g/cm² occurs only once in each of the first 50-second intervals of Table I and 5 times in the third for a total of 7 to be considered. On the other hand, 31 cases are deleted because of showers above the absorbers. Thus there is some doubt as to whether all the events are real. A histogram of them shows 6 in the $Z=1$ category and 1 in the $Z=2$. They will not therefore affect the proton/alpha-particle ratio obtained above. With some reservation we shall consider them as primaries which stop without producing penetrating secondaries. According to Camerini *et al.*[6] such events (O_p in their notation) have still some probability of occurrence for the primary energies at this latitude (>4 Bev for vertical incidence).

The T events appear to be a real phenomenon but not attributable to primaries. Of the 18 listed in the first three columns of Table I, 11 have ionization consistent with their being low energy electrons, 5 with protons, and 2 with protons or alpha-particles. It has not been found possible to explain away any but a quite small fraction as due to events in the rocket skin, counter walls, or absorber below. On the other hand, they are considerably too numerous to be regarded as stopped primaries having no penetrating secondaries. We conclude that they are returning particles of the earth's albedo. They form 15 percent of the incoming charged particle radiation. This compares to 13 percent found to be absorbed in 2 cm Pb by Golian and Krause[7] and 22 percent by Perlow and Shipman[8] in 2 cm Pb. The latter experiment probably had insufficient shower protection.

[6] Camerini, Davies, Fowler, Franzinetti, Muirhead, Lock, Perkins, and Yekutieli, Phil. Mag. 42, 1241 (1951).

[7] S. E. Golian and E. H. Krause, Phys. Rev. 71, 918 (1947).

ABSORPTION IN LEAD

It is instructive to plot as in Fig. 6 an integral absorption curve of the total charged radiation. The number of counts at a given thickness is not independent of the number at another thickness, only the difference being independent. The line drawn has therefore somewhat better statistical basis for its slope than the numbers might seem to imply. The T events appear as an extra group. The main portion of the curve corresponds to an absorption mean free path of 440 ± 70 g/cm² in lead.

Table II lists the intensities of the various components. The total primary intensity is obtained by extrapolating to zero thickness the main portion of the absorption curve of Fig. 6. The proton and alpha-particle intensities are obtained by applying the ratio 5.3 mentioned before to this number. The events of type T are considered as albedo particles.

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[8] G. J. Perlow and J. D. Shipman, Jr., Phys. Rev. 71, 325 (1947).

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The Superconductive Transition in Tantalum

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The construction of small coreless coils allows the simultaneous measurement of resistive and magnetic transitions in tantalum. As is the case with the other "hard" superconductors, these measurements give evidence of the presence of "filaments" in the metal. The results are explained on the basis of a modification of a two-phase model used previously, and critical field-temperature curves are derived for the bulk metal and for the filament material.

MAGNETIC and resistance measurements have been made on tantalum wire supplied by Fansteel Metallurgical Corporation that had been cold drawn to a diameter of 0.25 mm and heated in high vacuum at 2800°K for 100 hours. To prevent distortion and work hardening of the very soft wire resulting from this treatment, close fitting search coils were preformed and then slipped onto the specimen.[1] Nickel terminals were spot welded to the ends of the specimen, the potential and current leads being soft soldered to the nickel. This arrangement allowed magnetic and resistive measurements to be made simultaneously on the same specimen. Resistance measurements over the range 5°K to 300°K were made in a modified Collins A. D. Little cryostat[2] with a galvanometer amplifier[3] as the measuring instrument. θ-values based on the Bloch-Grüneisen formula were obtained from these measurements, the value of 210°K over a large part of the range comparing with the value of 245°K derived from the specific heat measurements. These results together with the low value of the residual resistance ($R/R_0=0.008$ and 0.0074 in the two specimens) suggest that the metal had a rather high degree of physical and chemical purity.

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[1] H. Preston-Thomas, (to be published).

[2] D. K. C. MacDonald, Phil. Mag. 43, 479 (1952).

[3] D. K. C. MacDonald, J. Sci. Instr. 24, 323 (1947).

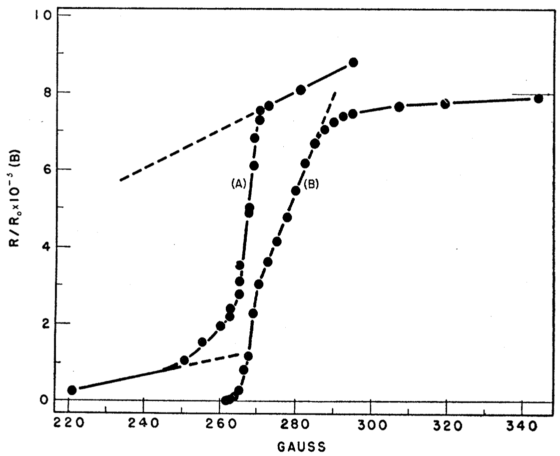

FIG. 1. Superconductive transition of tantalum at 3.61°K. The ballistic curve (A) has an arbitrary ordinate scale.

The ballistic method of Keeley and Mendelssohn[4] was used to determine field penetration changes in the specimen. In this method the external longitudinal magnetic field is abruptly removed, the resulting throw of the ballistic galvanometer being a function of the field strength and the shielding effect of the superconductor. Both resistance and magnetic measurements were made isothermally for a series of temperatures.

The observed results differed substantially from those obtained by Jackson and Preston-Thomas[5] from similar measurements on niobium which were accounted for on the basis of a model postulating a superconducting sponge (compare with Mendelssohn[6]) consisting of material which differed from the bulk metal in its critical field-temperature slope and normal transition temperature. The three main points of difference in the case of tantalum are that the penetration of magnetic field always takes place over a small range of field, indicating there is a low or zero coefficient of demagnetization; that there is no measurable frozen-in flux, indicating that no bulk metal is enclosed by filaments of higher critical field; and that the transition from zero to normal resistance is not sharp (except at temperatures very close to the normal transition temperature) but increases rapidly in width as the temperature is lowered (commencing at the same field at which substantial penetration of flux into the specimen begins to occur) and is a function of the flux penetration. Figures 1 and 2 show the form of the transition at 3.61°K and 2.635°K.

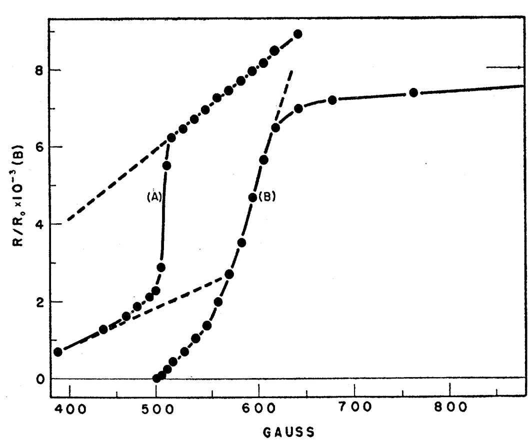

FIG. 2. Superconductive transition of tantalum at 2.635°K. The ballistic curve (A) has an arbitrary ordinate scale.

The form of these curves is explicable on the basis of a two-phase model similar in some respects to that postulated for niobium but with the difference that the sponge filaments are now so dispersed that they can no longer shield any part of the bulk metal. In Fig. 1 it may be seen that during the penetration of the magnetic flux into the bulk metal the resistance rises rapidly. The discontinuity of slope in the resistance curve then corresponds to the resistance of that part of the bulk metal that is connecting the still superconducting filaments. An assumed random orientation of the filaments with respect to the field (with corresponding variation in demagnetizing coefficient) accounts for the gradual rise of resistance from this point, the continuation of the straight portion of the curve to the normal value of the resistance of the tantalum giving the critical field for the filaments. In Fig. 2 the increased difference between the bulk and the filament critical fields allows the effect of those filaments so oriented as to have a higher demagnetizing coefficient to be observed. The final decrease in the rate of rise of resistance with field and the very slow approach to the normal value of resistance may

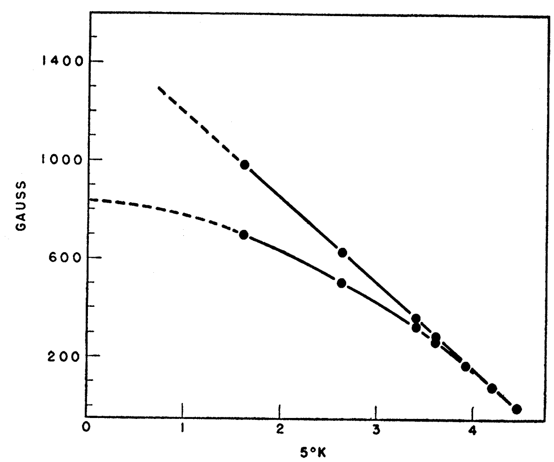

FIG. 3. Critical field curves of tantalum for the bulk material (lower curve) and for the filament structure.

[4] T. C. Keeley and K. Mendelssohn, Proc. Roy. Soc. (London) **A154**, 378 (1936).

[5] L. C. Jackson and H. Preston-Thomas, Phil. Mag. **41**, 1284 (1950).

[6] K. Mendelssohn, Proc. Roy. Soc. (London) **152**, 34 (1935).

tentatively be ascribed to the existence of a number of filaments so thin that their critical field has risen in a manner comparable with that observed in superconductors of small dimensions.[7]

Figure 3 shows the critical field-temperature curves for the bulk material and for the filaments as deduced from these measurements. It appears that the normal transition temperature of the filaments is the same as or slightly lower than that of the bulk material.

This work forms part of the program of the Low Temperature and Solid State Physics group, and the writer is grateful to Dr. D. K. C. MacDonald for very helpful discussions.

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Neutron Capture Cross Sections*,†

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Cross section formulas for neutron capture are developed by means of statistical theory, for intermediate and heavy weight nuclei for energies of the order of 1 kev to a few Mev. The formulas do not exhibit resonances, but are rather averages over resonances in the energy region where these exist. The case is treated where the residual nucleus levels are well separated, although the method is applicable in principle where these levels form a virtual continuum. The processes competing with capture in the energy range considered are elastic and inelastic scattering. The energy dependence of radiation widths is estimated. The ratio of energy level spacing to radiation width at the dissociation energy of a neutron enters as a parameter in the cross-section formulas. This ratio is chosen to make experiment and theory agree as well as possible. Taking the spacing of levels of a given spin and parity at the dissociation energy of a neutron to be 25 ev, the values of the radiation widths are found to be 0.08 ev for Ag^{108} and In^{116}, 0.10 ev for Ag^{110}, and 0.20 ev for Au^{198}.

INTRODUCTION

THE cross sections of atomic nuclei for bombarding particles of low enough energy are characterized by resonances and are explained by the well-known Breit-Wigner type formulas. For increasing kinetic energy of the bombarding particles, the resonances become more and more closely spaced until finally they overlap, i.e., the cross sections become smoothly varying functions of energy. Formulas will be developed here for neutron capture cross sections representing an average over resonances in the resonance region and the actual cross sections where they become smooth functions of energy. The validity of the compound nucleus concept underlies the development so that one cannot use this treatment for excessively high energies. (For energies of the order of 50 Mev the compound nucleus ceases to have any meaning, since the mean free path of the bombarding particles becomes of the order of size of a nuclear diameter.[1]) The paper may be considered a sequel to those of Feshbach, Peaslee, and Weisskopf[2]; and Feshbach and Weisskopf,[3] which consider nuclear reaction theory in which the target and bombarding particles are taken to have spins of zero. The approach here follows a similar one for inelastic scattering of neutrons by Hauser and Feshbach.[4]

The treatment is subject to the validity of the usual assumptions of statistical theory. In particular, the expression (17) for the partial neutron widths is used, an expression which can be true only on the average. Fairly large fluctuations from the widths given by (17) must be expected for any individual level. Since the (n, γ) cross sections are the result of competitions among several emissions by the compound nucleus, it is expected that these fluctuations are cancelled out to a large extent.

DERIVATION OF CROSS SECTION FORMULAS

Let i be the spin quantum number of the target nucleus. This spin can combine with the incident neutron spin $s=\frac{1}{2}$ to give a "channel spin" quantum number $j=j^{(\pm)}=i\pm\frac{1}{2}$ if $i\neq 0$, with azimuthal quantum number $m=-j,\ -j+1,\ \cdots,\ j$.[5] Let the z axis be chosen in the direction of the incident neutron beam. The cross section for the formation of a compound nucleus of spin J, by incident neutrons of orbital angular momentum l and energy E in the channel of spin j with z component m then, following H.F., is written

$$\sigma(l, j, J, m, E)=(2l+1)\pi\lambda\!\!\!^{-2}T_l(E)\,|(lj0m|Jm)|^2, \quad (1)$$

where $2\pi\lambda\!\!\!^{-}$ is the wavelength of the incoming neutrons, $(lj0m|Jm)$ is the Clebsch-Gordan coefficient relating to

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† Part of a doctoral thesis submitted to the Physics Department at the Massachusetts Institute of Technology.

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[3] H. Feshbach and V. F. Weisskopf, Phys. Rev. 76, 1550 (1949).

[4] W. Hauser and H. Feshbach, Phys. Rev. 87, 366 (1952). This paper will be called H.F.

[5] If $i=0$ the channel spin is $\frac{1}{2}$.