A New Method of Separation of the Isotopes He^3 and He^4*

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IN the course of experiments on the mechanocaloric effect in liquid helium II, first observed by one of us and Mendelssohn,[1] a new method of separation of the isotopes He^3 and He^4 has been developed. These experiments involved the transport of liquid helium II by super-fluid flow through a supra-surface film from one reservoir to another, in a manner similar to that used previously.[1,2] It was possible to confine the transport entirely to the surface film and so avoid the disturbing effects of flow of bulk liquid, such as may occur in flow through sub-surface channels.[3] The flow, therefore, could be employed as a decisive method of ascertaining whether the atoms of the isotope[4] He^3 do not partake in super-flow, a suggestion which has been put forward by Franck.[5]

The experimental arrangement is illustrated in Fig. 1. The vessel B represents the main liquid helium bath maintained at constant temperature below the λ-point. In the bath, B, was situated a glass vessel, A, which was partially filled with liquid helium condensed from a supply of atmospheric helium gas.[6] The vessel, A, was connected to a closed system at room temperature by means of the tube, a, and samples of the gas in this system could be withdrawn with balloons. Inside vessel A a small Dewar vessel, D, was placed, so constructed that the top was closed off by an evacuated glass plug which was ground to fit the Dewar. Leads (1 and 2) to a phosphor-bronze resistance thermometer, T_1, inside the Dewar were sealed through the plug.

The course of a typical experiment was as follows. Initially the small Dewar, D, was empty, although liquid helium II in A surrounded it. On supplying heat electrically by T_1, liquid was transferred from A into the Dewar, D, by super-fluid flow through the supra-surface film. Owing to the fact that the connecting channel was above the liquid levels, no flow of "bulk" liquid took place and the return flow of vapor through the

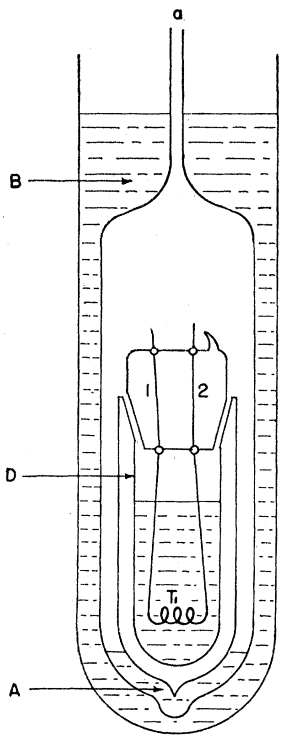

FIG. 1. Arrangement of the cryostat.

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[6] We are indebted to the generosity of Linde Air Products for providing large quantities of atmospheric helium gas.

ground joint was found to be negligible. The liquid in D was therefore completely isolated and the level could be increased above that in A to any desired amount. (This was generally 5 to 10 cm.)

Using the mass spectrometer previously described,[7] the abundance ratio of the isotope He^3 in He^4 for the gas used for condensation into A was found to be 1.20×10^{-6}, in excellent agreement with previous measurements[7,8] on atmospheric helium. Measurements were made on the abundance ratio of the helium collected in the Dewar, D. To collect this helium for measurement, first the liquid both in B and A was evaporated and the space A pumped out; then on waiting, the liquid in D slowly evaporated. Samples of this evaporated gas were taken until all the liquid in D vanished. The first sample taken off showed a ratio of $He^3/He^4\cong1.1\times10^{-7}$. Subsequent samples showed no measurable quantity of He^3, the limit for two of such samples being estimated as $He^3/He^4<5\times10^{-8}$, and for one other $<2\times10^{-8}$. For the whole volume of liquid evaporated from D the ratio He^3/He^4 was less than 5×10^{-8}.

Before concluding that this method of helium transfer acted as a filter for the rarer isotope, it was necessary to investigate the isotopic content of the helium in A. This was performed by connecting A via the tube, a, to a large balloon during the period in which D was filling. This process made at 1.5°K lasted for 90 minutes, allowing ample time for equilibrium to be reached between liquid and vapor. The measured abundance ratio for the vapor was 4×10^{-7}. This low value indicated (a) that a He^3 enrichment rather than a loss occurred in the liquid in A and (b) that the He^3/He^4 liquid-vapor equilibrium below the λ-point is a complicated effect.

One can therefore conclude that within the limits of measurement He^3 does not partake in super-flow. Whether or not this is an indication, as suggested by Franck,[5] that the super-flow of He^4 is essentially connected with the Bose-Einstein condensation phenomenon[9] is not yet clear. There remains the possibility that He^3 has a lower boiling point and a lower λ-point than He^4 and, consequently, super-flow might not be expected to occur until still lower temperatures are employed. This can only be decided by low temperature investigation of pure He^3.

This result also indicates that by using large volumes of liquid in A and transferring it by super-flow into large vessels, such as D, until only a very small quantity of liquid remains, strong concentrations of He^3 in these remainders can be obtained. Work on this is being carried out.

A number of determinations have been made of the relative abundance of He^3 in the vapor phase below the λ-point, using well helium in addition to the measurement reported above on atmospheric helium. These have been briefly reported elsewhere[10] and yield results strikingly different from the measurements above the λ-point carried out by an identical method by Fairbank and Lane.[8] The results indicate that for the vapor the abundance ratio is equal to or less than that for the unrefrigerated gas. This can be explained by our present results, since the tube leading from the liquid sample (e.g., tube A, of Fig. 1) to high temperatures must allow the supra-surface film to climb up and evaporate at a point high up inside the tube.[11] This will cause an excess of He^4 vapor at this point and forbid any but a small diffusion of He^3 from the liquid surface to the room temperature above.

Finally, it may be of interest to add that the mechano-caloric effect observed in these experiments shows that temperature differences of the order 10^{-2} degree can be obtained by mechanically altering the relative height of the liquids in A and D by a few centimeters, and that an exact measurement of the entropy of super-fluid helium II can thereby be obtained. A full description of the quantitative results will be given elsewhere.

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