Dynamic Pairing Effects on Low-Frequency Modes of Excitation in Deformed Mg Isotopes close to the Neutron Drip Line

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Low-lying modes unique to neutron-rich nuclei

Quadrupole vibration of neutron skin

Effect of Deformation?  Pairing?  Continuum?

In deformed superfluid system close to the drip line

Soft $K=0^+$ mode?
QRPA calculation simultaneously taking into account Deformation, Pairing, Continuum

Deformed HFB

Box discretization

Directly solving HFB eq. in coordinate-space mesh-representation

First results of such a calculation
Investigation of deformed neutron-rich nuclei

**Ground state**

Coordinate-space HFB equation

Mean-field

\[ \nu_{\text{pair}}(\mathbf{r}, \mathbf{r}') = V_0 \left( 1 - \frac{\rho(\mathbf{r})}{\rho_0} \right) \delta(\mathbf{r} - \mathbf{r}') \]

Pair-field

\[ \nu_{\text{pair}}(\mathbf{r}, \mathbf{r}') = V_0 \left( 1 - \frac{\rho(\mathbf{r})}{\rho_0} \right) \delta(\mathbf{r} - \mathbf{r}') \]

\[ V_0 = -450 \text{ MeV fm}^3 \]

\[ E_{\text{cutoff}} = 50 \text{MeV} \]

**Excited state**

QRPA equation in the AB matrix formulation

Residual interaction

p-h channel

\[ \nu_{\text{ph}}(\mathbf{r}, \mathbf{r}') = \left[ t_0 (1 + x_0 P_\sigma) + \frac{t_3}{6} (1 + x_3 P_\sigma) \rho(\mathbf{r}) \right] \delta(\mathbf{r} - \mathbf{r}') \]

p-p channel

\[ \nu_{\text{pp}}(\mathbf{r}, \mathbf{r}') = V_0 \left( 1 - \frac{\rho(\mathbf{r})}{\rho_0} \right) \delta(\mathbf{r} - \mathbf{r}') \]
Isoscalar quadrupole transition strengths (intrinsic)

$K^\pi = 0^+$

$K^\pi = 2^+$

Neutron number increasing

Enhancement of neutron excitation
Soft $K=0^+$ mode in deformed $^{40}\text{Mg}$

\[
\left| \frac{M_n}{M_p} \right| \sqrt{\frac{N}{Z}} = \frac{6.78}{2.33} = 2.9
\]

isoscalar

$^{40}\text{Mg}$

$K^\pi=0^+$

unperturbed

1 W.u. = 8.13 fm$^4$

\[ < \lambda | \hat{Q}_{20} | 0 > = \sum_{\alpha\beta} M_{20}^{\alpha\beta} \]

\[ \hbar \omega = 2.90 \text{ MeV} \]
Two-neutron pair transition strengths

\[ \hat{T}_{\text{add}} = \int d\mathbf{r} r^2 Y_{20} \psi^+(\mathbf{r}, \uparrow) \psi^+(\mathbf{r}, \downarrow), \quad \hat{T}_{\text{rem}} = \int d\mathbf{r} r^2 Y_{20} \psi(\mathbf{r}, \downarrow) \psi(\mathbf{r}, \uparrow) \]

\[ |< \lambda | \hat{T} | 0 >|^2 \]
Pair creation/annihilation in $^{40}$Mg

\[< \lambda | \hat{T}_{\text{add}} | 0 >= \sum_{\alpha\beta} M_{\text{pair-add}}^{\alpha\beta} \]

\[< \lambda | \hat{T}_{\text{rem}} | 0 >= \sum_{\alpha\beta} M_{\text{pair-rem}}^{\alpha\beta} \]
Collective both in p-h and in p-p channel

How to generate the coherent mode?

Why are the transition strengths large? \( \sim 10-20 \text{ W.u. (intrinsic)} \)

Two key points

**Pair correlation**
Effect of dynamical pairing

**Weakly bound system**
Spatial structure of quasiparticle wave functions
Dynamical pairing

Superposition of p-h, p-p and h-h vibrations

$K^\pi = 0^+$

$K^\pi = 2^+$

Generation of the coherence

Superposition of p-h, p-p and h-h vibrations

Generation of the coherence
Spatial structure of 2qp excitations (p-h channel)

\[ <\alpha | \hat{Q}_{20} | \beta > \equiv \int d\rho dz Q_{20}^{\alpha\beta}(\rho, z) \]

\[ \hat{Q}_{20} = \sum_{\sigma} \int d\mathbf{r} r^2 Y_{20}^* \psi^+(\mathbf{r}, \sigma) \psi(\mathbf{r}, \sigma) \]

\( Q_{20}^{\alpha\beta}(\rho, z) \)

(a) [310]1/2 → [310]1/2
(b) [312]3/2 → [312]3/2
(c) [310]1/2 → [301]1/2
(d) [301]1/2 → [301]1/2
(e) [303]7/2 → [303]7/2
(f) [321]3/2 → [321]3/2
Spatial structure of 2qp excitations (p-p, h-h channel)

\[ <\alpha\beta|\hat{T}|0 > = \int d\rho dz Q_{\text{pair-add}}^{\alpha\beta}(\rho, z) \quad \hat{T} = \int drr^2 Y_{20}\psi^+(\mathbf{r}, \uparrow)\psi^+(\mathbf{r}, \downarrow) \]

\( Q_{\text{pair-add}}^{\alpha\beta}(\rho, z) \)
We have investigated properties of excitation modes in deformed Mg isotopes close to the neutron drip line.

**Deformed QRPA calculation based on coordinate-space HFB including the continuum**

We have obtained soft $K=0^+$ and $2^+$ modes in $^{36-40}\text{Mg}$. 

- **Spatial extension of two-quasiparticle wave functions**
  - Large transition strengths

- **Coupling between quadrupole vib. and pairing vib.**

- **Similar spatial structure of quasiparticle w.f. near the Fermi level**
  - Generating coherent mode

$K=0^+$ mode is particularly sensitive to the dynamical pairing.

- **Good indicator of pair correlation in deformed drip-line nuclei**