TRANSPORT THEORY OF DISSIPATIVE HEAVY-ION COLLISIONS:
Dynamical treatment of strong coupling within a one-body theory

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The initial stage of a heavy-ion collision is characterized by the mutual approach of the nuclei in their ground states. Because of the long mean free path the motion of the nucleons during this first stage of the collision is expected to be governed by their self-consistent single-particle potential which evolves slowly in time (TDHF). Within times of the order 10^{-21}s residual interactions lead to a local statistical equilibrium where the system occupies the total phase space (total configuration space) which is 'locally' available, i.e. available for fixed values of the macroscopic (collective) degrees of freedom[1]. The close approach to local statistical equilibrium, however, is essential for the justification of all current transport theories. Therefore these theories are not expected to describe properly the initial stage of the collision process. In addition to the assumption of local statistical equilibrium, the non-perturbative transport theories suffer from the occurence of the strong-coupling limit in the collision kernel.

A way out of these difficulties is supplied by the observation[2,3] that (i) the occurence of the strong-coupling limit is essentially due to the introduction of many-body states in the formulation and (ii) that the strong coupling between these states is treated statistically. We have therefore developed a transport theory on the basis of a one-body theory. This one-body transport theory starts out from a dynamical single-particle basis which incorporates main parts of the coupling in a coherent way. By deriving transport equations for one-body quantities it is possible to avoid the strong-coupling limit with its apparent drawback due to off-shell contributions. As the essential tool in this formulation we apply a suitable time-averaging which

replaces the usual statistical assumptions in the derivation of (time-irreversible) transport equations.

For the occupation probabilities of the dynamical single-particle states we obtain the master equation

$$\frac{\partial}{\partial t}\rho_{\alpha\alpha}(t) = \sum_{\beta} W_{\alpha\beta}(t)\,[\rho_{\beta\beta}(t) - \rho_{\alpha\alpha}(t)] \tag{1}$$

with the transition probability given by

$$W_{\alpha\beta}(t) = 2\hbar^{-2}\,Re\int_0^{\infty} d\tau\,\{V_{\alpha\beta}(t)V_{\beta\alpha}(t-\tau)\}_{\Delta t} \tag{2}$$

where $\{\ldots\}_{\Delta t}$ denotes the average over the time interval Δt around t. The quantities $V_{\alpha\beta}(t)$ denote the time-dependent one-body interaction between the dynamical single-particle states. The residual two-body interactions $V_{\alpha\beta\gamma\delta}(t)$ modify the master equation (1) by an additional two-body collision term

$$\begin{aligned} K_{\alpha\alpha}(t) = 2\hbar^{-2} \sum_{\beta\gamma\delta} Re\int_0^{\infty} d\tau\,\{V_{\alpha\beta\gamma\delta}(t)\,V_{\gamma\delta\alpha\beta}(t-\tau)\}_{\Delta t} \\ \cdot [(1-\rho_{\alpha\alpha}(t))\,(1-\rho_{\beta\beta}(t))\,\rho_{\beta\beta}(t)\rho_{\delta\delta}(t) \\ - \rho_{\alpha\alpha}(t)\,\rho_{\beta\beta}(t)\,(1-\rho_{\gamma\gamma}(t))\,((1-\rho_{\delta\delta}(1))] \end{aligned} \tag{3}$$

which differs from usual collision terms in the time average of the correlation function.

The equation of motion for the collective variable $q(t)$ is obtained from the conservation of the total energy by considering

$$\frac{d}{dt}\langle H\rangle = \dot{q}\,\left(\frac{\partial U}{\partial q} + \xi\dot{q} + M\,\ddot{q}\right) = 0. \tag{4}$$

By ordering $d\langle H\rangle/dt$ according to terms proportional to $\dot{q}, \dot{q}^2$ and $\dot{q}\,\ddot{q}$ we determine the time-dependent potential $U(q,t)$, the friction coefficient $\xi(q,t)$ and the mass parameter $M(q,t)$.

If we regard the matrix elements $\langle\phi_\alpha|\partial/\partial q|\phi_\beta\rangle$ to be constant we can easily perform the average with a Lorentz weight function and obtain in this limit

$$\xi(q,t) \sim 0. \tag{5}$$

The vanishing of the friction coefficient reflects the more general feature that the collision terms (2) and (3) conserve the energy. Thus energy dissipation occurs only in a very specific way, namely by the time-dependent potential U(q,t) giving rise to considerable memory effects[1]. The mass parameter is given by

$$M(q,t) = 2h \sum_{\alpha\beta} \rho_{\beta\beta}(t) |\langle\phi_\alpha(q)|\frac{\partial}{\partial q}|\phi_\beta(q)\rangle_t|^2 \frac{\omega_{\alpha\beta}(t)}{\omega^2_{\alpha\beta}(t)+\Gamma^2_{\alpha\beta}(t)} \tag{6}$$

where $\Gamma_{\alpha\beta}=\Delta t|\dot{\omega}_{\alpha\beta}|$. This width vanishes for $\dot{\omega}_{\alpha\beta}=0$ and hence M(q) becomes the familiar cranking expression in the limit of uniform translation or rotation.

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