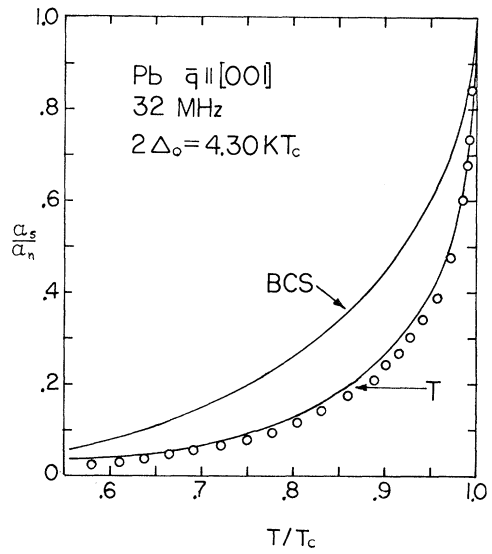

FIG. 2. Temperature dependence of α_s/α_n at 32 MHz compared with BCS theory and Eq. (3) of the text.

by the present measurements decreases more rapidly with decreasing temperature than that calculated by Ambegaokar and Woo.[10] While the ratio calculated in Ref. 10 is energy dependent, the one given here is not and represents an average over all electron energies. Using the values of l_S derived from the 51-MHz data together with the normal-state mean-free-path values derived from high-field data, Eq. (3) is compared with data at 32 MHz in Fig. 2. In Fig. 2 the curve labeled "BCS" shows the BCS prediction based on a zero-temperature gap of $4.30k_BT_C$, while the curve labeled "T" shows α_s/α_n calculated from Eq. (3). Similar results were obtained at other frequencies. At 90 MHz the fit was not as good as shown in Fig. 2 and at 12.8 MHz it was better. In all cases Eq. (3) reproduced the fast drop in the experimental α_s/α_n data at high reduced temperatures. No attempt was made to improve the fit by varying the zero-temperature gap.

In summary we find that α_s/α_n shows qualitatively different behavior in the phonon- and impurity-limited cases, and that the frequency dependence of α_s/α_n in the phonon-limited case is consistent with a change in the phonon-limited electron mean free path in the superconducting transition.

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ENERGY OF MOTION OF VACANCIES IN TUNGSTEN†

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Various indirect measurements of recovery phenomena in metals have been undertaken to establish the activation energies associated with the formation and motion of specific defects in a wide variety of metals.[1] In spite of the large amount of research in this area many specific defects remain unidentified primarily because of the indirect nature of the measurement (for instance, resistivity,[2] yield stress,[3] and stored energy[4]). It is known, though, that a direct measurement of excess defect configurations can be obtained through use of the field-ion microscope.[5,6] The capabilities of this tool have been used in the present study to observe directly the isothermal removal of single vacancies in neutron-irradiated tungsten and, thereby, to obtain an estimate of the energy of motion of single vacancies in tungsten. This estimate precludes the possibility that single vacancies move extensively in stage III of the recovery spectrum of tungsten.

Briefly, the procedure used in this study is as follows: Commercial-purity tungsten

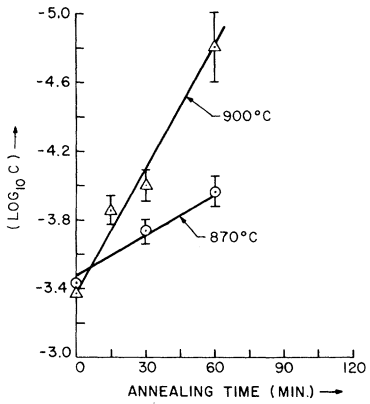

FIG. 1. Vacancy fraction functions versus annealing time (irradiated tungsten).

wire (0.05-mm-diam GE-218) was annealed prior to irradiation at 1600°C for a short time to stabilize the structure and insure a fine grain size (approximately 0.3 μ).[7,8] After irradiation (10^{18} nvt, $E \geq 1.45$ MeV), this material was annealed at 870 and 900°C for various times up to one hour, and characteristic vacancy fractions for each treatment were obtained by direct examination of the treated wire in the field-ion microscope. (Observation of vacancies in irradiated tungsten have been previously reported.[6,9]) The procedure used to establish the vacancy fractions will be fully discussed elsewhere.[10] The results obtained (see Fig. 1) demonstrate that excess vacancies are removed according to first-order kinetics, i.e., $C = C_0 \exp(-Kt)$,[11] with an activation energy of 3.3 eV. This activation energy was determined from the ratio of the slopes of the function ln$C$ as a function of time at 870 and 900°C. The slopes used were obtained mathematically by means of a weighted linear regression, the weighting factor being based on the actual number of observed vacancies. (An interval of +0.2 eV has a 95% confidence level.) This result was obtained through the examination of 8×10^5 lattice sites. The number of jumps indicated by this result is approximately 10^4, and the sink density required for this number of jumps is approximately 10^{15}/cc. This number is consistent both with the observed number of damage zones[12] and with calculated values of the sink density to be expected from the clustering of interstitial atoms to form interstitial loops.

The measured activation energy is in agreement with a result obtained indirectly from resistivity measurements of annealing of irradiated and deformed tungsten in the temperature range 600 to 900°C,[13] although this result was not identified as a vacancy migration energy. It is also in reasonable agreement with a vacancy motion energy inferred from the correlation of self-diffusion data[14,15] and a measured value of the energy of formation of a vacancy.[16]

To summarize, it is concluded that vacancies are responsible for the recovery stage at 870°C in irradiated tungsten and their energy of motion is 3.3 eV. The number of jumps to annihilation is approximately 10^4, and this indicates that irradiation-produced sinks are the effective sinks in the vacancy annihilation process. A complete description of this experiment will be given elsewhere.[10]

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