Energy Loss Per Ion Pair for Protons in Various Gases*

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Values of w for protons in A, N_2, CO_2, dry air, and "tissue-equivalent" gas were measured as 26.66±0.26, 36.68±0.34, 34.37±0.33, 35.18±0.42, and 30.03±0.29 ev/ion pair, respectively. A 2-Mev positive-ion accelerator was used as the source of protons. The energy of the protons was determined with a precision gaussmeter that was calibrated by the Li(p,n) and T(p,n) threshold reactions. These protons were scattered from a gold foil into a parallel plate ionization chamber. The fast-electron pulses were collected on one electrode, amplified, and counted. The positive-ion charge was collected on the other electrode and measured by means of a standard capacitor that was connected between the input and feedback terminals of a vibrating-reed electrometer.

INTRODUCTION

THE object of this experiment was to determine values of w for protons in A, N_2, CO_2, dry air, and "tissue-equivalent" gas in the energy range below 2 Mev. Values of w for "tissue-equivalent" gas are of special importance because of their application to neutron dosimetry. Although the literature is voluminous on the subject of w, very little of this information pertains to protons. Several early measurements[1,2] of w were made for protons in nitrogen and these data were corrected theoretically to w for air. Bakker and Segrè[3] determined values of w for very high-energy protons (340 Mev). Recently, Lowry and Miller[4] reported values of w for 25 to 250-kev protons in nitrogen and argon. Since the latter authors used a different experimental technique than the present one, the experiment described in this paper should substantiate their results.

EXPERIMENTAL

A 2-Mev positive ion accelerator was used as the source of protons. The protons were accelerated and allowed to enter between the pole faces of a magnet which deflected them through an angle of 25°. A precision gaussmeter was used to determine the strength of the magnetic field. The radio-frequency oscillator of the gaussmeter was calibrated with a radio receiver which in turn was calibrated by frequencies from radio station WWV. The energy of the protons was determined from the relationship $E \approx kf^2$. The constant k was determined by the use of the Li(p,n) and T(p,n) neutron threshold reactions. The difference in the values of k at 1.019 Mev and 1.8812 Mev was found to be 0.4%. Since this experiment was performed at 1.826 Mev, the value of the constant, k, that was found from the Li(p,n) experiment was used.

After being deflected by the magnet, the protons were scattered by a gold foil (Fig. 1) that was placed at 45° to the primary proton beam. Most of the protons passed through the gold foil and were collected on a Faraday cup that was externally connected to a current integrator. The protons that were scattered at 90° were collimated and allowed to pass through a 1-mg/cm² nickel foil into the parallel plate ionization chamber that is shown in Fig. 2. The probability of multiple scattering[5] of a 1.826-Mev proton by a 1-mg/cm² nickel foil into a solid angle of 15° is 0.99. This implies that the number of protons striking the walls of the chamber was negligible. A Frisch grid was used in front of the high-voltage electrode to provide uniform pulse height and to increase the signal-to-noise ratio.

For argon gas, the positive-ion charge, Q, was collected on one electrode. This charge was measured

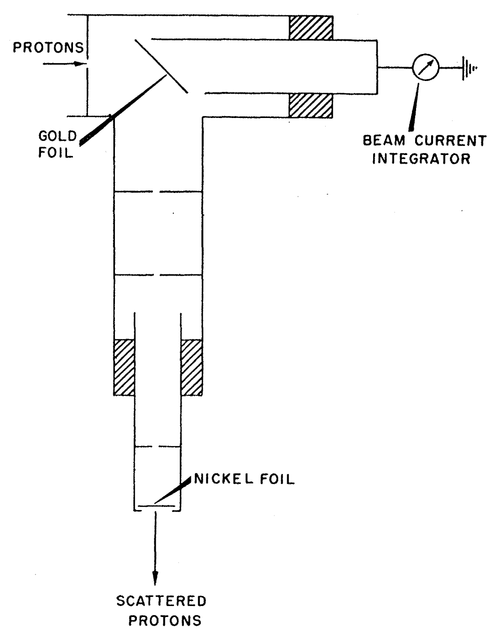

FIG. 1. The scattering chamber.

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1 C. Gerthsen, Ann. Physik 5, 657 (1930).
2 W. Jentschke, Physik. Z. 41, 524 (1940).
3 C. J. Bakker and E. Segrè, Phys. Rev. 81, 489 (1951).
4 R. A. Lowry and G. H. Miller, Phys. Rev. 109, 826 (1958).
5 G. Molière, Z. Naturforsch. 3a, 78 (1948).

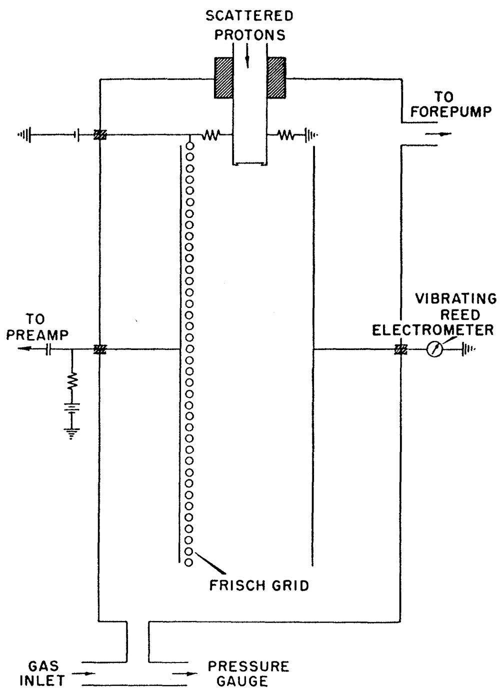

FIG. 2. The parallel plate ionization chamber.

in a modified Townsend balance circuit with a vibrating-reed electrometer ss the null instrument. The fast-electron pulses, N, were collected on the high-voltage electrode, amplified, and counted. For CO_2, N_2, air, and "tissue-equivalent" gas, the charge collected by the vibrating-reed electrometer per unit Faraday cup current was measured in the appropriate gas and the counts per unit Faraday cup current were measured in argon.

RESULTS

The values of w were determined from Eq. (1) and are listed in Table I.

TABLE I. Values of w for 1.826-Mev protons.

Gas	w(ev/ion pair)
A	26.66 ± 0.26
N_2	36.68 ± 0.34
CO_2	34.37 ± 0.33
Dry air	35.18 ± 0.42
"Tissue-equivalent" gas	30.03 ± 0.29

$$w(\text{ev/ion pair}) = \frac{1.692\times 10^{-13}\, E(\text{Mev/proton}) N(\text{protons})}{Q(\text{ionization charge})}. \quad (1)$$

The errors quoted in Table I include both the statistical and systematic errors. These data were corrected for the energy lost be recoil in the gold foil, for the energy losses in the gold and nickel foils, for a small leakage resistance across the standard condenser, and for the counting losses due to the finite resolving time of the counting apparatus. The energy corrections were made with the use of stopping power data that are summarized in the literature.[6]

The only gas purification used was to flush the gas through the chamber until the ionization charge per unit integrated charge readings became constant. An analysis of the gases used in this experiment showed that A, N_2, and CO_2 were better than 99.9% pure and that the "tissue-equivalent" gas was composed of 30.01% CO_2, 1.74% N_2, 67.92% CH_4, and 0.33% C_2H_4 (percentages by partial pressure).

As a final check on the experiment, a plutonium alpha particle source was placed in the center of the positive ion charge collecting electrode. This source was evaporated on a tantalum backing. After making the necessary corrections for backscatter,[7] a value of w for argon of 26.5 ev/ion pair was obtained from Eq. (1). This is in good agreement with the literature.[8]

[6] S. K. Allison and S. D. Warshaw, Revs. Modern Phys. **25**, 779 (1953).
[7] B. B. Rossi and H. H. Staub, *Ionization Chambers and Counters* (McGraw-Hill Book Company, Inc., New York, 1949), p. 240.
[8] W. P. Jesse and J. Sadauskis, Phys. Rev. **90**, 1120 (1953).