

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.

BIBLIOGRAPHY.

- Behrens, *Das Mikroskopische Gefüge der Metalle und Legierungen*, 1894.
 Campbell, "Alloys of Copper and Tin," *Proc. Inst. Mech. Eng.*, 1901.
 Charpy, *Bulletin de la Société d'Encouragement*, March 1897, "Contributions à l'étude des Alliages."
 Guillemin, *Commission des Méthodes d'essais*, 1894.
 Herschkowitsch, *Zeitschrift für physikalische Chemie*, vol. xxvii.
 Heycock and Neville, *Philosophical Transactions*, January 1904.
 Laurie, *Phil. Mag.*, vol. v.; *Jour. Chem. Soc.*, vol. cccii. and vol. cccxxv.
 Le Chatelier, *Bulletin de la Société d'Encouragement*, 1895.
 Neumann, "Ancient Copper Alloys," *Zeitschrift für angewandte Chemie*, vol. xx. 1907, p. 2019.
 Raven, *The Bells of England*.
 Roberts-Austen and Stansfield, "Third and Fourth Reports, Alloys Research Committee," *Inst. Mech. Eng.*
 Thurston, *Materials of Construction*; vol. ii., "Brasses and Bronzes."
 Zenghelis, *Chem. Zeit.*, 1907, p. 1116.

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

in England instead of being imported. For the purposes of memorial tablets the English brass was unsuitable, and, according to Mr Macklin, it "was cast, or more probably rolled, in thin plates which have worn grievously."

With regard to the manufacture of brass in England, Haines states that in 1565 Queen Elizabeth granted a patent to Wm. Humfrey, assay master of the Mint, and Christopher Shutz, to search and mine for calamine, and to have the use of it for making all sorts of battery wares, cast works, and wire, of latten. Similar privileges were granted to Cornelius Devoz, Daniel Houghsetter, and Thomas Thurland, and in 1568 the company of the mineral and battery works was incorporated. In 1584 a lease of works at Isleworth was granted to John Brode, and shortly afterwards several other mills were set up.

In 1700 the brass industry was firmly established in this country, and with the success of the famous Cheadle works, which were established in 1730, the industry soon grew to be one of the most flourishing. Owing to the fine colour of the alloy and the ease with which it lends itself to all kinds of mechanical treatment, it has become the most extensively used of the copper alloys. According to its composition, brass may be obtained hard and strong or sufficiently ductile to be drawn into wire or hammered out into sheets whose thickness is not more than $\frac{1}{50000}$ of an inch.

The properties and constitution of the copper-zinc alloys were naturally studied by the early workers, but it is unnecessary to consider their work in detail. The following table, drawn up by the Committee on Alloys appointed by the United States Board, contains in a condensed form the results of investigations down to the year 1881:—

[TABLE.

PROPERTIES OF COPPER-ZINC ALLOYS COLLATED FOR THE COMMITTEE ON ALLOYS APPOINTED BY THE UNITED STATES BOARD (Report, vol. ii. 1881).

No.	Composition of Original Mixture.		Composition by Analysis.		Atomic Formulae.	Fracture.	Tenacity in lbs. per square inch.	Order of Ductility. (Mallet.)	Relative Ductility. (Thurston.)	Order of Malleability. (Mallet.)	Hardness. (Mallet, Calvert, Johnson.)	Order of Fusibility. (Mallet.)	Conductivity for Heat. Silver=100.	Conductivity for Electricity. Silver=100.	Authority.	Remarks.
	Cu.	Zn.	Cu.	Zn.												
1	100	0	97.83	1.88	..	Fibrous. Earthy.	27,800	8	30.8	1	22	15	..	..	U.S.B.	Sheet copper.
2	100	0	97.8	2.2	..	..	55,104	..	..	..	30.1	..	..	..	U.S.B.	Mean of nine samples, for buttons.
3	100	0	97.5	2.5	..	..	..	..	..	..	..	..	..	..	U.S.B.	Buttons.
4	100	0	96.07	3.79	..	..	..	..	..	..	..	..	..	..	U.S.B.	Red tomback of Vienna.
5	100	0	92.32	7.68	..	..	24,252	..	..	..	..	..	..	..	Bo.	Railway axles porous.
6	100	0	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Defective bar.
7	100	0	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Finchbeck.
8	93.15	0.85	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bearings, Australia.
9	97.8	2.2	..	..	..	Vesicular.	27,240	..	118.9	..	..	..	..	..	U.S.B.	Red tomback of Paris.
10	97.5	2.5	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tomback.
11	97.2	2.5	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
12	95	5	..	..	..	Vesicular.	11,500	..	..	..	..	..	..	..	Bo.	..
13	93.6	6.4	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
14	92.5	7.5	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
15	92.5	7.5	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
16	92	8	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
17	91	9	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..

PROPERTIES OF COPPER-ZINC ALLOYS—continued.

No.	Atomic Formulae.	Composition of Original Mixture.		Composition by Analysis.		Specific Gravity.	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of Ductility. (Mallet.)	Relative Ductility. (Thurston.)	Order of Malleability. (Mallet.)	Hardness. (Mallet, Calvert, Johnson.)	Order of Fusibility. (Mallet.)	Conductivity for Heat. Silver=100.	Conductivity for Electricity. Silver=100.	Authority.	Remarks.
		Cu.	Zn.	Cu.	Zn.													
18	$Cu_{10}Zn$	90.72	9.28	..	..	8.605	Red-yellow.	Coarsely crystalline.	27,104	6	..	13	21	14	..	..	Ml.	Specific gravity of ingot 8.753.
19	$Cu_{10}Zn$	90.65	9.35	..	9.60	8.884	..	..	..	..	..	..	..	..	..	..	Ri.	..
20	..	99	10	90.56	9.42	8.773	Yellow-red.	Vesicular.	..	..	169.1	..	..	..	..	..	U.S.B.	French orsïde.
21	Cu_8Zn	90	10	..	..	8.607	Red-yellow.	Finely crystalline.	25,760	4	..	11	20	13	..	..	Bo. Ml.	..
22	Cu_8Zn	89.8	10.2	..	..	8.607	..	..	..	..	..	..	..	..	..	..	We. Ml.	..
23	Cu_8Zn	88.89	11.11	..	..	8.633	Red-yellow.	Finely crystalline.	23,672	2	..	10	19	12	..	..	We. Ml.	..
24	Cu_8Zn	88.6	11.4	..	..	8.633	Yellow-red.	Vesicular.	..	..	..	..	..	..	..	..	U.S.B.	..
25	..	87.5	12.5	88.94	10.97	..	..	..	23,568	9	..	9	18	11	..	..	Ml.	..
26	Cu_7Zn	87.3	12.7	..	..	8.587	..	..	..	..	..	..	..	..	..	..	We. Bo.	Very delicate castings.
27	..	86.67	13.33	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Ornaments of Hanover.
28	..	86.38	13.61	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	French orsïde.
29	..	86	14	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
30	..	85.5	14.5	..	..	8.591	Yellow-red.	Fine fibrous	31,584	5	..	8	17	10	..	..	Bo.	..
31	Cu_6Zn	85.34	14.66	..	..	8.71	..	..	..	..	..	..	..	..	..	..	Ml. Ri.	Specific gravity of powder 8.584.
32	..	85.3	14.7	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Paris jewellery.
33	..	85	15	89.8	10.06	8.656	Red-yellow.	Earthy.	..	..	280.1	..	..	..	..	..	Bo.	..

34	..	85	15	..	..	..	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	Tombac of oker.
35	..	84.6	15.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Gold-leaf.
36	..	84.21	15.79	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac for buttons.
37	..	83.9	16.1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bronze powder.
38	Cu_5Zn	83.02	16.98	..	..	8.415	Red-yellow.	Finely crystalline.	30,688	11	..	2	16	9	..	..	..	Bo.	Bath metal.
39	Cu_5Zn	82.95	17.05	..	..	8.573	..	..	..	..	..	..	..	..	..	..	..	Ml. C. J.	Alloy for jewellery.
40	..	82.54	17.46	..	..	8.633	Red-yellow.	Earthy.	32,600	..	..	..	..	..	..	..	..	Bo.	..
41	..	82.5	17.5	82.93	16.98	..	..	..	..	..	105.3	..	..	..	..	..	..	U.S.B.	Ornaments.
42	..	82.46	17.54	..	..	..	..	..	..	..	..	..	..	..	..	..	..	We.	..
43	..	82.3	17.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	Dutch metal.
44	..	80	20	81.91	17.9	8.598	Yellow.	Earthy.	32,670	..	..	..	..	..	..	..	..	Bo.	Specific gravity of powder 8.367.
45	Cu_4Zn	79.65	20.35	..	..	..	Yellow-red.	Finely crystalline.	52,928	7	..	3	15	8	..	..	..	U.S.B.	Vienna gold-leaf.
46	Cu_4Zn	79.56	20.44	..	..	8.650	..	..	..	..	..	..	..	..	..	..	..	Ml. C. J.	Bristol metal.
47	Cu_4Zn	79.51	20.49	..	..	8.638	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
48	..	77.9	22.1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Rolled sheet brass.
49	..	77.5	22.5	77.39	22.45	8.574	Yellow.	Earthy.	35,630	..	..	..	..	..	..	..	..	C. J.	Brass of thirty-two copper and twelve of zinc.
50	..	75.7	24.3	..	..	..	Yellow.	Earthy.	30,520	..	..	..	..	..	..	..	..	Bo.	..
51	..	75	25	76.65	23.08	8.528	..	..	..	..	..	..	..	..	..	..	..	Bo.	Chrysolin.
52	..	74.62	25.38	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Tombac.
53	Cu_3Zn	74.68	25.42	..	..	8.897	Pale yellow.	Finely crystalline.	29,344	10	..	4	14	7	..	..	..	Bo.	Suitable for forging or leaf.
54	Cu_3Zn	74.48	25.52	..	..	8.576	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	Suitable for forging.
55	..	72.73	27.27	..	..	..	Yellow.	Earthy.	31,580	..	..	..	..	..	..	..	..	Bo.	..
56	..	72.5	27.5	73.2	26.47	8.465	..	..	..	..	..	..	..	..	..	..	..	U.S.B.	..
57	..	72	28	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
58	..	71.5	28.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
59	..	70.1	29.9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
60	..	70	30	71.2	28.54	8.444	Yellow.	Earthy.	30,510	..	..	..	..	..	..	..	..	U.S.B.	..
61	..	67.74	32.26	..	..	..	..	..	..	..	..	..	..	..	..	..	..	We.	..
62	..	67.54	32.46	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	..
63	..	67.5	32.5	69.74	30.06	8.884	Yellow.	Earthy.	28,120	..	..	..	..	..	..	..	..	U.S.B.	Suitable for forging.
64	..	67.2	32.8	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Bristol metal.
65	..	66.7	33.3	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Chrysolin.
66	..	66.6	33.4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bo.	Common brass.

PROPERTIES OF COPPER-ZINC ALLOYS—continued.

No.	Atomic Formulæ.	Composition of Original Mixture.		Composition by Analysis.		Specific Gravity.	Colour.	Fracture.	Tenacity in lbs. per square inch.	Order of Ductility. (Mallet.)	Relative Ductility. (Thurston.)	Order of Malleability. (Mallet.)	Hardness. (Mallet, Calvert, Johnson.)	Order of Fusibility. (Mallet.)	Conductivity for Heat. Silver=100.	Conductivity for Electricity. Silver=100.	Authority.	Remarks.	
		Cu.	Zn.	Cu.	Zn.														
67	Cu ₂ Zn	66.13	33.82	..	..	8.299	Full yellow.	Finely crystalline.	28,000	3	..	6	13	6	..	..	..	Suitable for forging.	
68	Cu ₂ Zn	66.16	33.84	..	..	8.302	..	..	..	472.92	..	..	..	..	..	..	..	..	Suitable for forging. Specific gravity of powder 8.39.
69	Cu ₂ Zn	66.06	33.94	..	..	8.488	..	..	..	..	..	..	..	..	..	..	..	..	Good brass wire.
70	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Mosaic gold.
71	..	65.98	34.02	..	34.5	8.41	..	..	..	..	..	..	..	..	..	..	..	..	Suitable for forging.
72	..	65.4	34.6	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Suitable for forging.
73	..	65.3	34.7	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
74	..	65	35	..	66.27	8.371	Red-yellow.	Earthy.	37,800	..	..	..	..	..	..	..	..	..	Good brass wire.
75	..	65	34.76	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Mosaic gold.
76	..	63.5	36.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Suitable for forging.
77	..	62.5	37.5	..	63.44	8.411	Red-yellow.	Earthy.	48,300	..	60.6	..	..	..	..	..	..	..	..
78	..	61.25	38.75	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Strong solder for brass.
79	..	60.8	39.2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Bristol metal.
80	..	60.16	39.71	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Suitable for forging.
81	..	60	40	..	60.94	8.405	Red-yellow.	Earthy.	41,065	..	49	..	..	..	..	..	..	..	..
82	..	60	40	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
83	..	59.5	40.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
84	Cu ₃ Zn ₂	59.36	40.64	..	..	8.224	..	..	..	..	..	..	..	..	..	..	..	..	Muntz' metal. Ship's sheathing.

85	Cu ₂ Zn ₂	59.26	40.74	..	40.10	8.412	..	..	..	..	..	..	..	..	..	..	..	..	Specific gravity of powder 8.293. Suitable for forging.
86	..	58.33	41.77	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
87	..	57.5	42.5	..	58.49	8.363	Red-yellow.	Earthy.	50,450	..	12.1	..	..	..	..	..	..	..	Bath metal.
88	..	55	45	..	55.15	8.283	Red-yellow.	Earthy.	44,280	..	19.5	..	..	..	..	..	..	..	..
89	..	55	45	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
90	..	54.9	45.1	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
91	..	54	46	..	54.86	8.301	Red-yellow.	Coarsely granular.	46,400	..	7.4	..	..	..	..	..	..	..	..
92	..	52.5	47.5	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	Very ductile. Very ductile.
93	CuZn	50	50	..	49.66	8.291	Full yellow.	Coarsely granular.	30,990	12	..	5	12	..	..	..	..	..	..
94	CuZn	49.47	50.53	..	..	8.230	..	..	20,608	..	..	..	..	..	..	..	..	..	German brass.
95	CuZn	49.32	50.68	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
96	CuZn	49.23	50.76	..	50.30	8.304	..	..	..	..	..	..	604.17	..	..	..	..	..	Specific gravity of ingot 8.263.
97	..	47.5	52.5	..	48.95	8.216	Pinkish grey.	Coarsely granular.	26,050	..	..	..	..	..	..	..	..	..	..
98	..	45	55	..	47.56	..	..	..	24,150	..	..	..	..	..	..	..	..	..	..
99	..	43	57	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
100	..	42.5	57.5	..	43.36	8.035	Pinkish grey.	Finely granular.	9,710	..	..	..	..	..	..	..	..	..	..
101	..	40	60	..	41.3	8.061	Silver-white.	Vitreous conchoidal.	3,727	..	..	..	..	..	..	..	..	..	..
102	Cu ₂ Zn ₃	39.27	60.73	..	60.35	8.171	..	..	..	..	..	..	..	..	..	..	..	..	..
103	..	37.5	62.5	..	38.36	7.982	Silver-white.	Vitreous conchoidal.	3,087	..	..	..	..	..	..	..	..	..	..
104	Cu ₃ Zn ₅	36.88	63.12	..	..	7.939	..	..	..	..	..	..	..	..	..	..	..	..	..
105	..	35	65	..	36.62	7.974	Silver-white.	Vitreous conchoidal.	2,656	..	..	..	..	..	..	..	..	..	..
106	CuZn ₂	33.34	66.66	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
107	CuZn ₂	32.85	67.15	..	..	8.283	Deep (?) yellow.	Coarsely (?) crystalline.	43,232?	1	..	7	10	6	..	..	..	..	..
108	CuZn ₂	32.74	67.26	..	..	7.859	..	..	..	..	..	..	..	..	..	..	..	..	..
109	CuZn ₂	32.66	67.34	..	64.8	8.048	..	..	..	..	..	..	..	..	..	..	..	..	..

1 The properties mentioned by Mallet are wrong.

LIST OF AUTHORITIES REFERRED TO IN PRECEDING TABLE.

- Bo.—Bolley, *Essais et Recherches Chimiques*, Paris, 1869.
 Cr.—Croockewit, *Erdmann's Journal*, vol. xlv. 1848, pp. 87-93.
 C. J.—Calvert and Johnson, *Phil. Mag.*, vol. xviii. 1850, pp. 354-359; *ibid.*, vol. xvii. 1859, pp. 114-121; *ibid.*, vol. xvi. 1858, pp. 381-383.
 Ma.—Matthiessen, *Phil. Trans.*, 1860, pp. 161-184; *ibid.*, 1864, pp. 167-200.
 Ml.—Mallet, *Phil. Mag.*, vol. xxi. 1842, pp. 66-68.
 Ri.—Riche, *Annales de Chimie*, vol. xxx. 1873, pp. 351-410.
 U.S.B.—*Report of Committee on Metallic Alloys appointed by United States Board*, Thurston's investigations.
 We.—Weidemann, *Pogg. Annalen*, vol. cviii, 1859, pp. 393-407.

Prof. R. H. Thurston, who conducted the investigations for the United States Board, makes the following remarks on the preceding table:—

“Alloys having the name of Bolley appended give compositions and commercial values, and mention valuable properties, such as are given in the column of remarks, but do not give results in figures as recorded by other authorities. The same properties and the same name are recorded by Bolley for alloys of different compositions, such as those which in the column of remarks are said to be suitable for forging. It might be supposed that such properties belonged to those mixtures, and not to others of similar composition. It seems probable, however, that when two alloys of different mixtures of copper and zinc are found to have the same strength, colour, fracture and malleability, it will also be found that all alloys between these compositions will possess the same proportions; and hence that, instead of the particular alloys mentioned only being suitable for forging, all the alloys between the extreme compositions mentioned also possess that property.

“In the figures given from Mallet under the heads of order of ductility, order of malleability, hardness, and order of fusibility, the maximum of each of these properties is represented by 1.

“The figures given by Mallet for tenacity are confirmed by experiments of the author, with a few very marked exceptions. These exceptions are chiefly the figures for copper, for zinc, and for CuZn_2 (32.85 per cent. of copper, 67.15 per cent. of zinc). The figures for CuZn_2 , as given by Mallet, can, in the opinion of the author, only be explained on the supposition that the alloy

tested was not CuZn_2 , but another containing a percentage of copper, probably as high as 55. The figure for the specific gravity (8.283) given by Mallet indicates this to be the case, as also does the colour.

“The figure for ductility would indicate even a higher percentage of copper. The name watchmaker's brass in the column of remarks must be an error, as that alloy is brittle, silver-white, and extremely weak.

“The figures of Calvert and Johnson and Riche, as well as those of the author, give a more regular curve than can be constructed from the figures of Mallet.

“The specific gravities in Riche's experiments were obtained both from the ingot and from powder. In some cases one, and in some cases the other, gave highest results. In the table under the head of specific gravity Riche's highest average figures are given, whether these are from the ingot or from the fine powder as probably the most nearly correct. The figures by the other method, in each case, are given in the column of remarks.

“The figures of Riche and Calvert and Johnson are scarcely sufficient in number to show definitely the law regarding specific gravity to composition, and the curves from their figures vary considerably.

“The figures of the author being much more numerous than those of earlier experimenters, a much more regular curve is obtained, especially in that part of the series which includes the yellow or useful metals. The irregularity in that part of the curve which includes the bluish-grey metals is, no doubt, due to blowholes, as the specific gravities were in all cases determined from pieces of considerable size. If they were determined from powder, it is probable that a more regular set of observations could be obtained, and that these would show a higher figure than 7.143, obtained from cast zinc. Matthiessen's figure for pure zinc (7.148) agrees very closely with that obtained by the author for the cast zinc, which contained about 1 per cent. of lead.

“The figures for hardness given by Calvert and Johnson were obtained by means of an indenting tool. The figures are on a scale in which the figure for cast-iron is taken as 1000. The alloys opposite which the word 'broke' appears were much harder than cast iron; and the indenting tool broke them, instead of

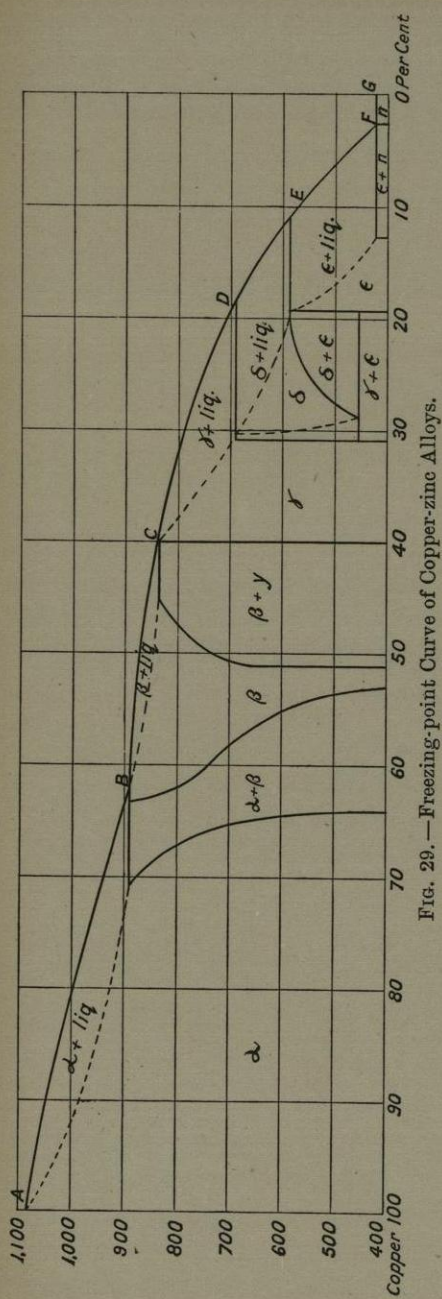


Fig. 29.—Freezing-point Curve of Copper-zinc Alloys.

making an indentation. The figures of alloys containing 17.05, 20.44, 25.52, and 33.94 per cent. of zinc have nearly the same figures for hardness, varying only from 427.08 to 472.92. This corresponds with what has been stated in regard to the similarity in strength, colour, and other properties of alloys between these compositions."

Since the publication of this table much has been added to our knowledge of the brasses by the work of Charpy, Roberts-Austen, Behrens, Le Chatelier, and many others. The melting-points of the copper-zinc alloys have been determined by Charpy and Roberts-Austen, and their work has been confirmed and amplified more recently by Shepherd, who gives the adjoining diagram (fig. 29) based on the complete freezing-point diagram first used by Roberts-Austen and elaborated by Heycock and Neville, expressing all that is at present

known of the constitution of the copper-zinc alloys. For the sake of comparison curves representing the mechanical properties of the copper-zinc alloys are plotted in fig. 30, which should be read along with fig. 29.

Most writers have concluded that copper and zinc form a definite compound corresponding to the formula CuZn_2 , and, possibly, other compounds corresponding to CuZn and CuZn_4 . Shepherd, on the other hand, argues that copper and zinc form six solid solutions, but do not form any definite compound. This opinion is difficult to reconcile with the very strong evidence which has been brought forward in support of the view that a compound CuZn_2 exists. Briefly, the experimental evidence in support of the existence of a compound is as follows:—(1) There is a rapid diminution in the strength of the alloys as the composition CuZn_2 is reached.

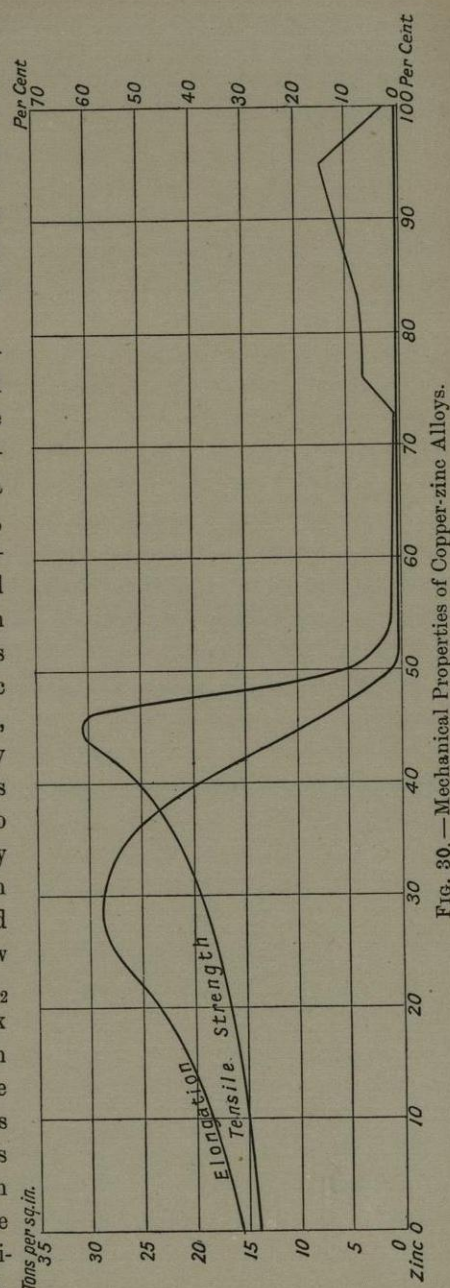


Fig. 30.—Mechanical Properties of Copper-zinc Alloys.

(2) The alteration in the electromotive force of the alloys, as shown by Laurie in 1888, and later by Herschkowitsch, points to the existence of a compound. (3) The electrical resistance of the alloys shows a sudden variation at the same point; and, finally (4), both Baker and Herschkowitsch have shown that the heat of formation of the alloys reaches a maximum at the point corresponding to the composition CuZn_2 . This maximum amounts, in Baker's experiments, to 52.5 calories per gram of the alloy, and his results also show a second rise at a point corresponding to the formula CuZn .

It is true that the microscopical examination of the alloys shows a continuous series of apparently solid solutions, but it must be remembered that Charpy has shown that compounds and solid solutions may be mutually soluble in one another, and this would be quite sufficient to account for any lack of discontinuity in the microstructure of the series.

A glance at the freezing-point curve of the series will show that the constitution of the alloys rich in zinc is very complex, but these alloys are of little industrial importance, and the constitution of the alloys rich in copper—that is to say, the brasses—is comparatively simple. With a few exceptions the alloys of industrial value may be said to lie within the limits of 55 and 70 per cent. of copper. The alloys containing more than 64 per cent. of copper consist of a single homogeneous solid solution, while those containing from 55 to 64 per cent. of copper are composed of two constituents, each of which is a solid solution. Photograph 12 shows the appearance of a brass containing 70 per cent. of copper, and photograph 13 is a typical yellow brass or Muntz metal. The alloys with the simple structure can be rolled cold, while those containing two constituents are rolled hot. Of course there is no sharply defined limit between the alloys which can be rolled hot and those capable of being rolled cold, but they can be classified in a general way according to their structure.

The early or calamine method of making brass, which has been referred to, consisted in heating a mixture of zinc oxide, charcoal or coal dust, and granulated copper in crucibles. The zinc oxide was reduced by the charcoal and the liberated metal then alloyed with the copper, forming brass. This process has,

however, long been abandoned in favour of a direct method, and is now only of historical interest. At the present time brass is made by the direct fusion of the metals, the copper being melted first under a layer of charcoal to prevent oxidation and the zinc added to the molten metal at as low a temperature as possible. The alloy is then stirred and, if necessary, allowed to cool somewhat before pouring. The melting is nearly always carried out in crucibles, usually of plumbago, heated in furnaces, which may be either coke- or gas-fired. Where large ingots of yellow brass or Muntz metal are required, the alloy is sometimes made in reverberatory furnaces, capable of melting two or three tons of metal; but the loss of zinc in reverberatory melting is very high, and the method is not employed for high-grade brasses.

The pouring or casting of the melted alloy is a very important operation, as the quality of the brass depends largely on the temperature at which it is carried out. If the temperature is too high it will be full of blowholes and will probably crack in rolling. Such defective metal is sometimes described as "spuey." If, on the other hand, the metal is poured at too low a temperature it tends to solidify as it touches the mould, with the result that there is imperfect cohesion of the metal, or, as the melter describes it, it is "spilly." This term is also applied to imperfect castings due to the presence of charcoal or dross. The moulds into which the metal is poured are previously heated and the insides coated with oil or mixtures of charcoal and oil or resin and oil.

The industrial brasses may be conveniently divided into three classes, viz. :—

1. Cast brass.
2. Low brass for hot rolling.
3. High brass for cold rolling.

Cast brass is very variable in composition; but, with the exception of a few alloys rich in copper used in the manufacture of cheap jewellery, etc., the usual composition of cast brass is in the neighbourhood of 66 per cent. of copper and 34 per cent. of zinc, which is known as English standard brass. It casts well, and is capable of being rolled and hammered and even drawn into wire. In most cases, however, cast brass is not required to

undergo much mechanical treatment, and it is consequently very impure. Large quantities of scrap are employed in its manufacture, and it usually contains relatively large amounts of impurities, such as tin, iron, and lead. These are of little consequence, and, in fact, if the metal is to be machined or filed the presence of lead, as will be seen later, is a distinct advantage in facilitating these operations. Further, the presence of tin and lead together gives rise to very fluid alloys invaluable for fine castings, and having a colour somewhat resembling bronze.

Low brasses, suitable for hot rolling, contain from 55 to 63 per cent. of copper. They are cast in large ingots, which are reheated and passed through the breaking down rolls, followed by a second reheating before passing through the finishing rolls. Hot rolling is therefore rapidly carried out, and only requires a single reheating from beginning to end of the rolling.

The commonest of the yellow brasses is that known as Muntz metal. In 1832 George Frederick Muntz took out a patent¹ for the use of an alloy containing 60 per cent. of copper and 40 per cent. of zinc as a sheathing metal for ships, and he claimed that in these proportions, "whilst the copper was to a considerable extent preserved, there was a sufficient oxidation to keep the bottom of a ship clean." In 1846 Muntz took out another patent for a cheaper alloy containing $3\frac{1}{4}$ per cent. of lead and 56 per cent. of copper, which was claimed to be equally satisfactory for the purpose. Although these alloys are no longer required for the particular purpose for which the patents were issued, the alloy containing 60 per cent. copper and 40 per cent. zinc is largely used for other purposes, and is still known under the name of Muntz metal.

As already mentioned, Muntz metal contains two constituents—a soft constituent α and a harder constituent β . In the cast state the alloy possesses a coarse structure, the two constituents separating in large masses, but the effect of hot rolling is to retard the growth of these masses with the production of a stronger metal possessing a finer structure. If the work takes place at temperatures below 600° the alloy is no longer capable of any molecular re-arrangement, and the only effect

¹ Pat. No. 6325.

is to distort the grains or crystals already formed. A temperature of 600° is therefore regarded by Bengough and Hudson as the limiting temperature dividing "hot" and "cold" work for this particular alloy. The effect of cold work is removed by annealing at about 800°, or by prolonged annealing at lower temperatures.

Muntz metal is hardened by quenching, and the explanation of this is readily seen from its structure. With increasing temperature the α constituent is dissolved by the harder β constituent until, at 720°, the alloy containing 60 per cent. of copper consists entirely of the β constituent. If, now, the alloy is quenched from this temperature the separation of the α constituent is hindered, and the alloy will be found to be stronger, but less ductile than before.

High brasses, suitable for cold rolling, usually contain more than 60 per cent. of copper, and the best class of brass for tubes and wire drawing contains 70 per cent. of copper and 30 per cent. of zinc. From the results of mechanical tests it will be seen that this alloy possesses the maximum elongation of the series combined with a considerable degree of strength.

Brass intended for rolling or drawing is cast in moulds of such shape that the work required on the alloy shall be reduced as far as possible. For plate or wire the moulds, which are made of iron, are from $\frac{5}{8}$ to $\frac{7}{8}$ of an inch thick, $3\frac{1}{2}$ to 12 in. wide, and 18 to 28 in. long. They are made in two pieces held together by the simple device of a ring and wedge. For wire drawing the plates cast in these moulds are rolled to a certain extent and then cut into strips, which are rolled into rods and finally drawn into wire. In any case, the mechanical treatment of brass in the cold must be interrupted by frequent annealing, or the results will be disastrous. Moreover, after each annealing the brass has to be cleaned in acid to remove the surface deposit of oxide. As an instance of this Sir William Anderson states that in the production of a brass cartridge case, measuring 16 in. in length and tapering from 7 in. diameter at the breech end to $6\frac{1}{2}$ in. at the muzzle end, made from a disc of brass $12\frac{5}{8}$ in. in diameter by $\frac{3}{4}$ in. in thickness and weighing $28\frac{3}{4}$ lbs., no less than eight annealings and cleanings in acid are necessary during the stages of drawing.

If an attempt is made to lessen the number of annealings the alloy in the finished product is in a state of molecular strain, and the effort of the metal to return to its natural state of equilibrium results, in the course of time, in the fracture of the metal. Instances of cartridge cases cracking in this manner while in the arsenal stores caused considerable trouble until the cause was discovered. This cracking, which may not take place until many months after the manufacture of the article, is known as "season" cracking, and is very liable to occur in drawn tubes if the pinch has been too great and the annealing insufficient. In an actual case under observation a tube was noticed, three months after the date of manufacture, to be slightly elliptical in section. After six months the effect was exaggerated, and not until one year had elapsed did the tube actually crack. The cracks always occur longitudinally, and the average time of appearance is from six to twelve months after manufacture. Season cracking is also liable to occur in spun brass.

The annealing of brass is carried out in reverberatory furnaces, which may be heated by solid or gaseous fuel; but in either case the object aimed at in the construction and working of the furnace is to maintain a reducing atmosphere so as to cause a minimum of oxidation. The temperature of annealing is of great importance, and much light has been thrown on the subject by the work of Charpy. He experimented on brasses of varying composition, which were hammered and rolled until a maximum hardness was reached. Mechanical tests were made on these brasses in their hardened condition, and also after annealing at gradually increasing temperatures. The results show that up to a certain temperature annealing is without effect. Above this temperature (which is not absolutely fixed, but depends on the amount of hardening the alloy has undergone) the effect of annealing increases with the increase in temperature until a maximum is reached. Above this point there is a range of temperature at which the properties of the brass remain unaltered, but beyond the upper limit of this range the alloy rapidly deteriorates and is said to be burnt. The figures obtained from the annealing of a brass containing 70 per cent. of copper and 30 per cent. of zinc may be taken as an example.

Annealing Temperature.	Tensile Strength in tons per sq. in.
0	31.4
200°	32.5
280	29.5
420	21.6
500	21.6
560	19.0
600	17.4
650	17.4
730	18.6
780	18.2
800	18.2
850	17.4

It will be seen that annealing below 280° has practically no effect. At 420°, however, there is a very marked softening of the alloy, and the maximum effect of annealing is reached at 600°. According to Charpy the alloy made from pure copper and zinc can be annealed at a temperature of 900° without being burnt, but the same brass containing 0.15 per cent. of tin and 0.2 per cent. of lead is burnt at about 800°. The mechanical properties of the series of alloys in a completely annealed condition containing from 0 to 50 per cent. of zinc have been determined, and the results of the tensile tests and elongations are plotted in the curves in fig. 30. Tests on the compressive strength of the alloys showed that this property varies inversely as the elongation, and the results of shock tests showed that with alloys containing less than 43 per cent. of zinc the fragility was negligible; but beyond this limit the alloys rapidly became brittle, and those containing more than 50 per cent. of zinc broke with the slightest shock. From these results Charpy concludes that as far as the mechanical properties of the brasses are concerned the alloys should not contain more than 45 per cent. of zinc, and that no useful purpose is served by having less than 30 per cent. of zinc.

The influence of prolonged annealing on brasses containing more than 65 per cent. of copper is of considerable interest. The structure of these alloys in the cast state consists of crystallites resembling those of bronze, but if the metal is annealed at about 600° the structure gradually changes, the crystallites disappearing and giving place to a well-defined crystalline structure resembling

that of a pure metal. With prolonged annealing these crystals increase in size; and if a sample of commercial rolled brass, whose structure consists of small crystals, is annealed, the crystals will attain a considerable size; but in this case the result of the mechanical treatment which the metal has undergone is made evident by the appearance of "twin" crystals. The large crystals are composed of a homogeneous solid solution, and are themselves structureless.

Up to the present we have regarded brass as a simple alloy of copper and zinc; but commercial brass invariably contains other metals, and, although they are only present in small quantities, their presence has an important influence upon the quality of the brass. It is therefore necessary to consider them in some detail. Some of these metals are added intentionally in order to confer certain properties upon the alloy, and others occur as impurities. Those added intentionally are lead, tin, and iron, while lead, arsenic, antimony, and more rarely bismuth, are introduced unintentionally.

Lead.—Brass is never entirely free from lead, as the zinc employed in its production invariably contains a small percentage of lead. High-grade brass, however, should never contain more than 0.10 per cent. of lead or its ductility will be impaired. In the case of brasses which are to be turned or machined lead is added intentionally, and the object of the addition is readily apparent when the structure of the brass is considered. Lead does not alloy with brass, but separates out in the form of globules and films between the crystals of the brass, a condition which necessarily weakens the metal, and is only permissible where strength is of secondary importance. The presence of $2\frac{1}{2}$ or 3 per cent. of lead cannot be detected in a polished surface without the aid of a microscope; but if the brass is broken the fracture is of a distinct grey colour, owing to the fact that the line of fracture passes through the lead. Now, it is well known that a pure brass is difficult to turn owing to the nature of the turnings, which are long and tenacious, and tend to obstruct the mechanism of automatic machines. A slow speed has to be employed, and frequently a burr is produced which is difficult to remove. Brass containing lead, however, behaves very differently. Owing to the fact that the lead is in a free state, the alloy is less

tenacious, and the turnings break off through the lines of weakness caused by the lead, so that chips are produced instead of long spiral turnings. Moreover the lead appears to act as a lubricant, with the result that a much higher speed can be employed, and a better finish given to the work.

The beneficial effect of lead in brasses intended for turning was known long before the nature of its influence was understood. Percy states that it is usual to introduce a small quantity of lead (about 2 per cent.) into brass in order that the chips may leave the tool easily. He mentions that the lead should be added after the crucible has been withdrawn from the fire; but the usual method is to add the lead after the zinc, and while the crucible is still in the fire, yet at as low a temperature as possible. In any case, the alloy is thoroughly stirred immediately before pouring.

The alloy is rolled cold, on account of its liability to crack if rolled hot, and the amount of lead which can be added, without seriously affecting it as regards its capability of being rolled, is about 2 per cent. The best alloy, and that which is most commonly used, contains about 60 per cent. of copper, 38 per cent. of zinc, and 2 per cent. of lead. Three samples of hard drawn screw-rods quoted by Sperry gave the following mechanical tests:—

	I.	II.	III.
Tensile strength per sq. in.	64,500 lbs.	62,400 lbs.	54,000 lbs.
Elongation on 8 ins.	10 per cent.	13 per cent.	26 per cent.
Reduction of area	58 "	63 "	53 "

Tin should not be present, as it imparts hardness and strength to the alloy, properties which are not aimed at in a brass intended for turning.

Tin.—This metal is often added to brass, and the alloy is known as "naval" brass. A small percentage of tin renders brass, and more especially low brasses of the Muntz metal type, less liable to corrosion by sea water when in contact with gun-metal. It is for this reason that brasses containing tin are employed in naval construction. Naval brass contains approximately 62 per cent. of copper, 37 per cent. of zinc, and 1 per cent.

of tin, while a softer alloy, suitable for tubes, etc., which has given good service, contains 78 per cent. of copper, 21 per cent. of zinc, and 1 per cent. of tin.

The addition of 1 per cent. of tin to brass gives an increase in the hardness of the alloy, but does not seriously affect its mechanical properties. Beyond this limit, however, there is a rapid increase in brittleness and hardness; and with more than 2 per cent. the alloys lose their useful properties.

Arsenic and Antimony.—Commercial copper usually contains these metals as impurities. Their presence has an important influence on the quality of the brass produced. Antimony appears to be more injurious than arsenic, and, even in small quantities, is capable of rendering brass unfit for rolling on account of cracking.

Sperry found that as little as 0.02 per cent. of antimony in an alloy of 60 per cent. copper and 40 per cent. zinc gave rise to incipient cracks during the necessary annealing and rolling.

Bismuth also occurs, though more rarely, in some qualities of commercial copper, and hence finds its way into brass. Its effect is very similar to that of antimony, but, according to Sperry, it is less injurious. For example, he found that brass composed of 60 per cent. copper and 40 per cent. zinc containing 0.02 per cent. of bismuth rolled almost as well as pure brass and was free from cracks. Sperry, therefore, gives this figure as the dividing line between good and bad brasses of this composition; but he states that high brasses intended for cold rolling should not contain more than 0.01 per cent. of bismuth.

It is not difficult to understand the nature of the behaviour of these impurities. Neither antimony nor bismuth is appreciably soluble in copper or in copper-zinc alloys. The result is that when the brass cools down and solidifies, the antimony and bismuth (either in the free state or containing small quantities of copper), having much lower melting-points than the brass, remain liquid, and finally solidify between the crystals of the brass. Consequently, each grain or crystal of the brass is separated from its neighbour by a thin, brittle film, and when the brass is rolled these separating layers are incapable of withstanding the strain, and the alloy cracks. Arsenic, on the other hand, is slightly soluble in copper, and is therefore less harmful. In fact, it has a hardening

effect upon the copper, and its presence is sometimes actually beneficial, provided the limit of solubility is not exceeded. As a rule 0.4 per cent. is considered the maximum.

Iron has been added to brass from early times, but it is probable that its presence in old brasses was accidental. At the present time, however, iron is deliberately added to brass in order to produce a stronger and harder alloy than ordinary brass. An alloy containing close on 3 per cent. of iron was suggested by Keir in 1779, and later the alloys known as *sterro metal* and *Aich's metal*¹ were introduced.

Sterro metal contains 60 per cent. of copper, 38 per cent. of zinc, and 1.5 to 2 per cent. of iron, and Aich's metal is practically the same, although various analyses show that the percentage of iron varies within wide limits.

One of the few reliable tests of these alloys is given by Baron Rosthorn, who tested a sample of sterro metal containing 55.04 per cent. of copper, 42.36 per cent. of zinc, 0.83 per cent. of tin, and 1.77 per cent. of iron, with the following results:—

Condition.	Tenacity in lbs. per sq. in.
Cast	60,480
Forged	76,160
Cold drawn	85,120

The very variable percentages of iron found in these alloys was probably due to the imperfect methods of manufacture, the iron being added in the form of a copper-iron alloy which was in all probability not properly alloyed. In 1883, however, Alexander Dick took out a patent² for the manufacture of iron brass which he called *Delta metal*, and since that time these alloys have been largely used.

The essential features of Dick's patent were—

- (1) The introduction of the iron in the form of an alloy of iron and zinc, which could be obtained of reliable composition; and
- (2) the addition of a small percentage of phosphorus, which has the effect of preventing oxidation.

In addition to iron and phosphorus, however, commercial Delta

¹ Patented 1860, No. 278.

² No. 2484.

metals frequently contain manganese, aluminium, tin, and sometimes lead, which accounts for the different compositions as shown by various published analyses of these alloys.

The average composition is approximately copper 55 per cent., zinc 42 per cent., with 1 to 2 per cent. of iron and small quantities of manganese, aluminium, etc.

Delta metal is stronger, harder, and tougher than brass. It is easily cast, and is capable of being rolled hot and drawn cold. In addition, it has a much greater power of resisting corrosion than ordinary brass, which enables it to be used for many purposes where brass is inadmissible.

The table on p. 149 gives some results of tests made at Lloyd's on samples of Delta metal.

Delta metal was employed for the manufacture of the worm wheels in the first locomotives used on the Pilatus mountain railway and gave very satisfactory results, as reported in the *Schweizerisches Gewerbeblatt* of 8th June 1889. The castings, which were tested by Prof. Tetmayer, showed a tensile strength of $21\frac{1}{2}$ to $23\frac{1}{2}$ tons per sq. in., with an elongation of 30 to 40 per cent. on a length of $7\frac{7}{8}$ ins.

An iron brass under the name of **Durana metal** is manufactured in Germany. It appears to closely resemble Delta metal in its properties, and is made in several qualities. Tests on a number of samples of this alloy gave results varying between 23 and 43 tons per sq. in. ultimate stress and $7\frac{1}{2}$ to 38 tons elastic limit, with elongations of 50 and $4\frac{1}{2}$ per cent. respectively on a length of four inches.

The constitution of the iron brasses has not been sufficiently investigated, but when present in small amounts the iron enters into the alloy in the form of a solid solution and does not form definite chemical compounds. When more than about 2 per cent. of iron is present a compound of iron and zinc is formed.

The majority of the commercial brasses are considerably complicated owing to the presence of manganese and aluminium in addition to the iron, and there is an increasing tendency at the present time to use brasses of a complex nature in preference to those containing, in addition to the copper and zinc, a single metal such as iron, manganese, or aluminium.

[TABLE.

Mark on Test.	Description.	Size and Specimen.	Original Area. Sq. in.	Fractured Area. Sq. in.	Permanent Set in tons per sq. in.	Maximum Stress in tons per sq. in.	Elongation per cent. in 8 ins.
No. 1	Square bar annealed	.5 dr. turned	.1963	.1288	Not taken.	27.8	39
No. 2	Flat plate annealed	1.44 × .128	.1843	.1102	12.1	30.0	36
No. 3	Round bar	.495 dr. turned	.1924	.1352	23.4	32.1	23
No. 4	Hexagonal bar	.49 dr. turned	.1885	.1256	25.0	31.3	11 Broke in extension mark.
No. 5	Flat plate	1.44 × .128	.1843	.1620	13.7	35.4	14

BIBLIOGRAPHY.

- Anderson, Sir Wm., "Fourth Report Alloys Research Committee," *Inst. Mech. Eng.*, 1897.
- Baker, *Phil. Trans.*, vol. cxvii. p. 529.
- Bengough and Hudson, *Jour. Soc. Chem. Ind.*, January 1908.
- Charpy, *Bulletin de la Société d'Encouragement*, "Contributions à l'étude des Alliages."
- Herschkwitsch, *Zeitschrift für physikalische Chemie*, vol. xxvii. (1898), p. 123.
- Le Chatelier, A., *Revue générale des Sciences*, 1891; *Comptes Rendus*, 1890.
- Le Chatelier, H., *Contributions à l'étude des Alliages*.
- Macklin, *The Brasses of England*.
- Roberts-Austen and Stansfield, "Fourth Report Alloys Research Committee," *Inst. Mech. Eng.*, 1897.
- Shepherd, *Jour. Phys. Chem.*, 1904.
- Sperry, *Jour. Amer. Inst. Min. Eng.*, July 1897, February 1898, October 1898.

CHAPTER IX.

COPPER ALLOYS. SPECIAL BRONZES AND BRASSES.

Phosphor-bronze.

THE addition of phosphorus to bronze has usually been attributed to Dr Künzel of Dresden, but it appears that De Ruolz and De Fontenay had carried out experiments on the introduction of phosphorus into bronze as early as 1853.

Phosphorus unites both with copper and tin, forming the alloys known as *phosphor-copper* and *phosphor-tin*; and as these products are used as the means of introducing the phosphorus into bronze, they may be briefly considered.

Phosphor-copper may be prepared in a variety of ways by reducing phosphates in presence of copper; but it is usually prepared by direct combination of copper with phosphorus.

Horns describes an ingenious apparatus for the manufacture of phosphor-copper and phosphor-tin, which is shown in fig. 31.

Phosphorus is placed in the lower vessel A, and the molten metal is poured in through the upper vessel B. Any phosphorus vapour which escapes combination in the lower vessel is caught as it passes through the molten metal in the upper vessel.

When phosphorus is added to copper the colour rapidly changes

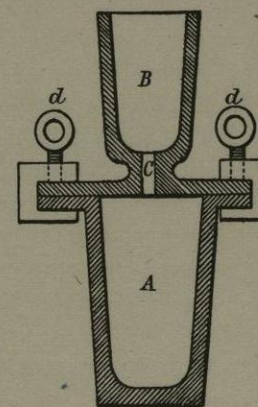


FIG. 31.—Phosphor-copper Crucible.