As the result of his experiments Mr Rhodin arrives at the conclusion that in a given series of copper alloys "the alloy which has the flattest and most regular dissolution curve does at the same time possess the best mechanical properties."

As regards the corrosion of steel and iron alloys Howe has made a number of exhaustive trials with wrought iron, steel and nickel steel. The plates tested in these experiments weighed 2597 lbs., and the total area exposed was 928 sq. ft. The results are summed up in the following table, wrought iron being taken as the standard in each case :—

| | Sea Water. | Fresh Water. | Atmosphere. | Average. |
|---|---|---|---|---|
| Wrought iron | 100 | 100 | 100 | 100 |
| Mild steel | 114 | 94 | 103 | 103 |
| 3 per cent. nickel steel | 83 | 80 | 67 | 77 |
| 26 per cent. nickel steel | 32 | 32 | 30 | 31 |

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## CHAPTER VII.

## COPPER ALLOYS, BRONZE.

It is customary to consider the alloys of copper under three heads, viz. (1) The bronzes, or alloys consisting mainly of copper and tin; (2) the brasses, consisting mainly of copper and zinc; and (3) other alloys of copper. Although not an entirely satisfactory classification, there is much to be said in its favour, and it is to be regretted that manufacturers in some instances use the terms brass and bronze indiscriminately. Alloys, for example, containing from 60 to 70 per cent. of copper and 30 to 40 per cent. of zinc, together with small percentages of iron, aluminium, or manganese, would be far more accurately described as brasses than bronzes, and yet these alloys are frequently described and sold as bronzes. If such alloys contain aluminium or manganese, or even if these metals have been employed in their manufacture, they might be described as aluminium-brasses or manganese-brasses, but not bronzes. The terms brass and bronze are so firmly established in the English language that it would be impossible (even if desirable) to adopt any other classification, and the words should therefore be employed with discretion.

### Bronze.

**Historical.**—The word *bronze*, derived from the Italian *bronzo*, appears to have been introduced into the English language in the 16th century. The alloy, however, was known in very early times, and a rod of metal found by Dr Flinders Petrie at Meydum, and estimated to belong to a period about 3700 B.C., was found to contain 89·8 per cent. of copper and 9·1 per cent. of tin, together with small quantities of impurities. Whether the tin is present as an impurity or whether it was added intentionally it would be difficult to say; but it is curious that the proportion of tin to copper is very nearly the same as that of modern bronze.

Some battle-axes and other objects from the deposits, which Schliemann dated at about 1200 B.C., and which he identified with Troy, were found to consist of copper and tin, the tin varying from 3·8 to 8·6 per cent.; whereas the objects found in the earlier deposits were of copper. The oldest relic which can be dated with any accuracy is a sceptre of Pepi I. (6th dynasty), which is almost pure copper. All the available evidence seems to prove that a copper age preceded the bronze age, and it is more than probable that the production of bronze was in the first place the result of accident, and that the intentional addition of tin to copper was only the result of experience. Bronzes have been found in Egypt dating from very early times. In Greece bronzes were very rare in Homeric times (900 B.C.), and the Greek and Trojan heroes (1194–1184) used copper for their armour, swords, knives, and spear-heads.

As regards the relation of the bronze age to the iron age there has been much controversy, and it has been proved by recent discoveries that the iron age is of a much earlier date than was formerly supposed. At Hallstadt, in Upper Austria, no less than 6084 objects were obtained from a prehistoric cemetery. These include tools of copper and bronze and swords both of copper and iron, together with those of a transition period having blades of iron and handles of copper. Montelius considers that the bronze swords belong to a period about 850 to 600 B.C., and the iron swords to a period about 600 to 400 B.C.

In Egypt, Assyria, and Babylonia instruments of bronze have also been found, together with those of iron; while in Ireland, India, Cyprus, and other countries, weapons of almost pure copper and similar in form to those of stone have been found; so that it appears safe to conclude that the bronze age overlapped on the one hand the age of copper, and possibly the age of stone; and, on the other hand, the great age of iron. The earliest bronzes consist almost entirely of copper and tin; but many of the Roman bronzes contain large quantities of lead. The addition of lead is, in fact, due to the Romans, and first appears in *aes signatum* (429–451 B.C.). The following table gives the analyses of some ancient bronzes:—

| | Copper. | Tin. | Lead | Iron. |
|---|---|---|---|---|
| Celtic vessels . . . . | 88·0 | 12·0 | ... | ... |
| Bronze nails . . . . . | 95·1 | 4·9 | ... | ... |
| Bronze (Troy, 1200 B.C.) . . | 90·7 | 8·6 | ... | ... |
| Bronze ,, ,, . . . | 93·8 | 5·7 | ... | ... |
| Roman sword blade . . . | 91·4 | 8·4 | ... | ... |
| Coin of Ptolemy IX. . . . | 84·2 | 15·6 | ... | ... |
| Athenian coin . . . . | 89·4 | 9·9 | ... | ... |
| Coin of Alexander the Great . . | 86 7 | 13·2 | ... | ... |
| Axe-head . . . . . | 88·0 | 11·2 | 0·8 | ... |
| Attic coin . . . . . | 88·5 | 10·0 | 1 1 | ... |
| Coin of Julius Cæsar . . . | 79·1 | 8·0 | 12 8 | ... |
| Roman As. (B C. 500) . . . | 69·7 | 7·2 | 21·8 | 0·5 |
| Sword blade . . . . . | 89·5 | 10·0 | ... | 0·4 |

The presence of lead in bronze was probably due, in the first place, to the fact that the tin was adulterated with that metal; but it was probably soon discovered that the addition of lead conferred valuable properties upon the alloy, and the bronzes of later date almost invariably contain appreciable amounts of lead.

The presence of zinc in bronze was also probably the result of accident, due to the introduction of zinc ore into the furnace charge. An Etruscan bronze, dated the fifth century B.C., was found to contain 0·73 per cent. of zinc. Early Japanese bronzes have also been found to contain appreciable quantities of zinc as well as lead.

In 1879 the Committee on Alloys appointed by the United States Board published a table in which the results of their own researches and those of previous workers were collected. This table has been frequently quoted in books dealing with alloys, and as it contains much valuable information in a condensed form it is inserted here:—

[Table.

## Properties of Copper-tin Alloys.

| No. | Atomic Formula. | Composition of Original Mixture. |  | Composition by Analysis. |  | Specific Gravity. | Colour. | Fracture. | Tenacity in lbs. per square inch. | Order of Ductility. (Mallet.) | Relative Ductility. (Thurston.) | Hardness. (Mallet, Calvert, Johnson.) | Order of Malleability. (Mallet.) | Order of Fusibility. (Mallet.) | Conductivity for Heat. Silver=100. | Conductivity for Electricity. Silver=100. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Cu. | Sn. | Cu. | Sn. |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | .. | 100 | 0 | .. | .. | 8·791*a*<br>8·874*b* | Copper-red. | Fibrous. | 27,800 | .. | 30·08 | .. | .. | .. | .. | .. | U.S.B. | *a.* Specific gravity of bar.<br>*b.* Specific gravity of turnings from ingot. |
| 2 | .. | 100 | 0 | .. | .. | 8·667 | Tile-red. | Earthy. | 55,104 | 1 | .. | 10 | 2 | 16 | .. | .. | Ml. |  |
| 3 | .. | 100 | 0 | .. | .. | 8·921 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 93·16 | Ma. |  |
| 4 | .. | 100 | 0 | .. | .. | .. | .. | .. | .. | .. | .. | 301 | .. | .. | 81·1 | .. | C. J. |  |
| 5 | .. | 100 | 0 | .. | .. | 8·794 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Cr. |  |
| 6 | .. | 100 | 0 | .. | .. | 8·921 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Mar. | Cast copper. |
| 7 | .. | 100 | 0 | .. | .. | 8·952 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Mar. | Sheet copper. |
| 8 | .. | 100 | 0 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 73·6 | 79·3 | We. |  |
| 9 | .. | 100 | 0 | .. | .. | 8·672 | .. | .. | 24,252 | .. | .. | .. | .. | .. | .. | .. | Wa. | Mean of nine samples. |
| 10 | .. | 98·59 | 1·41 | .. | .. | .. | .. | .. | .. | .. | 100·1 | .. | .. | .. | .. | 62·46 | Ma. |  |
| 11 | $SnCu_{96}$ | 98·1 | 1·9 | 97·89 | 2·11 | 8·564 | Red. | Vesicular. | .. | .. | .. | .. | .. | .. | .. | .. | U.S.B. | Defective bar. |
| 12 | .. | 98·04 | 1·96 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Can be forged like copper. |
| 13 | .. | 98 | 2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | La. | Ramrods for guns. |
| 14 | .. | 97·5 | 2·5 | .. | .. | 8·511 | Red. | Vesicular. | .. | .. | .. | .. | .. | .. | .. | .. | U.S.B. | Defective bar. |
| 15 | .. | 96·97 | 3·03 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Resists action of hydrochloric acid. |
| 16 | $SnCu_{48}$ | 96·27 | 3·73 | 96·06 | 3·76 | 8·649 | Reddish-yellow. | Vesicular. | 32,000 | .. | 70·3 | .. | .. | .. | .. | .. | U.S.B. |  |
| 17 | .. | 96 | 4 | .. | .. | 8·947 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Annealed and compressed. |
| 18 | .. | 95 | 5 | .. | .. | .. | Golden-yellow. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Hard, malleable. |
| 19 | .. | 94·1 | 5·9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Pieces of machines. |
| 20 | .. | 94 | 6 | .. | .. | 8·939 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Specific gravity after repeated tempering. |
| 21 | .. | 93·98 | 6·02 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 19·68 | Ma. |  |
| 22 | $SnCu_{25}$ | 93·17 | 6·83 | .. | .. | 8·82 | .. | .. | .. | .. | .. | 602·8 | .. | .. | .. | .. | C. J. |  |
| 23 | $SnCu_{24}$ | 92·8 | 7·2 | .. | .. | 8·694 | Reddish-yellow. | Vesicular. | 28,540 | .. | 21·9 | .. | .. | .. | .. | .. | U.S.B. |  |
| 24 | .. | 92·5 | 7·5 | .. | .. | 8·684 | ,, | .. | 27,900 | .. | 43·2 | .. | .. | .. | .. | .. | U.S.B. |  |
| 25 | .. | 92 | 8 | .. | .. | .. | .. | .. | .. | . | .. | .. | .. | .. | .. | .. | Bo. | Bronze for medals. |
| 26 | .. | 91·75 | 8·25 | .. | .. | .. | .. | .. | .. | ... | .. | .. | .. | .. | .. | .. | W. | Shows separation of metals when examined with a lens. |
| 27 | .. | 91·74 | 8·26 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | English ordnance. |
| 28 | .. | 91·7 | 8·3 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Ordnance metal. |
| 29 | .. | 91·66 | 8·33 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |  | Bo. | Eight - pounder guns. |
| 30 | $SnCu_{20}$ | 91·9 | 8·1 | .. | .. | 8·793 | .. | .. | .. | .. | .. | 63·958 | .. | .. | .. | .. | C. J. |  |
| 31 | .. | 91·3 | 8·7 | .. | .. | .. | .. | . | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Toothed wheels. |
| 32 | .. | 90·91 | 9·09 | .. | .. | .. | .. | .. | 32,093 | .. | .. | .. | .. | .. | .. | .. | Mus. | Prussian ordnance. |
| 33 | .. | 90·9 | 9·1 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Ordnance metal. |
| 34 | .. | 90·73 | 9·27 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | French ordnance. |
| 35 | .. | 90·1 | 9·9 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. |  |
| 36 | .. | 90 | 10 | 90·27 | 9·58 | 8·669 | Greyish-yellow. | Earthy. | 26,860 | .. | 18 | .. | .. | .. | .. | .. | U.S.B. | Compressed ordnance bronze. |
| 37 | .. | 90 | 10 | .. | .. | 8·875 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | De. | After repeated compression. |
| 38 | .. | 90 | 10 | .. | . | 8·935 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Railway - car bearings. |
| 39 | .. | 90 | 10 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Ordnance metal. |
| 40 | .. | 89·3 | 10·7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Small bar cast in iron mould. |
| 41 | .. | 89·29 | 10·71 | .. | .. | 8·953 | .. | .. | 37,688 | .. | .. | .. | .. | .. | .. | .. | Wa. | Small bar cast in clay mould. |
| 42 | .. | 89·29 | 10·71 | .. | .. | 8·313 | .. | .. | 25,783 | .. | .. | .. | .. | .. | .. | .. | Wa. | Mean of twelve gun-heads. |
| 43 | .. | 89·29 | 10·71 | .. | .. | 8·353 | .. | .. | 26,011 | .. | .. | .. | .. | .. | .. | .. | Wa. | Ordnance metal. |

### PROPERTIES OF COPPER-TIN ALLOYS—*continued*.

| No. | Atomic Formula. | Composition of Original Mixture. |  | Composition by Analysis. |  | Specific Gravity. | Colour. | Fracture. | Tenacity in lbs. per square inch. | Order of Ductility. (Mallet.) | Relative Ductility. (Thurston.) | Hardness. (Mallet, Calvert, Johnson.) | Order of Malleability. (Mallet.) | Order of Fusibility. (Mallet.) | Conductivity for Heat. Silver=100. | Conductivity for Electricity. Silver=100. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | Cu. | Sn. | Cu. | Sn. |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 44 | .. | 89·23 | 10·77 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. |  |
| 45 | $SnCu_{15}$ | 89 | 11 | .. | .. | 8·84 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Mean of eighty-three gun-heads. |
| 46 | $SnCu_{15}$ | 88·97 | 11·03 | .. | .. | 8·825 | .. | .. | .. | .. | .. | 77292 | .. | .. | .. | .. | C. J. |  |
| 47 | .. | 88·89 | 11·11 | .. | .. | 8·523 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Wa. | Gun-metal. |
| 48 | .. | 88·39 | 11·61 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 12·1 | Ma. |  |
| 49 | .. | 88 | 12 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | La. |  |
| 50 | .. | 87·65 | 12·35 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. |  | 10·15 | Ma. |  |
| 51 | .. | 87·5 | 12·5 | .. | .. | 8·648 | Greyish-yellow. | Earthy. | 31,100 | .. | 7·3 | .. | .. | .. | .. | .. | U.S.B |  |
| 52 | .. | 86·8 | 13·2 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | *a*. Specificgravity of bar. |
| 53 | $SnCu_{12}$ | 86·57 | 13·43 | 87·15 | 12·73 | 8·681*a*<br>8·943*b* | Mottled.<br>White and yellow. | Finely vesicular. | 29,430 | .. | 13·09 | .. | .. | .. | .. | .. | U.S.B. | *b*. Specific gravity of fine turnings. |
| 54 | .. | 86·21 | 13·79 | .. | .. | 8·87 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Densest of all alloys? (Riche). |
| 55 | .. | 86 | 14 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Axle-tree bed Seraing locomotive. |
| 56 | .. | 85·71 | 14·29 | .. | .. | .. | .. | .. | 44,071 | .. | .. | .. | .. | .. | .. | .. | Mus. |  |
| 57 | .. | 85·09 | 14·91 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 8·82 | Ma. |  |
| 58 | $SnCu_{10}$ | 84·33 | 15·67 | .. | .. | 8·87 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. |  |
| 59 | .. | 84·32 | 15·68 | .. | .. | 8·832 | .. | .. | .. | .. | .. | .. | 916·66 | .. | .. | .. | C. J. |  |
| 60 | .. | 84·29 | 15·71 | .. | .. | 8·561 | Reddish-yellow. | Finely crystalline. | 36,064 | 2 | .. | 8 | 6 | 15 | .. | .. | Ml. |  |
| 61 | .. | 84 | 16 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Carriage-wheel boxes. |
| 62 | .. | 83·3 | 16·7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Jeweller's punches. |
| 63 | $SnCu_9$ | 82·81 | 17·19 | .. | .. | 8·462 | Reddish-yellow. | Finely crystalline. | 34,048 | 3 | .. | 5 | 7 | 14 | .. | .. | Ml. |  |
| 64 | .. | 82·5 | 17·5 | .. | .. | 8·792 | Reddish-grey. | ,, | 36,200 | .. | 0·32 | .. | .. | .. | .. | .. | U.S.B. | Strongest of series. |
| 65 | .. | 82 | 18 | .. | .. | 8·927 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | R. | Annealed and tempered. |
| 66 | $SnCu_8$ | 81·15 | 18·85 | .. | .. | 8·86 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. |  |
| 67 | $SnCu_8$ | 81·1 | 18·9 | .. | .. | 8·459 | Yellowish-red. | Finely crystalline. | 39,648 | 4 | .. | 4 | 10 | 13 | .. | .. | Ml. |  |
| 68 | .. | .. | .. | 80·43 | 19·57 | 8·953 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Th. | Chinese gong. |
| 69 | .. | 80 | 20 | .. | .. | 8·7 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Bells of Reichenhall, 300 years old. |
| 70 | .. | 80 | 20 | .. | .. | .. | .. | .. | 35,739 | .. | .. | .. | .. | .. | .. | .. | Mus. |  |
| 71 | .. | 80 | 20 | .. | .. | 8·85 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Annealed and tempered. |
| 72 | .. | 80 | 20 | .. | .. | 8·955 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | After repeated compression. |
| 73 | .. | 80 | 20 | 80·95 | 18·84 | 8·74 | Reddish-grey. | Finely granular. | 32,980 | .. | 0·4 | .. | .. | .. | .. | .. | U.S.B. |  |
| 74 | .. | 79·2 | 20·8 | .. | .. | 8·927 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | Annealed and tempered. |
| 75 | $SnCu_7$ | 79·02 | 20·98 | .. | .. | 8·90 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. |  |
| 76 | $SnCu_7$ | 78·97 | 21·03 | .. | .. | 8·728 | Yellowish-red. | Vitreous conchoidal. | 30,464 | 5 | .. | 3 | 11 | 12 | .. | .. | Ml. |  |
| 77 | .. | 78 | 22 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. |  |
| 78 | .. | 77·5 | 22·5 | .. | .. | 8·917 | Pinkish-grey. | Finely granular. | 24,650 | .. | 0·03 | .. | .. | .. | .. | .. | U.S.B. |  |
| 79 | $SnCu_6$ | 76·32 | 23·68 | 76·64 | 23·24 | 8·565 | .. | Smooth. | 22,010 | .. | 0·02 | .. | .. | .. | .. | .. | U.S.B. |  |
| 80 | $SnCu_6$ | 76·31 | 23·69 | .. | .. | 8·91 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. |  |
| 81 | $SnCu_6$ | 76·29 | 23·71 | .. | .. | 8·75 | Bluish-red. | Vitreous. | 21,728 | 0 | .. | 2 | 12 | 11 | .. | .. | Ml. |  |
| 82 | .. | 76·2 | 23·8 | .. | .. | 9·1 (?) | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Church bell in Reichenhall, 600 years old. |
| 83 | .. | 75·2 | 24·8 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Swiss clock bells; brittle. |
| 84 | .. | 75 | 25 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. |  |
| 85 | $SnCu_5$ | 72·91 | 27·09 | .. | .. | 8·87 | Reddish-white. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. |  |

## PROPERTIES OF COPPER-TIN ALLOYS—*continued.*

| No. | Atomic Formula. | Composition of Original Mixture. | | Composition by Analysis. | | Specific Gravity. | Colour. | Fracture. | Tenacity in lbs. per square inch. | Order of Ductility. (Mallet ) | Relative Ductility. (Thurston ) | Hardness. (Mallet, Calvert, Johnson.) | Order of Malleability. (Mallet.) | Order of Fusibility. (Mallet.) | Conductivity for Heat. Silver=100. | Conductivity for Electricity. Silver=100. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cu. | Sn. | Cu. | Sn. | | | | | | | | | | | | | |
| 86 | $SnCu_5$ | 72·9 | 27·1 | .. | .. | 8·965 | .. | .. | .. | .. | .. | Broke | .. | .. | .. | .. | C. J. | |
| 87 | $SnCu_5$ | 72·8 | 27·2 | .. | .. | 8·575 | Bluish-red. | Conchoidal. | 10,976 | 0 | .. | 1 | 13 | 10 | 20·7 | .. | Ml. | |
| 88 | .. | 72·5 | 27·5 | . | .. | 8·925 | Reddish-white. | ,, | 6,493 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | |
| 89 | .. | 70 | 30 | 69·94 | 29·89 | 8·932 | White. | ,, | 5,585 | .. | ·008 | .. | .. | .. | .. | .. | U.S.B. | |
| 90 | .. | 68·82 | 31·18 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | Mirror of telescope. |
| 91 | $SnCu_4$ | 68·28 | 31·72 | .. | .. | 8·80 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 92 | $SnCu_4$ | 68·27 | 31·73 | .. | .. | 8·948 | .. | .. | .. | .. | .. | Broke | .. | .. | .. | .. | C. J. | |
| 93 | $SnCu_4$ | 68·25 | 31·75 | 68·58 | 31·28 | 8·938 | White. | Conchoidal. | 1,620 | .. | .. | .. | .. | .. | 15·5 | .. | U.S.B. | |
| 94 | $SnCu_4$ | 68·21 | 31·79 | .. | .. | 8·40 | Ash-grey. | ,, | 1,568 | 0 | .. | 6 | 14 | 9 | .. | .. | Ml. | |
| 95 | .. | 68·21 | 31·79 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo | Mirror metal. |
| 96 | .. | 67·5 | 32·5 | .. | .. | 8·907 | White. | Conchoidal. | 2,536 | .. | ·009 | .. | .. | .. | .. | .. | U.S.B. | |
| 97 | .. | 66·67 | 33·33 | .. | .. | .. | Steel grey. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Hard, uniform. |
| 98 | .. | 66·67 | 33·33 | .. | .. | .. | .. | .. | 1,017 | .. | .. | .. | .. | .. | .. | .. | Mus. | |
| 99 | .. | 65 | 35 | 65·34 | 34·47 | 8·947 | Bluish-grey. | .. | 2,201 | .. | ·002 | .. | .. | .. | .. | .. | U.S.B. | |
| 100 | .. | 62·5 | 37·5 | .. | .. | 8·956 | Dark grey. | Radiated crystalline. | 1,561 | .. | ·001 | .. | .. | .. | .. | .. | U.S.B. | |
| 101 | $SnCu_3$ | 61·79 | 38·21 | .. | .. | 8·954 | .. | .. | .. | .. | .. | Broke | .. | .. | 49·4 | . | C. J. | |
| 102 | $SnCu_3$ | 61·79 | 38·21 | .. | .. | 8·96 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 103 | $SnCu_3$ | 61·71 | 38·29 | .. | .. | 8·97 | Dark grey. | Rough, stony. | 688 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | Greatest density, weakest. |
| 104 | $SnCu_3$ | 61·69 | 38·31 | .. | .. | 8·539 | ,, | Tabular crystalline | 1,120 | 0 | .. | 7 | 16 | 8 | .. | .. | Ml. | |
| 105 | .. | 60 | 40 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | White bell-metal. |
| 106 | .. | 57·5 | 42·5 | .. | .. | 8·781 | Light grey. | Stony. | 1,377 | .. | ·001 | .. | .. | .. | .. | .. | U.S.B. | |
| 107 | $Sn_5Cu_{12}$ | 56·32 | 43·68 | 56·7 | 43·17 | 8·682 | ,, | ,, | 1,455 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | |
| 108 | .. | 52·5 | 47·5 | .. | .. | 8·643 | ,, | ,, | .. | .. | ·001 | .. | .. | .. | .. | .. | U.S.B. | Weakest under transverse stress. |
| 109 | $SnCu_2$ | 51·84 | 48·16 | .. | .. | 8·57 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 110 | $SnCu_2$ | .. | .. | .. | .. | 8·512 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Cr. | |
| 111 | $SnCu_2$ | 51·83 | 48·17 | .. | .. | 8·533 | .. | .. | .. | . | .. | Broke | .. | .. | 42·8 | .. | C. J. | |
| 112 | $SnCu_2$ | 51·8 | 48·2 | 51·62 | 48·09 | 8·56 | Light grey. | .. | 2,555 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | Remarkable for liquation. |
| 113 | $SnCu_2$ | 51·75 | 48·25 | .. | .. | 8·416 | Grey white. | Vitreous conchoidal. | 3,808 | 0 | .. | 9 | 15 | 7 | .. | .. | Ml. | |
| 114 | .. | 50 | 50 | .. | .. | .. | .. | .. | 725 | .. | .. | .. | .. | .. | .. | .. | Mus. | |
| 115 | .. | 50 | 50 | .. | .. | 8·79 | Bluish white. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Very slightly malleable. |
| 116 | $Sn_7Cu_2$ | 47·95 | 52·05 | 47·61 | 52·14 | 8·442 | Greyish white. | Fine grain. | 1,525 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | |
| 117 | .. | 47·5 | 52·5 | .. | .. | 8·446 | ,, | Crystalline. | 2,407 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | |
| 118 | $Sn_2Cu_3$ | 44·67 | 55·33 | .. | .. | 8·3 | ,, | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 119 | $Sn_3Cu_3$ | 44·63 | 55·37 | 44·52 | 55·28 | 8·312 | ,, | Crystalline. | 3,010 | .. | ·003 | .. | .. | .. | .. | .. | U.S.B. | |
| 120 | .. | 42·5 | 57·5 | .. | .. | 8·437 | ,, | .. | 2,098 | .. | ·006 | .. | .. | .. | .. | .. | U.S.B. | |
| 121 | $Sn_3Cu_4$ | 41·74 | 58·26 | 42·38 | 57·30 | 8·302 | ,, | .. | 3,910 | .. | ·007 | .. | .. | .. | .. | .. | U.S.B. | |
| 122 | .. | 40 | 60 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Bo. | White bell-metal. |
| 123 | $Sn_5Cu_6$ | 39·2 | 60·8 | 38·37 | 1· 3 | 8·182 | Greyish white. | Crystalline. | 2,820 | .. | ·005 | .. | .. | .. | .. | .. | U.S.B. | |
| 124 | .. | 37·5 | 62·5 | .. | .. | 8·101 | ,, | ,, | 2,400 | .. | ·004 | .. | .. | .. | .. | .. | U.S.B. | |
| 125 | SnCu | 34·99 | 65·01 | .. | .. | 8·12 | .. | ,, | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 126 | SnCu | 34·98 | 65·02 | .. | .. | 7·992 | .. | ,, | .. | .. | .. | Broke | .. | .. | 41·5 | .. | C. J. | |
| 127 | SnCu | .. | .. | .. | .. | 8·072 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Cr. | |
| 128 | SnCu | 34·95 | 65·05 | 34·20 | 65·8 | 8·013 | Greyish white. | Crystalline. | 3,371 | .. | ·005 | .. | .. | .. | .. | .. | U.S.B. | |
| 129 | SnCu | 34·92 | 65·08 | .. | .. | 8·056 | ,, | Tabular crystalline. | 3,136 | 0 | .. | 11 | 9 | 6 | .. | .. | Ml. | |
| 130 | .. | 33·33 | 66·67 | .. | .. | .. | White. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Brittle, uniform. |
| 131 | .. | 32·5 | 67·5 | .. | .. | 7·931 | Greyish white. | Crystalline. | 2,322 | .. | ·014 | .. | .. | .. | .. | .. | U.S.B. | |
| 132 | $Sn_4Cu_3$ | 28·72 | 71·28 | 25·85 | 74 | 7·918 | ,, | ,, | 1,648 | .. | ·011 | .. | .. | .. | .. | .. | T. | |
| 133 | .. | 27·5 | 72·5 | .. | .. | 7·915 | ,, | ,, | 4,380 | .. | ·018 | .. | .. | .. | .. | .. | T. | |
| 134 | .. | 25 | 75 | .. | .. | 7·813 | Bluish white. | ,, | .. | .. | .. | .. | .. | .. | .. | .. | W. | |
| 135 | $Sn_5Cu_3$ | 24·38 | 75·62 | 23·35 | 76·29 | 7·835 | Greyish white. | Finely crystalline. | 6,775 | .. | ·03 | .. | .. | .. | .. | .. | T. | |
| 136 | .. | 22·5 | 77·5 | .. | .. | 7·774 | ,, | ,, | 5,000 | .. | ·12 | .. | .. | .. | .. | .. | T. | |
| 137 | .. | 21·74 | 78·26 | 22·36 | 77·63 | 7·53 | Whitish. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Yellow, greenish white. |

PROPERTIES OF COPPER-TIN ALLOYS—*continued.*

| No. | Atomic Formula. | Composition of Original Mixture. | | Composition by Analysis. | | Specific Gravity. | Colour. | Fracture. | Tenacity in lbs. per square inch. | Order of Ductility. (Mallet.) | Relative Ductility. (Thurston.) | Hardness. (Mallet, Calvert, Johnson.) | Order of Malleability. (Mallet.) | Order of Fusibility. (Mallet.) | Conductivity for Heat. Silver=100. | Conductivity for Electricity. Silver=100. | Authority. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cu. | Sn. | Cu. | Sn. | | | | | | | | | | | | | |
| 138 | $Sn_2Cu$ | 21·21 | 78·79 | .. | .. | 7·738 | .. | .. | .. | .. | .. | 135·42 | .. | .. | 43·1 | .. | C. J. | |
| 139 | $Sn_2Cu$ | 21·21 | 78·79 | .. | .. | 7·74 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 140 | $Sn_2Cu$ | 21·18 | 78·82 | 20·25 | 79·63 | 7·77 | Greyish white. | Crystalline. | 4,337 | .. | ·06 | .. | .. | .. | .. | .. | T. | |
| 141 | $Sn_2Cu$ | 21·15 | 78·85 | .. | .. | 7·387 | ,, | ,, | 8,736 | 0 | .. | 12 | 8 | 5 | .. | .. | Ml. | |
| 142 | $Sn_5Cu_2$ | 17·68 | 82·32 | .. | .. | 7·652 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Cr. | |
| 143 | .. | 17·5 | 82·5 | .. | .. | 7·69 | Greyish white. | Crystalline. | 2,816 | .. | ·2 | .. | .. | .. | .. | .. | T. | |
| 144 | .. | 16·4 | 83·6 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 12·76 | Ma. | |
| 145 | $Sn_3Cu$ | 15·21 | 84·79 | .. | .. | 7·53 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 146 | $Sn_3Cu$ | 15·21 | 84·79 | .. | .. | 7·606 | .. | .. | .. | .. | .. | 104·17 | .. | .. | 42·3 | .. | C. J. | |
| 147 | $Sn_3Cu$ | 15·19 | 84·81 | 15·08 | 84·62 | 7·657 | Greyish white. | Crystalline. | 6,520 | .. | ·92 | .. | .. | .. | .. | .. | T. | |
| 148 | $Sn_3Cu$ | 15·17 | 84·83 | .. | .. | 7·447 | ,, | Coarsely crystalline. | 6,944 | 0 | .. | 13 | 15 | 4 | .. | .. | Ml. | |
| 149 | .. | 12·5 | 87·5 | .. | .. | 7·543 | ,, | Crystalline. | 3,798 | .. | 4·71 | .. | .. | .. | .. | .. | T. | |
| 150 | $Sn_4Cu$ | 11·86 | 88·14 | .. | .. | 7·558 | .. | .. | .. | .. | .. | 95·81 | .. | .. | 40·6 | .. | C. J. | |
| 151 | $Sn_4Cu$ | 11·84 | 88·16 | 11·49 | 88·47 | 7·552 | Greyish white. | Crystalline. | 6,380 | .. | 7·08 | .. | .. | .. | .. | .. | T. | |
| 152 | $Sn_4Cu$ | 11·84 | 88·16 | .. | .. | 7·5 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 153 | $Sn_4Cu$ | 11·82 | 88·18 | .. | .. | 7·472 | Greyish white. | Coarsely crystalline. | 6,944 | 8 | .. | 14 | 4 | 3 | .. | .. | Ml. | |
| 154 | $Sn_5Cu$ | 9·73 | 90·27 | .. | .. | 7·517 | .. | .. | .. | .. | .. | 83·33 | .. | .. | 39·6 | .. | C. J. | |
| 155 | $Sn_5Cu$ | 9·73 | 90·27 | .. | .. | 7·52 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Ri. | |
| 156 | $Sn_5Cu$ | 9·7 | 90·3 | 8·57 | 91·39 | 7·49 | Greyish white. | Granular. | 6,450 | .. | 23·47 | .. | .. | .. | .. | .. | T. | |
| 157 | $Sn_5Cu$ | 9·68 | 90·32 | .. | .. | 7 442 | ,, | Earthy. | 3,360 | 6 | .. | 15 | 3 | 2 | .. | .. | Ml. | |
| 158 | .. | 9·09 | 90·91 | .. | .. | 7·472 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | W. | Slightly malleable. |
| 159 | .. | 7·5 | 92·5 | .. | .. | 7·417 | Greyish white. | Granular. | 6,096 | .. | 40·06 | .. | .. | .. | .. | .. | U.S.B. | |
| 160 | .. | 6·43 | 93·57 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 12·03 | Ma. | |
| 161 | $Sn_{12}Cu$ | 4·29 | 95·71 | 3·72 | 96·26 | 7·36 | Greyish white. | Granular. | 4,780 | .. | 56·77 | .. | .. | .. | .. | .. | U.S.B. | |
| 162 | .. | 2·5 | 97·5 | .. | .. | 7·342 | ,, | Fibrous. | 5,600 | .. | 121·9 | .. | .. | .. | .. | .. | U.S.B. | |
| 163 | $Sn_{48}Cu$ | 1·11 | 98·89 | ·74 | 99·02 | 7·305 | ,, | ,, | 3,650 | .. | 133·9 | .. | .. | .. | .. | .. | U.S.B. | |
| 164 | $Sn_{96}Cu$ | ·56 | 99·44 | ·32 | 99·45 | 7·299 | ,, | ,, | 4,475 | .. | 208·8 | .. | .. | .. | .. | .. | U.S.B. | |
| 165 | Sn | 0 | 100 | .. | .. | 7·293 | ,, | ,, | 3,500 | .. | 219·8 | .. | .. | .. | .. | .. | U.S.B. | |
| 166 | .. | 0 | 100 | .. | .. | 7·291 | White. | ,, | 6,040 | 7 | .. | 16 | 1 | 1 | .. | .. | Ml. | |
| 167 | .. | 0 | 100 | .. | .. | 7·297 | .. | .. | 2,122 | .. | .. | .. | .. | .. | .. | .. | Wa. | |
| 168 | .. | 0 | 100 | .. | .. | 7·294 | .. | .. | .. | .. | .. | .. | .. | .. | .. | 11·45 | Ma. | |
| 169 | .. | 0 | 100 | .. | .. | 7·305 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | Cr. | |
| 170 | .. | 0 | 100 | .. | .. | .. | .. | .. | .. | .. | .. | 27 | .. | .. | 42·2 | .. | C. J. | |
| 171 | .. | 0 | 100 | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | .. | 15·2 | 17 | We. | |

### LIST OF AUTHORITIES REFERRED TO IN PRECEDING TABLE.

Bo.—**Bolley**, *Essais et Recherches Chimiques*, Paris, 1869, pp. 345, 348.
Cr.—**Croockewit**, *Erdmann's Journal*, 1848, vol. xlv. pp. 87–93.
C. J.—**Calvert** and **Johnson**, "Specific Gravities," *Phil. Mag.*, 1859, vol. xvii. pp. 114–121; "Heat Conductivity," *Phil. Trans.*, 1858, pp. 349–368.
De.—**S. B. Dean**, *Ordnance Notes*, No. xl., Washington, 1875.
La.—**Lafond**, *Dingler's Journal*, 1855, vol. cxxxv. p. 269.
Ml.—**Mallet**, *Phil. Mag.*, 1842, vol. xxi. pp. 66–68.
Ma.—**Matthiessen**, *Phil. Trans.*, 1860, p. 161; *ibid.*, 1864, pp. 167–200.
Mar.—**Marchand** and **Scheerer**, *Journal für praktische Chemie*, vol. xxvii. p. 193 (Clark's Constants of Nature).
Mus.—**Musschenbroek**, *Ure's Dictionary*, Article "Alloy."
Ri.—**Riche**, *Annales de Chimie*, 1873, vol. xx. pp. 351–419.
U.S.B.—*Report of Committee on Metallic Alloys appointed by United States Board to test Iron, Steel, etc.*
T.—**Thomas Thomson**, *Annales de Chimie*, 1814, vol. lxxxix. pp. 46–58.
W.—**Watts'** *Dictionary of Chemistry.*
Wa.—**Major Wade**, United States Army, *Report on Experiments on Metals for Cannon*, Phil., 1856.
We.—**Weidemann**, *Phil. Mag.*, 1860, vol. xix. pp. 243, 244.

In the foregoing table the figures of order of ductility, hardness, and fusibility are taken from Mallet's experiments on a series of sixteen alloys, the figure 1 representing the maximum and 16 the minimum of the property. The ductility of the brittle metals is represented as 0. The relative ductility given in the table of the alloys experimented on by the U.S. Board is the proportionate extension of the exterior fibres of the pieces tested by torsion, as determined by the autograph strain diagrams. It will be seen that the order of ductility differs widely from that given by Mallet.

The figures of relative hardness, on the authority of Calvert and Johnson, are those obtained by them by means of an indenting tool. The figures are on a scale in which cast iron is rated at 1000. The word "broke" in this column indicates that the alloy opposite which it occurs broke under the indenting tool, showing that the relative hardness could not be measured, but was considerably greater than that of cast iron.

Since the publication of this table the copper-tin alloys have been subjected to a very thorough investigation, and their physical and chemical as well as their mechanical properties have been studied. It would take too long to consider the various researches in detail, but the results may be briefly stated. The melting-points and the microscopical examination of the alloys have already been referred to, and in addition to these Laurie (and more recently Herschkowitsch) have determined the electromotive force; Lodge has determined the conductivity and Herschkowitsch has determined the heat of formation.

The variations in the physical properties of the series are plotted in fig. 21, and it will be observed that the evidence in support of the existence of a definite compound corresponding to the formula $Cu_3Sn$ is overwhelming.

A glance at the curves representing the physical and mechanical properties of the copper-tin alloys (figs. 21 and 22) will show that from a mechanical point of view the middle members of the series are valueless, and in fact the useful alloys do not contain more than 25 per cent. of copper. These in turn may be divided into two classes, viz.: (1) Gun-metal, containing from 8 to 14 per cent. of tin; and (2) bell metal, containing from 15 to 25 per cent. of tin.

**Gun-metal**, as is well known, derives its name from the fact that before the introduction of steel as a material for the manufacture of guns they were made of this alloy.

The following table, giving the composition of the actual alloys employed in the manufacture of ordnance by the different countries, shows that, with the exception of the Chinese, there is not much difference between them :—

| | Copper. | Tin. | Iron. | Zinc. | Lead. |
|---|---|---|---|---|---|
| English ordnance . . | 91 74 | 8·26 | ... | ... | ... |
| 8-pounder guns . . | 91·66 | 8·33 | ... | ... | ... |
| Prussian ordnance . . | 90·91 | 9·09 | ... | ... | ... |
| French ,, . . | 90·73 | 9·27 | ... | ... | ... |
| American ,, . . | 90·00 | 10·00 | ... | ... | ... |
| Russian ,, . . | 88·61 | 10·70 | ·69 | ... | ... |
| Swiss ,, . . | 88·93 | 10·38 | ·11 | ·42 | ·06 |
| Chinese ,, . . | 77·18 | 3·42 | 1·16 | 5·02 | 13·22 |
| ,, ,, . . | 93·19 | 5·43 | 1·38 | ... | ... |

The bronzes containing from 8 to 11 per cent. of tin are the most suitable where a combination of strength, elasticity, toughness, and ability to withstand shock are required. The alloy containing 9 per cent. of tin has a tensile strength of about 16 tons per square inch, with an elastic limit of 6·5 tons per square inch and an elongation of 16 per cent.

Gun-metal, as has already been stated, consists of a solid solution of tin in copper containing a certain amount of the definite compound $Cu_4Sn$. When viewed under the microscope the solid solution is yellow in colour, while the compound is almost white. It is curious that this constituent does not form until the alloy is completely solid; and moreover, as was first pointed out by Charpy, it never occurs in a uniform mass, but is always more or less broken up. Photographs 9 and 10 show the appearance of a gun-metal magnified 100 diameters, and photograph 11 shows the appearance of the $Cu_4Sn$ under a higher magnification.

**Influence of Heat Treatment on Bronzes.**—It has already been shown that the bronzes containing from 9 to 22 per cent. of tin pass through three distinct stages during solidification. In the first place, a solid solution of tin in copper (Heycock and Neville's $\alpha$ constituent) separates out at temperatures varying from 1020° in the case of the bronze containing 9 per cent. of tin to 860° in the bronze containing 22 per cent. of tin. At 790° the remainder of the alloy solidifies in the form of a second solid solution (Heycock and Neville's $\beta$ constituent) containing from 22·5 to 27 per cent. of tin. The solid alloy now consists of two solid solutions and undergoes no further change until the temperature falls to 500°, when the $\beta$ solution is no longer stable but breaks up with the formation of the $\delta$ constituent, which is probably the compound $Cu_4Sn$. The alloy now consists of a mixture of $\alpha$ and $\delta$, and is stable at the ordinary temperature.

It is obvious from the foregoing considerations that heat treatment must have a very decided influence on the physical properties of the alloy. If, for example, the bronze is quenched at a temperature above 500° the formation of $Cu_4Sn$ (a hard, brittle constituent) is prevented, and the alloy is more malleable and stronger. The change is most strongly marked in the case of the alloys rich in tin.

Guillet has made some experiments on the mechanical properties of bronzes quenched at various temperatures, and his results confirm the conclusions which would be drawn from theoretical considerations. The curves in fig. 28 are plotted from Guillet's figures, and represent the breaking strain of five bronzes containing respectively 95, 91, 87, 84, and 79 per cent. of copper. These results explain the fact, which has long been known,

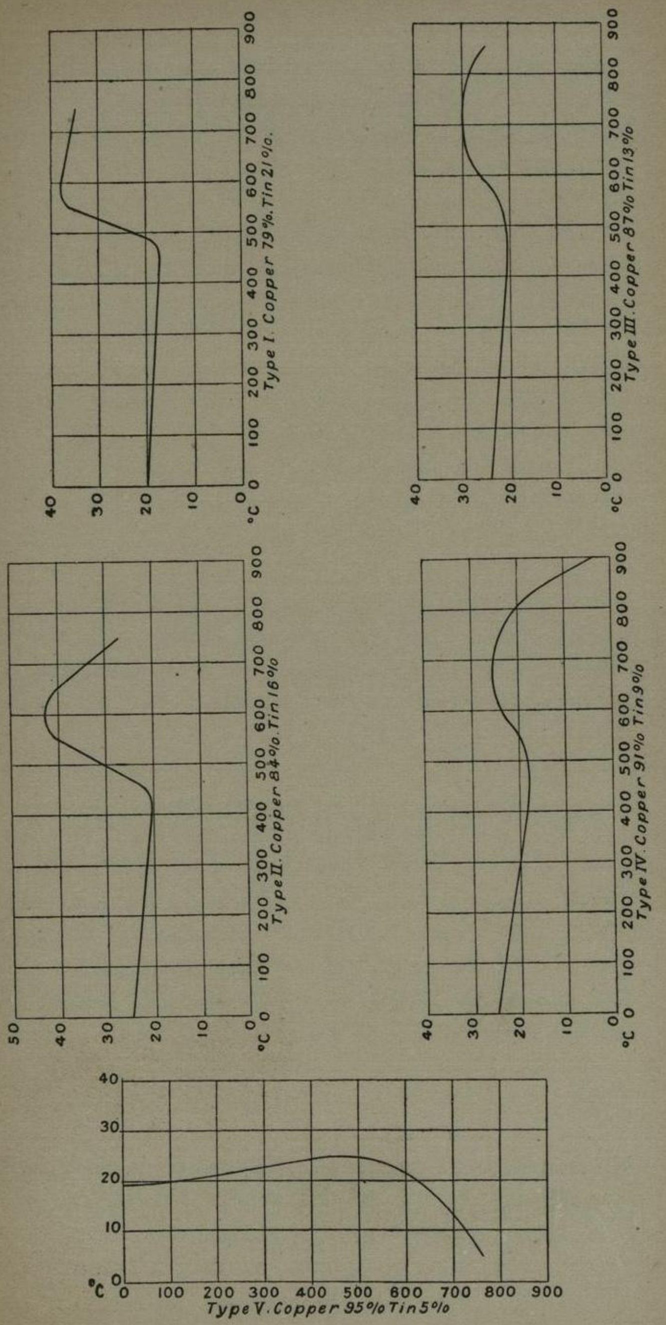

Fig. 28.—Tensile Strength of Quickly-cooled Bronzes.

that bronze can be forged at a temperature just below redness, and that bronzes quenched at or above that temperature become malleable. The Chinese were evidently well aware of this property of the bronzes; for their gongs have the composition of these bronzes, and were not cast, but hammered.

Zenghelis has described an ancient bronze coining die found in Egypt in 1904. It dates from 430–322 B.C., and is the only genuine example of an antique bronze die. An analysis of the die showed 69·85 per cent. of copper, 22·51 per cent. of tin, and 7·6 per cent. of oxygen. No impurities were detected, and from the analysis and the relative oxidation of the two metals Zenghelis concludes that the original composition was as nearly as possible 75 per cent. of copper and 25 per cent. of tin.

The die has not been examined microscopically, but there is little doubt that the alloy was quenched in order to enable it to stand the shock of coining.

Modern bronze nearly always contains small quantities of lead, zinc, and iron, which are often purposely added with the object of conferring special properties upon the bronze. If, however, a combination of strength and elasticity is required, the alloy should be as free as possible from these additions.

Lead, except in very small quantities, does not alloy with bronze, but separates out in the form of minute globules as the metal cools. The best bronzes should not contain more than 0·15 per cent. of lead; but in cases where an alloy of great strength is not necessary, a larger amount of lead is sometimes added, as it enables the metal to be more easily turned or filed. For special purposes, however, a much larger quantity of lead is added. The most important of these are the bronzes used for bearings and for statuary.

Zinc in small quantities has a very beneficial influence when added to bronze. Being an easily oxidisable metal it combines with any oxygen which may be present, either in the free state or in the form of dissolved oxides in the molten metal, with the result that the metal is more fluid—"runs thinner," as it is described, and gives castings free from the defects known as pinholes. A slight excess of zinc will merely alloy with the bronze, without materially affecting its quality; but the excess of zinc should not exceed 2 per cent., otherwise the colour of the bronze will be injured and the alloy will be harder, but weaker.

Iron alloys with bronze, making the resulting alloy lighter in colour and considerably harder. It increases the tenacity, and is useful where a very hard bronze is required.

**Bell-metal** contains from 15 to 25 per cent. of tin and the remainder copper. Lead, zinc and other impurities should not be present in more than traces in the best metal. Large bells contain the largest amounts of tin, usually about 25 per cent., while small bells contain about 15 per cent. The tone of a bell can be modified to a certain extent by altering its composition, but the purity of tone is a matter which depends more upon the skill of the designer and the founder than upon the composition. In fact, the shape of a bell is of the utmost importance, and it is probable that few metals or alloys could not be used in the manufacture of bells, if they were of the proper shape.

In this connection it is not without interest to recall the fact that as far back as 1726 Lemery noticed that under certain conditions even lead becomes almost as sonorous as bell-metal, and Réaumur, to whom Lemery communicated the fact, subsequently showed that it was necessary to cast the lead in the form of a segment of a sphere. The following table will give an idea of the very variable composition of the alloys used in the manufacture of bells:—

| | Copper. | Tin. | Zinc. | Lead. | Antimony. |
|---|---|---|---|---|---|
| Large bells . . . | 76 | 24 | ... | .. | ... |
| House bells . . . | 78 | 22 | ... | ... | ... |
| ,, ,, . . . | 80 | 20 | ... | ... | .. |
| Musical bells . . | 84 | 16 | ... | ... | ... |
| Clock bells . . . | 75 | 25 | ... | ... | ... |
| Old bell at Rouen . . | 71 | 26 | 1·8 | 1·2 | ... |
| Small bells . . . | 40 | 60 | ... | ... | ... |
| ,, ,, . . . | ... | 87·5 | ... | ... | 12·5 |

Bell-metal when slowly cooled is very hard and brittle. It consists largely of the compound $Cu_4Sn$, and is therefore very susceptible to heat treatment. When chilled from a low red heat (*i.e.* at a temperature above that at which $Cu_4Sn$ forms) it is more yellow in colour and malleable.

As regards English bells the earliest existing example to which a date can be affixed is to be found in the village of Claughton, near Lancaster. It is slightly over 16 inches in height, 21 in diameter at the lip, and bears the date 1296. From this time bells with inscriptions and dates are to be found, and the history of bell-founding in this country can be traced. The earliest instructions for bell-founding occur in a treatise by Walter of Odyngton, a monk of Evesham, in the time of Henry III., who describes the method of founding and also the method of determining the relative sizes of the bells necessary to produce the required notes.

Many of the well-known large bells have been recast from older bells. Thus "Great Dunstan" of Canterbury, weighing 3½ tons, was recast in 1762 from an old bell, originally the gift of Prior Molass in 1430. "Bell Harry" was likewise recast in 1635 from an old bell said to have been the gift of Henry VIII. The famous "Great Tom" of Oxford was removed from Oseney Abbey to Oxford at the time of the dissolution of the monasteries, and has passed through many vicissitudes. It was recast in 1612, again in 1654, and in 1680 three unsuccessful attempts to recast it were made, the mould bursting in the third attempt. The next attempt was successful, and the bell was again recast in 1741.

Of the more modern and largest bells may be mentioned "Peter" of York, cast by Charles and George Mears at the Whitechapel foundry in 1845. It weighs about 12½ tons, is 7 ft. 4 in. in diameter, and cost £2000.

The original "Big Ben" of Westminster was cast by Messrs Warner & Son in 1856, and weighed 14 tons, with a diameter of 9 ft. It was found to be cracked, and was recast by the Mears at Whitechapel with a slightly reduced weight and a very much lighter clapper—6 cwt. instead of a ton.

"Great Paul" of St Paul's Cathedral was cast at the Loughborough foundry in 1881. It weighs 16 tons 14 cwts. 75 lbs., and has a diameter of 114¾ inches.

**Statuary Bronze.**—The essential features of a statuary bronze are—(1) that it shall be very fluid and easily cast; (2) that it shall be capable of being finished and easily filed; (3) that its colour shall be as nearly that of gun-metal as is consistent with these requirements; and (4) that under the influence of the atmosphere it shall assume a pleasing oxidation tint or "patina," as it is called.

The alloy which has been found to possess these properties most nearly lies midway between the bronzes and the brasses, and usually contains a considerable percentage of lead. The following table shows the percentage compositions of a number of celebrated statues :—

| | Copper. | Tin. | Zinc. | Lead. | Iron. | Nickel. |
|---|---|---|---|---|---|---|
| Column Vendôme, Paris . . | 89·20 | 10·20 | 0·50 | 0·10 | ... | ... |
| Column of July, Paris . . | 91·40 | 1·60 | 5·60 | 1·40 | ... | ... |
| Henry IV., Paris . . | 89·62 | 5·70 | 4·20 | 0·48 | ... | ... |
| Louis IV. equestrian statue, Paris, 1699 | 91·40 | 1·70 | 5·53 | 1·37 | ... | ... |
| The Shepherd, Potsdam Palace | 88·68 | 9·20 | 1·28 | 0·77 | ... | ... |
| Bacchus, Potsdam Palace . . | 89·34 | 7·50 | 1·63 | 1·21 | 0·18 | ... |
| Germanicus, Potsdam Palace, 1820 | 89·78 | 6·16 | 2·35 | 1·33 | ... | 0·27 |
| Mars and Venus, Munich, 1585 | 94·12 | 4·77 | 0·30 | 0·67 | ... | 0·48 |
| Bavaria, Munich . . . | 91·55 | 1·70 | 5·50 | 1·30 | ... | ... |
| Grosser Kurfürst, Berlin, 1703 . | 89·09 | 5·82 | 1·64 | 2·62 | 0·13 | ... |
| Frederick the Great, Berlin . | 88·30 | 1·40 | 9·50 | 0·70 | ... | ... |
| Melanchthon, Wittenberg . | 89·55 | 2·99 | 7·46 | ... | ... | ... |

The addition of zinc renders the alloy more fluid, and greatly facilitates the operation of casting. Too much zinc, however, should be avoided, or the metal will have a brassy colour, and will not assume a pleasing "patina" on exposure to the atmosphere.

The presence of lead in statuary bronze is very important. In the first place, it appears to give a very fluid metal, but it also causes the bronze to acquire a beautiful brownish black patina, characteristic of many old bronzes on exposure to the atmosphere.

**Coinage Bronze.**—A bronze which is to be used for coinage must be malleable and ductile, so that it will take the impression of the die; and as hard as possible, in order to withstand wear. In May 1852 France adopted an alloy of 95 per cent. of copper, 4 per cent. of tin, and 1 per cent. of zinc, and the same alloy was first used in England in 1861. It is extremely durable, and is the alloy employed by both countries at the present time. The fact that a large number of the coins struck in 1861 are still in circulation and the date and lettering perfectly legible, is sufficient evidence of the hardness and durability of the alloy.

For medals where fine relief is required a somewhat softer alloy, containing less tin, is used.

**Speculum metal** derives its name from the fact that it was the alloy employed for the manufacture of reflectors. Until comparatively recently it was used for telescope and other optical reflectors, but these are now made of glass. Speculum metal contains 66·6 per cent. of copper and 33·4 per cent. of tin, and consists of the compound $SnCu_4$. It is extremely hard, brittle, white, and takes a very fine polish. The composition of well-known telescope mirrors varies from 65 to 70 per cent. of copper, the famous Ross reflector containing 68·21 per cent. and the Birr Castle 70·3 per cent.

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## CHAPTER VIII.

## COPPER ALLOYS, BRASS.

THE discovery of brass vessels and implements of very early origin is proof that the alloys of copper and zinc were known to the ancients; but there is no doubt that, just as in the case of bronze, the early brasses were produced accidentally owing to the admixture of zinc ores with the copper ores. Later on the addition of calamine to copper ores became the regular method of making brass, and was long practised without any knowledge of the part it played in producing the beautifully coloured metal.

The early history of brass in this country can be traced by means of the ecclesiastical brasses or *lattens* existing in our churches. Latten was the ancient name of the alloy (which is still retained in the French word *laiton*), and until the middle of the sixteenth century it was manufactured in Flanders and Germany and imported into this country, principally from Cologne, in the form of rectangular pieces known as Cullen plates. The alloy contained considerable quantities of lead and tin, and it is probably on that account that the brasses have lasted so well.

The earliest existing brass is that of Sir John Daubernoun at Stoke d'Abernon in Surrey, and dated about 1277. The brass, 76 in. in length, is in the pavement of the village church, and represents Sir John Daubernoun in a complete suit of chain mail.

From this date onwards there exist a complete series of brasses which have proved of the greatest historical value.

In the middle of the sixteenth century there is a marked change in the quality of the brass, which now began to be manufactured