Table I. Summary of results.

Altitude, km	Temperature in °K
100	215 ± 25
110	240 ± 30
120	275 ± 45
130	325^{+65}_{-50}
140	400^{+80}_{-70}
150	515^{+150}_{-115}

ods developed for the twilight flash.[7]

The results for the temperature given in Table I are in agreement with the values deduced by Hunten[4] from a consensus of spectroscopic observations on the airglow and the auroras but far below the values used in the ARDC (Air Research and Development Command) model atmosphere.[8]

*John Simon Guggenheim Fellow, 1960. On leave from the University of Pittsburgh, Pittsburgh, Pennsylvania.

[1]W. G. Stroud, W. Nordberg, and J. R. Walsh, J. Geophys. Research 61, 45 (1956).

[2]W. G. Stroud, W. R. Bandeen, W. Nordberg, F. L. Bartman, J. Otterman, and R. Titus, Fifth Assembly of the Comité Speciale pour l'Année Géophysique Internationale, Moscow, 1958, Annals of the International Geophysical Year (Pergamon Press, London, to be published).

[3]H. E. Newell, Jr., in Physics of the Upper Atmosphere, edited by J. A. Ratcliffe (Academic Press, Inc., New York and London, 1960), p. 73.

[4]D. M. Hunten, Symposium on Aeronomy at Copenhagen, 1960 (to be published).

[5]J. Bricard and A. Kastler, Ann. Geophys. 1, 53 (1944).

[6]T. M. Donahue, J. E. Blamont, and M. L. Lory, Planetary and Space Science (to be published).

[7]T. M. Donahue and R. Resnick, Phys. Rev. 98, 1622 (1955); T. M. Donahue and V. R. Stull, Ann. Geophys. 15, 481 (1959).

[8]R. A. Minzer, K. S. W. Champion, and H. L. Pond, Air Force Surveys in Geophysics No. 115, Geophysics Research Directorate, Bedford, Massachusetts, 1959 (unpublished).

SPECIFIC HEAT OF LIQUID He^3 DOWN TO 0.054°K*

Myron Strongin, George O. Zimmerman, and Henry A. Fairbank
Sloane Physics Laboratory, Yale University, New Haven, Connecticut
(Received March 29, 1961)

The intriguing question of whether liquid He^3 may undergo a phase transition into a superfluid state has acquired new interest with the recent predictions of several investigators[1-3] that a transition into such a cooperative state should occur at a sufficiently low temperature. These theories based on the BCS model of superconductivity in metals predict a transition temperature as high as 0.08°K, this temperature depending sensitively on the effective mass m^* of the quasi-particles and on the single-particle potential used in the calculations. No evidence for such a phase transition above 0.03°K was found by Anderson, Hart, and Wheatley[4] in measurements of the coefficient of self-diffusion and nuclear susceptibility. However, in view of the lack of any firm theoretical predictions about the coefficient of self-diffusion near the phase transition, the indication that there exist relative angular momentum states favorable to a transition which would yield no change in susceptibility,[5] and because in the analogous case of superconductors a surprisingly small decrease in the electron spin susceptibility in the superconducting state has been found in superconducting Sn and Hg,[6-8] it would seem desirable to have other evidence before ruling out a phase transition in this region.

In going from the normal to the superfluid state a discontinuous increase in the specific heat of about a factor of two is predicted,[2] thus making the measurement of specific heat a particularly sensitive test for such a transition. Earlier specific heat measurements of Brewer, Daunt, and Sreedhar[9] extending down to 0.085°K showed no anomaly. In the measurements reported here the specific heat of liquid He^3 at saturated vapor pressure has been measured down to 0.054°K and a linear dependence on temperature was found below 0.09°K. A phase transition above 0.054°K would seem, therefore, to be excluded.

The He^3 used in this experiment has been purified by pumping back 2/3 of a given amount of liquid He^3 at 0.4°K (starting purity, 99.9% He^3). This process was carried out twice giving a He^4 content estimated to be less than 1 part in 10^5. No trace of He^4 was found using a mass spectrometer which could detect a concentration of 0.01% He^4.

The liquid He^3, contained in a copper calorimeter can, was thermally connected to a cerium magnesium nitrate thermometer pill by a large number of No. 40 copper wires. The calorimeter was cooled by demagnetizing a large (150-g) pill of chromic methylammonium alum from a starting temperature of about 0.4°K obtained with a He^3 cryostat. Thermal contact and isolation between the working salt and the copper calorimeter was obtained by means of a superconducting tin heat switch. The specific heat was measured by observing the temperature rise produced by a known heat pulse applied to an electric heater wound on the calorimeter can.

The time of a typical pulse was from 1 to 10 sec, with powers ranging from 300 to 5000 ergs/sec. The largest relaxation time of a pulse was about 20 sec; the heat leak below 0.1°K was about 0.5 erg/sec. Further details of the apparatus and procedure are deferred to a later publication.

We estimate the over-all error in both the specific heat and the temperature to be ± 3%. These errors arise almost entirely from a systematic error of ± 3% in temperature due to instabilities in the ac bridge during calibration.

The experimental results for several runs and differing amounts of He^3 in the calorimeter are shown in Fig. 1. The open circle points between 0.1 and 0.2°K are given less weight because of the uncertainties arising from a large background heat leak which occurred during these measurements. Below 0.09°K the smooth curve drawn through the experimental points is a straight line through the origin in agreement with the predictions of Landau,[10] and Brueckner and Gammel,[11] who indicate that at a low enough temperature He^3 will behave as a degenerate

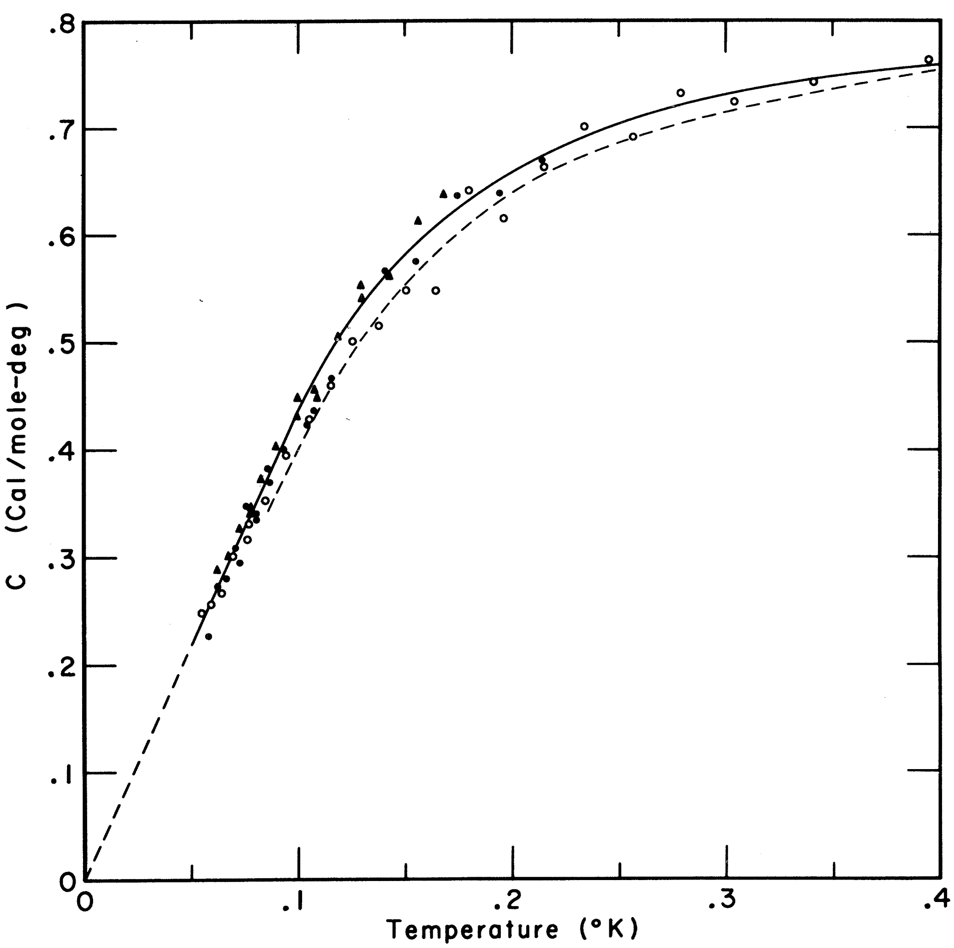

FIG. 1. The specific heat of liquid He^3 at saturated vapor pressure versus temperature. The dashed line is the smoothed curve through the experimental points of Brewer et al.[9] The open circles, closed circles, and triangles represent data obtained with 0.0319 mole, 0.0306 mole, and 0.0207 mole of He^3, respectively, in the calorimeter.

Fermi liquid with constant effective mass (see also Goldstein[12]). We obtain a limiting specific heat of 4.38 T which is somewhat higher than the value of 4.00 T quoted by Brewer et al.[9] For a Fermi liquid near 0°K the effective mass m^* and the measured specific heat C are related to C_F, the specific heat of an ideal Fermi gas of mass m, by $C/C_F = m^*/m$. m^*/m obtained from our data is 2.19 ± 0.13.

Table I gives the values of entropy calculated from our specific heat data. The entropy at 0.23°K is 0.92 ± 0.05 cal/mole-deg, which can be compared with the value of 0.96 ± 0.03 cal/mole-deg given by Weinstock, Abraham, and Osborne[13] and the value of 0.86 cal/mole-deg taken from the data of Brewer et al.[9] The latter quote an error of ± 0.01 cal/mole-deg and a possible systematic error of $+0.03$ cal/mole-deg due to the extrapolation of their data below 0.1°K.

Table I. Entropy of liquid He^3 at saturated vapor pressure.

T (°K)	S (cal/mole-deg)
0 to 0.09	$4.38T$
0.10	0.4378
0.12	0.524
0.14	0.606
0.16	0.683
0.18	0.756
0.20	0.824
0.23	0.918

We would like to thank Professor J. G. Daunt for suggestions in the design of our ac bridge, J. D. Reppy and Dr. D. J. Sandiford for many helpful suggestions, and D. Johnson for his expert help in the construction of the apparatus.

*Work assisted by the National Science Foundation and the Army Research Office (Durham).

[1]L. N. Cooper, R. L. Mills, and A. M. Sessler, Phys. Rev. 114, 1377 (1959).

[2]K. A. Brueckner, T. Soda, P. W. Anderson, and P. Morel, Phys. Rev. 118, 1442 (1960).

[3]V. J. Emery and A. M. Sessler, Phys. Rev. 119, 43 (1960).

[4]A. C. Anderson, H. R. Hart, Jr., and J. C. Wheatley, Phys. Rev. Letters 5, 133 (1960). See also E. D. Adams, H. Meyer, and W. M. Fairbank, Helium Three, edited by J. G. Daunt (Ohio State University Press, Columbus, Ohio, 1960), p. 57.

[5]L. H. Nosanow and R. Vasudevan, Phys. Rev. Letters 6, 1 (1961).

[6]F. Reif, Phys. Rev. 106, 208 (1957).

[7]G. M. Androes and W. D. Knight, Phys. Rev. Letters 2, 386 (1959).

[8]V. Heine and A. B. Pippard, Phil. Mag. 3, 1046 (1958).

[9]D. F. Brewer, J. G. Daunt, and A. K. Sreedhar, Phys. Rev. 115, 836 (1959).

[10]L. Landau, J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 1058 (1956)[translation: Soviet Phys.—JETP 3, 920 (1957)].

[11]K. A. Brueckner and J. L. Gammel, Phys. Rev. 109, 1040 (1958).

[12]L. Goldstein, Phys. Rev. 96, 1455 (1954); 112, 465 (1958).

[13]B. Weinstock, B. M. Abraham, and D. W. Osborne, Suppl. Nuovo cimento 9, 310 (1958).