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# Excited states of $^{26}$Al studied via the reaction $^{27}$Al(d,t)

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**Abstract**

The reaction $^{27}$Al(d,t) at 25 MeV was utilized to study the excited states of $^{26}$Al. The angular distributions of the observed excited states of $^{26}$Al were analyzed with zero range distorted wave Born approximation as well as by incorporating finite range correction parameters to extract spectroscopic factors. The two sets of extracted spectroscopic factors were compared with each other to see the effect of using finite range correction in the transfer form factor.

The nucleus $^{26}$Al is the first cosmic radioactivity detected in the interstellar medium and its half life ($7.2\times10^5$ years) is much shorter than the time for galactic evolution ($\sim10^{10}$ years) and its detection directly indicates that nucleosynthesis is currently active in our galaxy. The origin and importance of $^{26}$Al has been very much studied in Refs. [1–5]. To study the structure of the nucleus $^{26}$Al, excitation energies, spin and parity and spectroscopic factors etc. are required. Single nucleon transfer reactions are important

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tools to extract spectroscopic information about the nuclei of interest. Very recently, we studied the reaction $^{27}$Al(d,t) and extracted neutron spectroscopic factors for the observed excited states of $^{26}$Al in Ref. [6]. We also compared the results of our study of one neutron pick-up reactions with the previously reported values obtained using different reaction probes and the comparison has been given in Ref. [6].

In the present study, we extracted the spectroscopic factors for the observed states of $^{26}$Al produced through $^{27}$Al(d,t) reaction using zero range distorted wave Born approximation (ZR-DWBA) and also attempted the ZR-DWBA calculation by incorporating finite range correction parameters in ZR-DWBA computer code DWUCK4 [7]. So, to examine the effect of using finite range correction parameter in ZR-DWBA on spectroscopic factors was the main motivation of the present paper.

The experiment was performed at the Variable Energy Cyclotron Centre, Kolkata, India to study the reaction $^{27}$Al(d,t). The details of the experiment have been given in Ref. [6].

Table 1: The best fit OMPs used in DWUCK4 code for the reaction$^{27}$Al(d,t).

| Parameters | $^{a}$d+$^{27}$Al | $^{a}$t+$^{26}$Al | n+$^{26}$Al |
|---|---|---|---|
| $V_R$(MeV) | 90.301 | 161.91 | $V^{b)}$ |
| $R_R$(fm) | 1.055 | 1.20 | 1.20 |
| $a_R$(fm) | 0.675 | 0.72 | 0.65 |
| $W$ (MeV) | | 39.99 | |
| $W_D$(MeV) | 2.407 | | |
| $R_I$(fm) | 1.400 | 1.40 | |
| $a_I$(fm) | 0.850 | 0.84 | |
| $V_{ls}$(MeV) | 9 | 2.50 | |
| $r_{ls}$(fm) | 1.055 | 1.20 | |
| $a_{ls}$(fm) | 0.780 | 0.72 | |
| $R_c$ (fm) | 1.25 | 1.30 | |

$^{a}$taken from Ref. [6]
$^{b}$Adjusted to give the required separation energy transferred particle.

In this study, we used only one set of optical model potential parameters (OMP) from the Ref. [6] to extract spectroscopic factors of the different observed states of $^{26}$Al which are given in Table 1. The angular distributions of the observed states of $^{26}$Al were fitted with theoretical predictions from

ZR-DWBA calculations to extract the spectroscopic factors. The fitted angular distributions of the observed states of $^{26}$Al with and without using finite range correction parameter and nonlocal parameters were shown in Figs. 1 and 2. The value of the transferred angular momentum ($l_{tr}$) was estimated from the relation given in [8]. To extract spectroscopic factors, we used the following relation between experimental and theoretical cross sections as used in Refs. [6] and [9];

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp.} = \frac{NC^2S}{2J+1}\left(\frac{d\sigma}{d\Omega}\right)_{DWBA} \quad (1)$$

where $(\frac{d\sigma}{d\Omega})_{exp.}$ is the experimental differential cross-section and $(\frac{d\sigma}{d\Omega})_{DWBA}$ is the cross-section predicted by the DWUCK4 code. $C^2$ is the isospin Clebsch-Gordon coefficient, $S$ the spectroscopic factor and $J$ is the total angular momentum of that orbital from which the neutron was picked up.

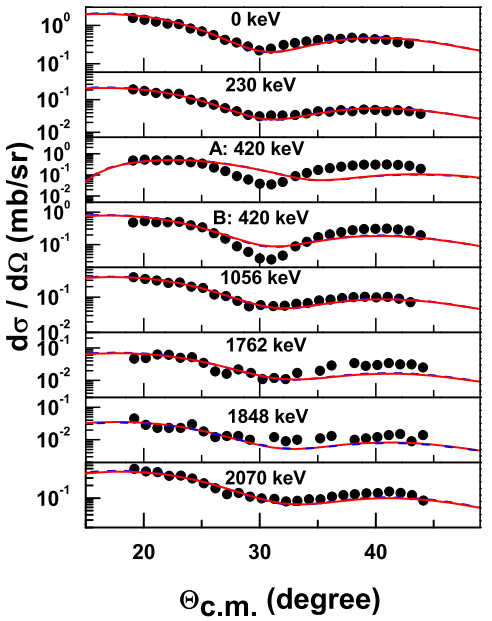


Figure 1: Fitted angular distribution of 0.0, 230, 420, 1056, 1746, 1848 and 2070 keV states of $^{26}$Al. The filled circles represent experimental data points, solid lines represents ZR-DWBA predictions without finite range parameter and dash-dash line represent ZR-DWBA predictions using finite range parameter 1.36 $fm^{-1}$.

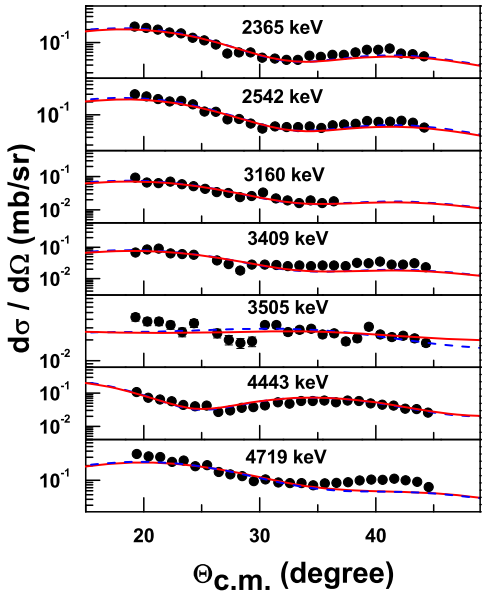


Figure 2: Fitted angular distributions of 2365, 2542, 3160, 3409, 3505, 4443 and 4719 keV states of $^{26}$Al (same notation as in Fig. 1).

In the present work, we extracted spectroscopic factors for 14 states of $^{26}$Al populated through the reaction $^{27}$Al(d,t) which are listed in Table 2. The ground, 230, 1056, 1762, 1848, 2070, 2365, 2542, 3160, 3409 and 4719 keV states of $^{26}$Al were studied by assuming pick up from $0d_{5/2}$ single particle orbital. The excited states at 3505 and 4443 keV were studied by assuming pick up from $0g_{9/2}$and $0p_{1/2}$ single particle orbitals respectively. The analysis of 420 keV state was performed for both $1s_{1/2}$ (shown by A:420 keV in Fig. 1) and $0d_{5/2}$ (shown by B:420 keV in Fig. 1) single particle orbitals separately. We performed ZR-DWBA calculation using the finite range correction value and nonlocal parameters 0.54, 0.25 and 0.85 for deuteron, tritium and neutron respectively. First a ZR-DWBA calculation was performed by using normalization $N = 3.33$ taken from Ref. [7] without finite range parameter and non local parameters. Then the ZR-DWBA calculation was again performed using a normalization constant $N = 2.54$ as used in [9] with a finite range parameter of 1.36 $fm^{-1}$ for (d,t) [10]. It

Table 2: Extracted values of $C^2S$ for different excited states of $^{26}$Al.

| Ex(KeV) | $J^\pi$ | $l$ | $^{a)}C^2S$ | $^{b)}C^2S$ |
|---|---|---|---|---|
| 0 | $5^+$ | 2 | 0.83 | 0.69 |
| 230 | $0^+$ | 2 | 0.10 | 0.08 |
| 420 | $3^+$ | 0 | 0.08 | 0.06 |
| | | 2 | 0.36 | 0.30 |
| 1056 | $1^+$ | 2 | 0.20 | 0.16 |
| 1762 | $2^+$ | 2 | 0.043 | 0.035 |
| 1848 | $1^+$ | 2 | 0.022 | 0.018 |
| 2070 | $2^+$ | 2 | 0.29 | 0.24 |
| 2365 | $3^+$ | 2 | 0.15 | 0.12 |
| 2542 | $3^+$ | 2 | 0.17 | 0.15 |
| 3160 | $2^+$ | 2 | 0.06 | 0.05 |
| 3409 | $5^+$ | 2 | 0.07 | 0.06 |
| 3505 | $6^+$ | 4 | 0.08 | 0.06 |
| 4443 | $2^-$ | 1 | 0.25 | 0.22 |
| 4719 | $4^+$ | 2 | 0.31 | 0.25 |

[a]Extracted from pure ZR-DWBA calculation.
[b]Extracted from ZR-DWBA calculation by incorporating finite range parameters.

was observed that the theoretical predictions, with and without using finite range correction parameters in ZR-DWBA calculation, were found to fit the experimental data in the same way. The extracted spectroscopic factor values were found to be reduced approximately by 10% to 25% for using finite range correction parameters 1.36 $fm^{-1}$ and $N = 2.54$ as compared with those without using finite range correction parameter in ZR-DWBA calculation. The deviation estimated may be more for the states with poor statistics in data. The extracted $C^2S$ values using the above two calculations were tabulated in Table 2 for comparison.

To sum up, the reaction $^{27}$Al(d,t)$^{26}$Al at $E_d = 25$ MeV was used to study ground as well as excited states of $^{26}$Al. A total of 14 states of $^{26}$Al were studied using ZR-DWBA calculation as well as by incorporating finite range correction parameters in DWUCK4 code. The theoretical predictions were found be in fair agreement with the data. Two different calculations were used to examine the variation in $C^2S$ values of the observed states of $^{26}$Al and approximately 10% to 25% reduction in $C^2S$ values was estimated using ZR-DWBA calculation with finite range effect comparative to ZR-DWBA

calculation without finite range parameters.

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