Exotic Neutron Magicities of the Proton Magic Ni isotopes

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Introduction

The search for doubly magic isotopes of Ni began with ^{58}Ni, which exists naturally, as a stable isotope. And Ni is unique in having three doubly magic isotopes. ^{56}Ni and ^{78}Ni is actually one of the most neutron rich nuclei. ^{48}Ni is also reported as doubly magic[1]; arised when the neutron and proton numbers are exchanged, ie., the mirror nucleus of ^{48}Ca and both are doubly magic. A sudden shortening of half-lives of Ni isotopes noticed beyond N=50 by Xu et al.[2] in the measurement of β-deacy half-lives of ^{76,77}Co, ^{79,80}Ni and ^{81}Cu and the gross property of the half-life evolution suggests a doubly magic character of the neutron rich nucleus ^{78}Ni. In fact the experimental progress allows us to study more and more exotic systems towards the still unknown. The region around ^{78}Ni is interesting since very neutron rich nuclei play an important role in *r*-process nucleosynthesis, and ^{78}Ni is one of its possible waiting points [3]. From the nuclear structure point of view, the doubly magic nucleus, ^{78}Ni, with the largest *N/Z* ratio, represents a unique possibility of exploring the properties of very neutron-rich nuclei. The knowledge of single-particle energies of ^{78}Ni is also crucial for shell-model studies which utilize this nucleus as a core [4] and which allow exploration of the properties of *A* = 80–90 neutron-rich nuclei, including those lying on the *r*-process path. The *N* = 50 gap along the nickel chain was shown to bear similarities to what is known in oxygen and calcium chains[5]. Very recently Hagen et al., [6] predicted the $J^\pi=2_1^+$ state in ^{78}Ni from a correlation with the $J^\pi=2_1^+$ state in ^{48}Ca using chiral nucleon-nucleon and three nucleon interaction.

Methodology

Since the isotopes of Ni are formed in supernova explosions through r-process a thermodynamical consideration of the evolution of the nucleus is more appropriate and hence the statistical model with temperature and rotation is followed in this study to obtain excitation energy, particle separation energy, level density, etc. The statistical theory coded by us is used for these calculations and is also used for ^{56}Ni earlier [7]. Necessary modifications in the code are carried out according to the nuclei considered. The single particle energies are calculated by CNSM for N=11 shells with oscillator frequency $\Omega=0.0\hbar\omega$ for deformation $\delta=0.0\text{-}1.2$ and $\gamma=-120^o$ - $-180^o(-20^o)$. The temperature is taken from T=0.1 MeV to 5.0 MeV(0.1) with spin $J=0\hbar\text{-}50\hbar$. As a total of 23 isotopes of Ni with A=40-84 are taken for this study. Among the 2,32,050 energy values for each isotope the E_{min} is obtained.

Result

Besides the energy of 2_1^+ state, the separation energies also yield valuable information regarding the magicity of the nucleus. The peaks of S_n at T=1.0MeV (Fig.1) obtained at A=44, 56 and 78 pronounces the possible shell gaps at N= 16, 28 and 50 and which provide the strong evidence of existence of magicity at these mass numbers for Z=28. The higher value of Sn obtained resembles the energy of the 2_1^+ state of these isotopes obtained by Hagen et al.[6]. According to Sn, the gap

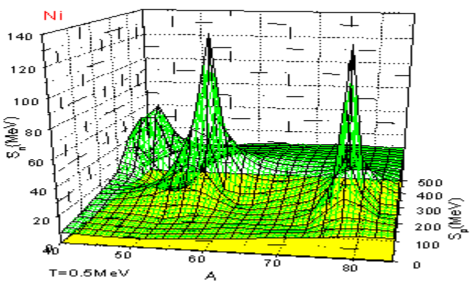

Fig. 1. Neutron separation energy of Ni isotopes.

(peak in fig.1) obtained at A=44 is in contrary to Blank et al.[1] since he reported ^{48}Ni as the doubly magic. But ^{48} Ni is having comparatively low S_n and is almost same as its neighbours. The shell effect gradually vanishes after T=2.0MeV since S_n shows a smooth trend at T > 2.0MeV. In astrophysics, the rates of neutron-capture reactions in r and s processes are proportional to the NLD and are important in the synthesis of elements heavier than iron. The ldp, an important ingredient in nuclear reaction studies, is also calculated at J=0ℏ (Fig.2) and which also pronounces the feasibility of having doubly magic nickel isotopes at A=56 and 78. The lowest ldp value at A=44 also strongly reveals that the possibility of having the neutron magic number N=16 instead of N=20, which supports Sorlin and Porquet[8].

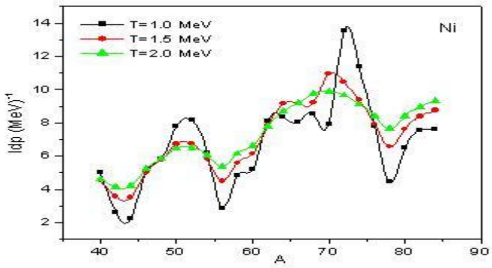

Fig. 2. ldp 'a' at diff. Temps. for Ni (A=40-84).

In the spherical shell model picture for N>40, Z=28 nuclei, the valance neutrons are starting to occupy the $g_{9/2}$ orbital. Two valance neutrons can be occupied to states with maximum available spin $J^{\pi}=8^{+}$. The positive parity and the high angular orbital momentum *l*=4 of the $g_{9/2}$ –orbital prevents this state from being mixed with *fp*-shell (*l* = 1,3; π = -1) states, hence the wave function of this state should be a two nucleon $(g_{9/2})^2$ excitation[9]. For ^{70}Ni, the energy difference between 8^+ and 6^+ state is 182 keV with life time 230ns decay via E2 photon emission. For ^{72}Ni & ^{74}Ni this transition is slowed down due to the B(E2) quenching in mid-shell. Our model also predicted the higher ldp values for these nuclei and which may be correlated with such effect and similar effect of slowing down in transition is observed for ^{66}Ni & ^{68}Ni which is evidenced from the very high ldp values at T≤1.0MeV and thus a high decay probability for $^{66-74}$Ni is possible. It is also found that, at low spin and high temperature, S_n is higher for ^{56}Ni and ^{78}Ni than S_p, but for A=62 to 74, $S_p > S_n$.

The stability of these doubly magic nuclei against temperature and rotation is determined from the state of spherical to deformed shape transition and is observed that ^{78}Ni shows comparatively higher stability than ^{56}Ni at higher spins and ^{44}Ni at lower spins. The observed drop in temperature around J=30ℏ (Fig.3) may be due to the phase transition and then the pairing effect get vanishes for A=56,78 but for A=44, at 12ℏ. The corresponding E_{min} at various T for each spin J=0-40ℏ also shows a phase transition

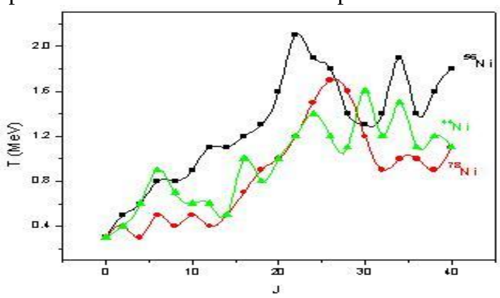

Fig. 3. Existence of nucleus with possible temperature and spin(ℏ) at E_{min}.

At J=30ℏ by the drop in E_{min} at this spin. The too low E_{min} obtained for ^{78}Ni at different spins compared to ^{56}Ni again conveys its higher stability against rotation. This study paves the way to further theoretical predictions in the nuclei lying in the r-process path.

References

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