Production of Li^8 in Boron-Loaded Photographic Emulsions

E. PICKUP
Division of Physics, National Research Council, Ottawa, Ontario, Canada

June 28, 1948

THE disintegration of B^{11} by fast neutrons to give Li^8 and an α-particle is now well known, and was first detected by Lawrance,[1] using an ionization chamber filled with boron trifluoride. The Q of the reaction, estimated from mass values in the Segrè chart is -6.7 Mev. For some time we have been working on the problem of trying to obtain Li^8 disintegrations in the gas in a cloud chamber with the object of getting information about the neutrino recoil. In the course of this work, and to obtain information about the yield of the $B^{11}(n, \alpha)Li^8$ reaction some Ilford C2, boron-loaded, photographic emulsions were exposed to the neutrons from a Li target bombarded with 600 kv deuterons, in the Ottawa ion accelerator. The neutron spectrum from such a target extends up to about 14.5 Mev with several peaks. This is well above the threshold for the B^{11} reaction, and examples of this disintegration have been observed in the emulsions as well as the usual B^{10} disintegrations. Measurements on the tracks are not yet complete, but one good typical case is shown in Fig. 1 below. This is a mosaic of four microphotographs, and shows clearly the recoil Li^8 nucleus together with the α-particle from the B^{11} disintegration, and the two oppositely directed α-particles of about equal range produced by the splitting of the Be^8 nucleus formed after β-decay of Li^8. This is a simple example of the so-called "hammer" tracks sometimes observed in cosmic-ray stars.

The total energy of the pair of α-particles in this particular case is 2.6 Mev, if we use the range energy data of Lattes, Fowler, and Cuer[2] for the emulsion. The energies of the other α-particle and the Li^8 recoil nucleus are 5.4 Mev and 1.7 Mev, respectively, the latter being extrapolated from the data of Lattes, Fowler, and Cuer for α-particles, assuming the Li^8 recoil to obey the range-energy relation $(m/Z^2)\cdot f(v)$, where $f(v)$ is the same as for α-particles in this energy region. Thus, the total energy of the incident neutron, taking into account the threshold energy for the reaction of -6.7 Mev, must have been 13.8 Mev, and this is consistent with its being a neutron from the high energy end of the Li-D spectrum.

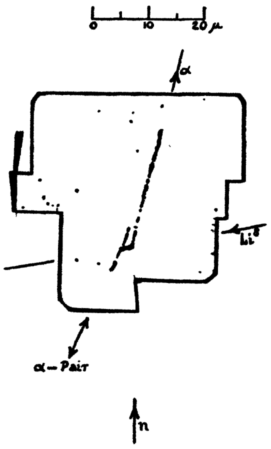

FIG. 1. Mosaic of photomicrographs showing $B^{11}(n,\alpha)Li^8$ reaction in Ilford C2, boron-loaded, photographic emulsion; Li^8 (β-decay; $t=0.88$ sec.; electron not visible in emulsion)$\rightarrow Be^8$; $Be^8\rightarrow\alpha$-pair. The direction of the incident neutron in this particular case was not very well defined because of proximity of neutron source and plate.

The ejection of Li^8 nuclei in cosmic-ray stars has been reported by Occhialini and Powell, and very recently in more detail by Franzinetti and Payne[3] of the Bristol group. In some observations by A. Morrison and myself here, on photographic emulsions exposed to cosmic radiation, which will be reported soon, we have obtained one definite example of a star showing a "hammer" track out of some 500 cosmic-ray stars. The estimated energy of the ejected Li^8 nucleus was 16 Mev, and the energy of the pair of α-particles was 3 Mev, these being about equal in length and oppositely directed.

The above work will be reported in more detail later.

[1] A. M. Lawrance, Proc. Camb. Phil. Soc. 35, 304 (1939).
[2] Lattes, Fowler, and Cuer, Proc. Phys. Soc. 59, 883 (1947).
[3] Franzinetti and Payne, Nature 161, 735 (1948).

Experiments on He^3 at Low Temperatures

J. G. DAUNT, R. E. PROBST, AND S. R. SMITH
The Cryogenic Laboratory, Department of Chemistry and Department of Physics, The Ohio State University, Columbus, Ohio

June 24, 1948

THE first experimental indications of a new method of separation of the isotopes He^3 and He^4 were given by us in observing the effects accompanying the superfluid transfer of matter in liquid helium II both in supra-surface film transfer[1] and through channels in the bulk liquid.[2] We established that, within the limits of measurement, He^3 atoms do not partake in superfluid flow, characteristic of liquid helium II, and pointed out that the separation of the isotope He^3 by superfluid flow in the liquid phase is a process which could lead to its eventual isolation.

Repetitions of the preliminary experiments[1] on separation by the method of supra-surface film transfer have been made and have shown, as did the first experiments, that the relative abundances of He^3 in He^4 in the two reservoirs connected by the mobile film could be made to differ in the process by a factor of at least 200. Subsequent experiments, using techniques based on the same principle, have yielded samples with He^3/He^4 concentration of approximately 5.10^{-4}. We conclude, therefore, that this process of separation is satisfactory.

Based on evidence thus provided[1,2] for the non-superfluidity of He^3 in low concentration ranges, Lane and collaborators have adopted an elegant method[3] of concentrating the rare isotope by initiating the superfluid flow in the bulk liquid by thermal means, a technique used by us for initiating the flow through films rather than the bulk liquid. The variation of the results obtained at different temperatures by this method, however, together with some unpublished results obtained by us on separation processes in the bulk liquid, have led us to believe that an exact interpretation of the mechanism involved cannot be obtained without information on the distribution of He^3 between vapor and liquid phases below the λ-point.

Early work[1] on the abundance ratio of He^3 to He^4 in the vapor in equilibrium with very dilute solutions of He^3 in He^4 in the liquid helium II phase showed that this ratio was equal to or less than that in the liquid solution. Subsequent work by Fairbank and Lane[4] with a similar method has shown that, within the limits of measurement, no He^3 exists in the vapor phase below 1.85°K, when the abundance ratio for the unrefrigerated gas was 1.2×10^{-6} (atmospheric helium gas). Using a new method in which precautions were taken to assure that any sampling of the vapor would not disturb the liquid-vapor equilibrium and to avoid any possible contamination of the results caused by unwanted film flow, we have measured the equilibrium abundance of He^3 between liquid and vapor phases. A description of the apparatus is left to a fuller article. The results are shown in Fig. 1 in which the ordinates give the logarithm of the ratio of the concentration of He^3 in He^4 in the vapor phase to the concentration in the liquid phase in equilibrium, ($\log C_V/C_L$), i.e., the logarithm of the coefficient of distribution. Above the λ-point we have plotted in Fig. 1 observations made both by us for atmospheric helium and those previously reported by Lane and collaborators.[5] Satisfactory agreement is shown. Below the λ-point we obtain two sets of points which lie roughly along two straight lines, one set for a concentration of the liquid of between 30 to 40×10^{-6} (the upper curve) and the other for a liquid concentration of between 9 and 13×10^{-6}. The variation in the liquid concentration in each set is due to the gradual depletion of the total He^3 content of the solution by successive sampling.

It will be seen from the curves that only for the very lowest temperatures and smallest liquid concentrations did the value of the coefficient of distribution fall below unity.

One must conclude that the coefficient of distribution shows a marked variation with concentration, indicating a departure from the laws of perfect solutions even for such dilute solutions as here employed. As yet the variation of the coefficient of distribution with concentration cannot be established, but the general results indicate that with increasing concentration in the liquid solution, relatively more and more He^3 goes into the vapor phase, in agreement with the theory put forward by London and Rice.[6] Such a departure from ideality was already evident from our measurements[7] of the osmotic pressures developed in dilute solutions of He^3 and He^4.

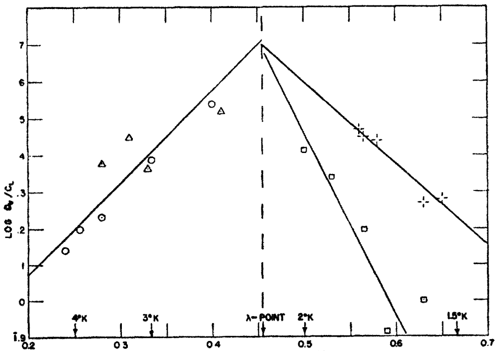

FIG. 1. Variation with temperature of the ratio, in the volume and liquid phases, of the concentration of He^3 in He^4. The triangles are for concentration He^3/He^4 in the liquid phase $=1\times 10^{-6}$. The squares are for $He^3/He^4=10\times 10^{-6}$. The crosses are for $He^3/He^4=30$ to 40×10^{-6}. The circles are the results of Lane and collaborators.[5]

If one applies the thermodynamic treatment of London and Rice,[6] one obtains for the difference of the enthalpies of condensation of He^3 and He^4: $\Delta\bar{H}_3-\Delta\bar{H}_4=-10$-cal. mole^{-1} for liquid concentrations of 30 to 40×10^{-6}, $\Delta\bar{H}_3-\Delta\bar{H}_4=-22$ cal. mole^{-1} for liquid concentrations of 9 to 13×10^{-6} and for liquid concentrations of 1×10^{-6} (not shown in Fig. 1) the value is approximately -25 cal. mole^{-1}. The latter figure, for atmospheric helium, as a result of the increased difficulty of mass spectrographic analysis for small concentrations, has not the same accuracy as the others. These values are a first approximation only since departures from ideality of the solutions have not been taken into account in the calculations; however, the marked difference between these results and those reported elsewhere[4] remains. Further experimental work on these measurements is being carried out to obtain the function giving the variation of C_V/C_L with initial concentration,[8] so that an exact computation can be made of the properties of pure He^3.

The results obtained so far, together with those on the osmosis,[7] have provided sufficient information for a large-scale separation process. For such a process, large superfluid flows through supra-surface films can be obtained by increasing the surface by wires[9] or foils. A technique for this has been outlined by us,[10] providing a film flow of 0.5 liter liquid per hour, and is being carried out here for continuous separation of He^3.

* This work was supported in part by the Office of Naval Research under a contract with the Ohio State Research Foundation.

[1] J. G. Daunt, R. E. Probst, H. L. Johnston, L. T. Aldrich, and A. O. Nier, Phys. Rev. **72**, 502 (1947).

[2] J. G. Daunt, R. E. Probst, and H. L. Johnston, J. Chem. Phys. **15**, 759 (1947).

[3] C. T. Lane, H. A. Fairbank, L. T. Aldrich, and A. O. Nier, Phys. Rev. **73**, 256 (1948).

[4] H. A. Fairbank, C. T. Lane, L. T. Aldrich, and A. O. Nier, Phys. Rev. **73**, 729 (1948).

[5] H. A. Fairbank, C. T. Lane, L. T. Aldrich, and A. O. Nier, Phys. Rev. **71**, 911 (1947).

[6] F. London and O. K. Rice, Phys. Rev. **73**, 1188 (1948).

[7] J. G. Daunt, R. E. Probst, and H. L. Johnston, Phys. Rev. **73**, 638, 1263 (1948).

[8] The importance of this is stressed by J. W. Stout in a private communication and is to be published in Phys. Rev.

[9] J. G. Daunt and K. Mendelssohn, Proc. Roy. Soc. **A70**, 423 (1939).

[10] J. G. Daunt and H. L. Johnston, The Ohio State University Research Foundation Report to U. S. Naval Office of Research, No. 6 (Jan. 1, 1948).

The Concentration of Helium 3

ALAN ANDREW AND W. R. SMYTHE
California Institute of Technology, Pasadena, California
July 6, 1948

WE have constructed a two-stage apparatus for concentrating the He^3 isotope. The first stage consists of four Clusius-Dickel columns of the concentric tube type connected in parallel. The second stage consists of 29 Hertz pumps connected in series.