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

ROBERT J. LEE AND RICHARD G. FOWLER
Department of Physics, University of Oklahoma, Norman, Oklahoma
November 13, 1950

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
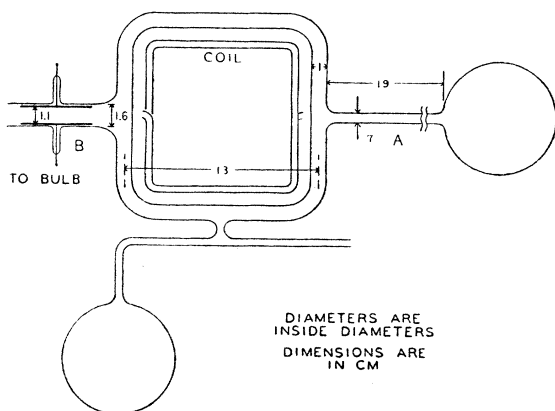

FIG. 1. Schematic design of electrodeless discharge to be used in observing Rayleigh phenomenon.

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.

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.
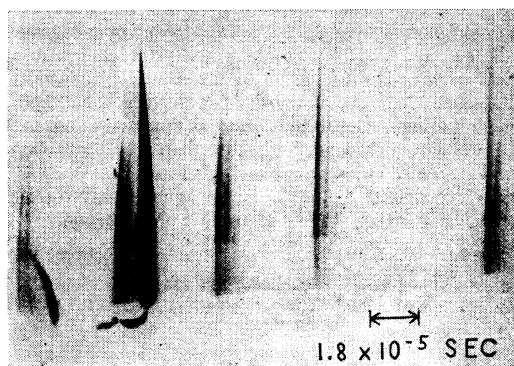

FIG. 2. A group of rotating mirror records of luminosity present in side tube A of Fig. 1 subsequent to discharges in the main tube. Note angle of inclination between stationary trace and moving mirror records.

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.

The striations evident in Fig. 2 did not appear in Rayleigh's mirrorgrams. This is apparently because the frequency in his circuit was so great that the mirror did not separate the successive oscillations. Rayleigh suggested that the gas excited in the discharge ring and heated to a very high temperature expanded into the neck, remaining luminous for 10^{-5} sec; and Zanstra[2] showed theoretically that ions expanding into the neck and recombining all along its length might account for Rayleigh's observations. It appears that if either of these processes were the major process in the neck, an instantaneous photograph of the tube should show a tongue rather than a front of luminosity. The front which is observed is more suggestive of an exciting process occurring in the neck, concurrently with the emission of radiation, such as a shock wave producing excitation or ionization as it proceeds along the neck. Such an exciting process is further suggested by the order of magnitude of the velocity of advance.

No experiments have been performed as yet which will enable us to decide whether recombination is active in the discharge. Rayleigh and Zanstra showed that the energy delivered to the discharge is adequate to produce a high average degree of ionization, yet how much of this energy is actually available in the excitation process in the neck is not so far known.

An electrodeless discharge pulse in a ring tube having appendages is followed by a discharge into these appendages which proceeds as a luminous front of local activity traveling with ultra-acoustical speeds. The excitation in the front is produced at or near the point where the luminosity is perceived. The "long lifetime of the Balmer series in hydrogen" is thus accounted for as a delay in production of excitation rather than a belated relaxation of excited systems.

The authors wish to acknowledge the benefit derived from the concurrent work of J. S. Goldstein on this phenomenon.

[1] R. J. Strutt (Lord Rayleigh), Proc. Roy. Soc. (London) 183, 26 (1944–45).
[2] H. Zanstra, Proc. Roy. Soc. (London) 186, 236 (1946).

Angular Distribution of Neutrons from the Bombardment of Be by 340-Mev Protons*

JAMES DeJUREN

Radiation Laboratory, Department of Physics, University of California, Berkeley, California

October 9, 1950

IN conjunction with the measurements of Miller, Sewell, and Wright[1] of the angular distribution of the neutrons produced by the bombardment of various targets with 330-Mev protons, a measurement was made using bismuth fission chambers[2,3] as detectors instead of the carbon $(n, 2n)$ reaction employed by the above group. Bismuth fission has its threshold at a neutron energy of about 50 Mev compared to 20 Mev for the $C(n, 2n)$ reaction. The data from 15° to 27° were taken using the neutrons produced from the bombardment of a 2.8-inch Be target with 330-Mev protons inside the cyclotron immediately after the $C(n, 2n)$ measurements. Shallow fission chambers containing two 4.5-inch diameter bismuth coated plates were employed as monitor and detector. The 8° result was obtained from the bombardment of a 2-inch Be target with 350-Mev protons at the standard probe position.

To extend the angular range, measurements were made with the neutrons knocked out of a $1\frac{11}{16}$-inch diameter beryllium rod by the electro-magnetically deflected, external 345-Mev proton beam. Since the fission counting rate was only about 70 counts per hour at 12°, it was necessary to find the fission pulse height distribution by means of a pulse height analyzer[4] to insure that "pile-ups" were not occurring during the 0.1 μsec deflected proton pulse. Satisfactory plateaus were obtained with the long bismuth fission counters previously employed for the 95- and 270-Mev neutron energy measurements of nuclear cross sections.[3]

The distance from detector to target was such that the angular resolution was within $\pm 1°$ of the indicated setting except at 62°
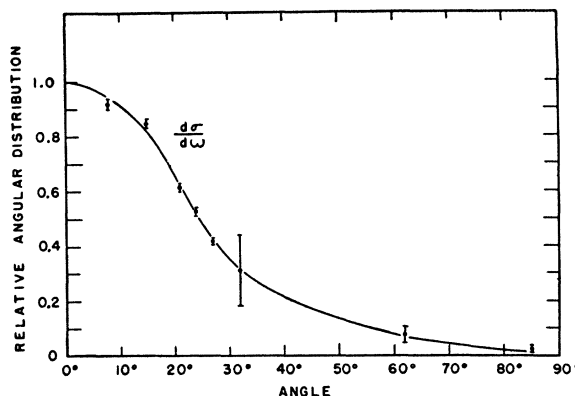

FIG. 1. Angular distribution of neutrons from the bombardment of Be by 340-Mev protons.

and 85° where it was $\pm 2°$. No attempt has been made to correct for neutron background scattered into the detector or produced by protons at regions other than the beryllium target. Four inches of lead was placed in front of the detector to prevent protons from entering it.

The measured angular distribution is shown in Fig. 1, and the statistical errors indicated are standard deviations based on counting. The full width at half maximum is 49° with an estimated probable error of 1° due to the scatter of the experimental points and statistical errors. By comparison, Miller, Sewell, and Wright[1] obtained for beryllium a width of 54±1 degrees using the lower threshold carbon $(n, 2n)$ detection.

If the angular distribution is graphically integrated the resultant total cross section for production of a high energy neutron is

$$\sigma_t = 1.05(d\sigma/d\omega)_0.$$

The neutron yield in the forward direction has been measured by Knox[5] for the neutrons knocked out of Be with 350-Mev protons using the same fission chambers. His result is $(d\sigma/d\omega) = 42.2 \times 10^{-27} \times \sigma_{p,pn}(350 \text{ Mev})/\sigma_{n,2n}(270 \text{ Mev})$ where the indicated cross sections are for carbon. When 38 and 17 millibarns are used for the carbon (p, pn)[6] and $(n, 2n)$[7] cross sections, respectively, the value of the total cross section is 100 millibarns (with an estimated accuracy of 50 percent). The total collision cross section for 270-Mev neutrons and a Be nucleus is 230 millibarns, as measured with bismuth fission detectors.

On the Anomalous Specific Heat of Lead Titanate

GEN SHIRANE AND ETSURO SAWAGUCHI

Tokyo Institute of Technology, Oh-okayama, Tokyo, Japan

November 30, 1950

IN an earlier letter[1] it was reported that the lattice spacing of lead titanate shows a large anomaly at the transition point 490°C. From this fact it might be anticipated that this transition would be accompanied also by a large anomalous specific heat. Using an adiabatic calorimeter of Nagasaki-Takagi type,[2] which is an improvement of that of Sykes,[3] we have measured the specific heat as a function of temperature.

We have used the same ceramic specimen as used for the x-ray analysis, which was prepared by sintering the mixture of PbO and TiO_2 at about 1100°C. The powdered specimen of about 25 g was
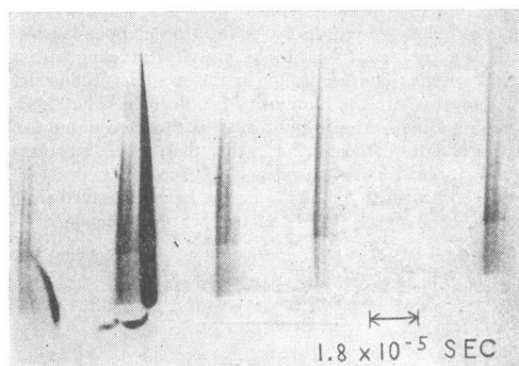
FIG. 2. A group of rotating mirror records of luminosity present in side tube *A* of Fig. 1 subsequent to discharges in the main tube. Note angle of inclination between stationary trace and moving mirror records.