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ABSTRACT

We show that the physics of collision terms, presently of widening application in connection with kinetic extensions of mean field descriptions, largely coincides with the physics behind the construction of density dependent effective interactions and mean fields in the context of static nuclear structure problems. The use of collision terms to extend mean field descriptions based on dynamical extrapolations of the static density-dependent mean field becomes therefore a delicate matter.

There are two main categories of problems in nuclear physics which call for the inclusion of correlations, i.e., descriptions which go beyond mean field descriptions: the static properties of nuclei[1] and nuclear reactions involving heavy ions[2].

In what regards static properties of nuclei, it has long been known that realistic versions of the nuclear force treated in the Hartree-Fock approximation do not give a quantitative account of, e.g., binding energies and nuclear radii[3]. In all calculations of this sort it becomes clear

that correlation corrections are very important and that it is impossible to do without them if one wishes to adjust these two properties simultaneously. Much of the present proficiency in this field hinges on the use of effective interactions, following the work of J. Negele[4]. These interactions include correlation corrections (which are density matrix as well as energy dependent) in an approximate way, namely an energy average is performed and a local density approximation substitutes the complicated density matrix dependence. The result of such calculations is an energy independent and density dependent effective interaction, which reproduces remarkably well both the binding energies and radii of nuclei.

On the other hand there is a different class of phenomena, the so-called deep inelastic collisions, which called attention for kinetic phenomena in the nuclear scale. Since then much effort has been put into deriving kinetic extensions of Time Dependent Hartree Fock. Usual treatments are strongly polarized in the direction of eventually obtaining a Boltzmann-like collision term[5]. In order to build the connection between the correlation effects to be added to mean field descriptions in these two categories of problems we need a neutral attempt to go beyond mean field descriptions. One possibility consists in considering the formal exact evolution of the nuclear one body density matrix. The complete microscopic description of the time evolution of the nuclear one body density (single particle states and occupation probabilities) can be formally given in terms of ingredients of two distinct types: unitary contributions which contain the usual time dependent Hartree-Fock plus unitary correlation corrections, and nonunitarity contributions which are essentially related to changes of the coherence properties of the one body density. Apart from initial correlation terms, the description is closed at the one body level, and derived in ref. [6]. In the weak coupling regime, (i.e., only terms up to second order in the two body potential are considered), one gets the simple equation:

$$i\dot{\hat{\rho}}(t) = \left[\hat{\hat{\ell}}_0(t) + \hat{\hat{\ell}}_1(t)\right]\hat{\rho}(t) + \hat{\mathcal{R}}(t) \tag{1}$$

where
$$\hat{\hat{\ell}}_0(t)\hat{\rho}(t) = \left[h[\rho(t)], \hat{\rho}(t)\right] \tag{2}$$

and
$$\left[\hat{\hat{\ell}}_1(t)\hat{\rho}(t)\right]_{\lambda\mu} = \frac{i}{2}\sum_{\beta\gamma\delta}\int_0^t dt' \times$$

$$\times \Big[\langle\gamma\delta|\tilde{v}|\mu\beta\rangle_t \langle\lambda\beta|\tilde{v}|\gamma\delta\rangle_{t'} (p_\lambda p_\beta q_\gamma q_\delta - p \leftrightarrow q)_{t'} + \langle\lambda\beta|\tilde{v}|\gamma\delta\rangle_t \langle\gamma\delta|\tilde{v}|\mu\beta\rangle_{t'} (p_\mu p_\beta q_\gamma q_\delta - p \leftrightarrow q)_{t'}\Big] \tag{3}$$

and

$$\hat{\mathcal{R}}_{\lambda\mu}(t) = \frac{1}{2}\sum_{\beta\gamma\delta} \frac{\langle\gamma\delta|\tilde{v}|\mu\beta\rangle\langle\lambda\beta|\tilde{v}|\gamma\delta\rangle}{\epsilon_\gamma + \epsilon_\delta - \epsilon_\lambda - \epsilon_\beta} \cdot (p_\lambda p_\beta q_\gamma q_\delta - p \leftrightarrow q) + \frac{\langle\lambda\beta|\tilde{v}|\mu\beta\rangle\langle\gamma\delta|\tilde{v}|\mu\beta\rangle}{\epsilon_\mu + \epsilon_\beta - \epsilon_\gamma - \epsilon_\delta} (p_\gamma p_\delta q_\mu q_\beta - p \leftrightarrow q) \tag{4}$$

The first term on the r.h.s. of eq. (1) represents the Hartree-Fock mean field contribution, the second term, correlation corrections and the third term represents initial

correlations treated to the same order in the coupling two body potential. The p_γ's are the occupation probabilities of the natural orbitals $|\gamma\rangle$ at time t, $q = 1-p$, and $\langle\alpha\beta|\tilde{v}|\gamma\delta\rangle_t$ represents antisymmetrized matrix elements of the two body potential.

It is easy to show that the correlation correction (second term on the r.h.s. of eq. (2)) corresponds to a Boltzmann type equation, provided a markovian approximation is performed[6]. In the semiclassical limit if a local density approximation is performed one gets the Boltzmann collision integral with Fermi statistics[7].

It is important to stress at this point, that the correlation corrections of eq. (1) <u>contain</u> contributions of the same sort which are considered in the construction of density dependent interactions. To show this we use eq. (1) with $|\lambda\rangle_t = e^{-i\epsilon_\lambda t}|\lambda\rangle_0$ and take $p_\lambda(t)$ at $t=0$ to perform the time integral. We get when $\dot{\rho} = 0$:

$$0 = \left[h[\rho], \rho\right] + \frac{1}{2}\sum_{\beta\gamma\delta} \frac{\langle\gamma\delta|\tilde{v}|\mu\beta\rangle_0 \langle\lambda\beta|\tilde{v}|\gamma\delta\rangle_0}{\epsilon_\gamma + \epsilon_\delta - \epsilon_\lambda - \epsilon_\beta} \cdot (p_\gamma p_\delta q_\lambda q_\beta - p \leftrightarrow q) + \frac{1}{2}\sum_{\beta\gamma\delta} \frac{\langle\lambda\beta|\tilde{v}|\gamma\delta\rangle\langle\gamma\delta|\tilde{v}|\mu\beta\rangle}{\epsilon_\mu + \epsilon_\beta - \epsilon_\gamma - \epsilon_\delta} (p_\gamma p_\delta q_\mu q_\beta - p \leftrightarrow q) \tag{5}$$

This corresponds to what is obtained by varying an energy functional involving the G-matrix, as done when discussing the physics of effective interactions[8], with obvious changes related to the particular structure of the G-matrix. Eq. (4) of ref. [8] contains an additional term which results here from taking into account the renormalization of occupation probabilities, as given by eq. (3), in $h[\rho]$.

Similarly, a linearized version of the collision term, eq. (3) , is found to include time (energy)-dependent self energy and induced interaction corrections to the $\tilde{v}$ terms in the RPA. These are crucial to screen over attractive G-matrix elements when they are used as residual interaction[9]. Also included are contributions changing occupation probabilities ($\lambda=\mu$ terms of eq. (3), usually not considered in the RPA)[10].

Now a word about the two-body potential is in order: eqs. (1)-(5) involve the two-body potential $\tilde{v}$ which is assumed to be smooth, so as to produce a reasonable enough Hartree-Fock mean field. Should there be strong short-range repulsion in $\tilde{v}$, the preceding arguments can still be carried through after replacing $\tilde{v}$ by an effective object, satisfying a Bethe-Salpeter equation, which essentially reduces to ladder sums in the static limit. This can be obtained by expansion and suitable ressumation of eq. (3.17a) of ref. [6][11].

Density-dependent interactions are known to give reasonable RPA modes in nuclei, as they incorporate enough screening effects, associated mainly with the induced interaction, albeit in approximate, energy independent form. From the preceding it follows that it is not consistent to extend such RPA descriptions by adding collision terms involving anything like the G-matrix interaction itself. A similar conclusion applies also to large amplitude motion. The subject of the appropriate effective interaction to be used in a dynamical context and the form of consistent collisional

connections can thus be profitably studied on basis of refs. [6] and [11].

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