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Implications of New Data on the Heat Capacity of Tungsten for the Powdered Cerium Magnesium Nitrate Temperature Scale *

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The tungsten critical field data obtained by Black, Johnson and Wheatley on the CMN temperature scale are reanalysed, using a new value of γ. The analysis requires $\Delta \neq 0$ at $T \leq 4.5$ mK, and positive temperature-independent values of Δ are ruled out.

A number of properties of He^3 and of dilute solutions of He^3 in He^4 have been measured on a magnetic temperature scale T* that is based on the susceptibility of a cylinder of powdered CMN (cerium magnesium nitrate).[1] The difference between this scale and the thermodynamic scale T, is usually represented by $\Delta \equiv T - T^*$. Black, Johnson, and Wheatley (BJW) have reported[2] measurements of the critical field for superconductivity in tungsten on the same scale to T* = 2 mK, and it has been pointed out[3] that the data can be used to test values of Δ derived in other ways. The test is based on the thermodynamic relation

$$H_c^2 = H_o^2 - (4\pi\gamma/V)\, T^2 \qquad (1)$$

which holds for $T \lesssim 0.3\, T_c$. (T_c is the critical temperature, H_c is the critical field and H_o is its value at 0 K, V is the molar volume, and γ is the coefficient of the electronic heat capacity.) The test is most useful if an accurate independent value of γ is available, and the purpose of this letter is to report on the implications for the T* scale of a new calorimetric γ value.

The heat capacity of tungsten has been measured between 0.35 and 25 K and analysis of the data gave $\gamma = 1.008 \pm 0.010$ mJ/mole K^2.[4] This value agrees to within the combined estimated uncertainties with several other values,[5] but is considerably higher than the value 0.90 mJ/mole K^2 obtained[2] by fitting the H_c data between 3 and 4.5 mK to Eq.(1) with $\Delta = 0$. (The critical field of tungsten has also been measured to 5.5 mK using a γ-ray anisotropy thermometer.[4] The H_c values are higher than those obtained by BJW but the difference could

be produced by different concentrations of magnetic impurities in the two samples and the new data are interpreted as confirmation of the temperature dependence reported by BJW).

In Figs. 1(a) and (b), the H_c data obtained by BJW below $T^* = 4.5$ mK are plotted as H_c^2 vs. $(T^*+\Delta)^2$ for five choices of $\Delta(T)$. Straight lines with the slope required by Eq.(1) are included for comparison. As shown in (a), the assumption $\Delta = 0$ leads to a significant discrepancy between the H_c data and Eq.(1), even in the range $T^* = 3$ to 4.5 mK. Positive, temperature-independent values of Δ increase the discrepancy as shown for $\Delta = 0.4$ mK, also in (a). Black[3] has already noted the inconsistency of the tungsten H_c data with the positive constant value of Δ inferred[6] from the temperature dependence of the heat capacity of CMN, and the inconsistency is even more apparent when the calorimetric γ value is used in the comparison. In fact, positive values of Δ can be consistent with Eq.(1) and the H_c data only if Δ decreases with increasing T more rapidly than T^{-1}. One relation for $\Delta(T)$ that gives positive values and reasonable agreement with Eq.(1), $\Delta T^2 = 9$ mK^3, is represented in (b). On the other hand, it is possible to find a negative constant value of Δ, - 0.4 mK, that is in reasonable accord with Eq.(1), as shown in (a).

Webb, Giffard and Wheatley[7] have determined Δ by comparing a CMN thermometer with a Johnson noise thermometer. They found $\Delta = 0.4$ mK at $T^* = 2$ mK and $\Delta = 0 \pm 0.12$ mK for $8 < T^* < 20$ mK. A qualitatively similar temperature dependence for Δ that is consistent with Eq.(1)

is $(\Delta+0.2)T^2 = 3.5\ mK^3$, represented in (b). This relation agrees with the noise thermometer data to within approximately 0.1 mK in the temperature interval included in Fig. 1 (the only region in which the H_c data give a useful test of Δ) but gives $\Delta = -0.15$ and -0.20 mK at 8 and 20 mK, respectively.

In summary, reanalysis of the tungsten H_c data using the calorimetric γ value confirms that positive temperature independent values of Δ can be ruled out and shows that $\Delta \neq 0$ at temperatures as high as $T^* = 4.5$ mK. The H_c data do not determine a unique $\Delta(T)$ relation (the criterion of conformity to the BCS expression for H_c is not useful because of the possible influence of magnetic impurities[4]) but they are consistent with $\Delta(T)$ relations qualitatively similar to that determined by noise thermometry.

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Figure Caption

Figure 1 The critical field of tungsten as reported by Black, Johnson and Wheatley, plotted as H_c^2 vs. $(T^*+\Delta)^2$ for different $\Delta(T)$ relations. The straight lines have the slope required by Eq.(1) and the calorimetric γ value.

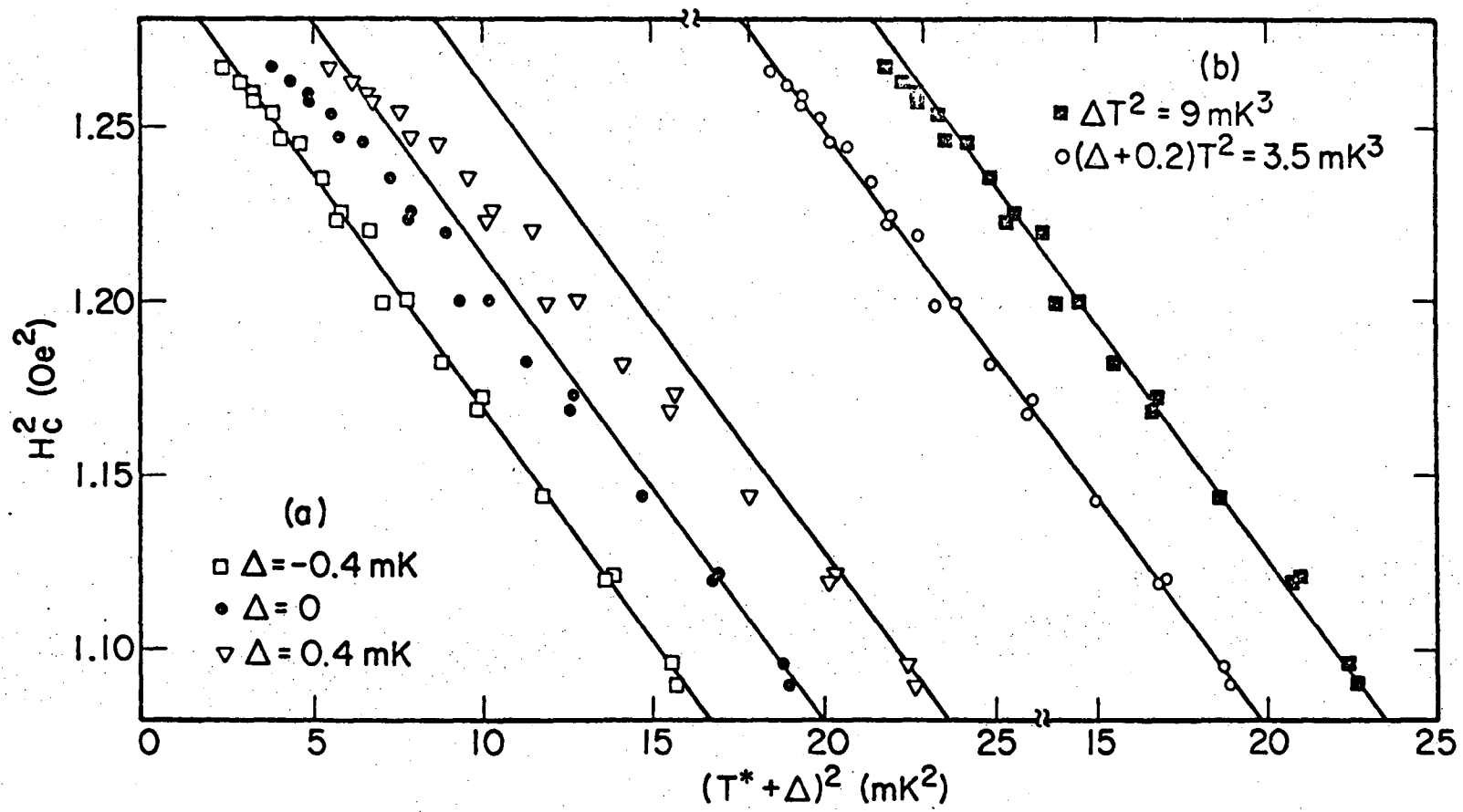

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Fig. 1

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