The corresponding expressions in the Gorter-Casimir two-fluid model are as follows:

$$K'(0)=-\tfrac{1}{2}, \tag{28GC}$$

$$K[\omega_e(t)]=t^2, \tag{29GC}$$

$$1-\omega_e(t)=t^4, \tag{30GC}$$

$$h^2=(1-t^2)^2, \tag{31GC}$$

$$(H_0/T_c)^2=2\pi\gamma, \tag{32GC}$$

$$-\left(\frac{dH_c}{dT}\right)_{T=T_c}=2\frac{H_0}{T_c}, \tag{33GC}$$

$$C(T_c^-)/C(T_c^+)=3. \tag{34GC}$$

As mentioned before, the variation of the surface energy with temperature is also changed from that given by the Gorter-Casimir model, but this will be discussed separately.

We exhibit in Figs. 1–4 for the "energy-gap" model with $\alpha=1.25$ and $\alpha=1.5$, $\omega_e(t)$, $K(\omega)$, $h(t)$ and $\lambda(t)/\lambda(0)=[\omega_e(t)]^{-\frac{1}{2}}$, respectively. In each case we have plotted the ratio to the corresponding expression for the Gorter-Casimir model, so that that model is represented by the horizontal line at unity. We show in Fig. 5 the ratio of the critical field in this model to that in the Gorter-Casimir model, when they are normalized to the same slope at $T=T_c$.

IV. DISCUSSION OF THE RESULTS

As one might expect, the main difference between the "energy-gap" model and the Gorter-Casimir model is that, in the former, all the physical quantities tend to their values at absolute zero more rapidly than in the latter. Thus, $C(T)$ goes to zero more rapidly, $\omega_e(t)$ goes to unity more rapidly, and H_c goes to H_0 more rapidly.

The jump in specific heat is changed, and for the chosen values of α, is reduced. This is given by (24).

The relation between H_0/T_c and the slope of the critical field curve at the transition temperature is changed to (33), so that parabolic extrapolation to find H_0 is no longer valid.

All these changes are quantitative rather than qualitative, and are subject to experimental check.

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Investigation of the Superconductivity of Hafnium

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The magnetic susceptibility of two polycrystalline rods of hafnium (Hf I and Hf II) was observed from 4.22°K down to 0.08°K. The electrical resistance of these specimens was also observed from room temperatures down to 0.08°K. While the magnetic measurements indicated unambiguously that no superconducting transition occurred, the electrical resistance did, however, exhibit a decrease at approximately 0.19°K for Hf I and 0.28°K for Hf II. The resistance did not fall to zero but remained finite down to the lowest temperatures obtained. The temperature at which this decrease occurred was found to be sensitive to an externally applied magnetic field. Critical field data were obtained for Hf I which indicated a $(dH/dt)_{T=T_c}$ of 450 gauss/degree. Magnetic and electrical measurements obtained for one of the specimens, subsequent to an anneal, indicated no marked change in these measured quantities. Both these specimens had a stated purity of 98.92%.

The magnetic susceptibility of a third specimen of hafnium was observed and a superconducting transition was noted at 0.173°K. This specimen was in the form of lathe turnings and was approximately 96% pure. A few critical field points were obtained which yield a value for $(dH/dT)_{T=T_c}$ of 130 gauss/degree.

From a consideration of all the available data concerning the superconductivity of hafnium, it is felt that pure hafnium is probably not a superconductor down to a temperature of 0.08°K.

I. INTRODUCTION

KURTI and Simon[1] observed the magnetic behavior of hafnium below 1.0°K and reported it to be a superconductor with a transition temperature (T_c) of 0.35±0.05°K. Roberts and Dabbs[2] investigated the magnetic susceptibility of several specimens of hafnium and detected no superconducting transitions down to 0.03°K. The specimens were then annealed after which one of the specimens exhibited a transition at 0.29°K. The specimen which showed superconductivity was in the form of lathe turnings and possessed a purity of 96%, the major impurity being zirconium (~4%). Smith and Daunt[3] failed to observe, magnetically, any superconductivity in a relatively pure hafnium sample (98.92%) down to a temperature of 0.15°K. The specimen was then annealed and a superconducting transi-

[1] N. Kurti and F. Simon, Proc. Roy. Soc. (London) **A151**, 610 (1935).

[2] L. D. Roberts and J. W. T. Dabbs, Phys. Rev. **86**, 622 (1952); and private communications.

[3] T. S. Smith and J. G. Daunt, Phys. Rev. **88**, 1172 (1952).

tion was detected at 0.37°K. The observed diamagnetism was small and it was estimated that less than 100% of the material became superconducting. Critical field data were obtained which yielded a value of 230 gauss/degree for the initial slope of the critical field curve.

In light of the paucity of Kurti and Simon's data and the results of Roberts and Dabbs, it was felt that additional information on the superconductivity of hafnium would be of interest. The work of Smith and Daunt, which was not published at the time the present work was initiated adds further interest to the problem in that although their sample was considerably purer than that of Roberts and Dabbs, the observed diamagnetism was much smaller.

II. SPECIMENS

The hafnium specimens used in the major part of this work were supplied by the Materials Section of the Wright Air Development Center at Dayton, Ohio. Specimen I, obtained March, 1952, was in the form of a cylindrical rod 16 mm in length and 3.4 mm in diameter. The hafnium was originally prepared[4] in the form of a polycrystalline rod formed by the thermal deposition from the iodide in which a tungsten wire, 0.004 in. in diameter, served as the core. The hafnium was then swaged to form a bar 3.4 mm in diameter. This bar was then annealed under an inert atmosphere and is referred to by Litton as bar No. 783. A second specimen of hafnium was obtained August, 1954 from the same source, and was also a section of bar No. 783. It was of the same physical dimensions as the first one and had also been annealed subsequent to the cold swaging. Both of these specimens had a stated purity of 98.92%. The major known impurity was zirconium which was present to the extent of 0.9%.

A third specimen of hafnium was most kindly supplied by Dr. L. D. Roberts and Dr. J. W. T. Dabbs of the Oak Ridge National Laboratory and was the hafnium chips, still imbedded in the salt pill, with which they had observed the reported superconductivity.

III. EXPERIMENTAL METHODS

A. Production and Measurement of the Temperatures

Temperatures below 1°K were produced by the magnetic method, using potassium chrome alum as the cooling agent. The exchange-gas technique was utilized and a Bitter-type solenoid provided the large magnetizing fields. Thermal contact between the salt and the specimen was achieved either by imbedding the specimens directly in the salt pill or by cementing the specimen, with the use of General Electric adhesive No. 7031, inside a copper sleeve, see insert Fig. 3, which in turn was in thermal contact with a copper fin imbedded in the salt pill. This latter technique had previously been shown to produce adequate thermal contact down to temperatures of the order of 0.2°K.[5]

Temperatures below 1.0°K were determined from the magnetic susceptibility of the salt pill as measured by the ballistic mutual inductance technique.[6] In order to express these extrapolated temperatures T^*, in terms of the Curie scale (T_s^*) for spherically shaped salt specimens, it is necessary to correct the observed T^* for the shape and density of the salt pill used. Details of the method employed in making this correction are given elsewhere.[7] The magnitude of this correction varied from 0.017°K to 0.022°K depending on the salt pill used.

B. Detection of Superconductivity

1. The ballistic mutual induction technique was also utilized to detect the occurrence of superconductivity in the hafnium samples. Details of this procedure have already been given.[1,8] When the metal specimen is imbedded in the salt pill it is customary to employ a secondary coil system consisting of two coils, having an equal number of turns, connected in series opposition. since, in the present investigation, the metal was separated from the salt, a three-coil secondary was employed. By means of an external switch, the appropriate pairs of secondary coils could be placed in series opposition. With this arrangement, Fig. 1, the differential magnetic susceptibility of the salt pill and of the metal could be independently observed. This

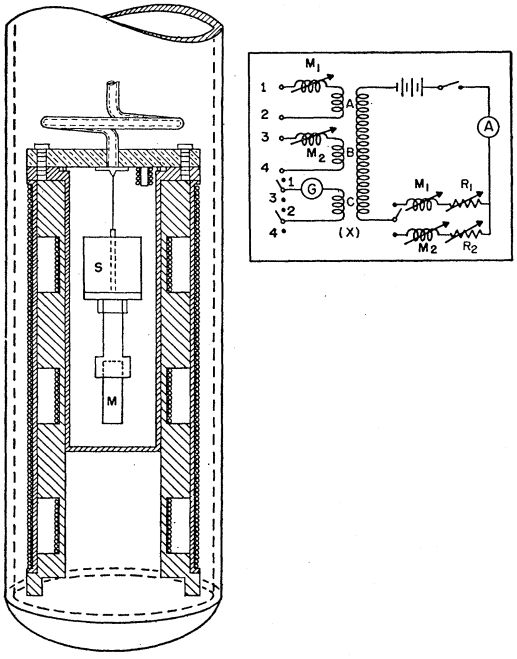


FIG. 1. Schematic diagram of the lower Dewar assembly.

[4] B. Litton, J. Electrochem. Soc. 98, 488 (1951).

[5] J. R. Clement *et al.*, Rev. Sci. Instr. 24, 545 (1953).

[6] N. Kurti and F. Simon, Proc. Roy. Soc. (London) A149, 152 (1935).

[7] N. Kurti and F. Simon, Phil. Mag. 26, 849 (1938).

[8] J. G. Daunt and C. V. Heer, Phys. Rev. 76, 1324 (1949).

provides greater sensitivity in the detection of superconductivity as the effect of the metal does not have to be separated from that of the salt, as is the case when a two-coil secondary is employed. This system has a further advantage in that it permits the calculation of the temperature, at any time, from the salt's susceptibility even if the metal exhibits a strong diamagnetism.[9]

2. In light of the results obtained with the ballistic method and the smallness of the effect observed by Smith and Daunt, it was decided to try to detect a superconducting transition in the hafnium by means of direct electrical resistance measurements. Such measurements would be pronouncedly effected if a small percent of the specimens volume went superconducting. The electrical resistance data for Hf I were obtained by utilizing a dc amplifier and recorder as a recording microvoltmeter. The data for the other specimens were obtained with a null circuit where the voltage drop across the specimen, for fixed values of current, was bucked against the voltage across a standard resistor. The voltage drop across the standard resistor was monitored by adjusting the current passing through it. With this arrangement the dc amplifier and recorder served as the null indicator. The sensitivity was such that an unbalance of 10^{-7} volt caused a full-scale deflection (50 divisions) of the recorder. The noise level was between two and three scale divisions.

Electrical contact to the specimen, for Hf I, was achieved by means of pointed brass screws. This technique was later discarded in favor of spot-welded contacts. The electrical leads in the vacuum chamber consisted of four Pb wires (0.010 in. in diameter) wound in the form of a helix in order to increase the thermal resistance of these leads. The necessary electrical leads were brought into the vacuum chamber (brass can) by either running them down the vacuum line and anchoring them to the bath temperature by means of a brass post and collodion, or by means of glass to metal seals soldered in the lid of the can, in which case the leads passed directly through the helium bath. This latter technique was somewhat troublesome because the seals were susceptible to low-temperature leaks and were not reliable upon cycling between room temperature and liquid helium temperatures.

IV. EXPERIMENTAL PROCEDURE

The salt pill was centered in coil A, and the specimen holder was of appropriate length so that the hafnium specimen was centered in coil B (Fig. 1). The ballistic galvanometer was always in series with coil C. With coils A and C in series opposition, the galvanometer deflection, caused by initiating a current in the primary coil, was proportional to the differential susceptibility of the salt pill. Similarly, with coils B and C in series opposition, the galvanometer deflection was proportional to the differential susceptibility of the hafnium sample. With exchange gas present and the system at 4.22°K the deflections were adjusted, by means of an external mutual inductance, to give a convenient value (usually 15 or 20 mm). The deflections for the salt and for the hafnium, as well as the electrical resistance of the hafnium, were then observed as a function of the temperature as the temperature of the helium bath was lowered to 1.3°K, from which point the magnetization cycle was initiated. Since it was not possible to work isothermally below 1.3°K, the above three quantities were observed as a function of time after demagnetization. A plot of these quantities as a function of the time after demagnetization will indicate (a) the occurrence of any superconducting transition (b) the time at which the transition occurred and (c) the galvanometer deflection due to the salt corresponding to this time, from which the temperature may be readily calculated.

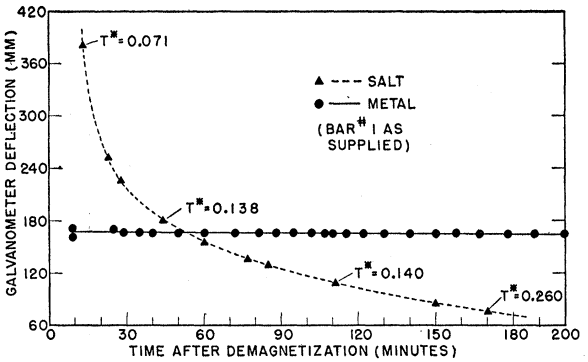


FIG. 2. Galvanometer deflections obtained for hafnium I and for the salt pill as a function of the time after demagnetization.

V. RESULTS

The results obtained for all the specimens are summarized in Table II and are presented here in detail.

A. Hafnium Rods

Figure 2 shows a portion of a warmup curve where the galvanometer deflections obtained for the salt and for hafnium I are plotted as a function of the time after demagnetization. For this particular run the time required for the system to warm up to the temperature of the helium bath was five and a half hours. From the constancy of the differential magnetic susceptibility of the hafnium sample as evidenced by the galvanometer deflection, which remained constant at its 4.22°K value, one can conclude that (a) the sample did not go superconducting or (b) even though the salt cooled to approximately 0.06°K the hafnium sample did not cool to such temperatures. In an attempt to check this second possibility, two previously calibrated carbon resistors were employed as shown in Fig. 3. The lower resistor was cemented to the hafnium sample, so that any cooling experienced by this resistor must arise from the cooling of the hafnium by the salt pill. The two plots included in Fig. 3 show that both resistors cooled to temperatures of the order of 0.08°K. The two curves ob-

[9] M. C. Steele and R. A. Hein, Phys. Rev. **92**, 243 (1953).

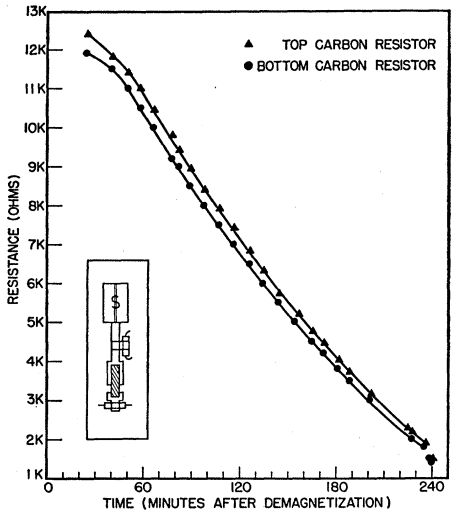


FIG. 3. Resistance of the carbon resistors as a function of the time after demagnetization.

tained for the carbon resistors result from the fact that the carbon resistors were of slightly different values and hence, have different calibration curves. The fact that no appreciable time lag was observed in the cooling down or the warming up of the two resistors, indicates the presence of intimate thermal contact between the salt and the hafnium.

The electrical resistance measurements conducted with Hf I were carried out in the hope of detecting a gross effect (i.e., $R \rightarrow 0$) and were not intended to be used in determining the precise values for the superconducing properties of the specimen. Measurements of this type being highly sensitive to impurities often yield erroneous values for T_c and dH/dT for slightly impure specimens. The results obtained by observing the resistance of the specimen as it warmed up after a demagnetization are plotted in Fig. 4. It is seen that immediately after demagnetization, the resistance had a considerably smaller value than it had at 1.3°K. As the specimen warmed up, the resistance increased and after approximately twenty minutes, corresponding to a temperature of 0.20°K, it had reached the value it had at 1.3°K. The resistance remained constant at this value throughout the remainder of the warmup. In the present work the transition temperature (T_c) is defined as that temperature at which the resistance first returns to its full normal value. This behavior is presented differently in Fig. 5, where it is noted that $R/R_{1.3°K}$ had a value of 0.61 at its lowest limit. Measuring currents of 147 and 232 microamperes were employed in making each resistance measurement and no dependence on current was noted. Critical-field data were obtained by observing several warmups in the presence of small magnetic fields. These fields were supplied by an auxiliary solenoid wound upon the casing of the Bitter magnet. A superconducting transition in a field of 25 gauss in also included in Fig. 4. The critical-field data are plotted in Fig. 6 and may be represented by a straight line with a slope of 450 gauss/degree.

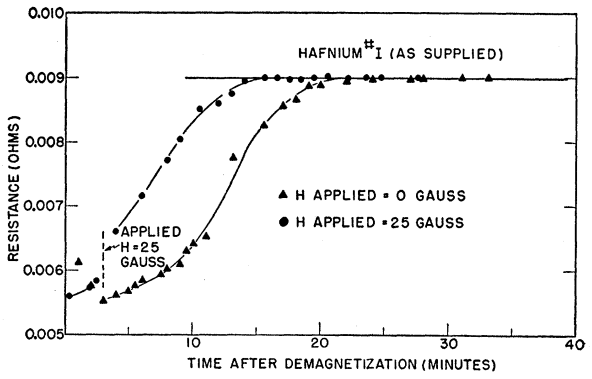
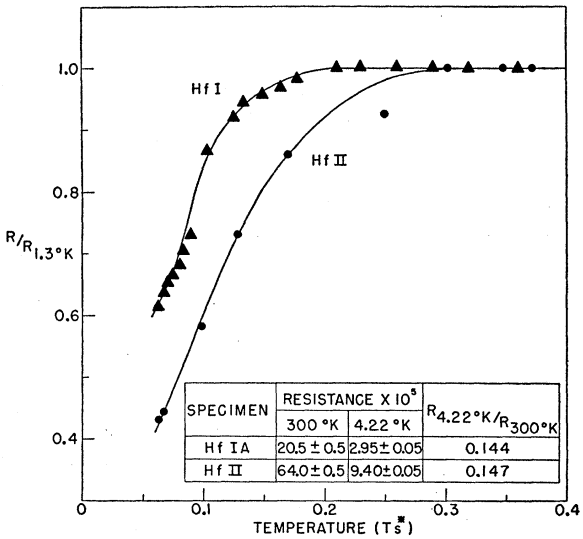


FIG. 4. Resistance of hafnium I as a function of the time after demagnetization.



SPECIMEN	RESISTANCE X 10^5		$R_{4.22°K}/R_{300°K}$
	300 °K	4.22 °K	
Hf IA	20.5 ± 0.5	2.95 ± 0.05	0.144
Hf II	64.0 ± 0.5	9.40 ± 0.05	0.147

FIG. 5. Resistance of the hafnium I and hafnium II as a function of the absolute temperature for temperatures below 1°K.

The specimen, hafnium I, was then annealed by Mr. E. Chapin of the Metallurgy Division of the Naval Research Laboratory, by subjecting it to a temperature of 800°C in a vacuum of 2×10^{-6} mm Hg. This temperature was maintained for a period of thirty minutes, after which the oven was allowed to cool overnight. The susceptibility measurements were repeated and again failed to show any signs of superconductivity in the hafnium down to a temperature of 0.08°K (see Fig. 7). Since an effect had been observed in the electrical resistance of the unannealed sample, it was decided to use a null technique to measure the resistance of the annealed sample. The resistance of this sample as a function of the absolute temperature from room temperature down to 1.3°K is plotted in Fig. 8. In measuring the resistance below 1.3°K, currents of 2.5 and 5.0 ma were employed and these measurements indicated that

the resistance started to decrease at temperatures ranging from 0.12 to 0.19°K. The data yield a value of 0.71 for the ratio of $R/R_{1.3°K}$ at the lowest temperature attained (~0.08°K). In these particular measurements rather fast warmup times were encountered. Because of the uncertainties in temperature introduced by such rapid warmups (~20 minutes) the data are not included in Fig. 5.

In order to ascertain if this decrease in resistance was perhaps peculiar to the specimen (hafnium I), a second hafnium sample (hafnium II) was obtained and the measurements repeated. The magnetic measurements again failed to reveal any superconduction transition. The electrical resistance, however, did show an abrupt decrease at 0.28°K. The ratio of $R/R_{1.3°K}$ was 0.42 at its lowest value, see Fig. 5. Measuring currents of 5.0 and 10.0 milliamperes were used and no dependence of the resistance on the currents used was noted. The

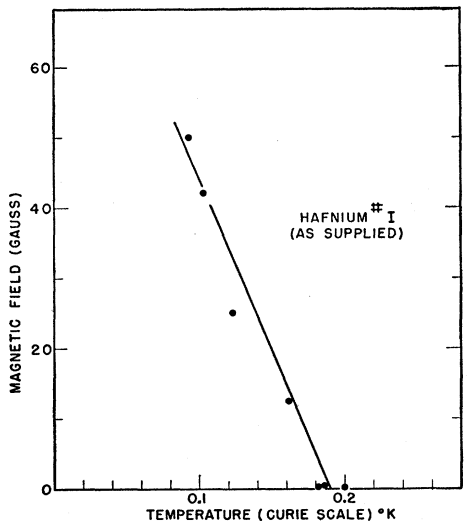


FIG. 6. Critical field curve for hafnium I.

electrical properties of Hf II were very similar to those of Hf I*A* with the exception of T_c.

B. Specimens Imbedded in the Pill

In an attempt to duplicate the experimental arrangement used by the other workers,[1-3] to facilitate the comparison of results, both hafnium samples were imbedded in a pill. A specimen of cadmium, the volume of which was one-half that of the hafnium's, was also imbedded in this pill to serve as a check on (a) the quality of the thermal contact and (b) the sensitivity of this arrangement. The results of observing the effective susceptibility of the pill by means of a two-coil secondary are plotted in Fig. 9. The only transition which is apparent occurred at a temperature of 0.555°K and is therefore attributed to the cadmium. If 100% of the hafnium had gone superconducting, it should have given rise to an effect, approximately twice as large as that due to the

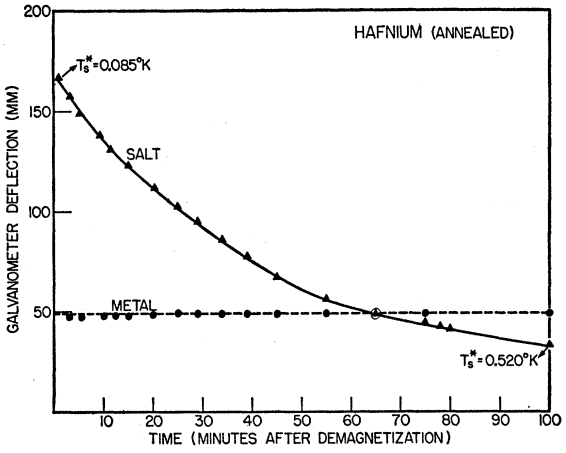


FIG. 7. Galvanometer deflections obtained for hafnium I*A* and the salt as a function of the time after demagnetization.

cadmium. The lowest temperature attained in this demagnetization was of the order of 0.06°K.

C. Hafnium Chips

Data obtained in zero applied magnetic field for the chips still imbedded in the pill used by Roberts and Dabbs, revealed a very strong diamagnetic component in the effective susceptibility of the pill below temperatures ranging from 0.22 to 0.29°K, see Fig. 10. This nonreproducibility of the zero-field transition temperature indicated a lack of thermal contact between the chips and the salt. Owing to the lack of thermal contact, no accurate-field data could be obtained. This apparent deterioration of the thermal contact between the hafnium chips and the salt is not surprising since the pill was about three years old. In light of this, the pill was dissolved in water and the chips were recovered. A new salt pill was fabricated into which two-thirds of the recovered hafnium was imbedded. With this pill, a zero-field transition was observed at 0.175°K and is

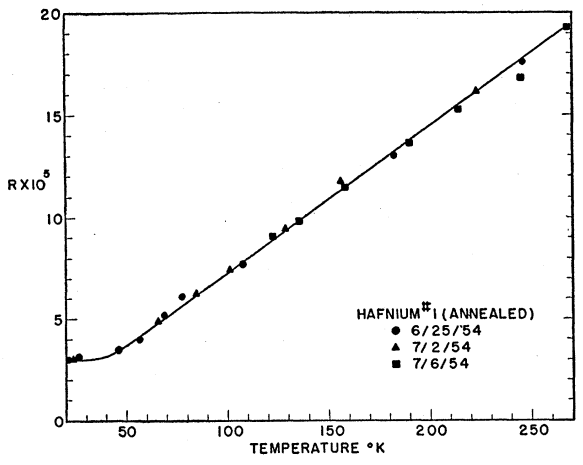


FIG. 8. Resistance of hafnium I*A* and II as a function of the absolute temperature from room temperature down to 1.3°K.

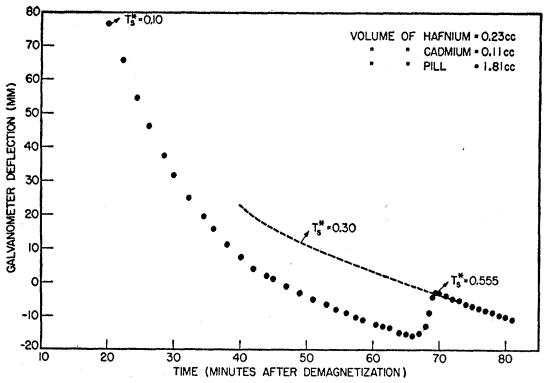


FIG. 9. Galvanometer deflections obtained as a function of the time after demagnetization for a salt pill containing hafnium I*A*, hafnium II, and cadmium.

depicted in Fig. 11. Additional critical-field data are given in Table I. While the critical-field data are not very conclusive, an estimate of 130 gauss/degree for the initial slope of the critical-field curve may be obtained.

VI. DISCUSSION OF RESULTS

The failure of the bulk specimens to exhibit the strong diamagnetism characteristic of the superconducting state is in disagreement with the results of other workers.[1,3] In the case of Kurti and Simon[1] no detailed comparison can be made as they presented no experimental data concerning the superconductivity of hafnium. Since the specimen used by Smith and Daunt[3] was a section of Litton's Bar No. 783, as were the bulk specimens used in the present work, the disagreement in the results is not readily explicable. While they attributed the smallness of the observed diamagnetism to the fact that less than 100% of their specimen became superconducting, in the present investigation if as little as 10% of the specimen had become superconducting it would have given rise to a detectable magnetic effect. This lower limit was arrived at by calibrating the coil system with a cadmium sample of known volume. The results of the electrical resistance measurements showed that the bulk specimens exhibited an "incipient superconductivity." Because of experimental difficulties the measurements obtained for Hf I were taken with only two contacts (0–80 brass screws) attached to the specimen. Therefore, the measured resistance includes the resistance of the contacts as well as any contact resistance which might have been present. The magnitude of the measured resistance as well as the magnitude of the observed decrease, Fig. 4, is too large to be attributed to the hafnium alone (compared with hafnium I*A* and hafnium II). In light of this, the observed decrease in resistance is interpreted as being due to a decrease in the contact resistance between the brass screws and the hafnium sample as the latter starts to go superconducting.[10] The data for hafnium I*A* and hafnium II were obtained with four contacts to the specimens. Since a null technique was employed, the above considerations do not enter. It is of interest to note that (1) the decrease in resistance was not sharp with respect to the temperature and (2) the resistance remained measureable down to 0.08°K. In other words, at a reduced temperature (T/T_c) of 0.28, the value of (R/R_{normal}) was only 0.41 indicating a relatively large transition interval. Spread-out transitions of this nature are not characteristic of "good" superconductors. This behavior and the failure of the specimens to exhibit the Meissner effect is suggestive of superconducting alloy.

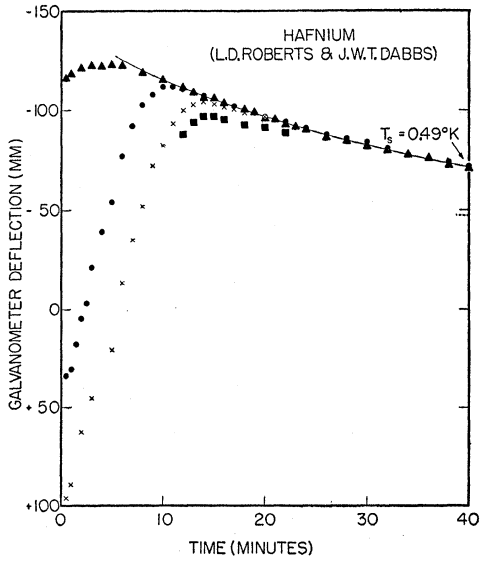


FIG. 10. Galvanometer deflections obtained for the "Oak Ridge" pill as a function of the time after demagnetization.

TABLE I. Critical-field data for the hafnium chips.

H(Gauss)	T°K(Curie)
0	0.172
0	0.175
1.0	0.148
4.95	0.121

The measured hardness of these bulk specimens was reported by Litton to be Rockwell *B*78; Smith and Daunt measured the hardness of their sample to be Rockwell *C*47 before and Rockwell *B*100 after they had annealed it. Mr. Alton R. Donaldson of the Metallurgy Division of the Naval Research Laboratory measured the hardness of Hf I as supplied, with a Wilson Tukon Tester, and observed that the indentations were most regular when taken from the center of the specimen out to approximately one-half its radius. The indentations from that point out to the periphery were irregular. This irregularity of the indentations may be interpreted as due to an inhomogeniety of the specimen. A micrograph of the specimen (Fig. 12) supports this conclusion.

[10] F. Bedard and H. Meissner, Phys. Rev. 98, 1539 (1955).

However, for the sake of comparison, a value for the hardness was calculated by using the indentations which were regular, to be 201.9 DPHN. While the conversion from this scale to the Rockwell scale is somewhat doubtful,[11] a value of 201.9 DPHN corresponds to approximately Rockwell *B*92, which is somewhat softer than Smith and Daunt's value, but harder than Litton's value.

The large diamagnetism observed with the hafnium chips substantiates, in effect, the findings of Roberts and Dabbs. In apparent contradiction with the results of Smith and Daunt, the diamagnetism observed with these chips was larger, by a factor of four or five, than what was expected on the basis of 100% of the specimen going superconducting. The excess diamagnetism is attributed to the formation of superconducting rings inside the pill. Since the specimens were in the form of

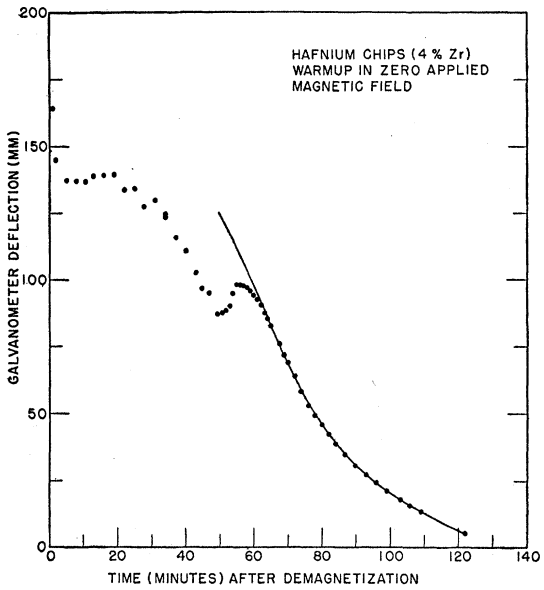


FIG. 11. Galvanometer deflections obtained for the hafnium chips as a function of time after demagnetization.

lathe turnings, such an assumption seems plausible. In light of this, it is not possible to calculate what percentage of the specimen became superconducting. The transitions were not very sharp and therefore introduce uncertainties in the calculation of the transition temperatures. Due to this, the critical-field data should be viewed with some reservations.

The warm-up curves obtained with the new salt pill are of somewhat unusual character. The constancy in the galvanometer deflections, observed in the early stages of the warmup, indicates that the diamagnetism caused by the hafnium chips must have been decreasing by the same order of magnitude as was the paramagnetism of the salt. This means that the hafnium never

[11] *Metals Handbook* (American Society of Metals, Cleveland, 1948), p. 103.

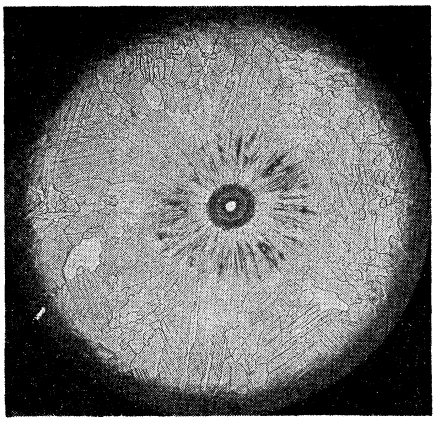


FIG. 12. A micrograph (12.5×) of the hafnium bar.

exhibited a constant diamagnetism of the sort demonstrated by the cadmium sample in Fig. 9. The results obtained with the pill supplied by Roberts and Dabbs (Fig. 10) also indicated that the diamagnetism was still increasing at the lowest temperatures attained.

The low transition temperature observed with the new pill, would indicate that the additional cold-working experienced by the chips in the fabricating of the pill, had the effect of lowering the transition temperature. This conclusion is based on the assumption of intimate thermal contact.[9]

VII. CONCLUSIONS

The results reported here serve to emphasize the nebulous nature of the superconducting state in hafnium. The magnetic susceptibility measurements conducted with the purer specimens indicate that hafnium is not a superconductor. The electrical resistance measurements, however, revealed an "incipient superconductivity." In drawing a conclusion from these results, the magnetic measurements are weighted more heavily because they are believed to be more characteristic of the specimen as a whole. With this in mind, it is felt that a tentative "no" must be rendered to the question of superconductivity in hafnium down to a temperature of 0.08°K.

No pertinent conclusions may be drawn from the work with the impure specimens because zirconium, the major impurity, is known to be a superconductor with a transition temperature as low as 0.56°K.[3]

While its position in the periodic table would make the superconductivity of hafnium not too surprising, a consideration of all the data in Table II reveals that the experimental evidence to date does not warrant such a conclusion. In light of the apparent contradictory results and the fact that the purest specimens used to date may not be representative of "pure" hafnium, it is felt that further work with purer samples, both physically and chemically, is necessary before the question

TABLE II. Summary of properties of hafnium specimens.

Workers	Specimens: Characteristics	Specimens: Prepared by	Treatment	Transition temperature: Resistance	Transition temperature: Magnetic	Comments
I. Kurti and Simon[a]	Polycrystalline bar (2 mm ×25 mm), "very pure"	deBoer and Fast[b]			0.35°K	
II. Smith and Daunt[c]	A. Polycrystalline bar (3.4 mm×505 mm), 98.92% pure. Major impurity 0.9% zirconium	Litton[d]	Cold-swaged and annealed		None down to $T_s^*=-0.15$°K	
	B. Same specimen as above		Re-annealed		0.37°K	Less than 100% of the specimen became superconducting
III. Roberts and Dabbs[e]	A. Irregularly shaped chips, approximately 96% pure; major impurity 4% zirconium		Lathe turnings		None down to $T_s^*=0.03$°K	
	B. Same specimen as above		Annealed in a high vacuum		0.29°K	Apparent diamagnetism in excess of 100% superconductivity
IV. Present work	A. Hf I. Polycrystalline bar (3.4 mm×16mm), 98.92% pure; major impurity 0.9% zirconium.	Litton[b]	Cold-swaged and annealed	0.19°K	None down to 0.08°K	
	B. Hf I4. Same specimen as above		Re-annealed	0.12 to 0.19°K	None down to $T_s^*=0.08$°K	
	C. Hf II. Polycrystalline bar (3.4×16 mm), 98.92% pure; major impurity 0.9% zirconium	Litton[b]	Same as Hf I	0.28°K	None down to $T_s^*=0.08$°K	
	D. Irregularly shaped chips; same specimen as used by Roberts and Dabbs	See III above	See III. B		0.22 to 0.29°K	Apparent diamagnetism in excess of 100% superconductivity
	E. Same as D above; new salt pill				0.17°K	Apparent diamagnetism in excess of 100% superconductivity

[a] See reference 1
[b] J. H. deBoer and J. D. Fast, Z. anorg. Chem. **187**, 193 (1930).
[c] See reference 3
[d] See reference 4
[e] See reference 2.

of superconductivity in hafnium can be incontestably answered.

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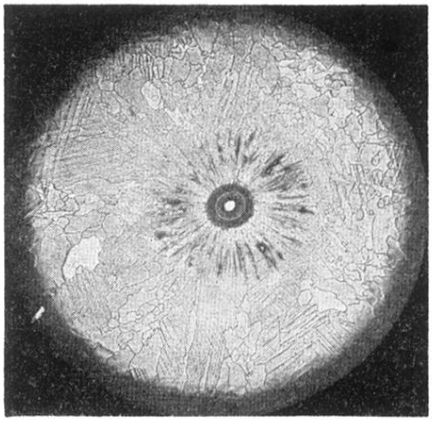

FIG. 12. A micrograph (12.5×) of the hafnium bar.