actual experimental geometry is cylindrical and not planar, and not enough is known about actual density distribution in the presence of a magnetic field.

We wish to thank Dr. J. A. Morrison and Dr. J. McKenna for helpful discussions regarding the validity of the method used in solving the Boltzmann equation.

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[9]This method may be used to solve the Boltzmann-Maxwell equation for arbitrary finite geometries. The details of the method will be published elsewhere.

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## SUPERCONDUCTIVITY OF TUNGSTEN

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(Received 1 May 1964)

Superconductivity has been observed in a sample of high-purity tungsten. At present our data indicate that the superconducting-to-normal transition occurs at a temperature less than 0.011°K. (Calculations suggest a lower limit of 0.005°K.) The data were obtained with the sample in zero external magnetic field using a dc measuring field of 0.10 oersted. A measuring field of 0.2 oersted is sufficient to drive the tungsten normal at the lowest temperature reached. The extremely low temperature necessary to observe the transition was produced by adiabatic demagnetization of about 28 grams of potassium chrome alum which had been allowed to crystallize around a system of copper wires. The single-crystal, high-purity tungsten sample was tightly enmeshed in these wires about 8 cm below the salt by using G.E. 7031 adhesive and nylon thread. Susceptibility of the salt and the tungsten were independently observed by a dc mutual inductance coil system and a ballistic type galvanometer.[1] Figure 1(a) shows the tungsten transition as the system warms up from the lowest temperature achieved. Galvanometer deflections (which are a linear function of the susceptibility) are plotted versus elapsed time after demagnetization. Figure 1(b) shows the changes in susceptibility of the potassium chrome alum for the same time intervals. Notice that the superconducting-to-normal transition of the tungsten occurs before the salt reaches its maximum susceptibility, which has been determined to be 0.011°K.[2]

A superconducting-to-normal transition was observed in two separate experiments. After the initial observation of the superconductivity of tungsten (Run 1), we failed in our efforts to reproduce these data, i.e., to observe superconductivity at all in the tungsten, until our ninth run five months later. We now believe that the main problem was one of reproducing the good thermal contact between the grown chrome alum and the copper wires that was achieved in the earlier experiment. Hence, we were not cooling the tungsten to a low enough temperature. By systematic investigation we now believe that we have devised a much more satisfactory technique for achieving good thermal contact, and this was manifest by the success of our Run 9 experiment with tungsten. A comparison of the two transitions is shown in Fig. 2. Both transitions occur at a temperature less than that of the maximum susceptibility of the salt (0.011°K). We believe these data

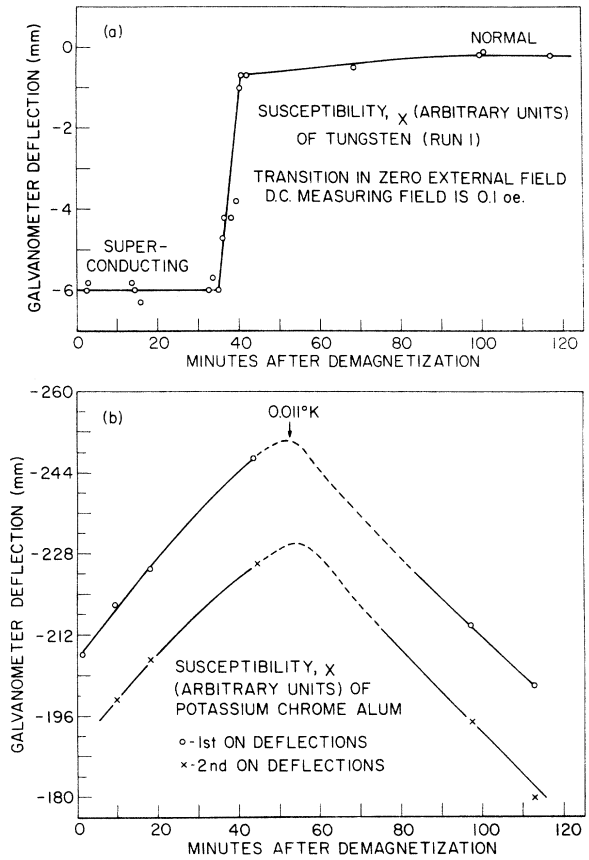


FIG. 1. (a) Changes in susceptibility of tungsten versus time after demagnetization. (b) Susceptibility of potassium chrome alum versus time after demagnetization. Susceptibility maximum is at 0.011°K. The differences in the first and second deflections reflect the hysteretic behavior of the salt in the vicinity of its susceptibility maximum. (Galvanometer deflections are a linear function of the susceptibility.)

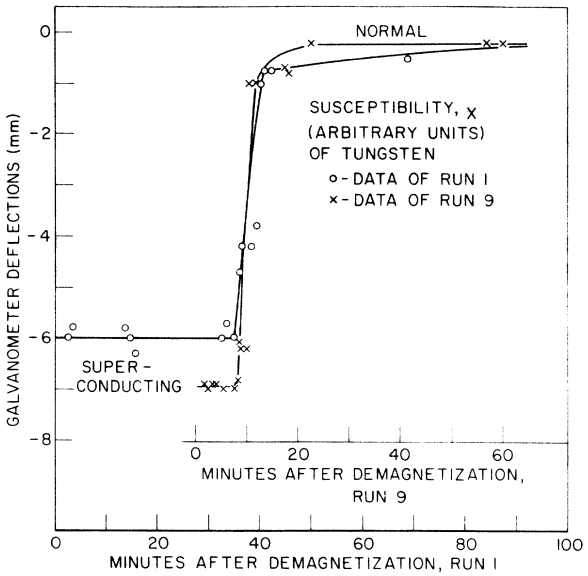


FIG. 2. Comparison of the susceptibility changes in tungsten for two separate experiments. For comparison the time scales were shifted so the transitions coincide. Both transitions occur at a salt temperature less than the susceptibility maximum (0.011°K). The difference in the value of the total change in susceptibility reflects a difference in the sensitivity of the measuring circuits used in the two experiments.

allow us to conclude that tungsten is a superconductor with a transition temperature not greater than 0.011°K. A more accurate determination of the transition temperature cannot be made because (1) measurements of the susceptibility of the salt in the vicinity of its maximum no longer yield reliable information about the thermodynamic temperature of the salt apart from fixing the position of the maximum, and (2) a temperature difference exists between the salt and copper wires which must be calculated. There are formulas in the literature which one can use to calculate this difference.[3,4] If we assume thermal equilibrium between the tungsten and the copper wires, then for our heat leak (~0.46 erg/sec, taken effectively[5] to be 0.23 erg/sec) and contact area (115 $cm^2$, salt to copper wires), the most optimistic of these (Wheatley's) leads to a calculated difference of 0.0003°K for a salt temperature of 0.010°K and 0.0046°K for a salt temperature of 0°K. Therefore, we consider 0.005°K to be the lower limit for the transition temperature of tungsten.

The sample is an ultrahigh-purity single crystal of tungsten in the form of a cylinder 1 inch long and $\frac{1}{8}$ inch in diameter.[6] Although a purity analysis of this particular sample was not performed, the supplier reports the following typical analysis (interstitial and metallic impurities in parts per million) for their tungsten samples: oxygen, 1.9 ppm; hydrogen, 0.3 ppm; carbon, 0 ppm; nitrogen, 5.0 ppm; Fe, 0 ppm; Mo, 0 ppm; Nb, 0 ppm. Resistivity ratio measurements performed by the supplier between room temperature and liquid helium temperature gave a value in excess of 1000 to 1 which would confirm a purity of 99.999% or better.

There exist in the literature both theoretical and empirical predictions by many authors that tungsten should become superconductive at very low temperatures.[7] We believe that the present data firmly establish the superconductivity of

tungsten. As far as a more accurate determination of the transition temperature goes, we believe that this is certainly possible utilizing a more favorable salt: one whose susceptibility maximum and associated hysteretic behavior does not occur near, or above, the transition temperature. Cerium magnesium nitrate would appear to be satisfactory on this point since its maximum occurs at 0.003°K. We hope to devise a satisfactory technique using a more suitable salt so that a transition temperature of the order of 0.010°K or below may be not only achieved but accurately determined. The occurrence of superconductivity at such a low temperature again emphasizes the idea that perhaps all nonferromagnetic metals will become superconductive in vanishingly small magnetic fields if the temperature can be made low enough and the purity high enough.

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## OPTICAL AND THERMAL BLEACHING STUDY OF IRRADIATED SODIUM CHLORIDE*

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An absorption maximum in the visible at approximately 670 mμ was observed in stressed, irradiated rocksalt[1] and more recently in optically bleached x-irradiated synthetic sodium chloride.[2] No satisfactory explanation of the origin of this band was offered. The important fact is that it cannot be identified with any of the well-known electron-excess color centers.

With the idea of understanding the origin of this 670 mμ band, its behavior and its relation, if any, to the other observed absorption bands, we have undertaken a systematic study of irradiated synthetic sodium chloride crystals subjected to a variety of treatments. Optovac sodium chloride crystals (20×20×2 mm), wrapped in aluminum foil, were irradiated, at room temperature, with $\gamma$ rays from a 1.2-MeV, $1.1\times10^6$-R/h $^{60}$Co $\gamma$-ray source, and they received a dose of $10^7$-$10^8$ R. After $\gamma$ irradiation the crystals were cleaved and the optical absorption was measured in the wavelength range 350-1200 mμ with a recording type Beckman DK-1A spectrophotometer. The absorption spectra were recorded at room temperature and in some cases, wherever necessary, they were recorded also at liquid nitrogen temperature.

In these Optovac crystals we have not observed any colloid band formation due to irradiation only, although in a typical case the crystals have received as high a $\gamma$-ray dose as $4\times10^8$ R. This result is in agreement with the observation by Compton.[3]

Figure 1(a) shows the results of progressively bleaching an irradiated crystal at room temperature with $F$-band light. First the $M$ and $R$ bands increase, and then the $N$ band, especially the $N_1$ (820 mμ) band, increases. Continued bleaching has the effect of decreasing the $M$ and $R$ peaks to the extent that they disappear, and only a long-wavelength tail to the $F$ band connecting the $N_1$ band remains. Further bleaching slowly decreases the $N_1$ band, and a new band grows in the region of 600-700 mμ. Because of its location we shall refer to this band as the 670-mμ band. With the evolution of this 670-mμ band the $N_1$ band broadens and shifts towards shorter wavelengths. As shown in Fig. 1(b), at liquid nitrogen temperature this 670-mμ band resolves into two bands having peak positions at approximately 610 mμ and 670 mμ and the $N_1$ band also resolves into two bands having peaks at approximately 770 mμ and 820 mμ. Similar results were observed with white-light bleaching as shown in Fig. 1(c). In this case the 770-mμ peak became prominent and the 820-mμ peak had disappeared. However by prolonged bleaching at room temperature we can reduce the $F$ and $N_1$ bands substantially, leaving the 670-mμ band as a prominent band. At this