He^3 Separation by a Heat Flux in Liquid Helium II*

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ACCORDING to current ideas, liquid helium in the temperature interval between absolute zero and 2.19°K (λ-point) can be envisioned as behaving like two interpenetrating fluids—a so-called "superfluid" phase and a "normal" phase. The density of superfluid states (ρ_s) and normal states (ρ_n) bear a temperature dependent relationship to each other such that all the atoms are in ρ_s states at absolute zero and all are in ρ_n states at, and above, the λ-point. The macroscopic current density (j) is given by

$$j=\rho_s v_s+\rho_n v_n,$$

where the v's refer to the respective velocities of flow. Thus it is possible to have countercurrent flow of the two phases in the liquid without giving rise to a macroscopic current. Such a case is believed to occur if a temperature gradient is maintained in liquid helium II. Here ρ_s atoms flow from the cold region to the hot, are there raised in energy to ρ_n levels, and a balancing flow of ρ_n atoms returns to the cold region, the process being such that $j=0$.

Just prior to the war, L. Onsager advanced the hypothesis that He^3 atoms might be expected to participate in the ρ_n flow but not in a ρ_s type flow because of the different kind of statistics obeyed by He^4 and He^3 atoms.[1] Recently, Daunt, Probst, Johnston, Aldrich, and Nier[2,3] have tested this hypothesis by allowing liquid helium II to flow through a superleak filter. The latter permits the flow of ρ_s atoms but not ρ_n atoms. The results showed that He^3 was at least partially filtered out by flow through the superleak but the effect was small, the concentration of He^3 being reduced by about a factor of 4 or 5.

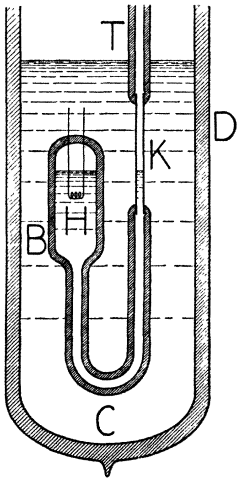

FIG. 1. Schematic drawing of the cryostat.

TABLE I. Summary of experimental data.

Sample	V_0 Volume of gas used to produce liquid cm^3(STP)	He^3/He^4 in V_0 $\times10^6$	Heat supplied watts	Time during which sample was held at temp. T min.	T °K	He^3/He^4 measured $\times10^6$
0	2040	1.3	—	—	300	1.3
1	2040	1.3	0	35	2.01	4.4
2	2032	1.29	0	—	2.01	10.4
3	2025	1.26	0.017	10.5	2.01	170
4	2016	0.63	0.017	—	2.01	52
5	2006	0.34	0	40	1.82	0.8
6	2000	0.34	0.017	15	1.82	<0.04
7	1963	0.34	0.023	14	1.82	<0.04
8	1932	0.34	0	2	1.82	<0.04

It occurred to us that perhaps a more clear-cut approach was to make use of the internal convection mentioned above due to a heat flux. Figure 1 is a schematic of our apparatus. A thick-walled glass bulb, B, contains an electrical heater, H. The bulb is connected *via* a 1½-mm glass capillary, C, a 1½-mm Kovar tube K, and thence *via* a 1½-mm capillary T to the outside of the cryostat. The whole was immersed in a bath of liquid helium contained in Dewar D and approximately 2.5 cm^3 of liquefied atmospheric helium condensed in the bulb, the level of the liquid being approximately as indicated. The temperature was now reduced below the λ-point to 2.01°K.

The procedure used in sampling and the results obtained are summarized in Table I. Sample 0 gives the amount of and He^3 concentration in the unrefrigerated gas. Sample 1 was evaporated from the liquid surface in the Kovar tube after the liquid had remained at 2.01°K for 35 minutes. The sampling time in this and subsequent samples was 1 minute. Sample 2 was taken immediately after sample 1. Sample 3 was taken after heat had been supplied to H for 10.5 minutes. Sample 4 was taken immediately after sample 3. The temperature was now reduced to 1.82°K and samples 5 through 8 taken under the conditions shown in the table. The last column in the table gives the value He^3/He^4 as measured for each sample by the mass spectrometer. Due correction has been made (columns 2 and 3) for depletion of He^3 resulting from sampling.

Samples 1 to 4 show conclusively that the He^3 isotope moves in the direction of the heat flow, and this supports the hypothesis that these atoms move only with the ρ_n flow, at least for these very dilute solutions. The lower concentration of sample 4 over sample 3 is to be expected inasmuch as 50 percent of the total He^3 was removed in sample 3. We note that both samples 1 and 2 show a considerably greater He^3 concentration than would be expected from our previous measurements either for the liquid or the vapor in equilibrium at this temperature.[4] We believe this is due to the small heat flux, in the same direction as that produced by the heater, produced by the evaporation in the Kovar tube during sampling.

It will be seen that the samples taken at 1.82°K all show very small He^3 concentration irrespective of the heat flux. We believe the explanation of this lies in our previous measurements on vapor-liquid equilibrium below the λ-

point.[4] In these measurements we showed that the concentration of He^3 in the vapor, while finite at 2.0°K, was immeasureably small at 1.82°K and quite possibly zero. The higher value for sample 5 is probably due to residual gas from sample 4 in the withdrawal line.

In view of an enrichment factor of 130 in sample 3, it appears that a very efficient He^3 separation apparatus could be designed using this heat flux method.

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[1] See Pollard and Davidson, *Applied Nuclear Physics* (John Wiley and Sons, Inc., New York, 1942), p. 183. We understand from Professor Pollard that the idea was due to Onsager. See also J. Franck, Phys. Rev. **70**, 561 (1946).

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

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

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

Search for Gamma-Radiation in the 2.2-Microsecond Meson Decay Process

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THE meson decay process which is identified by a mean life of 2.2 microseconds[1] has been usually thought of as consisting of the emission of an electron and a single neutrino, as suggested by the well-known Yukawa explanation of the ordinary beta-process in nuclei. However, the Yukawa theory is at variance with the results of the experiment of Conversi, Pancini, and Piccioni,[2] and since there remains no strong justification for the electron-neutrino hypothesis,[3] a direct experiment to test an alternative hypothesis—*that the decay process consists of the emission of an electron and a photon, each of about 50 Mev*—has been performed.

The apparatus, illustrated in Fig. 1, consists of three rows of Geiger-Müller counters, A, B, and C, each having an effective area of approximately 38 cm×20 cm. Above A there are 15 cm of lead, and between A and B, 1.5 cm of lead. Mesons traversing A and B, and stopped in a graphite absorber 38 cm×19 cm×5 cm thick, produce decay electrons which may be detected in either B or C. Decay photons, if present, could also be detected in B or C, whose efficiency for gamma-radiation was increased by introducing 2.1 mm of lead between the graphite and both B and C. The twofold function of B—first, detection of the passage of a meson by a coincidence with A (event "(A, B)"), and second, detection of a decay electron (or photon) following "(A, B)"—is permitted by the circuit design. Although one of the eight counters of B (that through which the meson passed) is insensitive to the decay particle because of the long counter dead time, the use of B in this manner allows an advantageous geometry. The outputs of the three rows are mixed by circuits whose function is schematically shown in the diagram, and the following delayed events are finally recorded:

Table I. Delayed single and coincidence counting rates.

	$(B)_{del}$ (Counts/hr.)	$(C)_{del}$ (Counts/hr.)	$(B)_{del}+(C)_{del}$ (Counts/hr.)	$(B, C)_{del}$ (Counts/hr.)
With graphite plus lead—(104.2 hours of observation)	11.93±0.34	12.26±0.34	24.19±0.48	0.21±0.05
Without graphite plus lead—(77.2 hours of observation)	6.48±0.29	4.64±0.25	11.12±0.38	0.43±0.08
Net effect due to decay electrons from graphite plus lead	5.45±0.45	7.62±0.42	13.07±0.62	

1. "$(B)_{del}$;" discharges of B occurring between 0.6 and 5.3 microseconds after "(A, B),"
2. "$(C)_{del}$;" discharges of C occurring between 0.6 and 5.3 microseconds after "(A, B),"
3. "$(B, C)_{del}$;" coincidences of B and C occurring between 0.6 and 5.3 microseconds after "(A, B)."

Runs were made with and without the graphite plus lead between B and C, and the results are presented in Table I. Other runs with graphite only, with lead only, and with other thicknesses of graphite and lead, were performed and these will be reported in a more complete account of the experiment. Check runs with a 1.6- to 6.3-microsecond delay gave results consistent with a mean life of 2.2 microseconds.

The observed rate $(B, C)_{del}$ could be due to the following causes:

(i) genuine electron-photon coincidences from the meson decay,

(ii) single decay electrons which traverse both B and C,

(iii) casual events.

The casual rate (iii), which is due essentially to mesons traversing B and C between 0.6 and 5.3 microseconds after an event "(AB)," has been estimated from the measured double and triple coincidence rates and from the characteristics of the circuits to be 0.22±0.02 counts per hour. It is independent of the presence or absence of graphite plus lead. Effect (ii) should be detected only in absence of graphite plus lead, since otherwise the total thickness of material between B and C is of the order of the expected range of the electrons. We observe, in fact, that $(B, C)_{del}$ increases appreciably when the graphite plus lead is removed. The presence of this effect was verified by a sub-

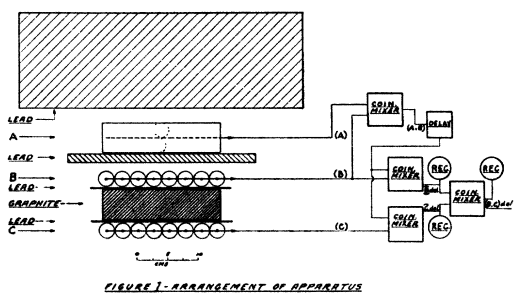

FIGURE 1 - ARRANGEMENT OF APPARATUS

FIG. 1. Arrangement of apparatus.