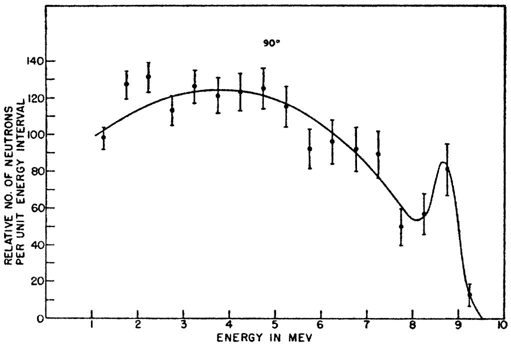

FIG. 3. The $T+T$ neutron energy distribution. Triton energy = 220 kev. Probable errors are indicated.

the formation of He^5 in its unstable ground state. Owing to its short lifetime, this nucleus disintegrates while in motion. This results in an energy spread of its disintegration products; the neutron energy lies between 0.05 and 1.93 Mev, the associated α-particle energy between 0.6 and 2.5 Mev. These particles are not resolved from the 3-body distribution from reaction (1).

The neutron measurements at 90° indicate that either the yield of reaction (2) is small or the neutron and the He^5 are emitted at angles near 0° or 180° to the beam. In the latter case only a few of the breakup α-particles can be observed at 90° owing to the large momentum of the He^5 nucleus. Thus, in either case, the observed α-particle energy distribution is due largely to the 3-body disintegration. Within the present experimental error, the α-particle energy distribution indicates the partition of energy among the products of the 3-body disintegration to be in fair accord with classical phase space considerations,[6] although there is some slight evidence for an angular correlation favoring emission of both neutrons in the same hemisphere.

In conclusion we should like to express our thanks to Dr. R. F. Taschek and his colleagues for valuable discussion of the Los Alamos experiments on the $T+T$ reactions.[7]

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Solidification of He^3

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WE have recently succeeded in solidifying He^3 and have determined a portion of the melting curve by the blocked capillary technique.[1] The melting pressure was found to change from 40.5 atmos at 1.02°K to 56.6 atmos at 1.51°K.

A schematic diagram of the apparatus is shown in Fig. 1. In order to perform the experiment with the amount of gas available (190 cc STP) it was necessary to keep the volume of the system small. This was accomplished by filling the Bourdon gauges (*B* and *G*) with mercury and by using 0.1-mm i.d. stainless steel tubing for the U-tube (*D*) in the helium cryostat $(E)^2$ and 0.5-mm i.d. tubing for the connections outside the cryostat. The other U-tubes (*C* and *F*) were immersed in liquid nitrogen to prevent mercury from plugging the smaller tubing in the cryostat. The apparatus was evacuated and filled through the high pressure valves (*A* and *J*). The gas in the reservoir (*H*) was compressed with mercury displaced by means of the hydraulic system (*I*). The Bourdon gauges, which had 1-lb/in.^{2} graduations and a range of 0 to 1000 lb/in.^{2}, were calibrated with a pressure balance while filled with mercury.

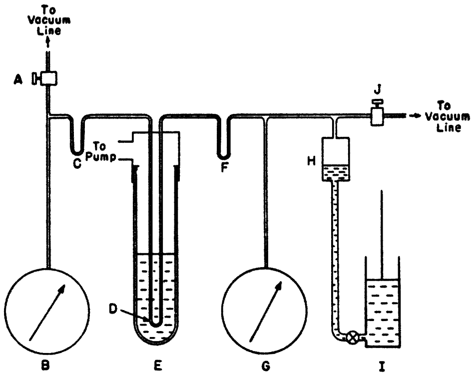

FIG. 1. Solidification apparatus (schematic).

As the pressure in the system was slowly increased, at a constant cryostat temperature, the two gauges gave the same reading until the solidification pressure was reached, and then gauge (*G*) continued to rise while gauge (*B*) remained constant. Upon lowering the pressure the gauge readings again became equal at the solidification pressure. A single measurement was made with He^4, and the solidification pressure was found to be 25.2±0.1 atmos at 1.09°K, in satisfactory agreement with the more accurate value of 25.10 atmos found by Swenson.[3] The data for He^3 are plotted in Fig. 2. The equation of the curve in this figure is

$$P = 27.0 + 13.0T^2 \text{ atmos } (1.02 \text{ to } 1.51°\text{K}), \tag{1}$$

and it represents the He^3 melting pressure in the range of the measurements with a mean deviation of 0.1 atmos.

With the aid of Eq. (1) an upper limit can be calculated for the volume change on melting, ΔV, by substituting the entropy of the liquid in equilibrium with the vapor[2] for the entropy of melting, ΔS, in the relation

$$dP/dT = \Delta S/\Delta V. \tag{2}$$

It is assumed that the thermal coefficient of expansion of liquid He^3 is positive, and hence that the entropy of the liquid decreases when the liquid is compressed from the vapor pressure to the melting pressure. The result is $\Delta V < 1.2$ cc/mole at 1°K. This is smaller than the volume change of 2.1 cc/mole for He^4 at this temperature[3] but is reasonable because of the higher melting pressure of He^3.

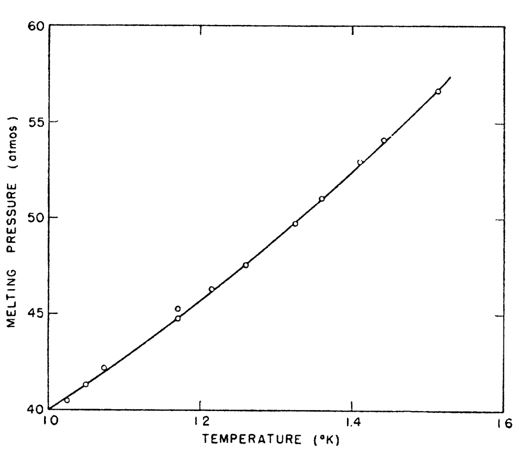

FIG. 2. Melting pressure of He^3.

Also, from the relation

$$\Delta U/\Delta V = TdP/dT - P \tag{3}$$

and Eq. (1) it can be seen that ΔU is zero at 1.44°K and that the internal energy of the liquid is less than that of the solid below this temperature.

The melting pressure data also point to another interesting result. Since any reasonable extrapolation of the data gives a positive melting pressure at absolute zero, it appears likely that He^3, like He^4, does not have a triple point and that the liquid is the stable condensed phase at absolute zero.

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Line Breadths of the Fine Structure of the Microwave Spectrum of Oxygen*

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IN a previous paper[1] we have reported on preliminary measurements of the widths of three fine structure lines of oxygen. These lines arise from reorientations of the oxygen electron spin vector $S(=1)$ with respect to the rotational angular momentum vector K, which is constant for the microwave transitions observed. It has since been possible to extend the determinations of the line-width parameter to include fourteen lines over the range of significant population.

The apparatus for detection of the lines is essentially that cited earlier.[1] To make the measurements more precise, a lattice of frequency markers of 5.70 megacycles spacing has been superimposed on the recorder trace. This superposition results in an individually calibrated recorder trace for each record made. With the detecting system used, the shape of the recorder tracing of an absorption line represents the second derivative of the line contour. Thus, it is easily demonstrated that the distance between the negative minima of the recorder trace is the full width ($2\Delta\nu$) of the line measured at half intensity.

Measurements on each of the lines have been made for at least three different pressures in the range 0.1 to 10 mm Hg. As in the earlier work, measurements at a constant pressure were made for successively decreasing modulations. Each time the measured widths were extrapolated to obtain the width for zero modulation. Since the modulating fields employed were of the order of the earth's field, it was necessary to orient the absorption cell along the earth's field and apply a dc current of proper direction and magnitude to prevent significant broadening of the lines by the earth's field. Corrections have been made, however, for broadening the lines by inhomogeneity of the magnetic field surrounding the cell. The observed line width parameter $\Delta\nu/c$ expressed in cm^{-1} per atmosphere is plotted in Fig. 1 together with a theoretical curve discussed subsequently. The data are in agreement with the single $K=11$ line reported by Gokhale and Strandberg,[2] and are of the same magnitude as the line widths observed by Beringer and Castle[3] for $\Delta J=0$, $\Delta K=0$, $\Delta M=\pm 1$ transitions occurring in the 3-cm region at high magnetic fields.

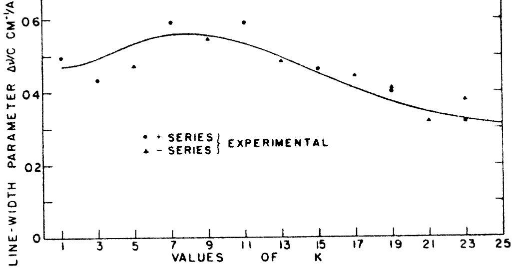

FIG. 1. Comparison of theoretical formula with experimental data. The solid curve is the plot of Eq. (2). The points represent measured values of the line-width parameter. The + series refers to transitions $J=K+1\rightarrow K$ and the − series refers to transitions $J=K-1\rightarrow K$.

Since oxygen lacks an electric dipole moment, interactions between molecules must take place through the mechanism of shorter range forces such as quadrupole ($V\sim 1/r^5$), polarizability ($V\sim 1/r^6$), or still shorter range nonelectric forces. The magnetic dipole interaction is sufficiently small that it can be neglected despite its long range ($V\sim 1/r^3$). Anderson[4] and Mizushima[5] have investigated, respectively, polarizability and quadrupole interactions for $\Delta K=0$. Both interactions yield line widths that decrease fairly rapidly with increasing K, the quadrupole line width decreasing as $K^{-\frac{1}{2}}$ for high K,[6] while the polarizability line width decreases somewhat more rapidly for low K, and attains a constant plateau for K greater than 15. The still shorter range nonelectric forces may be expected to be essentially independent of K, so that a combination of all three interactions (for $\Delta K=0$) may be expected to yield a line shape of the approximate form,

$$\Delta\nu_{\Delta K=0} = C_1 + C_2 K^{-\frac{1}{2}}. \tag{1}$$

The observed variation in $\Delta\nu$ with K shows an unmistakable peak about $K=7$. Since $K=7-9$ corresponds to the peak of the thermal population for room temperature, this suggests that resonance interactions contribute an important fraction of the line widths for these states. Both polarizability and quadrupole interactions have an angular $\cos^2\theta$ variation, where θ is the angle between the intermolecular distance r and the asymmetry axis of the molecule. This angular variation gives large matrix elements for $K\rightarrow K+2$ transitions. Since only odd K values are permitted for oxygen (spin $O^{16}=0$; ${}^3\Sigma^-$ ground state), the population of $(K\pm 2)$ states near the thermal maximum is particularly high with 28 percent of all molecules in $K=7$ or $K=11$ states. These facts suggest that the total line width should be of the form

$$\Delta\nu_{\text{tot}} = C_1 + C_2 K^{-\frac{1}{2}} + C_3[f(K-2)+F(K+2)], \tag{2}$$

where $f(K)$ is the fractional population of the Kth rotational state, and the resonance interaction has been assumed independent of K to a first approximation. Figure 1 is a plot of Eq. (2) for $C_1=0.027$, $C_2=0.012$, and $C_3=0.090$ cm^{-1} per atmosphere. The fit is seen to be satisfactory. The best fit of the data yields a fairly low value of C_2, which, moreover, includes part of the polarizability interaction along with the quadrupole interactions. Mizushima's expression for the quadrupole interaction alone is

$$\Delta\nu\ \text{cm}^{-1}/\text{atmos} = 2.24\times 10^{15} Q K^{-\frac{1}{2}}, \tag{3}$$

where Q is defined (as in Smith and Howard[7]) as the average Q of the rotating oxygen molecule ($\equiv$Margenau's Θ/e).[8] Arbitrarily assigning 3/4 of C_2 to a quadrupole interaction gives a value of $Q=0.04\times 10^{-16}$ cm^2 for oxygen. This value is in agreement with the upper limit of $Q\leqq 0.09\times 10^{-16}$ cm^2 deduced from the broadening of ammonia by oxygen.[7]

We wish to thank Professor Mizushima for sending us a prepublication copy of his paper. We have also benefited from correspondence with Dr. P. W. Anderson.

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