fore as shown by Fig. 5:

$$\zeta = \zeta_m' - W_m + W_s. \tag{23}$$

The semi-conductor is charged positively or negatively depending upon whether $\varphi_m > \varphi_s$ or $\varphi_m < \varphi_s$. (Figure 5 shows the semi-conductor positively charged.) In the first case the electron density in the conduction band will be less than normal and the reverse is true for the second case. The excess of deficiency in electrons will not be concentrated near the surface as in metals. Because the numbers of electrons in the conduction band and holes in the lower band are small a semi-conductor can support a space charge and appreciable potential difference. The density of conduction electrons at the contact surface is given by (22). The space charge (conduction electrons and holes in the lower band) inside the body is determined jointly by Poisson's equation and Boltzmann's distribution law. With the additional condition of equilibrium between the electrons in the two bands the density of conduction electrons and the density of the holes in the lower band can be determined separately.

The space variation of the density of conduction electrons to be expected in semi-conductors may be important in the explanation of certain phenomena. Upon this is based Schottky's theory[12] of semi-conductor rectifiers which assumes the semi-conductor to be charged positively with region of low electron density at the contact.

[12] W. Schottky, Zeits. f. Physik **113**, 367 (1939).

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Distribution in Angle of Protons from the D-D Reaction

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The angular distribution of the disintegration protons from the D–D reaction has been investigated as a function of energy from 60 kev to 390 kev. The distribution was found to be well represented by $I(\theta) = 1 + A \cos^2\theta$ at any one energy. The value of A increases smoothly with bombarding energy over the range investigated.

INTRODUCTION

MEASUREMENTS of the relative yield of protons from the reaction

$$H^2 + H^2 = H^3 + H^1$$

as a function of the angle of the emitted proton with the line of approach of the deuterons have shown an anisotropy of the form

$$I(\theta) = 1 + A \cos^2\theta$$

in the center of mass system of coordinates. Previous investigators[1,2] have disagreed markedly on the value of A and its dependence upon energy.

The desired condition for angular distribution measurements where the anisotropy is energy dependent is that all observed disintegrations be due to impinging particles having the same energy at the time of impact. This condition is most nearly realized in a gas target. Without using foils thick enough to invalidate the use of a gas target, permanent gases require the use of a very small capillary and high speed pumping at high vacuum and at an intermediate pressure. Vapors can be handled with a larger capillary and a cold trap, refrigerated with liquid air. This allows higher counting rates and a great reduction in statistical error without loss in angular resolution. Thus, since the deuteron reaction with oxygen is highly improbable below

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[1] Huntoon, Ellett, Bayley and Van Allen, Phys. Rev. **58**, 97 (1940).

[2] Kempton, Browne, and Maasdorp, Proc. Roy. Soc. **A157**, 386 (1936); Haxby, Allen, and Williams, Phys. Rev. **55**, 1940 (1939); H. Neuert, Ann. d. Physik **36**, 437 (1939).

300 kev, we have been led to the choice of heavy water for the target.

APPARATUS

Accelerating potentials were obtained from a Cockcroft-Walton voltage quadrupler and measured by a resistance voltmeter. The voltmeter was calibrated and periodically checked by measuring the voltage-current characteristics of the resistor. The beam was magnetically analyzed before entering the target assembly. This allowed a check for linearity of the voltmeter by setting the analyzing magnet and changing the voltage to bring the various m/e components of the beam into the target chamber and showed the voltmeter to be linear within 2 percent over the energies used.

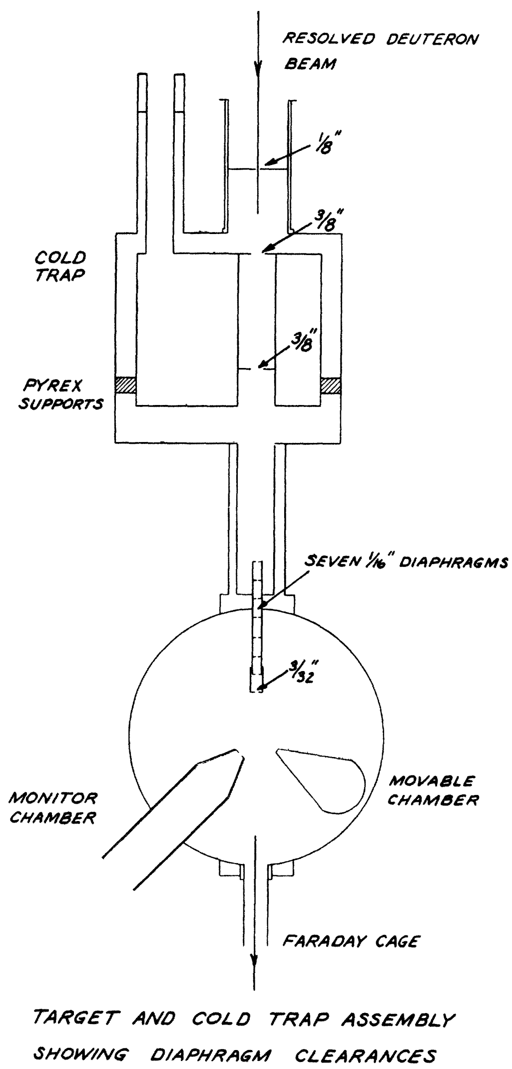

FIG. 1. Target and cold trap assembly showing the path of the beam and all diaphragm clearances beyond the analyzing magnet.

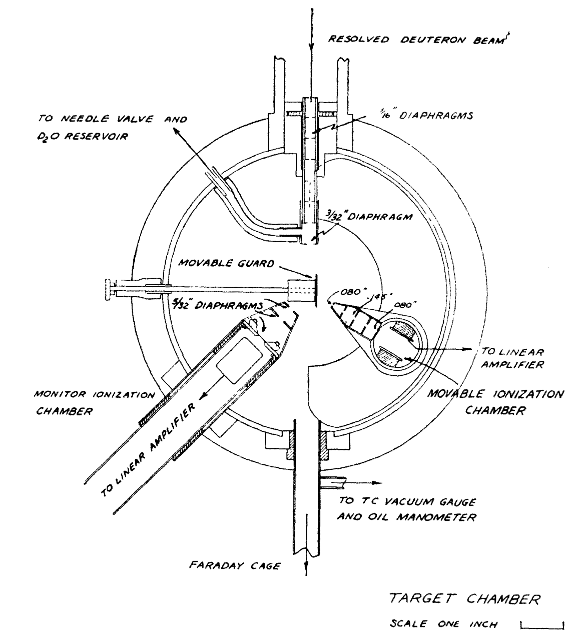

FIG. 2. Detailed drawing of target chamber. The guard, used to measure background of the counters, is shown in a position to block the movable ionization chamber.

In connection with a separate experiment, performed in this laboratory by Mr. C. M. Crenshaw, the loss of energy of the beam in traversing heavy water vapor was determined. The loss of energy in getting to the observation volume varied from 7 kev at 250 kev to 13 kev at 100 kev. The change in energy of the beam along the part viewed by the ionization chambers was 0.85 kev at 100 kev and 0.45 kev at 250 kev. This latter is the uncertainty in energy due to the thickness of the target.

The disintegration particles were observed by means of two ionization chambers, each one cm deep, and associated amplifiers. The signal to noise ratio of these amplifiers was never less than 10–1 for any of the data taken.

TARGET ASSEMBLY

Figure 1 shows a sketch of the entire assembly below the analyzing magnet. The diaphragms

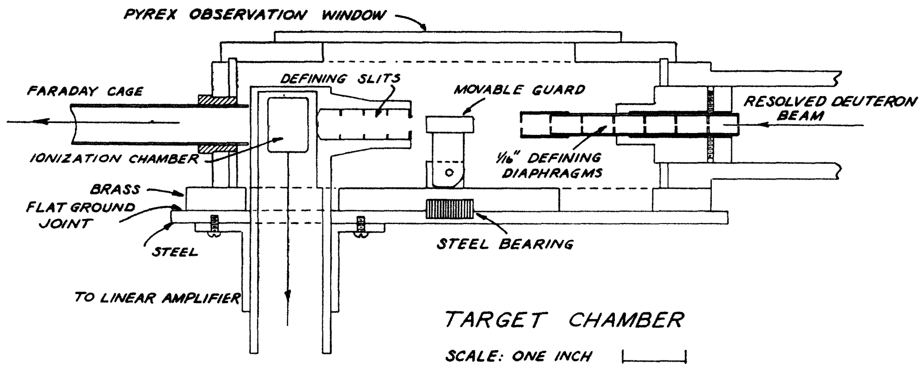

FIG. 3. Edgewise view of the target chamber.

through which the beam entered the target chamber were aligned optically. The seven $\frac{1}{16}$-inch diaphragms forming the entrance capillary to the target chamber, used in conjunction with the cold trap, permitted a pressure of water vapor of more than 1 cm Hg without affecting the pressure in the accelerating tube, although all the data were taken with a pressure of $1\frac{1}{2}$ mm.

Figures 2 and 3 show detailed views of the target chamber. The resolved deuteron beam entered through the diaphragm capillary and struck no solid material until completely out of the target chamber into the Faraday cage. The water vapor was admitted at the base of the entrance capillary to reduce flow through the observation volume. The monitor ionization chamber which was fixed at an angle of 45° to the incoming beam served to measure the relative beam intensity. The movable ionization chamber protruded through a semi-circular slot

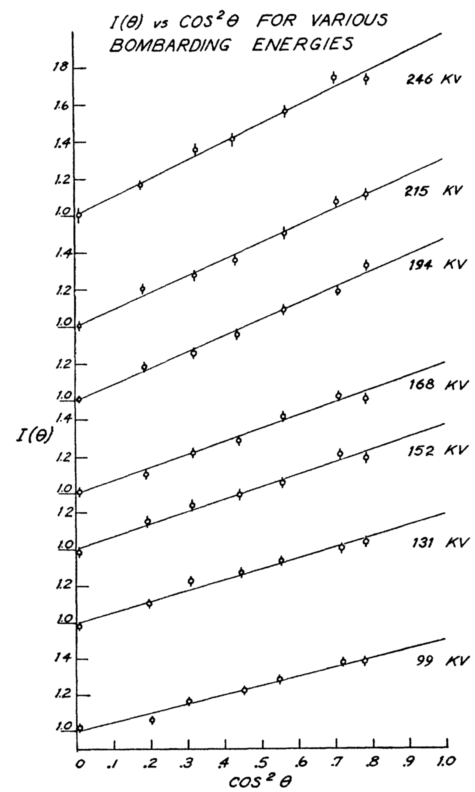

FIG. 4. Data from representative runs showing intensity as a function of $\cos^2\theta$ at various energies.

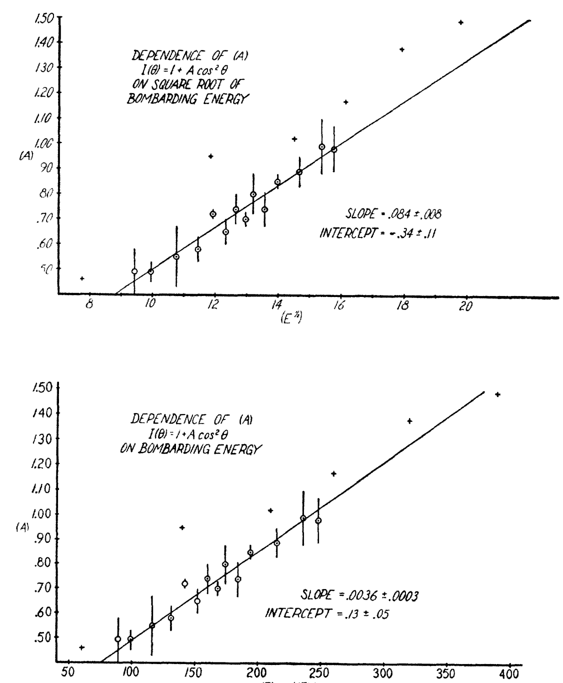

FIG. 5. Final results, showing A in $I(\theta)=1+A\cos^2\theta$ as a function of energy. Crosses indicate points taken from Iowa data.

in the back of the target chamber and was externally fastened to a steel plate. The steel plate was ground to the back plate of the assembly and a vacuum seal made with heavy stopcock grease. This type of vacuum seal has proven to be very satisfactory and requires no attention other than occasional greasing. The angular position of the movable chamber was read with an error of less than 5 minutes and was continuously variable from 20° to 160° to the direction of the beam. The entrance capillary and the two ionization chambers were aligned so that their three axes intersected within 0.001 inch of a point on the axis of rotation of the movable chamber.

The background of the movable chamber was found to be appreciable and the installation of a guard, which could be used to block the view of that chamber to the target volume, was necessary. At all times the guard was completely out of the line of the beam, and when not blocking the chamber was completely out of the cross fires of the chamber. When in position, the guard completely shielded the chamber from view of the beam at all positions of the chamber. The background of the monitor chamber was also checked but turned out to be proportional to the strength of the beam, so that it did not alter the results.

COUNTING PROCEDURE

Simultaneous counts were taken in the monitor and movable chambers at each energy for each angle investigated. The ratio of the number of counts in the movable chamber to the number in the monitor was taken and a background ratio subtracted from the total to give the net ratio at each angle. The net ratio was then corrected for geometrical changes from one angle to another and transformed into the center of mass coordinate system. The corrected ratio as a function of $\cos^2\theta$ was then analyzed by least squares and normalized to unity at $\cos^2\theta=0$.

TABLE I. Values of A obtained for the energies investigated. Probable errors are indicated.

kev	A	p.e. ±	kev	A	p.e. ±
89	0.49	0.09	168	0.70	0.03
99	0.49	0.04	174	0.80	0.08
116	0.55	0.12	184	0.74	0.07
131	0.58	0.05	194	0.85	0.03
142	0.72	0.02	215	0.89	0.06
152	0.65	0.05	236	0.99	0.11
160	0.74	0.06	246	0.98	0.09

The values of A all conform to certain requirements. Each angle has been observed at least twice, each observation including a background bracketed by two total counts. The total number of counts in the movable chamber for each angle of the run was more than four thousand. Because of its position in the forward direction and sensitivity to a larger solid angle, the number of counts in the monitor chamber always exceeded that in the movable one.

RESULTS

Figures 4 and 5 and Table I show the results obtained. These results are in fair agreement with those of Huntoon, Ellett, Bayley, and Van Allen,[1] whose data are indicated by crosses in Fig. 5. A comparison of Fig. 4 of this paper with Fig. 3 of theirs shows the decreased statistical error obtained by the use of a vapor target. The difference in the results obtained in the two laboratories can probably be ascribed largely to a difference in the two voltage scales. On this assumption, the combined data show that the coefficient A increases smoothly with bombarding energy over the range from 60 kev to 390 kev.

We are pleased to acknowledge the generous assistance of Mr. C. M. Crenshaw, not only for the measurements cited earlier, but also throughout the course of the experiment.