Investigation of ^{208}Pb (^{34}Na,^{33}Na)X reaction at 100 MeV/n beam energy

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Introduction

The nuclei lying near to the drip line are termed as exotic nuclei. These nuclei have large N/Z ratio compared to other stable nucleus due to which these have novel characteristics like low binding energy, large matter radii, large breakup cross section and narrow longitudinal momentum distribution of core fragment [1]. The study of these nuclei is important because of their key role in nucleosynthesis reactions. In recent years, ^{34}Na nucleus has attracted lot of attention because of its loosely bound valence neutron and its role in stellar reactions [2]. Also different experimental observations has shown large uncertainty in its single neutron binding energy i.e. S_n=(0.17±0.50) MeV and S_n =(0.80± 0.008) MeV [3,4] which plays an important role in finding reaction rates for its production and consumption in nucleosynthesis reactions. As per the trend of neutron rich isotopes of Ne, Mg and Al nuclei, there is strong possibility of ^{34}Na to be *p*- or *f*-wave dominant. Further, a recent theoretical study involving single neutron breakup from ^{34}Na on ^{208}Pb target at 100 MeV/n also endorse its *p* or *f*- wave dominance [4]. In theoretical studies of exotic nuclei breakup reactions, generally the core of the exotic nuclei has been assumed in its ground state but recent studies [5-8] reported that there is an appreciable effect of core excitation on width of longitudinal momentum distribution of core fragment and single neutron breakup cross-section. So for a lucid interpretation of experimental results it is very important to investigate this core excitation affect on breakup observables. Therefore, keeping in view the above facts of ^{34}Na, in this work we have investigated the effects of core excitation and various binding energies (in exp. Uncertainties 0.10 to 0.8 MeV) on longitudinal momentum distribution width and single neutron breakup cross section. We have considered both *p* and *f* states along with ground and excited state of the core.

Theoretical Formalism

Total nuclear breakup cross-section (Stripping and Diffraction) and respective Longitudinal Momentum Distribution (LMD) are calculated using standard computer MOMDIS code based on eikonal approximation [9].^{34}Na nucleus is assumed as two body system with ^{33}Na as a core plus neutron. So different projectile configurations are considered with possibility of core in ground ($3/2^+$) or in excited ($5/2^{+,}$ E_c^x = 0.429 MeV) state and valence neutron in either $2p_{3/2}$ or $1f_{7/2}$ state[4]. The respective projectile radial wave functions are calculated numerically by solving the Schrodinger wave equation. The depth of Woods-Saxon(WS) nuclear potential is adjusted to reproduce the effective binding energy (E_c^x +S_n) of the valence neutron. The WS parameter, r_0 and a_0 are taken 1.24 fm and 0.62 fm respectively for all the configurations. The ground state single neutron separation energies of ^{34}Na i.e., S_n varied from 0.1 to 0.8 MeV including experimental uncertainties. However, the core target and neutron target interaction s-matrices are calculated by $\tau\rho\rho$ formalism using Hartee-Fock matter densities of core and target nuclei [10].

Result and Discussion

The calculated results are shown in Table 1 and 2. Table 1 shows the single neutron breakup cross section for all the assumed $2p_{3/2}$ and $1f_{7/2}$ configurations with respect to the different separation energy. It is observed that in each configuration the breakup cross section is highly sensitive to the separation energy of valence neutron. Also the inclusion of core excitation energy reduces the breakup cross section (from ground state) from 40.8% to 16.9%, and 6.37% to 4.26% with variation in S_n from 0.1 to 0.8 MeV for *p* and *f* state respectively. Also the reduction in cross section is 50% to 30% and 9% to 7% for *p* and *f* state, for core in ground and excited state respectively with variation in S_n from 0.1 to 0.8 MeV. A similar trend is also seen in LMD width where FWHM increases from 30.8% to 13% and 7.5% to 4.13% for *p* and *f* states respectively for core in ground and excited state. However, variation in width with S_n from 0.1 to 0.8 MeV is 45.5% to 17.8% for *p* state for core in ground and excited state respectively and it is 11% to 7.5% for *f* state.

Table 1: Calculated nuclear breakup cross section(in mb) corresponding to each configuration with neutron separation energy for $J^{\pi}=2^+$

Config.	E_c^x (MeV)	S_n (0.10)MeV	S_n (0.14) MeV	S_n (0.17) MeV	S_n (0.34) MeV	S_n (0.51) MeV	S_n (0.80) MeV
$[3/2^+ \otimes 2p_{3/2}]$	0	908.23	837.06	794.06	635.23	545.42	453.72
$[5/2^+ \otimes 2p_{3/2}]$	0.429	537.63	522.25	511.56	461.38	423.70	376.61
% age Decrease		**40.8**	**37.60**	**35.5**	**27.36**	**22.31**	**16.9**
$[3/2^+ \otimes 1f_{7/2}]$	0	201.99	200.51	199.47	194.13	189.59	183.06
$[5/2^+ \otimes 1f_{7/2}]$	0.429	189.12	188.15	187.44	183.70	180.33	175.26
% age Decrease		**6.37**	**6.16**	**6.03**	**5.37**	**4.88**	**4.26**

Table 2: Calculated FWHM of LMD corresponding to each configuration with neutron separation energy

Config.	E_c^x (MeV)	S_n (0.10)MeV	S_n (0.14) MeV	S_n (0.17) MeV	S_n (0.34) MeV	S_n (0.51) MeV	S_n (0.80) MeV
$[3/2^+ \otimes 2p_{3/2}]$	0	50.94	52.80	54.08	60.52	66.04	74.15
$[5/2^+ \otimes 2p_{3/2}]$	0.429	66.63	67.85	68.73	73.34	77.55	83.82
% age Increase		**30.8**	**28.50**	**27.08**	**21.18**	**29.29**	**13**
$[3/2^+ \otimes 1f_{7/2}]$	0	229.42	231.37	232.75	239.88	245.99	254.71
$[5/2^+ \otimes 1f_{7/2}]$	0.429	246.63	247.88	248.82	253.84	258.45	265.24
%age Increase		**7.50**	**7.13**	**6.90**	**5.82**	**5.06**	**4.13**

Conclusion

In this work, we analyzed quantitatively the effect of core excitation with different binding energy on single neutron breakup cross section and width of LMD in $^{208}Pb(^{34}Na,^{33}Na)X$ reaction at 100 MeV/n incident energy using MOMDIS code[9]. We found that single neutron breakup cross section and LMD FWHM width is highly sensitive to the chosen separation energy and excited state of core. The *p* state is found more sensitive to separation energy of valence neutron and core excitation energy, as compared to *f* state. We hope that these results will help in better understand of experimental results.

References

[1] I. Tanihata, et. al. Phys. Rev. Lett 55, 2676 (1985).

[2] C Rolfs, H P Trautvetter and W S Rodney, Rep. Prog. Phys. 50, 233(1987).

[3] L. Gaudefroy et al., Phys. Rev. Lett. 109, 202503(2012).

[4] G. Singh, et.al. Phys. Rev. C 94, 024606(2016).

[5] A. Deltuva et al., Phys. Rev. C 99,024613 (2019).

[6] A. M. Moro et al., AIP Conf. Proc 2012, vol. 1491, pp. 335

[7] S Devi, R Kumar, proceedings of DAE symps. On nucl. Phys. 64,551(2019).

[8] Seema, R. Kumar, proceedings of DAE symps. On nucl. Phys. 64,543(2019).

[9] C.A. Bertulani, A Gade, Comp. Phys. Comm, Vol. 175, issue 5,372(2006).

[10] URL https:///www-nds iaea.org/RIPL/