Dudley

From the Philosophical Magazine, Ser. 7, vol. 44, p. 1281,
November 1953.

Superconductivity at Very High Pressures

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[Received August 24, 1953]

Abstract

A method is described for the realization of very high pressures at liquid helium temperatures. First results are given of its application to studies of superconductivity under pressures up to 44 000 atm. Bismuth is shown to become superconducting under pressure. T_c for tin is shown to vary approximately linearly with volume up to 17 500 atm. The value of dT_c/dp for thallium is found to be negative, in disagreement with previous work.

§ 1. Introduction

Recent theories of the origin of superconductivity make it desirable to obtain more experimental information on the effect of varying the pressure on the properties of superconductors, to supplement the growing mass of data on the effect of varying the isotope in a given superconducting metal. Indeed, the pressure (or volume) and the mass number would seem to be the only variables whose effect might be capable of immediate theoretical interpretation. In particular, it is of interest to determine the influence of pressure on the transition temperature, T_c, and on the value of the quantity dH_c/dT at T_c (where H_c is the threshold field at temperature T), and also to find whether the application of high pressures can destroy superconductivity, or cause it to appear in metals not normally superconducting.

The present paper describes some experiments of this kind which we have carried out at pressures up to about 40 000 atm.—over twenty times higher than the maximum pressures previously employed in similar investigations. The increase in the working range of pressure has been made possible by the use of a technique due to Bridgman adapted in a special way for use in low-temperature enclosures.

In a further paper the implications of some of the results obtained will be examined from the general standpoint adopted in the theories of Fröhlich (1950 a, b, 1951) and Bardeen (1950 a, b, 1951 a, b, c), in which superconductivity is attributed to interactions between electrons *via* their interactions with the lattice.

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* Communicated by the Authors.

§ 2. Summary of Previous Work

The earliest systematic study of the effect of compression on the properties of superconductors was carried out by Sizoo and Onnes (1925), who applied pressure to wires of tin and indium by compressing helium into the vessel in which they were mounted. For both metals the transition temperature (T_c), at which the resistance fell to half its residual value, was found to be depressed. However, the maximum pressures used were no greater than 300 atm., and the maximum observed depression of T_c was about 0·005°. The later discovery by Keesom (1926) of the solidification of helium under pressure threw doubt on the results obtained by Sizoo and Onnes for all but the lowest pressures used, and removed the last hope of using a transmitting fluid for the application of conventional high-pressure techniques to experiments at liquid helium temperatures.

An advance in technique which enabled appreciably higher pressures to be reached at low temperatures was made by Lazarew and Kan (1944), who generated pressures of about 1750 atm. by allowing water to freeze in a thick-walled ' bomb '. Electrical leads leading out of the ' bomb ' made it possible to measure the resistance of wires mounted in it as they were cooled, under pressure, to liquid helium temperatures. Of the metals (thallium, indium, tin, mercury, tantalum and lead) subsequently investigated by Kan, Sudovstov and Lazarew (1948, 1949), all but thallium showed a depression of T_c under pressure. Using the same technique, Alekseyevski and Brandt (1949, 1952) investigated the non-superconducting metal bismuth and its superconducting compounds $RhBi_4$, $NiBi_3$, KBi_2, LiBi and Au_2Bi. No signs of superconductivity could be observed in metallic bismuth at pressures up to 1050 atm. Compression lowered the transition temperatures of LiBi and Au_2Bi but raised those of the other compounds named. The absolute magnitude of the quantity dT_c/dp in these experiments ranged from $5{\cdot}8\times10^{-11}$ deg. dyne^{-1} cm^2 for tin to almost zero for $RhBi_4$. The maximum observed change in T_c was therefore about 0·1° ; in most cases the total change was much smaller. The fact that the transitions observed were fairly sharp was taken to imply that the pressure was uniform throughout the volume of the superconductor.

A number of other experiments, on specimens under non-uniform distributions of stress (such as linear extension), have also been carried out by the authors named above, but we do not discuss the results here.

§ 3. Experimental Method

In order to reach much higher pressures it was decided to adapt for our purpose the technique due to Bridgman (1935 a, 1949, 1950, 1952) by which quasi-hydrostatic pressures up to about 400 000 atm. may be generated in thin solid specimens. This technique depends on the fact that a small area of a massive block of metal is able to withstand stresses far greater than the normal breaking stress of the bulk material, because of the support afforded by the surrounding metal. In applying this principle to the study of the shear strength or electrical resistance of