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Absorption of Tritium Beta Particles in Hydrogen and Other Gases

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The absorption curves for tritium beta particles in hydrogen and helium have been determined by using a spherical ion chamber in which the particular gas serves both as the absorber and the ionization medium. The absorption curves give half-thickness values of 0.031 mg/cm² for hydrogen and 0.061 mg/cm² for helium. From the saturation currents obtained wlth a given amount of tritium the relative energy requirement per ion-pair has been measured for hydrogen, helium, oxygen, and argon. These values are compared with recent values in the literature.

INTRODUCTION

THE conventional method of determining the absorption curves for nuclear beta particles and thus measuring the half-thickness or mass absorption coefficient involves the use of thin metal foils and end-window counters or ionization chambers. Because of the relatively large stopping power of even the thinnest foils the method is restricted to beta particles with energies greater than approximately 0.1 Mev. The results, moreover, are strongly dependent on the geometric arrangement of the source, absorber, and counter.

For very soft beta particles, such as the tritium betas, with end-point energy[1,2] 18 kev and average energy[3] 5.69 kev, no absorption curves or half-thicknesses have been measured. It was desirable to have such information for the interpretation of results obtained in a kinetic investigation[4] of the hydrogen-tritium exchange. At the time an estimate of the mass absorption coefficient for tritium beta particles in hydrogen was made by extrapolation of the known energy-half thickness curve[5] and correction for absorber material on the basis of proportionality to Z/A, the ratio of atomic number to mass number.

A series of experiments has since been carried out in which the absorption curves for tritium beta particles in hydrogen, helium, and oxygen have been determined. The method involves the use of a spherical ionization chamber in which the particular gas serves both as the absorber material and the medium for the ionization produced by the beta particles. In addition to the absorption measurements, comparison of the saturation currents obtained with a given pressure of tritium gives a relative measure of the energy requirement per ion-pair in these various gases.

EXPERIMENTAL

The ionization chamber for the detection of current was used in conjunction with a vibrating reed electrometer, Applied Physics Corportion, Model 30-R. Currents on the order of 10^{-11} amp were measured by determining the voltage drop across a high external resistance. A vacuum-sealed Victoreen resistor having a resistance of 1.02×10^8 ohms was used. The resistor and the connections to the electrometer head were electrically shielded. The voltage reading, which is proportional to the ionization current being measured, was taken directly from the meter on the face of the electrometer.

The spherical ion chamber, of simple design, consisted of a glass bulb, silvered on the inside to provide a conducting shell. A negative potential was applied to this silvered surface. The collecting electrode consisted of a 40-mil tungsten wire and was operated at ground potential. A silver guard ring connected to ground prevented current leak from the shell to the central wire. Most of the data were obtained with an ion chamber having an internal diameter of 57.0 mm. A single set of readings was taken with a larger ion chamber having an internal diameter of 73.0 mm.

A stable source of the voltage applied to the chamber was provided by a set of B batteries. With these the applied potential could be varied in convenient steps from 22 to 300 v.

The ionization chamber was connected through a vacuum stopcock to the vacuum system and through a sidearm to a variable level manometer. The arrangement is shown in Fig. 1. The tritium gas consisted of a hydrogen-tritium mixture containing 4.6 percent tritium as determined mass spectrometrically. This gas was introduced into the chamber to a pressure, between 7 and 80 microns, which was read on a McLeod gauge. The gas in which the absorption was to be measured was introduced through a one-way bubbler valve consisting of a pool of mercury on a sintered glass disk. In this way there could be no back diffusion of tritium from the fixed volume which was kept constant by adjustment of the manometer level. A number of readings was taken on the electrometer at each pressure.

Purified gases were obtained in the following manner. Hydrogen was purified by sorption on a uranium bed and subsequent pumping, and could be evolved as

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* The Knolls Atomic Power Laboratory is operated by the General Electric Company for the U. S. Atomic Energy Commission.

[1] Curran, Angus, and Cockroft, Phil Mag. 40, 53 (1949).

[2] G. C. Hanna and B. Pontecorvo, Phys. Rev. 75, 983 (1949).

[3] Jenks, Ghormley, and Sweeton, Phys. Rev. 75, 701 (1949).

[4] L. M. Dorfman and H. C. Mattraw, J. Phys. Chem. 57, 723 (1953).

[5] C. D. Coryell and N. Sugarman, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Book 1, National Nuclear Energy Series Plutonium Project Record, Vol. 9, Div. IV, p. 18.

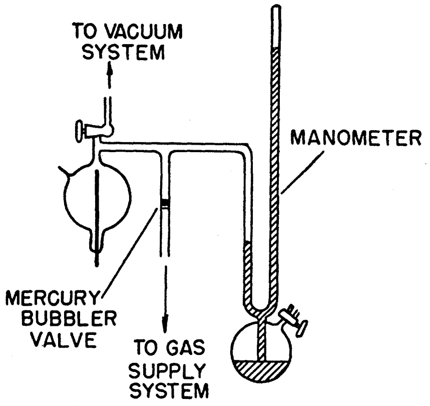

FIG. 1. Ion chamber—vacuum system arrangement.

needed. Pure, dry oxygen was obtained by thermally decomposing potassium permanganate, and passing the evolved gas through a glass coil immersed in liquid nitrogen. Tank helium was used directly. The only detectable impurity in the helium as determined mass spectrometrically was nitrogen, amounting to less than 0.02 percent. Argon was dried by passage through a trap immersed in liquid nitrogen. Mass spectrometric analysis showed the only impurity to be nitrogen, amounting to 0.13 percent.

The ion chamber could be evacuated to a pressure of less than 10^{-5} mm before each set of measurements. Background current, due to contamination of the apparatus with tritium, could easily be kept to 10^{-13} amp or less and was always negligible. It was, however, essential to keep that part of the vacuum system from which the gases were introduced absolutely free of tritium.

In determining the energy requirement per ion-pair in these various gases the same 4.6 percent tritium mixture was used with each gas. A set of readings was taken for each gas with nearly equal tritium pressures to cancel out any irregularities in the McLeod gauge.

RESULTS AND DISCUSSION

Care was taken in all measurements with the ionization chamber to avoid two specific sources of error namely, recombination, particularly in the high-pressure region, and gas multiplication in the low-pressure region. To this end the tritium pressure used was always less than 4 microns. At this pressure, with a potential of 300 v applied to the chamber, the beta-particle intensity was not high enough to give any measurable recombination even at one atmosphere pressure. This could be readily checked in that the ratio of saturation current to tritium pressure was constant for each individual gas. With hydrogen the ionization current amounted to 2.2×10^{-7} amp per mm of tritium. To avoid gas multiplication lower applied voltages were used in the low-pressure region. Indeed, the applied potential was varied for each pressure to insure that the meter reading was taken on a voltage plateau.

Data were obtained by successively increasing the pressure and determining the ionization current at each pressure by reading, on the meter, the voltage drop across the Victoreen resistor. The saturation current is reached as the absorption of beta particles in the gas phase approaches completion.

The absorption may be represented by an approximately exponential law, the result of continuous spectrum and scattering, which for the usual type of experiment may be written

$$A_d = A_0 e^{-\mu d}, \tag{1}$$

where A_0 is the activity measured without absorber, A_d the activity measured through absorber thickness d, and μ is the absorption coefficient. In the present case, where the pressure of a gaseous absorber, rather than the thickness, is increased, the data may be expressed by

$$V_P = V_S(1-e^{-\mu c P}), \tag{2}$$

where V_P, the voltage drop (or meter reading), is proportional to the ionization current at pressure P, V_S is the voltage reading at saturation current, and c is a constant which includes the cell factor and pressure-density conversion factor, or

$$\ln(1-V_P/V_S) = -\mu c P. \tag{3}$$

The absorption curves for hydrogen and helium, represented in this manner, are shown in Figs. 2 and 3

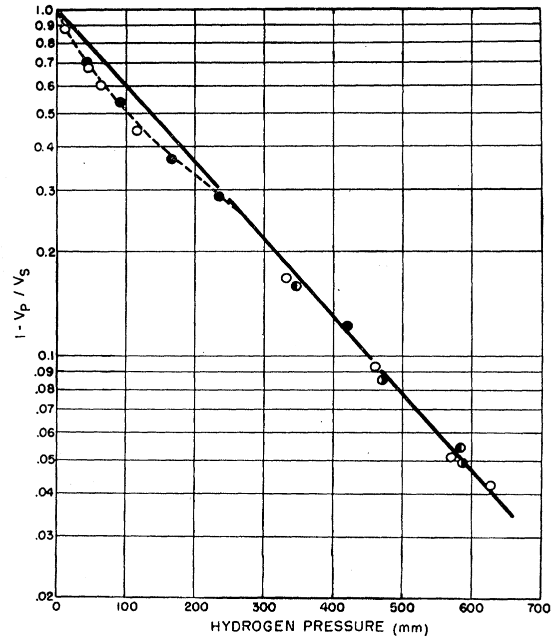

FIG. 2. The absorption curve for tritium beta particles in hydrogen. Chamber diameter 57 mm; temperature 25°C. The different points are for different tritium pressures: ○ 1.9 microns; ● 0.37 micron; ◑ 0.38 micron; ◐ 1.3 microns.

in which $1-V_P/V_S$ is plotted against pressure on a semilogarithmic scale. The different points on the hydrogen curve are for substantially different tritium pressures, ranging from 0.3 to 2 microns. These data were obtained with the small ion chamber. There is a slight deviation from linearity, which is more pronounced in the low-pressure region, where the values of V_P/V_S are somewhat higher than those fitting the linear plot. This deviation is attributable to scattering of the beta particles which strike the silvered shell and are reflected back to the gas phase, causing further ionization.

The pressures corresponding to the half-thickness have been taken from the straight line at the point where $1-V_P/V_S=0.5$. The values are:

$$P_{\frac{1}{2}}=135 \text{ mm for hydrogen,}$$

$$P_{\frac{1}{2}}=133 \text{ mm for helium.}$$

A similar curve, obtained for oxygen at substantially lower pressures, is shown in Fig. 4. The precision is not as good as for the two more transparent gases, giving

$$P_{\frac{1}{2}}=23\pm4 \text{ mm for oxygen.}$$

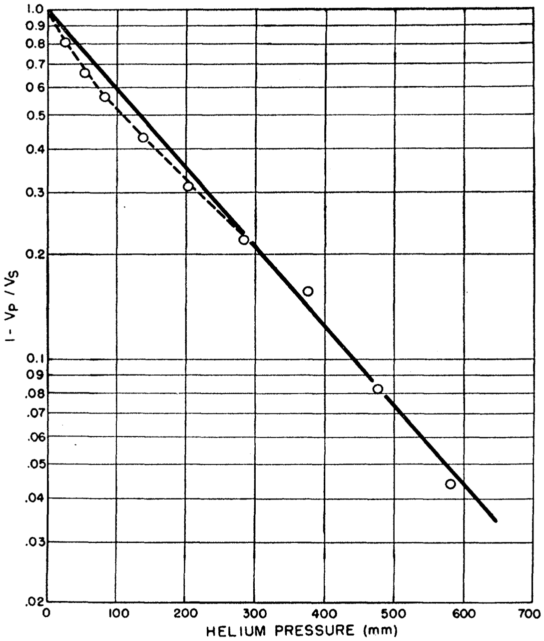

FIG. 3. The absorption curve for tritium beta particles in helium. Chamber diameter 57 mm; temperature 25°C. Tritium pressure, 2.0 microns.

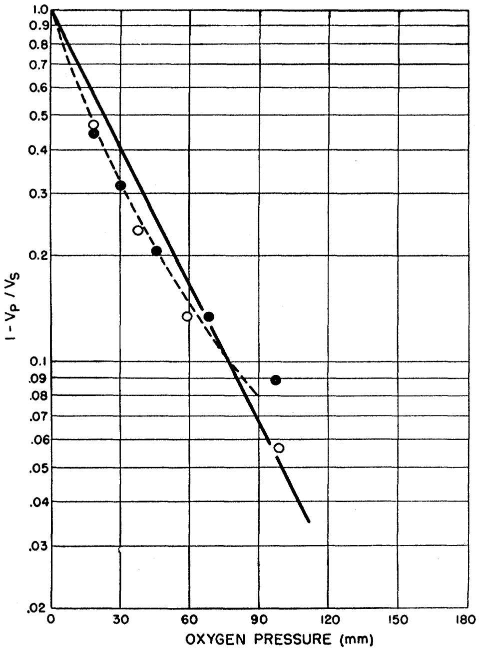

FIG. 4. The absorption curve for tritium beta particles in oxygen. Chamber diameter 57 mm; temperature 25°C. Tritium pressures: ○ 2.0 microns, ● 0.30 micron.

The half-thickness and mass absorption coefficient may be determined from these results as follows. The source of the beta radiation is uniformly distributed throughout the spherical volume. It may be shown[6] that the average distance from all points within a sphere to the shell is 0.75 times the radius. With the small ion chamber, diameter 57 mm, this gives half-thickness values of

$$d_{\frac{1}{2}}=0.031 \text{ mg/cm}^2 \text{ for hydrogen,}$$

$$d_{\frac{1}{2}}=0.061 \text{ mg/cm}^2 \text{ for helium,}$$

$$d_{\frac{1}{2}}=0.08 \text{ mg/cm}^2 \text{ for oxygen.}$$

The measurements for hydrogen have been repeated with the larger ion chamber to check on the inverse proportionality of $P_{\frac{1}{2}}$ to radius. The data for this chamber give $P_{\frac{1}{2}}'=108$ mm. The fact that $P_{\frac{1}{2}}$ is inversely proportional to the radius, and hence $d_{\frac{1}{2}}$ independent of radius, is thus verified since $P_{\frac{1}{2}}/P_{\frac{1}{2}}'=1.25$ and $r_2/r_1=1.28$.

The half-thickness values for hydrogen and helium show very close agreement with the empirical fact that $d_{\frac{1}{2}}$ is proportional to A/Z, the ratio of mass number to atomic number. Comparison of the half-thickness for helium and oxygen with the range[7] in aluminum for 18-kev beta particles indicates these experimental values to be approximately 1/10th the range, which is 0.7 mg/cm². The half-thickness for oxygen fits a straight line through the half-thickness-energy data of Engelkemeier.[5] This last consistency may be purely fortuitous, since the geometry considerations with aluminum absorbers are quite different from those in the present experiment.

The mass absorption coefficient is related to the half-

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[6] S. C. Lind, *The Chemical Effects of Alpha Particles and Electrons* (The Chemical Catalog Company, Inc., New York, 1928), p. 94.

[7] L. E. Glendenin, Nucleonics 2 (No. 1), 12 (1948).

TABLE I. Relative energy requirement per ion-pair.

Gas	This work	w_{gas}/w_{argon} V and C[a]	W, V, and K[b]
Argon	1.00	1.00	1.00
Hydrogen	1.45	1.41	1.55
Helium	1.28	1.20	1.26
Oxygen	1.18	1.19	—

[a] See reference 8.
[b] See reference 9.

thickness by

$$\mu/\rho = 0.693/d_{\frac{1}{2}}. \tag{4}$$

For tritium beta particles in hydrogen, then, the mass absorption coefficient is

$$\mu/\rho = 22 \text{ cm}^2/\text{mg}.$$

From the saturation current obtained with a known pressure of tritium for each of these gases, as well as for argon, the relative energy requirement per ion-pair may be determined. The values for w will be inversely proportional to the saturation current. These results are given in Table I which contains the numbers relative to argon. The results are compared with those of Valentine and Curran[8] for electrons and Wilzbach *et al.*[9] for tritium beta particles. There is reasonably close agreement among the values. The spread in the results for helium may be due to the trace impurity effect which has been pointed out in the recent work of Jesse and Sadauskis.[10] No attempt has been made to derive absolute values of the energy requirement from the data.

ACKNOWLEDGMENT

The author is grateful to Dr. D. L. Douglas for the advice he has given concerning the construction of the ion chamber and the operation of the electrometer.

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[8] J. M. Valentine and S. C. Curran, Phil. Mag. **43**, 964 (1952).
[9] Wilzbach, Van Dyken, and Kaplan, Argonne National Laboratory Report No. 5143, October, 1953; Anal. Chem. **26** (5), 880 (1954).
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Photodisintegration Thresholds of Deuterium and Beryllium*†

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The photodisintegration thresholds of deuterium and beryllium have been determined by using the bremsstrahlung produced by monoergic electrons. The absolute energy of the electrons was measured with a cylindrical electrostatic analyzer. The binding energy of deuterium was found to be 2.227±0.003 Mev and that of beryllium was found to be 1.662±0.003 Mev.

INTRODUCTION

THE photodisintegration thresholds of deuterium and beryllium have been measured using a number of methods. Stephens,[1] in 1947, presented an exhaustive discussion of the work done on deuterium up to that time. Since 1948 two important experiments have been performed.

Bell and Elliott[2] measured the energy of the gamma ray accompanying the capture of a neutron by a proton. Their spectrometer was calibrated with the 2.615±0.001 Mev gamma ray[3] of ThC″. Their value for the binding energy of the deuteron is 2.230±0.007 Mev.

Mobley and Laubenstein[4] determined the photodisintegration thresholds of beryllium and deuterium with a novel method. Using the Argonne National Laboratory electrostatic generator, they accelerated a proton beam down the normal accelerator tube while an electron beam was accelerated up the differential pumping tube to the high voltage electrode. The electrons were stopped in a gold target, producing x-rays which were used for the photodisintegration. Energy calibration was accomplished by *comparison* with the Li(p,n) threshold,[5] known to ±0.1 percent. The values obtained for the binding energies of beryllium and deuterium are 1.666±0.002 Mev and 2.226 ±0.003 Mev, respectively.

The present experiment was undertaken because it is the most direct method for determining the binding energies. It is an absolute method requiring no nuclear reaction data for calibration.

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[*] Supported in part by the joint program of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.
[†] Preliminary report: Phys. Rev. **85**, 727 (1952). A more extensive account of this work appears in a technical report.
[‡] Now at Boeing Aircraft, Seattle, Washington.
[1] W. E. Stephens, Revs. Modern Phys. **19**, 19 (1947).
[2] R. E. Bell and L. C. Elliott, Phys. Rev. **79**, 282 (1950).
[3] J. L. Wolfson, Phys. Rev. **78**, 176 (1950); W. L. Brown, Phys. Rev. **83**, 271 (1951); G. Lindstrom, Phys. Rev. **87**, 678 (1952).
[4] R. C. Mobley and R. A. Laubenstein, Phys. Rev. **80**, 309 (1950).
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