Studies on Energy Levels and Electromagnetic Properties in $N = 82$ Nuclei Using Pseudo $LS$ Coupling Shell Model

MASAO NOMURA

Institute of Physics, College of General Education University of Tokyo, Tokyo

In $N = 82$ nuclei, there occurs strong configuration mixing, especially, between $0g_{7/2}$ and $1d_{5/2}$ single-particle orbits. Our aim is to study how does it affect energy levels and electromagnetic properties of low-lying states.

Using the seniority scheme of pseudo $LS$ coupling in the configuration $(1d_{5/2} 0g_{7/2})^2$, shell model calculation is carried out for $Z = 51 - 59$ nuclei with $N = 82$. States with seniority $v \leq 4$ and those with $v \geq 3$ are exactly treated for even- and odd-nuclei, respectively. The two-body interaction is assumed to be Elliott’s realistic force

$$-p \sqrt{(2j_1 + 1)(2j_2 + 1)}\delta(J, J) - q \cdot r^2(C^{(\uparrow)} \cdot C^{(\downarrow)}),$$

where the last two terms represent the core-polarization effect. To evaluate a many-body matrix element of the interaction (1), we first express the interaction as the sum of central, vector and tensor force defined in pseudo $LS$ space:

$$\text{interactions } (1) = \sum_{k=0}^{2} G^{(k)}.$$  

Next, we make use of new reduction relations for many-body matrix elements of $G^{(k)}$. Particle-hole interaction $G^{(0)}(k = 0 \sim 2)$ plays an important role in the present formalism. The magnetic moment operator is expressed in the pseudo space as

$$13.0U^{(01)} - 1.71U^{(10)} + 16.2U^{(12)},$$

where $U^{(exp)}$ is the unit tensor operator of degree $x$ with respect to $S$ and of degree $y$ with respect to $L$, and $g_t = 1$ and $g_s = 5.58$ are used.

Level spacing between single-particle orbits $1d_{5/2}$ and $0g_{7/2}$ is kept to be observed value 0.963 MeV. We vary coupling constants $p$ and $q$ in the interaction (1), and find that energy spectra for even- and odd-nuclei are well reproduced with $p = 0.082$ and $q = 0.0013$. Some of results are shown in Fig. 1. The interaction (1) is found to have very small non-central parts $G^{(1)}$ and $G^{(2)}$. Wave functions of low-lying states of $Z \geq 54$ nuclei are expressed, in a good approximation, in terms of the possible lowest seniority. Occupation probability $\langle n \rangle$ of $0g_{7/2}$ in ground states are evaluated to be 2.57, 3.06, 3.77, 4.25, 4.80 and 5.31 for $Z = 53 \sim 58$, respectively, which agrees with results obtained from nuclear reaction.

Using the operator (3), $g$ factors of ground states are evaluated to be 0.4924 in Cs$^{137}$ and 0.4912 in La$^{139}$. These are almost equal to the single-particle $g$ factor $g_{sing} = 0.4911$, while observed $g$ factors are 0.811 in Cs$^{137}$ and 0.794 in La$^{139}$. For $l$-forbidden transition from 5/2 to 7/2 in odd nuclei, retardation is thousand times too large in comparison with observed values.

As another type of residual interaction, we use a central force with a Gaussian radial shape. We find that Rosenfeld force mixture with the force range 0.55 and the depth 35 MeV reproduces energy spectra very well. The $l$-forbidden transition can be fairly explained. However, $g$ factors in odd nuclei are almost the same as $g_{sing}$.

It is interesting that observed level schemes of $Z = 81$, 82 and 83 nuclei with $N = 126$ resemble somewhat to those of $Z = 51$, 52 and 53 nuclei with $N = 82$, respectively. It is then suggested that the strong coupling model, i.e. pseudo $LS$ coupling, defined in the $(1f_{7/2} 0h_{9/2})^{x = 82}$ configuration, would be also appropriate to describe $N = 126$ nuclei for the case $(Z = 82) \geq 3$.

If low-lying states of $N = 126$ nuclei can be
described by the main configuration \((0h_{1/2})^{2-82}\) and small configuration mixing, we get the following identity among \(g\)-factors of \(N = 126\) nuclei, assuming\(^5\) that effective magnetic moment is expressed in terms of one- and two-body operators:

\[
g(9/2) + g(21/2) = (2g(6) + 8g(8))/5, \tag{4}
\]

where \(g(9/2)\) represents the \(g\) factor of the ground state of \(\text{Bi}^{209}\) and \(g(21/2)\) is that of the \(21/2^-\) state of \(\text{At}^{211}\) and \(g(6)\) \((g(8))\) is that of \(6^+\) \((8^+)\) state of \(\text{Po}^{210}\). Observed \(g\) factors,\(^7\) however, do not seem to satisfy the identity (4), though observed \(g\) factors are not accurate enough to get definite conclusion. If really the identity (4) does not hold, we should have to expect very strong configuration mixing also in \((Z - 82) \geq 3\) nuclei with \(N = 126\).

References

4) M. Nomura: to be published.