Disintegration Scheme of Ra^{226}(1620 yr)*

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The excited states of Em^{222} were studied in connection with a survey of regularities in heavy even-even nuclei. Em^{222} was shown to have a second excited state of character 2+, 4+, or possibly 0+ at 448 kev. This result was obtained by confirming the existence of a weak γ ray of 260 kev in the Ra^{226} spectrum, which had previously been observed by Stephens in coincidence with Ra^{226} α rays. This γ ray was found to be in coincidence with the well-known 188-kev transition leading from the first excited state (2+) to the ground state. The intensity ratio $I_{\gamma 260}:I_{\gamma 188}=1:400$. From this ratio and the known value of 5.7% for the α branch feeding the 188-kev state, the intensity of the α branch feeding the 448-kev state was found to be $\sim$0.01%.

RADIUM[226] (1620 yr) is known[1] to decay mainly by an α-ray branch of 4.777 Mev leading to the ground state of Em^{222}, while 5.7%[2] of the α rays feed an excited state of energy 188 kev. Conversion electron studies[1,3] and α-γ angular correlation measurements[4] led to the assignment 2+ for the 188-kev state. In addition to the 188-kev transition, K-conversion electrons from a 663-kev transition were observed in a diffusion chamber placed in a magnetic field.[5] The angular correlation of the electron tracks with the α-particle tracks indicated a 2+ assignment for the 663-kev state, based on the assumption that the 663-kev transition leads to the ground state.[6] The ratio of the K-electron intensities reported was $I_K(663\text{ kev})/I_K(188\text{ kev})=0.47$. This result is in contradiction with previous α fine-structure measurements[2] which showed that an upper limit of 0.1% may be given for any alpha-branch going to an excited state of Em^{222} with 300 kev$\leq E\leq$800 kev. Recently F. S. Stephens, Jr., observed in coincidence with the Ra α rays a γ ray of about 255 kev with a γ intensity $\sim$1/500 of the intensity of the 188-kev transition.[7]

A study of the patterns of nuclear level schemes[8] in this region of Z led us to search for higher excited states of Em^{222}. For this purpose we prepared a Ra^{226} source by freeing $\sim$200 microcuries initially of Ra D, E, and F by scavenging with lead sulfide in dilute nitric acid and transferring the solution to a glass cell with flat side-walls 1×8 cm and an interior thickness of 2 mm. This cell was equipped with one outlet tube and two inlet tubes: one inlet tube ended above the surface of the liquid while the second, drawn out to a capillary, penetrated to the very bottom of the cell. Passage of air through the second tube produced a steady stream of bubbles in the solution which swept out the radium emanation (Em^{222}) as fast as it was formed, and additional air could be swept through the first tube to remove emanation before it could decay in the air-space above the liquid. The flat, thin shape of the cell which was placed between two NaI(Tl) scintillation counters permitted good geometry in the γ-γ coincidence studies. At "steady state," a nearly complete decontamination (>99.9%) of radium from its decay products was achieved and held for many hours. Figure 1 shows the γ-ray spectrum observed after optimum conditions were established. Besides Em K x rays and the strong 188-kev ground state transition as well as the remaining γ-rays of 290 and 350 kev from the decay of Pb^{214} and of 610 kev from that of Bi^{214}, a γ ray at 260±5 kev is clearly seen, confirming Stephens' result. A comparison of the areas of the 260- and 188-kev photoelectron peak yields, after correcting for counter efficiency and Compton background, the value $I_{\gamma 266}/I_{\gamma 188}=2.5\times 10^{-3}$. If we use the value[2] 5.7% for the α branch going to the 188 kev state and $\alpha_{tot}=0.57$ for the 188-kev transition,[4]

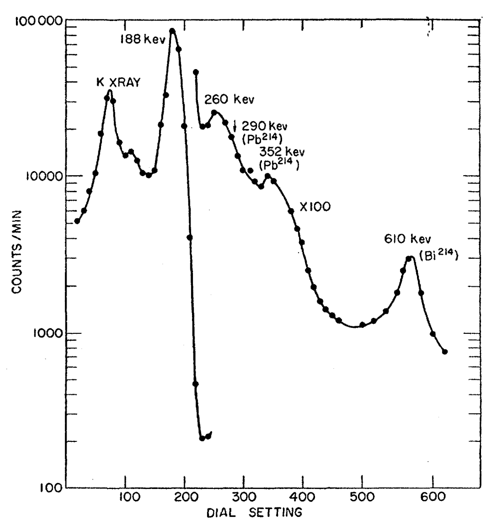

FIG. 1. NaI(Tl) scintillation counter spectrum of the γ rays from Ra^{226} (1620 yr). The spectrum was taken after the intensities of the 290- and 352-kev γ rays from Pb^{214} (26.8 min) and of the 610-kev γ ray from Bi^{214} (19.7 min) had been reduced to a minimum.

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[1] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).
[2] F. Asaro and I. Perlman, Phys. Rev. **88**, 129 (1952).
[3] M. K. Jurić and D. M. Stanojević, Bull. Inst. Nuclear Sci., Boris Kidrich **5**, 15 (1955).
[4] J. C. D. Milton and J. S. Fraser, Phys. Rev. **95**, 628(A) (1954).
[5] R. R. Roy and M. L. Goes, Compt. rend. **238**, 469 (1954).
[6] R. R. Roy and M. L. Goes, Compt. rend. **238**, 581 (1954).
[7] F. S. Stephens, Jr., thesis, University of California Radiation Laboratory Report UCRL 2970, (unpublished), p. 69.
[8] G. Scharff-Goldhaber, Phys. Rev. **103**, 837(L) (1956).

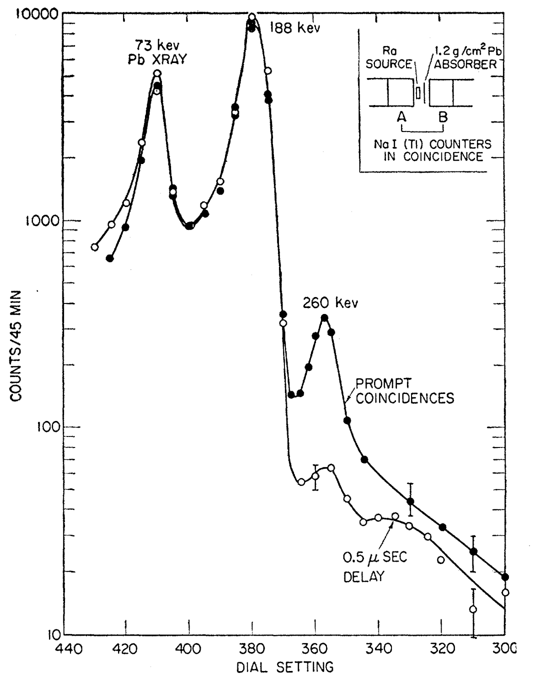

FIG. 2. Coincidence spectrum (●) recorded by counter B showing 260-kev γ rays in coincidence with triggering 188-kev γ rays (counter A). In order to reduce the relative intensity of 188-kev γ rays, 1.2 g/cm² Pb absorber was placed between Ra source and counter B. (This absorber removed the Em K x-rays from the spectrum, replacing them by the characteristic K x-rays from Pb.) The lower curve (○), taken with counter A being delayed by 0.5 μsec, shows a coincidence spectrum due to accidental coincidences. The resolving time of the circuit $2\tau=0.2$ μsec.

we deduce an α-branching ratio of $(5.7\times 2.5\times 10^{-3}/1.57)\times[1+\alpha_{tot}(260\text{ kev})]=0.0091[1+\alpha_{tot}(260\text{ kev})]\%$ feeding the 260-kev transition. No other γ rays were seen. In particular, the upper limit for a possible crossover transition of 448 kev may be given as $I_{448\text{ kev}}/I_{188\text{ kev}}<1.2\times 10^{-4}$. The upper limit for γ-rays from a 663-kev transition is found to be $<10^{-4}$ per 188-kev transition.

In order to find whether the 188-kev γ ray follows the 260-kev γ ray, a coincidence spectrum was obtained by photographing the pulses recorded by counter B in coincidence with the 188-kev γ ray registered by counter A[9] (Fig. 2). The resolving time of the coincidence output circuit was 0.2 μsec. In order to distinguish the true coincidences from accidental coincidences, the measurement was repeated using a delay of 0.5 μsec for counter A. This precaution had to be taken in view of the high intensity ratio between the γ rays of 188 and 260 kev which is responsible for a large number of accidental coincidences at 188 kev. It is seen that the 260- and 188-kev γ rays are indeed in coincidence; this observation leads to the disintegration scheme shown in Fig. 3. The character of the 448-kev state is probably 2+[10] or 4+, or possibly 0+. Spin 1 can be ruled out because of the absence of a crossover transition, and a spin 3 state of such low energy lying below a spin 1 state is most unlikely.[11] If we compare the relative intensity of the α branch leading to the 448-kev level with the theoretical value[12] not using any spin correction factor and assuming that the 260-kev transition is predominantly $E2$, we arrive at an alpha-hindrance factor ~ 5. This value is of the same order as that for the α branches leading to the second excited (4+) states of the nuclei with slightly higher Z.[13]

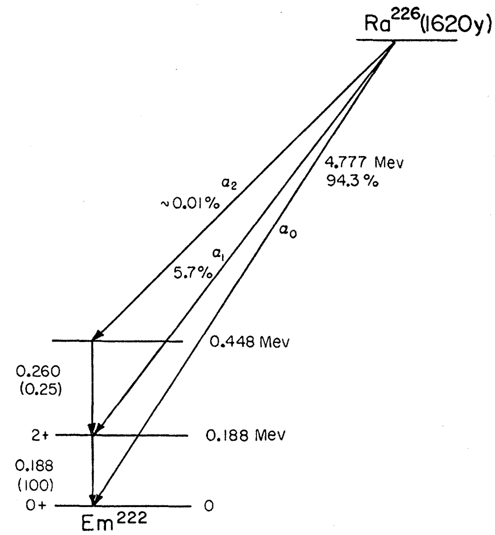

FIG. 3. Disintegration scheme proposed for Ra^{226}. The energy ratio $E_2/E_1=2.38$, indicating a near-harmonic pattern of the level-scheme.[8]

[9] The procedure used was described in more detail by Scharff-Goldhaber, der Mateosian, Harbottle, and McKeown, Phys. Rev. **99**, 180 (1955).

[10] Although the ratio $I_{448}/I_{260}<0.05$, this does not exclude a 2+ state; e.g., in Pt^{196} the intensity of the transition from the second excited state, which is known to be 2+, to the ground state, is less than 0.01 of the intensity of the transition leading to the first excited state [D. Alburger (private communication)].

[11] H. Morinaga [Phys. Rev. **103**, 503(L) (1956)] has recently made a survey of odd-spin states in even-even nuclei, showing that all known odd-spin states besides 1− states (occurring for $Z\geq 88$) have energies of 1 Mev and higher in this region of Z.

[12] J. M. Blatt and V. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 575.

[13] F. Perlman and I. Asaro, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Stanford, 1954), Vol. 4, p. 157, Fig. 11.