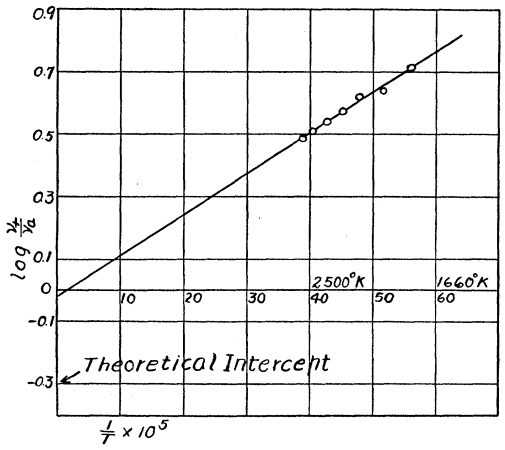

FIG. 2.

-0.30, is to be expected. The experimental data, however, exhibit an intercept of about -0.03. Several other preliminary experiments have led to intercepts which lie both above and below the origin, but within the limits ± 0.1. These observations point to the possibility that a factor, which multiplies the exponential term and cancels at least in part the statistical weights' ratio, has been omitted in Eq. (1). A somewhat more general equation may be written, which contains such a factor, involving reflection coefficients for ions and atoms, namely,

$$\frac{\nu_+}{\nu_a} = \frac{1-r_+}{1-r_a} \cdot \frac{\omega_+}{\omega_a} \exp\left[\frac{-(I-\phi)\epsilon}{kT}\right]. \quad (2)$$

If the ratio $(1-r_+)/(1-r_a)$ were equal to approximately 2, the absence (within experimental error) of an intercept would be accounted for. There are at present no experimental data upon the reflection coefficients of atoms or ions known to the writers. It has been assumed in the past that the ratio $(1-r_+)/(1-r_a)$ is nearly unity.

It may be significant that the dilemma which arises here is very similar to that which arose recently in the case of the thermionic emission of electrons,[6] and which led to the suggestion of a reflection coefficient for electrons of $\frac{1}{2}$. It will be apparent from the discussion above that very careful work would be necessary in order to establish or disprove the existence of zero intercept.

It should be stated here that the above experiment affords a method for the determination of the work function of tungsten independent of thermionic emission. The value of ϕ obtained from the slope in Fig. 2 is 4.56 e.v. Several other determinations have given values ranging from 4.50 to 4.57 e.v.

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February 5, 1934.

[6] See Fowler, *Statistical Mechanics*, p. 268, Cambridge Press (1929).

Gamma-Rays from Carbon Bombarded with Deutons

By using the method previously applied[1] to other elements we have observed a very penetrating radiation from carbon bombarded with deutons, and have attempted to analyze it. We have made measurements of the absorption of this radiation in lead and in paraffin, with two electroscopes, one lined with lead and the other with paraffin. The tube was operated at 900 kilovolts and 10 microamperes ion current. The hydrogen contained about 30 percent H^2. The ions were allowed to impinge alternately on a target of graphite and a target of some heavier element. Aluminum, copper and tantalum were tried, with the same hydrogen and also with ordinary hydrogen, and found to give readings which were practically identical among themselves and were presumably due to stray x-rays plus the residual ionization of the electroscope. These readings were taken as the background to be subtracted from the total effect obtained with the graphite target, and the difference was ascribed to the products of a reaction involving carbon and H^2.

The ionization produced in the lead-lined chamber was about 1.4 times that produced in the paraffin-lined chamber under the same conditions, which is approximately the ratio found for γ-rays. We have also compared the absorption in paraffin with the absorption in lead and found 25 mm of paraffin to be equivalent to less than 3 mm of lead. Both of these results indicate that neutrons are not

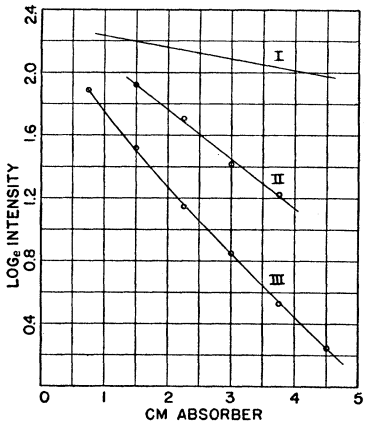

FIG. 1. Absorption in lead of I, neutrons; II, C+H^2 radiation and III, thorium γ-radiation.

present in sufficient numbers or with sufficient energy to be detected under the conditions of our experiment. We conclude therefore that the ionization is produced by very hard γ-rays.

[1] Crane, Lauritson and Soltan, Phys. Rev. **44**, 514 (1933).

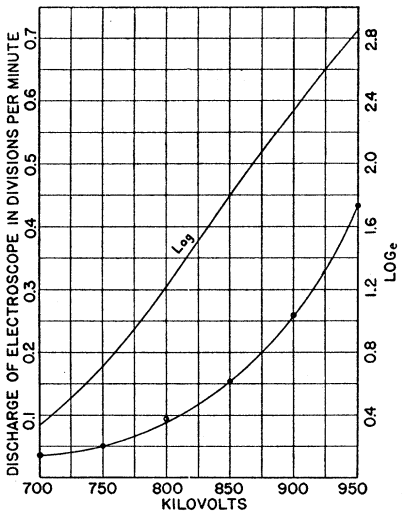

FIG. 2. Intensity of radiation as a function of accelerating voltage, after 1.5 cm lead filtration.

By comparing the absorption curve for the $C+H^2$ radiation in lead (Fig. 1, curve II) with the curve for the absorption of γ-rays from thorium (curve III) obtained with the same experimental arrangement, we find that the radiation from $C+H^2$ is considerably more penetrating. For thorium we find the apparent absorption coefficient in lead to be 0.42 cm^{-1}, while the true absorption coefficient is 0.478 cm^{-1}. This indicates that scattered radiation introduces an error of approximately 13 percent. For the $C+H^2$ radiation the apparent absorption coefficient is 0.31 cm^{-1}, and if we apply the same correction of 13 percent as in the case of thorium, this gives $\mu=0.35$ cm^{-1} as the most probable value. It is somewhat uncertain to what quantum energy this absorption coefficient corresponds, but it is probably in the neighborhood of 3.5×10^6 e.v.

By comparing the intensity of ionization produced by the $C+H^2$ radiation with that from a known quantity of radium we find our source to be approximately equivalent to 2.5×10^{-6} gram of radium. This amount of radium produces about 2×10^5 quanta per second, and allowing for the smaller absorption of our radiation in the ionization chamber, we estimate that we are producing roughly 3×10^5 quanta per second. Assuming that our beam contains 10^{13} H^2 ions per second which have velocities near the maximum, this means that three quanta are produced per 10^8 H^2 ions. Due to the much smaller absorption coefficient of neutrons in lead (indicated by curve I, Fig. 1) an appreciable number of neutrons could not escape detection, and we estimate that the number of neutrons present is less than one-fifth the number of quanta.

Lawrence, Livingston and Lewis[2] find protons having a range of 18 cm when they bombard carbon with deutons of 1.3×10^6 e.v. It would seem reasonable to associate the γ-rays which we observe with these protons. If this is correct the most probable process appears to be

$$C^{12}+H^2\rightarrow C^{13}+H^1+\gamma.$$

If we use the following values in mass units:

$C^{12}=12.0036$	kinetic energy of $H^2=0.0010$
$C^{13}=13.0039$	$H^1=.0030$
$H^1=1.0078$	$C^{13}=.0002$

we obtain $12.0036+2.0136+0.0010=13.0039+0.0002+1.0078+0.0030+\gamma$. This gives $\gamma=0.0033$ mass units, or 3.1×10^6 e.v., which agrees within the experimental uncertainty with the estimate made from our absorption measurements, and leads us to believe that the process here suggested is correct.

It is a pleasure to acknowledge our indebtedness to the Seeley W. Mudd Fund for the support of this work.

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February 15, 1934.

[2] Lawrence, Livingston and Lewis, Phys. Rev. **44**, 56 (1933).

Measurement of the Townsend Coefficients for Ionization by Collision—Additional Data

It has been brought to the writer's attention that in two recent papers[1] on the values of the Townsend coefficients in air, no mention was made of the temperature at which the measurements were carried on. The temperature is of considerable importance as the coefficient α is actually a function of X/(gas density) rather than X/pressure (X =field strength in volts/cm). All measurements were conducted in a room of sensibly constant temperature, the average being 22°C and the deviation above or below this value less than 1°C. This gives a maximum allowable error in the absolute temperature, and hence in the gas density, of about 0.3 percent. The maximum error in the case of the pressure was around 0.5 percent for values of X/p above 36.0 and 0.1 percent for X/p's of 36.0 and lower. The maximum error in field strength was about 0.1 percent. Thus, for X/p's above 36.0 the total allowable error in X/(gas density) is 0.9 percent and the probable error about 0.3 percent. For X/p's of 36.0 and lower the maximum allowable error is about 0.5 percent and the probable error less than 0.2 percent.

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February 15, 1934.

[1] F. H. Sanders, Phys. Rev. **41**, 667 (1932); **44**, 1020 (1933).