should be accurate to better than a factor of two. More accuracy should be obtainable with a judicious choice of rod lengths.

It is a pleasure to acknowledge numerous discussions with Dr. N. S. Shiren and Dr. E. H. Jacobsen, and the loan of the pulser from the latter. T. G. Kazyaka helped take a large part of the data.

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ANOMALIES IN THE MAGNETIC SUSCEPTIBILITY AND ELECTRICAL RESISTIVITY OF VANADIUM

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An anomaly in the temperature dependence of the electrical resistivity of vanadium has been reported by several workers.[1-4] The temperature at which this anomaly occurs and its exact form seem to be markedly dependent upon specimen purity. The anomaly has been reported as occurring at the following temperatures: 200°K,[1] 210°K,[2] 190°K,[3] and 245°K.[4] Loomis and Carlson[1] also report anomalies in the following physical properties at similar temperatures: lattice constant, Young's modulus, internal friction, thermal expansion, and intensity of x-ray reflections. Hren and Wayman,[2] however, do not find any discernible deviation from linearity in a plot of Young's modulus against temperature. The mechanism responsible for this behavior is not recognized.

The purpose of this communication is to report a previously undetected anomaly in the temperature dependence of the magnetic susceptibility and its association with the resistivity anomaly in the same specimen. Resistivity data on some vanadium-chromium and vanadium-cobalt alloys are also given.

The susceptibility of vanadium between 20 and 293°K has been discussed by Childs, Gardner, and Penfold.[5] Detailed measurements of the variation of susceptibility with temperature have not been previously reported, although it is known[5,6] that the susceptibility increases slightly with decreasing temperature. The variation of susceptibility with temperature for a specimen of 99.9% purity Van Arkel vanadium kindly supplied by the Batelle Memorial Institute, Columbus, Ohio is given in Fig. 1. The impurities (in wt.%) in the vanadium are as follows: C, 0.005; Si, 0.001; Cr, 0.001; Fe, 0.04; Al, 0.005; Cu, 0.001; H, 0.001; N, 0.008; O, 0.020. The measurements were taken on a Foëx-Forrer translation balance in Strasbourg. The relative error associated with each susceptibility measurement is indicated on the graph. The absolute

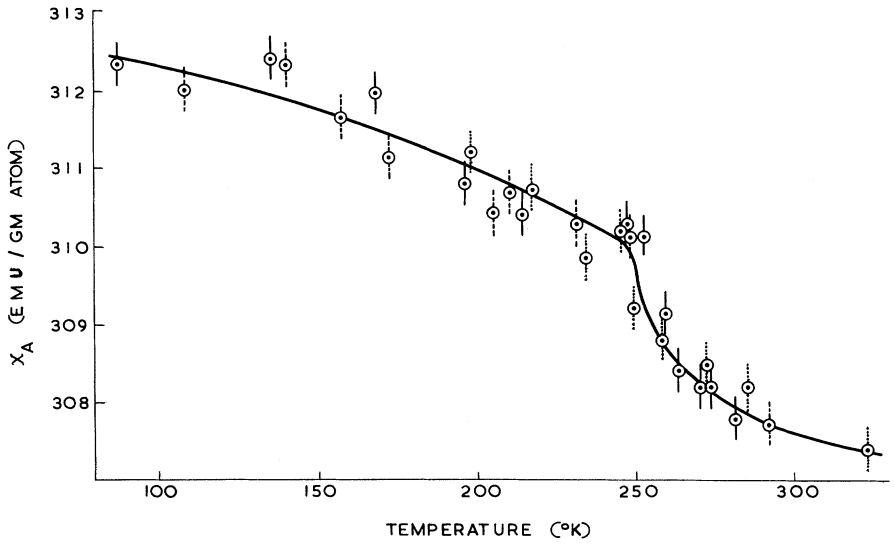

FIG. 1. Variation of susceptibility with temperature.

accuracy of the susceptibility measurements is ±2%; the temperature measurements are accurate to ±2°K. The results of three different runs are indicated (---, ···, —). The susceptibility was independent of magnetic field.

The variation of resistivity with temperature of the same specimen of vanadium is plotted in Fig. 2. The resistivity measurements were taken at Harwell using standard potentiometric techniques. The absolute value of the resistivity is only accurate to ±5%, but the relative accuracies of the measurements are very good, and the measurements are perfectly reproducible. The resistivity at room temperature is 23±1 μohm/cm.

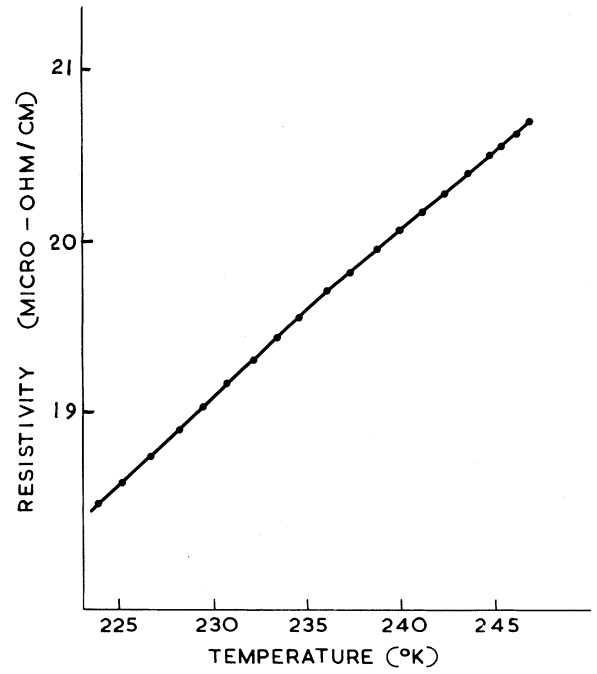

FIG. 2. Variation of resistivity with temperature.

The suggestion by Rostoker and Yamamato[4] that the resistance anomaly is due to a transformation to a body-centered tetragonal phase stable at low temperatures has been shown to be incorrect. No such phase has been detected in low-temperature x-ray investigations by Loomis and Carlson[1] and Hren and Wayman[2] or the present authors. Furthermore no well-defined discontinuity, such as would be expected for a first-order phase change, occurs in the resistivity-temperature plot.

Shull and Wilkinson[7] report that neutron diffraction shows no detectable antiferromagnetic reflection at the (100) position at 20°K and that any moment present must be less than $0.1\mu_B$; this conclusion has also been reached from preliminary neutron diffraction work at Harwell. However, the addition of 2% Cr into solid solution in vanadium lowers the temperature of the resistivity anomaly by 15°C, and the addition of 5% Co by approximately the same amount; this is strongly reminiscent of the results of de Vreis[8] on dilute solutions of transition-metal elements in chromium and seems to indicate that the anomaly is, after all, magnetic in origin and is possibly due to the onset of antiferromagnetism. The fact that no antiferromagnetic moment has yet been observed in vanadium does not prove conclusively that antiferromagnetism does not exist. The time taken by a thermal neutron in

passing from one atom to the next is $\sim 10^{-13}$ sec, whereas the time taken by an electron near the Fermi surface is $\sim 10^{-16}$ sec; therefore if the antiferromagnetism is subjected to some process fluctuating more rapidly than 10^{-13} sec, it is very probable that no (100) peak would be observed.

The problem of the nature of the anomaly is being further investigated.

Thanks are due to Dr. W. E. Gardner (Harwell) for valuable discussions and for providing the alloy specimens, and to Mr. T. E. Baker (Harwell) for carrying out the x-ray investigations.

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CAPTURE OF SLOW NEUTRONS BY NUCLEI BOUND IN CRYSTALS*

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The intense interest in the recent discovery[1] of recoilless emission and absorption of γ rays came as a sharp reminder of the classic paper in which Lamb foresaw the comparable effect for neutrons.[2] For neutrons the effect is manifested by the marked influence that crystalline binding of the target nucleus can have on the shape of a resonance. We have undertaken to determine whether the expected distortion in shape can be detected and, if so, to inquire whether it is large enough to give useful information about crystal dynamics.

As was shown by Lamb, it is convenient to consider two sets of conditions under which the shape of a resonance observed with a crystalline target may be expected to depart from the shape that applies to a gas target at the same temperature. First, if the temperature T is not much greater than the Debye temperature θ and if $k\theta$ is much less than the classical recoil energy R, the shape remains that of a Doppler-broadened resonance for a gas target but the effective temperature needed to characterize the magnitude of the Doppler broadening is greater than the physical temperature of the sample. The ratio of the effective temperature T' to the true temperature is given by the equation[3]

$$\frac{T'}{T}=\frac{C_v(\theta/T)}{24}+\frac{3\theta/T}{4[\exp(\theta/T)-1]}+\frac{3}{8}\frac{\theta}{T},$$

where $C_v(\theta/T)$ is the Debye specific heat. Second, under the more extreme conditions $\Gamma \lesssim R < k\theta$ and $T < \theta$, the shape departs significantly from that of a resonance in a gas target at any temperature. The conditions $R < k\theta$ and $T < \theta$ are necessary for a significant fraction of the neutron captures to take place without recoil of the individual target nucleus, and the condition $\Gamma \lesssim R$ is necessary so that the recoilless peak and other structure in the phonon-excitation spectrum of the crystal is not entirely obscured by the natural width of the nuclear level.

In nature there are few materials that satisfy the conditions needed to give a significant departure from the elementary Doppler-broadened shape. Probably the most favorable case is the 6.7-ev resonance in U^{238}. For it $\Gamma = 0.026$ ev and $R = 0.028$ ev so that, if θ is sufficiently high, the predicted effects should be observable. Consequently we have studied the line shapes for capture in two uranium samples, one a metallic foil of normal uranium, for which $k\theta = 0.017$ ev, and the other a sample of U_3O_8, for which $k\theta = 0.038$ ev at liquid nitrogen temperature, according to the available data on specific heats.

The shape of the uranium resonance was determined by transmission measurements with the Argonne fast chopper[4] operated under conditions such that the time-of-flight resolution width was about 0.038 μsec/m (full width at half maximum), a value which corresponds to an energy spread of 0.018 ev at 6.7 ev. Both the metallic foil and the oxide sample were studied at room temperature and at liquid nitrogen temperature, and the foil was studied at the temperature of