# Gamma Transitions in $Ta^{181}$†

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The nuclear spectrum of $Ta^{181}$ has been investigated. The excited levels have energies of 136.25, 482.0, 615.0, 618.9, and 958.0 kev. The gamma-ray energies are 3.9, 133.02, 136.25, 136.86, 345.85, 476.0, 482.0, and 615.5 kev. Multipolarities for the gamma rays are given and spin assignments to the levels are proposed.

THE levels in $Ta^{181}$, excited by beta decay of $Hf^{181}$, have been investigated. The instruments used are the crystal diffraction spectrometer, the ring-focusing beta spectrometer in connection with a fast-coincidence setup, and a semicircular low-energy beta spectrometer.

The results are compiled in Table I. The lines at 3.9 kev, 136.86 kev, and 476.0 kev have not been reported previously. The high resolving power required in order to separate the 136.25-kev and the 136.86-kev lines was achieved with the crystal spectrometer, using the fifth-order reflection on the (110) plane of quartz. The $K$-conversion electrons due to the 136.25- and 136.86-kev lines were well resolved using a 0.12% momentum resolution in the beta spectrometer. According to the conversion properties, the 345.85-kev line is pure $E2$, in disagreement with McGowan's[1] result, but in agreement with recent work by Heer *et al.*[2] $M_{III}$, $N$, and $O$ conversion peaks of the 3.9-kev line have been observed at electron energies of 1.7, 3.4, and 3.9 kev, respectively, with the semicircular spectrometer.

Beta-gamma coincidence experiments were carried out between an electron line selected in the beta spectrometer and a particular gamma line. A fast-slow coincidence system having a fast-coincidence resolving time of $2\times10^{-8}$ sec and a slow triple coincidence resolving time of 1 $\mu$sec was employed. It was possible to show, with the beta spectrometer set at 0.5% momentum resolution, that the 136.86-kev $K$-conversion line is in coincidence with the 482-kev gamma line and has the same coincidence rate as the 133.02-kev line. As expected, no coincidences with the 482-kev gamma line were found for the 136.25-kev conversion electrons.

From this and the results listed in Table I, we propose the following level arrangement (Fig. 1): ground state $(g_{7/2}, 7/2)7/2$;[3] first rotational state at

TABLE I. Energies, intensities, and multipolarities of the gamma rays in $Ta^{181}$.

| Gamma energy kev | Gamma intensity | Total transition intensity | $K$-internal conversion coefficient | Multipolarity[a] |
|---|---|---|---|---|
| 3.90±0.1 | ... | ... | ... | ... |
| 133.02±0.02 | 7 | 16.5 | 0.49[b] | $E2$ |
| 136.25±0.02 | 1 | 2.5 | 1.2[c] | 90% $M1$+10% $E2$ |
| 136.86±0.04 | 0.3 | 0.7 | 0.9 | $M1+E2$ or $E1+M2$ |
| 345.85±0.2 | 2.3 | 2.4 | 0.04[d] | $E2$ |
| 476.0 ±0.2 | ~0.3 | ~0.3 | 0.06[e] | ($M2$) |
| 482.0 ±0.2 | 14 | 14 | 0.027[f] | $E2+M1$ |
| 615.5 ±0.5 | 0.04 | 0.04 | 0.12 | ($M3$) |

[a] In assigning multipolarities, the theoretical $M1$ conversion coefficients for the $K$ and $L_I$ shell as calculated by *Rose* have been reduced by 30% in accordance with recent experimental findings [A. H. Wapstra and G. T. Nijgh, Nuclear Phys. **1**, 245 (1955)].
[b] $\alpha_{LI}:\alpha_{LII}:\alpha_{LIII}=1:4.8:3.8$.
[c] $\alpha_{LI,LII}:\alpha_{LIII}=1:0.17$.
[d] $\alpha_K/\alpha_L=4$.
[e] $\alpha_K/\alpha_L=4.3$.
[f] $\alpha_K/\alpha_L=4.7$.

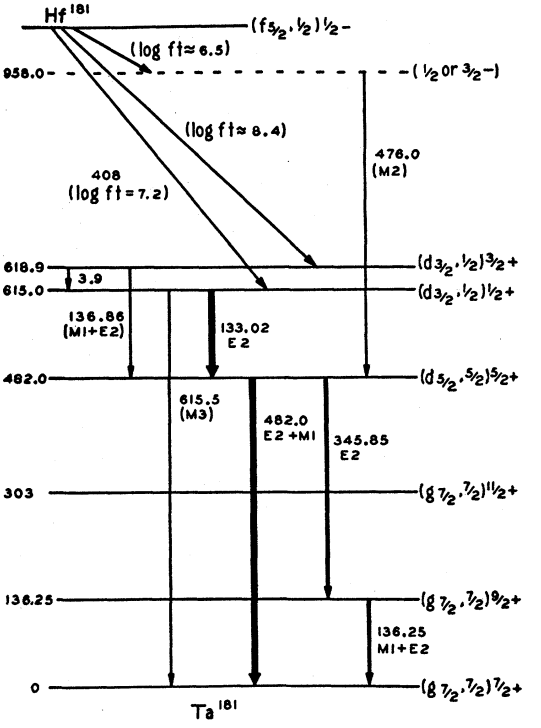


FIG. 1. Suggested energy level scheme for $Ta^{181}$. Multipolarities in parentheses are uncertain. The spin assignments to levels at 618.9 and 958 kev are tentative. A log $ft$ value of the order of 8.4 has been attributed to the beta transition leading to the 618.9-kev level on the basis of an estimated intensity of the 3.9-kev transition. The 303-kev level has not been observed, but has become evident from Coulomb excitation [see, for example, N. P. Heydenburg and G. M. Temmer, Phys. Rev. **100**, 150 (1955)].

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[1] F. K. McGowan, Phys. Rev. **93**, 163, 471 (1954).
[2] Heer, Ruetschi, and Scherrer, Z. Naturforsch. **10a**, 834 (1955).
[3] The three numbers characterizing the odd-nucleon state, according to B. R. Mottelson and S. G. Nilsson [Phys. Rev. **99**,

136.25 kev ($g_{7/2}$, 7/2)9/2; intrinsic excitation state at 482.0 kev ($d_{5/2}$, 5/2)5/2; intrinsic state at 615.0 kev ($d_{3/2}$, 1/2)1/2; first rotational state at 618.9 kev ($d_{3/2}$, 1/2)3/2 or intrinsic state. If the 618.9-kev level is a first rotational state, the small level spacing of 3.9 kev is striking but not uncommon for spin 1/2 ground states. The 476-kev line is probably a parity-change transition and might start from an odd-parity state at 958 kev which is fed by an allowed low-energy beta group from $Hf^{181}$. The spin assignment obtained by angular correlation measurements by Heer *et al.*[2] for some of the levels is in agreement with the present result although these authors have not taken into account the presence of the 136.86-kev line.[4]

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1615 (1955)], are: the configuration in the spherical limit, the component of the angular momentum along the symmetry axis, and the nuclear spin.

[4] *Note added in proof.*—P. H. Stelson and F. K. McGowan (meeting of the Southeastern Section of the American Physical Society, March 29–31, 1956) have reported a 5/2+ and a ½+ spin for the 482- and the 615-kev state respectively from polarization experiments.

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# Neutron Scattering at 2.45 Mev by a Time-of-Flight Method*

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Results have been obtained by a pulsed-beam time-of-flight method for the cross sections for excitation of various levels in many nuclides by inelastic scattering at 90 degrees. The incident neutrons had a mean energy of 2.45 Mev and a spread of plus and minus 100 kev. Detailed angular distributions are given for the neutrons of inelastic scattering, for the accompanying de-excitation gamma rays, and for the elastically scattered neutrons for iron, nickel, and titanium. Such results are also given for iron and titanium for a mean incident energy of 2.25 Mev. The angular distributions indicate that for these nuclides and excitations the statistical assumption is not applicable to states in the compound nucleus. Results on the spectrum of neutrons inelastically scattered by gold may be fitted over a limited range by an effective nuclear temperature of 0.3±0.03 Mev. The same temperature describes the data on uranium 238 after subtraction of a fission neutron spectrum.

## INTRODUCTION

THE significance of inelastic neutron scattering for understanding the mechanism of nuclear reactions is well known.[1] In particular the question of whether the neutron interacts directly with an individual bound nucleon or forms a compound nucleus may be tested by determining whether the angular distribution of the inelastically scattered neutrons is sensitive to the energy of the incident neutron.[2]

On the basis of the compound nucleus assumption together with the assumption that the excited states in the compound nucleus interfere in a random manner it has been possible to relate the angular distribution of the inelastically scattered neutrons corresponding to excitation of a particular state in the residual nucleus to the spin and parity of the level excited.[3] Further, if the levels in the residual nucleus are spaced sufficiently closely again the angular distribution of the scattered neutrons may be predicted (isotropic), and the shape of the energy distribution of the inelastically scattered neutrons may also be predicted.[3,4] Finally, inelastic neutron scattering provides a tool for locating energy levels in the residual nucleus, particularly in heavy nuclei where the detection of de-excitation gamma rays is sometimes difficult because of the extra complexity of the spectrum due to cascading effects, and the high Coulomb barrier makes it difficult to use charged particles.

An important obstacle to detailed study of the foregoing problems has been the lack of a rapid and efficient means of studying neutron spectra. Results have been obtained for 14-Mev neutrons by using an associated-particle-time-of-flight[5] technique. However, 14 Mev is a primary energy for which ($n$,$2n$) reactions are a complicating feature, and the difficulty of extending the associated particle method to lower energies is a serious limitation of the method.

Emulsion methods have been used with considerable

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[1] D. C. Peaslee, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Stanford, 1955), Vol. 5, p. 99.

[2] Proceedings of Brookhaven Conference, January 24 to 26, 1955, Brookhaven National Laboratory Report BNL-331 (unpublished), particularly p. 85, comment of R. M. Eisberg.

[3] W. Hauser and H. Feshbach, Phys. Rev. **87**, 366 (1952).

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

[5] G. K. O'Neill, Phys. Rev. **95**, 1235 (1954).