Observation of a 193-Millimicrosecond Metastable Level in Pu^{239}†

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A metastable level in Pu^{239} with a half-life of 193 mμsec has been observed in the beta decay of Np^{239}. This metastable state is assigned to a level 382 kev above the ground state of Pu^{239}, and appears to de-excite by parallel 61- and 105-kev $E1$ gamma transitions.

A METASTABLE level in Pu^{239} with a half-life of 193 mμsec has been observed in the beta decay of Np^{239}. Delayed coincidences were measured with a coincidence circuit similar to that described by McGowan.[1] Anthracene and sodium iodide scintillation counters served as beta and gamma detectors, respectively. Pulse-height analyzers accepted integral betas above 30 kev and integral gammas above 40 kev. Delays were introduced by means of calibrated lengths of Transradio C.22 coaxial cable or RG 65/U delay cable. A typical delay curve is shown in Fig. 1. Three measurements with RG 65/U cable gave half-lives of 192, 193, and 194 mμsec; and a single measurement with C.22 cable gave a half-life of 192 mμsec.

A search for gamma or x-radiation preceding the metastable level yielded negative results. It is estimated that the abundance of gamma transitions with energies greater than 23 kev populating the 193-mμsec level must be less than one percent of the beta disintegration rate.

The beta spectrum leading to the formation of the 193-mμsec level was measured with an anthracene scintillation spectrometer used in conjunction with the delayed coincidence circuit. A resolving time, 2τ, of 83 mμsec and a beta delay time of 111 mμsec were employed. Beta-conversion electron energy addition in the anthracene crystal was minimized by the use of a small solid angle (3.4 percent). A Kurie plot of the spectrum (Fig. 2) gives a maximum beta energy of 343 kev. This energy corresponds closely to the energies reported for the lowest-energy component in the total beta spectrum of Np^{239}. Tomlinson *et al.*[2] obtain 330 kev and Freedman *et al.*[3] 329 kev for the lowest energy component. The low-intensity tail on the curve of Fig. 2 is probably due to beta and conversion electron energy addition in the anthracene crystal. According to the decay schemes proposed by Fulbright,[4] and Asaro and Perlman[5] (Fig. 3), the 330-kev beta leads to a level in Pu^{239} which is 382 kev above the ground state. This level de-excites principally either by a 105-kev gamma transition to the 1.1-mμsec level in Pu^{239} reported by Graham and Bell[6] or by a 61-kev

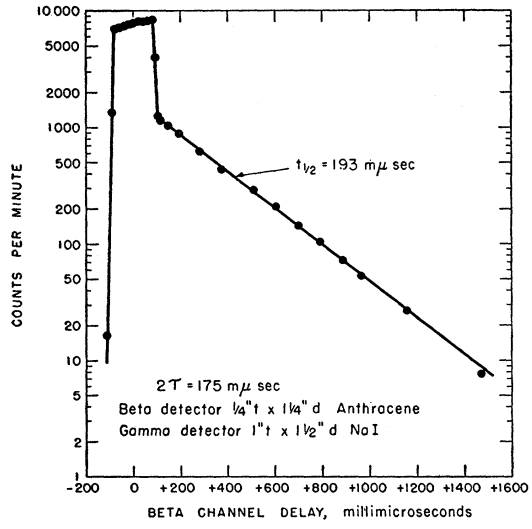

FIG. 1. Delay curve of β-γ coincidences in Np^{239}.

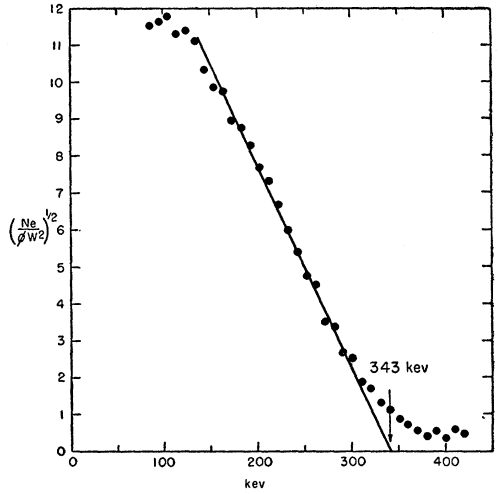

FIG. 2. Kurie plot of the beta spectrum of Np^{239} leading to the formation of the 193-mμsec level.

† Based on work performed under the auspices of the U. S. Atomic Energy Commission.

[1] F. K. McGowan, Phys. Rev. **93**, 163 (1954).

[2] Tomlinson, Fulbright, and Howland, Phys. Rev. **83**, 223(A) (1951).

[3] Freedman, Wagner, Engelkemeir, Huizenga, and Magnusson (private communication, 1953) reported by Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

[4] H. W. Fulbright (private communication to M. S. Freedman, February, 1952).

[5] F. Asaro and I. Perlman (private communication, November 1952) reported by Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

[6] R. L. Graham and R. E. Bell, Phys. Rev. **83**, 222(A) (1951).

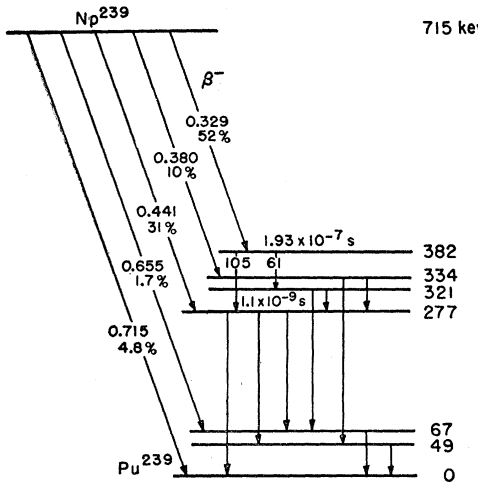

FIG. 3. Principal features of the disintegration scheme of Np^{239} (references 4 and 5) showing proposed position of the 193-mμsec level.

gamma transition. The total L conversion coefficient of the 105-kev gamma may be obtained by a comparison of the conversion electron and gamma intensities. The ratio, (a), of the number of L conversion electrons of the 105-kev gamma to the total number of K conversion electrons (from higher energy transitions) was taken from the relative intensity data of Fulbright.[4] The ratio, (b), of the number of 105-kev gammas to the total number of K x-rays was measured by Day[7] with a bent-crystal spectrometer. The total L conversion coefficient, Le^-/γ, is given by

$$Le^-/\gamma=(a/b)\times(1/f),$$

where f is the K shell fluorescence yield of Pu. Substituting the values: $a=0.11$, $b=0.50$, $f=0.97$, the total L conversion coefficient is found to be 0.23.

The total L conversion coefficient of the 61-kev gamma was calculated in the same way using the values: $0.066\geqslant a\geqslant 0.031$, and $b=0.08$. The total L conversion coefficient thus lies between 0.4 and 0.9.

The theoretical total L conversion coefficients of Gellman, Griffith, and Stanley[8] for $Z=92$ were interpolated to give the values shown in Table I for gamma energies of 61 kev and 105 kev. On the basis of their L conversion coefficients both the 61-kev and the 105-kev gammas are classified as $E1$.

[7] Paul Day (private communication, December, 1954).
[8] Gellman, Griffith, and Stanley, Phys. Rev. 85, 944 (1952).

From our scintillation spectrometer measurements, the absolute number of K x-rays plus 105-kev gammas was calculated to be 0.89 per disintegration. The disintegration rate of the sample was obtained from the growth of alpha activity of Pu^{239}. From the preceding data, the intensities of the unconverted 61- and 105-kev gammas are calculated to be 0.05 and 0.30, respectively, per disintegration. With the addition of the conversion electron intensities, the total number of 61 plus 105 kev transitions is found to be *ca* 0.5 per disintegration. This value is consistent with beta spectrometer measurements of the intensity of the beta branch populating the 382-kev level. The following intensities have been reported for the 330-kev beta branch: 0.52,[3] 0.47,[6] and 0.38[4] per disintegration.

A check on the assignment of the 193-mμsec metastable state to the 382-kev level was made by comparing the delayed and prompt coincidence rates in Fig. 1. If the beta and gamma detection efficiencies are assumed to be the same for delayed as for prompt events, the fraction of the total number of disintegrations which lead to the 193-mμsec metastable state is found to be 0.29. Correction for the estimated efficiencies lowers the result to *ca* 0.20 which is significantly lower than the values reported for the intensity of the 330-kev beta branch. The reason for this discrepancy is unknown.

TABLE I. Theoretical total L conversion coefficients for $Z=92$.

	61 kev	105 kev
$E1$	0.40	0.10
$E2$	140	11
$M1$	25	5.4

The following conclusions have been drawn from the data:

(1) A metastable state of Pu^{239} with a half-life of 193 ± 4 mμsec is formed in 20 to 50 percent of the Np^{239} beta decays.

(2) This metastable state is preceded by a 343 ± 15 kev beta and is the highest level of Pu^{239} formed in appreciable yield as is evidenced by the lack of delayed gamma-gamma coincidences.

(3) If the essential features of the currently accepted decay scheme for Np^{239} are correct, this metastable level is 382 kev above the ground state and is de-excited mainly by $E1$ transitions of 61 and 105 kev.