Adiabatic TDHF as a consistent theory for anharmonic collective motion

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Many large amplitude collective phenomena, like anharmonic vibrations, fission etc., can be characterised by one, or a few, collective coordinates $q=q(t)$. In microscopic theories of collective motion one links the q-description to the space of A-particle coordinates x_i, using a set of deformed Slater determinants, or BCS states resp., $\Phi_q(x_1,\ldots,x_A) = \langle x_i | q \rangle$. With this collective basis $|q\rangle$ and its dynamic generalisation $|q,p\rangle$, where p is the momentum conjugate to q, one obtains the (classical) collective Hamiltonian $\mathcal{H}(q,p)=\langle q,p|\hat{H}|q,p\rangle$, which is to be requantised in order to give the collective Schrödinger equation. The question of quantisation, although part of a consistent collective theory[1], will not be discussed here, because of limited space.

The topic of this contribution is the first point, the proper choice of the collective path $|q\rangle$. Usually, it is guessed by assuming a properly deformed shell model (e.g. the Nilsson model). A less ambigous way is, to solve constrained HF, where $\hat{H} \to \hat{H}-\lambda Q_c$. The constraint Q_c, however, is still at choice. ATDHF now aims to give a unique prescription for determining the path $|q\rangle$ <u>and</u> the collective operator Q. The full derivation[1], using TDHF in the limit of small velocities, is rather lengthy. Here, we merely try to make the ATDHF equations plausible.

Starting point is, of course, a constrained HF,

$$\langle q|[a^+a,\hat{H}-\lambda Q_c]|q\rangle = 0 \qquad (1)$$

where λ is a Lagrange multiplier, which finally becomes $\lambda=\partial_q\langle q|\hat{H}|q\rangle$. For small velocities, one obtains the dynamic extension from linear response to an additional dynamic constraint $\dot{q}P$, where $P=i\partial_q$. This leads to $|q,p\rangle=\exp(ipQ_d)|q\rangle=(1+ipQ_d)|q\rangle$, where the dynamic generator Q_d is given by the response equation

$$\langle q|[a^+a,[H,Q_d]+iP/M]|q\rangle = 0 \qquad (2)$$

and the collective mass is $M^{-1}=\langle q|[Q_d,[H,Q_d]]|q\rangle$ (the Thouless-Valatin mass). We thus have two collective operators Q_c and Q_d. If there is really a decoupling collective mode, one has place for only one operator Q. We therefore have to require <u>Q-consistency:</u> $Q_c=Q_d$. This feeds the dynamic generator Q_d from eq.(2) as static constraint Q_c back into eq.(1), leading to a coupled set of equations, which uniquely prescribes a collective path.

For its explicit construction, one combines eqs.(1) and (2) to one differential equation

$$\partial_q |q\rangle = (M/\lambda)[H,H_{ph}]_{ph}|q\rangle \qquad (3)$$

(where A_{ph} means the 1p-1h part of an operator A). The solution of eq.(3) requires as initial condition one point $|q\rangle$ with $\lambda \neq 0$, i.e. one point off the HF minimum. At the HF point itself, it may be labelled $|0\rangle$, the path has to join an RPA mode. Thus one can initialise the path by chosing one particular RPA mode at $|0\rangle$ and stepping to the first point off the minimum, $|\delta q\rangle = (1-i\delta qP)|0\rangle$, using the RPA momentum P. From $|\delta q\rangle$ on, eq.(3) is in action. The choice of an initial RPA mode is the only freedom left in the ATDHF scheme. With it one determines the sort of collective motion, one wants to study.

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