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FURTHER EVIDENCE FOR AN EXCEPTIONAL SUBSHELL CLOSURE AT 56 NEUTRONS IN $_{40}Zr^{96}$

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Due to configuration mixing there are generally no definite subshell closures when nucleons are added into a nucleus. This gives rise to smooth trends (rather than breaks) in the total nuclear binding energy and in the mass excess provided no magic numbers (including the less pronounced ones, 14 and 40) are crossed in either proton number Z or neutron number N.

The two upper curves on the left side of the figure and also the upper right diagram demonstrate this behavior for $N = 56$, where a transition from the $2d_{5/2}$ to the $1g_{7/2}$ neutron subshells should take place.

Mass excesses are based mainly on new measurements by Johnson *et al.* [**1**], not yet incorporated in the 1961 Mass Table. The mass excess Δ is enlarged by a linear function of the mass number A to compensate for its steep decrease. Progressing from one point to the next one, the constituents of an alpha particle are built into the nucleus. The protons increase between $Z = 40$ and 50 within the $1g_{9/2}$ shell.

In the right part of the figure, the mass excess Δ refers to ground states and excited states as well, therefore the level scheme appears above the lowest point (the ground state). Level schemes are taken from the « Nuclear Data Sheets » and their « Recent References ». Additional references are used for Mo^{97} [**2**], Ru^{103} [**3**], and $Pd^{105, 107, 109}$ [**4**]. Thin dashed lines connect ground states. Heavy full or dashed (doubtful) lines connect states of the same J^{π}.

The exceptionally low mass excess for $_{40}Zr^{96}_{56}$ with respect to the subsequent smooth trend indicates that the combination of 56 neutrons with 40 protons produce a shell closure at 56 neutrons. But no 56 neutron shell effect occurs at 42 or 44 protons in $_{42}Mo^{98}_{56}$ and $_{44}Ru^{100}_{56}$. There is only a small dip at the other 40-proton nuclei, $_{40}Zr^{92}_{52}$ and $_{40}Zr^{94}_{54}$.

The middle diagram of the odd-neutron nuclei has a particularly low Zr^{95} ground state; the probable $5/2+$ trend apparently resembles the lower left curve which includes Zr^{96}, i.e. the $5/2+$ hole essentially does not change it. The almost complete $1/2+$ trend, however, resembles the *smooth* curve which includes Zr^{94}, because just a $2s_{1/2}$ neutron is attached to each nucleus. Therefore we predict by interpolation the established (ref. [**3**]) level Ru^{103} 0.135 MeV to be $1/2+$.

In the somewhat incomplete diagram at the lower right, one can say that the $1/2+$ ground state of Zr^{97} is also exceptionally low, considering the high ground state of Mo^{101}. The expected $1/2+$ trend apparently resembles the lower left curve with a $2s_{1/2}$ neutron attached to these nuclei.

The exceptional doubly closed shell character of Zr^{96} was noted by Cohen *et al.* [**5**] in (d, p) and (d, t) reaction studies.

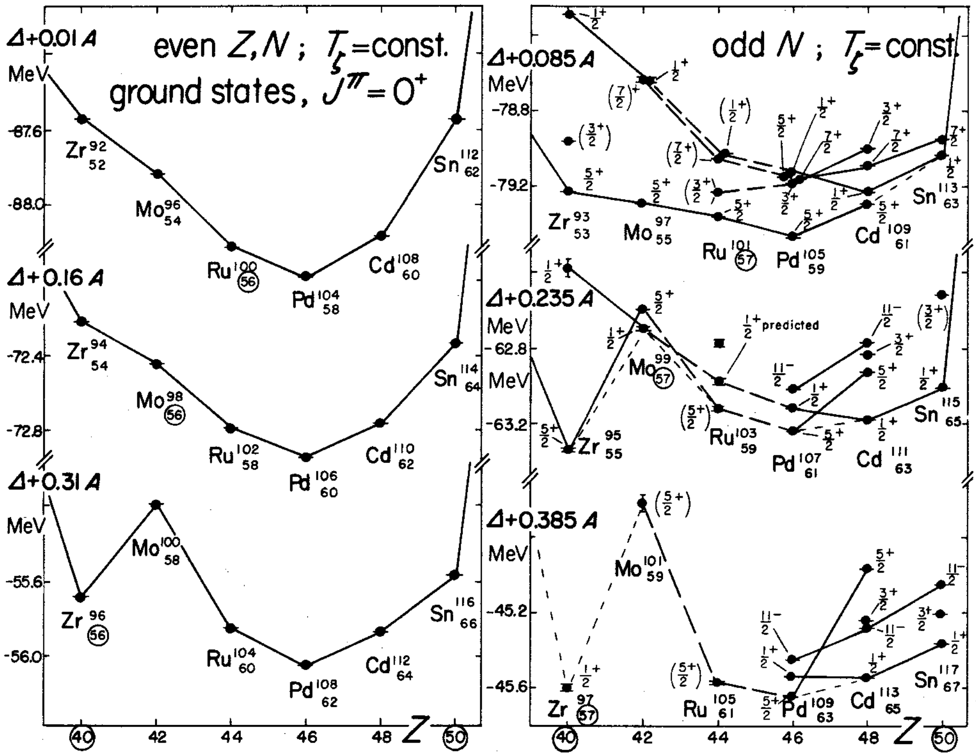

Fig. 1

Mass excess Δ (with a straight line added) *versus* proton number Z for constant neutron excess. Uncertainties are shown by only a single dash if $\leq$ 10 keV.

From the big step after Zr^{96} and the other facts shown, it seems unlikely that the Zr^{96} ground state is maintained as a core in subsequent nuclei containing two or more protons in addition. There seems to be a rearrangement at least of the $2d_{5/2}$ neutron subshell. We found similar steps after O^{16} and Ca^{40} (ref. [**6**]).

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