A NEW EFFECT PRODUCED BY ACTION OF X-RAYS ON MATTER

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Abstract

This paper describes an investigation of the weak radioactivity which some heavier elements acquire after being irradiated by x-rays. The first method of investigation of this effect is based on the measurement of the ionization produced by the sample after irradiation. The second method consists in the counting of the scintillations produced by particles emited by the irradiated substance. The combination of these two methods makes it possible to determine the mean energy of each emitted particle. This energy is of the order of 10^{-6} erg. It seems quite impossible that particles of such energy could be emitted from the extranuclear electrons. It is much more probable that they originate in the atomic nuclei. On the other hand it is not possible to explain such results by radioactive contamination. Some possible explanations of the phenomena observed are discussed.

I. The Ionization Effect Afteer X-Ray Irradiation

A. SMITS[2] some years ago pointed out, that lead irradiated by relatively very soft x-rays acquires feeble radioactive properties. The following apparatus shown in Fig. 1. was constructed in our institute for a more de-

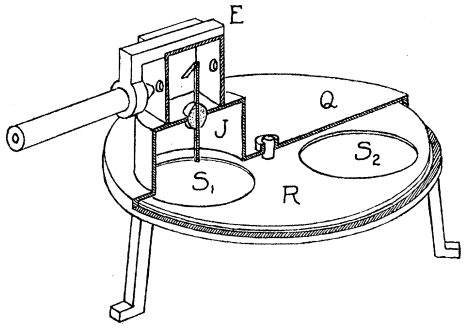

Fig. 1. Diagram of apparatus. E is the electrometer; J, the ionization chamber; R, the rotating disk; S_1 and S_2, the samples.

tailed investigation of this effect under conditions excluding the possibility of spurious effects due to radioactive contamination. It consists of the usual electrometer E for radioactivity measurements connected with a suitable ionization chamber. This chamber is connected with a cylindrical box Q in which is set a perforated resolving circle R for holding the materials to be tested. By revolving the circle any sample can be placed under the ionization

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[2] A. Smits and W. A. Frederikse, Zeits. f. Elektrochemie **34,** 350 (1928); A. Smits and H S. Vening, Meinesz Proceedings, Amsterdam **33,** 1 (1930).

chamber. Since the system is closed as tightly as possible, the testing samples in the cylindrical box are well protected from outside radioactive contamination. It is easy to remove the electrometer and to close the hole in the ionization chamber by means of a special cover, thus making it possible to expose the sample to x-ray irradiation. In addition to this the circle with samples can be revolved in such a manner that the irradiation of all samples will be uniform.

We used for the irradiation a Coolidge x-ray tube with tungsten anode, working at 140 kv_{eff} and 2 m.a. The time of irradiation was 30 minutes; the mean distance from the anode of the tube to the samples was 40 cm. The x-rays passed through the lead cover of the cylindrical box of 2 mm thickness.

After irradiation the instrument was removed to another room; the electrometer was placed back on the ionization chamber and the current in this chamber, produced by the different samples, was measured.

Preliminary experiments showed that, in accordance with the results of A. Smits, light elements like aluminum do not produce any effect. It was therefore possible to determine the zero current of the electrometer by placing an aluminum sample under the ionization chamber.

With that method of working the ionizing power of different elements after irradiation could be investigated. This ionizing power can be expressed as the difference between the ionization currents before and after irradiation produced by a unit of surface (1 cm^2) of the sample and measured by the number of ion pairs formed in unit of time (1 second).

The surface of all investigated samples was cleaned by scraping. Some days before the experiments, the box with the samples was closed and the circle was rotated for a long time. By this means we obtained a uniform distribution of radioactive matter and the dissociation of those contaminations, which are sufficiently unstable.

At first the effect was investigated as a function of time after irradiation. The results for lead obtained by Mrs. H. A. Gordon are given in Table I.

TABLE I. *Results for lead.*

J = ionization current, (ion pairs formed per sec.)	t = time in min. after the end of x-ray irradiation
910	10
560	20
390	33
230	50
110	70
60	90

Table I shows that the diminution of the effect after irradiation is of such a magnitude that the effect can be measured without difficulty. By extrapolating it is possible to determine the value of J directly after the end of irradiation. Mean values of J determined in the above mentioned way with a great number of samples of the several elements are given in the Table II. All these measurements have been made by Mrs. H. A. Gordon.

TABLE II. *Ionization current due to radiations from various metals after x-ray irradiation.*

Element	Atomic number	J
Al	13	no effect
Zn	30	no effect
Sn	50	170
W	74	550
Hg	80	1120
Pb	82	1390
Bi	83	1000

The mean error of J in Table II is about 20 percent. The experiments described did not make it possible to explain the origin of the observed ionization current. For such an explanation it is necessary to investigate the phenomenon from another point of view.

II. SCINTILLATIONS AFTER X-RAY IRRADIATION

The other method used by us is based on the counting of scintillations. Preliminary experiments described in another paper[3] showed, that after x-ray irradiation the heavier elements produce some feeble scintillations similar to the scintillations of α-particles of low energy.

Knowing the number of scintillations produced in 1 second by a unit of surface of a sample it is possible to determine the mean energy of each particle, as well as the energy losses of the particle in the surface layer of the sample. Table III shows the primary energy E of the particles emitted by unit of surface of the sample in 1 second (du/dt) extrapolated to the moment of stopping the x-ray irradiation.

TABLE III. *Energies of particles producing scintillations.*

Element	dn/dt	E
Zn	no effect	
Sn	0.038	0.5×10^{-6} erg.
W	0.087	0.7
Hg	0.095	1.3
Pb	0.090	1.7
Bi	0.089	1.3

The values of E show that the energy of the observed particles is much less than the energy of the α-particles emitted by radioactive substances. For a closer investigation of the scintillation effect we have constructed a specially designed apparatus.

A partial section of this instrument is given in Fig. 2. It consists of a revolving brass cylinder placed in a tight enclosed covering. The cylinder is driven by an electric motor with a suitable transmission. The testing sample put on the cylinder is a ring of suitable size.

The cylinder with the sample can be irradiated by x-rays at one side through an aluminium filter of 1 mm thickness. In these experiments we used an x-ray tube working only at 90 kv_{eff} and 3 m.a. We have determined that when the tension of the current in the tube was lowered from 140 kv to

[3] G. I. Pokrowski, Zeits. f. Physik **63**, 561 (1930).

90 kv the effect changed only very little. On the opposite side of the covering was placed a microscope with a zinc blende screen for counting the scintillations. The x-ray tube and the observer were separated by a wall in which the instrument was placed. Everywhere lead protection was so arranged that the minimal thickness of it met by x-rays should be equivalent to 1 cm of lead.

The inside of the rotating hollow cylinder was also covered with lead so that during the operation of the tube no luminiscence should be observed on the screen used for counting scintillations.

In addition the set was earthed before beginning the experiment. The box with the rotating cylinder and sample was closed for some days and the cylin-

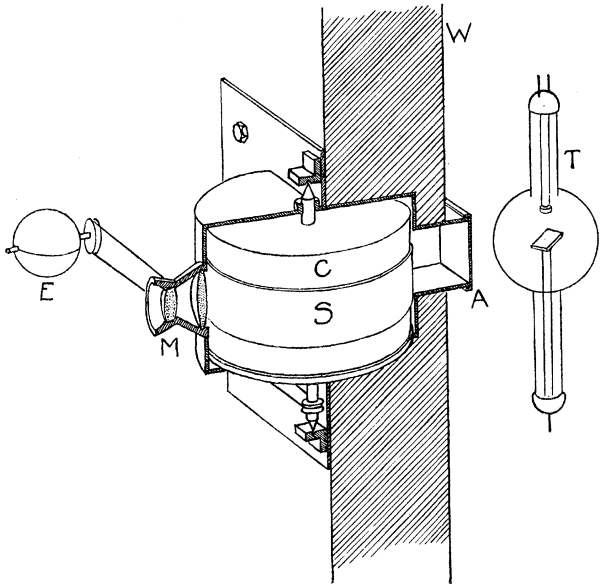

Fig. 2. Diagram of apparatus used in counting scintillations. *C* is the rotating cylinder; *S*, the sample under investigation; *M*, a microscope; *E*, an electric motor; *A*, aluminum window; *T*, x-ray tube; *W*, the wall.

der was rotated for a long time for the same purpose as with the apparatus for ionization measurement.

The principal results obtained as described above could be easily verified with this set.

The results obtained with lead, for instance, are given graphically in Fig. 3. Here dn/dt is the number of scintillations on the screen per second, t being expressed in days. Each point marked with an arrow was obtained during an x-ray irradiation. The number of revolutions of the revolving cylinder was 120 per minute. Thus the lapse of time between irradiation and observation was of the order of 0.25 second. The surface of the screen for counting scintillations was about 3 cm^2.

It is seen from Fig. 3 that in the case of many irradiations each about 2 hours in duration, the lead could be activated for a period of some days and

the effect could be made very large. The curve in Fig. 4 is based on a very large number of observations—approximately 181,000 scintillations. Taking into consideration the relative weakness of the scintillations here observed and the very large field of observation one must state that the experiments described are very laborious.

III. Discussion of the Possible Explanation of the Effect

The results indicate that the ionization effect is probably produced by the particles emitted by heavier elements after x-ray irradiation. These particles are like α-particles. Their energy has an order of 10^{-6} erg. It is quite improbable that particles of such energy could be emitted from the extranuclear

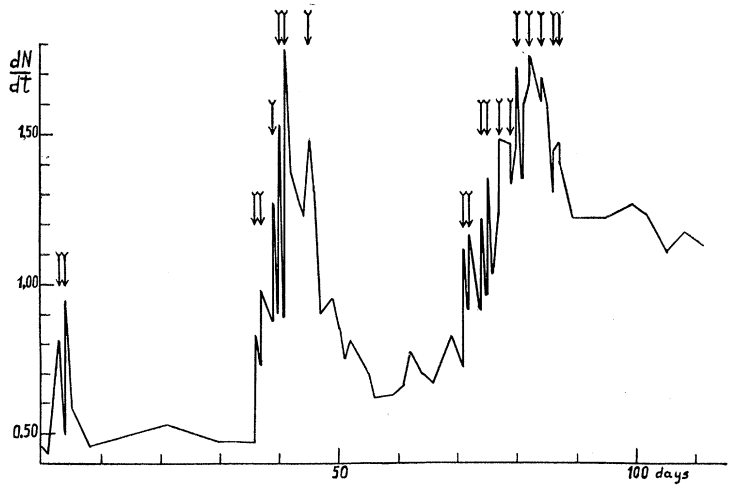

Fig. 3. Number of scintillations per second from lead. The arrows mark observations under x-ray irradiation.

electrons. It seems that the origin of such a phenomenon must be located in the atomic nucleus.

If nuclear transformations are examined from a thermodynamical point of view and if the equivalence of matter and energy is taken into consideration, it will not be difficult to divide all possible phenomena into exothermal and endothermal processes. Thus, if a given nucleus is splitting into two other nuclei and if the sum of their masses is not equal to the initial mass, then either an emission or an absorption of energy will result.

Obviously, when there is a decrease of mass, energy is liberated and, vice versa, energy absorption must be accompanied by a suitable increase of total mass. With the aid of accurate data concerning atomic weights, it can be readily shown that some cases of disintegration are accompanied by the emission of energy. The greatest energy per unit mass will be liberated when α-particles are thrown out of the nuclei the atomic numbers of which are greater than 40.[4]

[4] See G. I. Pokrowski, Zeits. f. Physik **63,** 561 (1930); G. Gamow, Proc. Roy. Soc London **A126,** 632 (1930).

It is possible that the energy necessary for starting such an exothermal process may be relatively very small, and it is therefore quite possible that x-ray quanta can liberate from thermodynamical unstable nuclei particles with energy of a much higher order than that of the quanta themselves. But certainly only very few nuclei, perhaps only an isotope of the activated element, can be thus influenced by means of irradiation. This follows from the weakness of the effect described. A calculation based on the experiments discussed shows that only one nucleus in 10^{15} can be influenced by irradiation.

A more detailed exposition of the theory of the phenomenon is given in another paper.[5]

[5] G. I. Pokrowski, Ann. d. Physik (1931).