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Effect of Pairing Correlation on the Ground State and Collective Excitations of Nucleus *

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Abstract The contribution of the resonant continuum to pairing correlations is properly treated in the RMF + BCS approximation with a constant pairing strength. The results show that the contribution of the proper treatment of the resonant continuum to pairing correlations for those nuclei close to neutron drip line is important. The quasiparticle relativistic random phase approximation is applied to investigate the collective excitations of the open shell nucleus. The numerical calculations are performed in the case of various isoscalar giant resonances of nucleus ^{120}Sn. The calculated results show that the quasiparticle relativistic random phase approximation approach could satisfactorily reproduce the experimental data of the energies of low-lying states.

Key words RMF + BCS theory, single-particle resonant state, width of single-particle resonant state, quasiparticle RRPA, low-lying states

1 Introduction

Currently there is, in nuclear physics community, a strong interest in the study of exotic nuclei both experimentally and theoretically. Due to the closeness of the Fermi surface to the particle continuum in exotic nuclei, the description of exotic nuclei in both relativistic and non-relativistic microscopic methods[1—5] must explicitly take into account the effect of the continuum. A key ingredient of those models is how to properly treat the pairing correlations, which have an important influence on physical properties in exotic nuclei. In general, the pairing correlations in open shell nucleus can be treated by the BCS theory or through the Bogoliubov transformation. The main feature of the Bogoliubov transformation, compared with the simple BCS theory, is that the Hartree-Fock equation or Dirac equation and the gap equations are solved simultaneously with self-consistent fields. Both of them could give a good description of the pairing correlation if the nucleus is not too far from the β-stable line[6]. The simple BCS method may not be reliable near the drip line because the continuous states were not correctly treated[6,7]. The contribution of the coupling to the continuum would be prominent when the nucleus close to the drip line, therefore a proper treatment of the continuum becomes more important[8,9]. In this paper, we aim at the investigation of the effect of resonant continuum on the pairing correlations of neutron-rich nucleus in the relativistic mean field theory plus BCS(RMF + BCS) approximation, especially in the width effect of single particle resonant states on the pairing correlation. A constant pairing strength is employed in the BCS calculations as usually did[10]. The proper treatment of the continuum is performed by using the single particle resonant states instead of the dis-

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cretized continuum, which is expected to give a good description on the ground state properties of neutron rich nucleus, even within the BCS approximation. The single particle resonance states are calculated by imposing a proper scattering boundary condition for the continuous spectrum. To investigate the width effect of single particle resonant states on pairing correlations, we study the results in the RMF + BCS approach with and without taking account of the widths of the resonances, which are abbreviatory as RMF + BCSRW and RMF + BCSR, respectively. The results are also compared with those given by the traditional RMF + BCS approach with discretized single particle states in the continuum.

It is well known that the pairing correlations play an important role in describing the ground state properties of open shell nuclei[1—5,11]. In order to describe the giant multipole resonances of open shell nuclei the pairing correlations have to be taken into account. Recently, a number of theoretical works have been devoted to study the properties of collective excitations of open shell nuclei in the framework of the quasiparticle random phase approximation (QRPA)[12—15]. Very recently, Paar et al.[16] have formulated the quasiparticle relativistic random phase approximation (QRRPA) in the configuration space formalism. The motivation of the present work is to extent the fully self-consistent RRPA[17—20] approach to take into account the effect of pairing correlations in studying the giant multipole resonances of open shell nuclei in the response function formalism. The BCS approximation is employed in open shell nuclei in order to describe the pairing correlations in calculations of the ground state properties and collective states. The empirical pairing gaps deduced from the experimental binding energies of neighbouring nuclei are adopted in the BCS calculations. The numerical calculations are performed in the case of various isoscalar giant resonances including isoscalar giant monopole resonance (ISGMR), giant quadrupole resonance (ISGQR) and giant octupole resonance (ISGOR) of nucleus ^{120}Sn.

2 Effect of the resonant continuum on the pairing correlation

In most previous theoretical nuclear structure calculations, single particle states in the continuum are treated in a discretization procedure by expanding wave functions in a set of harmonic oscillator basis or setting a box. This approximation, however, can be justified for very narrow resonances and gives a global description of the contributions from the continuum. In this work we introduce single particle resonant states into the pairing gap functions instead of the discretized continuous states and aim to investigate the width effect of resonances on pairing correlations. The S-matrix method is used to single out the single particle resonant states[21,22]. The wave functions of resonant states are obtained by imposing a proper scattering boundary condition. At the distance R where the nuclear potentials vanish, the upper component of the neutron radial wave function has the following asymprotic behaviour:

$$G_\nu(kr) = A_\nu[j_{l_\nu}(kr) - \tan\delta_\nu n_{l_\nu}(kr)], \quad \text{for} \quad r \geqslant R, \tag{1}$$

where j_{l_ν} and n_{l_ν} are spherical Bessel and Neumann functions, respectively, and δ_ν is the corresponding phase shift. For the case of proton, the asymptotic behaviour can be obtained by replacing the spherical Bessel and Neumann functions in Eq. (1) with the relativistic regular and irregular Coulomb wave functions[23], respectively. The energy of a resonant state is determined when the phase shift of the scattering state reaches $\pi/2$. The wave function of scattering state is normalized to a delta function of energy $\delta(E - E')$

Taking account of the widths of single particle resonant states, the gap equations[24] can be expressed as:

$$\sum_a \left(j_a + \frac{1}{2}\right) \frac{1}{\sqrt{(\varepsilon_a - \lambda)^2 + \Delta^2}} + \sum_\nu \left(j_\nu + \frac{1}{2}\right) \times \int_{I_\nu} g_\nu(\varepsilon_\nu) \frac{1}{\sqrt{(\varepsilon_\nu - \lambda)^2 + \Delta^2}} \mathrm{d}\varepsilon_\nu = \frac{2}{G}, \tag{2}$$

$$\sum_a \left(j_a + \frac{1}{2}\right)\left[1 - \frac{\varepsilon_a - \lambda}{\sqrt{(\varepsilon_a - \lambda)^2 + \Delta^2}}\right] + \sum_\nu \left(j_\nu + \frac{1}{2}\right) \int_{I_\nu} g_\nu(\varepsilon_\nu) \times \left[1 - \frac{\varepsilon_\nu - \lambda}{\sqrt{(\varepsilon_\nu - \lambda)^2 + \Delta^2}}\right] \mathrm{d}\varepsilon_\nu = N, \tag{3}$$

where λ, Δ, and G represent the Fermi energy, pairing gap, and the pairing force constant, respectively. The N is the number of neutrons or protons involved in the pairing correlations. The sums a and ν run over the bound states and resonant states involved in the pairing calculation, respectively, and I_ν is an energy interval associated with each partial wave (l_ν, j_ν). The factor g_ν is defined as:

$$g_\nu(\varepsilon_\nu) = \frac{1}{\pi} \frac{\mathrm{d}\delta_\nu}{\mathrm{d}\varepsilon_\nu}, \tag{4}$$

which is the level density of the resonant state. δ_ν is the corresponding phase shift of the scattering state with angular momentum $\nu = (l_\nu, j_\nu)$

The single particle energies and wave functions are first carried out by solving the Dirac equation self-consistently. Using those single particle states we can solve the BCS gap equations. The Fermi energy and pairing gap as well as the occupation probabilities of quasi-particle states are obtained simultaneously. Therefore the nuclear densities composed of quasi-particle states and potentials can be calculated. Then we solve Dirac equation again by an iterative way until the convergence is reached.

In the framework of the RMF + BCS we investigate the ground state property of the nucleus ^{84}Ni, which is far from the β-stability line. In particular we shall focus our attention on the effect of single particle resonant states on the pairing correlation in this neutron-rich nucleus. The calculations are carried out in the RMF with the parameter set NL3[25]. Three types of calculations: RMF + BCSRW, RMF + BCSR and traditional RMF + BCS are performed. The nucleus ^{84}Ni has the proton number $Z = 28$, which is a closed shell. Therefore, the proton pairing gap is taken to be zero. For the neutron pairing, we use a state-independent pairing strength $G = C/A$, where the constant $C = 20.5$MeV[10]. In the practical calculations, we restrict the pairing space to one harmonic oscillator shell above and below the Fermi surface in the RMF + BCS model. The low-lying quasi-particle resonant states $1g_{7/2}$ and $1h_{11/2}$ in nucleus ^{84}Ni are included in the extended RMF + BCS calculations, whereas the highly excited resonant states with large widths are ignored in our calculations. In Table 1 we list the restlts of the neutron pairing gap Δ_n, the Fermi energy λ_n, nenutron rms radius r_n, the pairing correlation energy E_p, and the total binding energy E_B at the ground states of ^{84}Ni calculated with excluding and including the widths effect of resonant states in the extended RMF + BCS, and the corresponding results obtained in traditional RMF + BCS approximation are also given.

In comparison of the results in the case of including and excluding the widths of the single particle resonances, we find that the inclusion of the width largely reduces the pairing correlation. The pairing gap and the Fermi energy are obtained from $\Delta_n = 1.620$MeV to 1.339MeV and from $\lambda_n = -1.905$MeV to -1.835MeV, respectively. The pairing energy is reduced from $E_p = -10.758$MeV to -7.357MeV. On the other hand, it shows that the traditional RMF + BCS approach produces the largest pairing gap and pairing correlation energy due to the fact that some non-resonant scattering states in the continuum, such as the discrete states $3p_{3/2}$ and $3p_{1/2}$ states, which are not resonance states due to the low centrifugal barrier, are included in the traditional RMF + BCS calculation. Therefore the traditional RMF + BCS approach overestimates the pairing correlations and produce large pairing energies and pairing gaps.

Table 1. The neutron pairing gap Δ_n, the Fermi energy λ_n, neutron rms radius r_n, the pairing correlation energy E_p, and the total binding energy E_b at the ground states of ^{84}Ni calculated with excluding and including the widths effect of resonant states in the extended RMF + BCS, and traditional RMF + BCS approaches.

	RMF + BCSRW	RMF + BCSR	RMF + BCS
Δ_n/MeV	1.399	1.620	1.773
λ_n/MeV	−1.835	−1.905	−1.958
r_n/fm	4.609	4.615	4.672
E_p/MeV	−7.357	−10.758	−12.888
E_b/MeV	654.472	655.678	656.092

We plot the neutron densities for ^{84}Ni in Fig. 1. It is observed that the tail of the density distribution gets larger when the pairing correlation is considered. The width effect on the density distribution is very small, therefore it does not change the neutron rms radius listed in Table 1. In the traditional RMF + BCS approximation, the unphysical particle gas may appear when the size of the box becomes larger. The non-resonant discretized states in the continuum are included in pairing correlation calculations, such as $3p_{3/2}$ and $3p_{1/2}$ states. Their wave functions have a long tail depending on the box size adopted in the calculations. It is found that this problem

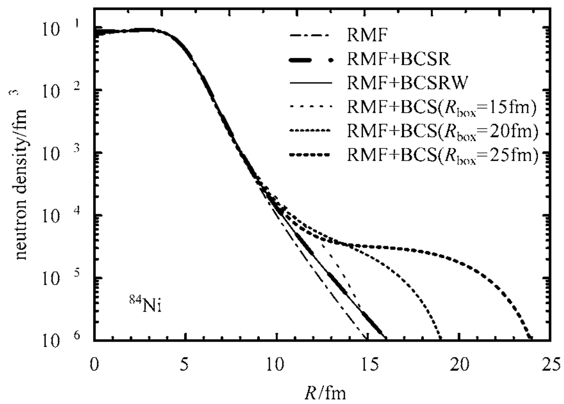

Fig. 1. Neutron density distribution for ^{84}Ni calculated in the RMF, RMF + BCS, RMF + BCSR, and RMF + BCSRW approaches, where the RMF + BCS results calculated with various values of the box size $R_{box} = 15, 20, 25$fm are also plotted.

is well overcome when one performs the calculations of the pairing correlation with a few narrow resonant states instead of those discretized states in the continuum.

3 Isoscalar giant resonances of ^{120}Sn in the QRRPA

In this part, we will investigate the isoscalar giant multipole resonances of open shell uncleus ^{120}Sn, the method we employed is the QRRPA which is an extended version of self-consistent RRPA by taking into account the effect of pairing correlations. In the RRPA calculation, early investigations[26—28] were based on Walecka's linear σ-ω models, which provides considerably larger incompressibility[29]. Therefore, one could not expect to obtain quantitative agreement with experimental data in those early calculations. Recently the meson propagators with non-linear self-interactions have been worked out numerically and the RRPA calculations with the non-linear terms were performed[30]. A fully consistent RRPA has been established in the sense that the RMF wave function of nucleus and particle-hole residual interactions in the RRPA are calculated from a same effective Lagrangian[17—20]. A consistent treatment of RRPA within the RMF approximation requires the configurations including not only the pairs formed from the occupied Fermi states and unoccupied states but also the pairs formed from the Dirac states and occupied Fermi states. It has been formally proved[19] that the fully consistent RRPA is equivalent to the time dependent RMF(TDRMF) at the small amplitude limit[31]. The ISGMR, ISGQR and IVGDR for some stable nuclei, such as ^{208}Pb, ^{144}Sm, ^{114}Sn, ^{90}Zr were performed with different effective Lagrangian parameter sets and a good agreement with experimental data is obtained[20].

The response function of a quantum system to an external field is given by the imaginary part of the polarization operator:

$$R(Q,Q;\boldsymbol{k},\boldsymbol{k}';E)=\frac{1}{\pi}\mathrm{Im}\Pi^{\mathrm{R}}(Q,Q;\boldsymbol{k},\boldsymbol{k}';E), \quad (5)$$

where Q is an external field operator. The RRPA polarization operator is obtained by solving the Bethe-Salpeter equation:

$$\begin{aligned}\Pi(Q,Q;\boldsymbol{k};\boldsymbol{k}';E) &= \\ \Pi_0(Q,Q;\boldsymbol{k},\boldsymbol{k}';E) &- \sum_i g_i^2\int \mathrm{d}^3k_1\mathrm{d}^3k_2\Pi_0 \times \\ &[(Q,\Gamma^i;\boldsymbol{k},\boldsymbol{k}_1,E)D_i(\boldsymbol{k}_1,\boldsymbol{k}_2,E)\times \\ &\Pi(\Gamma_i,Q;\boldsymbol{k}_2,\boldsymbol{k}',E)], \end{aligned} \quad (6)$$

In the relativistic approach, the residual particle-hole interactions are generated by exchanging various mesons. Therefore, in Eq.(6) the sum i runs over σ, ω and ρ mesons with g_i and D_i being the corresponding coupling constants and meson propagators, $\Gamma_i=1$ for σ meson and $\Gamma_i=\gamma^{\mu}$, $\gamma^{\mu}\tau_3$ for ω and ρ mesons, respectively, The meson propagators for non-linear models are non-local in momentum space, and therefore have to be calculated numerically. The detailed expressions for $D_i(\boldsymbol{k}_1,\boldsymbol{k}_2,E)$ can be found in Ref.[30]. Π_0 is the unperturbed polarization operator. The standard expression for unperturbed polarization operator can be obtained in Refs.[17,18].

The pairing correlations are treated in the Bardeen-Cooper-Schrieffer(BCS) approximation in this work. When the pairing correlations are taken into account, the elementary excitation is a two-quasiparticle excitation, rather than a particle-hole excitation. The unperturbed polarization operator in the QRRPA in the response function formalism can be constructed in a similar way to the RRPA[18]:

$$\begin{aligned}\Pi_0^{\mathrm{R}}(P,Q;k,k';E) &= \frac{(4\pi)^2}{2L+1}\Bigg\{\sum_{\alpha,\beta}(-1)^{j_\alpha+j_\beta}A_{\alpha\beta}\times \\ &\Bigg[\frac{\langle\bar{\phi}_\alpha\|P_{\mathrm{L}}\|\phi_\beta\rangle\langle\bar{\phi}_\beta\|Q_{\mathrm{L}}\|\phi_\alpha\rangle}{E-(E_\alpha+E_\beta)+\mathrm{i}\eta} - \\ &\frac{\langle\bar{\phi}_\beta\|P_{\mathrm{L}}\|\phi_\alpha\rangle\langle\bar{\phi}_\alpha\|Q_{\mathrm{L}}\|\phi_\beta\rangle}{E+(E_\alpha+E_\beta)+\mathrm{i}\eta}\Bigg] + \\ &\sum_{\alpha,\beta}(-1)^{j_\alpha+j_\beta}\nu_\alpha^2\Bigg[\frac{\langle\bar{\phi}_\alpha\|P_{\mathrm{L}}\|\phi_{\bar{\beta}}\rangle\langle\bar{\phi}_{\bar{\beta}}\|Q_{\mathrm{L}}\|\phi_\alpha\rangle}{E-(E_\alpha+\lambda-\varepsilon_{\bar{\beta}})+\mathrm{i}\eta} - \\ &\frac{\langle\bar{\phi}_{\bar{\beta}}\|P_{\mathrm{L}}\|\phi_\alpha\rangle\langle\bar{\phi}_\alpha\|Q_{\mathrm{L}}\|\phi_{\bar{\beta}}\rangle}{E+(E_\alpha+\lambda-\varepsilon_{\bar{\beta}})+\mathrm{i}\eta}\Bigg]\Bigg\}, \end{aligned} \quad (7)$$

with

$$A_{\alpha\beta}=(u_\alpha\nu_\beta+(-1)^{\mathrm{L}}\nu_\alpha u_\beta)^2(1+\delta_{\alpha\beta})^{-1}, \quad (8)$$

where ν_α^2 is the BCS occupation probability and $u_\alpha^2=1-\nu_\alpha^2$. $E_\alpha=\sqrt{(\varepsilon_\alpha-\lambda_n)^2+\Delta_n^2}$ is the quasiparticle energy, where λ_n and Δ_n are the neutron Fermi energy and pairing correlations gap, respectively. In Eq.(7), the first term represents the excitations with one quasiparticle in positive energy fully or partial occupied states and one quasiparticle in the partial occupied or unoccupied states. The last term describes the excitations between positive energy fully or partial occupied states and negative energy states in Dirac sea. For unoccupied positive energy states outside the pairing active space, their energies are $E_\beta=\varepsilon_\beta-\lambda_n$, occupation probabilities $\nu_\beta^2=0$ and $u_\beta^2=1$. For fully occupied positive energy states, the quasiparticle energies and occupation probabilities are set as $E_a=\lambda_n-\varepsilon_\alpha$ and $\nu_\alpha^2=1$ in Eq.(7), respectively. The states in Dirac sea are not involved in the pairing correlations, therefore the quantities ν_β^2 and u_β^2 are set to be 0 and 1, respectively.

In this study we apply the QRRPA to nucleus ^{120}Sn which is a typical open shell nucleus and is known to be of spherical shape[32]. The ground state properties of the nucleus ^{120}Sn are calculated in the RMF + BCS with the parameter set NL3. The proton pairing gap is set to be zero due to the magic number $Z=50$. A constant neutron pairing gap is adopted in the calculation of neutron pairing correlations. which is obtained from the experimental binding energies of neighbouring nuclei by the formulae:

$$\Delta_n=\frac{1}{8}[B(Z,N-2)-4B(Z,N-1)+6B(Z,N)-4B(Z,N+1)+B(Z,N+2)], \quad (9)$$

In our calculations, the neutron pairing active space in the nucleus ^{120}Sn includes states up to the $N=82$ major shell and the states of $1g_{7/2}, 2d_{5/2}, 2d_{3/2}, 3s_{1/2}$, and $1h_{11/2}$. The neutron pairing gap Δ_n is 1.392MeV given by Eq.(9). The calculated neutron Fermi energy λ_n is -7.842MeV. The calculated binding energy of the nucleus ^{120}Sn is 1022.584MeV. Compared to the experimental binding energy 1020.544 MeV[33], the values predicted by the theoretical approach and by the experimental result are in good agreement. Neutron single particle energies and BCS occupation probabilities for those states close to neutron Fermi energy are shown in Table 2.

Table 2. Neutron single-particle energy ε_α and occupation probabilities v_α^2 of levels close to the neutron Fermi energy in ^{120}Sn.

level	ε_α/MeV	ν_α^2
$1g_{7/2}$	−11.423	0.966
$2d_{5/2}$	−10.063	0.923
$2d_{3/2}$	−8.279	0.649
$3s_{1/2}$	−7.926	0.530
$1h_{11/2}$	−7.062	0.256

We now study the isoscalar giant multipole resonances of ^{120}Sn by the QRRPA approach, and the effect of pairing correlations on the giant multipole resonance is also discussed. The isoscalar operator is $Q=\gamma^0 r^L Y_{L0}$, except $Q=\gamma^0 r^2 Y_{20}$ for the ISGMR mode. In the QRRPA the quasiparticle-hole residual interactions are taken from the same effective interaction NL3 which is used in the description of the ground states of ^{120}Sn. The occupied states and states in the pairing active space are calculated self-consistently in the RMF + BCS approach in the coordinate space. The unoccupied states outside the pairing active space are obtained by solving the Dirac equation in the expansion on a set of harmonic oscillation bases. The response functions of the nuclear system to the external operator are calculated at the limit of zero momentum transfer. It is also necessary to include the space-like parts of vector mesons in the QRRPA calculations, although they do not play any role in the ground state[1]. The consistent treatment guarantees the conservation of the vector current.

In Fig.2 we show, as an example, the response functions for the ISGQR modes of ^{120}Sn calculated by the RRPA and QRRPA approaches to illustrate the importance of including the effect of pairing correlations in the calculations of multipole collective excitations for open shell nuclei. It can be seen that the inclusion of pairing correlations has a strong effect on the low-lying states, while the effect on higher energy region is weak. A similar result has been obtained by Hagino in the framework of HF + BCS + QRPA[15].

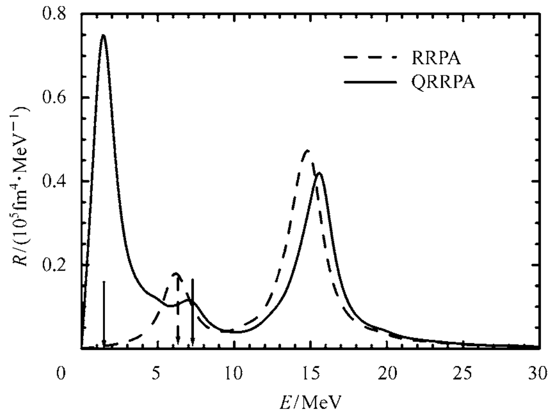

Fig. 2. Response function for the isoscalar giant quadrupole resonance(ISGQR) mode calculated by the RRPA (dashed line) and the QRRPA (solid line), respectively. The arrows indicate the position of low-lying 2^+ states obtained by the(Q)RRPA approach.

In Table 3 we list the low-lying 0^+, 2^+ and 3^- states calculated by the RRPA and QRRPA approaches, respectively. The third line in Table 3 is the corresponding experimental data taken from Refs.[15,34]. It can be seen that the RRPA approach can not produce the low-lying 0^+ state, while the inclusion of pairing correlations can reproduce the experimental data of the low-lying 0^+ state reasonably. The low-lying 2^+ state is located at 6.11MeV given by the RRPA approach, which is much larger than the corresponding experimental data of 1.17MeV, the low-lying 2^+ state obtained in the QRRPA approach is located at 1.39MeV which is in a good agreement with the experimental data. For the ISGOR mode listed in Table 3, the experimental value of the low-lying 3^- state is at 2.40MeV, while the RRPA and QRRPA give 1.06 MeV and 2.94 MeV, respectively. It is shown that the RRPA without pairing correlations underestimates the low-lying 3^- state and the QRRPA is more satisfactory compared with the experimental result.

Table 3. The low-lying 0^+, 2^+ and 3^- state in ^{120}Sn calculated by the RRPA and QRRPA approaches, respectively. The third line represents the corresponding experimental results[15,34].

	E_{0^+}/MeV	E_{2^+}/MeV	E_{3^-}/MeV
RRPA		6.11	1.06
QRRPA	2.55	1.39	2.94
Expt.	1.87	1.17	2.40

4 A brief summary

In a summary, we have investigated the pairing correlation for neutron-rich nucleus in the RMF + BCS approximation with a constant pairing strength. A proper treatment of the resonant state in the continuum on pairing correlations has to include not only its energy, but also its width. The resonant continuum is solved by imposing a proper scattering boundary condition. By introducing a level density in the continuum into the pairing gap equations, we include the effect of width of the resonant state in the pairing correlation calculations. The investigation is performed in three approaches: RMF + BCSRW, RMF + BCSR and traditional RMF + BCS with effective Lagrangian parameter set NL3. The results show that the contribution of the resonant continuum treated properly to pairing correlations is important for nucleus far from the β-stability line. It is found that the width effect on the pairing is to reduce the pairing correlations. The unphysical particle gas appeared in the traditional mean field plus BCS calculation in the vicinity of drip line can be well overcome when one performs the pairing correlation calculations using several resonant states instead of the discretized states in the continuum.

We have formulated the quasiparticle relativistic random phase approximation (QRRPA) model in the response function formalism. The pairing correlations are taken into account in the BCS approximation with a constant pairing gap extracted from the experimental binding energies of neighbouring nuclei. We apply the QRRPA to calculate giant multipole resonances of the nucleus ^{120}Sn in the case of various isoscalar modes including ISGMR, ISGQR and ISGOR. It is shown that the inclusion of pairing correlations has a strong effect on the calculation of multipole collective excitations of open shell nuclei. We found that the QRRPA approach could satisfactorily reproduce the experimental data of the energies of low-lying states, while the giant resonance is not much affected by taking into account the effect of pairing correlations.

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对关联对核基态和集体激发态性质的影响*

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摘要 基于相对论平均场和 BCS 理论,研究了共振连续对奇特核对关联性质的影响.利用 S 矩阵方法,通过设定合理的散射态边界条件来得到单粒子共振态的能量和宽度.通过引入连续态能级密度的方法来处理共振态宽度对核对关联的贡献.计算结果显示合理地处理共振态对对关联性质的贡献在研究滴线附近核性质时很重要.它可以影响中子的对隙、费米能级、对关联能以及总结合能.其次,基于 RMF + BCS 基态,采用线性响应理论给出了描述开壳核集体激发态性质的准粒子相对论无规位相近似理论.并且将该方法应用于开壳核 ^{120}Sn的各种同位旋标量集体激发态性质的研究中.研究表明:对关联对核的集体激发性质的影响主要表现在低能集体激发态上,考虑对关联后的相对论无规位相近似理论能够很好地再现低能集体激发的实验结果.

关键词 RMF + BCS 理论 单粒子共振态 共振宽度 准粒子 RRPA 低能集体激发态

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