The Induced Radioactivity of Krypton and Xenon

EDWARD P. CLANCY
Harvard University, Cambridge, Massachusetts
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Irradiation of krypton with deuterons of 11 Mev produces krypton activities with half-lives of 102 minutes, 4.0 hours, and about 35 hours. When selenium is bombarded with 22-Mev alpha-particles, there appear krypton activities of 114 minutes and about 33 hours. The 114-minute period coincides with that reported by other investigators as due to a krypton isotope growing out of Br^{83}, and hence is assigned to Kr^{83*}. The 102-minute period observed in deuteron irradiation is considered to be the same activity. Kr^{87}, an isotope which cannot be formed from alpha-particle reactions with selenium, is probably the source of the 4.0-hour activity. The weak 33–35 hour activity is due to Kr^{79} or Kr^{81}. Kr^{85} is presumed to have an activity long or fairly short. Irradiation of xenon with deuterons produces xenon activities of 68 minutes, 9.6 hours, and 5.4 days. Of these, the last also appears in the irradiation of tellurium with alpha-particles, and is due to Xe^{133}. The 9.6-hour activity is assigned to Xe^{135}. Xe^{137} is the most probable source of the 68-minute activity.

APPARATUS

A STUDY has been made of the induced radioactivity of the rare gases krypton and xenon. The results, many of which have already been reported briefly,[1,2] are here presented in more detail. Bombardments were made with the Harvard cyclotron, at energies of 11 Mev for deuterons and 22 Mev for alpha-particles.

A target chamber for irradiating the gases was constructed in the following way (Fig. 1). A flanged Pyrex pipe of two inches internal diameter was cut off and closed four inches from one of the flanged ends. This forms the bombardment chamber proper; a tube and stopcock permit the introduction of gas. By means of a cast bronze collar lined with a cushioning material, the flanged end is pressed down upon a brass plate, the seal being accomplished with a rubber gasket. In the center of the plate is a rectangular hole through which the beam comes. To prevent the bombarding particles from striking the glass at the end of the chamber, a shallow molybdenum cup is provided. The wire supporting this cup may be connected to the beam galvanometer at the control desk to give a measure of the current traversing the chamber. Since no provision is made for cooling the cup, the beam current must be limited to about 10 microamperes.

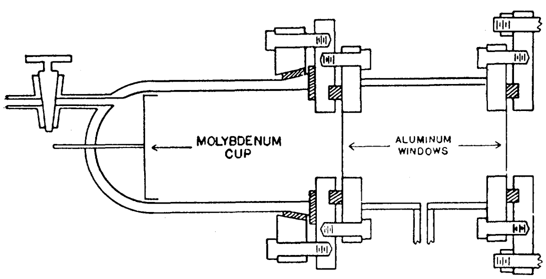

FIG. 1. Gas bombardment chamber.

Figure 1 shows that there is an intervening chamber which the beam must traverse. This chamber, kept evacuated, has holes at each end closed by 1-mil aluminum windows supported on grids. The latter are not shown. Were there only one window between the target chamber and the cyclotron chamber, fracture of this window would mean losing a quantity of rather expensive gas, and possible damage to the cyclotron itself. The whole assembly is sealed with rubber gaskets, and is bolted to the target opening of the cyclotron.

A glass ionization chamber for the radioactive gases was made as shown in Fig. 2. The outer electrode consists of a platinum film on the inside of the glass, covering some two-thirds of the surface. The film was formed from "platinizing paint." Between this film and the point where the central electrode enters the chamber

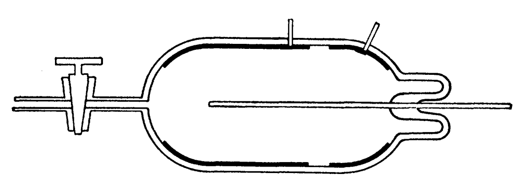
FIG. 2. Gas ionization chamber.

[1] Edward P. Clancy, Phys. Rev. **58**, 88 (1940).
[2] Edward P. Clancy, Phys. Rev. **59**, 686A (1941).

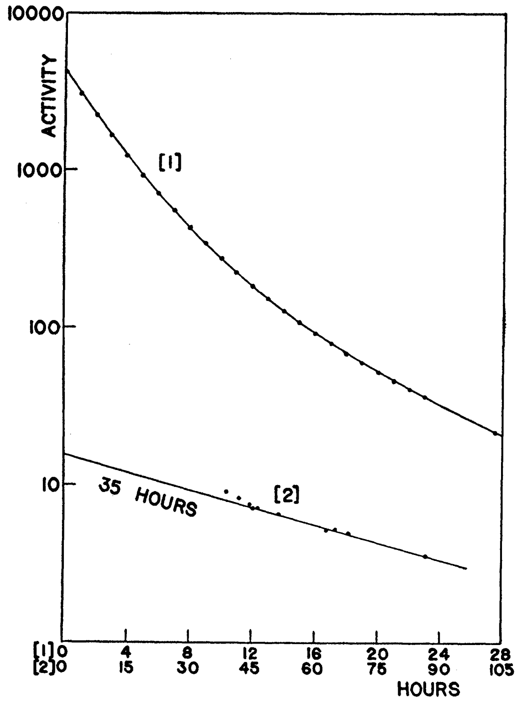

FIG. 3. Total activity of Kr from Kr+D. Activity is expressed in arbitrary units.

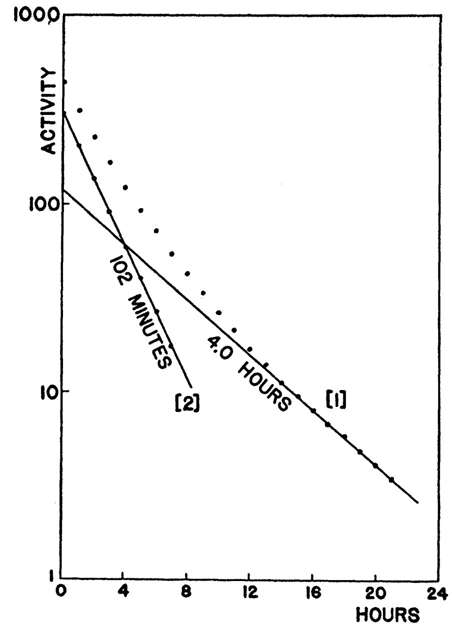

FIG. 4. Kr from Kr+D. Curve (1) represents the total activity indicated in Fig. 3, minus the 35-hour component. Curve (2) is the result of subtracting from (1) the 4.0-hour component.

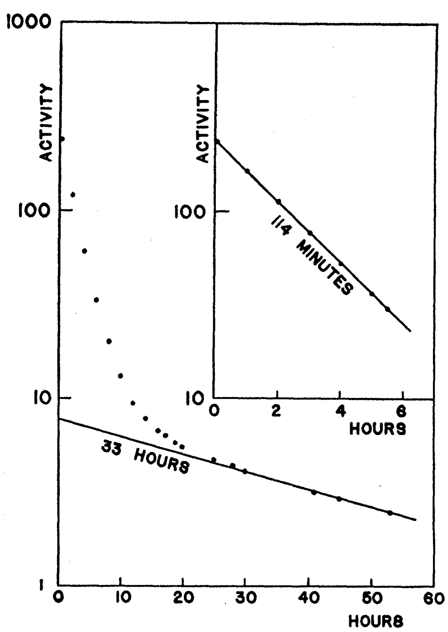

FIG. 5. Kr activities produced by alpha-particle irradiation of Se. The 114-minute activity is the result of subtracting the 33-hour component from the total activity.

there is a strip of film which forms a guard ring. Wires sealed in the glass wall make contact on the inside with the films. A supporting clamp holds the device in a vertical position above an ordinary ionization chamber, whose window has been removed to permit the central electrode of the glass ionization chamber to be fastened to the same electrode of the ordinary chamber. The latter chamber is connected to a d.c. amplifier using an FP54 electrometer tube. Recording is done automatically by means of a revolving drum covered with sensitized paper, upon which the galvanometer spot falls. An auxiliary device causes a zero reading to be taken every six minutes.

The transfer of gas from bombardment chamber to ionization chamber is effected by means of a Toepler pump. Connections are made with ground glass joints.

RADIOACTIVE KRYPTON ($Z=36$)

Irradiation of krypton with deuterons produced strong activities with periods of 102 minutes and 4.0 hours, and a weak activity of about 35 hours. The decay curve is shown in Fig. 3, and the subtracted curves in Fig. 4. These results are only in rough agreement with those of Snell,[3] who, in the only previous irradiation of krypton, reported deuteron-induced activities of 74 minutes, 4.5 hours, and about 18 hours.

In the hope of obtaining further information to make possible isotope assignments, selenium ($Z=34$) was irradiated with alpha-particles. Such bombardment might be expected to produce krypton isotopes by (α, n) reactions. At the end of the irradiation the selenium was placed in a glass tube, the tube was evacuated, and the selenium was boiled to drive out the active krypton. Then the tube was cooled in CO_2-acetone slush to condense any active bromine ($Z=35$) that might have been formed by an (α, p) reaction, and finally the krypton was allowed to flow into the ionization chamber. A strong activity with a period of 114 minutes was observed, and also a weak activity of about 33 hours. These are shown in Fig. 5.

The 114-minute period can be assigned to the excited level of the stable isotope Kr^{83} (which decays by a gamma-ray transition to the ground state), since the period coincides with that reported for this isotope by Langsdorf and Segrè.[4] These investigators found a radioactive Kr^{83}, of 113-minute period, growing out of Br^{83}. In the present work, Kr^{83*} is being formed, either directly by the reaction

$$Se^{80}(\alpha, n)Kr^{83*},$$

or indirectly according to the reactions

$$Se^{80}(\alpha, p)Br^{83}$$
$$Br^{83} \rightarrow Kr^{83*} + e^-.$$

The 102-minute period observed in deuteron irradiation of krypton is obtained upon the second subtraction from the decay curve, and the margin of error is therefore likely to be large. It is probable that this activity is really that of Kr^{83*}, formed by a (d, p) or (d, d) reaction. The fact that the 4.0-hour period is not produced in the alpha-particle bombardment of selenium means that this activity must be assigned to Kr^{87}, an isotope which cannot be formed from alpha-particle reactions with selenium.

Other investigators[5] have irradiated bromine with protons, separated the krypton product, and observed a long period of 34 hours due to Kr^{79} or Kr^{81} formed by a (p, n) reaction. The weak 35-hour period found in the present work can probably be assigned to the same isotopes. When this activity is produced by alpha-particle bombardment, the reaction has therefore been

$$Se^{76,78}(\alpha, n)Kr^{79,81}.$$

We should expect Kr^{85} to appear from Se^{82} as the result of an (α, n) reaction when selenium is irradiated with alpha-particles. Since no activity other than the 114-minute and 33-hour periods was apparent, one must presume that the period of Kr^{85} is long or fairly short. In the latter case it might easily have been undetected in the present work, since there was necessarily a delay of several minutes between the end of the bombardment and the first reading.

RADIOACTIVE XENON ($Z=54$)

Deuteron irradiation of xenon produces activities with periods of 68 minutes, 9.6 hours, and

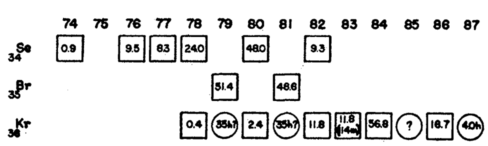

FIG. 6.

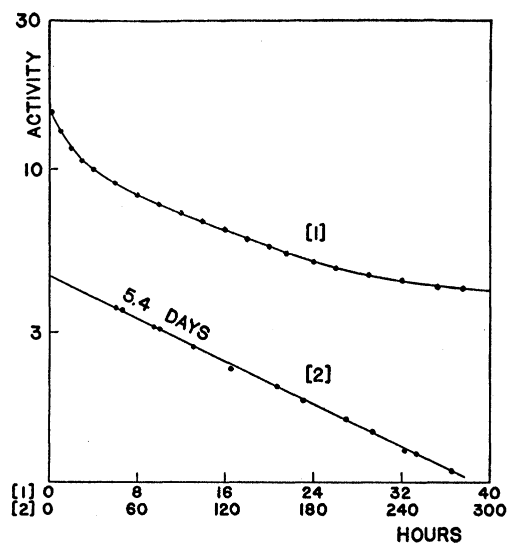

FIG. 7. Total activity of Xe from Xe+D.

[3] Arthur H. Snell, Phys. Rev. **52**, 1007 (1937).

[4] Alexander Langsdorf, Jr., and Emilio Segrè, Phys. Rev. **57**, 105 (1940).

[5] E. C. Creutz, L. A. Delsasso, R. A. Sutton, M. G. White and W. H. Barkas, Phys. Rev. **58**, 481 (1940).

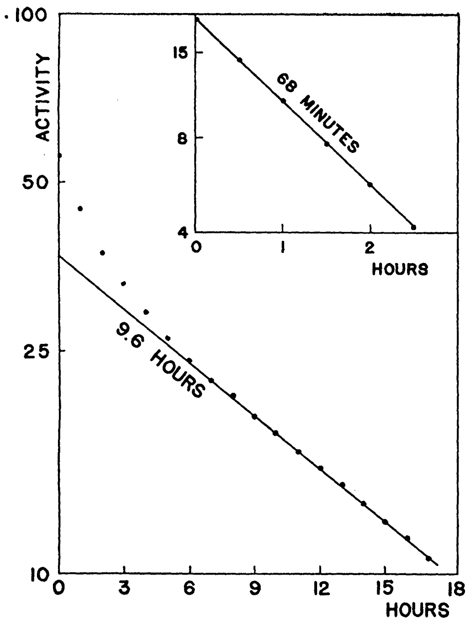

FIG. 8. Xe from Xe+D. The lower curve represents the total activity indicated in Fig. 7, minus the 5.4-day component. The curve in the inset is the result of subtracting the 9.6-hour component.

5.4 days. The decay curve is shown in Fig. 7, and the subtracted curves in Fig. 8. Of these periods, the longest is unambiguously due to Xe^{133}, since Wu[6] has found a 5-day period when activating the single isotope of caesium through an (n, p) reaction. This isotope has also been formed in the present investigation by bombarding tellurium with alpha-particles, through the reaction

$$Te^{130}(\alpha, n)Xe^{133}.$$

The experimental procedure here was practically the same as that used in the case of selenium, except that tellurium, on account of its high boiling point, could not be boiled directly in a glass tube. Instead, a small cup was constructed of sheet Nichrome. After irradiation, the tellurium was put in the cup, and the cup, placed in an evacuated glass vessel, was heated almost white-hot by means of an induction furnace. In addition to the long period due to Xe^{133}, there appeared an activity of about three hours. Definite assignment of this activity cannot be made, because it might result from any of several possible (α, n) reactions. It is not due to Xe^{137}, an isotope which cannot be formed in such a reaction. It is probably not due to Xe^{127}, since others[5] irradiated the single isotope of iodine with protons and found an active xenon with periods of 75 seconds and 34 days. A possible source is Xe^{125}, produced in the reaction $Te^{122}(\alpha, n)Xe^{125}$.

The 9.6-hour period produced in deuteron bombardment is undoubtedly the same as Wu's 9.4-hour xenon[6] obtained from an (n, α) reaction on barium, and assigned by her to Xe^{135}.

Assignment of the 68-minute period resulting from deuteron bombardment is uncertain. It can most logically be ascribed to Xe^{137}, since it did not appear among the activities produced in alpha-particle irradiation. No daughter activity

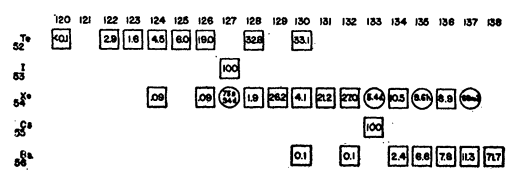

FIG. 9.

corresponding to the unstable decay product Cs^{137} has been found.

It is interesting that the 9.6-hour and 5.4-day periods correspond to xenon periods observed in uranium fission.[7,8]

The assistance and encouragement of Professor K. T. Bainbridge during the course of this work is gratefully acknowledged.

[6] C. S. Wu, Phys. Rev. 58, 926 (1940).

[7] E. Segrè and C. S. Wu, Phys. Rev. 57, 552 (1940).

[8] R. W. Dodson and R. D. Fowler, Phys. Rev. 57, 966 (1940).