Title
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DECAY SCHEMES OF 2.1-hour Ta^{178}

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Printed for the U. S. Atomic Energy Commission of 90, 213, 330, and 426 kev were found in the gamma-ray spectrum of Ta^{178}, with relative intensities of 38, 17, 30, 27, and 16 respectively. Coincidence measurements showed that each of these gamma rays was in coincidence with all the others. In addition, consideration of the relative intensities of the peaks in the coincidnece spectra revealed the following facts: (a) The intensity of the K x-rays in all the coincidence spectra was much less, relative to the other peaks, than in the singles gamma-ray spectrum noted above. In some cases the K x-ray intensity was less than one-third that of one of the other peaks in the coincidence spectrum. (b) In the spectrum in coincidence with K x-rays the 330-kev peak was enhanced relative to the other peaks. (c) The 213-, 330-, and 427-kev peaks were of almost exactly the same intensity (after correction for counting efficiencies of the NaI crystal) in the spectrum in coincidence with 90-kev photons. Also, when any one of these three gamma rays was used as the gate, the intensities of the other two were the same within experimental error.

The absence of intense K x-rays from the coincidence spectra suggests that there is a delay occurring between the electron-capture event and the gamma-ray emission. For this reason a search was made for the isomeric state in Hf^{178}, and it was found to have a half-life of 4.8 seconds.[4] The half-life measurement was made by chemically milking hafnium from the tantalum parent and following the decay on a single-channel differential pulse-height analyzer connected through a count-rate meter to a Speedomax recorder. The 4.8-second half-life was too short to make gamma-ray or electron studies of the isomer convenient.

In constructing the decay scheme of Ta^{178} it is essential to bear in mind that Hf^{178} lies in a region of the periodic table where the "strong coupling" approximation of the unified nuclear model of Bohr and Mottelson[5,6] is good. Specifically, for an even-even nucleus the lowest-lying energy levels are expected to be given approximately by the formula

$$E = \frac{\hbar^2}{2\mathcal{J}} \quad I\,(I + 1),$$

where is the energy of the level, $\mathcal{J}$ is the moment of inertia, and the spin, I, can b take on values 0, 2, 4, 6, ... These levels should be connected by cascading E2 transitions. It would further be expected that the value of $\frac{\hbar^2}{2\Im}$ should be similar to that of the neighboring even-even nucleus, Hf^{180}, or about 15 kev.[7]

The decay scheme shown in Fig. 1 may now be deduced in the following manner. The 330-kev peak seen in the gamma-ray spectrum is expected to include both the 325.8- and the 331.9-kev transitions. From the facts that this peak is enhanced relative to the others when observed in coincidence with K x-rays, but drops in relative intensity when any other photons provide the gating pulse, it is concluded that one of these transitions precedes the isomeric state, but that the other one, along with the rest of the transitions, follows the delay. The selection of the 325.8-kev transition as the one that follows the delay is made because the energy of the peak coincident with the 213- or 425-kev photons was found to be 327 ± 2 kev. This is supported by the fact that the energy agreement with the rotational formula is considerably better than it would be for 331.9 kev. Of the five remaining transitions now thought to follow the isomeric state, four give excellent agreement with the rotational formula if assigned as shown in Fig 1 (this agreement will be considered quantitatively below). To support this cascade arrangement are the facts that these transitions have all been shown to be in coincidence with one another, and that the intensities of the 213.7-, 325.8-, and 427.0-kev transitions have been shown to be very nearly equal. Also the 93.17- and 213.7-kev transitions have been shown to be E2, in agreement with the Bohr-Mottelson theory, and if the electron and gamma-ray intensities are related by assuming the theoretical E2 conversion coefficients of the 213.7-kev transition, then the conversion coefficients of the 325.8-, 331.9-, and 427.0-kev transitions give the best agreement with E2 assignments also. The relative intensities of the 325.8- and 331.9-kev photons in this case are deduced from the coincidence measurements.

The only choice remaining for the slow transition is the one of 88.81 kev. It can be shown that this gamma ray is very probably E1. Although the 88.81- and 93.17-kev photons cannot be resolved in the scintillation counter spectrum, an estimate of the intensity of the 93.17-kev photons can be made by assuming this transition has the same intensity as the other three rotational transitions. Correction of this intensity for conversion, using the theoretical E2 conversion coefficients of Rose,[3] gives the photon intensity. This relatively small contribution was then subtracted from the 90-kev peak, and the residual amount ascribed to 88.81-kev photons. Now, since the 88.81-kev transition feeds the sequence of rotational levels, its intensity must be equal to or less than that of the individual rotational transitions. Thus, having a maximum transition intensity and a photon intensity, a maximum conversion coefficient of 0.5 may be calculated for the 88.81-kev transition, which allows only an E1 assignment. The similarity of the lower part of the decay scheme in Fig. 1 to that of 5.5-hour Hf^{180m} [7] is indeed remarkable.

Including a second-order correction term to the rotational equation given above, one obtains:

$$E = \frac{\hbar^2}{2\Im} \; I\,(I+1) - B\,[\,I\,(I+1)\,]^2,$$

where B (given explicitly in Bohr and Mottelson)[5] has to do with rotation-vibration interaction, but for these purposes can be considered a parameter to be empirically fixed. If the energies of the 2+ and 4+ states shown in Fig. 1 are used to fix $\frac{\hbar^2}{2\Im}$ and B, then they may be determined to be 15.61 and 0.013 kev respectively. Calculated energies for the 6+ and 8+ states are then 632.3 and 1056 kev, to be compared with experimental values of 632.7 and 1060 kev. The agreement is considered to be quite good.

Since the 4.8-sec isomer de-excites by an E1 transition to a level of spin 8+, possible spins of the isomeric state are 7-, 8-, and 9-. The absence of decay to the 6+ state makes 7- seem unlikely. If the 331.9-kev gamma ray represents a transition between the first two levels of a rotational band based on the isomeric state, then $\frac{\hbar^2}{2\Im}$ for this band may be calculated to be 16.6 or 18.4 kev, depending on whether the base spin is chosen to be 9- or 8- respectively. Since $\frac{\hbar^2}{2\Im}$ for the ground state band is 15.6, a spin of 9- seems somewhat preferable to 8-. The slowness of the 88.81-kev E1 transition may be understood in terms of the K quantum number, which represents the projection of the spin, I, on the nuclear symmetry axis. For the ground-state band K must be 0; however, for the 1148-kev state K is probably equal to the spin, either 8 or 9. Thus while Δ I is only one for the 88.81-kev transition, Δ K is very likely 8 or 9, and in so far as K is a good quantum number E1 radiation is completely forbidden. The very long observed life-time indicates that K is, indeed, a rather good quantum number in this region of the periodic table.

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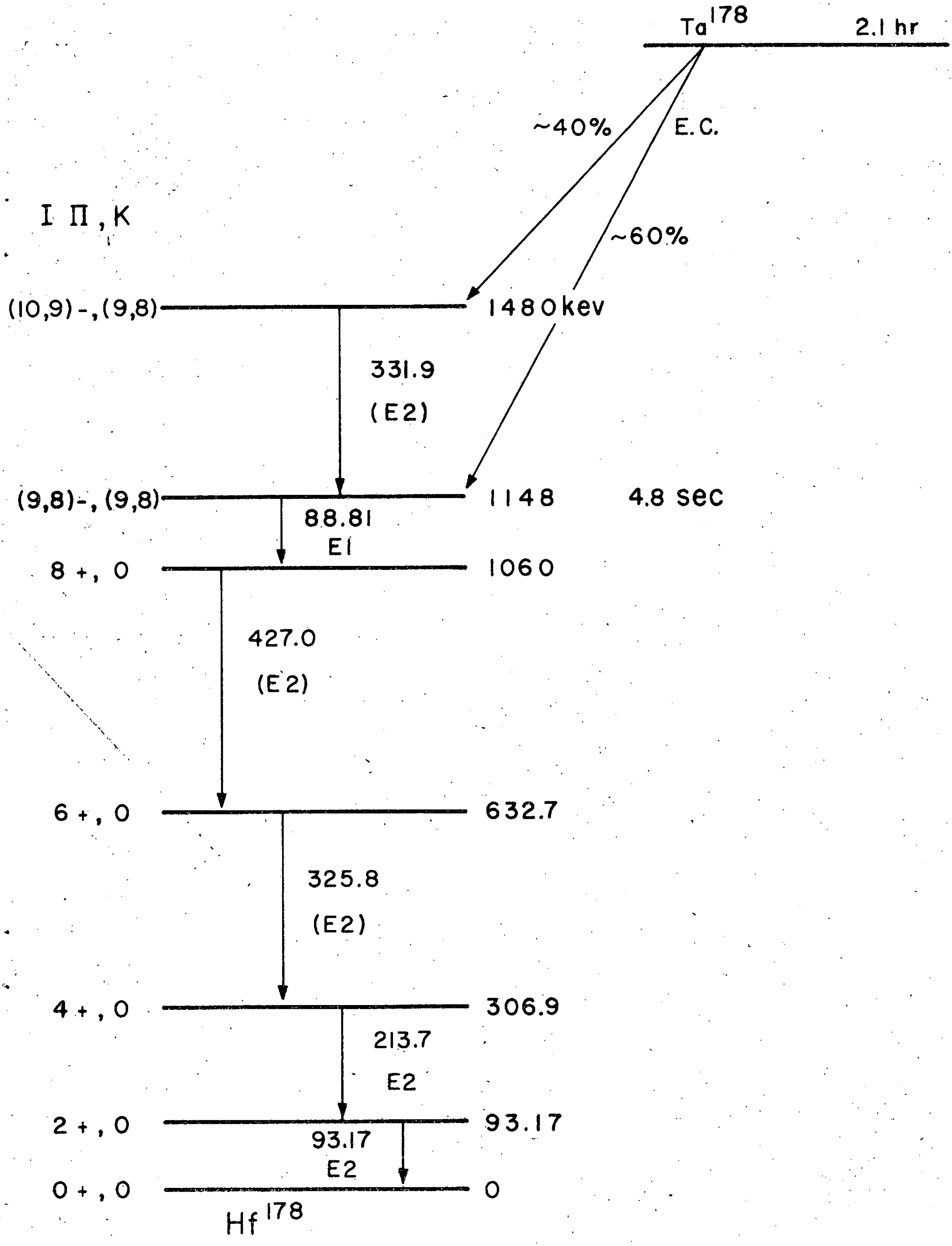
Ta^{178}
2.1 hr
~40%
E.C.
~60%
I Π, K
(10,9)-,(9,8)
1480 kev
331.9
(E2)
(9,8)-,(9,8)
1148
4.8 sec
88.81
E1
8 +, 0
1060
427.0
(E2)
6 +, 0
632.7
325.8
(E2)
4 +, 0
306.9
213.7
E2
2 +, 0
93.17
93.17
E2
0 +, 0
0
Hf^{178}

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