# Structure of $^{31}$Na studied by the Monte-Carlo shell model[†]

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Since anomalous properties of $^{31}$Na concerning the mass[1)] and the ground-state spin and magnetic moment[2)] were observed in the 1970's, the structure of neutron-rich nuclei around $N = 20$ has attracted much interest, particularly concerning vanishing of the $N = 20$ magic number. Based on the Monte-Carlo shell model (MCSM),[3)] we performed a systematic shell-model calculation for even-even $N \sim 20$ exotic nuclei with full mixing between the normal, intruder, and higher intruder configurations for the first time,[4)] and gave a comprehensive picture of the region. As for odd-$A$ nuclei, since we should adopt the $J$-compressed bases,[3)] which require much computational time in the MCSM calculation, such a calculation was unfeasible until the Alphleet computer system[5)] was introduced at RIKEN. In this report, the structure of a neutron-rich odd-$A$ nucleus $^{31}$Na, which is expected to be in the "island of inversion",[6)] is studied by the MCSM with the Alphleet computer system.

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$$Y = a + b + c + d + e + f + g \tag{1}$$

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$$Y = \sum_{i=\infty} a_i + h + i + j + k + l + m \tag{2}$$

The energy levels of $^{31}$Na are shown in Fig. 1. The ground-state spin $3/2^+$ agrees with an experiment, in contrast to the $sd$-shell model prediction of $5/2^+$. The calculated magnetic moment of the ground state is $2.17\,\mu_N$ with free-nucleon $g$ factors being consistent with the experimental value of $2.283\ (38)\,\mu_N$.[2)] The present study shows that, while the ground state is dominated by the 2-particle 2-hole ($2p2h$) excitations from the $N = 20$ core, $4p4h$ and higher excited configurations are mixed and lower the ground-state energy by more than 700 keV. This energy gain gives rise to a better two-neutron separation energy. The first excited state obtained by the MCSM calculation is a $5/2^+$ state located at 310 keV, in good agreement with a recent measurement of $350 \pm 20$ keV.[7)] On the other hand, this level was calculated to lie around 200 keV in the $0p0h + 2p2h$ truncation. A comparison between the truncated and full calculations clearly indicates the importance of the higher intruder configurations (*i.e.*, $4p4h$ and higher excited configurations from $N = 20$ core):[a)] these configurations lower the ground state more than the first excited state, giving rise to a better agreement with experiment. The higher intruder

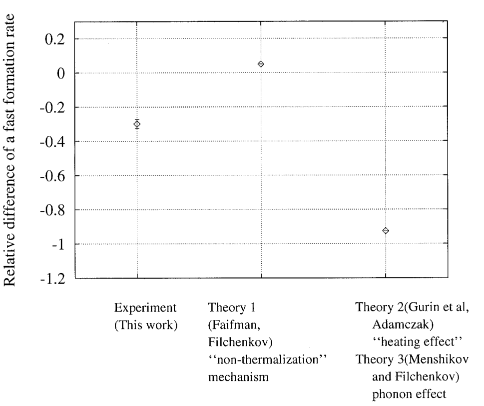


Fig. 1. Experimental energy levels of $^{31}$Na (Exp.) compared with those of the MCSM calculation (MCSM).

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a) aaaaaaaaaaaaaa

Table 1. aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaaaaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa aaa

| AAA | BBB | CCC | DDD | EEE | FFF | GGG | HHH | III | JJJ | KKK | LLL | MMM | NNN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a | b | c | d | e | f | g | h | i | j | k | l | m | n |

configurations occupy the ground state by about 10%. The $B\ (E2; 3/2^+ \rightarrow 5/2^+) = 200\ \mathrm{e}^2\mathrm{fm}^4$ is obtained with the effective charges $e_p = 1.3\,\mathrm{e}$ and $e_n = 0.5\,\mathrm{e}$, suggesting a strong deformation similarly to the adjacent even-$A$ nucleus, $^{32}$Mg. This $B(E2)$ value corresponds to $\beta_2 = 0.53$ by assuming an axially symmetric rotor with $K = 3/2$ (Table 1).

$$\begin{aligned} Z &= a + b + c + d + e + f + g \\ &= \sum_{i=\infty} a_i + h + i + j + k + l + m \\ &= o + p + q + r + s + t + \boldsymbol{g^x} \end{aligned} \tag{3}$$

The negative-parity states are also of interest, partly because the competition and mixing between the $1p1h$ and $3p3h$ configurations can be compared with those of the $0p0h$ and $2p2h$ configurations in the positive-parity states. The present calculation indicates that the yrast negative-parity states shown in Fig. 1 are dominated by $3p3h$ configurations (Table 2). The truncated shell-model calculation with the same interaction shows that states dominated by $1p1h$ are expected to lie higher than the yrast negative-parity states by more than 1 MeV. This picture is in sharp contrast with the former shell-model prediction,[6] in which the yrast negative-parity states are composed of $1p1h$ configurations for all nuclei in this region.[b]

In order to confirm the validity of our calculation concerning the competition and mixing of various configurations, the role of $pf$-orbits on the observed quantities is examined in more detail.

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In the MCSM calculation, the $3^-_1$ state of a neutron-rich nucleus, $^{28}$Mg, lies at 5.28 MeV, very close to the experimental position of 5.17 MeV. The two-neutron separation energies of $N = 20$ nuclei, which are also very sensitive to the *effective single-particle energy*[4] of the $pf$ shell, are in excellent agreement with an experiment for $N = 20$ isotones ranging from $Z = 10$ to 14.

(1) aaaa aaaa aaaa aaaa

Table 2. aaa

| AA | b |
|---|---|
| a | b |

[b] aaaaaaaaaaaaaa

aaaa aaaa aaaa aaaa

(i) bbbb bbbb bbbb bbbb

(a) cccc cccc cccc cccc

(b) cccc cccc cccc cccc

(ii) bbbb bbbb bbbb bbbb

(2) aaaa aaaa aaaa aaaa

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References


1) S. Noh and I. Yamaguchi: Jpn. J. Appl. Phys. **40**, L1299 (2001).
2) S. Ambe et al.: Chem. Lett. **2001**, 149.
3) P. S. Ho: in *Principles of Electronic Packaging*, edited by D. P. Seraphim, R. Lasky, and C. Y. Li (McGraw-Hill, New York, 1999), p. 809.
4) J. A. Dean: *Lange's Handbook of Chemistry* (McGraw-Hill, New York, 2000).
5) F. Martinerie et al.: Proc. 41st IEEE Conf. on Decision and Control, Vol. 3 (2000), p. 3803.
6) B. D. Campbell, P. M. Simon, J. T. Triplett, and R. E. Taylor: Proc. 35th Int. Wire and Cable Symp., Cherry Hill, USA, 2000-12 (Elsevier Science, 2001), p. 149.
7) B. V. Prityckenko et al.: submitted to Phys. Rev. Lett.