# The Isomer $Rb^{84m}$†

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With the help of scintillation counters information on the isomer $Rb^{84m}$ has been obtained. The isomer was produced by an $(n,2n)$ bombardment of ordinary Rb salts. The half-life has been determined as 21 min. Three gamma-rays have been observed at 0.239, 0.463, and 0.890 Mev. The last gamma-ray occurs in the product $Kr^{84}$. Coincidence measurements show coincidences between the gamma-ray at 0.239 Mev and another of nearly the same energy, while coincidences between the 0.463 and the gamma-rays at 0.239 Mev are essentially negligible. A possible level scheme is discussed.

FLAMMERSFELD[1] has recently discovered an isomer of $Rb^{84}$ which has a half-life of 23 min. The isomer was prepared by bombarding rubidium salts with fast neutrons from a Li+D reaction. In his experiments $Rb^{88}$(17.5 min) was always present to some extent. The experiment showed that there is a metastable state which emits internal conversion electrons of energy about 0.32 Mev, which would correspond to a gamma-ray energy of 0.335 Mev. Since experiments on the long-lived $Rb^{84}$(34 days) were in progress in this laboratory,[2] the present experiments were undertaken to obtain more information on the isomeric state.

The following experiments were performed with a scintillation spectrometer equipped with a differential pulse-height analyzer. $RbNO_3$, placed in a cadmium container, was bombarded with Li+D neutrons from the cyclotron. The results, Fig. 1, show two gamma-rays having energies of 0.239 Mev (discriminator setting 14) and 0.463 Mev (discriminator setting 28). The half-life of both lines was 21 min. $RbNO_3$ bombarded with Be+D neutrons slowed down in paraffin gave the same peaks, but of much weaker intensity, superimposed on a high background from the 17.5-min $Rb^{88}$. In order to be sure that the activity was not produced by the nitrate ion, $NH_4NO_3$ was bombarded with Li+D neutrons. In this case only annihilation radiation having a half-life of 11 min was seen. Finally, in order to test the purity of the rubidium, active $Rb^{84}$(34 days) was added to the Rb salts and these were passed through an ion exchange column. The resultant purified rubidium salts were bombarded both as RbCl and $RbNO_3$ with fast neutrons. In both cases the line at 0.239 Mev was seen to decay with a 21-min half-life. Annihilation radiation from the long-lived $Rb^{84}$ was also present. After allowing the short-lived radiations to die out and correcting for the annihilation radiation from the $Rb^{84}$, we found that the line at 0.463 Mev, of 21-min half-life, was also present.

The question arises as to whether one of these gamma-rays comes as a result of a transition to an excited state of $Kr^{84}$ or whether they are both in $Rb^{84m}$. Experiments[1] on $Rb^{84}$ show a gamma-ray at 0.890 Mev. To test the two above-mentioned possibilities, a line at 0.890 Mev in $Rb^{84m}$ was looked for and found. The half-life was 21 min but the intensity was extremely weak compared to the line at 0.463 Mev. The actual relative intensities, corrected for the photoelectric absorption in the crystal using the data of Davisson and Evans,[3] are in the ratio $I_{463}/I_{890}=7$. It, therefore, seems unlikely that the two gamma-rays are in cascade or that the line at 0.463 Mev is in the product.

Another difficulty arises if the line at 0.239 Mev is the line which governs the half-life of the metastable state. The calculated half-lives, made using the emperical formulas of Goldhaber and Sunyar[4] and including corrections for internal conversion, give $M4$, $2\times10^6$ sec; $E3$, 4 sec; $E4$, $2\times10^4$ sec. The actual half-life is $1.26\times10^3$

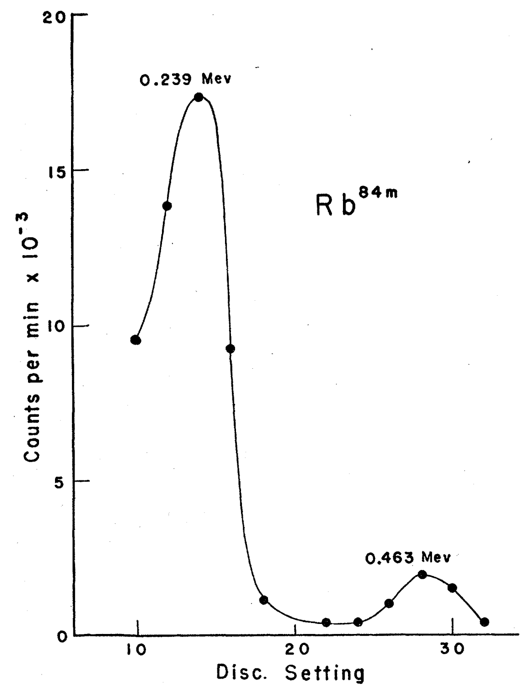


FIG. 1. Lines from $Rb^{84m}$ (line at 0.890 Mev not shown).

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[1] A. Flammersfeld, Z Naturforsch. 5a, 687 (1950).
[2] C. M. Huddleston and A. C. G. Mitchell, Phys. Rev. 89, 1350 (1952).
[3] C. M. Davisson and R. D. Evans, Revs. Modern Phys. 24, 79 (1952).
[4] M. Goldhaber and A. W. Sunyar, Phys. Rev. 83, 906 (1951).

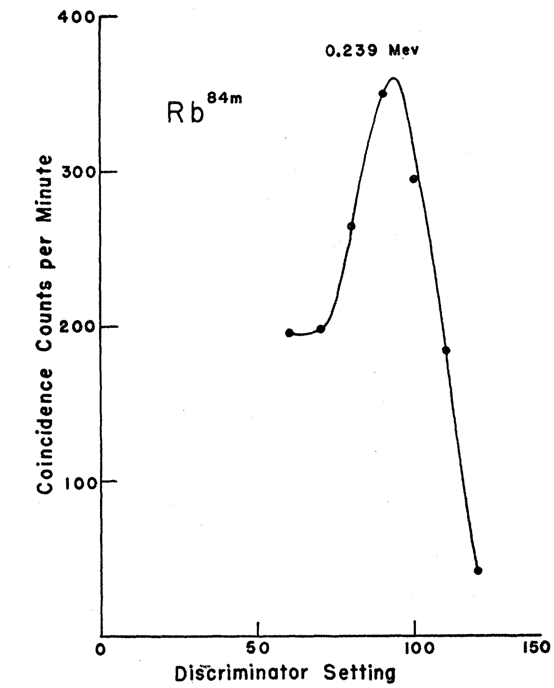


FIG. 2. Coincidence spectrum of $Rb^{84m}$ Channel I set on line 0.239 Mev; Channel II variable.

sec. All of these are considerably longer than the observed half-life and, in addition, the internal conversion is high enough so that strong x-rays should be seen. $X$-rays were looked for in a proportional counter and none were seen. On the other hand, if both gamma-rays are in the parent and the line at 0.463 governs the half-life, the theoretical half-life for an $M4$ transition would be $5\times 10^3$ sec in reasonable agreement with the observed value, and, in addition, the internal conversion coefficient would be quite small.

To test the possibility whether the line at 0.463 Mev could be in cascade with and presumably followed by that at 0.239 Mev, the relative intensities of the two lines were measured. When corrected for photoelectric cross section, the relative intensity is $I_{239}/I_{463}=2.5$. Assuming that the line at 0.463 Mev is $M4$ and that at 0.239 Mev is of low multipole order, corrections for internal conversion cannot possibly bring this ratio below 2.

Since the intensity of the line at 0.239 Mev is approximately twice that of the line at 0.463 Mev and since its energy is roughly half of the latter, it was deemed possible that there are two lines whose energies are roughly 0.239 Mev which are in cascade and that the cascade pair is in parallel with the line at 0.463 Mev. In order to test this possibility, two scintillation counters were used in a coincidence circuit. If, for example, Channel I is set on the line at 0.239 Mev and Channel II run over the line at 0.463 Mev, the coincidence rate is negligible. If, on the other hand, Channel I is set on the line at 0.239 Mev and Channel II run over this same line, a large coincidence rate was found, as shown in Fig. 2. This experiment shows that there are two gamma-rays of approximately 0.239 Mev energy in cascade and that one is not delayed appreciably behind the other.

The evidence appears to show that there are two lines of energy 0.230–0.239 Mev in cascade and that the line of energy 0.463 Mev is probably in parallel with this pair. A possible level scheme for the isomeric states, showing spins and parities, is shown in Fig. 3. Here it is assumed that the line at 0.463 Mev is an $M4$ transition and that the two lines near 0.239 Mev

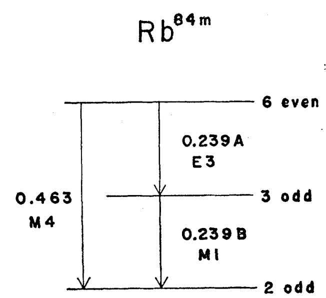


FIG. 3. Tentative level scheme for isomeric states of $Rb^{84m}$.

(called 0.239$A$ and 0.239$B$) are $E3$ and $M1$, respectively. In order that the $M4$ transition can compete with the $E3$ transition, the square of the matrix moment of the latter must be $\sim 10^{-6}$. According to Goldhaber and Sunyar,[4] the value of $|M|^2$ for $E3$ transitions varies from $10^{-3}$ to $10^{-6}$ if one uses the Weisskopf[5] transition formulas, as has been done here. It is not impossible that all three gamma-rays are in cascade with a delay greater than $10^{-6}$ sec between the line at 0.463 Mev and the line labeled 0.239$A$. It is difficult to believe that there are three metastable states above the ground level of $Rb^{84}$ so that the parallel-cascade arrangement seems to be preferred.

Experiments are planned to make more exact measurements of the energies of the lines at 0.239 Mev as well as the $K/L$ ratios of these and the one at 0.463 Mev.

[5] V. F. Weisskopf, Phys. Rev. 83, 1073 (1951).