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THERMAL EQUILIBRIUM BETWEEN LIQUID He³ AND POWDERED CERIUM MAGNESIUM NITRATE AT VERY LOW TEMPERATURES*

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We have discovered that the thermal relaxation time of a mixture of powdered cerium magnesium nitrate (CMN) and liquid He³ is anomalously small at very low temperatures. We believe that this effect is important for the future development of experimental physics at low temperatures. It may also be used to explain the heat-capacity results of Peshkov[1] without recourse to the assumption of superfluidity in He³. Moreover, a certain interpretation of the experimental results may bear on the temperature dependence of the thermal conductivity of He³ down to magnetic temperatures of order 2 mdeg K on the temperature scale valid for powdered CMN in the form of a right circular cylinder with diameter equal to height.

The observations reported here were obtained from an analysis of the temperature-time curves of the heat-capacity experiment of Abel et al.[2] In this experiment, by a difference method, it was possible to obtain both the heat capacity of the He³ and of the powdered CMN, the latter being used to cool the He³ and to measure its temperature. It has long been supposed that the principal thermal resistance between the He³ and the CMN is the Kapitza thermal boundary resistance, although the latter is very poorly understood from an experimental viewpoint.[3] A bath of He³ and a bath of CMN would come to thermal equilibrium in a time

$$\tau = RC_3 C_{CMN}/(C_3 + C_{CMN}), \tag{1}$$

where R is the thermal resistance between the two baths ($\propto T^{-3}$ for a "normal" Kapitza resistance[3]), C_3 is the heat capacity of He³ (nearly proportional to T at low T), and C_{CMN} is the heat capacity of the CMN (nearly proportional to T^{-2} at high temperatures). Thus if R is the Kapitza resistance, one expects $\tau \propto T^{-5}$ at high temperatures and $\tau \propto T^{-2}$ at low temperatures. The experimental results for τ are shown in Fig. 1. Neither of the above limits is observed, but rather a maximum in τ is found, the actual values of τ being remarkably short for the present temperature range and the size and heat capacity of the sample.

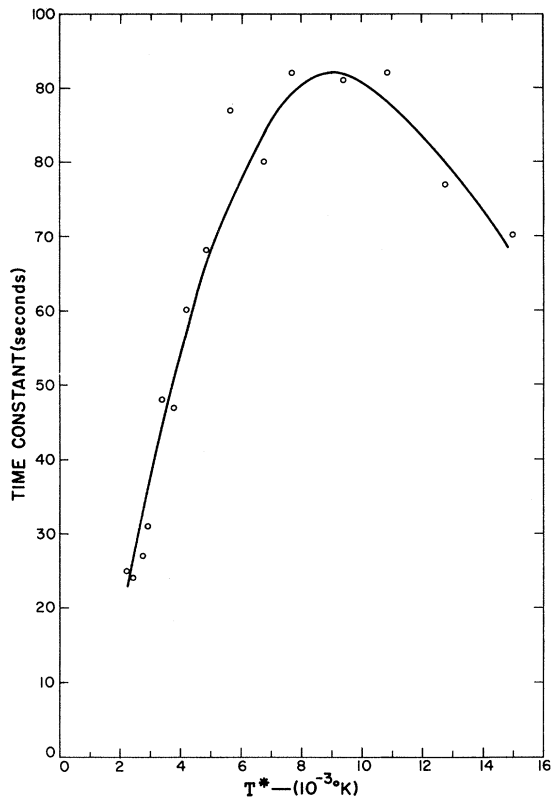FIG. 1. Effective thermal time constant of the mixture of powdered CMN and low-pressure He³ for the experiments of Ref. 2.
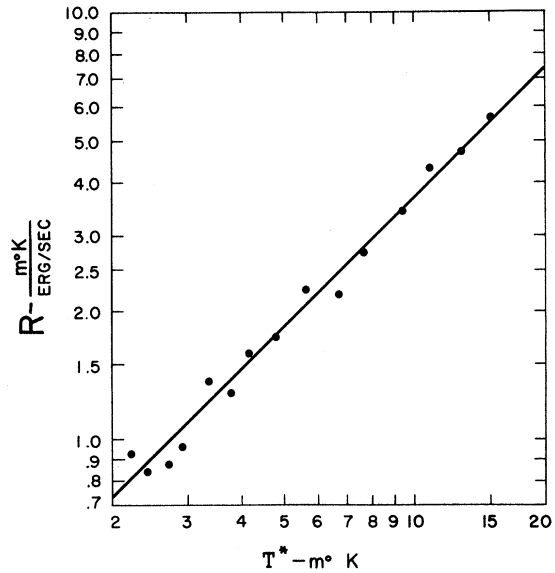

FIG. 2. Effective thermal resistance deduced from the data of Fig. 1 using a two-bath model and the measured heat capacities of He³ and CMN.

The time constant at the lowest temperature was about 25 sec. If the thermal conductivity of the He³ were not impaired by the powder, one would expect a time constant for thermal equilibrium of the He³ to be about 1 sec at 2 mdeg K. Thus it seemed reasonable to analyze further the data of Fig. 1 in terms of the simple two-bath model, for which the time constant is given by Eq. (1). Since both C_3 and C_{CMN} were measured, R may be evaluated directly from the data. It is plotted on Fig. 2. Within scatter the data fit a linear dependence on T^*. According to the simple picture of a normal Fermi liquid,[4,5] the thermal conductivity κ is proportional to T^{-1}, so the thermal resistance of He³ is proportional to T. If R is written as $(l/A)\kappa^{-1}$, then the straight line in Fig. 2 corresponds to $(l/A) = 18$ cm^{-1}, characteristic of a long, thin geometry.

The smallest low-temperature Kapitza resistance measured thus far is that between He³ and epoxy,[3] for which $R = (3 \times 10^{-6}/AT^3)$ sec

cm^2 °K^4/erg, where A is the area. The present powder has an average grain size of about 10^{-2} cm and, on this basis, an estimated area of 2×10^3 cm^2. If this value of A and the above value of R are used to estimate the CMN-He³ Kapitza resistance, one finds $R \approx 2 \times 10^2$ mdeg K/(erg/sec) at $T = 2$ mdeg K. The value of R deduced from our analysis is $R \approx 1$ mdeg K/(erg/sec) at $T^* = 2$ mdeg K. It appears that the Kapitza resistance to powdered CMN is much less than expected. The effect was seen somewhat obscurely in some of our earlier work and a discussion given,[6] to which the reader is referred. Whatever the explanation for the small thermal time constants observed here, the fact that they are indeed small is very encouraging both for the possibility of other experiments in the present temperature range and for the possibility of extending even lower the present range of temperatures accessible for measurements.

A maximum in the thermal time constant of a mixture of CMN and He³ rather than a monotonically increasing time constant as T decreases may also be used to explain the bump in the heat capacity of the mixture of CMN and He³ measured by Peshkov[1] if one assumes that in Peshkov's experiments there is a heat loss during heating periods. A max-

imum in the time constant reflects a minimum in the thermal diffusivity which in turn leads to a maximum in the fraction of the applied heat which escapes due to the heat-loss defect. This leads to an erroneous relative increase in calculated heat capacity near the maximum of τ. The details of the τ-vs-T^* curve will be different for different apparatus. A further discussion is given in Ref. 6.

It is tempting to regard the resistance plotted in Fig. 2 as that of He^3. If this is done then the data of Fig. 2 show that the temperature dependence of the thermal conductivity of He^3 does not depart strongly, if at all, from that expected for a normal Fermi liquid down to temperatures of a few millidegrees. This cannot be regarded as a strong conclusion, however.

Further experimental work on this point is required.

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FINITE-WELL, SINGLE-PARTICLE WAVE FUNCTIONS IN TWO-NUCLEON STRIPPING*

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Much interest centers on the multinucleon-transfer reaction as a possible testing ground[1] for nuclear-structure models, because the probability amplitude is a coherent sum of terms, each involving a product of single-particle wave functions.[2-5] A distorted-wave Born-approximation (DWBA) theory suitable for calculating the coherent sum has been developed in detail.[6-11] In all applications of this theory, harmonic-oscillator single-particle functions have been used.[8-15] Not only are oscillator wave functions particularly convenient for separating the relative and center-of-mass motions[16] of the several nucleons that are transferred, but they are the wave functions normally used in structure calculations, for example those which predict the coefficients in the coherent sum.

An oscillator wave function has, of course, a (Gaussian) tail which decays too rapidly to approximate the (exponential) tail of a wave function for a finite well, say one of Woods-Saxon shape. The shape of this tail is important in nuclear reaction applications; in all (d,p) calculations, for example, it is necessary to use finite-well wave functions to avoid gross error. Fortunately, finite-well single-particle (FWSP) eigenfunctions have excellent overlap with oscillator single-particle (OSP) eigenfunctions within the nuclear interior and, therefore, it is not difficult to carry over into correct reaction calculations the already available results of typical structure calculations.

It is the purpose of this Letter to point out that there are marked changes in reaction calculations of multinucleon transfer if eigenfunctions of a finite well are used instead of oscillator eigenfunctions. Further, it is easy thus to dispense with the use of oscillator eigenfunctions.

Figure 1 shows the results of zero-range DWBA calculations for the reactions $^{40}Ca(^3He, p)^{42}Sc$ and $^{54}Fe(t,p)^{56}Fe$, along with the corresponding experimental data.[17,18] The curves labeled OSP and FWSP were calculated by using oscillator and finite-well single-particle wave functions, respectively. A configuration of $(f_{7/2})^2$ was assumed for the ground state of ^{42}Sc and $(p_{3/2})^2$ for the ground state of ^{56}Fe, although additional admixtures are to be expected. No attempt to fit data by varying parameters was made in the FWSP calculations, except to consider different families of potentials for the strongly absorbed $A = 3$ particles. Nonetheless, the FWSP angular distributions, calculated without any radial cutoff in the matrix element, are in reasonable agreement with