applications
and new physics

ZPF of the vacuum (ground) state, nucleon ~~de~~ dressing and new physics.

ZPF of vacuum (ground) state and nucleon dressing

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The ground state of an even-even nucleus displays zero point fluctuations (ZPF) associated with collective vibrations (Fig. 1(a)). The bare properties of an odd nucleon moving around the core (Fig. 1(b)) get modified through Pauli principle (Fig. 1(c)), and through the associated clothing process resulting from time ordering (Fig. 1(d)).

@-@ p. 1b

Because of spatial quantization, finite nuclei display an asymmetry between occupied and empty states. As a consequence process (c) of Fig. 1 may be allowed and (d) not or viceversa. This is particular true for light nuclei, for example

¶ ^{11}Be. In the core $^{10}_{4}Be_6$, six neutrons occupy the $1s_{1/2}$ and $1p_{3/2}$ levels (Fig. 3). The dominant ZPF is of quadrupole type, the main component being associated with the $((p_{1/2}, p_{3/2}^{-1}) \otimes 2^+)_{0^+}$ ZPF (Fig. 4(a)).

Because $\varepsilon_{p_{1/2}} - \varepsilon_{p_{3/2}} \approx 3.8$ MeV and $\hbar\omega_{2^+} \approx 3.37$ MeV, the largest amplitude of the quadrupole mode is associated with the particle-hole excitation $(p_{1/2}, p_{3/2}^{-1})_{2^+}$. The repulsion due to Pauli (Fig. 4(b)) is ≈ 2.8 MeV. The clothing of the $2s_{1/2}$ bare level by the quadrupole mode (Fig 5(a)) makes it heavier, lowering its energy by almost an MeV (710 keV). The result is parity inversion (Fig. 3), and the appearance of

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@ Within the scenario of quantum electrodynamics (QED) where Feynman diagrams were developed and in keeping with the symmetry existing between electron and positron phase spaces, **N**- and **I**-like processes (Figs. 1(c) and (d)) are operative. Observation of any of the associated virtual processes clothing the electron through the action of an external field (e.g. Fig. 2(b)), carries similar information concerning the presence of vacuum fluctuations as, for example, the process (a) of Fig. 2 does. @

the N=6 closed shell.

In a similar way in which the Lamb shif (Fig. 3, inset) provides a quantitative measure of the fluctuations of the QED vacuum, parity inversion measures the ZPF of the nuclear vacuum (ground) state.

Interpreting in Fig. 2(a) the arrowed lines as electron and positron, the wavy curve as a photon and the external field (cross + dashed line) as the event horizon of a black hole one has a Feynman representation of Hawking radiation. A nuclear analogue of such radiation, to the extent that one considers only the wavy line and detector click, is provided by ~~the~~ graph 2(b), interpreting the arrowed line as a nucleon, and the external field as a nucleon pickup process (see Fig. 4, in particular process (d)) for a concrete nuclear embodiment.

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pickup process, ~~for a nuclear embodiment~~. (2)
a

A concrete example is provided by the one-neutron pickup reaction of the single halo valence nucleon of ^{11}Be, leading to the population of the low-lying quadrupole, first excited state, vibration of the core ^{10}Be (shown in Fig. 5 (see also Fig. 6 in relation with the γ-decay of the 2^+, in coincidence with the reaction process).

Light halo nuclei at the drip line provides with another paradigmatic example of parity inversion and of a nuclear analogue, again in the sense of a virtual processes becoming real through the action of an external field, of Hawking radiation: the process in question being $^1H(^{11}Li, {^9Li}(1/2^-; 2.69\ MeV))^3H$ (Fig. ~~8~~ 7),

The nucleus is ^{11}Li,

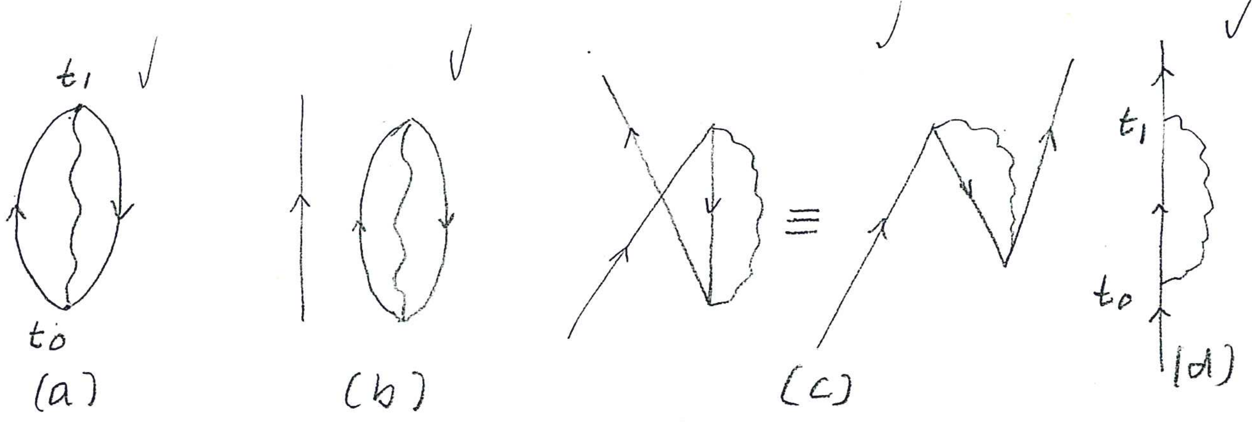


Fig. 1

(a) ZPF of the vacuum (ground) state of an even nuclear system; (b) odd system; (c) Pauli principle correction; (d) time ordering of the previous process.

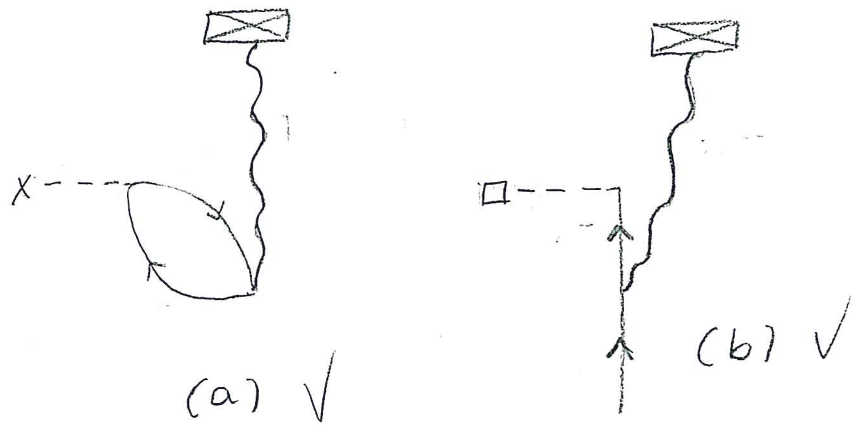
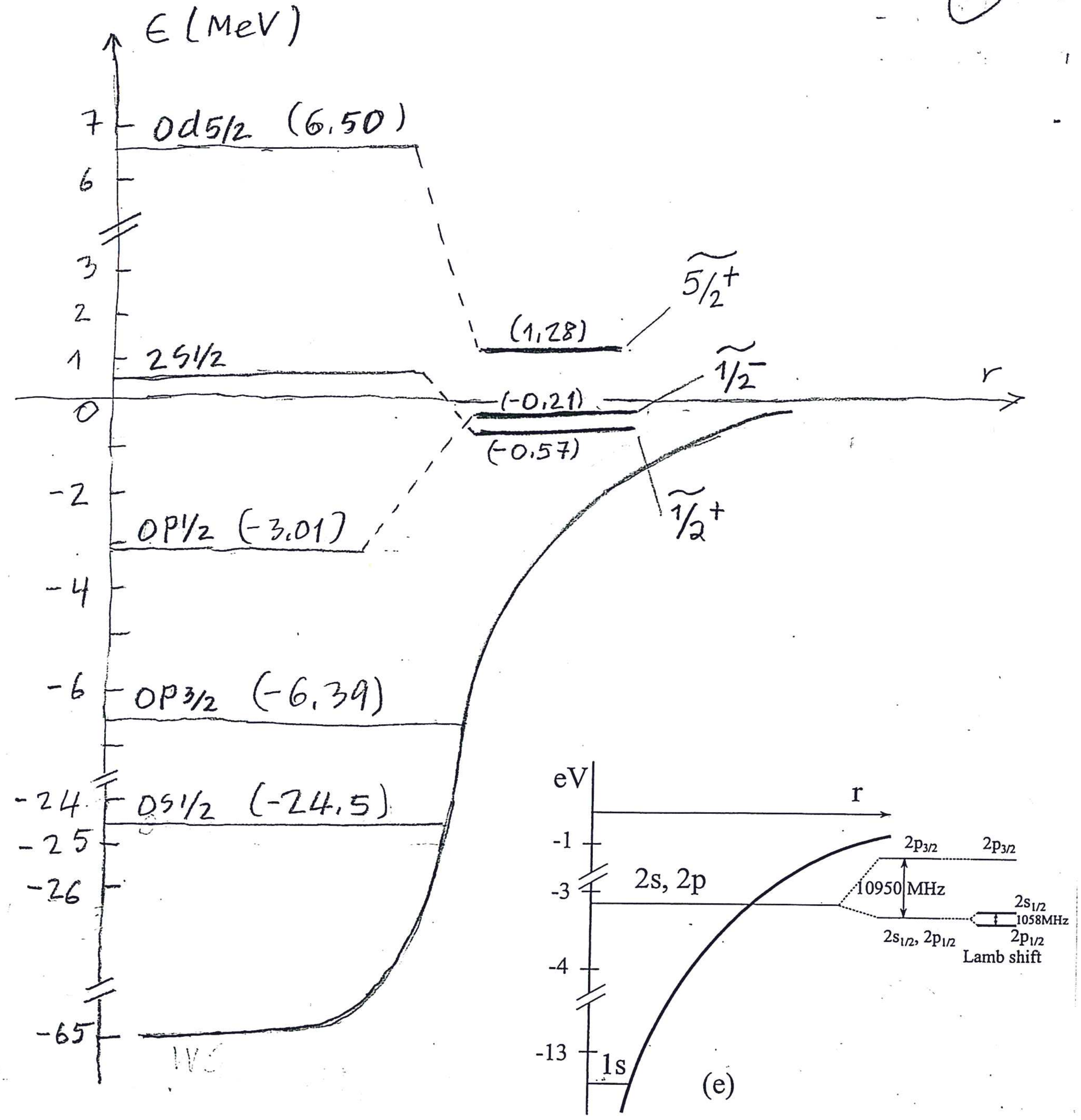


Fig. 2

Acting with an external field (cross + dashed line) on process (a) of Fig. 1 before it closes, that is at a time $t_0 < t < t_1$, one can force the virtual fluctuations of the vacuum to become real, and eventually observe a click in the detector (crossed rectangle). Similar information is obtained by intervening process (d) of Fig. 1 with the appropriate external field (empty square + dashed line).



The Woods-Saxon mean field is indicated.

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~~the~~ (bold face ~~he~~)

Fig. 3 (thin horizontal lines) and clothed

Bare single-particle levels of ^{11}Be

The number in parenthesis are ~~the~~ energies in MeV. In the lower right hand side the lowest energy levels of hydrogen are shown (Coulomb field indicated). Effect of the spin-orbit coupling, and Lamb shift associated with the splitting of the $2s_{1/2}$ and $2p_{1/2}$ level are indicated.

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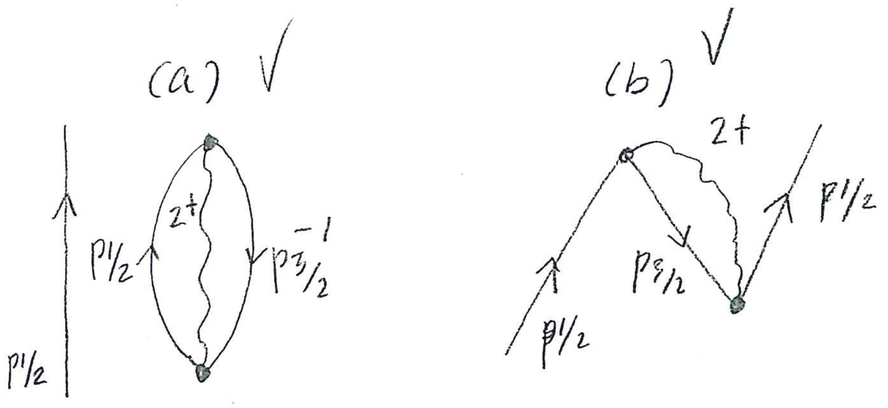
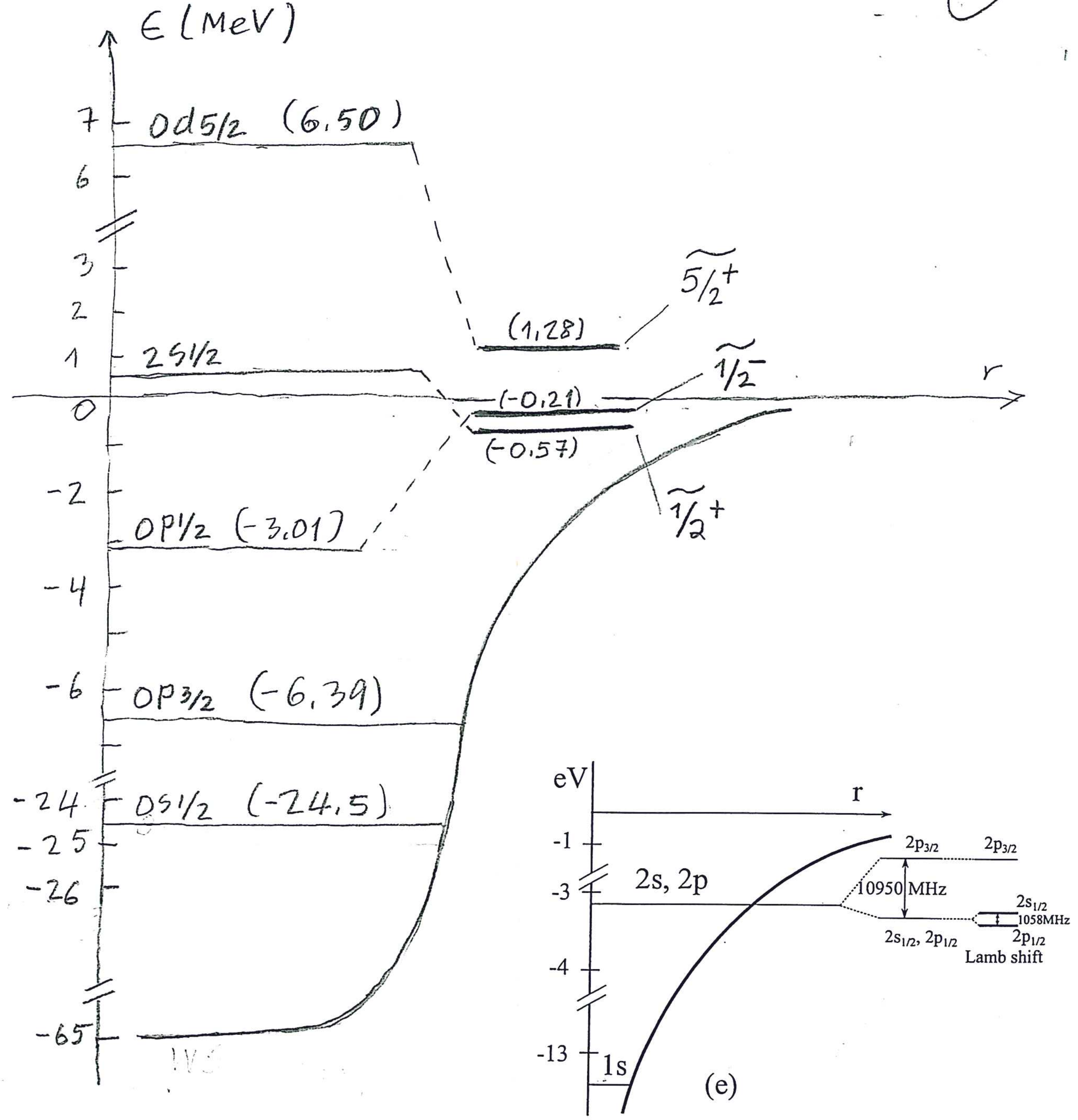


Fig. 4

Zero point fluctuation (ZPF) of ^{11}Be.
(a) The dominant component of the dominat ZPF associate with the core ^{10}Be and leading with Pauli principle violation between the odd valence partice, and those participating in the vibration; **(b)** Pauli principle correction



The woods-Saxon mean field is indicated.

Fig. 3 (thin horizontal lines) they and clothed (bold face ~~lt~~) Bare single-particle levels of ^{11}Be The number in parenthesis are ~~the~~ energies in MeV. In the lower right hand side the lowest energy levels of hydrogen (Coulomb field indicated). Effect of the spin-orbit coupling, and Lamb shift associated with the splitting of the $2s_{1/2}$ and $2p_{1/2}$ level are indicated.

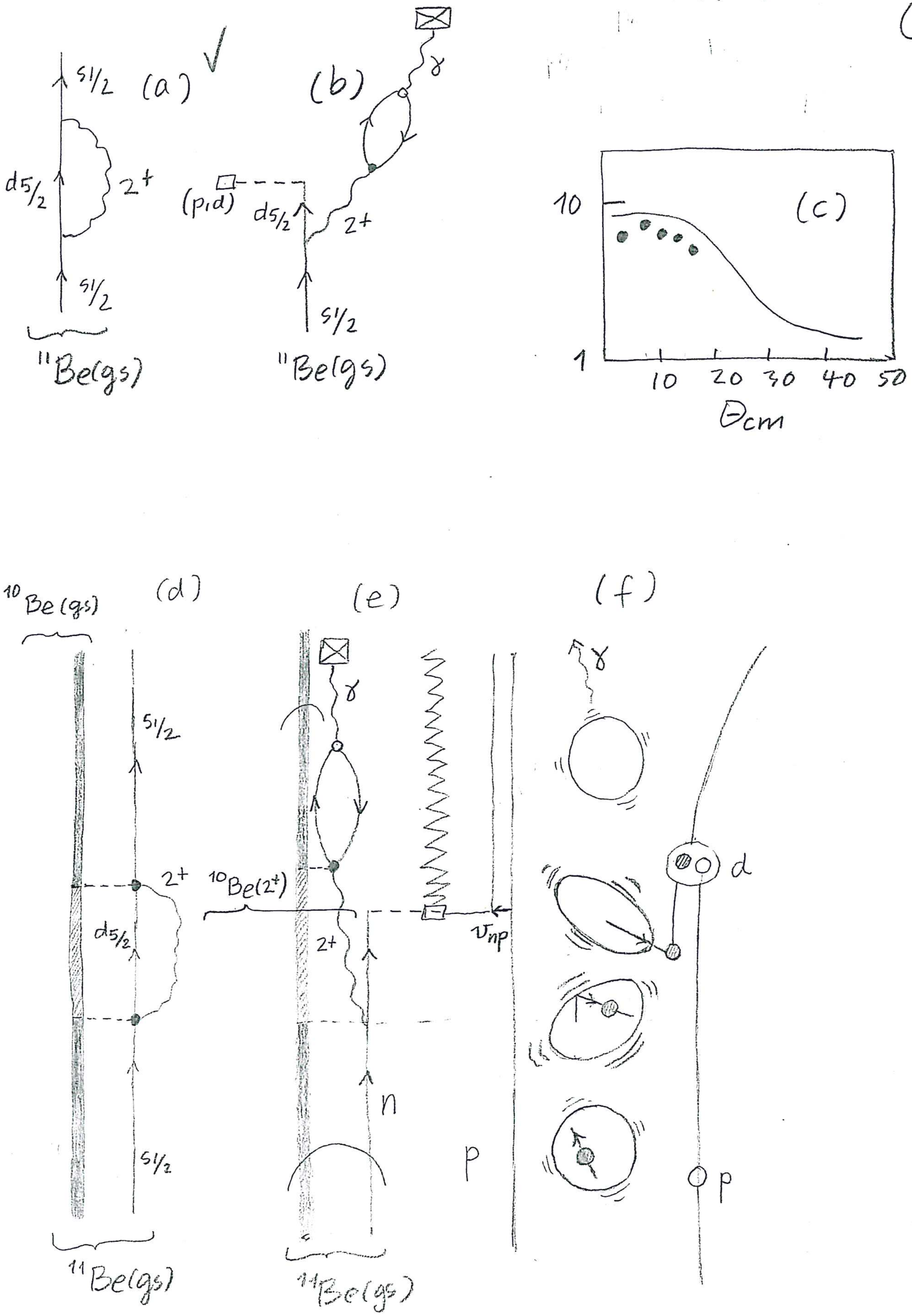

(a)
$s_{1/2}$
$d_{5/2}$
2^+
$s_{1/2}$
^{11}Be(gs)
(b)
γ
(p,d)
$d_{5/2}$
2^+
$s_{1/2}$
^{11}Be(gs)
(c)
10
1
10 20 30 40 50
θ_{cm}
^{10}Be(gs)
(d)
$s_{1/2}$
2^+
$d_{5/2}$
$s_{1/2}$
^{11}Be(gs)
(e)
γ
^{10}Be(2^+)
2^+
v_{np}
n
p
^{11}Be(gs)
(f)
γ
d
p

Fig. ~~B~~ 5

the detailed structure NFT diagram is displayed in (d);

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FIG. ~~A~~

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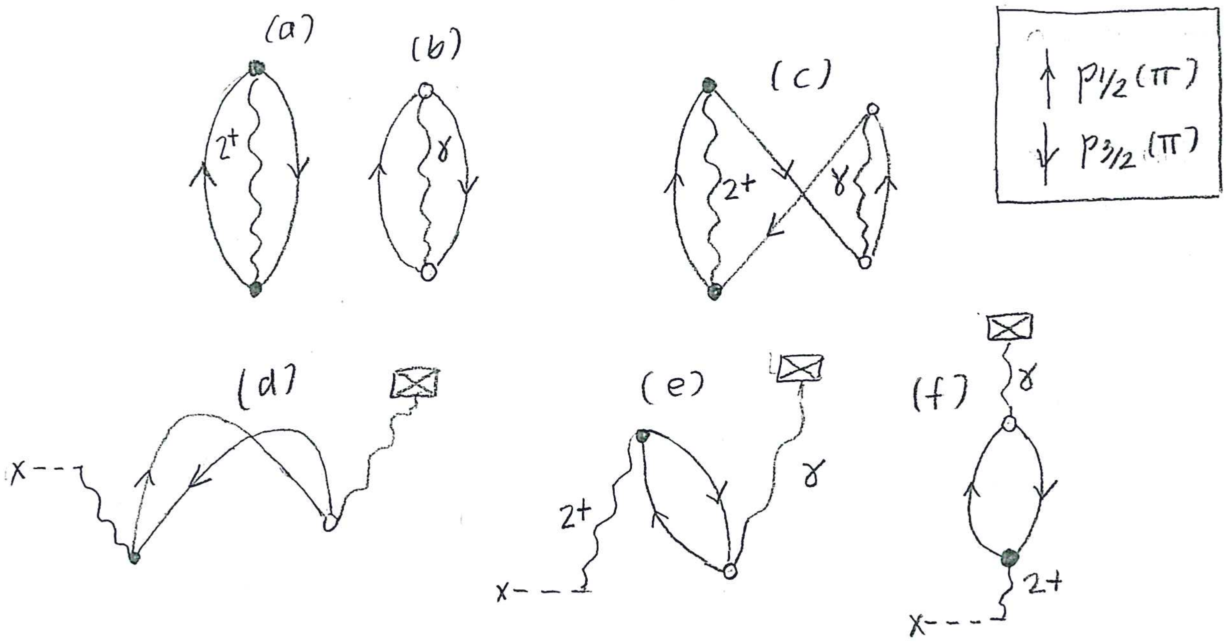
A virtual process becomes real through the action of an external field in nuclear physics. (a) Clothing process of the $1/2^+$ parity inverted ground state of $^{11}_{4}Be_7$ trough the coupling to the low-lying quadrupole vibration of the core $^{10}_{4}Be_6$; (b) schematic representation of the pickup of the neutron moving ~~moving~~ around an N=6 closed shell and populating the low-lying quadrupole vibrational state of this core, in coincidence with the corresponding γ-decay (see also Fig. A (f)); the detailed structure and reaction NFT diagram shown in (e) together with a cartoon reppresentation in (f); (c) predicted (continuous curve) and experimental (solid dots) absolute differential cross section associated with the pickup process.

(e) predicted (continuous curve

describing the pickup process in inverse kinematics, i.e. $^1H(^{11}Be, ^{10}Be(2^+, 3.368\,MeV))^2He$ is



~~4~~ 6

~~Fig A~~ ~~New~~

Fig. 6

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(11)

Fig. ~~#~~ 6

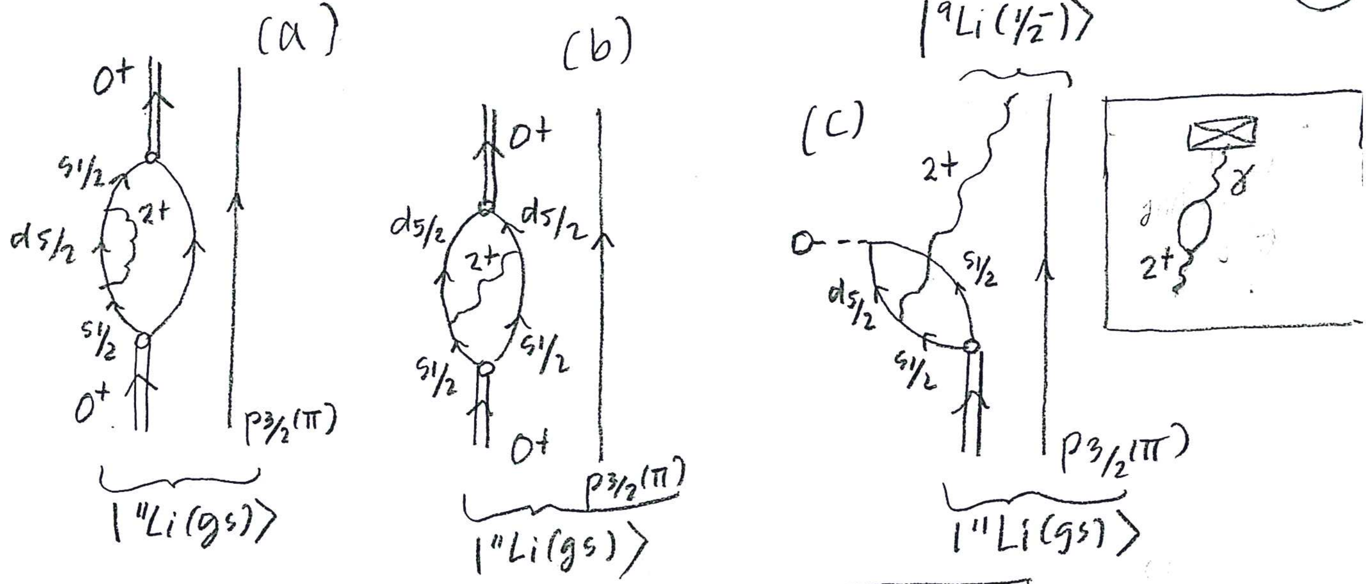
β_L: dynamical distortion parameter, $U(r)$ central potential

Interaction of protons in a nucleus with nuclear vibrations (solid dot, PVC vertex $\beta_L R_0 \partial U/\partial r \, Y_{LM}(\hat{r})$ [1]) and photons (open circle, electromagnetic interaction $e\int d^4x\, J_\mu(x) A^\mu(x)$, A^μ being the vector potential, $e J_\mu$ the current density ($\mu = 1, \ldots, 4$) [2]). While the variety of diagrams shown have general validity, we have assumed we are dealing with ~~the nucleus~~ ${}^{10}_{4}Be_6$ the low-lying correlate particle-hole quadrupole vibration ($L=2$) of ${}^{10}_{4}Be_6$ lying at 3.37 MeV, its $B(E2; 2^+ \to 0^+) =$ $e^2 fm^4$ being associated with a $\beta_2 \approx 0.9$. An upward (downward) pointing arrowed line describes a proton (proton hole) moving in the $1p_{1/2}$ ($1p_{3/2}$) orbital.

Zero point fluctuations of the nuclear ground ~~state~~ associated with: (a) the nuclear vibration, (b) the electromagnetic field associated with the corresponding spontaneous γ-decay. (c) Pauli principle correction to the simultaneous presence of the above two ZPF processes. (d) Intervening the virtual excitation of the nuclear vibration (graph (c)) with an external (inelastic) field (cross followed by a dashed line) in coincidence with the gamma-decay (γ-detector, crossed box), the virtual process (c) becomes real. (e) (f) time ordering of the above process correspond to the two RPA contributions through backwardsgoing and forwardsgoing [1] and subsequent γ-decay.

[1] A. Bohr and B.R. Mottelson, Nuclear Structue, Vol II, Benjamin, New York (1975).

[2] Holstein, B.R, Weak interactions in Nuclei, Princeton University Press, New Jersey (1989).



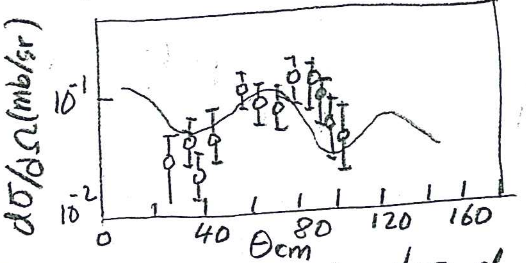


Fig. ~~5~~ 7

(a), (b); Virtual processes associated with the correlation of the two halo neutrons of $^{11}_{3}Li_{8}$ moving around the closed shell $N=6$ core $^{9}_{3}Li_{6}$. The odd $p_{3/2}$ proton (π) is assumed to act as a spectator; (c) an external two-neutro pickup field (open circle + dashed line) as provided by the inverse kinematic reaction $^{1}H(^{11}Li, ^{9}Li(1/2^-))^{3}H$ populates the lowest excited state of ^{9}Li, $1/2^-$ member of the multiplet $(p_{3/2}(\pi)\otimes 2^+)_{1/2^-}$, forcing the 2^+ vibration of the core to become real, ~~and eventually γ-decay, as shown in the inset to the right of (c) (the physics associated with the dashed circle is explained in the upper right inset of Fig. 4.~~

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core to become real, and eventually γ-decay (aspects of the physics associated with this process is ellaborated in connection with Fig. 6).