Pressure Dependence of the Superconducting Transition Temperature of Vanadium and Niobium

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The pressure dependence of the superconducting transition temperature T_c of vanadium ($\partial T_c/\partial P = 11\pm3 \times10^{-6}$ °K bar^{-1}) and niobium ($\partial T_c/\partial P = 0\pm3\times10^{-6}$ °K bar^{-1}) has been studied up to a maximum pressure of 10 kbar. The observed values are compared with values calculated from calorimetric and thermal-expansion data. A possible explanation of the observed variation in the sign of the pressure dependence of T_c in the transition-metal superconductors is offered.

OBSERVATIONS of the pressure dependence of the superconducting transition temperature T_c of vanadium and niobium have been made up to a maximum pressure of 10 kbar. Three samples of vanadium and two of niobium, obtained from various sources and of differing, but high, purities were examined. The analyses, as supplied by the manufacturers, of the samples are given in Table I. The cylindrical samples, ($\frac{1}{4}$ in. diam$\times\frac{3}{8}$ in. long) were prepared from the "as received" material with the exception of sample V3, which was cut from an ingot which we cast in an argon arc furnace. In order to minimize the introduction of strain into the samples during preparation all were cut using spark erosion.

Measurements were made in a Be-Cu alloy pressure capsule similar to that of Bowen and Jones.[1] Superconducting transitions were detected by a standard ac bridge technique with a signal frequency of 1 kc/sec. Temperatures were measured with a Honeywell germanium resistance thermometer, model MHSP 2401, which was calibrated against the vapor pressure of liquid helium 4 at temperatures below 4.2°K using the 1958 helium-4 vapor-pressure–temperature scale. The calibration points were fitted, with no significant deviation, to a function of the form, $\log R = \text{constant} - \log T$. This relationship was used for extrapolation of the calibration to temperatures above 4.2°K. The superconducting transition temperature of pure lead, as determined in the pressure capsule at atmospheric pressure, using the extrapolated temperature calibration was 7.24±0.02°K, as against the accepted value of 7.19°K. The superconducting transition temperature of the vanadium sample V2, determined as 5.00±0.01°K at atmospheric pressure, was independently checked in another laboratory,[2] a value of 4.97±0.01°K being obtained. From these measurements it is concluded that the uncertainty in the absolute temperature, as determined with this thermometer, is ±0.05°K between 4.2 and 7°K and that it may be as high as ±0.1°K for temperatures between 7 and 10°K. However, in the present measurements we are primarily concerned with the variation of the transition temperature and this can be determined to ±0.01°K.

Superconducting transition curves were continuously recorded on a Moseley Autograf recorder. The X and Y fixes of the recorder were driven, after suitable ampliacation, by the voltage developed across the thermometer and by the rectified off-balance voltage from the detector bridge. The latter changed appreciably only during the superconducting transition.

Typical superconducting transition curves, which have been taken directly from the recorder trace, are shown in Fig. 1 for a sample of each element. All of the vanadium and niobium samples examined showed struc-

TABLE I. Sample analysis; all impurities are in ppm by weight.

Sample	Source	Purity (wt%)	O	N	H	C	Fe	Ni	Mg	Si	Mn	Mo	Ta	Cr	Ti
V2	Materials Research Corporation	>99.97	100	30	0.7	65	20	<10	<5	25	···	15	···	···	···
V3	Ames, Iowa	>99.9	345	35	10	150	330	40	<20	<40	<20	···	···	<80	45
V4	U. S. Bureau of Mines	>99.8	830	30	···	···	900	···	···	···	···	···	···	30	···
Nb2	Wah Chang Corporation	>99.9	<50	46	3.8	30	<100	<20	<20	<100	<20	<20	<500	<20	···
Nb3	Materials Research Corporation	>99.99	10	10	···	8	<10	···	···	<5	···	20	20	<10	···

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[1] D. H. Bowen and G. O. Jones, Proc. Roy. Soc. (London) A254, 522 (1960).
[2] We are indebted to Dr. T. Geballe of the Bell Telephone Laboratories, Murray Hill, New Jersey for this measurement.