The Radioactivity of Potassium

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The radioactivity of K was measured with a Geiger counter by placing a thick layer of the salt under a thin Al window. The results agree with those of Mühlhoff and give for the radioactive constants when corrected for the relative abundance of K^{40} the following values: $\lambda = (1.56 \pm 0.6) \times 10^{-17}$ sec.$^{-1}$, and $T = (14.2 \pm 3.0) \times 10^{+8}$ yr.

POTASSIUM has long been known to be radioactive. It emits two hard β-rays of velocity 0.83C and 0.93C in proportions 60 and 40 percent.[1] The disintegration constant has been determined by three different methods. Holmes and Lawson[2] using the data of Hoffmann give for the half-life, $T = 1.5 \times 10^{12}$ years and for the disintegration constant $\lambda = 1.40 \times 10^{-20}$ sec. Orban[3] by means of expansion chamber methods obtained $T = 5 \times 10^{12}$ years and $\lambda = 5 \times 10^{-21}$ sec. Mühlhoff,[4] from Geiger counter measurements, obtained $T = 1.5 \times 10^{13}$ years and $\lambda = 1.5 \times 10^{-21}$ sec. It will be observed that the various measurements differ by a factor of 10. The present experiment was undertaken, for the purpose of deciding which of these values was the more reliable.

Apparatus and Technique

The counter employed in these measurements was of the cylindrical form of metal construction. The counter chamber was made of heavy copper tube, with a perforated brass plate soldered to the lower end. An aluminum foil, 0.002 cm in thickness, was waxed over the plate. The area of the perforations was 1.4 square centimeters while the free inside dimensions of the chamber were 4.4×1.9 cm. The inner electrode was a polished nickel wire 0.15 cm in diameter supported by a hard rubber plug inserted in the upper end of the cylinder and extending for 2.5 cm down the barrel of the tube. The counter was operated at 1 cm of Hg pressure of dry air; the corresponding voltage lying in the range between 700 and 800. In normal operation the counter

was run at 20 volts above the starting potential; under these conditions slight changes in pressure did not affect the counting rate.

The counts were amplified and recorded by means of a three-tube vacuum circuit and watch recorder described by Johnson and Street.[5] The technique employed was to measure the number of counts in the absence of any radioactive material. This was followed by measurements on a sample of finely powdered KCl supported in a glass dish placed directly below the aluminum foil window. These measurements were all made for an interval of either 6 or 15 minutes each depending on the set of experiments. They were repeated over a period of many hours.

Since commercial potassium salts are apt to be contaminated with radium, the KCl used in these experiments was prepared from K_2SO_4 and $BaCl_2$; any radium that might be present is removed along with the $BaSO_4$. Various samples of salt crystallized during the evaporation of the KCl containing filtrate showed no variations in radioactivity.

In the previous measurements performed by Mühlhoff with a Geiger counter, the salt was introduced into the counter itself whereas here the activity of the salt placed outside of the counter was measured. This procedure was followed because it was felt that the constants of the circuit such as number of spontaneous counts and sensitivity could be kept better under control. It had the disadvantage that the sensitivity was so low that thin films of KCl could not be used. However, for the thick films this was an advantage. In this case, the number of counts per minute for KCl was such that no correction need be applied to take care of the possibility that

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[*] Washington, D. C.
[1] D. Bocciarilli, Atti accad. Lincei **17**, 830 (1933).
[2] A. Holmes and R. W. Lawson, Phil. Mag. **2**, 1218 (1926)
[3] Orban, Akad. Wiss. Wiess. Ber. **140**, 121 (1931).
[4] W. Mühlhoff, Ann. d. Physik **7**, 205 (1930).

[5] Johnson and Street, J. Frank. Inst. **215**, 293 (1933).

counts were missed on account of the low resolving time of the recording apparatus. Further, the number of counts arising from the β-ray emission was always greater than the spontaneous counts. In order to ascertain whether or not the performance of the counter was independent of the working conditions two independent sets of readings were taken. In the first set, the background was fairly high, of the order of 7 counts per minute, but this was compensated for to some extent by the higher efficiency of the counter. In the second set the background was exceptionally low. Although the count was as low as 2 per minute, the efficiency was less by only 10 percent on the average. It is gratifying to observe that these two independent runs lead to the same value for the disintegration constant to an accuracy far within the probable error. For the purpose of convenience in recording the data, these two runs will be described separately.

COUNTER EFFICIENCY

The absolute efficiency of the counter was measured in the first series of runs by means of recording the counts from measured quantities of U_3O_8 and from $UO_2(NO_3)_2+6H_2O$. In the case of U_3O_8, 902 counts were obtained in 30 minutes from a sample containing 2.1×10^{-4} g per cm^2 total weight. The background count for a similar period was 240. This gives 15.2 counts per minute per cm^2. The number of counts to be expected is equal to one half the number of disintegrations per gram of uranium times the amount present per cm^2. According to Rutherford, the number of disintegrations per gram of uranium per minute is 1.43×10^6. Since the sample contained 1.78×10^{-4} grams of uranium per cm^2, 135 counts per minute per cm^2 should have been recorded. The efficiency of the counter is in consequence $15.2/135=11.2$ percent. The efficiency obtained by using uranium nitrate instead of uranium oxide was 12.2 percent. The average efficiency is, therefore, 11.7 percent. The low efficiency observed is to be expected from the design of the counter. The geometry of the apparatus was such that only about one-half the β-particles leaving the surface can enter the chamber even if they were not absorbed by the thin Al window. Further the distribution of potential within the counter requires that a large part of the space adjacent to the window is insensitive. In addition the ionizing power of β-particles in air at N.T.P. for potassium and UX_2 varies from 28 to 23 ions per cm of path. At 1 cm pressure, therefore, the mean free path between ionizing collisions is about 3 cm. In consequence many β-rays will pass through the counter without ionizing, and hence will not be recorded.

Since the β-rays from UX_2 are slightly more penetrating than those from potassium it seems advisable to apply a correction factor of about 44 percent to the efficiency obtained for uranium. The effective efficiency for KCl is, therefore, close to 16.8 ± 4.0 percent. This estimate of the efficiency for KCl as compared to that for U_3O_8 was computed from the known differences in the hardness of the rays. The two beta-rays designated as UX_2 and UX_1 which are emitted in equal numbers from thin layers of uranium have an absorption coefficient in Al of 14.4 and 510, respectively. The percentage transmitted by the Al window on the counter—thickness 0.02 mm—is 97 and 36 percent, respectively. From the known values of 80×10^4 and 4.2×10^4 ev for the average energy of these same rays, the number of ions formed per cm of path in air under normal conditions is computed to be 25.2 and 60. With the aid of these numbers the probability of ionization in a chamber 3 cm long filled with air at 1 cm pressure can be found.[6] This probability turns out to be 0.63 and 0.79. Thus the value for the probability of ionization in the counter of a β-particle emitted by uranium is

$$(\tfrac{1}{2})(0.97\times0.63+0.36\times0.79)=0.46.$$

Potassium also emits two rays in the proportions of 40 to 60whose average energies are 350 and 133×10^3 ev, respectively. For these rays the average number of ions per cm of path in air at N.P.T. is 28 and 37. From a calculation similar to that for uranium, the final value of the probability of ionization in the counter for a beta-particle from potassium is 0.67. According to this reckoning the relative efficiency of potassium as compared to uranium in tripping off the counter should be $67/46=1.44$.

These limits of error were computed from estimates of the variability of the deposit of the

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[6] Loeb, *Kinetic Theory of Gases* (McGraw-Hill), p. 45.

TABLE I. *Results obtained with a thick layer of pure KCl. Average number of counts/min./cm² 6.3±0.3, The error is the probable error of the total number of counts.*

SALT	MINUTES	COUNTS	COUNTS/MIN.	COUNTS/MIN.·CM²
Sample 1				
Blank	72	592	8.22	
KCl	72	1228	17.00	6.1±0.3
Sample 2				
Blank	120	251	2.09	
KCl	315	3117	11.19	6.5±0.3

uranium salts in thin films and of the path length of the β-particles in the counter. This last factor must be known before an adequate correction can be applied for the difference in ionizing power for the β-rays from uranium and potassium.

In the second set of experiments in which the sensitivity was tested with a sample of U_3O_8, the measured efficiency of 10.3 was somewhat lower. This gives for the effective efficiency for KCl, 14.8±0.4.

RESULTS

The results obtained with pure KCl are given in Table I. The difference between these two sets of data is not significant from a statistical viewpoint even when allowance is made for the difference in the effective efficiency of the counter for KCl, namely, 16.8 as compared to 14.8. For the purpose of future calculation, it is justifiable to treat the combined data as if it were a single sample.

Since the counts in any one interval are necessarily grouped statistically, the following examples given in Table II for typical six-minute intervals from which the above data were compiled will serve to illustrate the type of variations obtained. It will be observed that the net number of counts from KCl is materially in excess of the background and that the results for unit intervals do not scatter badly.

DISCUSSION

The computation of the disintegration constant from the results obtained with a thick layer of salt necessitates a knowledge of the absorption within the body of the salt. Orban[3] has treated this point in detail, hence only a brief outline of

the method will suffice here. The number of disintegrations observed per second per square centimeter "n" is equal to the disintegration constant divided by two times the number of potassium atoms from which the β-rays can reach the surface. This latter quantity is equal to the number of potassium atoms per cubic centimeter in KCl times the average thickness from which the rays can penetrate. If the reciprocal of the absorption coefficient μ measured in KCl is taken for the average thickness, it follows that

$$n = \frac{\lambda}{2}\left(\frac{\rho}{\mu}\right)_{Al} \frac{6.06 \times 10^{23}}{77}.$$

The most difficult point in the calculation of the disintegration constant from the observed number of counts is that of choosing an appropriate value for μ from the various estimates given in the literature. Campbell and Wood[7] give the absorption coefficient in cm^{-1} of aluminum for the two β-rays of potassium as 29 and 75 for the hard and soft rays, respectively. Since 40 percent of the rays are hard, the average absorption coefficient is computed to be 46 cm^{-1}. This value is in agreement with the determination of Orban of 46 cm^{-1} Al for a thickness of 0.05 cm Al. His calculation of the disintegration constant[3] of potassium is based on the validity of this measurement of the absorption coefficient. This value for the absorption coefficient is materially greater than that found by Kuban.[8] He gives for the absorption coefficient in Al 28 cm^{-1}. Since the values taken with an ionization chamber might well give an erroneous estimate of the number of beta-particles absorbed, it was decided to measure the absorption coefficient with this apparatus. The results of these measurements agree within the limit of error with the value determined by Kuban. For this reason the computation for $(\mu/\rho)_{Al}$ was made with a value of 10.4.

TABLE II. *Statistical variation in the number of counts obtained during typical six-minute intervals.*

BLANK	34	46	46	46	48	44	48
KCl	90	104	108	110	82	92	88
Counts/cm²·min.	6.4	6.6	7.0	7.2	3.9	5.5	4.6

[7] Campbell and Wood, Proc. Camb. Phil. Soc. **14**, 15 (1906).
[8] Kuban, Wien Ber. **137**, 241 (1928).

The disintegration constant computed by the above method is

$$\lambda = (1.73 \pm 0.6) \times 10^{-21} \text{ sec.},$$

the average life is

$$\theta = 1.83 \times 10^{13} \text{ years}$$

and the half-life is

$$T = (12.8 \pm 3.0) \times 10^{12} \text{ years.}$$

The principal sources of error in the above values appear to enter through the method employed in determining the thickness of the layer from which rays reach the counter and through the estimation of the counter efficiency. In so far as can be told from the data at hand, these errors lie within the limits given. The present value of 13×10^{12} is to be compared with the previous values of 15×10^{12} obtained by Mühlhoff and 5×10^{12} years given by Orban.

It is now known that potassium is composed of three isotopes with mass numbers 39, 40 and 41.[9, 10] Smythe and Hemmendinger[11] have recently shown that of these only K^{40} is radioactive. Since the abundance[10] of K^{40} is given by the ratio $K/K^{40} = 9000$, the disintegration constant for K^{40} is obtained by multiplying the values given above by 9000. The radioactive constants for K^{40} then become:

$$\lambda = (1.56 \pm 0.6) \times 10^{-17} \text{ sec.}^{-1},$$
$$\theta = 20.3 \times 10^8 \text{ yr.},$$
$$T = (14.2 \pm 3.0) \times 10^8 \text{ yr.}$$

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[9] A. O. Nier, Phys. Rev. 48, 283 (1935).
[10] A. Keith Brewer, Phys. Rev. 48, 640 (1935).
[11] Smythe and Hemmendinger, Phys. Rev. 51, 178 (1937).

The Nuclear Isomers of In^{116}

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The isomeric periods of In^{116} (13 seconds and 54 minutes), produced by the capture of slow neutrons by In^{115}, have been studied with the purpose of determining the energy level scheme for In^{116}. The γ-ray of energy 1.4 Mev previously measured by the authors has been shown to have a period of 54 minutes. No γ-ray of 13 second period could be found. The percentage transmission by boron of resonance neutrons which effect the two periods has been measured and found to be the same within the experimental error, for both periods. The value obtained for the percentage transmission of 0.0252 g/cm^2 B (uncorrected for obliquity) is 73.5 $\pm$ 3.0. The branching ratio $R(13 \text{ sec.})/R(54 \text{ min.})$ has been shown to be independent of the method of excitation and has the value 1.12 $\pm$ 0.06. From the known beta-ray end points and the energy of the gamma-ray an energy level diagram has been drawn up which accounts for all the experimental facts. The two excited levels of In^{116} from which disintegration takes place are separated by 0.3 Mev, the level corresponding to the 13 second period lying higher. Gamma-ray transitions between these two levels can be forbidden by choosing quantum numbers which differ by 5 units.

INTRODUCTION

THE element indium, when subjected to neutron bombardment, becomes radioactive and shows several periods. The most prominent periods are those of 13 seconds and 54 minutes discovered by Amaldi, d'Agostino and Segrè[1, 2] which were shown to result from the capture of slow neutrons by indium. Szillard and Chalmers[3] also found a period of 3.5 hours which they attributed to the action of fast neutrons on indium, since they obtained it when the neutrons were not slowed down by paraffin. They pointed out that, since indium has only two known isotopes, one of the isotopes must be responsible for two periods.

[1] E. Amaldi, O. d'Agostino, E. Segrè, Ricerca Scient. 5, 2 (1934).
[2] E. Amaldi, O. d'Agostino, E. Fermi, B. Pontecorvo, F. Rasetti, and E. Segrè, Proc. Roy. Soc. 149, 522 (1935).
[3] L. Szillard and T. A. Chalmers, Nature 135, 98 (1935).