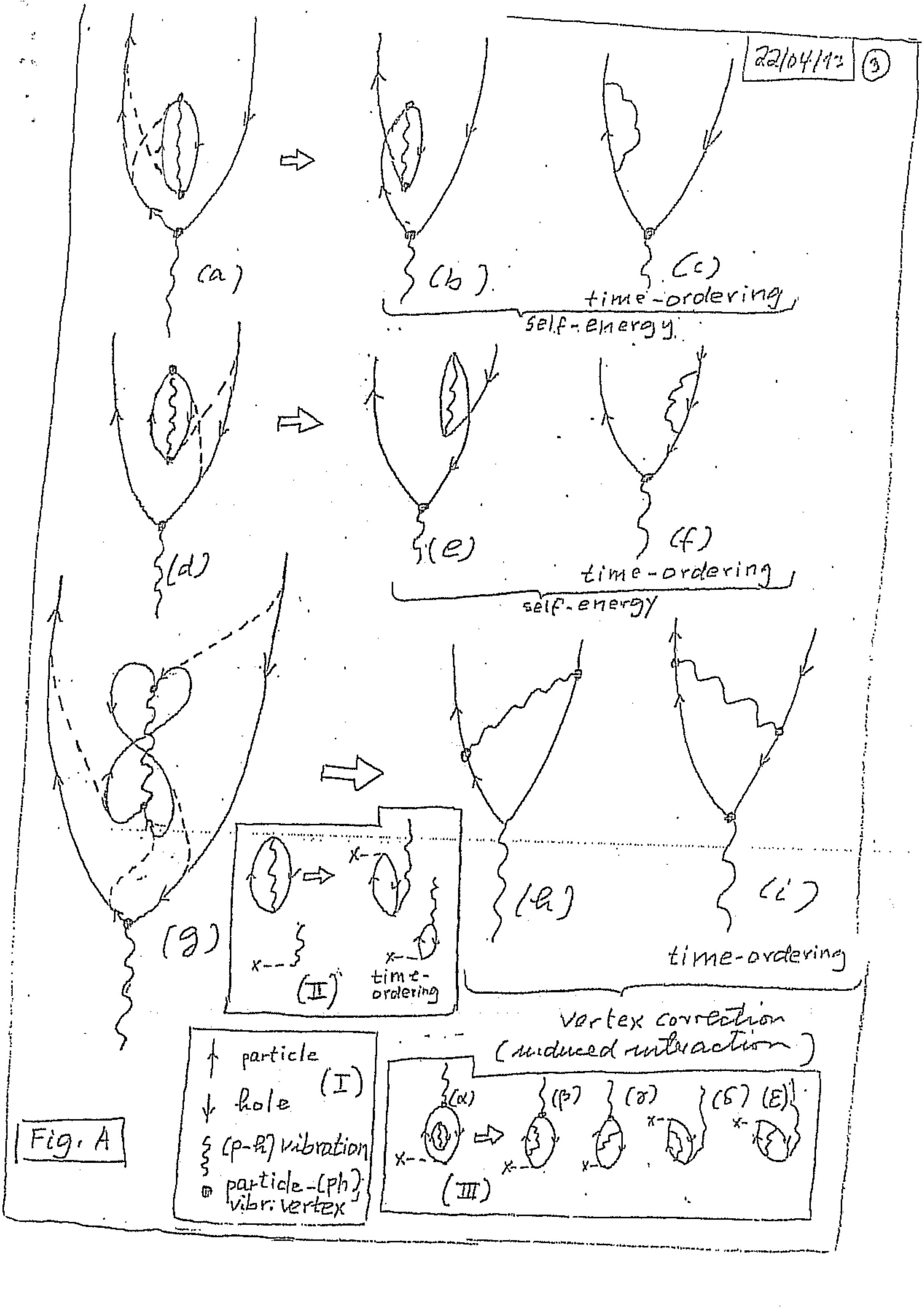
on the basis of medium polari- (1)
zation effects: self-energy, vertex corrections and induced interaction

22/04/13

In keeping with a central objective of the formulation of quantum mechanics, namely that the basic concepts on which it is based relate directly to experiment, Heisenberg's elementary modes of nuclear excitation (single-particle, collective vibrations and rotations), are solidly anchored on observation (inelastic and Coulomb excitation, one- and two-particle transfer reactions).

Of all quantal phenomena, zero point fluctuations (ZPF), closely connected with virtual state, ~~are likely~~ to be most representative of the essential differences existing between quantum and classical mechanics. In fact, ZPF are intimately connected with the complementary principle (Bohr), and thus with the indeterminacy (Heisenberg) and non-commutative (Born, Jordan) relations, and with the probabilistic interpretation (Born) of the (modulus squared) of the wavefunctions, solution of Schrödingers or Dirac's equations.

Pauli principle brings about essential modifications of the virtual fluctuations of the many-body system, modifications which are instrumental in the dressing and interweaving of the elementary modes of excitation (see Figs. A and B; within the present context, see also J.R. Schrieffer, Theory of superconductivity, Benjamin, N.Y (1964) p. 134).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(3)
(a)
(b)
(c)
time-ordering
self-energy
(d)
(e)
(f)
time-ordering
self-energy
(g)
x--
(II)
time-ordering
(h)
(i)
time-ordering
vertex correction
(induced interaction)
particle
hole
(I)
(p-h) vibration
particle-(ph) vibr. vertex
(α)
(β)
(γ)
(δ)
(ε)
x--
(III)
Fig. A

Caption Fig. A

Nuclear field theory (NFT) diagrams corresponding to the lowest order medium polarization effects renormalizing the properties of a particle-hole collective mode (wavy line) ~~linear~~ combination of particle-hole (up-going) - (down-going) arrowed lines excitations calculated within the random phase approximation (RPA) in of a bare interaction, and leading to the particle vibration coupling vertex (solid dot, see inset (I), bottom). The action of an external field on the zero point fluctuations (ZPF) of the vacuum (inset (II)), forces a virtual process to become real, leading to a collective vibration by annihilating a (virtual, spontaneous) particle-hole excitation (backwardsgoin RPA amplitude) or, in the time ordered process, by creating a particle-hole excitation which eventually, through the particle-vibration coupling vertex, correlate into the collective (coherent state; forwardsgoing amplitudes). Now, oyster-like diagrams associated with the vacuum ZPF can occur at any time (see inset III). Because the texture of the vacuum is permeated by symmetry rules (while one can violate energy conservation in a virtual state one cannot violate e.g. angular momentum conservation or the Pauli principle), the process shown in the inset III (a) leads, through Pauli principle correcting processes (exchange of fermionic arrowed lines) to self-energy (inset III (β), (δ)) and vertex corrections (induced p-h interaction; inset III (γ), (ε)) processes. The first ones are detailed in graphs (a)-(f), while the second ones in graphs (g)-(i). In keeping with the fact that the vibrational states can be viewed as a <u>coherent states</u> exhausting a large fraction of the EWSR (e.g. a Giant Resonance) for which the associated uncertainty relations in momentum and coordinate <u>fulfill the absolute minimum consistent with quantum mechanics</u> ($\Delta\alpha_{\lambda\mu}\Delta\Pi_{\lambda\mu} = \hbar/2$, $\alpha_{\lambda\mu} = (\hbar\omega_\lambda/2C_\lambda)^{1/2}(\Gamma^{\dagger}_{\lambda\mu}+\Gamma_{\lambda\mu})$ being the (harmonic) collective coordinate, $\Pi_{\lambda\mu}$ being the conjugate momentum; cf. e.g. R. Glauber, in Proceedings of the International School of Physics E. Fermi, on Quantum Optics, Course XLII, ed. R. Glauber, Ac. Press, N.Y. (1969) p. 15), there is a strong cancellation between the contribution of self-energy and vertex correction diagrams (P.F. Bortignon and R.A. Broglia, Nucl. Phys,), implying small anharmonicities and long lifetimes ($\Gamma/E \ll 1$, where Γ is the width and E the centroid of the mode $|\lambda\mu\rangle = \Gamma^{\dagger}_{\lambda\mu}|0\rangle$, $(\hbar\omega_\lambda/2C_\lambda)^{1/2}$ being the ZPF amplitude (cf. e.g. Brink and Broglia, Nuclear Superfluidity, pp 185, 298)

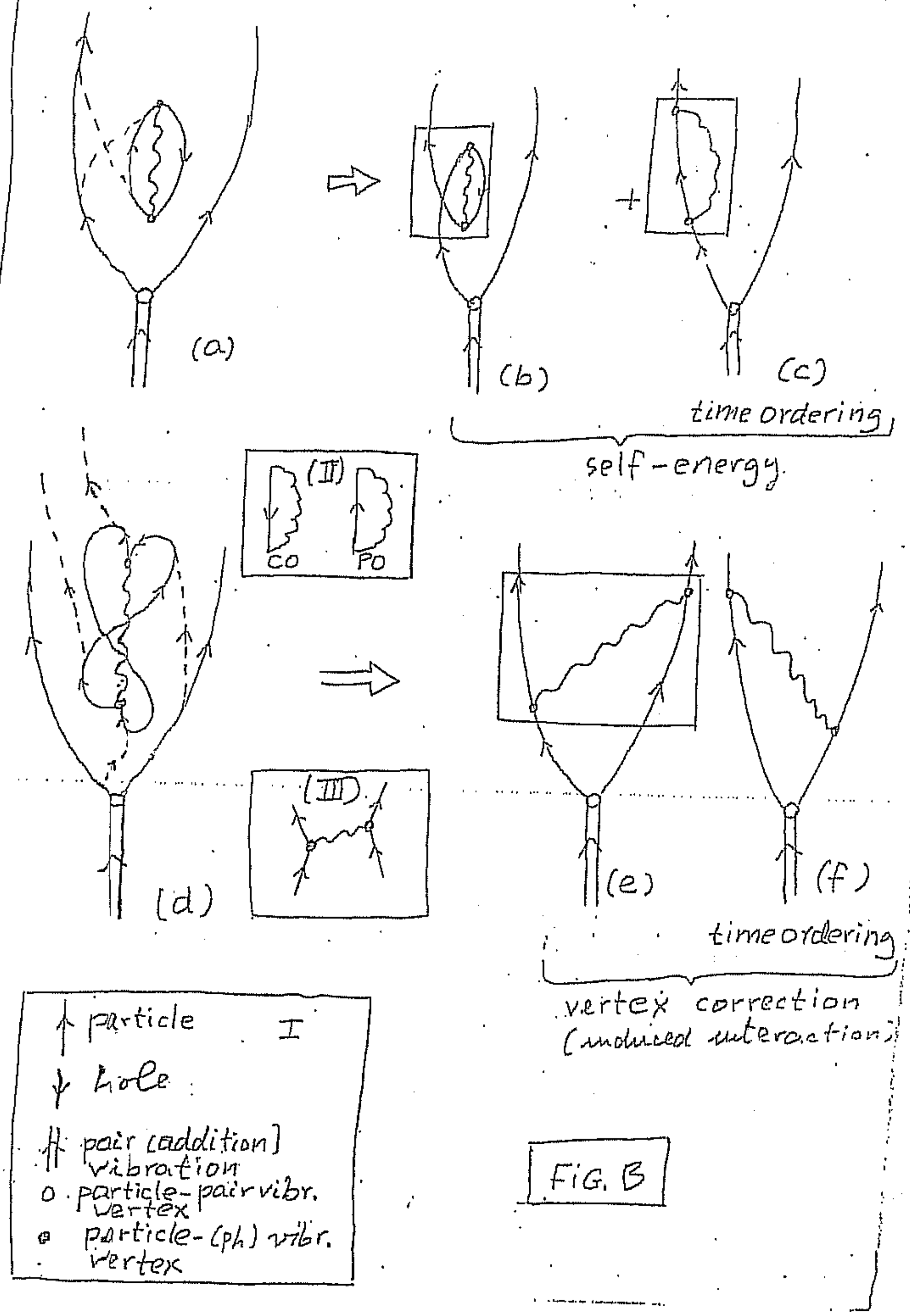
(a)
(b)
(c)
time ordering
self-energy
(II)
CO
PO
(d)
(III)
(e)
(f)
time ordering
vertex correction
(induced interaction)
particle
I
hole
pair (addition) vibration
particle-pair vibr. vertex
particle-(ph) vibr. vertex

FiG. B

Caption Fig, 13

22/04/13 (7)

Pauli effects associated (p-h) ZPF dressing pairing vibrational modes (see inset, bottom left) in terms of self-energy (graphs (a)-(c); correlation (CO) and polarization (PO) diagrams, inset II) and vertex correction (graph (d)-(f); induced particle-particle interaction, inset (III)) processes.

~~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

are assumed

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

Example of coherent state

Cf. Sect 4 and App. B Ch II HIR

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

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 $\exp\{\frac{i}{\hbar}\hat{O}\}\phi(t)$ 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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