NUCLEAR COLLECTIVE MOTION: THEORETICAL CHALLENGES

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Motivation

***C**ollective motion on the border of continuum*

***H**eavy nuclei mechanisms of clustering*

***A**nharmonic collective Hamiltonian for soft nuclei*

***L**ocation of collectivity on the map of interactions*

***L**arge amplitude collective motion beyond mean field*

***E**xplanation and justification of IBM, GM, CM models*

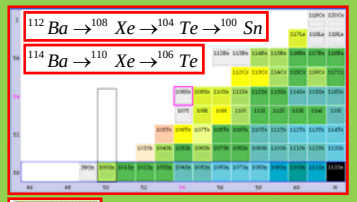
***N**uclear rotation modes at large neutron excess*

***G**eometric chaoticity, random interactions, thermalization*

***E**xistence of meson fields in nuclei and collective motion*

Collective effects

Pair and Quartic correlations



α-Clustering in light nuclei

Be isotopes, Hoyle state in ^{12}C

New Physics around $N = Z$

BEC of α-clusters: $B(E2)$ *for* $^{56}Ni^{100}Sn$

Competition with *rp*-process

$$O(E\lambda) = r^{\lambda} Y^{\lambda}_{\mu}(\hat{r})$$
$$B_{E\lambda}(i \rightarrow f) = \frac{\left|\langle J_f \| O(E\lambda) \| J_i \rangle\right|^2}{2J_i + 1}$$

2 and 4-clusters do not coexist

Quartic condensate with $N = Z$

$$|\Psi_0\rangle = \prod_{\nu} \left[u_{\nu} + \sum_{\tau=0,\pm 1} v_{\nu\tau} A^{\dagger}_{\tau}(\nu) + z_{\nu} \alpha^{\dagger}_{\nu} \right] |0\rangle$$

Neutron excess – 1st order transition to BCS state

α-decay increases around ^{100}Sn with fast α-decay branches

α-decay for $^{105}Te \rightarrow ^{101}Sn$ larger then best α-emitter ^{212}Po

Absence of Satisfactory Theory!

Pairing beyond BCS

BCS and HFB are *asymptotically* exact

Nuclear structure of adjacent nuclei?

BCS problem #1 $\hat{N} = a^{\dagger} a \neq$ *conserved*

Zero pairing strength for weak pairing?

BCS problem #2 $G < G_{cr} \rightarrow ^{48}Ca$

The Solution Route

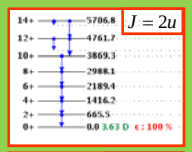
N-dependent amplitudes!

$$v_{\mu}(N) = \langle N-1, \bar{\mu} \,|\, a_{\mu} \,|\, N, 0 \rangle$$
$$u_{\mu}(N) = \langle N+1, \mu \,|\, a^{\dagger}_{\mu} \,|\, N, 0 \rangle$$

$$|v_{\mu}(N)|^2 + |u_{\mu}(N)|^2 = 1$$
$$\sum_{\mu} \left[|v_{\mu}(N)|^2 + |u_{\mu}(N)|^2 \right] = N$$

Microscopic BCS Theory is Most Wanted!

Quadrupole Modes



$J = 2u$

$^{100}_{46}Pd$

$$\hat{p} = \frac{\sqrt{m\omega\hbar}}{\sqrt{2}i}(a - a^{\dagger})$$
$$\hat{x} = \sqrt{\frac{\hbar}{2m\omega}}(a + a^{\dagger})$$

$$H = C\alpha^2 + \frac{\pi^2}{B} + \Lambda\alpha^4$$

$$E_u = C(u+5/2)(u+7/2)^{1/3}$$

$$R_u = (E_u - E_0)/(E_1 - E_0)$$

Experiment	Theory
1.00	1.00
2.13	2.09
3.29	3.26
4.49	4.50
5.81	5.81
7.16	7.17
8.58	8.58

$J = 2u$

QRPA returns harmonic normal modes

Adiabatic low-frequency limit

Vibrational frequency goes into pairing gap

Vibrational amplitude blows up

Anharmonic terms beat harmonic ones

Simplest quartic Hamiltonian $\mathscr{H}$

Large Amplitude – Angular moment terms

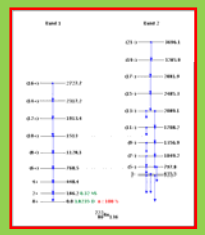
Long quasi vibrational bands, e.g., **Cd** isotopes

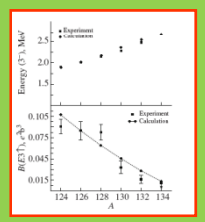
Good description by the *phenomenological* $\mathscr{H}$

Parameters used in the phenomenological $\mathscr{H}$

Correct Theoretical Description is Needed!

Interaction of Collective modes





Coexistence of low-lying quadrupole and octupole bands

The interrelation between the modes: Electric dipole gamma-transitions

$$E(3^-) = A - \frac{B}{E(2^+)}$$

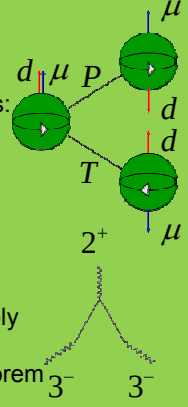
Correlation between soft modes in **Xe** isotopes

Simple interaction model considerably underestimate the correlation effect

Particle-hole symmetry – Furry Theorem

Microscopic Theory is Absent!

Symmetries



Search for nuclear P-, and T- violation

Simultaneous PT violation

Non-zero electric dipole moment

$$d[^{199}Hg] < 3.1 \times 10^{-29}\, e{\cdot}cm$$

P-violation nuclear enhancement

Mixing of compound states of opposite parity at the energy of neutron resonances

Nuclear enhancement

Combination of quadrupole and octupole deformation

Good Theory is Needed!