The Nuclear Energies of Aluminum and Beryllium

According to the theory recently suggested by the writer[1] the nuclei of the radioactive atoms have possible energies equal to multiples of 3.85×10^5 electron-volts. This idea was suggested by the fact that the gamma-ray, beta-ray and disintegration energies form many pairs with sums equal to multiples of 3.85×10^5 electron-volts.

When aluminum is bombarded by alpha-rays it emits protons and there are several alpha-ray energies for which the proton emission has maximum values. These alpha-ray energies probably correspond to energy levels of the aluminum nucleus. The values found for these resonance levels by Chadwick and Constable[2] are 52.5, 48.6, 44.9 and 40 with 10^5 electron-volts as unit. The differences between these energies are 3.9, 3.7 and 4.9 which do not differ from 3.85 by amounts greater than the possible errors.

In the same way when beryllium is bombarded by alpha-rays the emission of neutrons varies with the energy of the rays and has maximum and minimum values. The minimum values found by Kirsch and Slonek[3] occur at about 52.5, 48.5, 44, 40 and 37 and the differences between these values are equal to 4, 4.5, 4 and 3. These differences are not far from 3.85. The mean value is 3.88.

These results together with those for the radioactive atoms, suggest that the nuclei of the atoms of all the elements have possible energies equal to $3.85n$ or to $3.85n+c$ where $n=0, 1, 2, 3\cdots$ and c is a constant.

H. A. WILSON

Rice Institute,
Houston, Texas,
February 27, 1934.

[1] Wilson, Phys. Rev. **44**, 858 (1933).

[2] Chadwick and Constable, Proc. Roy. Soc. **A135**, 48 (1932).

[3] Kirsch and Slonek, Naturwiss. **4**, 62 (1933).

Radioactivity from Carbon and Boron Oxide Bombarded with Deutons and the Conversion of Positrons into Radiation

In a note to *Science* we announced that we had observed radioactivity from certain light elements after they had been bombarded with deutons of 0.9×10^6 e.v. energy, and, in particular, that we had been able to verify the prediction of Curie-Joliot and Joliot,[1] that carbon bombarded with deutons should yield the same radioactive end product as they obtained by bombarding boron with α-particles. The particles which we obtained from the bombarded carbon were identified as positrons having energies distributed from about 0.7×10^6 e.v. downward, by Dr. Carl D. Anderson and Seth H. Neddermyer, using a Wilson cloud chamber. We have since investigated this and some other processes more closely, and have determined the decay constants with more precision. We have also found that γ-rays are associated with the radioactivity in at least some of these processes.

The procedure is as follows: A target of the substance to be investigated is first bombarded for a suitable length of time, generally fifteen minutes, with an ion current of 10 microamperes, consisting principally of H^2, at 0.9×10^6 volts. The target is then removed from the tube and placed in the bottom of an ionization chamber, and the rate of production of ionization as a function of time is measured. The ionization observed is attributed to particles ejected from the target, and also to γ-rays, if such are present. In order to separate the effect contributed by γ-rays alone, a second ionization chamber is placed directly below the first. The walls and linings of the chambers are sufficiently thick to prevent charged particles from entering the lower chamber and giving a direct effect. Therefore any ionization recorded in the lower chamber is to be attributed to γ-rays, unless neutrons are present, which does not seem probable.

In Fig. 1 are plotted the log intensities for the two chambers against time after bombardment when a carbon target was placed inside the upper chamber. Curve I refers to the upper chamber and curve II to the lower chamber.

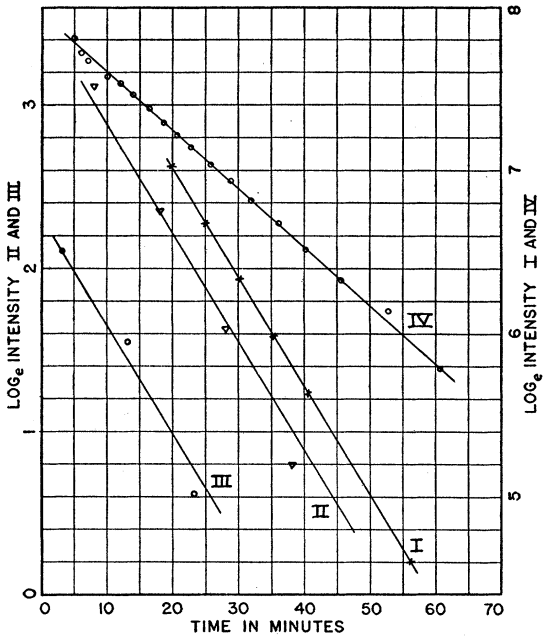

FIG. 1. Intensity of ionization as a function of time after bombardment due to: I, positrons from carbon target; II, γ-rays from carbon; III, γ-rays from carbon after 7.1 cm lead filtration; IV, positrons (?) from B_2O_3 target.

It is seen from these plots that the half period (10.3 minutes) is the same within the experimental error, whether determined from the rate of emission of positrons or from the γ-rays associated with the process. This would

[1] Curie and Joliot, Comptes Rendus **198**, 254 (1934).

seem to indicate that the same radioactive process is responsible for both the positrons and the γ-rays, and the most attractive assumption is that the γ-rays have their origin in the annihilation of the positrons together with electrons.

To determine the absorption coefficient of the γ-rays, we made provision for interposing a sheet of lead 7.1 mm thick between the two chambers. For the first half hour after bombardment, readings were taken every minute on the lower chamber and the lead was put in and removed at intervals of five minutes. We thus obtained alternately four one-minute readings with lead and four one-minute readings without lead. These are plotted on a log scale in Fig. 1, curves II and III, each set of four one-minute readings being averaged. The log difference between the positions of the two curves is 1.23, corresponding to a linear absorption coefficient of 1.58 per cm. Since the source was very close to the lead sheet, a large part of the radiation would necessarily pass through the lead at an angle, tending to compensate the effect of scattering. A calculation from the Gray formula and the Klein Nishina scattering give as the absorption coefficient for 24 x.u. (mc^2) radiation 1.67 per cm, so it seems that the quantum energy of the radiation here observed is, to within our experimental error, equal to mc^2, the rest mass of the electron.

In order to ascertain further that the γ-rays originate in the annihilation of the positrons, we performed the following experiment. A piece of freshly bombarded carbon was placed, active side up, directly above one of the chambers. Supposedly in this case half the positrons are ejected in the downward direction and are annihilated in the carbon, while the other half escape and are annihilated in the air at a considerable distance away from the target and the ionization chamber. However, by covering the target with a sheet of some dense material, the positrons can be prevented from escaping, and they will all be annihilated in, or very near the carbon. Alternate readings were made on the chamber with the carbon covered with aluminum and with it uncovered. The result was that the rate of production of ionization in the chamber was about twice as great with the carbon covered as with it uncovered. In Fig. 2, curve I refers to carbon covered with aluminum, curve II to carbon without aluminum.

As an additional check, we wished to compare the number of γ-ray quanta emitted with the number of electrons. By calibrating the ionization chamber against a standard radium source, we determined that immediately after bombardment about 6×10^4 photons per second are emitted from the carbon target. Making appropriate allowance for solid angle and considering that half of the positrons die in the target and the other half on the walls of the upper chamber, it turns out that there are 500 ion pairs to be associated with each positron passing through the upper chamber. The mean length of path in the chamber is approximately 5 cm, therefore the positrons would be producing, on the average, 100 ions per cm of path, which is a reasonable figure and constitutes evidence that the number of photons is very nearly twice the number of positrons.

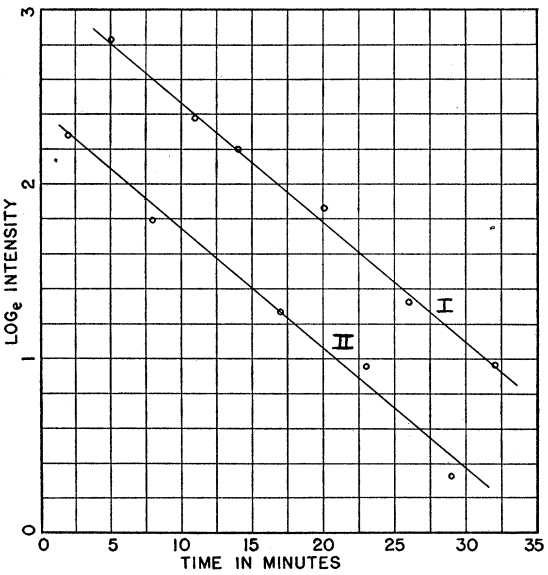

FIG. 2. Intensity of ionization in the chamber: I, with the carbon covered; and II, with the carbon uncovered.

By comparing this with our previous work on carbon,[2] it appears that carbon can be transformed by deutons in the following two ways:

$$(1)\quad {}_6C^{12}+{}_1H^2\rightarrow{}_6C^{13}+{}_1H^1+\gamma,$$

$$(2)\quad {}_6C^{12}+{}_1H^2\rightarrow{}_7N^{13}+{}_0n^1$$
$${}_7N^{13}\rightarrow{}_6C^{13}+(+\epsilon).$$

From our estimate of the number of photons obtained in each case, we are led to believe that the first process takes place about 10 times as frequently as the second. This is on the assumption that the annihilation of one positron produces two photons.

A search for radioactivity produced in a number of other light elements bombarded with deutons was made, namely, LiF, Be, B_2O_3, Mg and Al. The B_2O_3 target gave an effect which was somewhat smaller than that obtained from carbon, and decreased at a rate corresponding to a half life of about 20 minutes. γ-rays were observed in the lower chamber, and the ratio of the effects in the two chambers was the same as in the case of carbon. Although this target has not yet been tested in a cloud chamber, the activity here concerned seems to be of the same nature as that of carbon, and by analogy we suppose that the transmutations are

$${}_5B^{10}+{}_1H^2\rightarrow{}_6C^{11}+{}_0n^1,$$
$${}_6C^{11}\rightarrow{}_5B^{11}+(+\epsilon).$$

A curve showing the rate of decay of the activity of the B_2O_3 target is shown as curve IV in Fig. 1. Appreciable

[2] Lauritsen and Crane, Phys. Rev. **45**, 345 (1934).

activity was observed from all the other substances, but at least a large component of the effect, seemed to have a half life of 10 minutes, which would lead one to suspect that it was due to carbon contamination on the surface of the targets. A closer investigation of their rates of decay will help to decide whether or not carbon is responsible for the whole effect.

We wish again to express our gratitude to the Seeley W. Mudd Fund, through which this work was supported.

H. R. CRANE
C. C. LAURITSEN

Kellogg Radiation Laboratory,
California Institute of Technology,
March 1, 1934.

A Method for Investigating Electrical Breakdown Processes

The ordinary methods of studying spark gap and related types of electrical discharges depend upon the Kerr cell, the rotating mirror, the cathode-ray oscillograph or the use of travelling waves in some type of transmission system. In the Kerr cell and rotating mirror methods luminosity must appear in the gap before any information can be obtained. This luminosity appears after the breakdown process is at least partially completed and it is consequently difficult or impossible to determine the initial conditions of the discharge. The other two methods obviously can yield only information concerning the potential and current-time relations.

The method which we are now using enables us to study the processes occurring before the appearance of luminosity and to obtain the ion distribution before breakdown has been completed. It consists in producing the discharge in a Wilson cloud chamber and was suggested in principle by Professor J. W. Beams. This of course has the disadvantage that the processes must be investigated in an atmosphere saturated with water vapor but for a study of breakdown mechanism this is relatively unimportant.

The circuit which is in use is designed to give voltage impulses of the shortest possible duration. The impulses are applied to the end of a short two-wire transmission line from a condenser spark gap circuit. The sending end of the line is shunted by a second gap arranged so that it is about 30 percent overvolted and also irradiated by ultraviolet light from the first gap. The duration of the voltage impulse applied to the line corresponds consequently to the time taken to build up the voltage across the shunted gap plus the time necessary for the gap to break down. Since this gap is overvolted and at the same time irradiated its time lag is very short. The total duration of the impulse is certainly not over 10^{-7} sec. The cloud chamber is placed at the terminal end of the line which is six meters in length. This end is terminated by the characteristic impedance of the line to prevent reflections. The expansion of the chamber is synchronized with the electrical system by using a third gap energized from a separate transformer to start the discharge in the supply circuit by means of ultraviolet irradiation. The time of the irradiation can be adjusted with respect to the time of expansion. It is perhaps needless to state that great care has been taken to prevent any extraneous voltage impulses from occurring on the transmission system.

For our preliminary work we have used as electrodes a steel needle and a 1/8 inch brass rod rounded to hemispherical shape at the end. With the needle negative the ion cloud is cone shaped, and rather uniform in appearance, with the apex at the needle. Its length is variable sometimes extending the entire distance between the electrodes and sometimes only a part of the distance. It is relatively easy to obtain, appearing on 80 percent of the discharges. With the needle positive the appearance is decidedly different. The discharge is in the form of single streamers usually multiple in number. They have the appearance of single particle tracks but as yet their exact nature has not been determined. They are, however, due to the field as they never appear without the voltage impulse. They are relatively difficult to obtain and are very sensitive to voltage change, a slight increase in voltage producing a diffuse cloud throughout the chamber of no very definite shape.

This study is being continued with electrodes of various geometrical arrangements and with the chamber in a magnetic field, etc. The method is also applicable to the study of breakdown over surfaces and some experiments of this kind are in progress. We believe that it will give information that can be obtained by no other known method.

L. B. SNODDY
C. D. BRADLEY

University of Virginia,
Rouss Physical Laboratory,
March 3, 1934.