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Three-body breakup of ^{11}Li with the eikonal method

E. C. Pinilla*, P. Descouvemont and D. Baye
*Email: epinilla@ulb.ac.be

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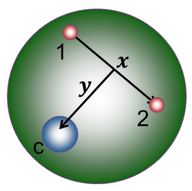
Direct reactions with exotic beams

Abstract

The ^{11}Li breakup on a ^{208}Pb @ target 70 MeV/nucleon is studied in the eikonal approximation by using a ^{9}Li+n+n three-body description in hyperspherical coordinates. The breakup cross sections shows a peak at low energies in correspondence with the experimental data. The calculated breakup cross section and angular distribution are in good agreement with the experimental data.

Three-body model



We wish to solve the three-body Schrödinger equation

$$H_{3B}\Psi^{J\pi} = E\Psi^{J\pi},$$

for

$E < 0 \rightarrow$ Bound state,
$E > 0 \rightarrow$ Scattering states,

With the Hamiltonian

$$H_{3B} = -\frac{\hbar^2}{2m_n}(\Delta_x + \Delta_y) + V_{cn1} + V_{cn2} + V_{nn}.$$

We make the partial wave expansion

$$\Psi^{J\pi} = \rho^{-5/2}\sum_{K=0}^{\infty}\sum_{\gamma}\chi_{\gamma K}^{J\pi}(\rho)\mathcal{Y}_{\gamma K}^{JM}(\Omega_5),$$

Where

$\mathcal{Y}_{\gamma K}^{JM}(\Omega_5) \rightarrow$ Hyperspherical Harmonics (known functions)

$\chi_{\gamma K}^{J\pi}(\rho) \rightarrow$ Hyperradial functions (Unknown functions) .

Coordinates

$$\rho^2 = x^2 + y^2,$$
$$\alpha = \arctan\left(\frac{y}{x}\right),$$
$$0 \le \alpha \le \frac{\pi}{2},$$
$$\Omega_5 = (\alpha, \Omega_x, \Omega_y).$$

Quantum numbers and operators

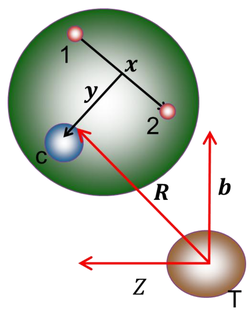
$$\gamma = (l_x, l_y, L, S),$$
$$\hat{L} = \hat{l}_x + \hat{l}_y,\ \hat{S} = \hat{S}_1 + \hat{S}_2$$
$$\hat{J} = \hat{L} + \hat{S}.$$

Four-body model

The idea is to solve the four-body Schrödinger equation

$$H_{4B}\Phi = E_T\Phi,$$

With $E_T = -\frac{\hbar^2 K^2}{2\mu_{PT}} + E_0 \rightarrow$ the total energy , $E_0 \rightarrow$ the Bound state energy of the projectile and $\mathbf{K} = k\hat{z} \rightarrow$ the incident relative wave vector.



The four-body Hamiltonian is

$$H_{4B} = -\frac{\hbar^2}{2\mu_{PT}}\Delta_R + H_{3B} + V_{PT}.$$

With $V_{PT} \rightarrow$ Nuclear+Coulomb optical potentials.

Factorizing $\Phi(\boldsymbol{R},\boldsymbol{x},\boldsymbol{y}) = e^{iKZ}\,\hat{\phi}(\boldsymbol{R},\boldsymbol{x},\boldsymbol{y})$ and ignoring terms at high energies.

We have for breakup

$$\frac{d\sigma}{dE}, \frac{d^2\sigma}{d\Omega dE} \propto \left\langle \underbrace{\Psi^{-}_{k_x k_y s\nu}}_{\text{3B continuum state (R-matrix)}} \middle| e^{i\chi(b)} \middle| \underbrace{\Psi^{J_0 M_0 \pi_0}}_{\text{3B Bound state}} \right\rangle$$

and for elastic scattering

$$\frac{d\sigma}{d\Omega} \propto \left\langle \Psi^{J_0 M_0{}' \pi_0} \middle| e^{i\chi(b)} \middle| \Psi^{J_0 M_0 \pi_0} \right\rangle.$$

With $\chi(\boldsymbol{b}) = -\frac{i}{\hbar v}\int_{-\infty}^{\infty}[V_{CT}(\boldsymbol{b}) + V_{nT}(\boldsymbol{b}) + V_{nT}(\boldsymbol{b})]\mathrm{d}Z.$

R-matrix

It allows to calculate continuum states with the correct asymptotic behavior. The unknown hyperradial wave function is found from the matching of the internal wave function with the external wave function in a.

Internal region

$$\chi_{\gamma K}^{J\pi} = \sum_{i=1}^{N} C_{\gamma K i}^{J\pi} u_i(\rho)$$

External region

$$\chi_{\gamma K}^{J\pi}(\rho) \rightarrow A_{\gamma K}^{J\pi}\left[H_{\gamma K}^{-}(k\rho)\delta_{\gamma\gamma'}\delta_{KK'} - U_{\gamma K,\gamma' K'}^{J\pi} H_{\gamma K}^{+}(k\rho)\right]$$
$$\rho \rightarrow \infty$$

Nuclear + Coulomb + Centrifugal potential

Coulomb + Centrifugal potential

$u_i(\rho) \rightarrow$ Lagrange basis functions
$U_{\gamma K,\gamma' K'}^{J\pi} \rightarrow$ Collision matrix,
$H_{\gamma K}^{\pm}(\kappa\rho) \rightarrow$ Haenkel functions and $\kappa = \sqrt{2m_n E/\hbar^2}$.

Breakup cross section

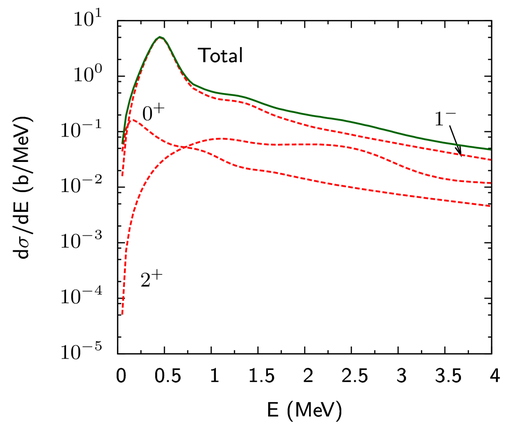


Fig. 2. Total (solid line) and partial wave decomposition (dashed lines).

Non negligible contributions of 0^+ and 2^+ off resonance.

Elastic scattering

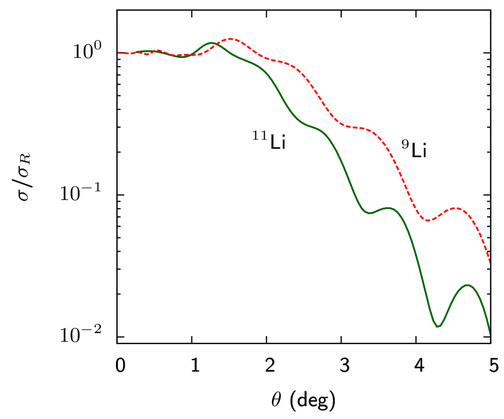


Fig. 3. Elastic scattering of ^{11}Li (solid line) and ^{9}Li (dashed line) on ^{208}Pb.

Reduction of ^{11}Li+^{208}Pb elastic scattering that may due to flux going to the breakup channel.

Eigenphases

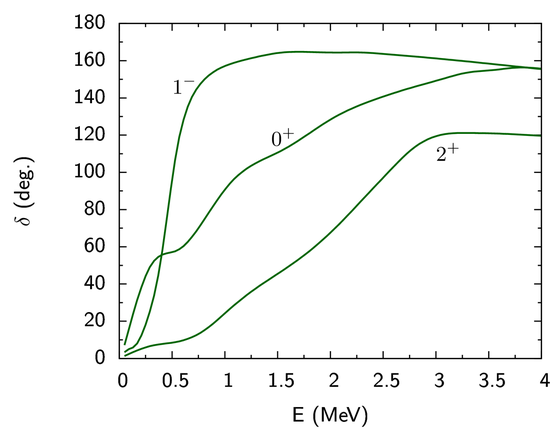


Fig. 1. Dominant 1^- , 0^+ and 2^+ eigenphases of the ^{9}Li+n+n system.

We predict a narrow resonance near 0.5 MeV above threshold.

Breakup cross section

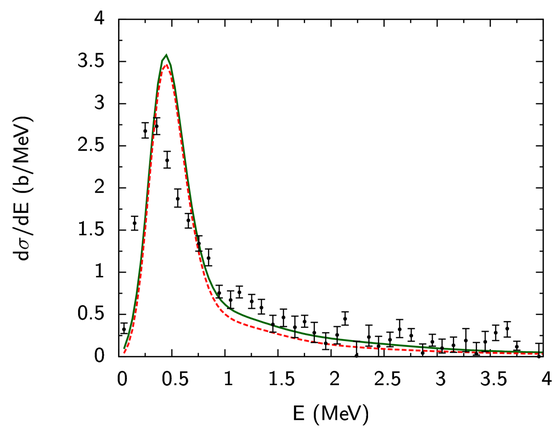


Fig. 4. Total (full line) and 1^- contribution (dashed line).

Peak at low energies

Breakup angular distribution

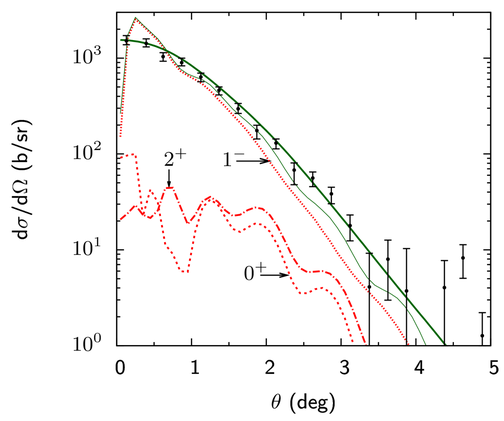


Fig. 5. Total (thin solid), partial wave decomposition (broken lines) and convoluted total (thick solid).

Very good agreement with the experimental data.

Conclusions and Remarks

- Our prediction strongly suggests the existence of a 1^- resonance in correspondence with the experimental data.
- The present model allows to introduce other contributions in addition to 1^- that are far from negligible.
- We introduce an accurate 3B description of the continuum wave functions through the R-matrix method.
- Accurate projectile wave functions are needed for a precise description of the breakup.