Physics Letters B 790 (2019) 308–313

Contents lists available at ScienceDirect

Physics Letters B

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Proton–neutron asymmetry independence of reduced single-particle strengths derived from (p,d) reactions

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ARTICLE INFO

Article history:
Received 3 October 2018
Received in revised form 23 December 2018
Accepted 17 January 2019
Available online 23 January 2019
Editor: V. Metag

Keywords:
(p,d) reactions
Spectroscopic factors
Quenching factors
Reduced single-particle strength

ABSTRACT

An overall reduction factor (ORF) is introduced for studying the quenching of single-particle strengths through nucleon transfer reactions. The ORF includes contributions of all the probed bound states of the residual nucleus in a transfer reaction and permits a proper comparison with results of inclusive knockout reactions. A systematic analysis is made with 103 sets of angular distribution data of (p,d) reactions on 21 even–even targets with atomic mass numbers from 8 to 56 using the consistent three-body model reaction methodology proposed in Lee et al. (2006) [25]. The extracted ORFs are found to be nearly independent on the proton–neutron asymmetry, which is different from the systematics of inclusive knockout reactions but is consistent with the recent measurement of (d,t), $(d,{}^3\mathrm{He})$, $(p,2p)$, and (p,pn) reactions on nitrogen and oxygen isotopes and *ab initio* calculations.

1. Introduction

Quenching of single-particle strength (SPS) is an important subject in nuclear physics studies [1–13]. It was firstly observed in $(e,e'p)$ reactions on some stable nuclei [14–16]. Spectroscopic factors (SFs) deduced from those experimental data are found to be 40–60% lower than the sum-rule limit given by independent-particle shell model. Such quenching of SPS has been attributed to some profound questions in nuclear physics, such as short- and medium-range nucleon–nucleon correlations and long-range correlations from coupling of the single-particle motions of the nucleons near the Fermi surface and the collective excitations [14,17,18].

Systematic studies of nucleon knockout reactions performed with radioactive nuclei on light targets (Be and C) suggest that the quenching factors, or the reduction factors (RFs), R_s, of the SPS carry a strong dependence on the proton–neutron asymmetry, ΔS, of the projectile nuclei [3,9]. ΔS is defined to be the difference between the neutron and proton separation energies (S_n and S_p, respectively) of the particles concerned, i.e., $\Delta S = S_n - S_p$ for neutron removal and $\Delta S = S_p - S_n$ for proton removal. (In practice, effective ΔS values are defined, which take into account the excitation energies of the reaction residues [9,19].) The R_s values deduced from knockout reactions are found to be close to unity when the removed nucleons are weakly-bound ($\Delta S \lesssim -20$ MeV) and are very small when they are strongly-bound ($\Delta S \gtrsim 20$ MeV). However, there is no clear evidence for such strong dependence in the R_s values obtained from systematic studies of transfer reactions, such as $(p,d)/(d,p)$ [6,7] and $(d,t)/(d,{}^3\mathrm{He})$ reactions [8,13]. Such discrepancy also exists in structure theory. By solving the Pinkston–Satchler inhomogeneous equation with correlation-dependent effective nucleon–nucleon interactions, N.K. Timofeyuk found that strong ΔS dependence of the quenching factors exist with light exotic nuclei [4]. But such dependence was not found to exist in some *ab-initio* calculations [10,20,21]. Recently, the RFs are also found to be independent on ΔS in $(p,2p)$ and (p,pn) reactions on nitrogen and oxygen isotopes [10–12].

It is still an open question about why the dependence on ΔS differ systematically between the RFs obtained from knockout and transfer reactions. One important thing to notice is that the R_s values are defined differently in these two types of reactions. In knockout reactions, such as those compiled in Ref. [9], the experimental one-neutron removal cross sections, σ_{-1n}, are mostly inclusive, that is, contributions from all the bound excited states of the

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https://doi.org/10.1016/j.physletb.2019.01.034

knockout residues were included in the measured data. Therefore, σ_{-1n} were calculated as sums of the single-particle cross sections [19]:

$$\sigma_{-1n} = \sum_{nlj} \left[\frac{A}{A-1}\right]^{N_{nl}} C^2S(J^\pi, nlj)\sigma_{\rm sp}(nlj, S_n) \quad (1)$$

where $C^2S(J^\pi, nlj)$ are the shell model SFs, which depend on the spin-parties of the core states, J^π, and the quantum numbers of the single-particle states of the removed nucleon, nlj. The factors $[A/(A-1)]^{N_{nl}}$ are for the center-of-mass corrections to the shell model SFs, where N_{nl} is the number of the oscillator quanta associated with the major shell of the removed particle, which depends on the node number n and orbital angular momentum l, and A is the mass number of the composite nucleus [9,22]. For the sake of clarity, we designate $\left[\frac{A}{A-1}\right]^{N_{nl}} C^2S(J^\pi, nlj)$ by $\mathrm{SF^{th}}$, which stands for a theoretical spectroscopic factor. The single-particle cross sections, $\sigma_{\rm sp}$, which depend on the quantum numbers (nlj) and the binding energies of the removed nucleons, include contributions from both the stripping and diffraction dissociation mechanisms [23] and are calculated using the eikonal model assuming unit SFs. The RFs in knockout reactions, $R_s^{\rm ko}$, are defined as the ratio between the experimental and theoretical one-neutron removal cross sections, $\sigma_{-1n}^{\rm exp}$ and $\sigma_{-1n}^{\rm th}$, respectively:

$$R_s^{\rm ko} = \frac{\sigma_{-1n}^{\rm exp}}{\sigma_{-1n}^{\rm th}} = \frac{\sigma_{-1n}^{\rm exp}}{\sum_{nlj} \mathrm{SF^{th}}(J^\pi, nlj)\sigma_{\rm sp}(nlj, S_N)}. \quad (2)$$

In a transfer reaction, the reduction factor $R_s^{\rm tr}$ was used to be defined as the ratio between the experimental and theoretical SFs [6,24–26]:

$$R_s^{\rm tr} = \frac{\mathrm{SF^{exp}}(J^\pi, nlj)}{\mathrm{SF^{th}}(J^\pi, nlj)}, \quad (3)$$

where the experimental spectroscopic factor, $\mathrm{SF^{exp}}$, is obtained by matching the theoretical differential cross sections by the experimental ones, usually at the angles where the experimental cross sections are the largest:

$$\mathrm{SF^{exp}} = \left(\frac{d\sigma}{d\Omega}\right)^{\rm exp} / \left(\frac{d\sigma}{d\Omega}\right)^{\rm th}. \quad (4)$$

The theoretical transfer cross sections are also calculated assuming the SFs being unity. Combining Eq. (4) and Eq. (3), one gets the RF associated with a specific channel (J^π, nlj) of transfer reaction:

$$R_s^{\rm tr}(J^\pi, nlj) = \frac{\left[\frac{d\sigma}{d\Omega}(J^\pi, nlj)\right]^{\rm exp}}{\mathrm{SF^{th}}\left[\frac{d\sigma}{d\Omega}(J^\pi, nlj)\right]^{\rm th}}. \quad (5)$$

Comparisons between the so-defined RFs in knockout and transfer reactions, in Eqs. (2) and (5), respectively, have been made in, *e.g.*, Refs. [6,8,13,25]. However, the difference in Eqs. (2) and (5) is obvious. The reduction factor defined in Eq. (2) for an inclusive knockout reaction corresponds to, in principle, all the bound states of the knockout residue. Such RFs represent the *averaged* deviation of the experimental SPSs from the theoretical ones. On the other hand, the reduction factor defined in Eq. (5) corresponds to only one state (usually being the ground state) of the residual nucleus. One may argue that the two definitions of RFs correspond to different quantities and should not be compared directly.

A proper comparison between the RFs from transfer and knockout reactions may be made by assuming the transfer cross sections to be measured inclusively as well. In such a case, similar to Eq. (2), one can define an *overall* reduction factor (ORF) for a transfer reaction:

$$R_s^{\rm tr} = \frac{\sum_i \left(\frac{d\sigma}{d\Omega}\right)_i^{\rm exp}}{\sum_i \mathrm{SF}_i^{\rm th}\left(\frac{d\sigma}{d\Omega}\right)_i^{\rm th}} = \frac{\sum_i \mathrm{SF}_i^{\rm exp}\left(\frac{d\sigma}{d\Omega}\right)_i^{\rm th}}{\sum_i \mathrm{SF}_i^{\rm th}\left(\frac{d\sigma}{d\Omega}\right)_i^{\rm th}}, \quad (6)$$

where the sums run over all the measured bound states of the residual nucleus. If we define a coefficient A_i for each state by:

$$A_i = \left(\frac{d\sigma}{d\Omega}\right)_i^{\rm th} / \left[\sum_i \mathrm{SF}_i^{\rm th}\left(\frac{d\sigma}{d\Omega}\right)_i^{\rm th}\right], \quad (7)$$

and assign an uncertainty for each $\mathrm{SF}_i^{\rm exp}$ by $\Delta_{\mathrm{SF}_i^{\rm exp}}$, the uncertainty in $R_s^{\rm tr}$, which is now $R_s^{\rm tr} = \sum_i \mathrm{SF}_i^{\rm exp} A_i$, can be expressed as:

$$\Delta R_s^{\rm tr} = \sqrt{\sum_i A_i^2 \Delta^2_{\mathrm{SF}_i^{\rm exp}}}. \quad (8)$$

As usual, R_s in Eq. (6) and A_i in Eq. (7) are evaluated at the peaks of the angular distributions.

The cross sections from which the RFs were used to be extracted are integrated and differential for knockout and transfer reactions, respectively. This may be another source of the discrepancy between the RFs from these two types of reactions because reaction theory can not always describe the angular distributions of transfer reactions perfectly well. In view of this problem, we introduce an ORF for integrated transfer cross sections, $R_s^{\rm tr,int}$:

$$R_s^{\rm tr,int} = \frac{\sum_i \sigma_i^{\rm exp,int}}{\sum_i \mathrm{SF}_i^{\rm th}\sigma_i^{\rm th,int}}, \quad (9)$$

where $\sigma_i^{\rm exp,int}$ and $\sigma_i^{\rm th,int}$ are the integrated experimental and theoretical transfer cross sections for each bound state i of the reaction residue. In this work, $\sigma_i^{\rm exp,int}$ are obtained by fitting the angular distribution data with Legendre polynomials and integrating the resulting functions within the angular ranges covered by the experimental data. The same angular ranges are used for $\sigma_i^{\rm th,int}$.

In order to see how the ORFs defined in Eqs. (6) and (9) depend on the proton–neutron asymmetry, we analyze 103 sets of angular distributions of (p,d) reactions on 21 even–even nuclei, namely, ^{8}He, ^{12,14}C, ^{14,16,18}O, ^{22}Ne, ^{26}Mg, ^{28,30}Si, ^{34}S, ^{34,36,38}Ar, ^{40,42,44,48}Ca, ^{46}Ar, ^{46}Ti, and ^{56}Ni. The choice of target nuclei are mainly limited by the availability of the experimental data. Even–even targets are chosen by practical reasons. In (p,d) reactions with an even–even target, which has nil spin, there is only one single-particle state corresponds to a state of the residue, which makes the theoretical analysis much easier than for (p,d) reactions on a target with nonzero spin. Our analysis take into account several $(2\sim4)$ bound states of the residual nuclei except for the ^{8}He$(p,d)^{7}$He and ^{14}O$(p,d)^{13}$O reactions, which have only ground state data available. The ΔS values range from -22.3 MeV to 18.6 MeV for these reactions.

2. Data analysis

It is well-known that reaction theories have been very successful in describing the main features of the angular distributions of transfer cross sections. But the amplitudes of these cross sections suffer from considerable uncertainties and the resulting SFs can be

uncertain by around 30% even if the statistical errors of the experimental data are reported small [24–27]. Besides the uncertainties in experimental data [27] and in the choice of reaction models [28,29], the uncertainties of the SFs are typically attributed to the ambiguities in the entrance- and exit-channel optical model potentials (OMPs) and the single-particle potential (SPP) parameters. In view of such problems, the authors in Ref. [25] proposed a consistent three-body model reaction methodology (TBMRM) for the analysis of (p,d) and (d,p) reactions. Such a methodology consists of adopting the zero-range Johnson–Soper adiabatic wave approximation (ZR-ADWA) for $(p,d)/(d,p)$ reactions [30], of constraining the SPP parameters using modern Hartree–Fock calculations, and of calculating the nucleon-target OMPs by folding the effective JLM nucleon–nucleon interaction [31] with the nucleon density distributions from the same Hartree–Fock calculations.

The details of the TBMRM can be found in Ref. [25]. We hereby only briefly describe how it is applied in this work. With the ZR-ADWA, we only need OMPs for the p-A, p-B, and n-B systems in a $A(p,d)B$ reaction. These potentials are obtained by folding the effective JLM nucleon–nucleon interaction with nucleon density distributions given by Hartree–Fock calculations. The real and imaginary parts of these nucleon OMPs are scaled with the conventional factors $\lambda_V = 1.0$ and $\lambda_W = 0.8$ [25,32]. The p-B and n-B potentials are evaluated at half energy of the deuteron in the exit channel. The consistent TBMRM adopts the same procedure as that used in the systematic analysis of knockout reactions [3,9] for determining the geometry parameters, r_0 and a_0, of conventional Woods–Saxon potentials that generate the neutron single-particle wave functions, or overlap functions. With such a procedure, the diffuseness a_0 is fixed to be 0.7 fm. The radius parameter r_0 is adjusted so that the mean square radius of the transferred neutron orbital is $\langle r^2\rangle = [A/(A-1)]\langle r^2\rangle_{\rm HF}$, where $\langle r^2\rangle_{\rm HF}$ is the value given by HF calculations and A is the mass number of the composite nucleus. This adjustment is carried out with the separation energy given by HF calculation. The factor $[A/(A-1)]$ corrects the fixed potential center assumption used in the HF calculations. For all the cases studied in this work, the HF calculations are made with the Skyrme SkX interaction [33], which is the same as those adopted in analysis of transfer and knockout reactions in, *e.g.*, Refs. [2,3,6,9,25]. Once r_0 and a_0 are determined, the depths of the single-particle potentials are determined using the separation energy prescription with *experimental* separation energies.

The ZR-ADWA calculations are made with the zero-range normalization factor $D_0 = -122.5$ MeV fm$^{3/2}$ with a finite-range correction parameter of 0.746 fm. These parameters are compatible with the deuteron wave function with the Reid-soft-core interaction [34]. All calculations are made with the computer code TWOFNR [35]. Information of these reactions are listed in the Supplemented Materials, which include the target nuclei, the incident energies, the excited states of the residue, the nlj values of the transferred neutrons, the r_0 values confined by HF calculations, the experimental and shell model SFs, and the resulting ORFs. Recently, by a detailed analysis of (d,t) and $(d,{}^3\mathrm{He})$ reactions on ^{14,16,18}O isotopes, Flavigny et al. demonstrated that the ΔS independence of the reduction of the single-particle strengths is not affected by different choices of reaction model parameters, such as optical model potentials and overlap functions nor by choices of reaction models such as the DWBA and coupled-reaction channels [13]. We would expect that the results in this work are not affected by these choices as well.

As an example, we show the analysis of the ^{14}C$(p,d)^{13}$C reaction at an incident energy of 35 MeV [36]. The reaction residue ^{13}C has only four bound states below its particle emission threshold, which is 4.946 MeV for neutron decay. The angular distributions corresponding to these states are depicted in Fig. 1 together

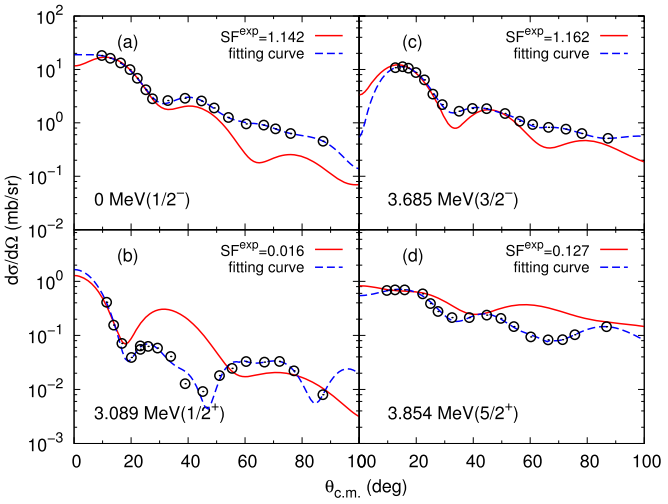

Fig. 1. Comparisons between theoretical (curves) and experimental (circles) angular distributions for the ^{14}C$(p,d)^{13}$C reaction at an incident energy of 35 MeV. Theoretical results are normalized to the experimental data with the spectroscopic factors indicated in the figures for the 0.0 MeV (a), 3.089 MeV (b), 3.685 MeV (c), and 3.854 MeV (d) states of ^{13}C. The dashed curves are results of fittings with Legendre polynomials.

Table 1
Spectroscopic factors (SF$^{\rm exp}$ and SF$^{\rm exp,int}$ from differential and integrated cross sections, respectively) extracted from the ^{14}C$(p,d)^{13}$C reaction at an incident energy of 35 MeV. Listed are the excitations energies of ^{13}C($E_{\rm ex}$), their corresponding single-particle states (nlj), the HF confined r_0 values and shell model predicted SFs (SF$^{\rm th}$).

E_x	nlj	$r_0^{\rm HF}$	SF$^{\rm exp}$	SF$^{\rm exp,int}$	SF$^{\rm th}$
0.000	$0p_{1/2}$	1.344	1.142	1.477	1.607
3.089	$1s_{1/2}$	1.250	0.016	0.006	0.024
3.685	$0p_{3/2}$	1.299	1.162	1.384	2.207
3.854	$0d_{5/2}$	1.159	0.127	0.076	0.114

with the theoretical ones, which are normalized to the former at the largest cross sections, from which we obtained the experimental SFs. One sees that the calculations reasonably reproduced the two negative-parity state data, namely, the ground- and the 3.685 MeV states with $J^\pi = \frac{1}{2}^-$ and $\frac{3}{2}^-$, respectively. Data of the other two states are not reproduced as satisfactorily but they are close to those reported in the original paper [36]. By adopting the three-body model reaction methodology [25], which defined all quantities used in $(d,p)/(p,d)$ reaction calculations without free parameters, we do not attempt to improve the reproduction to these data by adjusting any reaction calculation parameters. On the other hand, as we will see below, the contributions to the ORF from these two positive-parity states are negligible. The fit of the experimental angular distributions using Legendre polynomials are also shown in Fig. 1, from which we obtain the integrated transfer cross sections. The details of this reaction are listed in Table 1 together with the SFs from shell model calculations with the YSOX interaction [37]. The uncertainties of the extracted SFs, which contains both experimental and theoretical uncertainties, are difficult to evaluate. We adopt the global uncertainty of 20% deduced in the systematic analysis of $(d,p)/(p,d)$ reactions by Tsang et al. [27] in this work. In addition, if one takes the uncertainty induced by different choices of reaction models, which is suggested to be around 16% [28], the uncertainties of the SFs extracted from experimental data will be 26%.

With the experimental SFs extracted for each state, we apply Eq. (6) to calculate the ORF for ^{14}C from the ^{14}C$(p,d)^{13}$C reaction. The details are shown in Fig. 2, where the individual contributions of the terms in the numerator of the right hand side of Eq. (6) are

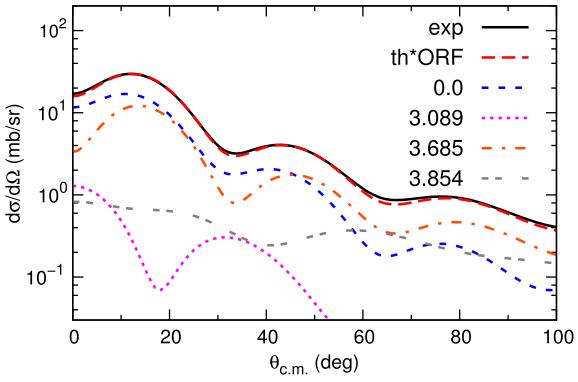

Fig. 2. Angular distributions for the determination of the ORF from the $^{14}C(p,d)^{13}C$ reaction at 35 MeV. Shown are curves for the summed cross sections in the numerator (solid) and the denominator (dashed) of Eq. (6) and for the 0.0 MeV (short dashed), 3.089 MeV (dotted), 3.685 MeV (dash-dotted), and 3.854 MeV (double-dashed) MeV states of ^{13}C.

shown as short dashed, dotted, dash-dotted, and double-dashed curves and their summed experimental angular distributions are plotted as the solid curve. The corresponding individual contributions in the denominator are not shown for the sake of clarity. Their sums are shown as the dashed curve after being normalized to the summed experimental cross sections at $\theta_{\rm c.m.} = 12$ degrees. This results in an ORF of $R_s^{\rm tr} = 0.627 \pm 0.113$. Our previous statement that the contributions of the two positive-parity states to the ORF are negligible becomes obvious in this figure. The uncertainty of this R_S value is evaluated with Eq. (8). The ORF from integrated cross sections evaluated with Eq. (9) is $R_s^{\rm tr,int} = 0.749 \pm 0.132$. Their averaged values, $\langle R_s^{\rm tr} \rangle$ and $\langle R_s^{\rm tr,int} \rangle$, of measurements at three incident energies are 0.566 ± 0.063 and 0.606 ± 0.067, respectively.

Similar analysis have been made for all the other reactions. Details of these reactions can be found in the Supplemental Materials. The results are plotted in Fig. 3 against their corresponding effective proton–neutron asymmetry $\Delta S^{\rm eff} = S_n - S_p + \bar{E}_f$ [19], where $\bar{E}_f$ is the effective final state excitation energy, which is, similar as that defined in Refs. [9,19] for knockout reactions, an average of the excitation energies of each state weighted by the corresponding integrated transfer cross sections.

Although obtained using the consistent three-body model reaction methodology with which all reactions are analyzed with the same procedure without free parameters, the ORFs and their averaged values still scatter considerably in the $\langle R_s^{\rm tr} \rangle$-$\Delta S^{\rm eff}$ plot. Results of the systematic analysis of knockout reactions in Ref. [9] suggest that the RFs $R_s^{\rm ko}$ depend linearly on $\Delta S^{\rm eff}$: $R_s^{\rm ko} = -1.46 \times 10^{-2} \times \Delta S^{\rm eff} + 0.596$, which is obtained by fitting the data in Fig. 1 of Ref. [9]. We also assume linear dependence of ORFs on the $\Delta S^{\rm eff}$ values in transfer reactions: $R_s^{\rm tr} = a \times \Delta S^{\rm eff} + b$. The slope a and the parameter b are obtained by least square fitting of the scattered data in Fig. 3. These fittings are made with (i) assuming $a = -1.46 \times 10^{-2}$ MeV^{-1}, which is the same as that of knockout reactions, and letting b to vary freely, and (ii) letting both a and b to vary freely. The results are shown in Table 2 for both $\langle R_s^{\rm tr} \rangle$ and $\langle R_s^{\rm tr,int} \rangle$ and are visualized as shaded bars in Fig. 3. The widths of these bars, listed in the last column of Table 2, represent the standard deviations of the distances of the scattered points from the fitted lines. The fact that the χ^2 value associated with $a = -4.03 \times 10^{-4}$ MeV^{-1} (for $\langle R_s^{\rm tr} \rangle$) and $a = 2.39 \times 10^{-3}$ MeV^{-1} (for $\langle R_s^{\rm tr,int} \rangle$) are considerably smaller than that with $a = -1.46 \times 10^{-2}$ MeV^{-1} suggests that the ORFs are nearly independent on ΔS. These values of a are very close to those obtained in Ref. [11] for $(p,2p)/(p,pn)$ reactions.

Table 2
Parameters of the linear fitting of the data in Fig. 3 and their corresponding χ^2 per degree of freedom for ORFs obtained from differential and integrated cross sections, $\langle R_s^{\rm tr} \rangle$, and $\langle R_s^{\rm tr,int} \rangle$, respectively. The last column is for the standard derivations of the distances between the points and the fitted lines weighted with their error bars.

	slope	a (MeV^{-1})	b	χ^2	ΔR_s
$\langle R_s^{\rm tr} \rangle$	fixed	-1.46×10^{-2}	0.572	3.5	0.0948
	free	-4.03×10^{-4}	0.566	2.0	0.0895
$\langle R_s^{\rm tr,int} \rangle$	fixed	-1.46×10^{-2}	0.625	4.6	0.117
	free	2.39×10^{-3}	0.618	2.6	0.0960

3. Summary

In summary, to understand the reduction of the single-particle strength and its dependence on the proton–neutron asymmetry, ΔS, is an important subject in nuclear physics. The RFs that were used to be referred to are found to be defined differently in transfer and knockout reactions. The RFs defined in knockout reactions involve all the bound excited states of the reaction residues but those in transfer reactions are for each single-particle state. We define an overall reduction factor for the analysis of (p,d) reactions, which include contributions from, in principle, all the probed bound states of the residual nuclei. This permits a proper comparison between the RFs extracted from transfer and knockout reactions. A systematic analysis is made with 103 sets of angular distributions of (p,d) reactions on 21 even–even nuclei with atomic mass numbers ranging form 8 to 56 using a consistent three-body model reaction methodology. The ORFs obtained from both differential and integrated transfer cross sections are found to have nearly no dependence ΔS over a wide range of ΔS values. This is consistent with the recent measurement of (d,t), $(d,{}^3{\rm He})$, $(p,2p)$, and (p,pn) reactions on nitrogen and oxygen isotopes and *ab initio* calculations [7,8,10–12,20]. Our result suggests that the systematical discrepancy in the dependence of the RFs on ΔS obtained from transfer and knockout reactions is not due to the

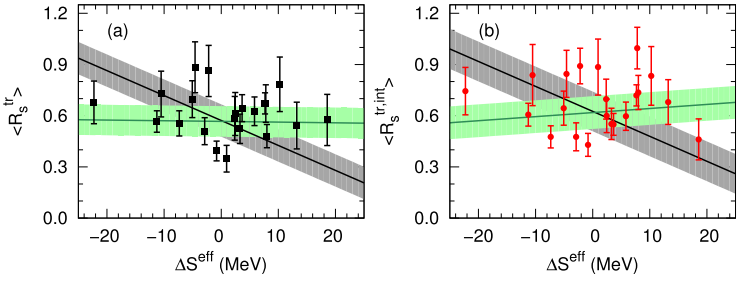

Fig. 3. Averaged ORFs from the reactions analyzed in this work (symbols) with differential (a) and integrated (b) cross sections. The green and grey bars represent the linear dependence of the ORFs on the $\Delta S^{\rm eff}$ values fitted assuming a free or a fixed slope, respectively. See the text for details.

exclusive or inclusive treatment of the experimental data. It is worthy note that although nuclear structure theories always endeavor to describe the properties of nuclei as precisely as possible, overall comparisons between bulk properties of experimental and theoretical results may also be valuable. The ORF inducted in this work for the analysis of transfer reactions would be useful for such purposes.

A relatively simple model, namely, the ADWA is used in this work in order to compare the reduction factors, now treating the (p,d) cross sections inclusively, with those obtained using the same model but treating $(p,d)/(d,p)$ reactions exclusively [24–27]. Great advances have been achieved in recent years in theories of (d,p) and (p,d) reactions that go beyond the adiabatic approximation by using, for example, the continuum discretized coupled channels method [38] or by solving the Faddeev-AGS equations [39]. Effects of nonlocality of the nucleon potentials [40, 41] and core excitations [42–44] have been investigated in details. A systematic analysis of the overall reduction factors for (p,d) reactions within a large ΔS region with these theories state-of-the-art would be interesting and may help to further understand the systematic discrepancy between results with transfer and knock-out reactions. Results of HF calculations are used in this work to constrain the parameters for the parameters, which may not be optimum for some nuclei, especially for the properties of their excited states. Further study on better constrains on the calculations of single-particle overlap functions will also be interesting and important.

Acknowledgements

This work is supported by the National Natural Science Foundation of China (Grants Nos. U1432247, 11775013, 11775004, and 11775316) and the National Key Research and Development Program (2016YFA0400502). D.Y.P. thanks Prof. J.A. Tostevin for stimulating communications in the Summer of 2015. The authors thank the anonymous referees for valuable suggestions.

Appendix A. Supplementary material

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.physletb.2019.01.034.

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