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EFFECT OF STRESS ON THE SUPERCONDUCTING TRANSITION TEMPERATURE OF V_3Si

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Several experiments indicate that some intermetallic compounds which have the β-W crystal structure, and the composition V_3X (X = Ga, Si, Ge, etc.), have rather peculiar electronic properties. These properties manifest themselves in strong anomalies in the temperature dependence of the susceptibility,[1] Knight shift,[1] nuclear relaxation times[2] T_1 and T_2, electronic specific heats,[3] etc. These anomalies can be explained as being due to a very narrow d-band structure.[4] It has been suggested that these anomalies are in part due to an extremely anisotropic electronic band structure, which in turn is due to the particular crystal structure.[5] In an attempt to determine whether the electronic band structure is indeed extremely anisotropic, we investigated the effects of uniaxial and hydrostatic stress on the superconducting transition temperature and on the electrical resistance. Previous experiments by Muller and Saur[6] on polycrystalline Nb_3Sn indicate that the effect of stress on the transition temperature is indeed very large. The present experiments were carried out on single crystals of V_3Si.[7]

Uniaxial stress was applied along the [100] or [111] direction, and the resistance of the sample was measured as a function of temperature by a dc method. Typical transition curves are shown in Figs. 1(a) and 1(b). It is found that the transition temperature drops when a stress is applied along the [100] direction, the drop being a linear function of the applied stress, and is approximately 0.5°K at a stress of 1000 kg/cm^2. When the stress is applied along the [111] direction, the effect on the transition temperature is negligible [see Fig. 1(b)]. The effect of hydrostatic pressure on the transition temperature was investigated by applying helium gas at a pressure of 408 atmospheres. It is found that the hydrostatic pressure does not change the transition temperature (to within ±0.05°K). A sketch of the experimental apparatus is shown in Fig. 2.

Simple theoretical considerations indicate[8] that in a cubic crystal, a linear stress effect must be isotropic. The experimental results are at variance with these considerations; here the change of the transition temperature as function of the stress tensor s_{ij} is given by

$$\Delta T_c = a(|s_{xx}-s_{yy}| + |s_{yy}-s_{zz}| + |s_{zz}-s_{xx}|),$$

where $a = -0.25$°K/1000 kg/cm^2. Thus the transition temperature, and the other thermodynamic functions, are singular at zero stress.

The change in the resistivity in the normal state under stress was also measured. At 77°K and 295°K the applied stress has only a small

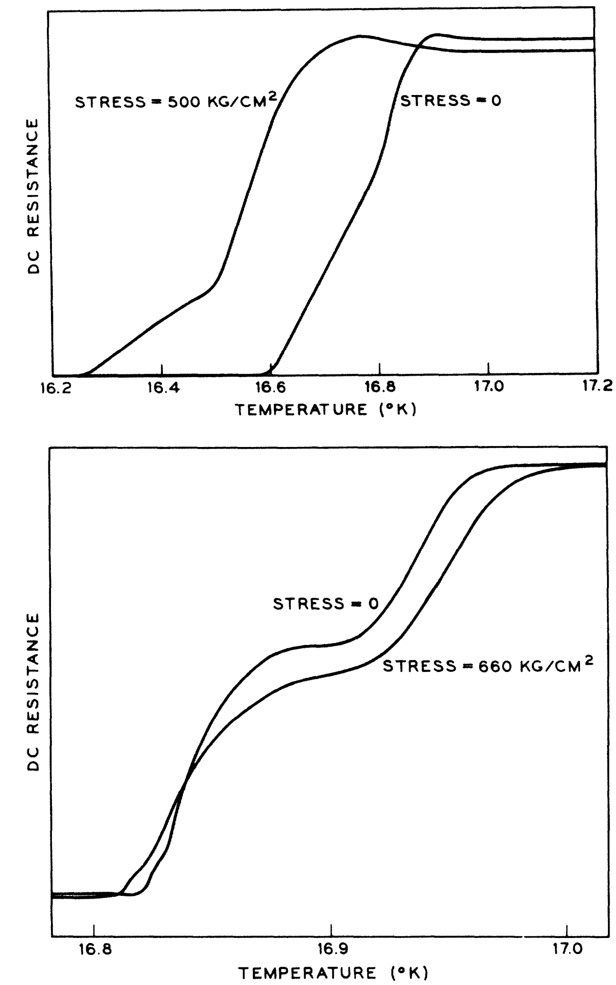

FIG. 1. Effect of stress on the transition temperature of V_3Si. (a) Stress applied in [100] direction. (b) Stress applied in [111] direction. The two samples are different, therefore, the transition temperatures and widths of the transition regions are slightly different.

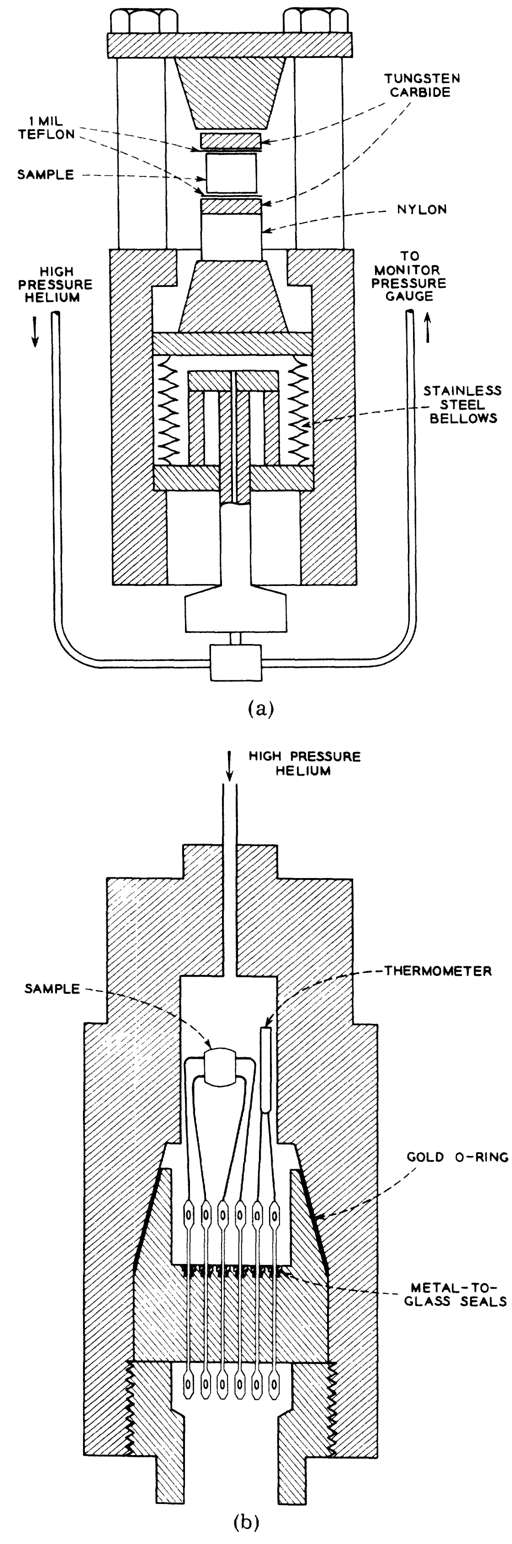

FIG. 2. The experimental apparatus used to produce uniaxial and hydrostatic stress. (a) Hydraulic press working at cryogenic temperatures. (b) Hydrostatic pressure bomb. Helium gas is used as fluid to insure that the pressure is purely hydrostatic.

effect. At 20°K and 17°K a stress applied in the [100] direction reduces the resistivity considerably; the reduction is linear and amounts to about 5% at a stress of 1000 kg/cm² [see Fig. 1(a)]. The resistivities in the direction of the stress, and perpendicular to it, change by about the same amount. A stress along the [111] direction has little effect (at least 10 times less than a stress applied in the [100] direction). Also, no effect of hydrostatic pressure of 400 atmospheres on the resistivity could be observed. (A change of 0.2% would have been detected.) Thus, the behavior of the resistivity under stress is also singular. (The resistivity of the investigated samples at 20°K is approximately 40 times less than at room temperature.) To investigate how singular is the dependence of the transition temperature on the stress, ΔT_c was measured at very low stresses. It is found that, as ΔT_c becomes of the order of the width of the transition curve, or smaller, the change in the transition temperature at different parts of the crystal is different, and therefore, ΔT_c is not very well defined. The singularity observed in this work is probably closely associated with the spontaneous distortion discussed in reference 5 and observed by Batterman and Barrett.[9]

The effect of the stress in the [100] direction can be tentatively described as a broadening of the narrow Clogston-Jaccarino peak. This broadening reduces the density of states at the Fermi level and therefore results in a lowering of the transition temperature, and less impurity scattering from s to d states, resulting in a lower electrical resistance. We have no theory to account for the singular behavior of V_3Si under stress; however, the extremely anisotropic behavior seems to confirm the suggestion that the electronic band structure of V_3Si is extremely anisotropic.

The present experiment was suggested by Dr. G. Feher. The work was initiated and carried out with the support of Dr. V. Jaccarino and Dr. A. M. Clogston. Several suggestions and discussions with Dr. W. Kohn were of considerable help. One of us (M.W.) wishes to acknowledge with thanks many stimulating discussions with Dr. B. T. Matthias and Dr. H. Suhl, and considerable assistance in the experimental work by Dr. M. Merriam. Discussions with Dr. Olsen, Dr. Reed, Dr. Hauser, and Dr. Bommel were also very helpful. We are also thankful to Dr. Mattheiss and Dr. Batterman for showing us their unpublished results. The experimental setup was constructed with the assistance of Mr. J. Froman.

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EVIDENCE OF SPIN-ORBIT COUPLING IN METALLIC TUNGSTEN

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Among the transition metals, i. e., those whose conduction electrons have appreciable d character, tungsten ($5d^46s^2$) has proved most easily obtainable in high-purity, single-crystal form. As a result, most of the available techniques for studying electronic properties of metals have been applied to tungsten. The experimental data, many of which remain to be published in detail, are generally compatible with the Fermi surface model for chromium-group metals without spin originally proposed and recently modified by Lomer.[1] Augmented-plane-wave calculations by Mattheiss[2] for the specific case of tungsten confirm Lomer's qualitative predictions. In this Letter we present measurements of extremal linear dimensions of the tungsten Fermi surface which show that, while the shapes of the principal sheets are correctly given by the model, they fail to contact each other as predicted. This discrepancy provides clear evidence of appreciable spin-orbit coupling, an interaction thus far not included in the calculations. A quantitative evaluation of the spin-orbit coupling parameter from our data is given in the following Letter by Mattheiss and Watson.[3]

The experiment is similar in principle to those