Potassium-44

BERNARD L. COHEN
Oak Ridge National Laboratory, Oak Ridge, Tennessee
(Received September 18, 1953; revised manuscript received October 26, 1953)

Potassium-44 was produced by an (n,p) reaction on calcium and found to decay by negatron and gamma emission with a 22.0±0.5 minute half-life. The identification was ascertained by comparison of yields from normal and isotopically enriched calcium, cross section measurements, chemical processing, and investigation of impurity effects. The beta-ray spectrum is quite complex but includes strong components with maximum energies of about 4.9 and 1.5 Mev. The gamma-ray spectrum includes strong gammas at 1.13, 2.07, and 2.48 Mev, and a probable 3.6-Mev gamma.

IN 1937 Walke,[1] while irradiating calcium with fast neutrons to produce 12.4-hour potassium-42 by an (n,p) reaction, detected a short-lived activity that followed the potassium chemistry. He measured the half-life as 18±1 minutes and surmised that it must be either potassium-43 or potassium-44 since only these could be produced by (n,p) reactions on the stable calcium isotopes known at that time. Potassium-43 has since been produced by an (α,p) reaction on argon[2] and found to decay with 22.4-hour half-life. The mass number for this activity, hitherto[3] considered "probable," was confirmed by bombarding isotopically enriched Ca^{43} with high-energy neutrons from the Oak Ridge National Laboratory 86-inch cyclotron. However, since Walke's paper appeared, two new stable calcium isotopes, Ca^{46} and Ca^{48}, have been discovered. Recent isotope tables[3,4] report Walke's 18-minute activity as "element probable, mass number unknown."

Potassium-44 has been produced by irradiating both natural calcium and isotopically enriched[5] calcium-44 with neutrons from a beryllium target bombarded with about 1000 μa of 22-Mev protons; its half-life was determined to be 22.0±0.5 minutes. The following tests were made to ascertain the element and the mass assignment:

1. The ratio of the 22-minute activities produced per unit mass by bombarding enriched (98 percent) Ca^{44} and natural calcium (2.1 percent Ca^{44}) was found to be 60±15 which is roughly proportional to the relative amounts of Ca^{44} present. Since the enriched sample contains a smaller percentage of all other calcium isotopes than normal calcium, there is no possibility that the 22-minute activity is produced by any of these.

2. The cross section for production of the 22-minute activity [assuming it to be produced by $Ca^{44}(n,p)$] was determined to be about nine percent of the cross section for $Ca^{42}(n,p)$. This is roughly what is expected in view of the fact that the Ca^{42} threshold is lower (i.e., the maximum beta energy of K^{42} is lower), and its (n,p) cross section is abnormally large.[6] The cross section for production of the 22-minute activity is sufficiently large to completely eliminate the possibility that it is produced by an (n,p), $(n,2n)$, or (n,α) reaction on an impurity; and the possibility that it is produced by an (n,γ) reaction on an impurity seems obscure since the cadmium ratio was measured and found to be near unity.

3. The 22-minute activity was chemically identified as potassium to the extent that it does not precipitate with scavengers as a hydroxide, carbonate, or sulfide in basic solution. The fact that it was recovered from the solution with nearly 100 percent efficiency by evaporating to dryness eliminates the possibility that the 22-minute activity is produced by an (n,α) reaction since that reaction would result in an isotope of argon.

4. To check the possibility that the 22-minute activity may be due to an impurity, a survey was made of all known isotopes with half-lives between 20 and 25 minutes to determine if any of them exhibit the properties of the isotope here being identified as K^{44}, as follows (a) It is produced by neutron bombardment; (b) it is a beta emitter but not a positron emitter; (c) no other activity of less than one-day half-life is produced simultaneously with an intensity as large as 0.2 percent of the 22-minute; (d) its decay scheme includes strong gamma rays at 1.13, 2.07, and 2.48 Mev; and (e) the activity follows the potassium fraction in the chemical processing described above. It was found that each of the twenty-seven known activities fulfilling the half-life requirement has properties contrary to at least *three* of the above even with a very broad interpretation of property (d) to make allowances for poorly investigated spectra. Since neutron-induced activities have been widely studied, it seems highly unlikely that a 22-minute activity with a high production cross section in naturally occurring material would be unknown.

5. The gamma-ray spectrum accompanying the 22-minute activity was compared with that following the decay of scandium-44 since, if our assignment is correct,

[1] H. Walke, Phys. Rev. **52**, 663 (1937).
[2] Overstreet, Jacobson, and Stout, Phys. Rev. **75**, 231 (1949).
[3] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).
[4] K. Way *et al.*, *Nuclear Data*, Natl. Bur. Standards Circ. No. 499 (U. S. Government Printing Office, Washington, D. C., 1950).
[5] Enriched stable isotopes were obtained from Isotope Research and Production Division, Oak Ridge National Laboratory.
[6] B. L. Cohen, Phys. Rev. **81**, 184 (1951).

both are due to transitions between excited states of calcium-44. The Sc^{44} decay is accompanied by only one gamma, with an energy 1.16 Mev.[3] This agrees well with the very intense 1.13-Mev gamma found with the 22-minute activity. The other gammas found with the 22-minute activity are probably due to transitions between states of too high an excitation energy to be reached by the Sc^{44} decay.

The best half-life determination was obtained by using the enriched sample, employing chemical processing, and counting under a thick ($\frac{1}{4}$-in.) lead absorber. The decay was followed through nine half-lives (maximum counting rate of chart recording equipment to 25 percent of cosmic ray background) without noticeable deviation from the reported half-life.

The beta-ray spectrum of 22-minute K^{44} was studied with an anthracene scintillation spectrometer and by absorption techniques. The spectrum is quite complex,

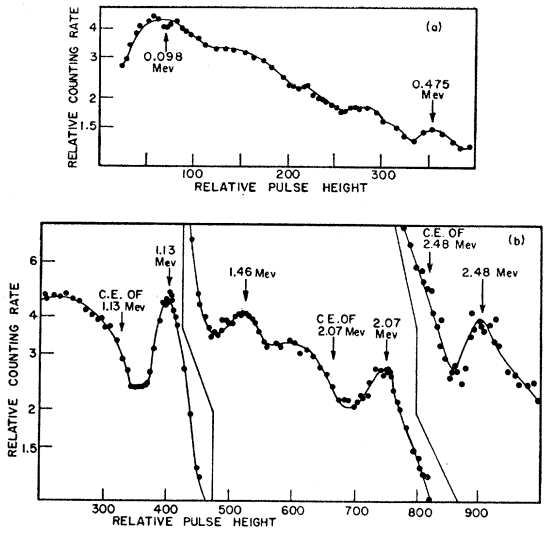

FIG. 1. Gamma-ray spectrum of K^{44} as measured with NaI scintillation spectrometer. The sample was placed about $\frac{1}{2}$ in. above a NaI(Tl) crystal $1\frac{1}{2}$ in. in diameter and 1 in. high. Background was never more than a few percent. "C.E." denotes the theoretical position of the Compton edge for the specified gamma ray. (a) Low-energy portion; (b) high-energy portion.

but seems to include strong components with maximum energy about 4.9 and 1.5 Mev.

The gamma-ray spectrum, as measured with a NaI(Tl) scintillation spectrometer is shown in Fig. 1. The various portions of that figure were obtained with different amplifier settings. Each portion of the spectrum was measured at least three separate times, and each major feature was evident on every run.

From Fig. 1 it is apparent that there are strong gamma rays at 1.13 Mev, 2.07 Mev, and 2.48 Mev. Each is evidenced by a well resolved photoelectric peak and a Compton edge at the calculated position. The 1.46-Mev pair-production peak for the 2.48-Mev gamma is also well resolved, and there are obvious reasons why the pair peaks for the other two gammas are not resolved. The high-energy part of the spectrum, not shown in the figure, exhibits a relatively slow fall-off to about 3.3 Mev followed by a much more rapid decrease with barely discernible peaks at about 3.1 and 3.6 Mev. Tests in which the sample to crystal distance was varied and various absorbers were interposed indicate that this is not due to addition pulses from coincident gammas; it is probably due to a 3.6-Mev gamma as evidenced by the positions of the aforementioned peaks, the rapid fall-off at the energy calculated for the Compton edge of a 3.6-Mev gamma, and the fact that the energies of the 1.13- and 2.48-Mev gammas add up to 3.6 Mev.

The low-energy portion of the spectrum is very difficult to interpret, although the general rise indicates that there are probably several low energy gammas. The peak at 0.475 Mev is not accompanied by the proper Compton edge, and the maximum at 0.098 Mev does not have the proper shape for a photoelectric peak at that energy, although both of these lackings could be accounted for by the presence of other low energy gammas. There is no evidence for 0.511-Mev annihilation gammas; this proves that the 22-minute activity is not a positron emitter and that it must therefore be a negatron emitter as expected.

In summary, gammas at 1.13, 2.07, and 2.48 Mev seem quite certain, a 3.6-Mev gamma seems probable, and there is evidence for several gammas below 0.5 Mev.