

the c.m. scattering angle of the neutron. Least squares fits to the data were made for three functions: $\sigma(\theta) \sim 1$, $1+k \cos\theta$, and $1+k \cos^2\theta$.

A measure of the goodness of fit is

$$s^2 = \frac{1}{n-2} \sum_{i=1}^n \left[\frac{\sigma_{\text{calc}}(\theta_i) - \sigma_{\text{exp}}(\theta_i)}{\epsilon_i} \right]^2,$$

where n is the number of points—11 in this case—and ϵ_i is the error assigned to the i th point. A good fit has $s^2 \approx 1$. For the three functions—1, $1+k \cos\theta$, and $1+k \cos^2\theta$ —the values of s^2 were 3.0, 2.0, and 1.4, respectively. For the two latter functions $k = 0.08 \pm 0.04$

and 0.08 ± 0.03 , respectively. In order to compare the data at 17.9 Mev with those at other neutron energies, $1 + (0.08 \pm 0.03) \cos^2\theta$ was taken to be the best fit, and the relative yields measured here were normalized to the total cross section of 535 mb. There is no intention to imply that symmetry about 90° has been observed.

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Half-Life of Tritium*

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A value of 12.262 ± 0.004 years has been found for the tritium half-life by measurement of the He^3 growth in two samples.

THE availability at this laboratory of sufficient amounts of tritium gas of about 99.5 percent isotopic purity has made possible a more precise determination of the tritium half-life by measurement of the amount of He^3 produced in a known length of time from a known initial amount of tritium gas.

Half-life determinations were made on two samples. Sample I was sealed off in a 200 cc cylindrical lime glass vessel, and Sample II in a similar Pyrex vessel. A blank mixture of He^4 and H_2 , in proportions approximating the final He^3/T_2 ratio in Sample II, was put into a lime glass vessel and stored for about the same length of time and in the same manner as Sample I. Each vessel was well baked out and provided with two break-off seals in series in order to prevent contact of the gas with material other than clean glass, and in order to check possible diffusion through the first break-off seal during the decay. Each vessel was enclosed in an evacuated Pyrex sheath, also provided with a break-off seal, and stored at liquid nitrogen temperature for the duration of the decay period. The low temperature storage minimized diffusion of the gases, especially helium, into the vessel walls. Lime glass was employed in Sample I since it is considerably less permeable to helium than Pyrex.¹ The He^3 contents of Samples I and II were determined within a few days of each other. The He^4 in the blank was then separated

to prove the effectiveness of the storage and separation methods. The separation of tritium (hydrogen) from He^3 (He^4) was made with a small palladium thimble, operated at 350°C and causing negligible holdup. The gas to be separated communicated with the inside of the palladium thimble by means of a Kovar tube, welded to the palladium. The arrangement insured that the gases to be separated would not come in contact with hot glass. The gas undergoing separation was exposed only to mercury, clean glass, and the palladium thimble. The contact time of tritium with hot glass on the low pressure side was short enough so that diffusion or exchange effects were negligible. After the gas had been removed from the separation system, further traces were recovered by heating the walls of the system.

The tritium gas used had been enriched in a system of Hertz pumps constructed by R. M. Potter, J. R. Mosley, and F. J. Dunn. The gas to be sealed up for decay was analyzed with a mass spectrometer immediately after passage through a palladium valve and compressed into a volume of about 100 cc for measurement. This volume included a limb of the $\frac{3}{4}$ in. I. D. Trubore tubing manometer with which the pressure was measured. The volume was calibrated with mercury to about one part in 50 000. The meniscus positions were estimated to 0.001 cm Hg with a cathetometer, which was intercompared with a standard meter bar suspended between the limbs of the manometer. The temperature was estimated to 0.005° with a mercury-in-

* This paper is based on work performed under University of California contract with the U. S. Atomic Energy Commission.

¹ S. Dushman, *Vacuum Technique* (John Wiley and Sons, Inc., New York, 1949), p. 536.

TABLE I. Summary of experimental data.

Sample	Initial T ₂ , cc	He ³ , cc	Decay time, mean solar days	Final T ₂ plus $\frac{1}{2}$ He ³ , cc	T _{1/2} , years
I	78.204±0.020	20.178±0.003	892.76±0.02	78.197±0.020	12.265±0.004
II	105.245±0.025	18.016±0.003	578.09±0.02	105.285±0.025 accepted value	12.259±0.004 12.262±0.004

glass thermometer taped to the measuring volume and insulated from the room. The thermometer was graduated to 0.02°, and its calibration was checked against a standard platinum resistance thermometer. The average temperature of the gas exceeded the measured temperature slightly due to radioactive heating. The calculated correction averaged about 0.03°. After measurement, practically all the tritium was transferred into the decay vessel through a capillary lead-in with a mercury Toepler pump. The lead-in was sealed off, and the very small amount of gas not transferred was measured and then analyzed on a mass spectrometer. The helium was measured in a volume of about 35 cc, which was known to one part in 15 000. Pressure and temperature measurements were similar to those above. Appropriate reduction of pressures to international cm Hg were made. Corrections for gas imperfections were made using the virial coefficient data for H₂ and He⁴ summarized by Keyes.² Comparison of data for H₂ and D₂³ indicates that isotope effects in the virial coefficients may for present purposes be neglected.

The initial and final tritium and the helium were analyzed on a Consolidated-Nier mass spectrometer, using a high-pressure leak. Several independent analyses were made. The instrument was well baked out, sometimes with high purity tritium gas flowing through, in order to minimize memory and exchange effects. Analyses were continued until there were no changes in the indicated composition. This sometimes required two hours or more and replacement of sample. Making some allowance for absolute errors, an uncertainty of about 0.02 percent is estimated for the initial and for the final amounts of tritium due to the mass spectrometer analysis. The tritium isotopic content of the initial tritium in Sample II was checked to 0.01 percent on a different mass spectrometer, using a molecular leak. Corrections for the small amounts of non-isotopic impurities, amounting to a few hundredths of a percent, were made on the basis of known mixtures of small amounts of such gases with hydrogen. The mass spectrometer was calibrated with these mixtures at approximately the time of analysis.

Since the initial tritium to be used for decay was measured as a function of time as it passed through the palladium thimble, the average time at which the tritium sample started to decay was known. Similarly,

² F. G. Keyes, *Temperature* (Reinhold Publishing Corporation, New York, 1941), p. 41.

³ Wooley, Scott, and Brickwedde, J. Research Natl. Bur. Standards 41, 379 (1948).

in the final separation of tritium and He³, the average time at which the tritium was separated was known. It is estimated that the effective decay time is known to a half-hour or better.

Following the He³-T₂ separations, the separation system was exposed to several samples of pure hydrogen in order to remove possible traces of tritium. The He⁴ was then separated from the hydrogen in the blank and analyzed on the mass spectrometer. The helium recovered was 0.001₆ cc less than had been measured out in the blank preparation. This result is well within the errors of the several measurements and is evidence for the adequacy of the storage and separation procedure. The probability that a recoiling He³ would penetrate the glass of the decay vessel was estimated to be negligible. In this estimate collisional slowing down was taken into account, and the assumption was made that the energy required for entry into the glass was equal to the activation energy for diffusion. Columns 2 and 5 of Table I show that the material balance is within experimental error.

Results

The experimental data for the two samples is summarized in Table I. The amounts of gases are expressed in cc NTP, corrected for gas imperfections.

TABLE II. Comparison with other determinations.

Observer	Half-life, yr	Method
Novick ^a	12.1±0.5	He ³ growth.
Jenks, Ghormley, and Sweeton ^b	12.46±0.1	Steady state rate of diffusion of He ³ from a thin quartz capsule containing tritium oxide.
Jones ^c	12.41 ^{+0.15} _{-0.25}	Absolute counting.
Present data	12.262±0.004	He ³ growth.

^a A. Novick, Phys. Rev. 72, 972 (1947).

^b Jenks, Ghormley, and Sweeton, Phys. Rev. 75, 701 (1949); Jenks, Sweeton, and Ghormley, Phys. Rev. 80, 990 (1950).

^c W. M. Jones, Phys. Rev. 83, 537 (1951).

Comparison with Other Data

The present value is compared with other determinations in Table II.

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