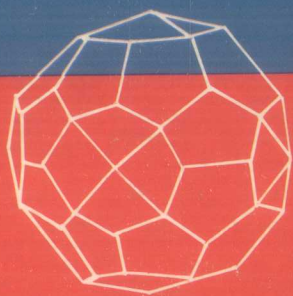


**The
THEORY
of the
PROPERTIES
of
METALS
and
ALLOYS**



by

F. MOTT and H. JONES

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The Theory of
THE PROPERTIES OF
METALS AND ALLOYS

by
N. F. MOTT, M.A., F.R.S.
and
H. JONES, Ph.D.

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PREFACE

SINCE the introduction of quantum mechanics the theory of metals has developed rapidly. The first stage of the development led to an understanding of many of the electric and magnetic properties common to all metals. In more recent investigations attempts have been made to explain the differences between individual metals and alloys in terms of the properties of their constituent atoms. It is our principal aim in this book to give an account of the properties of individual metals and alloys, and in particular to show how their crystal structure, magnetic susceptibility, and electrical and optical properties are related to one another and to their more chemical properties. For this reason we have given no description of the phenomenon of superconductivity, since it has not yet proved possible to relate its occurrence to any of the other properties of the superconducting materials. We have also omitted any discussion of the properties of surfaces (thermionic emission, adsorption of gas atoms, work function, etc.), since these phenomena bear only a small relation to the subject-matter of the rest of the book.

We should like to express our thanks to Dr. W. Heitler and to Mr. K. Fuchs, who have read the book in manuscript and have helped us in the correction of the proofs, and to Dr. H. H. Potter, Dr. R. Peierls, and Dr. E. J. Williams, who have advised us on various points.

N. F. M.
H. J.

BRISTOL. *May* 1936

INTRODUCTION

METALS are distinguished from other solids primarily by their high electrical and thermal conductivities. Since the discovery of the electron in 1897 by J. J. Thomson[†] and by Wiechert,[‡] it has been recognized that the electric current in metals is carried by electrons. Before the introduction of quantum mechanics several attempts were made to give a quantitative theory of conduction, some of the most important being due to Riecke,^{||} Drude,^{††} J. J. Thomson,^{‡‡} and Lorentz.^{||||} In these theories a certain number of electrons were supposed to become detached from their atoms and to be free to move through the solid metal. Perhaps the greatest success of the theory was the explanation of the fact, discovered empirically by Wiedemann and Franz, that the ratio of the thermal to the electrical conductivity is approximately the same for all metals. The theory, however, led to inconsistent estimates of the number of electrons which are actually free in a metal. On the one hand, the optical properties of metals could be accounted for qualitatively^{†††} on the assumption that the number of electrons is comparable with the number of atoms; on the other hand, according to the equipartition theorem, each electron ought to have thermal energy $\frac{3}{2}kT$, and should thus make a contribution $\frac{3}{2}k$ to the heat capacity. Except at high temperatures, however, the heat capacity of most metals does not rise appreciably above the value given by the law of Dulong and Petit, which is reached also for insulators and which can be accounted for by the vibration of the atoms. It follows, therefore, either that the number of electrons is very much less than the optical measurements suggest, or that the heat capacity per electron is much less than $\frac{3}{2}k$.

No satisfactory explanation of these divergent results could be obtained until the introduction of quantum mechanics. Then,

[†] *Phil. Mag.* **44** (1897), 298.

[‡] *Verh. d. Phys. Ges. zu Königsberg i. Pr.* (1897).

^{||} *Ann. d. Phys. u. Chem.* **66** (1898), 1199; *Ann. d. Physik*, **2** (1900), 835.

^{††} *Ann. d. Physik*, **1** (1900), 566.

^{‡‡} *Int. Phys. Congress, Paris, Report*, **3** (1900), 138.

^{||||} *Proc. Amsterdam Acad.* **7** (1905), 684.

^{†††} Lorentz, *Proc. Amsterdam Acad.* **5** (1903), 666; Bohr, *Studier over Metallernes Elektrontheori*, Copenhagen, 1911; Lindemann, *Phil. Mag.* **24** (1915), 127; Livens, *ibid.* **30** (1915), 434; H. A. Wilson, *ibid.* **20** (1910), 835; Schuster, *ibid.* **7** (1904), 151. Cf. also Chapter III of this book.

however, Sommerfeld† applied the newly formulated Fermi-Dirac statistics‡ to the electrons in metals and was able to show that the heat capacity per electron ought to be very much less than its value according to the equipartition theorem. Following Sommerfeld, other research workers built up a quantum theory of electrical conductivity, of which an account is given in Chapter VII of this book. This theory has been able to account qualitatively for the dependence of resistance on temperature, pressure, and constitution of many metals and alloys, and in fact leaves only the major phenomenon of superconductivity unexplained in principle.

Quantum mechanics has also enabled great progress to be made in the understanding of the magnetic properties of metals. Pauli's|| treatment of the weak paramagnetism of metals was the first application of the new theories in this field, and Heisenberg's work on ferromagnetism†† gave a quantum-mechanical background to the phenomenological theory previously developed by Weiss. These theories are discussed in Chapter VI of this book.

Possibly even more fundamental than the problems of electrical conductivity and magnetism is that of metallic cohesion. For polar crystals of the alkali-halide type, a quantitative theory based on electrostatics has been given by Born‡‡ and his co-workers; for many insulating crystals, such as diamond, the forces holding the molecules together are similar to the homopolar bonds familiar in chemistry; solid rare gases and certain molecular lattices seem to be held together by the van der Waals forces between the constituent atoms or molecules. None of these modes of description has proved suitable for metals; many attempts have been made to explain the structures of metallic alloys in terms of the homopolar bond, but without very much success.

The first successful application of quantum mechanics to the problem of metallic cohesion was made by Wigner and Seitz,||| and is discussed in Chapter IV of this book. Their calculations show that a typical metal may be regarded as an array of positive ions embedded in a cloud of negative electrons, and that the cohesive force is mainly the electrostatic attraction between the electrons and the ions.

† *Zeits. f. Phys.* **47** (1928), 1.

‡ Fermi, *Zeits. f. Phys.* **36** (1926), 902; Dirac, *Proc. Roy. Soc. A*, **112** (1926), 661.

|| *Zeits. f. Phys.* **41** (1926), 81.

†† *Ibid.* **49** (1928), 619.

‡‡ Cf., for example, Born, *Atomtheorie des festen Zustandes*, Leipzig (1923).

||| *Phys. Rev.* **43** (1933), 804.

According to quantum mechanics these electrons are moving rapidly through the metal, even at the absolute zero of temperature, and therefore any purely electrostatic theory of metallic cohesion is impossible. Calculations based on quantum mechanics, however, enable the heat of sublimation, compressibility, and elastic constants to be estimated for certain metals, and also (cf. Chap. V) the crystal structure of some metals and alloys to be accounted for.

Any theoretical account of the properties of metals must be based on a theory of the behaviour of electrons in a crystal lattice. Chapters II and III are devoted to the development of such a theory. The optical properties of metals, discussed also in Chapter III, give perhaps the most direct experimental evidence in favour of the preceding theoretical conclusions. Chapter I deals with those thermal properties of metals which can be discussed without knowing the nature of the interatomic forces.

In this book we make no mention of that property of metals which is of the greatest technical importance, namely that of strength. It has not yet been possible to apply the methods of atomic physics to this problem, though recent work by G. I. Taylor† inspires the hope that it may soon be possible to do so. No apology is needed, however, for the appearance of a book at this stage, because a theory of metallic cohesion is certainly a necessary preliminary to an attack on the problem of strength.

† *Proc. Roy. Soc. A*, **145** (1934), 362.

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