~~even for rather small energy losses. The relation of this open question to the observed "macroscopic" transfer of mass observed in, for example, the Ca + U reaction is a central topic in the field of heavy ion reaction.~~

~~The results of the above model, which account for the main features experimentally observed, can be summarized as follows. At an early stage of the collision when the two surfaces get into contact, energy and angular momentum is absorbed at a fast rate by the damped giant resonances. Low-lying modes with small restoring forces are important towards the final stages of the collision where they give rise to large deformations keeping the nuclear surfaces into contact. This "neck" formation is responsible for the experimentally observed fact that the two nuclei often emerge with relative kinetic energy which is below the Coulomb barrier of the corresponding spherical nuclei. The exchange of nucleons between the nuclei removes energy and angular momentum from relative motion throughout the collision.~~

The central feature of heavy ion collisions seems to be the importance of the coherent response of the different degrees of freedom. Thus in the description of the excitation of the surface modes it is not enough to know the population of the vibrational states ~~[illegible]~~ but also the relative phases which determine the shape of the nuclei as a function of time (cf. fig. ~~14~~ 15). Although it is difficult to document such a result in a more intuitive way it is possible to obtain a more accurate mathematical description. Thus solving the problem quantum mechanically we obtain the following total wavefunction - X

In a heavy ion collision in which the two nuclei are assumed interact through the Coulomb

Example of coherent state

Cf. Sect 4 and App. B Ch II HIR

$$|\psi(t)\rangle = e^{-i\frac{H_0 t}{\hbar}} |\phi(t)\rangle$$
$$= \sum_{\{n_\mu\}} \left(\prod_\mu e^{-\frac{|I_\mu(t)|^2}{2}} \frac{(I_\mu(t))^{n_\mu}}{\sqrt{n_\mu!}} \right) |\{n_\mu\}\rangle,$$

where

$$I_\mu(t) = \frac{1}{\hbar} \int^t f_\mu^*(t') e^{i\omega t'} dt',$$

and where H_o is the Hamiltonian describing the intrinsic degrees of freedom of each nuclei. The wavefunction $\phi(t)$ is the solution of the Schrödinger equation

$$i\hbar \frac{\partial \phi}{\partial t} = \tilde{V} \phi$$

where $\tilde{V} = \exp(i H_o t/h)\, V \exp(-i H_o t/h)$, V being the external field.

The integral I_μ is related to the average number of phonons by

$$\langle n_\mu \rangle = |I_\mu(t)|^2,$$

the corresponding values for the reaction Xe + Pb at the instant of maximum deformation are quoted in table 1.

The state $|\psi(t)\rangle$ is known in quantum mechanics as a coherent state.[14] Its name stems from the fact that the associated uncertainty relations in momemtum and coordinate associated with it fulfills the absolute minimum consistent with quantum mechanics, that is,

$$\Delta x_\psi \, \Delta \pi_\psi = \frac{\hbar}{2} .$$

Note that this value is normally associated with the ground state. In general states described by a wavefunction of the type exp $\{\frac{i\hat{O}}{\hbar}\}\phi(t)$ exhaust the energy weighted sum rule of the associated operator[15] which in the present case is the Hamiltonian.

Heavy ion collisions seem thus specific to study the nuclear spectroscopy of the coherent nuclear state. Note that we have left behind the field of experiments where the system that is probed can be described as if the probe was not present.

The coherent state which pictorially looks so simple, being almost a classical state, arises from the excitation and delicate phase relation of many collective and non-collective states of the individual nuclei. Thus, the full response function is tested in these reactions in a totally novel way. Note that collective vibrations as those discussed in connection with e.g. figs. 3 and 4 are also coherent states and arise from the correlated efforts of many particle-hole excitations.

It is interesting to speculate whether the coherent excitation of the gas of phonons will lead to new super-collectivities displaying different condensation or phases as a function of the continuous excitation energy.

The behavior of the total energy absorbed by the coherent state in the reaction Kr + Pb as a function of angle (or linear momentum) shown in fig. ~~15~~ 16 is suggestively reminiscent of the behavior of the coherent state excited in liquid helium (cf. fig. 1).

A first step in relating microscopically the coherent state to the nuclear response function is provided by the analysis of the $^{16}O + {}^{208}Pb$ reaction at 340 MeV summarized in fig. ~~15~~ 17.

The usefulness of a model is measured by the ratio between the amount of experimental data it correlates and the number of concepts upon which it is based. There is a good chance that the model discussed in this comment can lead to a large value. The possibility to make rigorous statements about the different physical processes seem also to be quite large.

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