# Mass dependence of proton and neutron spin-orbit splitting

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## Introduction

Incorporation of spin-orbit interaction potential in shell model potential led to the establishment of magic numbers in shell model and it plays a key role in understanding the nuclear structure in magic nuclei and nuclei away from closed shells. The difference between the splitting of proton and neutron in orbits is found to be almost equal for nuclei whose number of protons and neutrons are equal, whereas there is a deviation from this, when neutron number of a nuclear species increases when compared to proton number. This was analyzed by considering doubly magic $^{16}$O, $^{40}$Ca and $^{100}$Sn for equal number of protons and neutrons and $^{132}$Sn and $^{208}$Pb for neutron rich nuclei. Also the difference between single particle energies of proton and neutron is found to depend on the mass number through the expectation value of spin-orbit interaction term in potential.

Isakov *et al* [2] analyzed the isotopic dependence of the difference between the proton and neutron spin-orbit splittings for two groups of doubly closed shell nuclei. Further they confirmed that the neutron spin-orbit splitting in neutron rich doubly closed nuclei is systematically larger. Recent experimental and theoretical works [1] have confirmed the weakening of the spin-orbit interaction in neutron-rich nuclei far from stability. Aim of the present work is to examine the dependence of magnitude of reduced spin-orbit splittings of proton and neutron on mass number of the nucleus.

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TABLE I: List of spin-orbit splittings $\epsilon_{so}$

| Nucleus | Protons | | Neutrons | |
|---|---|---|---|---|
| | $n\ell$ | $\epsilon_{so}/MeV$ | $n\ell$ | $\epsilon_{so}/MeV$ |
| $^{16}$O | 1p | 6.32 | 1p | 6.17 |
| $^{40}$Ca | 1d | 6.00 | 1d | 6.00 |
| $^{48}$Ca | 1f | 4.95 | 1f | 4.88 |
| $^{100}$Sn | 1g | 6.82 | 1g | 7.00 |
| $^{132}$Sn | 1h | 6.53 | 1h | 4.73 |

## Results and discussion

The spin-orbit splitting can be written as

$$\epsilon_{so} = \frac{1}{2}(2\ell + 1)\zeta \qquad (1)$$

where the first factor comes from the expectation value $< \ell.s >$ and $\zeta$ contains the expectation value of $(1/r)dV/dr$, which depends on depends on $1/R^2$, the dependence of spin-orbit splitting is checked with the expression for radius $R = 1.28A^{1/3} - 0.76 + 0.8A^{-1/3}$. This factor arises from the Woods-Saxon potential form.

Table 1 contains the list of spin-orbit splittings $\epsilon_{so}$ for protons and neutrons taken from tables 1-5 of [2]. Tables 1-5 of Ref. [2] lists the energies of a particle/hole state nearer to the Fermi level, calculated from the differences in binding energies of core nucleus and its adjacent odd-A nucleus, for doubly magic nuclei. From these tables, the difference between the splitting is calculated for both protons and neutrons and are presented in table 1. Here we have considered only for $n = 1$. If we plot the reduced spin-orbit splitting values $(2\epsilon_{so}/(2\ell + 1)/MeV)^{-1/2}$ with value of R, we get a straight line fit as shown in Fig. 1.

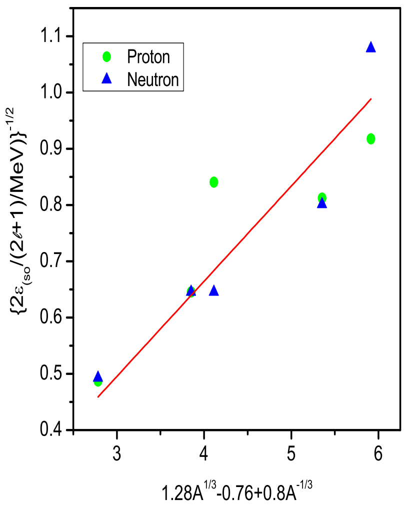


FIG. 1: Mass dependence of the reduced spin-orbit splitting.

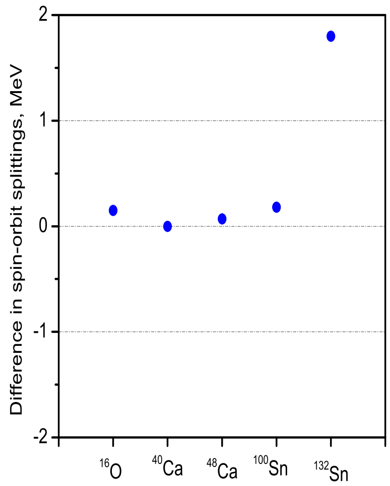


FIG. 2: Difference between spin-orbit splitting of proton and neutron for $N = Z$ and $N \neq Z$ nuclei.

From the straight line fit we get the relation,

$$\epsilon_{so} = \frac{1}{2}\frac{(2\ell + 1)}{(0.1466R + 0.09)^2} \quad (2)$$

This relation is used to calculate the spin-orbit splitting for higher $\ell$ orbits with $n = 1$. Such calculated values are found to differ nearly by 1 MeV from the experimental values. Hence a better fitting can be achieved if we include the higher values of $n$ and heavier nuclei are included. It is to be mentioned that, in the present calculation we have considered only nuclei upto $A = 132$; if we proceed for higher mass nuclei, we have to include the value of $n = 2, 3$ and the factor $n$ is to be included in the above relation.

In Fig. 2, the difference between the proton splitting and neutron splitting are presented. Difference is found to be significant only for $A$ =132, whereas for other nuclei it is around 0. Though $^{48}$Ca is an $N \neq Z$ nucleus, the difference is negligible.

The results pertaining to the dependence of reduced spin-orbit splitting on mass number by incorporating the experimental values for higher $A$ and $n$ will be presented.

## References


[1] R. Orlandi *et al*, Phys. Lett. B **785**, 615 (2018).

[2] V.I. Isakov *et al*, Eur. Phys. J. A **14**, 29 (2002).