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Coupled channels calculations for ^{18}O and ^{16}O break-up reaction

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Abstract. α angular correlations were calculated using the coupled channels formalism for ^{16,18}O break-up reactions. Prominent Z dependency was observed in both the cases. ^{16}O break-up shows distinctively different behavior with different target materials.

Keywords. Break-up; coupled channels calculations.

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1. Introduction

In a heavy-ion induced reaction the measurement of deexcited gamma-ray or particles in coincidence with the correlated particles is one of the powerful and elegant tools to investigate the nuclear dynamics and structure. It directly probes the different magnetic sub-state distribution and their probability of population since the different magnetic sub-state probability directly depends on the magnitude and phase of the transition amplitude. In general, for nuclear reactions induced by light-ions the excitations of different magnetic sub-states due to the long range forces are reasonably weak. Hence one can neglect the effects of the Coulomb contribution in their calculations. But in the heavy-ion induced reactions, low excitation energy allows large contributions from the Coulomb excitation and hence interference between the Coulomb and the nuclear interactions play a prominent role in the particle–gamma or particle–particle correlation.

This correlation is in general analysed in the framework of the DWBA which only includes the first order effects. Strong absorption model (SAM) is also used to extract the information from the correlation experiments [1]. This model has its own limitations due to several parametrizations. Therefore more sophisticated calculations are needed to extract the information accurately. The coupled channels calculations can be used to extract the information more accurately and it is possible to predict the significant region of the phase space where such type of reactions can be studied.

In the present paper we are reporting the theoretical calculations of the alpha decay of the states in ^{18}O through sequential break-up reaction ^{12}C(^{18}O, ^{18}O$^{*} \rightarrow {}^{14}$Cα) at 82 MeV using coupled channels form factor. We predicted the possible nature of double differential cross section for α decay of states of ^{16}O in the sequential breakup reaction ^{12}C(^{16}O,

$^{16}O^* \rightarrow ^{12}C\alpha$) at different phase space. The calculations were also performed with different targets to investigate the effect of the Coulomb and nuclear contributions to the correlation.

2. Analysis and discussion

We have applied the coupled channels analysis to data described in ref. [1]. The coupled channels code FRESCO [2] was modified to calculate the angular correlations.

Consider a reaction,

$$A + a \rightarrow b^* + B \rightarrow c + C + B.$$

The angular correlation in the final system in terms of the m-state population $f_{JM}(\theta^*, \phi^*)$ of the intermediate state b^* is given by [3]

$$\frac{\mathrm{d}^2\sigma(\theta^*, \phi^*, \chi, \psi)}{\mathrm{d}\Omega^* \mathrm{d}\Omega_\Psi} = \frac{2J+1}{4\pi} \left| \sum_M f_{JM}(\theta^*, \phi^*)(-)^M \mathrm{e}^{-iM\psi} d^J_{M0}(\chi) \right|^2.$$

Here ψ, χ for the decay particle C are measured with respect to the quantization axis used to calculate the form factor $f_{JM}(\theta^*, \phi^*)$. d^J_{M0} are the rotational matrix elements. The f_{JM} were calculated from the coupled channels formalism (see figure 1 of ref. [1] for the definition of angles). The form factor was f_{JM} calculated from the strong absorption model. The reduced electromagnetic excitation probabilities $B(E\lambda)$ for continuum state was estimated from the relations given below [for 2^+ (8.56 MeV) state of ^{16}O]

$$\frac{\mathrm{d}B(E\lambda)}{\mathrm{d}E_{\mathrm{cm}}} = \frac{\mu}{\pi^2\hbar^2} \frac{(2I_a+1)(2I_b+1)}{(2I_i+1)} \frac{\lambda(2\lambda+1)!!^2}{8\pi(\lambda+1)} \left(\frac{\hbar c}{E_\gamma}\right)^{(2L+1)} \mathrm{e}^{2\pi\eta} S_{E\lambda}(E_{\mathrm{cm}}),$$

where $S_{E\lambda}(E_{\mathrm{cm}})$ is the astrophysical S-factor.

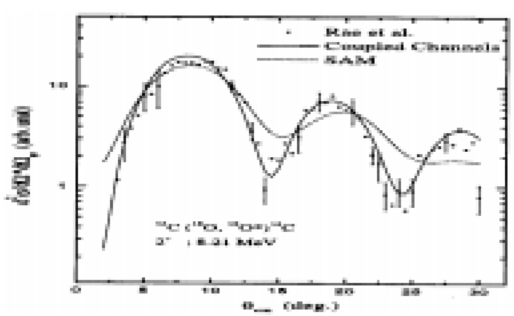

Figure 1. Double differential cross sections for α angular correlation. Solid line is the coupled channels and dotted line represents the SAM calculations (see text). Experimental cross sections are taken from ref. [1] at a constant emission angle $\psi = 72^\circ$ for the α particle. θ_{cm} is the c.m. angle of the 8.21 MeV state in $^{18}O^*$.

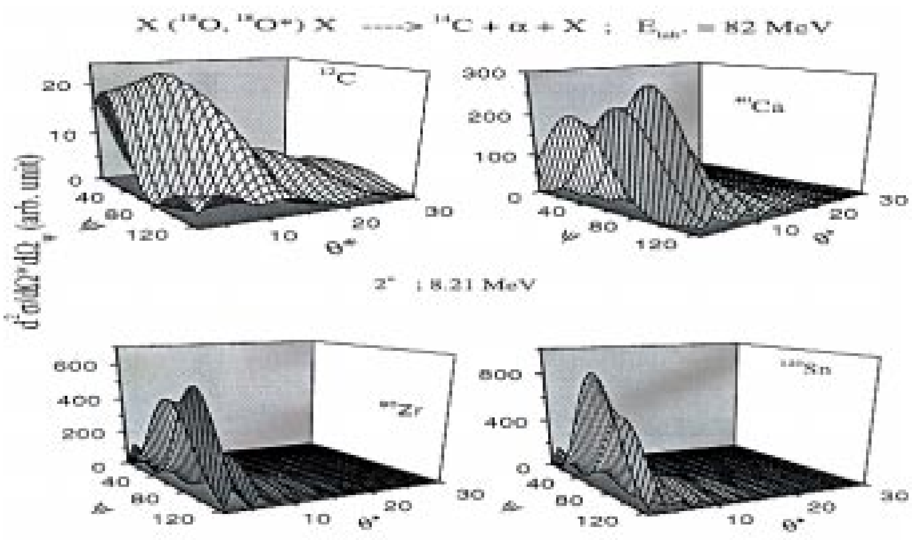

Figure 2. Three dimensional plots for the theoretical calculations with coupled channels form factor of α correlations for ^{18}O break-up in different target materials. θ^* is the c.m. angle of the intermediate state ^{18}O* and ψ the c.m. angle of emission of the α particle.

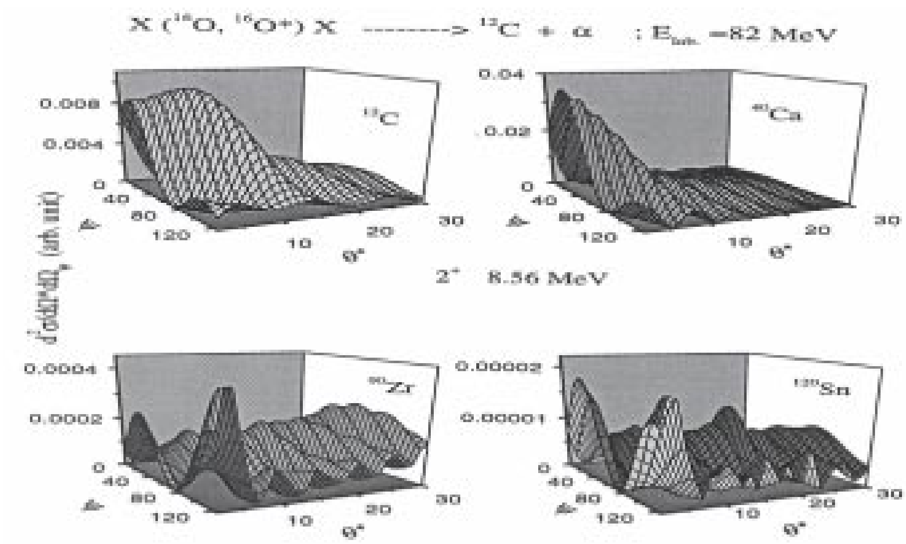

Figure 3. Three dimensional plots for the theoretical calculations with coupled channels form factor of α correlations for ^{16}O break-up in different target materials.

Using this formalism we explain the correlations for 8.21 MeV resonance for ^{18}O break-up into α and ^{14}C. The coupled channels calculations were performed by considering only two channels. The reduced electromagnetic excitation probability values were taken from the literature [4]. Figure 1 shows excellent agreement between theoretical calculations (straight line) with experiment. A SAM calculation (dotted line) was also performed with the parameter set given in ref. [1].

We have further calculated the correlations for 8.21 MeV resonances for ^{18}O break-up into α and ^{14}C, 8.56 MeV continuum state for ^{16}O break-up into α and ^{14}C for three different target elements ^{40}Ca, ^{90}Zr and ^{120}Sn (figures 2 and 3). Though calculations for both ^{16}O and ^{18}O show the prominent Z dependence, double differential cross section for α correlations of ^{16}O break-up behaves differently from ^{18}O with increasing Z [5]. This effect is most probably due to the two sd-shell neutrons present in the ^{18}O nuclei.

3. Conclusions

We have calculated the double differential cross section for α decay of 2^+ state of ^{18}O in the sequential breakup reaction $X(^{18}\text{O}, {}^{18}\text{O}^* \rightarrow {}^{14}\text{C}\alpha)$ at 82 MeV with SAM and coupled channels form factor ($X = {}^{12}$C, ^{40}Ca, ^{90}Z, ^{120}Sn). Good agreement was observed with experimental results using the coupled channels form factor of the double differential cross section for α decay from the 8.21 MeV, 2^+-states of ^{18}O. We predicted the nature of double differential cross section for α decay from the 8.56 MeV, 2^+-states of ^{16}O in the sequential break-up reaction $^{12}\text{C}(^{16}\text{O}, {}^{16}\text{O}^* \rightarrow {}^{12}\text{C}\alpha)$ at 82 MeV using the coupled channels form factor. Further calculations and experiments are needed to extract more information about the dynamics of the reaction in the significant region of phase space for the above system.

References

[1] W D M Rae and R K Bhowmik, *Nucl. Phys.* **A420**, 320 (1984); **A427**, 142 (1984)
[2] I J Thompson, *Comp. Phys. Rep.* **7**, 167 (1988)
[3] F Poughen, P Roussel, M Bernas, F Diaf, B Fabbro, F Naulin, E Plagnol and G Rotbard, *Nucl. Phys.* **A325**, 481 (1979)
[4] D R Tilley, H R Weller, C M Cheves, R M Chasteler, *Nucl. Phys.* **A595**, 1 (1995)
[5] Samit Mandal and R K Bhowmik, under preparation