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ANALYSIS OF THE REACTION $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ TO DETERMINE THE ANC FOR THE $^{25}\mathrm{Mg} \to {}^{24}\mathrm{Mg} + n$ CONFIGURATION

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Abstract. The $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction was studied at the energy of 14.5 MeV with transitions to the ground $(5/2^+)$ and low-lying excited 0.58 MeV $(1/2^+)$ and 0.98 MeV $(3/2^+)$ states of $^{25}\mathrm{Mg}$ nucleus. The analysis of the measured angular distributions was carried out using a modified distorted wave method, assuming a one-step neutron transfer mechanism. The reliability of the criterion of proton transfer peripherality used in the modified distorted wave method was studied in detail. It was shown that at small angles (in the region of the main diffraction maximum) this reaction occurs commonly on the nuclear surface with the dominance of a one-step process. The values of the squares of the asymptotic normalization coefficients for $^{24}\mathrm{Mg} + n \to {}^{25}\mathrm{Mg}$ were obtained, which are equal to 1.64 ± 0.38 fm^{-1}, 22.5 ± 4.6 fm^{-1} and 0.81 ± 0.19 fm^{-1} for the lowest $5/2^+$, $1/2^+$ and $3/2^+$ states of the $^{25}\mathrm{Mg}$ nucleus, respectively.

Key words: differential cross section, spectroscopic factor, asymptotic normalization coefficient, modified distorted wave born approximation.

I. INTRODUCTION

The (d,p) reactions were widely studied in the 1970s–1990s, mainly to compare nucleon binding spectroscopic factors (SFs) extracted using the DWBA method with shell model predictions. Later, interest in these studies declined due to strong model dependence of the SFs extracted within the DWBA, which have a spread of values of 1.5 - 2 times or more [1–3]. Currently, (d,p) reactions are again attracting the attention of both theorists [4–6] and experimentalists [7, 8] due to the possibility of extracting asymptotic normalization coefficients (ANC) for external neutron coupling at the periphery of the nucleus. These values, obtained from reaction analysis [9], are virtually independent of uncertainties in the model binding potential if the proton transfer is peripheral. This turned out to be extremely important not only for refining the structure of nuclear states, but also for the correct calculation of cross sections of peripheral processes, especially nuclear-astrophysical neutron capture reactions ($s-$ and $r-$ processes of nucleosynthesis of medium nuclei [10]). The (d,p) reaction are convenient for ANC obtaining, since in the energy range of $\sim$ several tens of MeV the neutron transfer is in most cases one-step process and occurs at the periphery of the acceptor nucleus. Nowadays it is often used in inverse geometry experiments to find the ANC of radioactive short-living nuclei.

The ANC values of low-lying states of magnesium nuclei are in great demand because (n,γ) reactions on them can reduce the neutron concentration in the stellar environment, which greatly affects subsequent nucleosynthesis processes. When studying moderately light nuclei of the $2s-1d$ shell, the reaction $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ was investigated in a number of papers [1, 11–16].

To date, there are only two studies that report the ANC value solely for the ground state of the $^{25}\mathrm{Mg}$ nucleus ($= {}^{24}\mathrm{Mg} + n$). In the paper [17], the ANC was obtained from an analysis of the $^{25}\mathrm{Mg}(d,t)^{24}\mathrm{Mg}$ reaction. In the paper [18] the possibility of refining the spectroscopic factor value by comparing the data of peripheral $^{25}\mathrm{Mg}(d,t)^{24}\mathrm{Mg}$ and non-peripheral $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reactions is shown.

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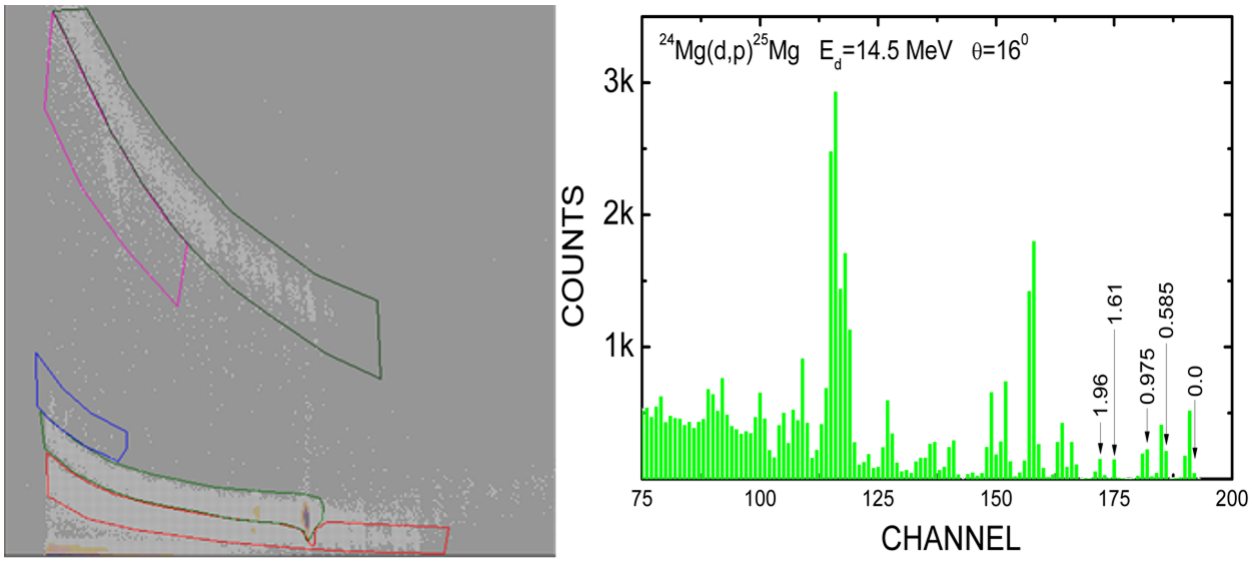


FIG. 1: The two-dimensional $\Delta E - E$ spectrum (left) and energy (E) spectrum of protons from interaction of the 14.5 MeV deuteron beam with the ^{24}Mg target, measured under the angle of 16° (Lab).

However, as it turned out, the assessments of the peripherality of the particle transferring are often ambiguous due to the strong dependence of the peripherality criterion analysis on such factors as the uncertainty of the OP parameters, the choice of the range of the single-particle ANC variation and the emission angle of the registered particle.

The aim of the work is to obtain experimental DCS of the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction to the states of ^{25}Mg with different angular momenta of the transferred neutron and to find the ANC values of neutron binding in low-lying states, which play an important role in the nucleosynthesis through radiative neutron capture. Particular attention is paid to establishing the peripherality of neutron transfer in the region of the main maximum of the DCS angular distribution. Specifically, the dependence of the neutron transfer peripherality estimate in the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction used in the modified DWBA (MDWBA) on the choice of optical potential (OP) parameters for the input and output reaction channels. The reliability of MDWBA criterion on peripherality is also analyzed when considering the DCS for different emission angles of the registered particle within the main maximum at different angular momenta of the transferred neutron.

II. EXPERIMENT DETAILS

Experiments to measure the elastic scattering of deuterons on the ^{25}Mg nucleus and the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$, reaction at an energy of $E_d = 14.5$ MeV were performed on the isochronous cyclotron beam of the Institute of nuclear physics of Kazakhstan (Almaty). A detailed description of the experimental setup is given in the Ref. [19]. Registration and identification of reaction products were realized by two $\Delta E - E$ telescopes of semiconductor silicon detectors. The so-called "far" telescope was placed far from the target in an additional volume of the reaction chamber for small-angle measurements at high intensity, and the "near" telescope was placed in the main volume of the chamber for measurements at other angles. The acquisition and primary processing of two-dimensional spectra of reaction products were carried out using software-controlled two-dimensional amplitude analyzers [20] and original software [21]. Metal foils of ^{24}Mg enriched to 99% manufactured in the Oak Ridge laboratory (USA), with a thickness of 0.82 $\mathrm{mg/cm^2}$, were used as target.

Figure 1 shows a typical two-dimensional $\Delta E - E$ spectrum for singly charged reaction products of a deuteron beam interaction with the ^{24}Mg target and the corresponding energy spectrum of deuterons.

The angular distributions of differential cross sections (DCS) for the $^{24}\mathrm{Mg} + d$ elastic scattering as well as for the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction, which are presented in the next section along with the calculated ones, were measured in the angular range of 8° – 40° (lab) with a step of 2°. The systematic error in the measured cross sections is associated with the uncertainty of the target thickness (6 - 8%), the solid angle of the spectrometer (1%), and the integration of the beam current, and does not exceed 10% overall. The statistical errors were generally $\sim$ 1 - 4% and only at the minima of the cross sections at large angles did they reach $\sim$ 10%

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III. THEORETICAL APPROACH AND ANALYSIS OF NEUTRON TRANSFER REACTIONS

In the used MDWBA approach [22–24], the calculated DCS in the region of the main stripping peak of the angular distribution for the reaction $\mathrm{A}(x,y)\mathrm{B}$ ($y+n\to x$ and $\mathrm{A}+n\to\mathrm{B}$) is parameterized in terms of the product of the squares of ANCs, and the corresponding DCS has the form:

$$\frac{d\sigma}{d\Omega}=C^2_{\mathrm{A}n}\times C^2_{yn}\times R(E_i,\theta;b_{yn},b_{\mathrm{A}n}) \tag{1}$$

where the factor

$$R(E_i,\theta;b_{yn},b_{\mathrm{A}n})=\frac{\sigma^{\mathrm{DWBA}}_{\mathrm{A}n}(E_i,\theta;b_{yn},b_{\mathrm{A}n})}{b^2_{yn}\times b^2_{\mathrm{A}n}} \tag{2}$$

contains the dependence on the geometric parameters of the W-S neutron binding potential for each considered state of B. Here, b_{yn} is the "single-particle" normalization coefficient of the model wave function of the projectile (here d) at large radii with respect to the Whittaker function and $b_{\mathrm{A}n}$ is the same for the residual nucleus (here $^{25}\mathrm{Mg}$). $C_{\mathrm{A}n}$ and C_{yn} are the ANCs for $\mathrm{A}+n\to\mathrm{B}$ and $y+n\to x$, which determine the amplitudes of the tails of the radial B and x nuclei wave functions in the $(\mathrm{A}+n)$ and $(y+n)$ channels.

The calculations of $\sigma^{\mathrm{DWBA}}(...)$ were carried out using the DWUCK5 code [25] in the finite range approximation. Based on the results of Ref. [26], the value of ANC $(C_{pn;0\frac{1}{2}})^2$ for $p+n\to d$ in $s-$ state was taken equal to 0.77 fm^{-1}. The calculations used the generally accepted form of the optical model (OM) potential - see, for example, [27]. The available global optical potentials based on experimental data (elastic DCSs and total cross sections) corresponding to the energy and mass range of the reaction under consideration were utilized – see Table I. The parameters of the optical potentials (OP) for the entrance channel of the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction (which labeled as D1-D5), are taken from Refs. [28–32] and were tested by applying them to the description of elastic $^{24}\mathrm{Mg}+d$ scattering measured in the same experiment [33] (see Fig. 2). For the exit $(^{25}\mathrm{Mg}+p)$ channel, global OPs presented in the Refs [34–36] were used, as well as local OPs from the Perey-Perey compilation [27].

	Set1		Set2		Set3		Set4		Set5	
OP Parameters	D1	P1	D2	P2	D3	P3	D4	P4	D5	P5
V_0	84.249	50.449	80.165	42.82	91.593	49.447	88.39	50.621	90.935	42.82
r_0	1.174	1.17	1.25	1.26	1.13	1.173	1.17	1.165	1.13	1.26
a_0	0.809	0.75	0.741	0.67	0.8	0.69	0.733	0.674	0.755	0.67
W	19.817	1.53				1.598	0.262	1.721	2.006	
r_W	1.328	1.32				1.186	1.325	1.165	1.34	
a_W	0.465	0.538				0.69	0.731	0.674	0.567	
W_D	4.102	7.473	13.00	6.88	12	6.954	12.315	7.794	10.386	6.88
r_D	1.563	1.32	1.25	1.42	1.41	1.186	1.325	1.296	1.387	1.42
a_D	0.7	0.538	0.73	0.37	0.729	0.69	0.731	0.532	0.71	0.37
V_{SO}	3.703	6.2	6.00	4.18	5.2	5.9	6.91	5.377	3.557	4.18
r_{SO}	1.234	1.01	1.25	1.04	0.85	0.93	1.07	0.964	0.972	1.04
a_{SO}	0.813	0.75	0.731	0.34	0.475	0.63	0.66	0.59	1.011	0.34
r_C	1.698	1.3	1.30	1.34	1.30	1.30	1.30	1.30	1.303	1.34
Refs.	[28]	[34]	[29]	[27]	[30]	[35]	[31]	[36]	[32]	[27]

TABLE I: The parameters of the OP used in the calculation of the differential cross sections of the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction.

The quality of the elastic scattering fit in the entrance $(^{24}\mathrm{Mg}+d)$ and exit $(^{25}\mathrm{Mg}+p)$ channels was assessed by comparing the calculated and experimental DCS measured by us in the entrance channel $d+{}^{24}\mathrm{Mg}$ at $E_d=14.5$ MeV [33]), as well as in the exit channel $p+{}^{25}\mathrm{Mg}$ at an energy close to the energies in the output channels [37]. Fig. 2) shows that in the region of the forward angles, all the used OPs satisfactorily describe the elastic scattering in both the entrance and exit reaction channels.

First, the peripheral nature of proton transfer in the reaction channels under consideration was verified. Typically, within the MDWBA method, this can be done by studying the behavior of the test function $R(E_i,\theta;b_{yn},b_{\mathrm{A}n})=R(b_{^{24}\mathrm{Mg}+n})=R(b)$ (2) or the dependence of the calculated DCS value at the main diffraction maximum on the cutoff radius of the radial overlap function.

This is important because MDWBA is only applicable when the reaction is predominantly peripheral. Furthermore, the uncertainty in the extracted ANC $C^2_{^{24}\mathrm{Mg}+n}$ value, due to the ambiguity of the model parameters for the proton binding potential in

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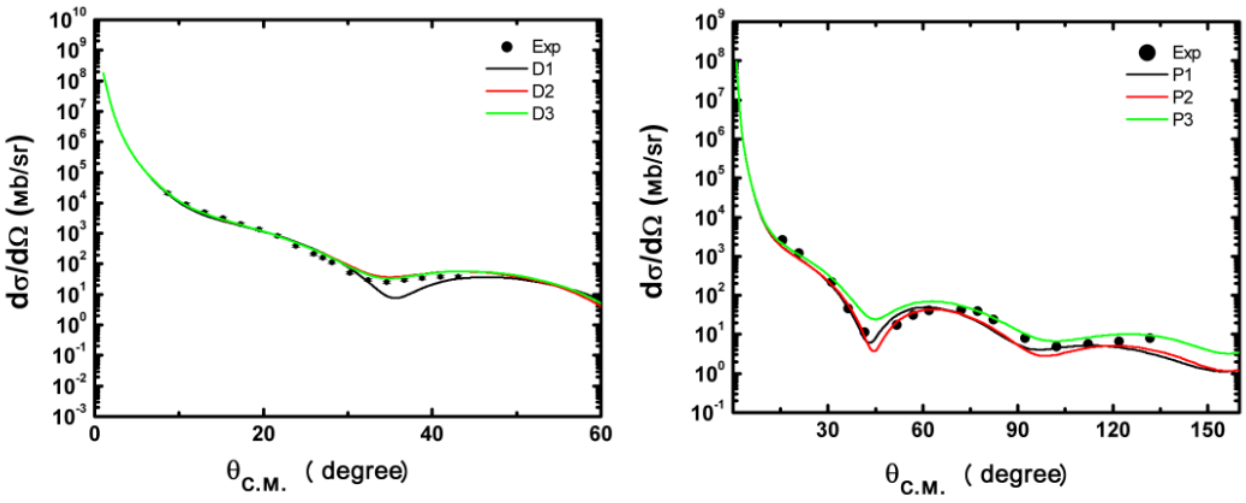


FIG. 2: Angular distribution of elastic scattering of deuterons on the ^{24}Mg nucleus (left) at an energy of $E_d = 14.5$ MeV (our data, see also [33] and protons on the ^{25}Mg nucleus at an energy of $E_p = 17.5$ MeV [37]. Squares are experimental elastic scattering values (experimental errors are smaller than their sizes). The curves are calculations using the entrance and exit OPs, accordingly, from the sets pointed at the picture.

the resulting nucleus (usually Woods-Saxon (W-S) potential), is estimated through the spread $\delta R = 0.5 \times (R^{\max} - R^{\min})/R^{\text{aver}}$ of $R(b)$ values.

Obviously, the spread of the $R(b)$ function depends on the range of variation of the b_{An} argument, which in turn is determined by the variation interval of the geometric parameters of W-S binding potential. The reference point for a physically reasonable interval of values of the parameters r_0 and a can be the estimates of the RMS of the nucleus A (here ^{25}Mg). Taking into account such evaluations (see for example [38] and references therein), we vary the parameters r_0 and a of the W-S potentials for ^{25}Mg states in the intervals $1.10 \leq r_0 \leq 1.40$ fm and $0.50 \leq a \leq 0.80$ fm. The test was carried out by adjusting the depth of the W-S potential for each pair of r_0 and a to correctly reproduce the proton binding energy.

However, it should be noted that the spread of the $R(b)$ values depends significantly on the choice of the OP parameters in both the entrance and exit channels. Thus, for a neutron transfer to the ground state $(5/2^+)$ of the ^{25}Mg nucleus, the spread $\delta R = 0.5 \times (R^{\max} - R^{\min})/R^{\text{aver}}(\%)$ of the $R(b)$ function when using set 1 of the OP ($\delta R = 12\%$, minimum value among all OP sets) is half the spread for set 2 ($\delta R = 24\%$, maximum value) at the emission angle corresponding to the maximum in the angular distribution of the DCS. Almost the same situation occurs when the transfer of a neutron to the 2$^{\text{nd}}$ excited state $(3/2^+)$. For the transition of a neutron to the 1$^{\text{st}}$ excited state $(1/2^+)$, this difference is 0.7 times for the minimum emission angle in measurements. Note that the pointed sets of OPs provide approximately the same description of the experimental DCS in the region of normalization angles and fitting in the entire range of measurements according to the χ^2 criterion.

Moreover, the spread of the $R(b)$ function depends on the shift of the emission angle value from the main maximum of the angular distribution, which is most significant at zero angular momentum of the transferred neutron. Thus, when a neutron is transferred to the first excited state ($1/2^+$, $l_n = 0$), the spread δR increases by a factor of 1.4 for a proton emission angle of $\theta = 8^\circ$ compared to zero angle (the position of the maximum of the angular distribution), and rapidly increases with θ increasing.

As a whole, for all sets of OPs, the variations δR in the values of $R(b)$ functions lie between 9% - 24% for the neutron transfer to the considered ^{25}Mg states. It follows that, despite the noticeable sensitivity of the $R(b)$ function to the choice of the OP, their variations are smaller or comparable to experimental errors. (see Fig. 3). Consequently, peripheral proton transfer, at least within the main maximum of the DCS of the indicated reactions, dominates.

As can be seen from the figures, the DCSs calculated within the framework of the MDWBA reproduce well the experimental data in the region of the main peak of the angular distribution.

The squared ANC values were extracted by norming the calculated curves for each OP set using the relation (1). To do this, the calculated angular distribution is adjusted to the experiment using several experimental values of DCS in the angular region of the main maximum (or as close as possible to the maximum). The obtained values of the squares of the ANC were found as weighted averages with weighting coefficients inverse to the relative standard deviations of the calculated DCS from the experimental ones for each set of OP. Fig. 4 illustrates the spread of the ANCs corresponding to each experimental θ point within the main peak of the angular distribution when using set 1 of the OP parameters in the calculations. The solid lines show the weighted average values of the ANC square, and the gray bands associated with the weighted uncertainties.

The resulting values of ANC squares are presented in Table II along with the previously obtained data. The total errors were

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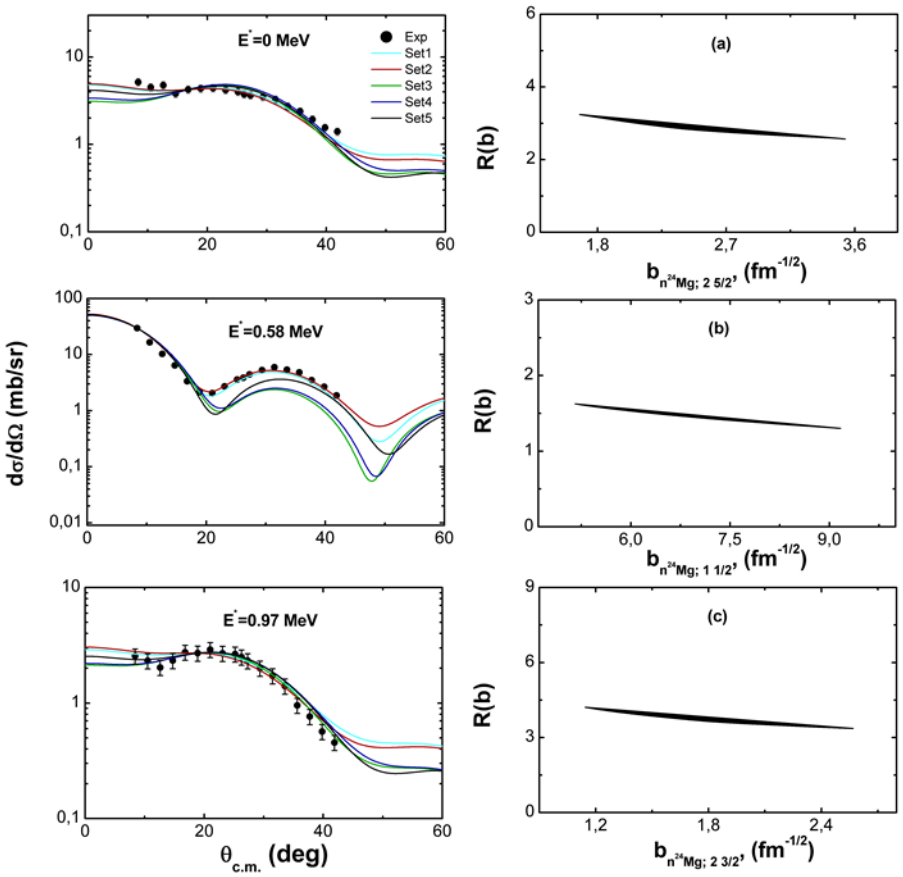


FIG. 3: Angular distribution of the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction at an energy of $E_d = 14.5$ MeV (left panel) and the range of the function $R(b)$ values. Squares are the experimental points, curves are the calculated DCS calculated with different sets of OP.

taken into account in a statistically independent manner including the spread of the calculated DCS values, conditioned by the ambiguity of the OP parameters, the range of the test functions $R(b)$ values as well as the experimental errors and the error in the ANC $(C_{pn;0\frac{1}{2}})^2$ value.

$C^2_{n^{24}\mathrm{Mg};2\frac{5}{2}}$ [fm^{-1}]	$C^2_{n^{24}\mathrm{Mg};0\frac{1}{2}}$ [fm^{-1}]	$C^2_{n^{24}\mathrm{Mg};2\frac{3}{2}}$ [fm^{-1}]	Ref
1.64 ± 0.38	22.5 ± 4.6	0.81 ± 0.19	This work
1.88; 1.64	20.4	0.67	[17]

TABLE II: Resulting values of the ANC squares for the $^{25}\mathrm{Mg} \to {}^{24}\mathrm{Mg} + n$ configurations. Also the corresponding values from the Ref [17] are presented.

The obtained values of the ANC squares are generally in good agreement with the results presented in the Ref [17]. For the ground state, this value obtained in [17] from an analysis of the more peripheral reaction $^{25}\mathrm{Mg}(d,t)^{24}\mathrm{Mg}$, is notably larger, but agrees within the error limits with the value obtained here. Note, however, that the ANCs for excited states of the $^{25}\mathrm{Mg}$ nucleus cannot be obtained in the (d,t) reaction. The other ANCs for $^{25}\mathrm{Mg} \to {}^{24}\mathrm{Mg} + n$ cited in Table II were estimated in [17] by the relation between ANC C^2 and spectroscopic factor S via the single particle ANC b: $C^2 = S \times b^2$ [26]. At that the b value was found at "standard" r_0 and a values in the neutron binding W-S potential without the peripherality evaluation. Surprisingly, they agree rather well with the values obtained here.

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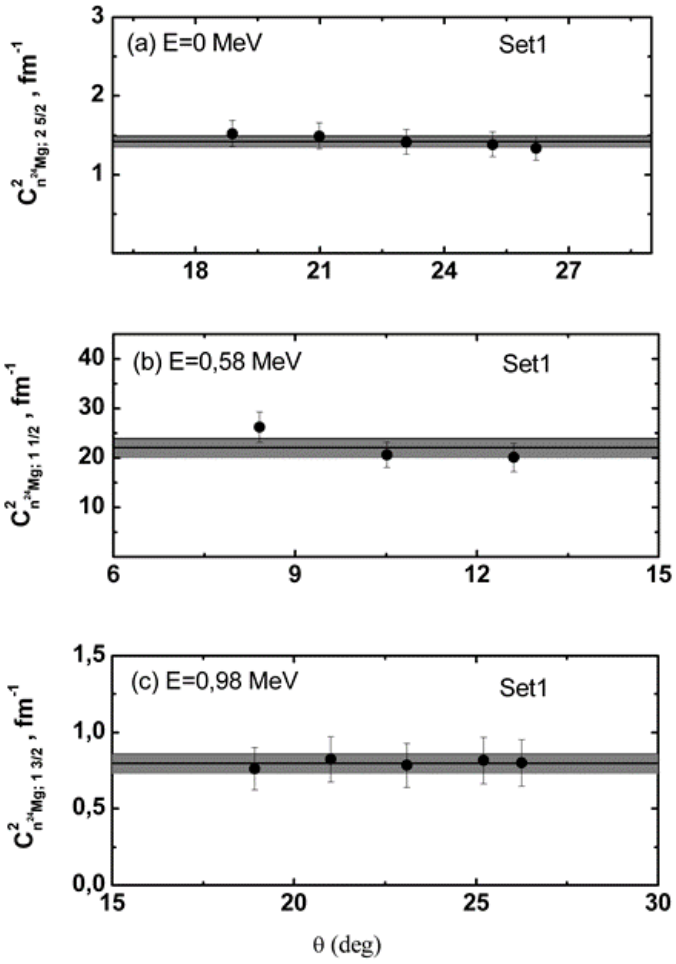


FIG. 4: The values of ANC squares extracted at each experimental point of angles when the set 1 of the OP. Solid lines are the weighted average values of the ANC squares. The bands are the corresponding weighted uncertainties.

IV. SUMMARY AND CONCLUSION

The angular distributions of the neutron transfer $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction leading to the ground and first two excited states of the $^{25}\mathrm{Mg}$ nucleus have been analyzed within the modified distorted wave born approximation. The peripheral nature of the reaction under consideration was verified and it was established that the assessment of peripherality is rather sensitive to the ambiguity of the OP parameters and to the angles for which the normalization of the calculated DCS to the experiment is performed. The results of the analyses showed that in all cases, peripheral neutron transfer dominates in the region of the main maximum of angular distributions. Thus, the (d,p) reaction can be used with some caution to extract the ANC values. The new values of the asymptotic normalization coefficients for the $^{24}\mathrm{Mg}+n\rightarrow{}^{25}\mathrm{Mg}$ ground and first two excited states with correctly evaluated uncertainties have been extracted from the experimental DCS of the $^{24}\mathrm{Mg}(d,p)^{25}\mathrm{Mg}$ reaction measured at deuteron energy of 14.5 MeV.

The obtained ANC values are planned to use for calculation the contribution of direct radiative neutron capture to the astrophysical S factor of the $^{24}\mathrm{Mg}(n,\gamma)^{25}\mathrm{Mg}$ at low energies.

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REFERENCES

[1] U. Sheib *et al*., Nucl. Phys. A **203** (1973) 177.
[2] A.J. Howard *et al*., Nucl. Phys. A **528** (1991) 298.
[3] J.T. Uchiyama *et al*., Phys. Rev. C **41** (1990) 862.
[4] A.M. Mukhamedzhanov *et al*., Phys. Rev. C **77** (2008) 051601(R).
[5] G.W. Bailey *et al*., Phys. Rev. Lett. **117** (2016) 162.
[6] G.W. Bailey *et al*., Phys. Rev. C **95** (2017) 024603.
[7] Z.H. Liu *et al*., Phys. Rev. C **64** (2001) 034312.
[8] T.L. Belyaeva *et al*., Phys. Rev. C **98** (2018) 034602.
[9] H.M. Xu *et al*., Phys. Rev. Lett. **73** (1994) 2027.
[10] C. Sneden *et al*., Annu. Rev. Astron. Astrophys. **46** (2008) 241.
[11] R. Middleton, S.Hunds, Nucl. Phys. A **34** (1962) 404.
[12] B. Gujes, Phys. Rev. **136** (1964) 1305.
[13] K. Hosono, J. Phys. Soc. Japan **25** (1968) 36.
[14] H. Schultz *et al*., Nucl. Phys. A **159** (1970) 3249.
[15] V.V. Tokarevsky, V.N. Shcherbin, Yad. Fiz. **22** (1975) 917 (in russian).
[16] J. Bommer *et al*., Nucl. Phys. A **263** (1976) 93.
[17] S.V. Artemov *et al*., Int. Jour. Mod. Phys. E **19** (2010) 1102.
[18] O.R. Tojiboev *et al*., Acta Phys. Pol. B Proc. Supp. V **14** (2021) 665.
[19] S.V. Artemov *et al*., Izv. NAN RK, Ser. f.-m. №6 (2006) 61 (in russian).
[20] S.V. Artemov *et al*., Pribori i texnika eksperimenta **№1** (2009) 168 (in russian).
[21] Artemov S.V. *et al*., Svidetelstvo ob ofitsialnoy registratsii programmi dlya elektronno-vichislitelnix mashin **№ DGU 02401** "Programma avtomaticheskogo chteniya i prosmotra dvumernix matris Win_EDE" (in russian).
[22] A.M. Mukhamedzhanov *et al*., Phys. Rev. C **56** (1997) 1302.
[23] O.R. Tojiboev *et al*., Phys. Rev. C **94** (2016) 054616.
[24] S.V. Artemov *et al*., Eur. Phys. J. A **58** (2022) 24.
[25] Kunz P D, code DWUCK5, `http://spot.colorado.edu/~kunz/DWBA.html`.
[26] L.D. Blokhintsev *et al*., Fiz. Elem. Chas. At. Yad. **8** (1977) 1189 [Sov. J. Part. Nucl. **8** (1977) 485].
[27] C.M. Perey and F.G. Perey, At. Data Nucl. Data Tables **17** (1976) 1.
[28] Yinlu Han *et al*., Phys. Rev. C **74** (2006) 044615.
[29] F. Hinterberger *et al*., Nucl. Phys. A **111** (1968) 265.
[30] G. Perrin *et al*., Nucl. Phys. A **282** (1977) 221.
[31] W.W. Daehnick *et al*., Phys. Rev. C **21** (1980) 2253.
[32] Haixia An and Chonghai Cai, Phys. Rev. C **73** (2006) 054605.
[33] S.V. Artemov *et al*., Dokl. Akad. Nauk Uzb. **3** (2018) 38 (in russian).
[34] D. Becchetti. G.W. Greenlees, Phys. Rev. V **182** (1969) 1190.
[35] R.L. Varner *et al*., Phys. Rep. **201** (1991) 57.
[36] A.J. Koning, Nucl. Phys. A **713** (2003) 231.
[37] G.M. Crawley, G.T.Garvey, Phys. Rev. V **167** (1968) 1070.
[38] I. Angeli, K.P. Marinova, At. Data Nucl. Data Tables **99** (2013) 69.

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