Microscopic collective inertial masses for nuclear reactions in the presence of the nucleonic effective mass†

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A theoretical description of low-energy nuclear reactions with a solid microscopic foundation is still a challenging subject in nuclear physics. It may provide us with a deep insight into the reaction mechanisms and quantum dynamics of many-nucleon systems. Our strategy is as follows. First, we find a collective subspace spanned by a few selected collective canonical variables, which is decoupled from the intrinsic excitations. The collective subspace and collective variables can be extracted using the adiabatic self-consistent collective coordinate (ASCC) method.[1] The collective subspace in the adiabatic regime is given by a series of time-even Slater determinants and generators of the collective coordinates and momenta locally defined for each state. We apply the method to low-energy nuclear reactions, to identify the optimal reaction path and canonical variables. The self-consistently determined collective reaction path is requantized. The procedure results in the reaction model

$$\left\{-\frac{d}{dR}\frac{1}{2M(R)}\frac{d}{dR}+\frac{\ell(\ell+1)}{2\mathcal{J}(R)}+V(R)\right\}u_\ell(R) = Eu_\ell(R), \quad (1)$$

where R is the relative distance between the projectile and the target nuclei. The wave function for the relative motion is given by $\psi(\mathbf{R})=u_l(R)Y_{lm}(\hat{R})/R$.

The key ingredients of the requantization procedure are the potential $V(R)$, the inertial mass parameters with respect to the collective coordinates $M(R)$, and the rotational moment of inertia $\mathcal{J}(R)$ in Eq. (1). For the nuclear reaction, the relative distance R between two colliding nuclei should be properly chosen collective coordinates in the asymptotic region ($R\to\infty$). The corresponding inertial mass should be the reduced mass $\mu_{\rm red}=A_PA_Tm/(A_P{+}A_T)$, where A_P (A_T) is the mass number of the projectile (target) nucleus and m is the bare nucleon mass. The moment of inertia $\mathcal{J}(R)$ in Eq. (1) also has an asymptotic value, $\mathcal{J}(R)\to\mu_{\rm red}R^2$ at $R\to\infty$. Therefore, the theory can be tested by examining its asymptotic limit. However, the inertial masses in the interior region where two nuclei touch each other are highly nontrivial. Thus, a microscopic theory for calculating the mass over the entire reaction path is necessary.

In our previous studies,[2] we calculated the ASCC inertial masses for the relative motion between two nuclei for the velocity-independent mean-field potential. We also examined those of the cranking formula, which turned out to be almost identical to the ASCC mass at $R\to\infty$. However, this is not true in general. In particular, the nonlocal mean-field potential produces the effective mass $m^*/m<1$. In this case, in order to guarantee the Galilean invariance of the energy density functional, we need densities that are time-odd with respect to the time-reversal transformation. The time-odd mean fields play important roles in the time-dependent dynamics because the time-odd densities are nonzero in general for the time-dependent states. Since the ASCC equations are derived from the time-dependent mean-field theory, they are able to take into account the effects of the time-odd mean fields in calculations of the inertial masses. We have found that the ASCC inertial masses reproduce the correct asymptotic values, whereas the cranking formula fails to do so.

Figure 1 shows the results for the moments of inertia $\mathcal{J}(R)$. The velocity dependence in the mean-field potential violates the local Galilean invariance. The calculated cranking moments of inertia (dashed line) are significantly smaller than the rigid-body value $\mathcal{J}_{\rm rig}$ (dotted line). They are also smaller than the point-particle value $\mu_{\rm red}R^2$ (dash-dot line) at large R. In contrast, the ASCC calculation (solid) includes the residual effects of the time-odd mean fields, which restore the local Galilean invariance, nicely reproducing $\mu_{\rm red}R^2$ at $R>7.5$ fm. Near the equilibrium state ($R\sim 5.5$ fm), it also reproduces the rigid-body value.

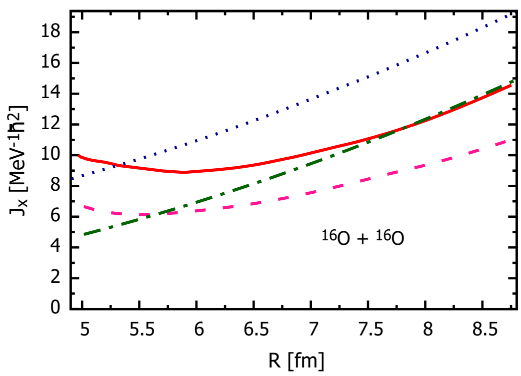

Fig. 1. Rotational moments of inertia as a function of the relative distance R for $^{16}O{+}^{16}O$. See text for details.

References
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2) K. Wen *et al.*, Phys. Rev. C **94**, 054618 (2016); *ibid.* **96**, 014610 (2017).

† Condensed from the article in Phys. Rev. C **105**, 034603 (2022)
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