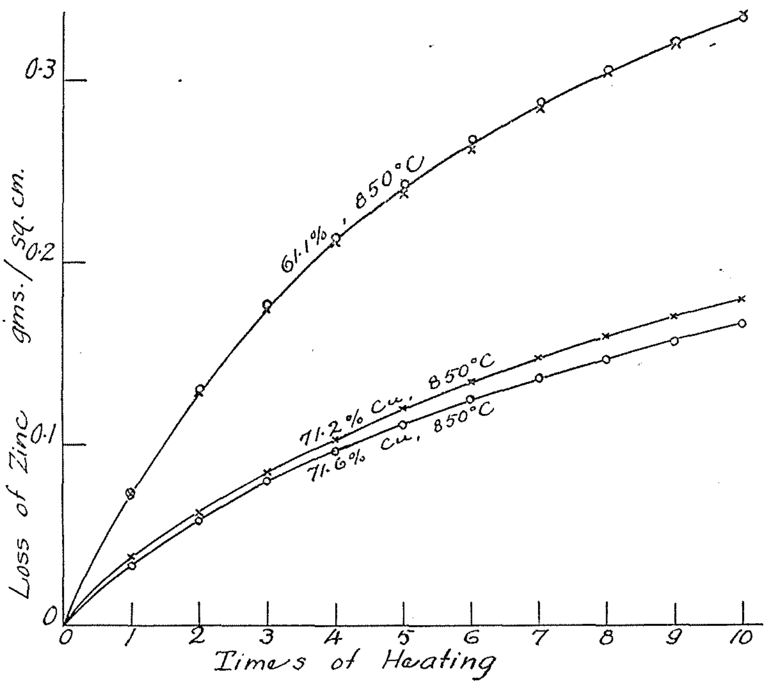

Loss of Zinc, gms./sq. cm.
0
0·05
0·10
0·15
0·20
0·25
0
1
2
3
4
5
6
7
Time in hours
61.1% Cu, 850°C
62% Cu, 794°C

Fig. 10


Loss of Zinc gms./sq. cm.
0
0·1
0·2
0·3
0
1
2
3
4
5
6
7
8
9
10
Times of Heating
61.1%, 850°C
71.2% Cu, 850°C
71.6% Cu, 850°C

### 6. Appearance and Microstructure

When brass is heated in a hydrogen atmosphere, it changes colour on the surface, according to the amount of zinc lost, till it looks like pure copper, and shrinks. If the specimen is cylindrical in form, its length as well as its diameter show a greater shrinkage at the periphery than at the centre on account of the vaporisation of zinc being great there.

Brass increases in density with decreasing zinc content, but in this case its density decreases through the giving off of zinc, as is shown in the following results obtained with brass containing 61.1 % Cu, heated ten times for 45 minutes at 850°C.

| | Before Treatment | | After Treatment | |
|---|---|---|---|---|
| | 1 | 2 | 1 | 2 |
| Weight in gms. | 3.4978 | 3.7818 | 2.5206 | 2.7491 |
| Volume in cb. cms. | 0.416 | 0.450 | 0.346 | 0.375 |
| Density | 8.40 | 8.41 | 7.30 | 7.34 |

Specimens with 65 % and 66.7 % Cu respectively have $\alpha$ structure regardless of the temperature at which they are heated. Photos. $A_1$, $A_2$ and $A_3$ show respectively the microstructure of specimens with 63.6 % Cu as cast and after being heated at 654° and 847°C. for 30 minutes. In $A_2$, it seems nearly homogeneous because the specimen was annealed to some extent by heating at 654°C. for 30 minutes; in $A_3$, $\beta$ crystals are still observed at the central part notwithstanding that about 8 % of the total zinc is lost. The microstructure of annealed specimens with 60.2 % Cu ($B_1$, $B_2$ and $B_3$) and that of specimens with 58.8 % Cu ($D_1$, $D_2$ and $D_3$) show that crystalline grains grow as they are heated at high temperatures. The specimens as cast respectively with 50.1 % and 50.6 % Cu show a homogeneous structure ($F_1$ and $E_1$). In the case of those heated at high temperatures, however, the $\alpha$ crystals become more and more numerous near the surface ($F_3$ and $E_3$).

## III. Experiments with Special Brass

In order to study the effect of a third element added to the ordinary brass on the vaporisation of zinc at high temperatures, the following experiments were carried out :—

## 1. Specimen

Up to 2 % of lead, tin, iron, manganese or aluminium was added to brasses containing copper and zinc in the ratio of approximately 6 : 4 and 7 : 3 respectively.

Table XIII shows the result of analysis of the specimens prepared and Table XIV that of the brasses used with these specimens for comparison.

Table XIII

| No. of specimen | A (Pb) | | B (Sn) | | C (Fe) | | D (Mn) | | E (Al) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cu % | Pb % | Cu % | Sn % | Cu % | Fe % | Cu % | Mn % | Cu % | Al % |
| 1 | 70.82 | 0.16 | 70.82 | 0.25 | 69.92 | 0.31 | 70.42 | 0.22 | 70.22 | 0.22 |
| 2 | 69.82 | 0.34 | 70.61 | 0.53 | 68.21 | 0.55 | 70.22 | 0.54 | 70.32 | 0.78 |
| 3 | 69.62 | 0.65 | 69.62 | 0.98 | 71.02 | 1.03 | 70.61 | 0.80 | 69.31 | 1.12 |
| 4 | 69.12 | 1.09 | 66.33 | 1.97 | 70.61 | 2.25 | 65.77 | 1.96 | 67.81 | 2.10 |
| 5 | 59.67 | 0.20 | 61.56 | 0.24 | 58.95 | 0.32 | 60.56 | 0.31 | 60.60 | 0.19 |
| 6 | 59.96 | 0.32 | 60.96 | 0.56 | 58.35 | 0.58 | 60.25 | 0.48 | 60.96 | 0.61 |
| 7 | 59.15 | 0.66 | 59.96 | 1.15 | 59.55 | 1.14 | 60.15 | 0.85 | 60.76 | 1.25 |
| 8 | 58.55 | 1.37 | 57.54 | 2.13 | 57.95 | 2.21 | | | 59.77 | 2.13 |

Table XIV

| No. of Specimen | Cu-content in % | Remarks |
|---|---|---|
| I | 71.42 | Heated with Specimens 1, 2, 3 and 4 in Tab. XIII at 600°C. |
| II | 70.62 | " " " " " " " " " " " " 700°C. |
| III | 70.62 | " " " " " " " " " " " " 800°C. |
| IV | 59.76 | Heated with Specimens 5, 6, 7 and 8 in Tab. XIII at 600°C. |
| V | 60.56 | " " " " " " " " " " " " 700°C. |
| VI | 60.56 | " " " " " " " " " " " " 800°C. |

## 2. Experimental Procedure

Five specimens having the composition given in the same line in Table XIII and the corresponding brass given in Table XIV were placed in a row in a porcelain boat, which was covered with a sheet of copper plate in order to maintain it at a uniform temperature, and heated in vacuo as well as in hydrogen at 600°, 700° and 800°C. for one hour.

## 3. Experiments carried out in Vacuo

The results obtained with the specimens containing 70 % copper are given in Table XV and are shown graphically in Fig. 11, and those with the specimens containing 60 % copper in Table XVI and in Fig. 12. In these tables, the data are given in terms of the ratio of the amount of zinc lost per unit surface of the specimen to that of the brass used for comparison. The variation of the latter with temperature is given in Fig. 13 in the case of brass containing 70 % copper and in Fig. 14 in the case of that containing 60 % copper.

Fig. 11

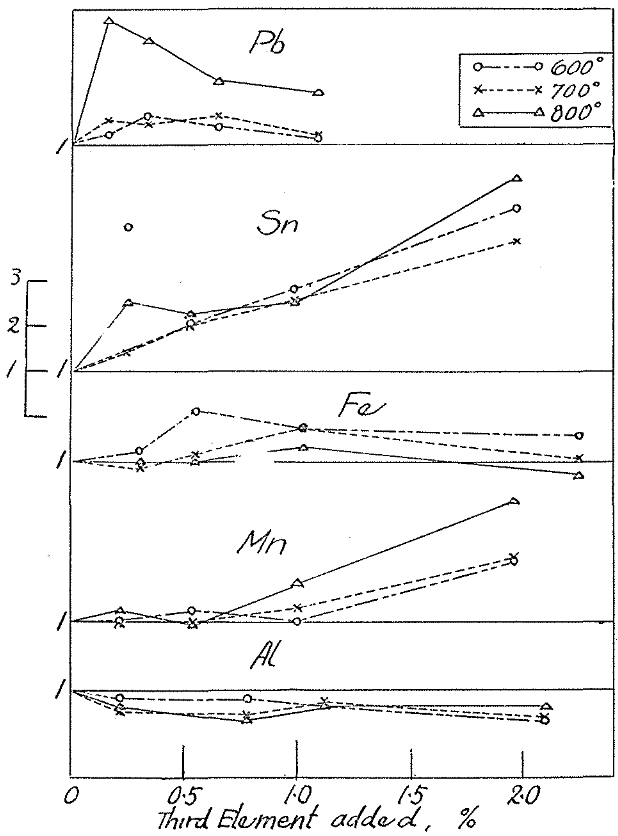


Table XV

| Temp. °C. | No. of Specimen | Loss of Zinc, taking that from Brass used for Comparison as Unit | | | | | No. of Brass used for Comparison |
|---|---|---|---|---|---|---|---|
| | | A (Pb) | B (Sn) | C (Fe) | D (Mn) | E (Al) | |
| 600 | 1 | 1.20 | 4.19 | 1.24 | 1.02 | 0.85 | I |
| | 2 | 1.62 | 2.05 | 2.13 | 1.23 | 0.81 | |
| | 3 | 1.36 | 2.78 | 1.75 | 1.00 | 0.66 | |
| | 4 | 1.09 | 4.56 | 1.57 | 2.33 | 0.36 | |
| 700 | 1 | 1.53 | 1.41 | 0.87 | 0.98 | 0.49 | II |
| | 2 | 1.45 | 2.23 | 1.17 | 1.01 | 0.46 | |
| | 3 | 1.63 | 2.57 | 1.74 | 1.30 | 0.78 | |
| | | 1.67* | 2.68* | 1.61* | 1.41* | 0.49* | |
| | 4 | 1.20 | 3.88 | 1.08 | 2.41 | 0.41 | |
| 800 | 1 | 3.75 | 2.52 | 0.99 | 1.24 | 0.61 | III |
| | 2 | 3.31 | 1.98 | 1.01 | 0.94 | 0.36 | |
| | 3 | 2.38 | 2.49 | 1.31 | 1.85 | 0.63 | |
| | 4 | 2.13 | 5.26 | 0.72 | 3.64 | 0.65 | |

* The results obtained by changing the order of specimens in a boat.

Table XVI

| Temp. °C. | No. of Specimen | Loss of Zinc, taking that from Brass used for Comparison as Unit | | | | | No. of Brass used for Comparison |
|---|---|---|---|---|---|---|---|
| | | A (Pb) | B (Sn) | C (Fe) | D (Mn) | E (Al) | |
| 600 | 5 | 1.09 | 1.06 | 1.05 | 0.83 | 0.62 | IV |
| | 6 | 0.67 | 1.23 | 1.65 | 0.85 | 0.46 | |
| | 7 | 0.69 | 1.63 | 1.09 | 0.91 | 0.78 | |
| | 8 | 0.49 | 3.78 | 1.24 | | 2.01 | |
| 700 | 5 | 1.20 | 1.10 | 1.35 | 0.98 | 0.90 | V |
| | 6 | 1.13 | 1.15 | 1.64 | 0.91 | 0.85 | |
| | 7 | 1.17 | 1.32 | 1.17 | 0.86 | 0.84 | |
| | 8 | 1.03 | 2.80 | 1.21 | | 1.56 | |
| 800 | 5 | 1.24 | 0.90 | 1.35 | 0.97 | 1.05 | VI |
| | 6 | 1.17 | 1.05 | 1.31 | 0.91 | 0.96 | |
| | 7 | 1.13 | 1.36 | 1.20 | 0.75 | 1.00 | |
| | 8 | 1.09 | 2.04 | 1.07 | | 1.16 | |

Fig. 12

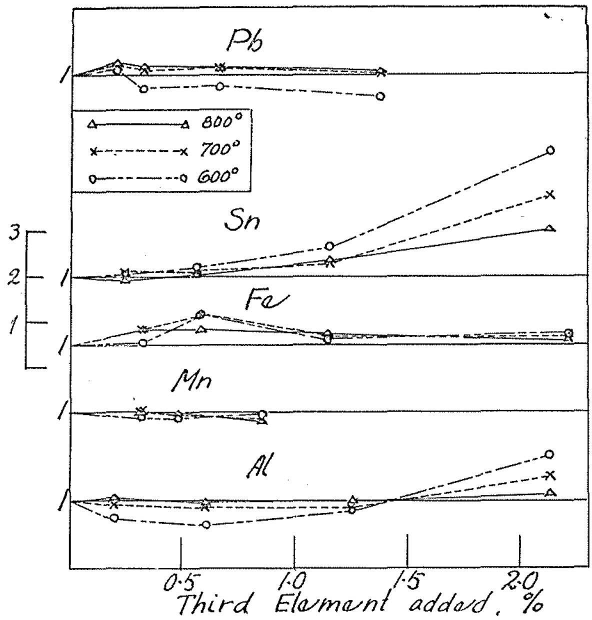



Fig. 13

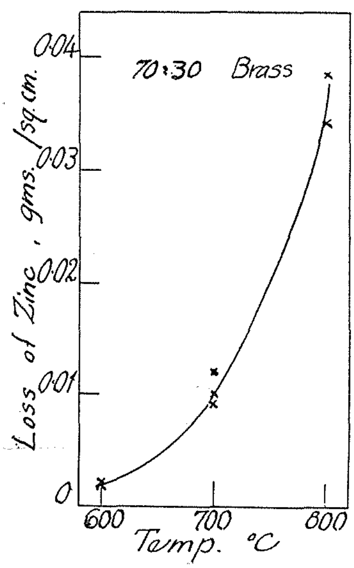
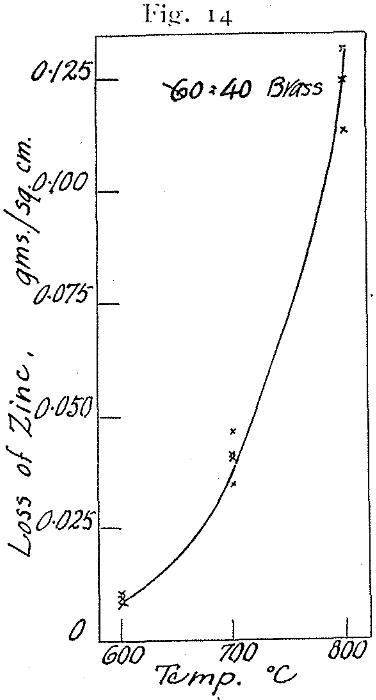



Fig. 14



From the results obtained with specimens containing 70 % of copper, the following facts are deduced :—

(1) The loss of zinc increases with the addition of lead, which is intensified as the temperature to which the alloy is heated increases, but the amount of lead added seems not to have an appreciable influence.

(2) Tin promotes the evaporation of zinc most effectively and this effect becomes more marked the more tin is added.

(3) Iron also increases the loss of zinc but its effect becomes less at high temperatures, forming a contrast to lead.

(4) Manganese increases the loss of zinc though to a small extent than the former three elements.

(5) Aluminium, on the contrary, reduces the evaporation of zinc almost by half in all cases.

(6) The great values obtained with specimen containing 1.97 % of Sn and that containing 1.96 % of Al are partly due to their zinc content greater than that of the brass used for comparison (see Table XIII).

In the case of the specimens containing about 60 % of copper, the effects of adding a third element are not so marked as in the case of those with about 70 % copper.

Lead retards the evaporation of zinc at 600°C. and manganese at all temperatures, while aluminium promotes it at 800°C.

## 4. Experiments carried out in Hydrogen Atmosphere

As the amount of evaporation of zinc is very small at 600°C. in this case, only the results of experiments at 700° and 800°C. are given in Table XVII and are shown graphically, in Fig. 15 with specimens containing 70 % of copper, and in Fig. 16 with those containing 60 % of copper in the same way as those in vacuo.

The same specimens generally show lower values in this case than in the previous one, but the general features of the curves in Figs. 15 and 16 are similar to those in Figs. 11 and 12 respectively.

## 5. Relation between Loss of Zinc and Temperature

The relation between the loss of zinc and temperature was examined by plotting the logarithm of the former ($\log \Delta W$) against the reciprocal of absolute temperature ($1/T$). Examples are shown in

Table XVII

| Temp. °C. | No. of Specimen | Loss of Zinc, taking that from Brass used for Comparison as Unit | | | | | No. of Brass used for Comparison |
|---|---|---|---|---|---|---|---|
| | | A (Pb) | B (Sn) | C (Fe) | D (Mn) | E (Al) | |
| Cu and Zn are at the ratio of 70 to 30. | | | | | | | |
| 700 | 1 | 1.17 | | 0.88 | 0.93 | 0.61 | II |
| | 2 | 1.08 | 1.14 | 0.92 | 0.57 | 0.73 | |
| | 3 | 0.98 | 1.66 | 0.59 | 0.66 | 0.68 | |
| | 4 | 0.83 | 4.69 | 0.90 | 2.07 | 0.08 | |
| 800 | 1 | | | | | | III |
| | 2 | 1.61 | 1.55 | 1.41 | 1.15 | 0.62 | |
| | 3 | 1.45 | 1.70 | 0.74 | 0.85 | 0.36 | |
| | 4 | 1.24 | 4.35 | 0.52 | 2.20 | 1.16 | |
| Cu and Zn are at the ratio of 60 to 40. | | | | | | | |
| 700 | 5 | 0.74 | 0.64 | 0.33 | 0.58 | 0.21 | V |
| | 6 | 0.91 | 0.76 | 1.53 | 0.58 | 0.34 | |
| | 7 | 0.46 | 0.99 | 0.70 | 0.41 | 0.32 | |
| | 8 | 0.67 | 3.88 | 0.61 | | 0.13 | |
| 800 | 5 | 1.14 | 0.47 | 1.28 | 0.57 | 0.36 | VI |
| | 6 | 0.92 | 0.83 | 1.51 | 0.69 | 0.19 | |
| | 7 | 0.85 | 1.09 | 1.13 | 0.56 | 1.13 | |
| | 8 | 0.83 | 2.57 | 1.12 | | 0.95 | |

Fig. 15

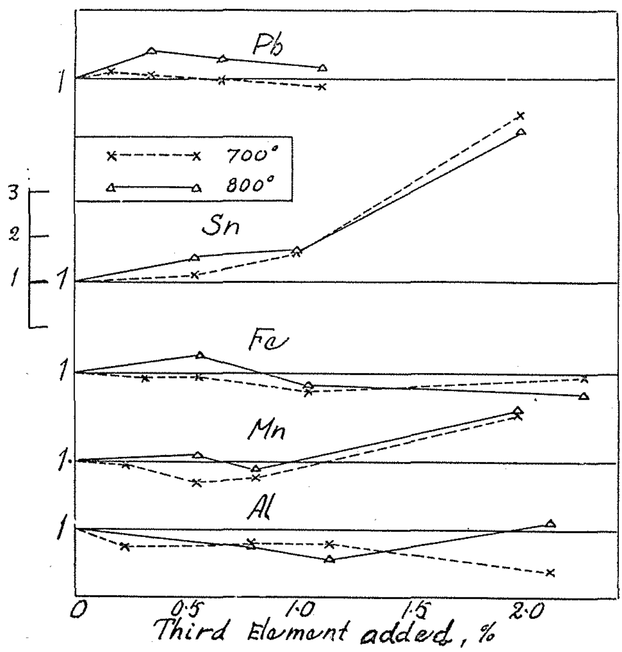


Fig. 16

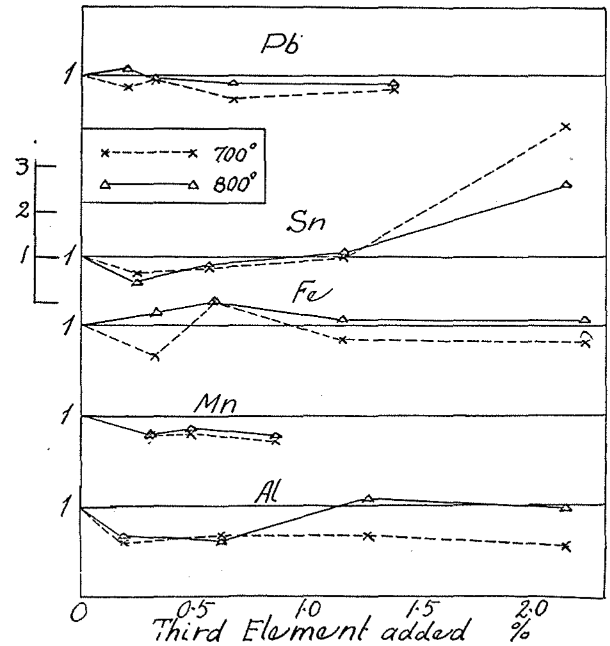

Pb
Sn
Fe
Mn
Al
700°
800°
1
3
2
0
0.5
1.0
1.5
2.0
Third Element added %

Fig. 17

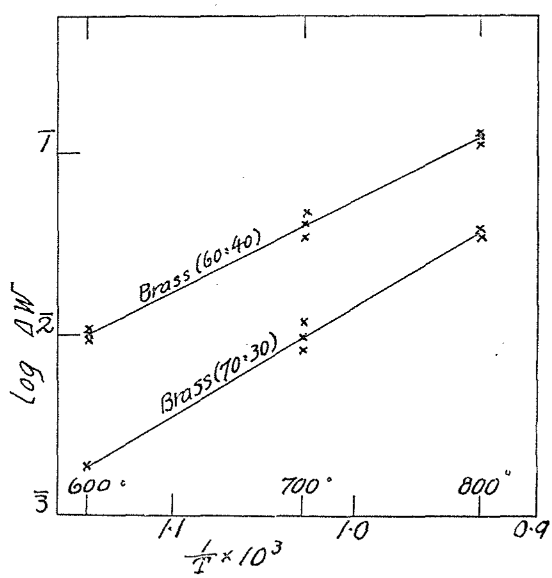

Brass (60:40)
Brass (70:30)
600°
700°
800°
1.1
1.0
0.9
Log ΔW
1/T × 10³

Fig. 18

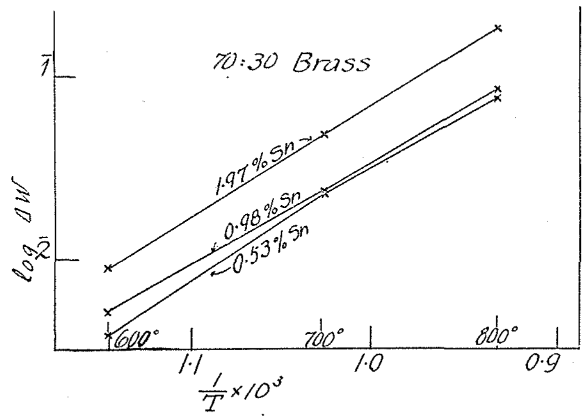



Fig. 19

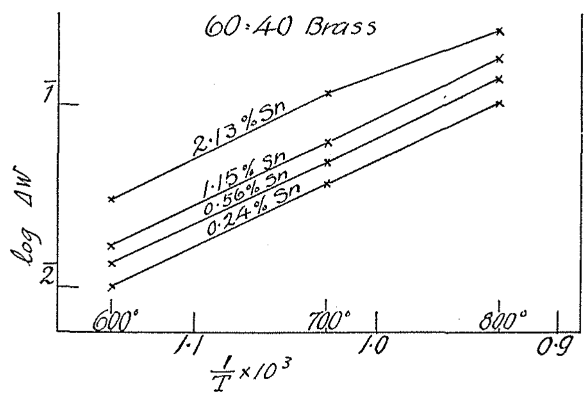



Fig. 17 with the brasses used for comparison and in Fig. 18 and Fig. 19 with those containing tin.

Though the duration of heating is long, fairly straight lines are obtained with plain brasses; the special brasses containing tin, however, show some irregularity. The other special brasses behave almost in the same manner.

## Summary

1. By heating copper in contact with zinc vapour in a hydrogen atmosphere, the penetration of copper by zinc was studied with reference to the influence of temperature and time.

2. The loss of zinc from the surface of heated brasses ranging over the $\alpha$, $\alpha+\beta$ and $\beta$ fields was also studied with reference to the influence of composition, temperature and time.

3. The empirical formulas for the relation between the amount of zinc diffused into or out of copper and temperature, as well as for that between the loss of zinc from a heated brass surface and the composition, were established.

4. The effect of the addition to the brass of up to 2 % of third elements (lead, tin, iron, manganese and aluminium) on the evaporation of zinc from the brass at 600°, 700° and 800°C. in vacuo as well as in hydrogen was studied.

In conclusion, the author desires to express his sincere thanks to Prof. Dr. M. Chikashige, Director of the Institute, for his encouragement throughout the course of this work.

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Imperial University, Kyoto.

## Plate I

No. 1

Cu treated three times at 500°C. for 30 mins. with a gain of 0.0325 gm. Zn per sq. cm.

↑
Edge

No. 2

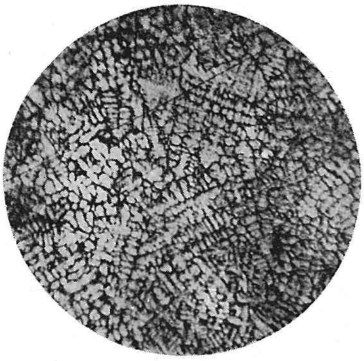
Cu treated at 600°C. for 30 mins. with a gain of 0.0780 gm. Zn per sq. cm.

↑
Edge

63.6 % Cu

$A_1$

As cast



$A_2$

Heated at 654°C. for 30 mins.

$A_3$

Heated at 847°C. for 30 mins.

## Plate II

60.2 % Cu

Annealed for 1.5 hrs. at 650—670°C.

$B_1$

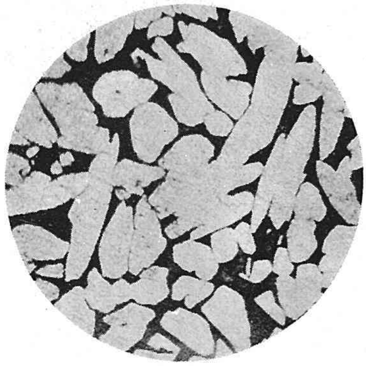
As annealed

$B_2$

Heated at 630°C.
for 30 mins.

$B_3$

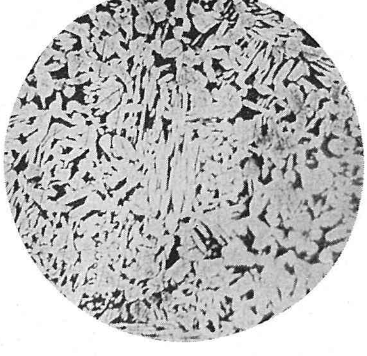
Heated at 855°C.
for 30 mins.



59.2 % Cu

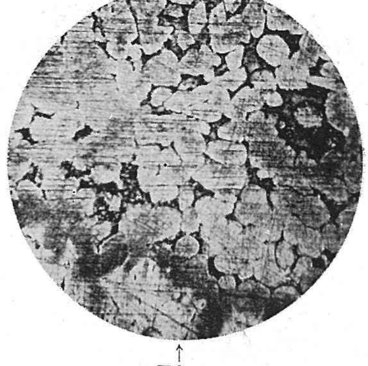
$C_2$

Heated at 665°C.
for 30 mins.



$C_3$

Heated at 851°C.
for 30 mins.



↑
Edge

## Plate III

58.8 % Cu

$D_1$

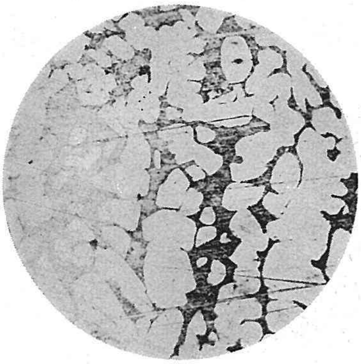
As cast

$D_2$

Heated at 668°C.
for 30 mins.

$D_3$

Heated at 850°C.
for 30 mins.

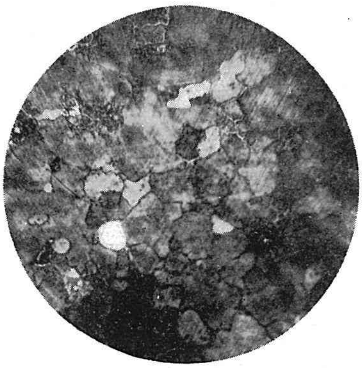


## Plate IV

50.6 % Cu

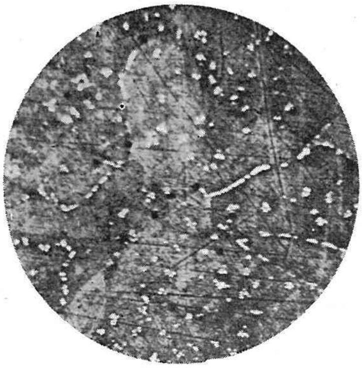
$E_1$

As cast



$E_2$

Heated at 663°C.
for 30 mins.



$E_3$

Heated at 839°C.
for 30 mins.

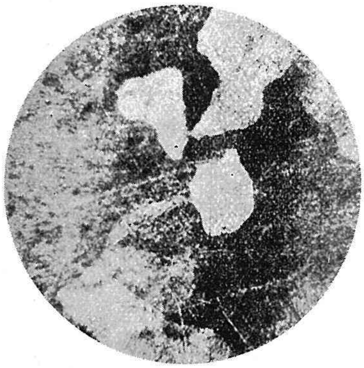
↑
Edge

## Plate V

50.1 % Cu

$F_1$

As cast

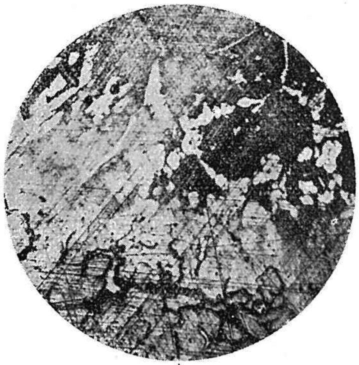


$F_2$

Heated at 660°C.
for 30 mins.

$F_3$

Heated at 840°C.
for 30 mins.



Edge