B. Analysis of Experimental Uncertainties

Counter Angle θ

Assuming that Q_2 is the accurately known Q-value, then the error in Q_1 due to the uncertainty in the counter angle θ is

$$(\Delta Q_1)_\theta = (2/A_1)(2E_{p1}E_{d1})^{\frac{1}{2}}\sin\theta_1\Delta\theta_1 - (2/A_2)(2E_{p2}E_{d2})^{\frac{1}{2}}\sin\theta_2\Delta\theta_2.$$

Thus for a given error in θ, the minimum error in Q for a heavy nucleus is obtained for small angles for a heavy reference nucleus. However, elements heavier than aluminum either do not have well-resolved ground-state peaks or their Q-values are not accurately known. This is the reason for selecting aluminum for a reference and choosing an angle of 30°. The counter can be aligned to the deuteron beam to an accuracy of about 1°. There are two small effects that change the effective angle of the counter. One effect, owing to the finite solid angle and size of the deuteron beam on the target, increases the angle. At 30° the effective counter angle is increased by about 0.5°. The other small effect is a result of the angular distribution of the protons. Since for light elements the distribution is strongly forward, the effective angle is less than the measured angle. However, since the aluminum ground-state peak has a maximum[44] at 30°, this second effect is not present. For the aluminum ground-state peak at 30° with 13.9-Mev deuterons and 19-Mev protons, an error in angle

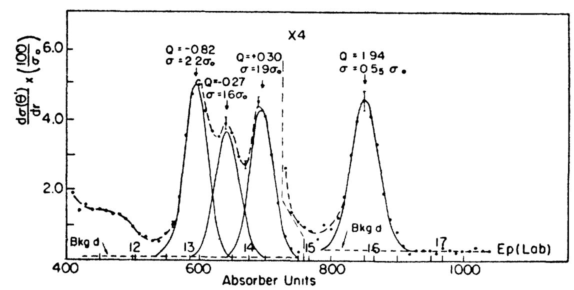

FIG. 1. Proton spectrum at $\theta = 50°$ from a 10-mg/cm² bismuth target bombarded with 14-Mev deuterons from the reaction $Bi^{209}(d, p)Bi^{210}$. The ordinate is the differential cross section in the center-of-mass system per absorber unit in terms of the ground-state proton peak from aluminum $(\sigma_0)\cdot\sigma_0 = 2.5\pm1.0\times10^{-27}$ cm²/steradian. θ' is the angle measured in the center-of-mass system. The abscissa is in units of 0.416 mg/cm² of Al. The proton energy in the laboratory system is also given. The vertical bar represents the square root of the number of counts.

of 1.5° results in an error in the Q-value for a heavy nucleus of 20 kev.

Range of Protons R

The center of the proton peak is chosen as a measure of the mean range of the proton group, since this corresponds to the protons produced at the center of a thick target. The range is measured in absorber units, which are then converted into mg/cm² of aluminum by the conversion factor that 1 absorber unit = 0.416 mg/cm² of aluminum. To the range measured in the foil changer must be added the thickness of foils and gas in the triple counter (10 mg/cm²). There are two other small corrections to be applied to the range. By changing the gate settings, the peak can be made to shift in range. This correction can be approximately determined by comparing a differential and an integral run. For the gate settings used, this correction amounted to about 4 mg/cm². The other small effect is due to the large solid angle and the size of the deuteron beam on the target. Thus, the protons do not pass through the foils exactly at right angles. The average angle is about 4° from the normal, resulting in a correction of 1.5 mg/cm² for the aluminum ground-state peak. The mean range is accurate to a few mg/cm². The difference between the range of 2 proton peaks is accurate to 1 mg/cm² (20 kev).

Range-Energy Curve

The range-energy curve used is that calculated by Smith.[45] Assuming that the computed values for the energy loss per mg/cm² are accurate to 1 percent, the difference in energy of the two proton groups will be accurate to 1 percent.

Energy Loss in Target

In order to obtain sufficient counting rates, targets were of the order of 20 mg/cm² thick. Since the center of the proton peak is taken as a measure of the proton energy, Q-values must be calculated at the center of the target. Bethe and Livingston[46] have calculated the atomic stopping power of various elements at different proton energies. This can be converted into mg/cm² of the various elements equivalent to 1 mg/cm² of aluminum. For a 20-mg/cm² lead target, the deuteron energy loss is about 200 kev in reaching the center of the target and the proton energy loss another 100 kev. Thus, it is necessary that the measured mass/cm² and the calculated conversion values be accurate to 5 percent. Therefore, it was decided to measure the thickness of all targets for 14-Mev deuterons and for high energy protons. This was done by inserting the target in the deuteron beam or the ground-state aluminum protons and measuring the shift of the aluminum ground-state peak at 30°. Since in both cases the target thickness is measured over the same central region as is bombarded, this eliminates errors due to the non-uniformity of the foils. The target thickness for the deuteron beam and for the protons can be measured to 20 kev, and thus the half-target thickness is accurate to 10 kev. The error due to uncertainty in the target angle is negligible.

C. Factors Contributing to the Spread

Since the proton peaks are broad (full width at half-maximum is 500 kev for the aluminum ground-state

[44] H. E. Gove, Phys. Rev. **81**, 364 (1951).

[45] J. H. Smith, Phys. Rev. **71**, 32 (1947).

[46] M. S. Livingston and H. A. Bethe, Revs. Modern Phys. **9**, 272 (1937).

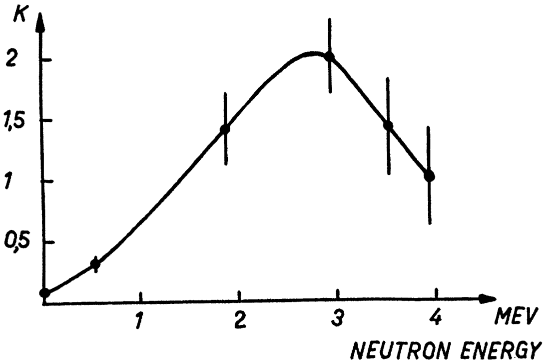

FIG. 1. Dependence of the cross section ratio on neutron energy.

has been measured for thermal neutrons and neutrons with 0.5-, 1.9-, 2.9-, 3.5-, and 3.9-Mev energy. The reactions were generated in an ionization chamber filled with 8 atmos argon and 1 atmos BF_3; and the events were registered in the usual fashion,[1] by means of a photographic pulse spectrograph. The neutrons of 0.5-Mev energy originated in the $C^{12}(d, n)N^{13}$ reaction, a thin graphite layer (0.07 mg/cm^2) serving as the target. The higher energy neutrons were generated in the $D(d, n)He^3$ reaction using a thick heavy-ice target.

The measured values of K are given in Fig. 1. The errors to be associated with each measurement are indicated.

A detailed report of this work will appear in the Helvetica Physica Acta.

[1] A. Stebler and P. Huber, Helv. Phys. Acta 21, 59 (1948).

Rayleigh Afterglow in Hydrogen Discharges

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IN 1943 Lord Rayleigh[1] induced an electrodeless hydrogen discharge in a continuous tube, or discharge ring, to which a side tube, or neck, was attached. He observed that the luminosity extended several centimeters into the neck, and determined with a rotating mirror that it advanced along the neck, out of the exciting field, with a velocity of the order of 4×10^5 cm/sec, as some sort of afterglow. Coupling this with photometric measurements at two points along the flame, he concluded that approximately 10^{-5} sec represented the time interval during which the luminosity moving along the neck decreased in intensity by a factor of $1/e$. This afterglow time is several hundred times the lifetimes of the excited states, so that some process other than relaxation of the atoms must occur to account for the total duration. At present, the process is not completely explained. We have undertaken to investigate this afterglow, in an attempt to discover as much as possible about the processes involved.

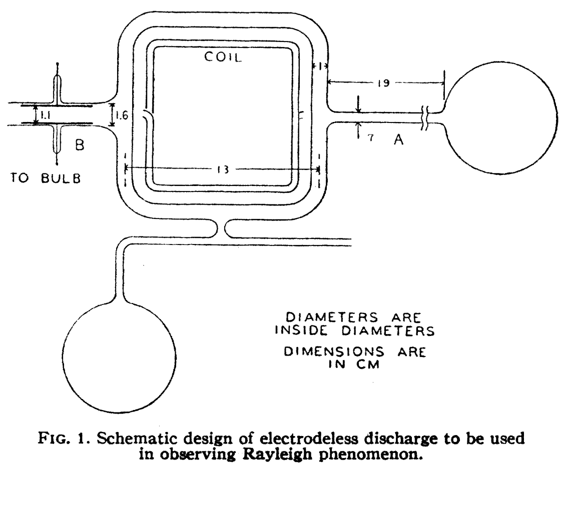

FIG. 1. Schematic design of electrodeless discharge to be used in observing Rayleigh phenomenon.

The tube was similar to that used by Rayleigh. The discharge ring was bent from 1-cm diameter glass tubing as shown in Fig. 1. Two side tubes were attached to opposite sides of the discharge ring, terminating in large bulbs, and the tube was pumped out through a side tube joined to a third side. One of the two opposite necks was 0.7 cm in diameter, and the other was 1.6 cm in diameter with copper plates built in as shown Rotating mirror pictures were taken of neck A in Fig. 1 through a 0.7-mm slit parallel to the axis of the neck. The exciting circuit consisted of a 10-kv transformer in series with a spark gap of about 7 mm and an exciting coil of 11.5 turns of 4.5-mm outside diameter copper tubing, bent square, 10 cm on a side, with $0.1\mu f$ across the secondary terminals of the transformer. The frequency of the circuit was about 1.5×10^5 cps. The rotating mirror turned at 50 rps, and rotating mirror pictures were recorded with an f:4.5 camera on Super XX film.

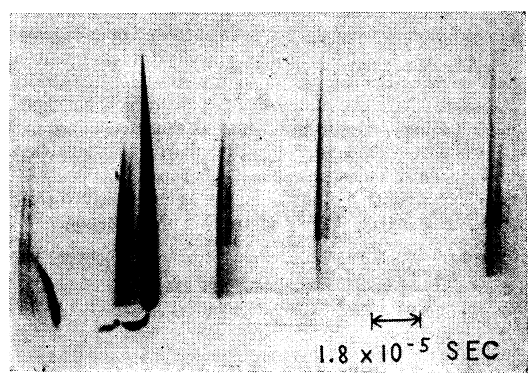

FIG. 2. A group of rotating mirror records of luminosity present in side tube A of Fig. 1 subsequent to discharges in the main tube. Note angle of inclination between stationary trace and moving mirror records.

Hydrogen was used in the discharge tube at pressures varying from 0.1 to 0.8 mm Hg, values which constituted limits on the operation of this particular circuit. The velocity of the advance of luminosity along neck A, calculated from rotating mirror measurements, was about 2×10^6 cm/sec, and showed a tendency to increase with lower pressure. The afterglow times were about 3×10^{-6} sec.

Figure 2 is a sample mirrorgram, taken at 0.40 mm Hg. The very dark trace is taken with the mirror stationary and the striated traces are taken with the mirror turning. The angle between a striation and the stationary trace provides the basis for calculating the velocity of advance. The striations were caused by the condenser oscillations, and the discontinuity in intensity near the base is due to a $1/e$ filter. Since lines of the mirrorgram parallel to the dark trace represent instantaneous slit images, it is apparent from Fig. 2 that the luminosity is highly concentrated in a series of advancing fronts, rather than ejected as a tongue or jet.

Ions were shown to exist in the afterglow by completion of a circuit between the plates in side tube B through a milliameter, and discharging the tube with a small U magnet hanging over neck B between the plates and the discharge ring. The ammeter showed a small deflection; and when the magnet was reversed, the ammeter deflected in the opposite direction, showing that ions were deflected to the plates by the magnet.

It was also observed that the luminosity went much farther along the large side tube than along the smaller, going far beyond the plates in the large tube, whether or not the plates were grounded.