Effect of valence-core destruction in the dependence on isospin asymmetry for single-nucleon knockout "quenching" factors

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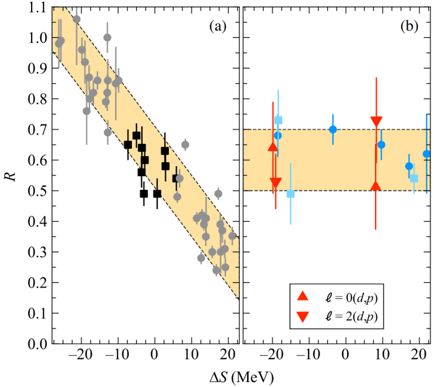
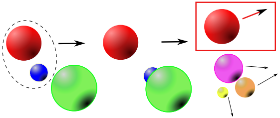
Contents

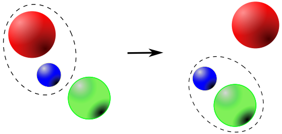
Contents

Isospin-dependence open question

Knockout: *J. A. Tostevin and A. Gade* PRC **103** 054610 (2021)
Transfer: *B.P. Kay et al* PRL **129** 152501 (2022)

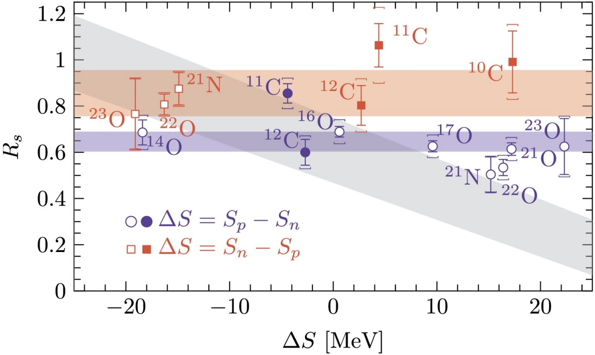


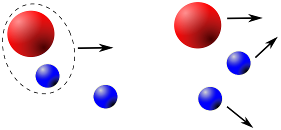




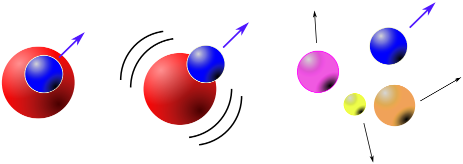
Isospin-dependence open question

$(p, 2p)$: *M. Holl et al* PLB **795** 682 (2019)





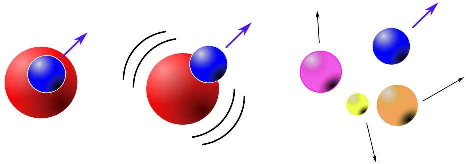
Absorption effects



- $N - T$ and $C - T$ absorption: Included in all descriptions through optical potentials
- $N - C$ absorption: In the final channel, E_{NC} is positive so open channels can lead to core destruction
- $(p, 2p)$: Included in distorted final nucleon wavefunction

$$T_{DWIA} \sim \langle \chi_{pC} \chi_{\mathbf{NC}} | V_{pN} | \chi_{pA} \phi_{NC} \rangle$$

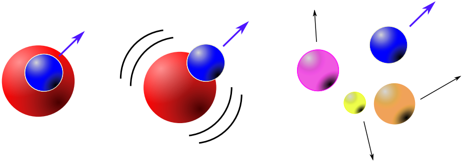
Absorption effects



- $N-T$ and $C-T$ absorption: Included in all descriptions through optical potentials
- $N-C$ absorption: In the final channel, E_{NC} is positive so open channels can lead to core destruction
- Transfer (i.e. (p,d)): Included in final ejected wavefunction $W_d \sim 2W_p$

$$T_{p,d} \sim \langle \chi_{\mathbf{dC}} \phi_d | V_{pN} | \chi_{pA} \phi_{NC} \rangle$$

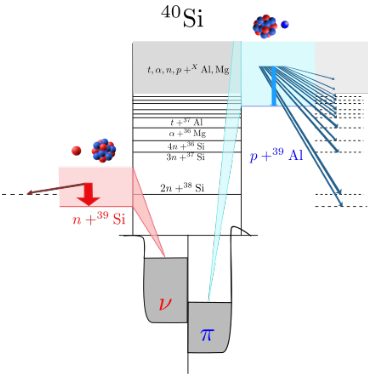
Absorption effects



- $N - T$ and $C - T$ absorption: Included in all descriptions through optical potentials
- $N - C$ absorption: In the final channel, E_{NC} is positive so open channels can lead to core destruction
- Knockout: Not included

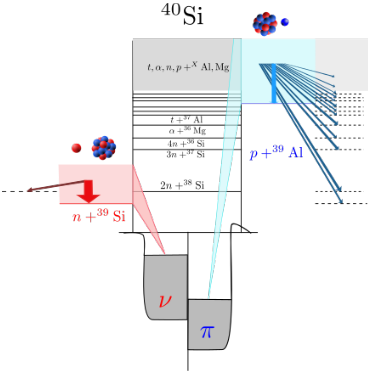
$$\sigma_{\text{str}} \sim \left\langle \phi_{NC} \middle| |S_{CT}|^2 \left(1 - |S_{NT}|^2\right) \middle| \phi_{NC} \right\rangle$$

Does N-C absorption depend on ΔS?



- Weakly-bound $N - C$: almost no non-elastic open channels (small absorption)
- Deeply-bound $N - C$: many open non-elastic channels at 0 energy (large absorption)
- Deeply-bound $N - C$ couple to higher-energy states (broad momentum distribution): even more open channels
- N-C absorption **larger** for deeply-bound nucleons

Does N-C absorption depend on ΔS?



- Already mentioned in Y. Sun *et al* PRC **93** 044607 (2016) “The experimental results are consistent with INC predictions, indicating that non-direct reaction processes, which are not considered in the eikonal model, play an important role in the deeply bound nucleon removal from asymmetric nuclei at intermediate energies.”

$N - C$ absorption in knockout (stripping)

- Standard eikonal treatment: closure to obtain a density of the bound nucleon

$$\rho(\mathbf{r_1}, \mathbf{r_2}) = \phi_b^*(\mathbf{r_1})\phi_b(\mathbf{r_2}) \int \mathrm{d}\mathbf{k}\phi_{NC}^{(-)}(\mathbf{k}, \mathbf{r_1})\phi_{NC}^{*(-)}(\mathbf{k}, \mathbf{r_2}) = \delta(\mathbf{r_1} - \mathbf{r_2})\phi_b^*(\mathbf{r_1})\phi_b(\mathbf{r_2}) = |\phi_b(\mathbf{r_1})|^2$$

- Only true for real, energy-independent V_{NC}, otherwise density is non-local
- For W_{NC} we can define an effective density for an average position

$$\rho(\mathbf{r_1}, \mathbf{r_2}) = \phi_b^*(\mathbf{r_1})\phi_b(\mathbf{r_2}) \int \mathrm{d}\mathbf{k}\chi_{NC}^{(-)}(\mathbf{k}, \mathbf{r_1})\chi_{NC}^{*(-)}(\mathbf{k}, \mathbf{r_2})$$

$$\rho^{\mathrm{eff}}(x, y) = \int \mathrm{d}\mathbf{r_1}\mathrm{d}\mathbf{r_2}\delta(x - \frac{x_1 + x_2}{2})\delta(y - \sqrt{\frac{y_1^2 + y_2^2}{2}})\rho(\mathbf{r_1}, \mathbf{r_2})$$

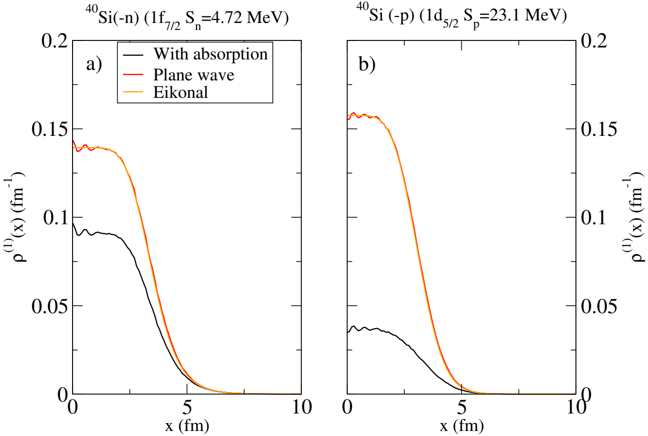
- This ρ^{eff} can be used in standard eikonal calculations

$$\sigma_{\mathrm{str}} = \int \mathrm{d}\mathbf{b} \int \mathrm{d}\mathbf{b_{NC}}\rho^{\mathrm{eff}}(x, y)|S_{CT}|^2(1 - |S_{NT}|^2)$$

Contents

Effective density

- U_{NC}: Imaginary part of Morillon potential (to avoid bound states)



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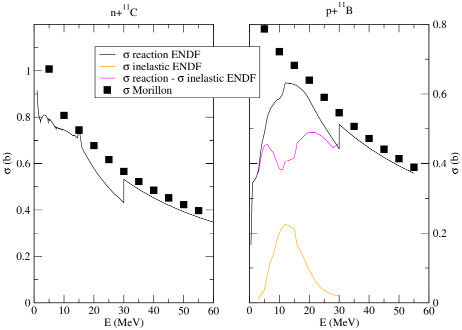
- Significant reduction, larger for deeply-bound nucleon
- Why such reduction for weakly-bound?

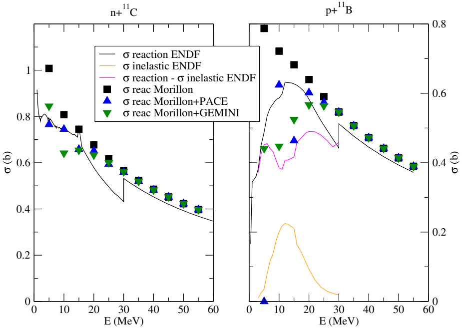
Elastic compound scattering

- Optical potential gives finite reaction cross section at low energies for weakly-bound nucleons (But there are no open channels!!!)
- This corresponds to compound nucleus which decays to elastic channel (This is not absorption)→ Must be removed from potential



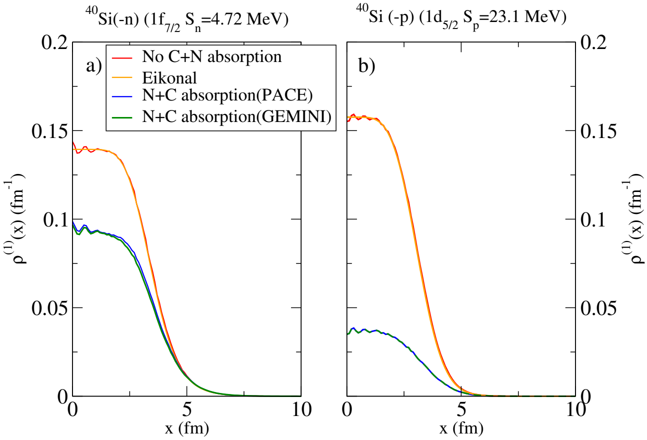
Elastic compound scattering

- Optical potential gives finite reaction cross section at low energies for weakly-bound nucleons (But there are no open channels!!!)
- This corresponds to compound nucleus which decays to elastic channel (This is not absorption)→ Must be removed from potential
- Use compound-nucleus calculation (PACE4, GEMINI) to estimate and remove flux to elastic



- Absorption unchanged for deeply-bound nucleons but severely reduced for weakly-bound at low energies
- More knowledge on low-energy exotic $C - N$ cross sections would be useful

Effective density



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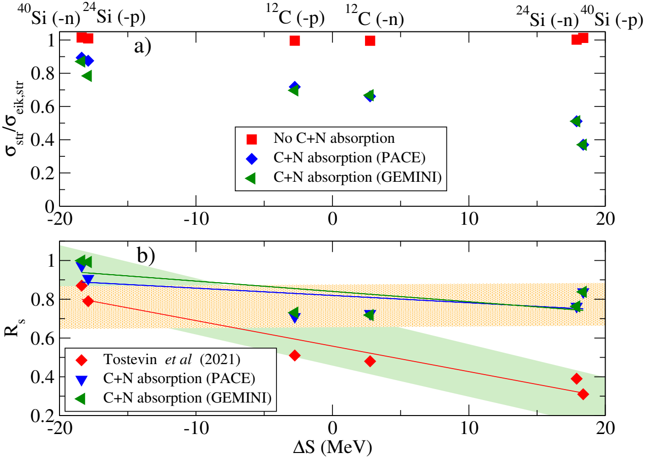
- Modification in tail (relevant for stripping)

“Quenching factors”



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- Significant flattening, consistent with transfer and (p,2p)

Problem solved? 😃

Problem solved? 😐

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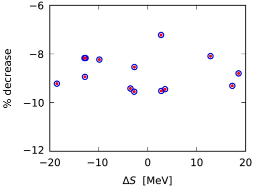
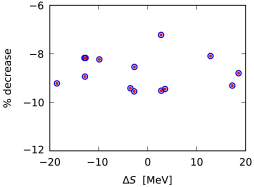


- Knockout taken as NN quasifree-collision
- No ΔS dependence
- Effect of low-energy N-C continuum?

Problem solved?

C. Bertulani PLB **846** 138250 (2023)



- Knockout taken as NN quasifree-collision
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- Effect of low-energy N-C continuum?

- Ab-initio bound-state wf?

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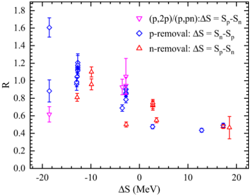
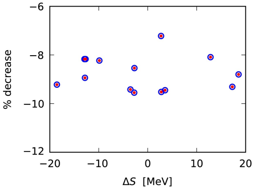


Problem solved?

C. Bertulani PLB **846** 138250 (2023)



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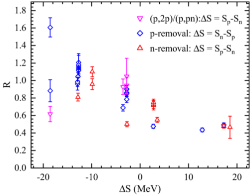
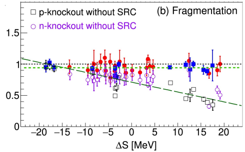
J. Li *et al* PRC **105** 024613 (2022)



- Short-Range Correlations?

J.L Rodríguez-Sánchez *et al* PLB **851** 138559 (2024)



Contents

Conclusions and outlook

- Valence-core absorption effects introduced in knockout (stripping) eikonal formalism via effective density
- Inclusion leads to significant reduction in isospin dependence of “quenching factors” (consistent with transfer and $(p, 2p)$)
- Low-energy nucleon-core cross sections would be useful to better constrain potentials
- Other analyses show different causes for isospin dependence
- Experimental results may help disentangle causes (Y. Sun *et al* PRC **93** 044607 (2016)): Products of valence-core absorption may be different from the decay of high-energy core states populated by SRC

Y. L. SUN *et al.*

TABLE I. Summary of cross sections for different exit channels using ^{14}O at 60 MeV/nucleon.

Exit channels	$\sigma_{\rm expt}$ [mb]	$\sigma_{\rm INC}$ [mb]	$\sigma_{\rm eik}$ [mb]
^{13}O	16.8(12)[a]	13	57.6
^{11}C	60(9)	66	Not applicable
^{13}O* $\rightarrow p + {}^{12}$N	<2.0(14)[b]	0	
^{13}O* $\rightarrow 2p + {}^{11}$C	<2.6(14)[b]	2.5	
^{13}O* $\rightarrow$ others	Not measured[c]	3.7	

[a]Deduced from previous measurement in Ref. [10].

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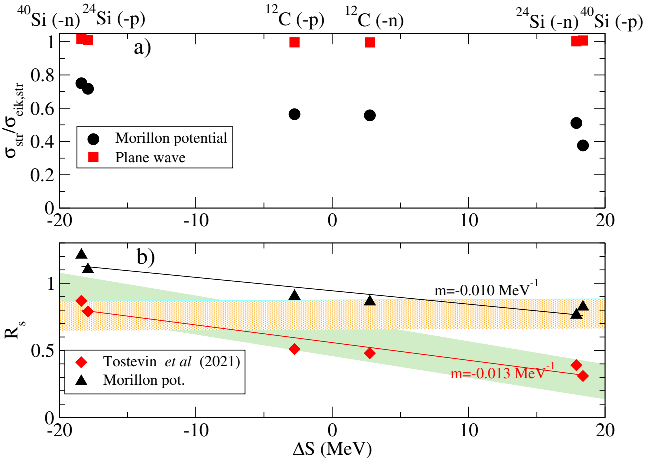
Backup: Uncorrected Morillon



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- Small reduction in slope
- $R_s > 1$ for weakly-bound nucleons... problematic