ENGLISH LANGUAGE BOOK SOCIETY

WILLIAM ALEXANDER
ARTHUR STREET

METALS IN THE SERVICE OF MAN

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METALS IN THE SERVICE OF MAN

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METALS IN THE SERVICE OF MAN

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Preface

The science of metals is a specialized one and, although it overflows into other realms of knowledge, it tends to be shut away from the general reader in rather grim-looking text-books and papers. This is a pity, because metals retain the attraction and wonder they had for us in our youth and they are of great importance to mankind. We hope this book will interest the many who handle metals in their daily work and perhaps also those whose acquaintance with them is in the home, school, or university.

We have tried to avoid the 'sensational discovery' style and have not hesitated to include discussions of some complex subjects. At the same time we have attempted to present our material in a readable form; where technical terms have been introduced they have been defined in a glossary at the end of the book.

Helpful suggestions for this revised edition have been provided by members of the Iron and Steel Institute, the Institute of Metals, and the Institution of Metallurgists. For the first time a chapter on metals in nuclear energy has been introduced; we are grateful to those who helped us to present this complex subject in what we hope is a clear manner.

During the last nineteen years many readers have kindly advised us about new developments, which have been mentioned wherever possible in revised editions. We again thank Dr Francis A. Fox and Dr Alan E. W. Smith who, in the early nineteen-forties, helped and encouraged us to embark on the first edition of this book which, we understand, has persuaded many young people that metallurgy as a career is both interesting and rewarding.

A. C. S.
W. O. A.

'*Dramatis Personae*'

Principals

IRON	The most important metal
ALUMINIUM	The light metal
COPPER	The conductivity metal
ZINC	The galvanizing metal
LEAD	The plumbers' metal
TIN	The metal that tins the can
NICKEL	The versatile metal

Supporting Characters

MAGNESIUM, BERYLLIUM	The ultra-light metals
TITANIUM	The strong middleweight
CHROMIUM	The stainless metal
TUNGSTEN	The lamp filament metal
GOLD, SILVER, PLATINUM	The precious trio
IRIDIUM, PALLADIUM, RHODIUM	Their valuable cousins
GERMANIUM	The transistor metal
TANTALUM	The condenser metal
MANGANESE, VANADIUM	The scavenging metals
COBALT, MOLYBDENUM	Some other metals that give new properties to steel
CADMIUM	The weather-resister
OSMIUM	The heaviest metal
LITHIUM	The lightest metal
BARIUM, CALCIUM, POTASSIUM, SODIUM	Some reactive metals
MERCURY	The liquid metal
ANTIMONY, ARSENIC, BISMUTH, BORON	The half-metals
NIOBIUM, ZIRCONIUM, SELENIUM, TELLURIUM	Some new arrivals
GALLIUM, HAFNIUM, INDIUM, RHENIUM	Some rare metals
CERIUM, DYSPROSIUM, ERBIUM, EUROPIUM, GADOLINIUM, HOLMIUM, LANTHANUM, LUTETIUM, NEODYMIUM, PRASEODYMIUM, PROMETHIUM, SAMARIUM, TERBIUM, THULIUM, YTTERBIUM, YTTRIUM	The 'rare earth' metals
PLUTONIUM, RADIUM, THORIUM, URANIUM	The radioactive metals
CARBON, SILICON	Two useful 'non-metals'

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(*Courtesy I.C.I. Metals Division*)

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CHAPTER I

Metals and Civilization

LONG before our primitive forefathers made a deliberate use of metals, they were already acquainted with agriculture, the rearing of livestock, the building of dwellings, weaving, pottery, and the shaping of stones. Nevertheless, although metal-working was not the first craft known to mankind, our present material civilization has been largely due to our knowledge and use of metals.

From the time of Tubal Cain* onwards, the early users of metals would probably have described them as bright substances which were hard but could be hammered into various useful shapes. All the metals which they knew must have appeared surprisingly heavy – iron, for instance, being nearly three times as heavy as granite. If the metal worker was also a hunter or warrior he might speak with satisfaction of the sharpness of the weapons which could be formed with metal and of their endurance through many combats. Craftsmen in wood or in stone would praise the new metal cutting-tools which made their job so much easier. Thus, even in the very early days, there grew an appreciation of the value of metals.

Man learned to make fires hot enough to melt metals in earthenware containers, which the Romans called 'crucibuli' and which we now call 'crucibles'. He discovered that the molten metal could be poured into the cavity made by placing together two halves of a hollowed-out clay or stone mould: the metal filled the cavity and, when solid, it was found to have taken the shape of the cavity. Archaeologists have discovered ancient bronze swords and arrow-heads, made by casting in this manner.

The art of blending metals was gradually developed and it became known that an 'alloy' formed in this way was sometimes stronger, harder, and tougher than the metals of which

*Genesis iv, 22.

it was composed. Probably the first alloy to be made was a bronze, consisting of copper, with about one part in ten of tin. There is evidence that the early workers understood that if higher contents of tin were used the alloy was harder, while less tin gave a softer alloy, so that for different purposes bronzes with varying tin contents were deliberately produced. By the time the Romans came to Britain, they were using iron and bronze for weapons, tools, and farming implements; copper for vessels and ornaments; lead for water pipes, baths, and even coffins; tin, gold, and silver for ornaments; and silver, brass, and bronze for coinage.

Gold and, to a lesser extent, silver, were regarded as 'noble metals' because they could be exposed to the atmosphere for a long time without tarnishing and because they could be melted repeatedly without much loss in weight. These characteristics led to their being used for jewellery and eventually coinage. The possession of noble metals consequently became a measure of wealth so that gold and silver were coveted for their monetary as distinct from their utilitarian value. All the other metals then known, such as tin, lead, copper, and iron, were by contrast considered 'base metals'. Owing to the general similarities between all metals it was perhaps natural to imagine that one metal could be changed into another, and it seemed particularly desirable that base metals should be transmuted into noble ones – gold for preference. Beginning in the Middle East in the early part of the Christian era, and thriving in that part of the world and in Europe till the end of the seventeenth century, the art of alchemy became associated with the search for the elusive Philosophers' Stone, which was supposed to be capable of turning base metals into gold or silver.

As recently as the end of the eighteenth century a writer defined alchemy as 'a science and art of making a fermentative powder which transmutes imperfect metals into gold and which serves as a universal remedy for all the ills of man, animals, and plants.' The great and clear-thinking philosopher Francis Bacon spoke the truth when he commented: 'Alchemy may be compared to the man who told his sons that he had left them gold buried somewhere in his vineyard; where they by digging found no gold, but by turning up the mould about the roots of the vines, procured a plentiful vintage. So the search and endeavours to make gold have brought many useful inventions and instructive experiments to light.'

While the alchemists and their wealthy, and often exasperated, patrons were trying all kinds of experiments to produce the Philosophers' Stone, the metal-workers, though using fewer incantations, were continuing to get more solid results in almost as wonderful a process – the changing of dull, earthy minerals or 'ores'* into metals by smelting them with charcoal in a fire or furnace. They learned how to recognize those metallic ores which could be smelted profitably and how to apply the requisite cycle of operations to transform them into metal. It is not surprising that their efforts were sometimes unsuccessful. Even today, producers of metal encounter difficulties because of the presence of impurities in the ore, which upset smelting operations or have a harmful influence on the resulting metal. In those early days such happenings were freely attributed to the Evil Eye, or to the attention of hobgoblins, or Old Nick himself. The name of nickel was derived from this, while the name for cobalt originated from the friendly spirits called kobolds.

Between the Middle Ages and the beginning of the industrial era, the main progress in the art of making metals was the building of larger and more efficient furnaces to produce metal in greater quantity. In 1740, when Dr Johnson used to drink tea with Sir Joshua Reynolds and Mr Garrick, Britain, which was at that time the world's greatest producer of metals, made less than twenty thousand tons of iron per year. (We make that amount in about eight hours in this country now.) A hundred years later, when the penny post had just been introduced, Britain made one and a quarter million tons of iron annually, and by the end of the nineteenth century the figure had risen to about nine million tons per year.

*In the Glossary on page 307 definitions are given of a number of words which may be unfamiliar.

About twenty years after the beginning of Victoria's reign, the manufacture of steel was becoming a major industry, which dated from 1856, when Henry Bessemer made public his process for rapidly converting large quantities of crude pig iron into steel. This was soon followed by another big-scale steel-making method, the open-hearth process, introduced by Charles W. Siemens. The rapid development of the use of iron and steel throughout the civilized world was, of course, outstanding, though other metals, such as copper, tin, lead, and zinc, were also being produced in increasing quantities. Metals in general, and steel in particular, came to be used for making bridges, railway lines, ships, guns, implements of all kinds, and, towards the end of the nineteenth century, those noisy 'horseless carriages' which chugged their way along the roads at a rattling speed sometimes exceeding five miles per hour.

Queen Victoria's reign therefore extended over a period during which important developments occurred in the history of metals; the *art* of metal-working was slowly growing into the *science* of metallurgy. In 1861 Professor Henry C. Sorby of Sheffield initiated the systematic examination of metals through the microscope and thus laid the foundations of that branch of metallurgy called metallography. Properties of metals and alloys – their melting points, strength, hardness, and electrical properties – were studied and correlated. A new, unusually light metal, aluminium, was discovered; nickel and then other metals were being alloyed with steel to form alloy steels of improved properties.

In the twentieth century the expansion of the use of metals has been so rapid that considerably more metal has been extracted during the last sixty years than during the ages from the beginning of man's history till A.D. 1900. Table 1 shows a comparison of the world production of some well-known metals for two fifty-year periods: 1858–1907 and 1908–1957. The emergence of aluminium, magnesium, and nickel will be particularly noted. The very considerably greater output of iron than all non-ferrous metals will be made clear from the table.

TABLE I

World Production of the Common Metals

Metal	*Period* 1858–1907 *Tons*	*Period* 1908–1957 *Tons*
Copper	13,000,000	87,000,000
Lead	25,000,000	71,000,000
Tin	3,000,000	7,000,000
Zinc	15,000,000	70,000,000
Aluminium	100,000	38,000,000
Magnesium	Nil	2,000,000
Nickel	175,000	4,000,000
Pig iron	689,170,000	4,549,330,000
Crude steel	576,200,000	5,885,560,000

How many people realize that our material civilization and every amenity of life depend on the work of the metallurgist and on his ability to produce just the right metal for each particular purpose? In the morning we are awakened by an alarm clock, the working components of which are certainly metallic. We press an electric switch and current passes along a copper wire to light a lamp with a tungsten filament. We wash in water which has come through copper or lead pipes, shave with a steel razor-blade, whilst anticipating breakfast that is to be cooked on a cast-iron stove; meanwhile tea is being made in a metal tea-pot, with water heated in an aluminium kettle. Then, whilst eating our bacon and egg, with the aid of a stainless steel knife and fork, we read a newspaper that has been printed from a lead alloy type-metal. Having finished breakfast, we rush to catch a bus or train which is almost entirely made of metal, and, on handing the conductor a copper–nickel alloy sixpence, we may receive change in the form of copper–tin–zinc alloy pennies. This is only the beginning of a day during which hundreds of metallic objects may be used, whether we happen to operate a lathe, computer, or tractor, pilot an aeroplane, or travel to work on a motor scooter.

The whole of our present material civilization depends on the efficient harnessing of power, but the control of this power is made possible only by the use of metals and alloys. Without metals no railway, aeroplane, motor-car, electric motor, or interplanetary space vehicle could operate.

The variety of metals which is now available has certainly benefited mankind, but it has made discrimination necessary so as to get the best use from each metal or alloy. Designers who are planning the construction of an aeroplane propeller can consider the advantages of magnesium or aluminium alloys or alloy steel. Electric cables can be of copper or aluminium or of these metals strengthened by a core of strong steel or phosphor–bronze wire. For the cutting tool on a lathe there is an almost bewildering choice of high-speed steels and of other materials which have been developed in the present century.

During the last twenty years many metals have emerged from laboratory curiosities to a position of some importance: tantalum, titanium, niobium, zirconium; these and many others are now extending the repertoire of the metallurgist. The requirements of nuclear energy, the jet aircraft, and the space missile have provided incentives to overcome the immense problems of winning these new metals from their ores and in fabricating them. Sometimes completely new methods have been developed to shape metals which a generation ago were thought quite intractable.

While development of the new metals is proceeding, fresh endeavours are continually being made to widen the scope of the well-known materials. New ways of producing steel, new alloys, improved methods of welding, are just a few of the