Eur. Phys. J. A **25**, s01, 573–574 (2005)
DOI: 10.1140/epjad/i2005-06-095-y

EPJ A direct
electronic only

Pairing effects on the collectivity of quadrupole states around ^{32}Mg

M. Yamagami[1,a] and Nguyen Van Giai[2]

[1] Heavy Ion Nuclear Physics Laboratory, RIKEN, Hirosawa 2-1, Wako, Saitama 351-0198, Japan
[2] Institut de Physique Nucléaire, IN2P3-CNRS, 91406 Orsay Cedex, France

Received: 10 December 2004 / Revised version: 11 January 2005 /
Published online: 11 May 2005 – © Società Italiana di Fisica / Springer-Verlag 2005

Abstract. The anomalous $E2$ properties of the first 2^+ states in neutron-rich nuclei ^{32}Mg and ^{30}Ne are studied by the Hartree-Fock-Bogoliubov (HFB) plus quasiparticle random phase approximation (QRPA) calculations. The large $B(E2)$ values and the low excitation energies of the first 2^+ states are well described by the HFB plus QRPA calculations with spherical symmetry. We conclude that pairing effects account largely for the anomalously large quadrupole collectivity.

PACS. 21.10.Ky Electromagnetic moments – 21.10.Re Collective levels – 21.60.Ev Collective models – 21.60.Jz Hartree-Fock and random-phase approximations

1 Introduction

The breaking of the $N = 20$ shell closure is clearly shown in the observed anomalous $E2$ properties; the large $B(E2)$ value [1] and the low excitation energy, of the first 2^+ state in ^{32}Mg. Several theoretical studies have shown the importance of the neutron $2p$-$2h$ configurations across the $N = 20$ shell gap to describe the anomalous $E2$ properties (*e.g.*, [2]). Although the appearance of the $2p$-$2h$ configurations imply deformation of the ground state, the microscopic origin is still under great debate. The observed energy ratios $E(4_1^+)/E(2_1^+)$ is 2.6 in ^{32}Mg [3,4], and this value is in between the rigid rotor limit 3.3 and the vibrational limit 2.0. The $B(E2)$ value (in single-particle units) is 15.0 ± 2.5 in ^{32}Mg, and this value is smaller than that in "deformed" Mg isotopes (21.0 ± 5.8 in ^{24}Mg, 19.2 ± 3.8 in ^{34}Mg [5]). Moreover, the calculated ground state in ^{32}Mg have been found to be spherical in mean-field calculations (*e.g.*, [6]). In general, the neutron $2p$-$2h$ configurations can originate not only from deformation but also from neutron pairing correlations. In ^{32}Mg these two effects may coexist and help to make the anomalous $E2$ properties. In the previous studies it is not clear which effect is more essential to describe the anomalous properties.

2 Ground-state properties in N = 20 isotones

HFB calculations with Skyrme SkM* force are performed for $N = 20$ isotones from ^{30}Ne to ^{40}Ca [7]. The density-

[a] Conference presenter; e-mail: `yamagami@riken.jp`

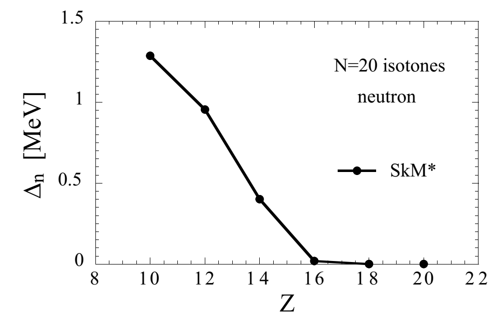

Fig. 1. The neutron pairing gaps in $N = 20$ isotones by HFB calculations with Skyrme SkM* force.

dependent pairing interaction,

$$V_{\rm pair}(\boldsymbol{r}, \boldsymbol{r}') = \frac{1}{2} V_{\rm pair}(1 - P_\sigma)[1 - \rho(\boldsymbol{r})/\rho_c]\delta(\boldsymbol{r} - \boldsymbol{r}'), \quad (1)$$

is used for the pairing field. The parameters $V_{\rm pair} = -418\,{\rm MeV} \cdot {\rm fm}^{-3}$ and $\rho_c = 0.16\ {\rm fm}^{-3}$ with the quasiparticle cut-off energy $E_{\rm cut} = 50$ MeV reproduce the experimental neutron pairing gap in ^{30}Ne. As shown in fig. 1 the calculated neutron pairing gaps change from 1.26 MeV in ^{30}Ne to almost zero in ^{36}S, although the size of the $N = 20$ shell gaps changes slowly as approaching ^{30}Ne (fig. 2). The mechanism can be understood by the change of the level density in the fp shell. As close to ^{30}Ne, the single-particle energy (SPE) of the high-l orbit $1f_{7/2}$ change almost linearly while the changes of $2p_{3/2}$ and $2p_{1/2}$ SPEs become very slow. Moreover, the spin-orbit splitting between $2p_{3/2}$ and $2p_{1/2}$ states becomes smaller. Consequently the level density in the fp shell becomes higher in ^{32}Mg and ^{30}Ne.

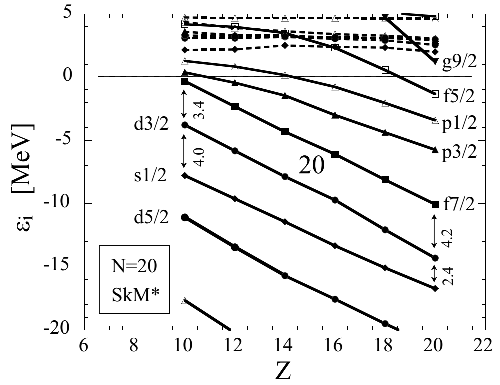

Fig. 2. Neutron single-particle energies in $N = 20$ isotones by HF calculations with Skyrme SkM* force. Single-particle energies of bound and resonant states are connected by solid lines. The energies of (discretized) non-resonant continuum states are also shown by dashed lines.

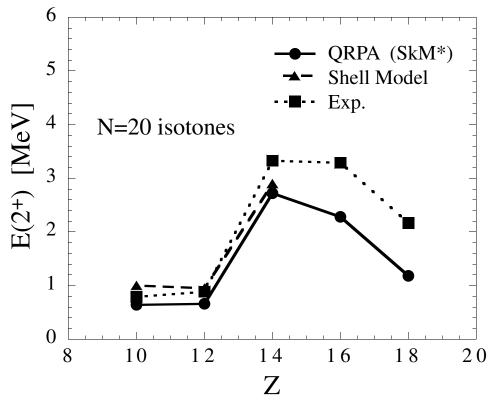

Fig. 4. The excitation energies of the first 2^+ states in $N = 20$ isotones by HFB plus QRPA calculations with Skyrme SkM* force. For comparison the available experimental data [1,9] and the results of shell model calculations [2] are also shown.

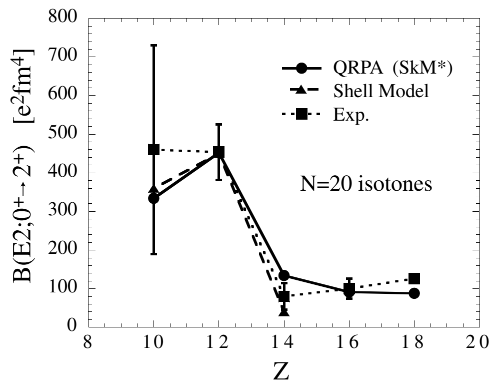

Fig. 3. The $B(E2, 0_1^+ \to 2_1^+)$ transition probabilities of the first 2^+ states in $N = 20$ isotones by HFB plus QRPA calculations with Skyrme SkM* force. For comparison the available experimental data [1,9] and the results of shell model calculations [2] are also shown.

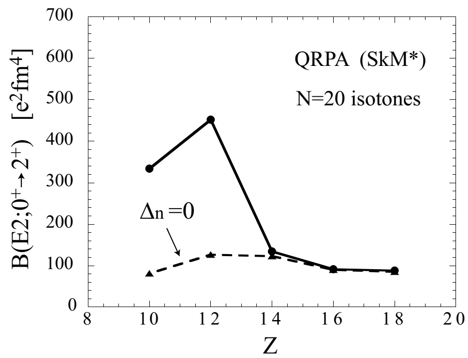

Fig. 5. The $B(E2, 0_1^+ \to 2_1^+)$ values of the first 2^+ states in $N = 20$ isotones with/without neutron pairing. Proton pairing is included in both calculations.

Within HFB calculations with spherical symmetry, the $N = 20$ shell gap is naturally broken by neutron pairing correlations.

3 Anomalous E2 properties in N = 20 isotones

We have performed HFB plus QRPA calculations for the first 2^+ states in $N = 20$ isotones [7]. The QRPA equations are solved in coordinate space by using the Green's function method [7,8]. To emphasize the role of neutron pairing correlations, spherical symmetry is imposed. The residual interaction is consistently derived from the hamiltonian density of Skyrme force that has an explicit velocity dependence. To reduce the numerical task, the spin-spin parts, the Coulomb parts, and the spin-orbit parts in the resiual interactions are dropped. We impose an approximate self-consistent condition on the residual interaction with a renormalization factor f_R, $V_\mathrm{res} \to f_\mathrm{R} V_\mathrm{res}$, so as to have the spurious $J^\pi = 1^-$ state at zero energy. The typical value is $f_\mathrm{R} \approx 0.93$ in this study. A detailed account of our QRPA calculation can be found in ref. [7]. In figs. 3 and 4 our QRPA results are compared with the available experimental data [1,9] and the results of shell model calculations [2]. The QRPA calculations have been done with SkM* and the fixed pairing strength. The general properties of the first 2^+ states in $N = 20$ isotones, especially large quadrupole collectivity in ^{32}Mg and ^{30}Ne, are well reproduced. In fig. 5 the $B(E2)$ values with/without neutron pairing are shown. Proton pairing is included in both calculations. Without neutron pairing, we cannot explain the anomalous $E2$ properties. Under these considerations, we can conclude that the neutron pairing correlations account largely for the anomalous $E2$ properties in ^{32}Mg and ^{30}Ne.

References

1. T. Motobayashi *et al.*, Phys. Lett. B **346**, 9 (1995).
2. Y. Utsuno, T. Otsuka, T. Mizusaki, M. Honma, Phys. Rev. C **60**, 054315 (1999).
3. K. Yoneda *et al.*, Phys. Lett. B **499**, 233 (2001).
4. D. Guillemaud-Mueller, Eur. Phys. J. A **13**, 63 (2002).
5. H. Iwasaki *et al.*. Phys. Lett. B **522**, 227 (2001).
6. P. -G. Reinhard *et al.*, Phys. Rev. C **60**, 014316 (1999).
7. M. Yamagami, Nguyen Van Giai, Phys. Rev. C **69**, 034301 (2004).
8. E. Khan *et al.*, Phys. Rev. C **66**, 024309 (2002).
9. Y. Yanagisawa *et al.*, Phys. Lett. B **566**, 84 (2003).