ALLOYS

AND THEIR
INDUSTRIAL
APPLICATIONS

E. F. LAW

GRIFFIN'S
METALLURGICAL
SERIES

J. B. LIPPINCOTT
COMPANY

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BY

EDWARD F. LAW,
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With Numerous Illustrations and Plates.

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PREFACE.

It is now nearly seven years since the late Sir William C. Roberts-Austen asked the author of this treatise (who was at that time his assistant) to help him in the preparation of a book on Alloys. Unfortunately that work was never completed, for before it had advanced beyond the preliminary stages, the illness from which Sir William had been suffering terminated fatally, and the science of metallurgy lost its most brilliant exponent. And so it is that, to the regret of all his admirers, there is no comprehensive treatise on the subject of alloys by the man who made it a lifelong study, and who did more than any other to raise it to the important position which it occupies at the present time. It was at first hoped that the work might be completed, but the available material was insufficient and too disconnected to be suitable for the purposes of a text-book, and the project had to be abandoned. Subsequently, at the request of the publishers, the author undertook to write a book on Alloys to fill the gap in their Metallurgical Series.

During the last few years an enormous amount of research work has been carried out with the object of determining the nature and physical properties of alloys, and much valuable information has been accumulated. This information, which deals mainly with the simple alloys of two metals, is scattered throughout the numerous periodicals and publications in which the original communications have appeared, and up to the present no attempt has been made to collect the facts or to apply them to the more complex commercial alloys.

Moreover, much of the work is of a purely scientific nature, and written in a style which is hardly calculated to appeal to those who are not in close touch with recent advances in physical science. The manufacturer, for example, may be readily excused for hesitating to plunge into the intricacies of solid solutions, hyper-eutectics, solidus curves, and phases. In this volume, therefore, an attempt has been made, first, to summarise the existing state of our knowledge of mixed metals, paying special attention to the general principles and essential facts while omitting all unimportant details; and secondly, to apply that knowledge to the industrial alloys in everyday use. An attempt has also been made to present the subject in such a manner that it will be intelligible not only to the student but also to the manufacturer and the engineer, for whom, indeed, the volume is primarily intended.

The complete freezing-point curves and the photo-micrographs have been made a special feature of the book, and it is hoped that they will prove useful. The freezing-point curves have been entirely replotted to one uniform scale, so that they are strictly comparable, while the photographs, with one or two exceptions, are taken from samples of commercial alloys and not from small samples made in the laboratory. It will also be noticed that the magnifications employed are in most cases 100 and 1000 diameters respectively. Experience has shown that these magnifications fulfil all that is necessary in the great majority of cases, but the important point is that the magnification should always be the same, so that the mind may easily and instinctively compare the size of grain, constituents, flaws, etc. The importance of this is not sufficiently appreciated, and it would be well if authors would adhere, as far as possible, to certain standard magnifications.

The colour photographs reproduced in the frontispiece, illustrating the heat tinting of alloys, were taken by the author on Lumière autochrome plates, and were the first examples of the practical application of colour photography to metallography.

The author desires to express his gratitude to many friends for kind assistance, more especially to Mr R. Lagerwall of the Phosphor Bronze Company, and Mr Parsons of the Manganese Bronze and Brass Company, who have kindly supplied him with samples and information; Mr A. J. Williams, who has supplied samples of magnalium alloys, and Messrs Carl Zeiss and W. Watson, who have supplied the illustrations of photo-micrographic apparatus. To Mr J. H. Blakesley the author is indebted for many useful suggestions and kind help in reading and correcting the proofs.

Lastly, the author thankfully acknowledges his great indebtedness to his friend the late Mr Bennett H. Brough, whose technical and literary skill and large experience were ever available in all matters in which counsel was sought. In the press of his own exceptionally busy life he always found time to help, and ungrudgingly gave of his wide knowledge. This generous assistance and unfailing kindness will ever remain the pleasantest memory connected with the preparation of this volume.

EDWARD F. LAW.

January 1909.

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PHYSICAL CONSTANTS OF METALS.

Metal.	Symbol.	Atomic Weight.	Atomic Volume.	Specific Gravity.	Specific Heat.	Melting Point. °C.	Coefficient of Linear Expansion.	Thermal Conductivity in cal. cm. secs.	Electrical Conductivity. Ag. = 100.
Aluminium .	Al	27·1	10·6	2·56	0·218	657	0·0000231	0·502	57·9
Antimony .	Sb	120·2	17·9	6·71	0·051	630	0·0000105	0·042	4·2
Arsenic . .	As	75·0	13·2	5·67	0·081	450	0·0000055	..	..
Barium . .	Ba	137·4	36·3	3·78	0·047	850	..	..	..
Bismuth . .	Bi	208·0	21·2	9·80	0·031	266	0·0000162	0·019	11·3
Cadmium .	Cd	112·4	13·2	8·60	0·056	322	0·0000306	0·219	14·7
Cæsium . .	Cs	132·9	71·1	1·87	0·048	26	..	..	..
Calcium . .	Ca	40·1	25·5	1·57	0·170	780	..	..	..
Cerium . .	Ce	140·2	21·0	6·68	0·045	623	..	..	..
Chromium .	Cr	52·1	7·7	6·80	0·120	1482	..	..	..
Cobalt . .	Co	59·0	6·9	8·50	0·103	1464	0·0000123	..	..
Columbium .	Cb	94·0	7·4	12·70	0·071	..	..	..	..
Copper . .	Cu	63·6	7·1	8·93	0·093	1084	0·0000167	0·924	94·2
Gallium . .	Ga	70·0	11·8	5·90	0·079	30	..	..	..
Glucinum .	Gl	9·1	4·7	1·93	0·621	..	..	..	..
Gold . .	Au	197·2	10·2	19·32	0·031	1065	0·0000144	0·700	66·7
Indium . .	In	115·0	15·5	7·42	0·057	155	0·0000417	..	..
Iridium . .	Ir	193·0	8·6	22·42	0·033	1950	0·0000070	..	..
Iron . .	Fe	55·9	7·1	7·86	0·110	1505	0·0000121	0·147	16·4
Lanthanum .	La	138·9	22·4	6·20	0·045	810	..	..	..
Lead . .	Pb	206·9	18·2	11·37	0·031	327	0·0000292	0·084	7·3
Lithium . .	Li	7·0	13·0	0·54	0·941	186	..	..	..
Magnesium .	Mg	24·4	14·0	1·74	0·250	633	0·0000269	0·343	33·7
Manganese .	Mn	55·0	6·9	8·00	0·120	1207	..	..	..
Mercury . .	Hg	200·0	14·7	13·59	0·032	−39	0·0000610	0·020	1·6
Molybdenum .	Mo	96·0	11·2	8·60	0·072	2500	..	..	..
Nickel . .	Ni	58·7	6·7	8·80	0·108	1451	0·0000127	0·141	11·9
Osmium . .	Os	191·0	8·5	22·48	0·031	2500	0·0000065	..	..
Palladium .	Pd	106·5	9·3	11·50	0·059	1535	0·0000117	0·168	14·5
Platinum .	Pt	194·8	9·1	21·50	0·032	1710	0·0000089	0·166	13·4
Potassium .	K	39·1	45·5	0·86	0·170	62	0·0000841	..	..
Rhodium .	Rh	103·0	8·5	12·10	0·058	1660	0·0000085	..	..
Rubidium .	Rb	85·5	55·9	1·53	0·077	38	..	..	..
Ruthenium .	Ru	101·7	8·3	12·26	0·061	1800	0·0000096	..	..
Silver . .	Ag	107·9	10·2	10·53	0·056	961	0·0000192	0·993	100·0
Sodium . .	Na	23·0	23·8	0·97	0·290	95	0·0000710	0·365	..
Strontium .	Sr	87·6	34·5	2·54	..	800	..	..	..
Tantalum .	Ta	181·0	16·7	10·80	0·036	2910	0·0000079	..	..
Tellurium .	Te	127·6	20·4	6·25	0·049	440	0·0000167	..	..
Thallium .	Tl	204·1	17·2	11·85	0·033	303	0·0000302	..	..
Thorium .	Th	232·5	20·9	11·10	0·028	..	..	..	..
Tin . .	Sn	119·0	16·3	7·29	0·055	232	0·0000223	0·155	11·3
Titanium .	Ti	48·1	9·9	4·87	0·130	..	..	..	..
Tungsten .	W	184·0	9·6	19·10	0·034	3100	..	..	..
Uranium .	U	238·5	12·8	18·70	0·028	..	..	..	..
Vanadium .	V	51·2	9·3	5·50	0·125	1680	..	..	..
Yttrium . .	Yt	89·0	23·4	3·80	..	..	..	..	..
Zinc . .	Zn	65·4	9·1	7·15	0·094	419	0·0000291	0·269	25·6
Zirconium .	Zr	90·6	21·8	4·15	0·066	1500	..	..	..

ALLOYS.

CHAPTER I.

INTRODUCTION

THERE has been some difference of opinion as to the origin of the word alloy, but according to Roberts-Austen it is derived from the Latin word *alligo* (*ad ligo*), "to bind to," and refers to the union or binding together of the metals constituting the alloy.

From the earliest times alloys were produced accidentally by the simultaneous reduction of mixtures of metallic ores, but there is little doubt that the first metals to be intentionally alloyed were the precious metals, and more especially gold, and it is equally certain that these attempts to alloy the precious metal were of a fraudulent character, and carried out with the object of producing a metal which might be substituted for the pure metal. How long these fraudulent but successful practices were carried on without any adequate means of detection it is impossible to say, but they received their first check when Archimedes conceived the brilliant idea that all bodies when immersed in water must displace their own volume of water irrespective of their weights, and that their weights in water would be less than their weights in air by the weight of the water thus displaced. From this he argued that if gold were alloyed with another metal its presence could be detected by determining the displacement in water, and the story of his detection of the addition of an alloy to the gold used in making the king's crown is too well known to need repetition.

The alloying of gold and silver plays a prominent part throughout the entire history of the metals, and this probably accounts