STUDY OF THE PRODUCTION AND DECAY OF ^{89}Mo ISOMERS AND ^{96}Pd

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Abstract

The production and decay of 190-ms ^{89}Mo^{m}, 2.15-min ^{89}Mo^{g}, 8.2-min ^{88}Mo, and 2.0-min ^{96}Pd have been studied using sources produced at the Maryland Cyclotron. The resulting γ-ray spectra have extended the systematics of the N=47 and 48 isotones to higher Z and revealed sharp differences between the N=47 isotones and Z=47 isotopes. The low-lying 1^{+} states identified in ^{96}Rh following the decay of ^{96}Pd further supports the hypothesis of strong interaction between protons and neutrons with identical ℓ values.

1. Experimental Procedures

The neutron deficient nuclides 8.2-min ^{88}Mo, 2.15-min ^{89}Mo^{g}, and 190 ms ^{89}Mo^{m} were produced at the Maryland Cyclotron in proton irradiations of enriched ^{92}Mo at beam energies ranging from 40 to 75 MeV. The study of activities with half lives greater than 1.5 min was done by manually transferring the target from the irradiation station to a high resolution large volume Ge detector in a low-background area. For the study of shorter-lived activities, a fixed target and detector setup was used and the

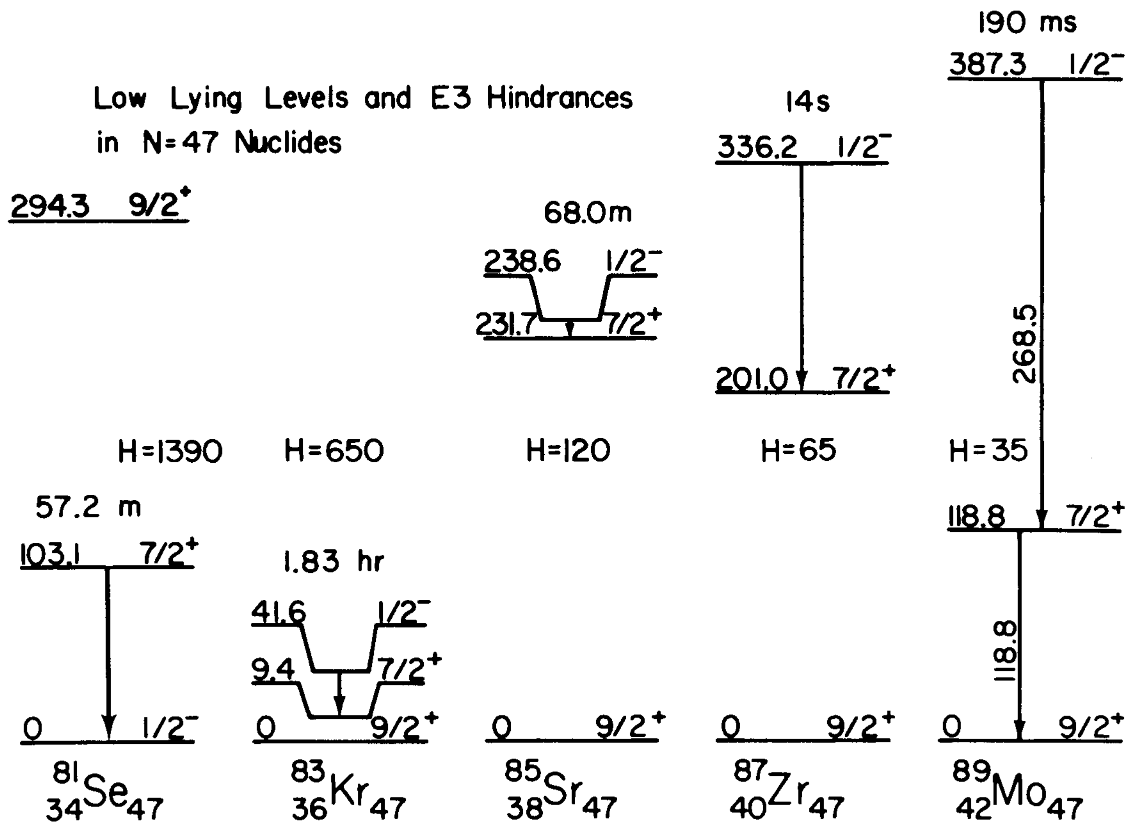

Fig. 1 Decay Scheme of 190-ms ^{89}Mo^{m} and the systematics of the low-lying $9/2^{+}$, $7/2^{+}$ and $1/2^{-}$ levels and E3 hindrances in the N=47 isotones.

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irradiation and counting periods determined by a variable speed rotating mechanical beam chopper (wheel). The wheel[1] was designed to provide a 3:1 ratio between counting and irradiation time by the presence of four 22.5° slots in a 5 cm thick Al disc. The wheel could be rotated continuously from 2 rpm to ~200 rpm and could also be controlled by a switch to provide longer irradiation and/or counting periods. The position of the slots in the wheel was monitored by an optical sensor whose output was coupled to the Cyclotron Computer to gate the storage of γ rays into twelve 8192 channel spectra as a function of time-after irradiation. A manual start was used for this data collection system for the longer-lived activity studies.

Four 3 mg/cm^2 ^{92}Mo foils enriched to 96% were used in both studies to minimize the buildup of longer-lived activities, particularly 5.9-h ^{90}Mo and 14.6-h $^{90}Nb^{g}$. Strong activities were also observed from the Nb isotopes produced in the $^{92}Mo(p,\alpha xn)$ reactions.

2. ^{89}Mo Studies

As the study[2] of the $^{92}Mo(^{3}He,^{6}He)^{89}Mo$ reaction revealed the presence of $7/2^+$ and $1/2^-$levels in the low-lying level structure of ^{89}Mo and a Q value of 5.6 MeV for $^{89}Mo^{g}$ decay, it was possible to estimate a half life for the E3 I.T. decay of a few hundred milliseconds for $1/2^{-}$ $^{89}Mo^{m}$ and a half life of 15 sec or greater for the β^+/EC decay of $9/2^+$ $^{89}Mo^{g}$. Thus, the rotating wheel setup was used to make the initial studies for both isotopes. The wheel was rotated to give 50 ms irradiations and 1050 ms counting periods in the initial measurement of $^{89}Mo^{m}$ decay. For the initial study of $^{89}Mo^{g}$, the wheel was manually operated to give 45-sec irradiations and 300 sec counting periods. Subsequent studies of $^{89}Mo^{g}$ decay were done using the manual target transfer procedure when the half life was found to be ~2 min.

2.1 $^{89}Mo^{m}$ Studies

The results of our study[3] of $^{89}Mo^{m}$ decay are shown in Fig. 1 along with the data for other N=47 isotones. These studies reveal a sharply decreasing hindrance factor for the $1/2^{-}$-$7/2^{+}$ E3 transition as Z increases and a $7/2^{+}$-$9/2^{+}$ difference that peaks in ^{85}Sr. The hindrance was calculated as the ratio $t_{1/2}$ (radiative)/tw where the theoretical E3 half life tw was calculated by the formula[4] $tw=0.693/35A^{2}E_{\gamma}^{7}S$. Extensive calculations of the level energies and transition rates of the N and Z=47 nuclides by Paar[5] using a cluster-vibration model

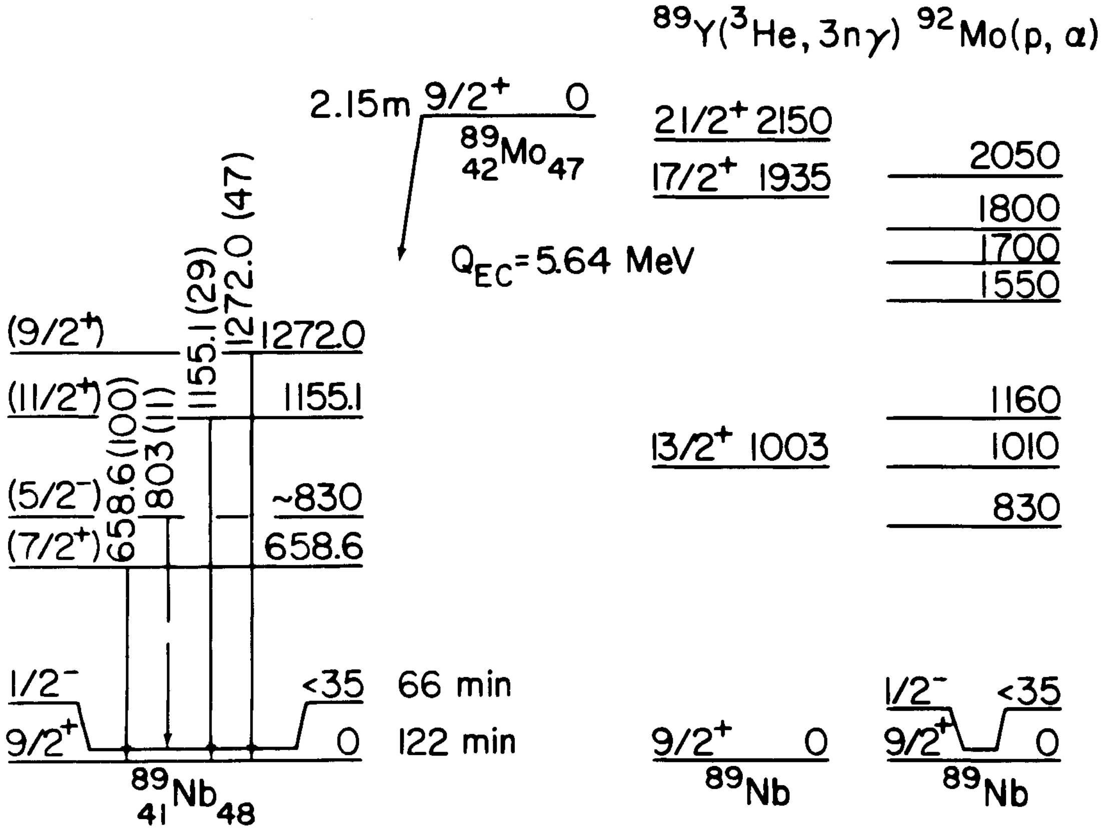

Fig. 2 Decay scheme of 2.15-min $^{89}Mo^{g}$ and levels of ^{89}Nb observed in the $^{89}Y(^{3}He,3n\gamma)$ and $^{92}Mo(p,\alpha)$ reactions.

have successfully accounted for many of the observed features of these nuclides particularly for the Z=47 isotopes. The $7/2^{+}$-$9/2^{+}$ difference in the N=47 isotones, however, shows a very different behavior that reflects the strong interaction between the three-neutron $g_{9/2}$ hole cluster and the occupancy of the $g_{9/2}$ proton orbital which becomes significant for Z>38. This phenomenon is not important for the $(g_{9/2})^{-3}$ proton cluster in the Ag nuclides as the $g_{9/2}$ neutron shell is fully occupied throughout the Ag isotopes. The filling of the $g_{7/2}$ neutron orbitals in the Z=47 isotopes does not appear to play a significant role in the general properties of those nuclides.

2.2 $^{89}Mo^{g}$ Studies

Our results[6] from the study of the decay of $^{89}Mo^{g}$ are shown in Fig. 2 for $^{89}_{41}Nb$ along with the levels observed in the study of the $^{89}Y(^{3}He,3n\gamma)$ reaction[7] and the $^{92}Mo(p,\alpha)$ reaction.[8] These data show very little change in the overall structure of $^{89}_{41}Nb$ relative to $^{87}_{39}Y$ except for the 658-keV level, as shown in Fig. 3. If that $7/2^{+}$ assignment is correct, then the presence of two additional $g_{9/2}$ protons to the $^{87}_{39}Y$ core permits the formation of a $(g_{9/2})^{3}$ cluster and the sharp drop in the position of the $7/2^{+}$ level because of the substantial $(g_{9/2})^{3}$ admixture in its wavefunction. The study of the level structure of ^{91}Tc would particularly important to further observe how additional protons affect the position of this $7/2^{+}$ level in nuclides where no $g_{7/2}$ neutrons are present. The behavior of the $7/2^{+}$ state in the N=52 isotones with increasing Z is well established, as shown in Fig. 4.

2.3 ^{88}Mo Studies

In seeking to confirm the identity of the 2.15-min activity associated with the 658.6-keV γ ray, we studied its yield at 40, 50, 70 and 75 keV. The threshold was found to lie between 40 and 50 MeV and the peak yield below 70 MeV. We also observed the 80-, 131-, and 171-keV γ rays attributed to 8.6-min ^{88}Mo decay by Doron and Blann.[9] We did not observe these γ rays at 50 MeV and only very small peaks were seen at 60 MeV. Significant peaks were observed at 75 MeV and a half life of 8±1 min determined. As all three of these γ rays are parts of complex structures, substantial uncertainty is associated with the half life measurement.

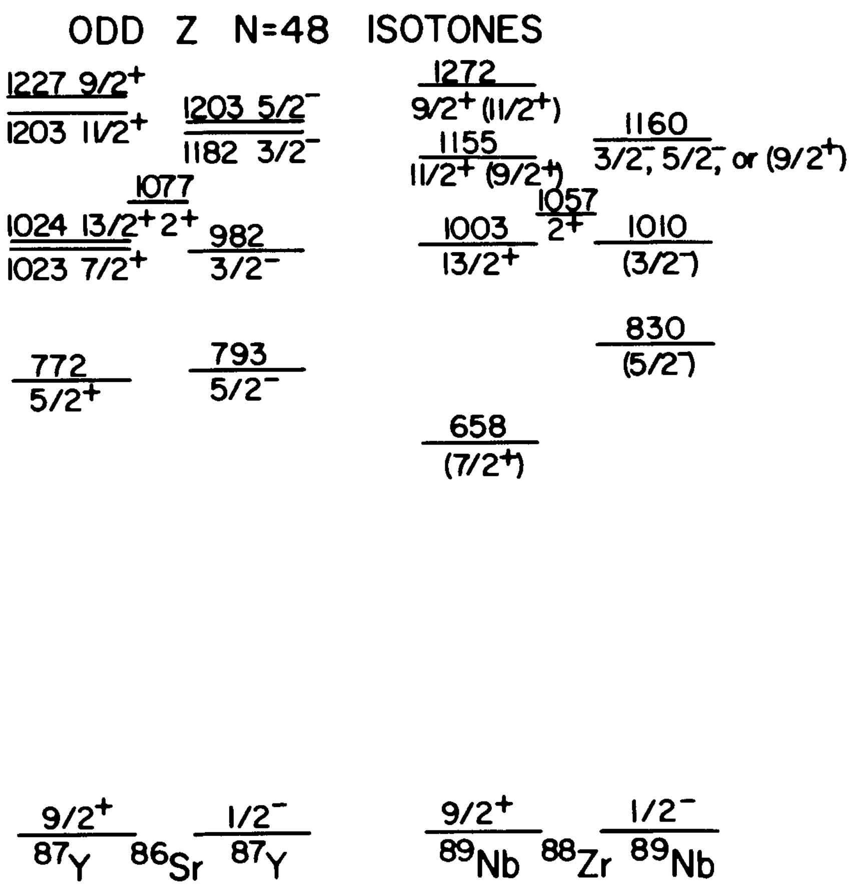

Fig. 3 Comparison of ^{87}Y and ^{89}Nb levels.

3. ^{96}Pd Studies

These same facilities were also utilized to identify the closed shell nuclide $^{96}_{46}Pd_{50}$ and study[10] its decay. As the earlier identification of the "further-from-stability" nuclides[11,12] 15-sec ^{97}Ag and 8-sec ^{98}Cd permitted an estimate of 2-4 min for the half life of ^{96}Pd, the initial experiments utilized the manual transfer of the enriched ^{96}Ru target to the detector area following irradiation of the target with 60-MeV ^{4}He ions. Two strong γ rays at 125 and 500 keV were observed and placed as feeding the well established 2^+ isomer in ^{96}Rh, as shown in Fig. 5.

The positions of these two 1^+ levels are of particular interest as they confirm a continued trend of 1^+ states in the odd-odd N=51 isotones that lie well below the odd N $7/2^+$ states in the adjacent odd N core. The odd Z isotones with Z>40 and N>52 are characterized by the presence of low-lying $9/2^+$ and $1/2^-$ states as shown in Fig. 4. In Fig. 6 we show the odd N nuclides with 51 neutrons. They are characterized by a $d_{5/2}$ ground state and an excited $g_{7/2}$ state whose position is lowered with increasing Z by both the increased size of the nucleus and the increased occupancy of its spin-orbit partner $g_{9/2}$ protons. The significant feature of these odd-odd N=51 isotones that include a single $d_{5/2}$ or $g_{7/2}$ neutron coupled to an increasing number of $g_{9/2}$ protons lies in the very much lowered 1^+-2^+ energy gap compared to the $5/2^+$-$7/2^+$ neutron gap responsible for these states. This lowered gap likely arises from the much stronger interaction between the $g_{9/2}$ protons and the $g_{7/2}$ neutron relative to the interaction between the $g_{9/2}$ protons and the $d_{5/2}$ neutron. It appears that the size of this interaction (~1 MeV) is large and not very dependent on the occupancy of the proton orbitals. The importance of neutron-proton interactions where $\ell n=\ell p$ has been recently discussed by Federman and Pittel[13] and these studies serve as a source of a quantitative measure of that interaction.

Extrapolation of the trends observed here suggest that the 1^+ level will lie below the 2^+ level in ^{98}Ag and possibly ^{100}In as well.

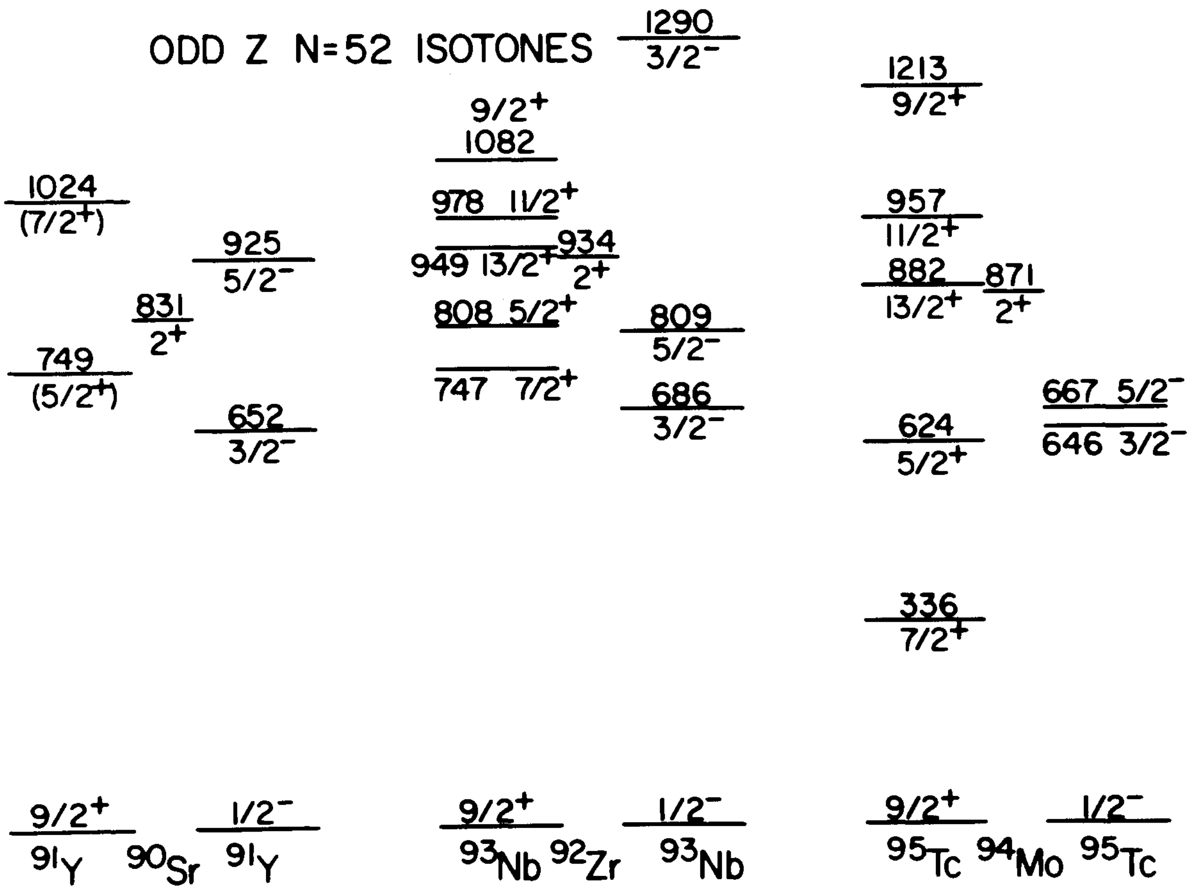

Fig. 4 Comparison of the level structure of the N=52 isotones.

4. Acknowledgements

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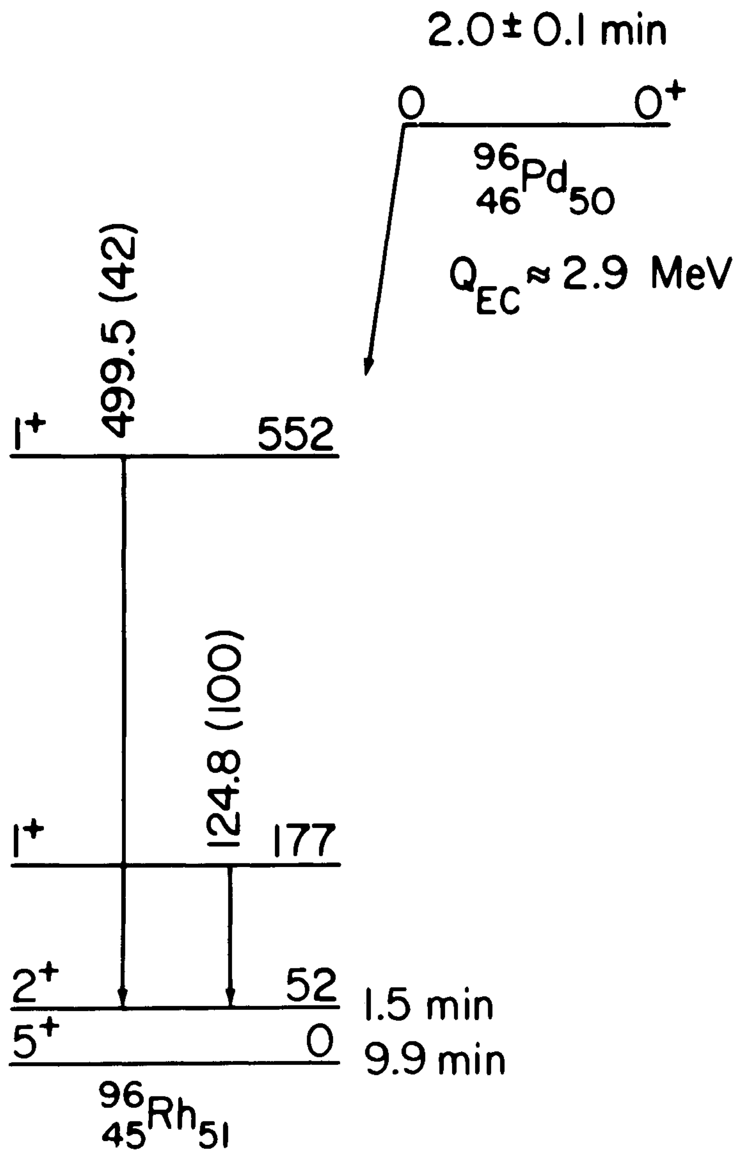

Fig. 5 Decay scheme of 2.0-min ^{96}Pd.

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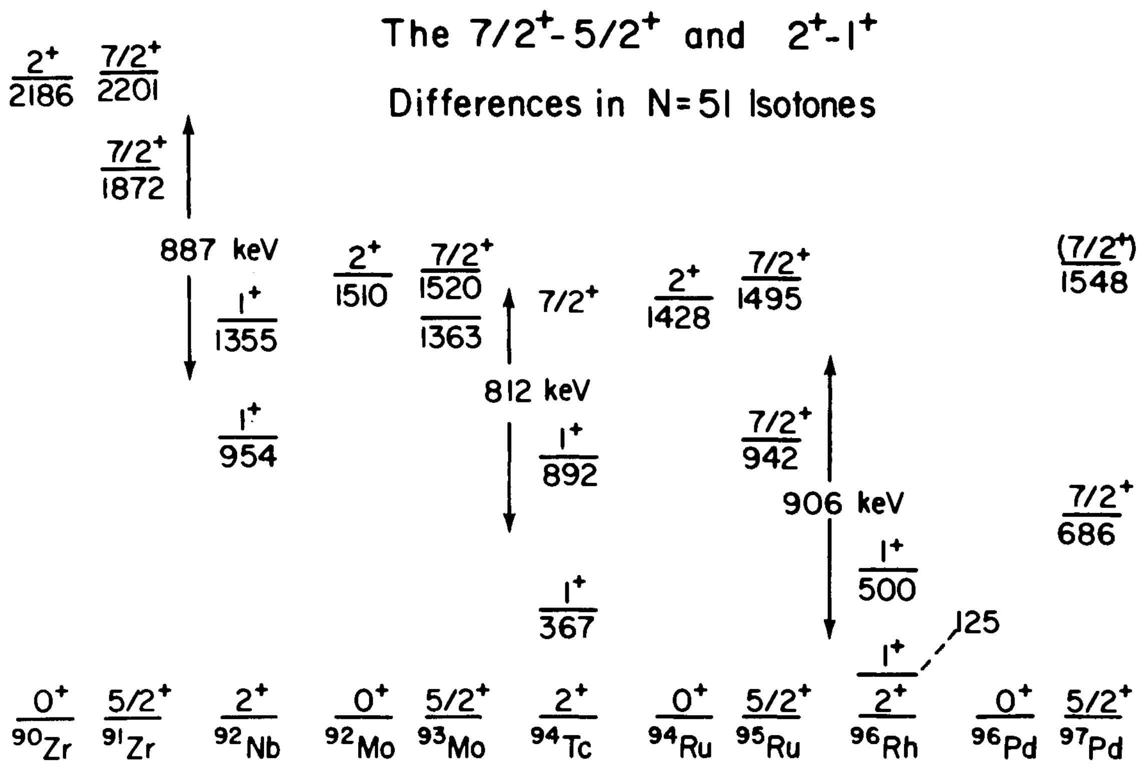

Fig. 6 The $5/2^+$, $7/2^+$, 1^+ and 2^+ levels in the N=51 Zr, Nd, Mo, Tc, Ru, Rh and Pd isotones along with the 2^+ level in the adjacent N=50 core.