Luminescence Excited by Exposure to Neutrons*

Since many elements, during exposure to neutrons, release energy in the form of gamma-rays, beta-rays and alpha-particles, it is reasonable to expect that these radiations may be used to excite luminescence. We have made observations which show that certain luminescent materials, which are known to be excited by x-rays, cathode rays, and radiations from radium, emit light as a result of exposure to neutrons. We have used photographic methods to detect this emission during exposure, and have made visual observations, after exposure, of thermoluminescence excited in many substances and of phosphorescence in luminescent ZnS.

Exposures were made for varying lengths of time up to several hours at distances up to 50 cm from a neutron source with radium equivalent 100 kg and at a distance of a few cm from a source with radium equivalent about 1 kg. Specimens were simultaneously exposed in black paper, inside a solid box of paraffin 12 cm thick, and in a lead box 1 cm thick placed inside this same paraffin box. The effect was observed to be least in the specimens wrapped in black paper and exposed to fast neutrons. The two sets of specimens inside the paraffin box were observed to emit luminescence of practically the same intensity although one set was enclosed in a lead box and the other was not.

Photographic observations.—Two identical specimens of luminescent $CaWO_4$, one wrapped in black paper and the other in Cellophane, were placed in contact with the sensitive side of a panchromatic film and exposed to neutrons as described. The part of the film under the Cellophane was strongly blackened while the part under the black paper showed little or no blackening. A similar difference was observed when the $CaWO_4$ was painted on black cardboard with a binder and part of it covered with black paper during exposure. Other materials were observed to show this same effect especially $CdWO_4$ activated by 1 percent Mn and phosphorescent ZnS. It is of interest to note that the three substances which we have found to be most strongly luminescent under neutron exposure are all known to show scintillations under alpha-particles from radium.

Thermoluminescence.—After exposure to neutrons, about thirty substances were found to emit light when they were heated on a small electric stove to a temperature considerably below that of red heat. The strongest effect was shown in fluorites from certain localities, kunzite, ThO_2 activated by Tb, and in $CaSO_4$, CaF_2, and $CdSO_4$ activated by Mn. The thermoluminescence is, in most cases, very dim and not comparable in intensity with that excited by x-rays. The intensity may be increased by mixing with the luminescent material some substance which reacts strongly with neutrons such as $GdSO_4$. The effect is diminished by screening the luminescent substance during exposure with boron carbide. The effect of surrounding some specimens such as fluorite and $CaSO_4$ excited by Mn, with cadmium metal during exposure is to increase the intensity of thermoluminescence excited because, although cadmium absorbs slow neutrons, it emits,[1] as a result of this absorption, radiations which are effective in excitation.

Summary of results.—(1) Luminescence is excited in some materials as a result of exposure to neutrons. In a material for neutron excitation it is desirable that the luminescent material contain some element which is highly reactive to neutrons and that it contain some heavy element capable of absorbing radiations such as gamma-rays. Materials excited by neutrons are excited also by x-rays, cathode rays or the radiations from radium. (2) Slow neutrons are more effective as a source of excitation than fast neutrons. (3) The intensity of luminescence may be increased by mixing with the luminescent material a small quantity of some material containing an element which is highly reactive to neutrons. (4) Excitation of luminescence by exposure to neutrons may be explained as follows: Neutrons react with the nuclei of certain atoms which form a component part of the luminescent substance or with the nuclei of atoms of some other substance highly reactive to neutrons which may be mixed with the luminescent substance or placed near it. As a result of this reaction, radiations are emitted which excite luminescence. Gamma-rays appear to be a factor in the excitation and secondary radiations and internal conversions may also play a part.

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FRANCES G. WICK
MABEL S. VINCENT

Department of Physics,
Vassar College,
Poughkeepsie, New York,
August 15, 1940.

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[1] J. G. Hoffman and R. F. Bacher, Phys. Rev. **34**, 644 (1938).

On the Isotopic Weights of Chlorine, Argon and Iron by the Doublet Method

With a mass spectrograph of Bainbridge-Jordan type whose resolving power is about 17,000, the isotopic weights of Cl^{35}, Cl^{37}, A^{40} and Fe^{56} were measured by the doublet method.

The cylindrical discharge tube employed in this work was provided with an aluminum bar anode and an iron concave cathode. All photographic plates used were of the Schumann type prepared in our laboratory.

The plate was calibrated with the bromine isotopes Br^{79} and Br^{81}, for the mass difference of which we accepted 250.0 packing fraction units as determined by Aston.

(1) *Chlorine.*—Three doublets $C^{12}{}_3-HCl^{35}$, $C^{12}{}_3H-Cl^{37}$ and $C^{12}{}_3H_2-HCl^{37}$ were obtained by electric discharge through the vapor mixture of normal hexane and carbon tetrachloride.

These mass differences were as follows:

$$C^{12}{}_3-HCl^{35}=246.7\pm1.7,\quad(\Delta M.10^{-4})$$
$$\left.\begin{aligned}C^{12}{}_3H-Cl^{37}&=421.7\pm0.9,\\ C^{12}{}_3H_2-HCl^{37}&=419.8\pm1.1,\end{aligned}\right\}420.8\pm0.7.$$

From these results and from the values $H^1=1.00812\pm0.00004$ [1] and $C^{12}=12.00394\pm0.00018$,[2] the following isotopic weights of Cl^{35} and Cl^{37} were obtained:

$$Cl^{35}=34.97903\pm0.00038,$$
$$Cl^{37}=36.97786\pm0.00036.$$

(2) *Argon.*—By introducing the mixture of normal hexane vapor and argon into the discharge tube, the two doublets $C^{12}{}_3H_4-A^{40}$ and $C^{12}{}_3H_5-HA^{40}$ were photographed. The following mass differences of these doublets are obtained,

$$C^{12}{}_3H_4-A^{40}=679.3\pm0.7, \quad (1)$$

$$C^{12}{}_3H_5-HA^{40}=693.0\pm2.3. \quad (2)$$

From the results (1) and (2), the isotopic weight of A^{40} is as follows:

(1) $A^{40}=39.97637\pm0.00057$,
(2) $A^{40}=39.97500\pm0.00062$.

At present, we have no interpretation of the discrepancy between the mass differences of the above two doublets.

(3) *Iron.*—The wide and faint doublet $C^{12}{}_4H_8-Fe^{56}$ was photographed, from which we obtained 1235 ± 17 as its mass difference. The ion of Fe^{56} was considered to originate from the iron cathode. We obtain a provisional value 55.9572 ± 0.0012 as the isotopic weight of Fe^{56}. Its packing fraction -7.7 is smaller than Dempster's value -7.0 ± 0.4.[3]

T. OKUDA
K. OGATA
K. AOKI
Y. SUGAWARA

Physical Laboratory,
Osaka Imperial University,
Osaka, Japan,
July 22, 1940.

[1] F. W. Aston, Proc. Roy. Soc. **A163**, 391 (1937).
[2] Asada, Okuda, Ogata and Yoshimoto, Nature **143**, 797 (1939).
[3] A. J. Dempster, Phys. Rev. **53**, 64 (1938).

Electrostatic Generator with Concentric Electrodes

Our 2.6-million-volt generator has been described in previous issues of this journal.[1, 2] It was housed in a tank 20 ft. long and $5\frac{1}{2}$ ft. in diameter, with a working pressure of 100 lb. per sq. in. With only high pressure air in the tank this generator was limited to approximately 2.2 Mv by sparking directly across the air gap. As Freon was added to the high pressure air the direct spark-over voltage rose, but at 2.6 Mv sparking set in along the charging belt and additional Freon then gave no improvement.

This apparatus was dismantled, the tank was provided with a large, removable end plate, and new apparatus was installed as shown in Fig. 1. In the new installation the apparatus is supported from one end only by three Textolite tubes, *T*, of $3\frac{3}{4}$ inches outside diameter and $\frac{3}{8}$ inch wall thickness. This arrangement gives a charging belt length and a minimum insulator length (except for insulator *t*) almost twice as great as in the previous installation. The new tube consists of 62 sections, each $2\frac{1}{2}$ inches long, compared to 53, $2\frac{1}{2}$-inch sections for the old tube.

Electrodes *B* and *C* were expected to give improvement in the spark-over voltage for two reasons: First, they provide a more uniform gradient between electrode *A* and the tank wall; and second, test work indicated that high pressure air withstands higher gradients in a short gap than in a long gap.

Adjustable corona gaps provide potential distribution along the supporting structure and determine the potentials of electrodes *B* and *C* relative to the potential of *A*. Insulator *K* supports the hemispherical end of electrode *C*. Flexing of the structure by electrostatic forces would probably cause trouble if this electrode were supported only from its open end.

The potential of electrode *C* is measured by means of a generating voltmeter. This measurement also gives a rough indication of the total voltage. In a recent test run the ion beam was brought out into the air through an aluminum foil with an air equivalent of approximately 12 mm and the range of the proton beam, measured visually, was used to determine the generator voltage.

With an air pressure of 100 lb./in^2. in the tank, the maximum range of the proton beam was 18 cm (room temperature 27.2°C, barometric pressure 742 mm of Hg). After adding the air equivalent of the aluminum foil this gave a voltage of 3.5 Mv from the 1937 range curve of Bethe and Livingston. When 10 lb. (weight) of Freon was added, the maximum range of the proton beam was 27 cm, giving a voltage of 4.3 Mv. The voltage was limited by direct spark-over, although insulator *K* gave some trouble. With 15 lb. of Freon the maximum range was 29 cm (4.5 Mv). The voltage was then limited by sparking along insulator *K*. In previous tests it withstood higher voltage, but in recent

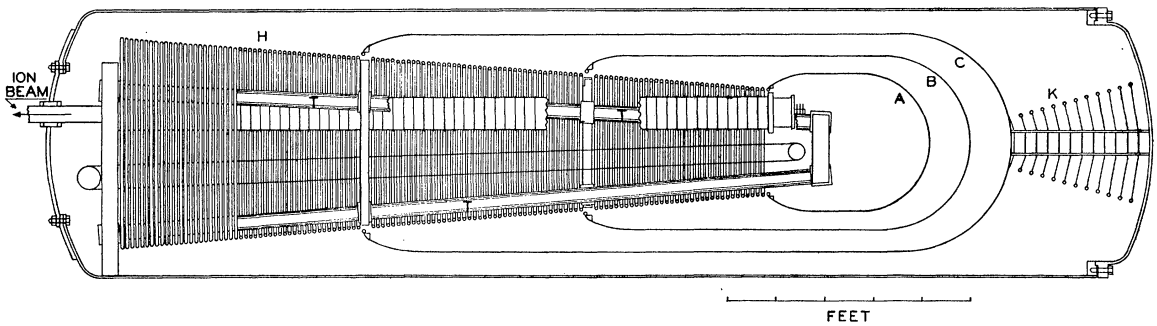

FIG. 1. *A*, *B*, *C*; aluminum shells $\frac{1}{8}$ inch thick. *T*; Textolite tubes $3\frac{3}{4}$ inch outside diameter and $\frac{3}{8}$ inch wall thickness. Each Textolite tube is equipped with aluminum rings, made up from $\frac{1}{2}$-inch diameter rod, clamped tightly to the Textolite and spaced $1\frac{1}{4}$ inches apart (not shown in the drawing). *H*; aluminum hoops supported by studs with saddle-shaped ends. One stud projects from each ring. *K*; Textolite tube equipped with metal diaphragms and a corona gap system for potential distribution. Porcelain rings for the accelerating tube are $2\frac{1}{2}$ inches long, corrugated inside and outside. The separating electrodes are steel spinnings. Gaskets of rubber dam 0.01 inch thick make the seals. Springs apply a compressional force of 5000 lb. on the tube. Belt; cotton fabric, woven endless, 16 inches wide.