Knock–Out in Finite–Range DWBA

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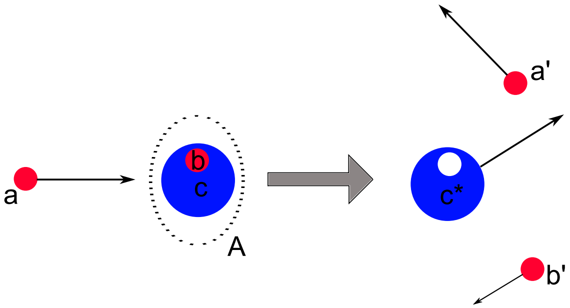
Paris, February 7th, 2013



- Reaction $A + a \longrightarrow a + b + c'$, in which the cluster b is knocked out from the nucleus A(= c + b).
- Residual nucleus c may be left in an excited state $c*$.
- Energies, scattering directions and polarization of some of the products are measured.

Motivation

Knock–Out reactions being used for

- spectroscopy of deeply bound single–particle states,
- determination of spectroscopic factors,
- probe in–medium nucleon–nucleon interaction.

We will aim at a reaction formalism that

- neatly incorporate structure ingredients in the reaction formalism,
- can be consistently applied to other reaction channels (one– and two–particle transfer) within the same structure theoretical framework,
- reproduce the absolute values of

$$\frac{d\sigma}{dE_a d\Omega_a d\Omega_b}(E_a, \hat{\mathbf{k}}'_a, \hat{\mathbf{k}}'_b)$$

Eikonal

$$\sigma_{strip} = \int d\mathbf{b} \langle \Phi | (1 - |S_n|^2) |S_c^2| | \Phi \rangle$$

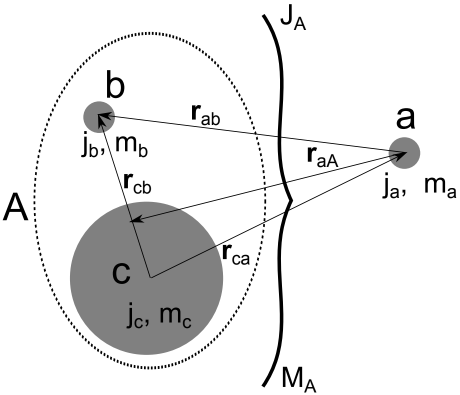
- high energy approximation,
- describe only residual nucleus observables,
- approximate description of scattering states,
- relatively easy to use,
- recent developments incorporate coupling to other channels

CDCC–CRC

$$[E - \varepsilon_n - T_R - V_{n,n}(R)]\, \chi_n(R) = \sum_{n \neq n'} V_{n,n}(R) \chi_{n'}(R)$$

- correct description of scattering states,
- coupling to other channels,
- problem to describe knock–out observables (scattering angles and momenta)

Transition Amplitude in the DWBA

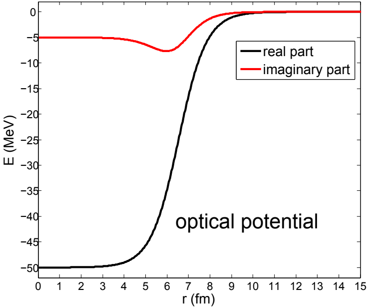


- first order in the interaction potential,
- transition amplitude explicitly in terms of knock–out observables $\mathbf{k}'_a, \mathbf{k}'_b$,
- no explicit coupling to other reaction channels.

$$T^{m'_a,m'_b}_{m_a,m_b}(\mathbf{k}'_a,\mathbf{k}'_b) = \sum_{\sigma_a,\sigma_b}\int d\mathbf{r}_{aA} d\mathbf{r}_{bc} \chi^{(-)*}_{m'_a}(\mathbf{k}'_a;\mathbf{r}_{ac},\sigma_a)\chi^{(-)*}_{m'_b}(\mathbf{k}'_b;\mathbf{r}_{bc},\sigma_b)$$

$$\times V(r_{ab},\sigma_a,\sigma_b)\chi^{(+)}_{m_a}(\mathbf{r}_{aA},\sigma_a)\psi^{l_b,j_b}_{m_b}(\mathbf{r}_{bc},\sigma_b).$$

From optical potentials $U(r) + iW(r) + V_{SO}(r)\mathbf{l}\cdot\mathbf{s}$ (with absorption and spin–orbit terms)...



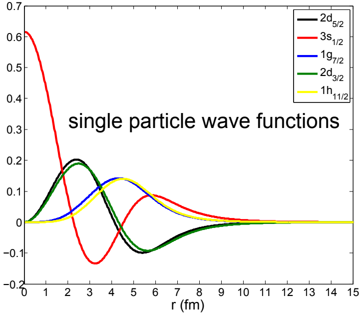
...we obtain distorted waves (after partial wave decomposition):

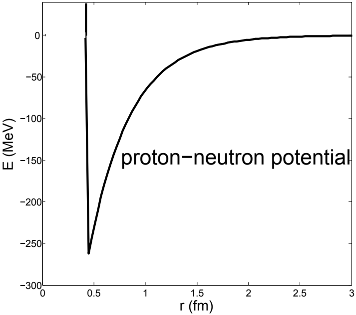
$$\chi_m^{(+)}(\mathbf{r},\mathbf{k},\sigma) = \sum_{l,m_l,j} \frac{4\pi}{kr} i^l (-1)^{l+m_l} e^{i\sigma^l} F_{l,j}(r)$$

$$\times \langle l\ m_l\ 1/2\ m | j\ m_l + m\rangle \left[Y^l(\hat{\mathbf{r}})\phi^{1/2}(\sigma)\right]^j_{m_l+m} Y^l_{-m_l}(\hat{\mathbf{k}}),$$

From Structure to Reactions (II): Wavefunctions and Interactions

From structure models (Nuclear Field Theory, Shell Model...) we get single–particle states $\psi_m^{l,j}(\mathbf{r},\sigma) = u_{l,j}\left[Y^l(\hat{\mathbf{r}})\phi^{1/2}(\sigma)\right]_m^j$, spectroscopic factors S_F and nucleon–nucleon interaction $V(|\mathbf{r}_a - \mathbf{r}_b|, \sigma_a, \sigma_b)$





Consistency between structure and reaction theory

Assume contact interaction $V(|\mathbf{r}_a - \mathbf{r}_b|, \sigma_a, \sigma_b) = T(\sigma, \sigma', \mathbf{k}, \mathbf{k}')\delta(\mathbf{r}_a - \mathbf{r}_b)$.
Matrix T fitted from N–N scattering in vacuum for asymptotic $\mathbf{k}, \mathbf{k}'$

unreliable absolute value of cross sections?

$$T^{m'_a,m'_b}_{m_a,m_b}(\mathbf{k}'_a, \mathbf{k}'_b) \sim \frac{T(\sigma, \sigma', \mathbf{k}, \mathbf{k}')}{k_a k'_a k'_b} \sum_{l_a,j_a} \sum_{l'_a,j'_a} \sum_{l'_b,j'_b} e^{i(\sigma^{l_a}+\sigma^{l'_a}+\sigma^{l'_b})}$$
$$\times \langle l'_a\ m_a - m'_a - M\ 1/2\ m'_a | j'_a\ m_a - M\rangle \langle l'_b\ m_b - m'_b + M\ 1/2\ m'_b | j'_b\ M + m_b\rangle$$
$$\times \langle l\ 0\ 1/2\ m_a | j\ m_a\rangle Y^{l'_b}_{M+m_b+m'_b}(\hat{\mathbf{k}}'_b) Y^{l'_a}_{m_a+m'_a-M}(\hat{\mathbf{k}}'_a) \mathcal{I}_{ZR}(l_a, l'_a, l'_b, j_a, j'_a, j'_b),$$

where the 1–dimensional integral to evaluate for each $\{l_a, l'_a, l'_b, j_a, j'_a, j'_b\}$ is

$$\mathcal{I}_{ZR}(l_a, l'_a, l'_b, j_a, j'_a, j'_b) = \int dr\, u_{l_b,j_b}(r) F_{l_a,j_a}(\tfrac{c}{A} r) F_{l'_a,j'_a}(r) F_{l'_b,j'_b}(r)/r.$$

Assume an interaction separable in spin/spatial coordinates
$V(|\mathbf{r}_a - \mathbf{r}_b|, \sigma_a, \sigma_b) = v((|\mathbf{r}_a - \mathbf{r}_b|) v_\sigma(\sigma_a, \sigma_b)$.
The 3–dimensional integral to be evaluated now is

$$\mathcal{I}(l_a, l'_a, l'_b, j_a, j'_a, j'_b, K) = \int dr_{aA} dr_{bc} d\theta r_{aA} r_{bc} \frac{\sin\theta}{r_{ac}} u_{l_b}(r_{bc}) v(r_{ab})$$
$$\times F_{l_a,j_a}(r_{aA}) F_{l'_a,j'_a}(r_{ac}) F_{l'_b,j'_b}(r_{bc})$$
$$\times \sum_{M_K} \langle l_a\ 0\ l'_a\ M_K | K\ M_K \rangle \left[Y^{l_b}(\cos\theta, 0) Y^{l'_b}(\cos\theta, 0) \right]^K_{-M_K} Y^{l'_a}_{M_K}(\cos\theta_{ac}, 0).$$

should obtain reliable absolute values

Consistency with other channels: The R_S problem

PHYSICAL REVIEW C **77**, 044306 (2008)

Reduction of spectroscopic strength: Weakly-bound and strongly-bound single-particle states studied using one-nucleon knockout reactions

A. Gade,[1,2] P. Adrich,[1] D. Bazin,[1] M. D. Bowen,[1,2] B. A. Brown,[1,2] C. M. Campbell,[1] J. M. Cook,[1,2] T. Glasmacher,[1,2] P. G. Hansen,[1,2] K. Hosier,[3] S. McDaniel,[1,2] D. McGlinchery,[3] A. Obertelli,[1] K. Siwek,[1,2] L. A. Riley,[3] J. A. Tostevin,[4] and D. Weisshaar[1]

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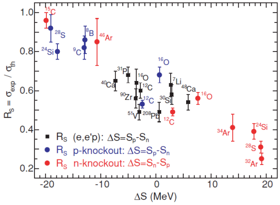
(Received 27 September 2007; published 10 April 2008)



Measured from knock-out within eikonal approximation

Limited asymmetry dependence of correlations from single nucleon transfer

F. Flavigny,[1,2] A. Gillibert,[1] L. Nalpas,[1] A. Obertelli,[1] N. Keeley,[3] C. Barbieri,[4] D. Beaumel,[5] S. Boissinot,[1] G. Burgunder,[6] A. Cipollone,[4,7,8] A. Corsi,[1] J. Gibelin,[9] S. Giron,[5] J. Guillot,[5] F. Hammache,[5] V. Lapoux,[1] A. Matta,[5] E.C. Pollacco,[1] R. Raabe,[6,2] M. Rejmund,[6] N. de Séréville,[5] A. Shrivastava,[6] A. Signoracci,[1] and A. Utsuno[10]

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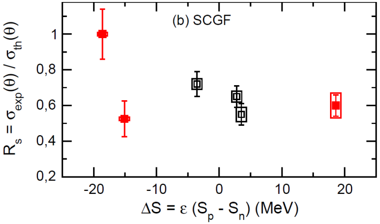
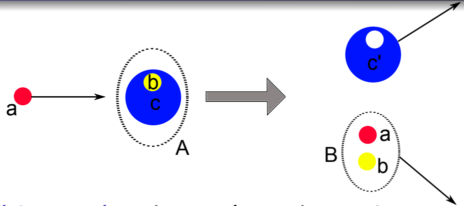


Measured from transfer with CDCC-CRC

Need for a unified reaction formalism

Consistency with other channels: 1-nucleon transfer



The 3–dimensional integral to be evaluated now is

$$I(l_a, l'_a, j_a, j'_a, K) = \int dr_{aA} dr_{bc} d\theta r_{aA} r_{bc}^2 \frac{\sin\theta}{r_{Bc}}$$
$$\times F_{l_a,j_a}(r_{aA}) F_{l'_a,j'_a}(r_{ac}) u^*_{l'_b,j'_b}(r_{ab}) u_{l_b,j_b}(r_{bc}) v(r_{ab})$$
$$\times \sum_{M_K} \langle l_a\ 0\ l'_a\ M_K | K\ M_K \rangle \left[Y^{l_b}(\cos\theta, 0) Y^{l'_b}(\cos\theta_{ab}, 0) \right]^K_{-M_K} Y^{l'_a}_{M_K}(\cos\theta_{Bc}, 0),$$

- replace the final scattering state for b with a bounded state to form nucleus B,
- same structure ingredients as for knock–out

Issues to address

- role of nucleon–nucleon interaction (need to include spin–orbit, L–dependence, tensor term...?)
- application to deformed states,
- include static and dynamic core excitations,
- extend to 2–nucleon knockout (possible loss of coherence in two–nucleon correlation?),
- full relativistic treatment of scattering states (solve Dirac equation)