非エルミート境界条件下の3体量子反応ダイナミクス

自然科学一般
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研究概要・成果

Background and Framework

Background

1. Theory of the resonant and continuum states

Complex scaling method (CSM)
Complex scaling is performed on the position and momentum.
$r \to re^{i\theta}$ 　 $k \to ke^{-i\theta}$

Absorbing boundary condition (ABC)
The absorbing potential is placed outside of the total system.
$H \to H - iW$

The continuum states can be handled by the B.S. technique.

2. Previous works of the three-body problem

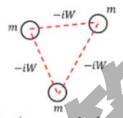
CSM; ^{6}He coulomb breakup reaction T. Myo et al., PRC63 (2001)
Full coordinate rearrangement (FCR) is considered.

ABC; Deuteron breakup reaction 　M. Ueda et al., PRC67 (2003)
NO coordinate rearrangement is taken into account.

Our subject

① Formulation of ABC in the 3-body problem with FCR

- We consider the resonance problem of the simple 3 boson system.
- We introduce the absorbing potential in the relative coordinate of the boson pair.



- The resonance parameters and the strength function are calculated.

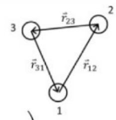
Checked by the CSM calculation.

② Application to the 3α −OCM calculation (Preliminary)

- We discuss the energy distribution of the 0^+ states.

Framework ①

1. Schrödinger equation for the 3-body system

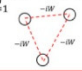


Kinetic energy

$$\left(-\frac{\hbar^2}{2\mu_{r_c}}\nabla_{r_c}{}^2 - \frac{\hbar^2}{2\mu_{R_c}}\nabla_{R_c}{}^2 + \sum_{i>j=1}^{3} V(r_{ij}) - i\eta W\right)\Psi = E(\eta)\Psi$$

2-body interaction
$V(r_{ij}) = -2e^{-0.16 r_{ij}^2} + e^{-0.04 r_{ij}^2}$

Absorbing potential (η : Strength)
$W \equiv \sum_{i>j=1}^{3} (r_{ij} - r_m)^4 \theta(r_{ij} - r_m)$



Kinematic factor
$\frac{\hbar^2}{m} = \frac{1}{2}[\mathrm{MeV \cdot fm^2}]$ 　 $\mu_{r_c} = \frac{m}{2}$, $\mu_{R_c} = \frac{2}{3}m$

We consider an identical three-boson system.
Wave function is completely symmetrized by introducing the coordinate rearrangement.

Framework

Framework ②

2. Setting of the wave function

The wave function is expanded by the oscillating Gaussian bases.

$$\Phi^c(\boldsymbol{r}_c, \boldsymbol{R}_c) = \sum_{n_c N_c} A^{(c)}_{n_c N_c} \phi_{n_c}(r_c)\psi_{N_c}(R_c)[Y_0(\hat{r}_c)Y_0(\hat{R}_c)]_{00}$$

$$\phi_n(r) = N_n e^{-\nu_n r^2}\{\cos(\omega\nu_n r^2)\ or\ \sin(\omega\nu_n r^2)\}$$
$$\psi_N(R) = N_N e^{-\lambda_N R^2}\{\cos(\omega\lambda_N R^2)\ or\ \sin(\omega\lambda_N R^2)\}$$

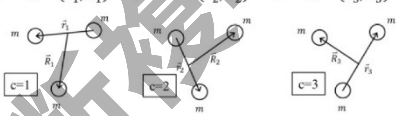
M. Kamimura et al., PRA85(2012)

Only the s wave state is considered.

3. Boson symmetry and Rearrangement channel

We explicitly include the rearrangement channels by considering the boson symmetry.

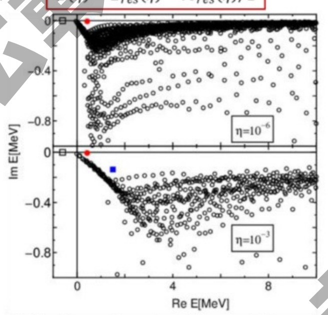
$$\Psi = \Phi^{c=1}(\boldsymbol{r}_1, \boldsymbol{R}_1) + \Phi^{c=2}(\boldsymbol{r}_2, \boldsymbol{R}_2) + \Phi^{c=3}(\boldsymbol{r}_3, \boldsymbol{R}_3)$$



Result

Energy distribution

$H(\eta) = H - i\eta W$
Resonance
$E(\eta) = E_{res}(\eta) - i\Gamma_{res}(\eta)/2$



η is fixed so as to reduce the expectation value of the absorbing potential.

Y. Takenaka et al., PTEP2014

Resonance parameters for the optimal strength

1st resonance(●)

	ABC	CSM
E_{res} [MeV]	0.424	0.424
$\Gamma_{res}/2$[MeV]	5.239×10^{-3}	5.260×10^{-3}
$\overline{W}_{min}$ [MeV]	7.118×10^{-7}	X
η_{opt}	8.0×10^{-6}	X

2nd resonance(■)

	ABC	CSM
E_{res} [MeV]	1.500	1.498
$\Gamma_{res}/2$[MeV]	0.144	0.142
$\overline{W}_{min}$ [MeV]	7.015×10^{-5}	X
η_{opt}	6.2×10^{-4}	X

Result

Strength function

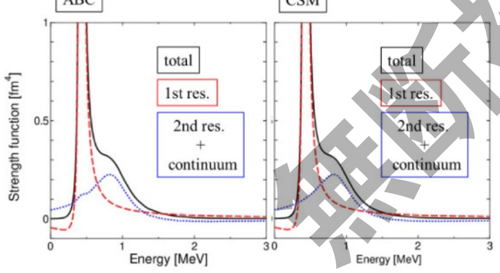
Extended completeness relation (ECR) of the ABC solutions

$$S(E) = -\frac{1}{\pi}\sum_m \mathrm{Im}\left[\frac{\langle\Psi_0|\hat{O}^\dagger|\Psi_m\rangle\langle\tilde{\Psi}_m|\hat{O}|\Psi_0\rangle}{E-(\varepsilon_m - i\gamma_m)}\right]$$

ECR is available for the calculation of the strength function.

Monopole operator: $\hat{O} = \sum_{i=1}^{3} r_i^2$

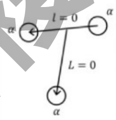
M. Iwasaki et al., PTEP2015

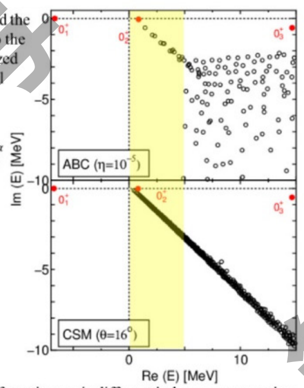


⇒The ABC method nicely works in the 3-body calculation with FCR.

3α-OCM calculation (Preliminary)

We have applied the ABC method to the 3α orthogonalized condition model (OCM) in ^{12}C.





Level density of continuum is different in low energy region.
→The strength function may be affected.

Summary

1. The ABC results nicely agree with CSM.
→We succeed in formulating the ABC method to the 3-body problem with FCR.
2. We will investigate the influence of the difference of the level density of the 0^+ states in ^{12}C on the strength function.

応用分野、実用化可能分野

天体核物理・原子力工学などの
核データ分野に応用可能

例）恒星の進化に必要なトリプルα反応率の計算に適用が期待される

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