Measurements of Gap Anistropy in $A15$ Nb_3Sn

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A recent suggestion by Farrell and Chandrasekhar that a major part of the critical-temperature (T_c) reduction in $A15$ superconductors, caused by radiation-induced defects, is a manifestation of a large gap anisotropy is examined for Nb_3Sn. Electron-irradiation data show that the T_c changes with damage are inconsistent with a large gap anisotropy. However, if one assumes that the initial changes in T_c with fluence are indeed due to gap anisotropy, then it is shown that the anisotropy parameter $\langle a^2\rangle$ for Nb_3Sn is $\lesssim 0.03$.

In a recent Letter Farrell and Chandrasekhar[1] have suggested that the drastic reduction of T_c on introducing defects into $A15$ superconductors is in a major part due to a reduction of a large gap anisotropy. It is our contention that this explanation is not correct, and we present data on electron-irradiated samples of Nb_3Sn to show that observed changes in T_c due to the introduction of defects is inconsistent with a very large gap anisotropy. From an analysis of the data at low fluences we estimate an upper limit for the effect of gap anisotropy which will be seen to be rather small, and of the order of the values usually found for superconductors other than $A15$'s.

Within the framework of a gap-anisotropy model, Markowitz and Kadanoff[2] have shown the influence of dilute nonmagnetic impurities or defects on T_c. In their theory, the change in T_c is given by

$$\Delta T_c = -T_{c0} I_c(\chi)\langle a^2\rangle, \tag{1}$$

where T_{c0} is the transition temperature of the intrinsic material and $\langle a^2\rangle$ is the angular average of the square of the anisotropy coefficient $a(\Omega)$. The function $I_c(\chi)$ is given by

$$I_c(\chi) = \int_0^{2\beta_c\omega_D/\chi} \frac{\tanh(\chi y/4)}{y(1+y^2)}\,dy, \tag{2}$$

where $\chi = (kT_{c0}\tau_a)^{-1}$. $\beta_c = 1/kT_{c0}$ and ω_D is the Debye frequency. τ_a is interpreted as a collision time which describes the mean time for smoothing out the gap. χ can be written as equal to $5.56\xi_0/l$ if τ_a is taken equal to the transport collision time τ_{tr}, where l is the mean free path and ξ_0 is the coherence length. For the purposes of comparing with experiment, the dimensionless parameter χ can be written as $\chi = 0.37\rho_0$, where the residual resistivity ρ_0 is in microhm-centimeters. This assumes that $\rho_0 l = 7.5\times 10^{-12}$ Ω cm^2 and $\xi_0 = 50$ Å, which are appropriate for Nb_3Sn. In Fig. 1 the function $-I_c(\chi)$ is shown for different values of $\beta_c\omega_D$. The important feature is the large positive curvature as $\chi\to 0$, and since ΔT_c is proportional to $-I_c(\chi)$, T_c is expected to have a similar behavior for small χ or for large l. The curve appropriate for Nb_3Sn is labeled b. We mention that the Markowitz-Kadanoff[2] theory was constructed for simple metals and we follow Farrell and Chandrasekhar[1] with some caution in applying this theory to transition metals.

In Fig. 2 is shown a plot of T_c vs the residual resistance, ρ_0, for vapor-deposited Nb_3Sn samples irradiated with 2.0-MeV electrons at ~ 50°C. Figure 3 shows a similar plot of T_c against the electron fluence. Similar results have been obtained for α-irradiated Nb_3Sn samples[3] and neutron-irradiated Nb_3Sn[4] and V_3Si single crystals[5] when T_c is plotted against fluence. However, in these cases there is a possibility of inhomogeneous damage causing the slow initial change in T_c with fluence or ρ_0. The present experiment using electrons is not marred by this type of difficulty since only single Frenkel pairs are created uni-

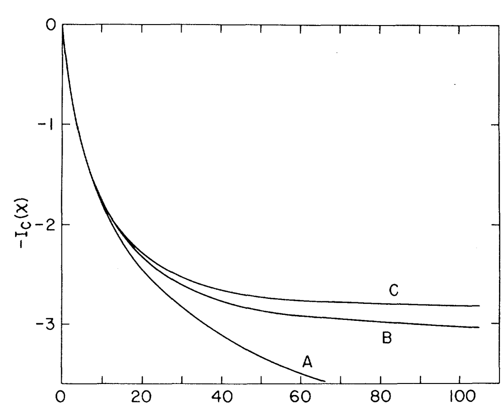

FIG. 1. The integral $I_c(\chi)$ [Eq. (1)] is shown as a function of χ for several values of $\beta_c\omega_D$: curve A, 200; curve B, 20; and curve C, 15.5 (which is appropriate for Nb_3Sn).

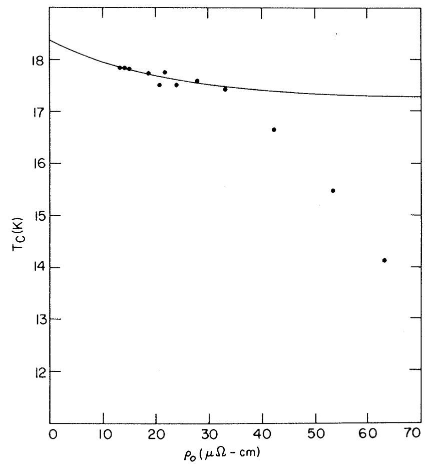

FIG. 2. Nb_3Sn: T_c vs the residual resistivity ρ_0. The curve is drawn from Eq. (2) with $T_{c0} = 18.4$ K, $\langle a^2\rangle = 0.025$, $\xi_0 \sim 50$ Å, and $\rho_0 l = 7.5\times10^{-12}\ \Omega\ cm^2$.

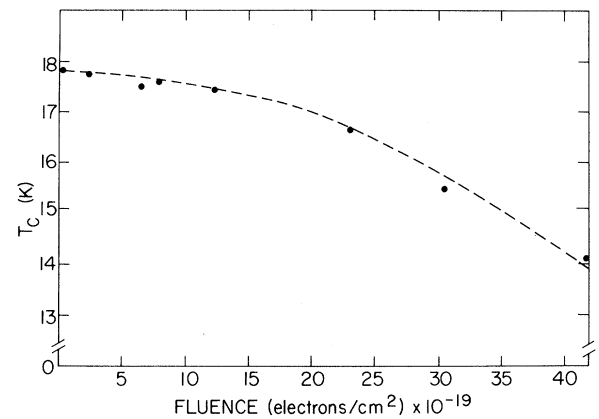

FIG. 3. Nb_3Sn: T_c vs electron fluence.

formly throughout the specimen. Since both interstitials and vacancies are mobile at the irradiation temperature, the remaining defects following displacement and migration will be Nb atoms occupying Sn vacancies and vice versa. It is also expected that the effect of clustering will be small at these low fluences.[6]

From the data in Figs. 2 and 3 it can be seen that there is no sharp change of T_c with ρ_0 for small ρ_0, i.e., for large l. This has already been discussed in another context.[3] Here it illustrates that the entire T_c behavior with fluence or ρ_0 does not have the general functional behavior that is expected from gap-anisotropy reduction. However, the small initial changes of T_c with ρ_0 for $\rho_0 < 30\ \mu\Omega$ cm, may be due to a reduction of gap anisotropy. Making this assumption, then in Fig. 2 the initial T_c data have been fitted by the solid curve which is obtained using Eq. (1) with $T_{c0} = 18.4$ K and $\langle a^2\rangle = 0.025$. This compares to the value of $\langle a^2\rangle = 0.68$ used by Farrell and Chandrasekhar.[1] We emphasize that while the value of $\langle a^2\rangle = 0.68$ might be consistent with the large T_c depression found when $\rho_0 > 30\ \mu\Omega$ cm, it is completely inconsistent with the overall data shown in Figs. 2 and 3. This large value of $\langle a^2\rangle = 0.68$ would imply a large positive curvature, in the T_c vs ρ_0 or fluence curves, with large initial changes in T_c with ρ_0 or fluence. Actually a negative curvature is observed in the total T_c vs ρ_0 curve and the smaller observed changes, in the low-fluence regime, as mentioned above, are consistent with $\langle a^2\rangle \sim 0.03$. The large T_c changes seen at higher fluence, where $\rho_0 > 30\ \mu\Omega$ cm, has been suggested[7] to be due to a reduction in the density of states $N(0)$ with disorder. It is also emphasized that the small initial changes in T_c can also be due to changes in $N(0)$ with disorder and hence we have only obtained an upper limit in the value of $\langle a^2\rangle$, assuming $T_{c0} \sim 18.4$°K.

The small–gap-anisotropy picture presented above is reasonable since the value of $\langle a^2\rangle$ is not too different from that of niobium.[8] Furthermore for Nb_3Ge, with an initial $\rho_0 \sim 45\ \mu\Omega$ cm, an explanation based on a large gap anisotropy[1] would require the T_c of a well-ordered material to be >40°K. This large increase in T_c, over the present value of ~ 23°K, as ρ_0 changes from $>40\ \mu\Omega$ cm to a small value characteristic of the ordered sample would be very different from the behavior of other $A15$'s such as Nb_3Sn for which T_c only changes ~ 1.5°K over this regime.[3]

In conclusion, we think that the data shown here cannot be explained solely on the basis of a smoothing of gap anisotropy. The initial changes in T_c with ρ_0 up to $\sim 30\ \mu\Omega$ cm may be attributed to such a mechanism. This would imply that $\langle a^2\rangle \sim 0.03$. It is strongly suggested that the more rapid depression in T_c observed for heavier irradiations, when $\rho_0 > 30\ \mu\Omega$ cm, is related to decreases in the density of states, which has been discussed elsewhere.[7]

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Distinguishing between Stars and Galaxies Composed of Matter and Antimatter Using Photon Helicity Detection

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The positrons produced in fusion processes in matter stars will have predominantly a "right" helicity due to the nonconversation of parity in weak interactions. This helicity is transferred to bremsstahlung and forward in-flight annilation radiation, which will be right-circularly polarized. In antimatter stars, *CP* symmetry will make the equivalent radiation left-circularly polarized. The helicity of such radiation can be used to distinguish between astronomical objects composed of matter and antimatter.

The tantalizing possibility that macroscopic quantities of antimatter may exist in our universe has been the subject of calculation and speculation for more than two decades.[1] Baryon-symmetric cosmologies have been proposed which would required equal amounts of matter and antimatter to be present in the universe.[2] It has also been proposed that a black hole composed of normal matter may "evaporate" equal amounts of matter and antimatter,[3] tending to symmetrize the matter-antimatter balance of the universe if it were not *a priori* symmetric.

In a recent review article, Steigman[4] pointed out that all methods of locating antimatter in the universe which have so far been suggested (except for antineutrino detection) require the introduction of normal matter into a region of space which contains antimatter, or vice versa, so that matter-antimatter annihilation takes place and can be observed. In the present work we suggest an alternative method which uses the helicity of secondary electromagnetic radiation produced by stellar fusion processes to distinguish between stars composed of matter and antimatter. This method, though very difficult, does not require matter-antimatter annihilation or antineutrino detection.

It would seem at first sight that the symmetry of the physical processes in stars composed of matter and of antimatter would make them observationally identical so that no way could be found of distinguishing between them. However, there is one exception to this general symmetry which arises from the nonconservation of parity in the weak interactions and from *CPT* symmetry.[5] The thermonuclear processes which occur in stars, whether involving the hydrogen cycle, the carbon cycle, or nucleosynthesis of heavier elements, systematically convert protons into neutrons. This conversion takes place through the weak-interaction processes of β^+ decay and electron capture. When positrons (β^+) are emitted they will be preferentially in a "right"-helicity state of strength v/c as a consequence of the nonconservation of parity and the maximal parity nonconservation in β decay. Thus the positron spins will be aligned along their lines of flight.[5] The emission of these positrons may be accompanied by the emission of *inner* bramsstrahlung,[5] and when they are slowed in matter they are likely to pro-