BEYOND THE TDHF

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The mean-field description of low-energy heavy-ion scattering [1] is extended to include the residual nucleon-nucleon interaction. The collision term is derived from a random-matrix model for this interaction in the weak-coupling limit [2]. The TDHF equation for the A-body density matrix $\varrho^{(A)}(\vec{x}_1 \ldots \vec{x}_A; \vec{x}_1' \ldots \vec{x}_A'; t)$

$$i\dot{\varrho}^{(A)} = [H_{HF}, \varrho^{(A)}]$$

with the Hartree-Fock Hamiltonian H_{HF} is replaced by

$$i\dot{\varrho}^{(A)} = [H_{HF}, \varrho^{(A)}] + [V, \varrho^{(A)}]$$

in order to include the statistical fluctuation of the mean field due to the residual force V. We assume that the matrix elements of the residual force in the diabatic basis have a Gaussian distribution with mean value zero and second moment

$$\overline{\langle\alpha\beta|V|\gamma\delta\rangle\langle\gamma'\delta'|V|\alpha'\beta'\rangle} = \overline{V^2_{\alpha\beta\gamma\delta}}\,(\delta_{\alpha\alpha'}\delta_{\beta\beta'} - \delta_{\alpha\beta'}\delta_{\beta\alpha'})(\delta_{\gamma\gamma'}\delta_{\delta\delta'} - \delta_{\gamma\delta'}\delta_{\delta\gamma'})$$

where $|\gamma\delta\rangle$ are antisymmetrized 2-body states and $\overline{V^2_{\alpha\beta\gamma\delta}}$ the strength of the residual interaction. The ensemble-average $\overline{\varrho}^{(A)}$ of the A-body density is found to obey a time-irreversible equation

$$i\dot{\overline{\varrho}}^{(A)} = [H_{HF}, \overline{\varrho}^{(A)}] - i\,\overline{[V, [W, \overline{\varrho}^{(A)}]]}$$

where $W(t) = \int_{t_0}^{t} ds\, O_t^{-1} O_s V O_s^{-1} O_t$ and $O_t = \overrightarrow{T} \exp\left\{ i \int_{t_0}^{t} ds\, H_{HF}(s) \right\}$.

This equation includes the effect of 2-body dissipation due to the nucleon-nucleon collisions in the limit of weak coupling [2]. Its reduction to the average 1-body density matrix $\bar{\rho}^{(1)}(\vec{x}_1, \vec{x}_1{}'; t)$ provides the extension of the TDHF equation. For the diagonal elements of $\bar{\rho}^{(1)}$ it can be reduced to

$$i\,\dot{\bar{\rho}}^{(1)}_{\alpha\alpha} = [h_{HF}(\bar{\rho}^{(1)}), \bar{\rho}^{(1)}]_{\alpha\alpha} + i \sum_{\alpha_2\beta_1\beta_2} \overline{V^2_{\alpha\alpha_2\beta_1\beta_2}} \cdot G_{\alpha\alpha_2\beta_1\beta_2} \cdot$$

$$\cdot \left\{ \bar{\rho}^{(1)}_{\beta_1\beta_1} \bar{\rho}^{(1)}_{\beta_2\beta_2} (1-\bar{\rho}^{(1)}_{\alpha\alpha})(1-\bar{\rho}^{(1)}_{\alpha_2\alpha_2}) - \bar{\rho}^{(1)}_{\alpha\alpha} \bar{\rho}^{(1)}_{\alpha_2\alpha_2} (1-\bar{\rho}^{(1)}_{\beta_1\beta_1})(1-\bar{\rho}^{(1)}_{\beta_2\beta_2}) \right\}$$

which differs in the collision term from the standard Boltzmann-like form [3] because of the finiteness of the system. The structure of $G_{\alpha\alpha_2\beta_1\beta_2}$ ensures energy conservation. The time scale relevant for the validity of the equation is determined by the change of the single-particle energies in time. A numerical calculation with a simplified form of the collision term [4] exhibits sizable effects. It can force the system to form an equilibrated compound nucleus.

References

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