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Effective M1 Operators in the Nuclei with $N = 29$ and 30

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The magnetic moments in nuclei with $N = 29$ and 30, and $Z = 21 - 27$ are investigated within the framework of the shell model.

First, the magnetic moments are calculated by making use of the wave functions obtained in ref. 1, in which the assumed configurations for the nucleons outside the ^{48}Ca core are $(f_{7/2})_p^{Z-20}(p_{3/2}, p_{1/2}, f_{5/2})_n^{N-28}$. The calculated values μ_{cal} are shown in Table I together with the experimental ones μ_{exp} and the ones predicted from the lowest-seniority approximation μ_{sp}. As shown in Table I this calculation changes the magnetic moments from the lowest-seniority predictions by appreciable amount and are in reasonable agreement with the observed ones μ_{exp}.

These changes are ascribed to the effect of the proton-neutron interactions, which break the seniority scheme in the proton configuration and mix appreciably the excited neutron configurations into the state of each nucleus. The situations concerning the breakdown of the simple *jj*-coupling scheme are the same for the two exceptional cases of the nuclei ^{53}Cr ($J = 3/2^-$) and ^{57}Co ($J = 7/2^-$), the calculated moments of which still deviate significantly from the experimental values. In particular, the wave function of the ground state of ^{53}Cr includes large amplitudes of the excited configurations, *e.g.* $|f_{7/2}^4(v = 2, J_p = 2)p_{3/2}\rangle$ and $|f_{7/2}^4(v = 2, J_p = 2)p_{1/2}\rangle$, but, in spite of the large mixing, the final result does not change so much from the Schmidt value.

The magnetic moments receive the important corrections from the excitation of the $f_{7/2}$ particles to the $f_{5/2}$ orbit both for protons and neutrons, which is omitted in this shell model calculation. Here we estimate the contributions of this effect by the first-order configuration mixing to the wave functions mentioned above.

The configuration mixing to the first order can be expressed by the following effective operator $\tilde{\mu}$.

$$\begin{aligned}\tilde{\mu} &= \mu + \mu\frac{Q}{E-H_0}V + V\frac{Q}{E-H_0}\mu \\ &= \mu + \delta\mu^{p} + \delta\mu^{n} + \delta\mu^{pp} + \delta\mu^{pn} + \delta\mu^{nn},\end{aligned}$$

where the operator Q excludes the configurations $f_{7/2}^{Z-20}(p_{3/2}, p_{1/2}, f_{5/2})^{N-28}$, μ is a magnetic moment operator of free nucleons and V is a coupling interaction. In the energy denominator, E is an energy of the state which we are concerned with and H_0 is an unperturbed Hamiltonian of single particle. For convenience of calculation, the energy E is approximated to the unperturbed energy $E_0 = (Z-20)\varepsilon_{f_{7/2}} + (N-28)\varepsilon_{p_{3/2}}$. Furthermore the unperturbed excitation energies of the particles which are not connected by the coupling interaction V are neglected. The effective operator μ is decomposed into the one-body operators $\delta\mu^p$ and $\delta\mu^n$ and the two-body ones $\delta\mu^{pp}$, $\delta\mu^{pn}$ and $\delta\mu^{nn}$. The typical diagrams corresponding to the operators are shown in Fig. 1. Under these approximations, the operators $\delta\mu$'s are independent of state and nucleon number.

The coupling interaction V is assumed as central force of Gauss type with a range parameter $\lambda = 0.6$

Table I. Magnetic moment of the nuclei with $N = 29$ and 30.

Nuclei	J^π	μ_{exp}	μ_{sp}	μ_{cal}	$\delta\mu^p$	$\delta\mu^n$	$\delta\mu^{pp}$	$\delta\mu^{nn}$	$\delta\mu^{pn}$	$\tilde{\mu}_{cal}$
^{53}Cr	$3/2^-$	−0.474	−1.913	−1.430	−0.017	0.485	−0.028	0.231		−0.759
^{54}Mn	3^+	3.302	4.965	3.030	−0.178	0.398	−0.477	0.368		3.141
^{56}Co	4^+	3.803	4.276	3.644	−0.224	0.511	−0.714	0.405		3.622
^{55}Mn	$5/2^-$	3.468	4.138	3.846	−0.162	0.003	−0.344	0.004	0.001	3.348
^{56}Fe	2^+	1.16 ±0.34		1.335	−0.059	0.032	−0.082	−0.035	0.008	1.199
^{57}Co	$7/2^-$	4.58 ±0.05	5.79	5.398	−0.228	0.010	−0.729	−0.009	0.003	4.445

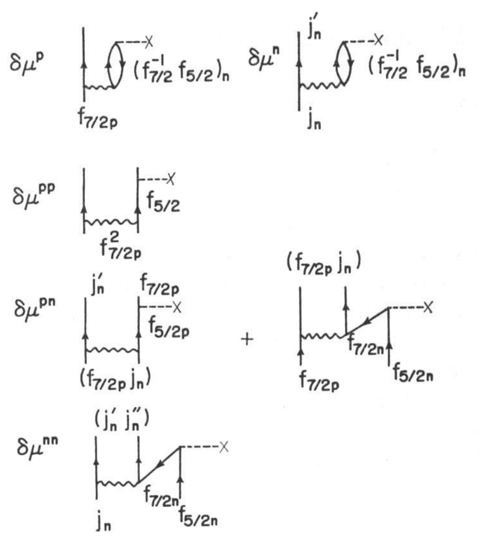

Fig. 1

($\lambda = r_0\sqrt{\nu/2}$) and a strength $V_0 = -40$ MeV. Various mixture parameters are used and the dependence of the final results on the parameters are examined. The spin-orbit splitting between $f_{5/2}$ and $f_{7/2}$ is set equal to 8.8 MeV.

The results for six nuclei with the Rosenfeld force are summarized in Table I.

Table I shows that the deviations in odd-Z (odd-N) systems are mainly caused by the $\delta\mu^{p}$ and $\delta\mu^{pp}$ ($\delta\mu^{n}$ and $\delta\mu^{pn}$) terms and also that the terms originated from the interactions between identical particles (*i.e.* $\delta\mu^{pp}$ and $\delta\mu^{n}$) are large. The $\delta\mu^{pn}$ and $\delta\mu^{p}$ terms, however, originated from the proton-neutron interactions are not negligible, since the Rosenfeld force works strongly repulsive in odd states. If we adopt the Serber force, which does not act in odd states (*i.e.* $V_{SO} = V_{TO} = 0$), the values of the $\delta\mu^{p}$ and $\delta\mu^{pn}$ terms decrease, but the resultant values of $\tilde{\mu}_{cal}$ remain substantially unaffected. It is likely that the sums $\delta\mu^{p} + \delta\mu^{pp}$ and $\delta\mu^{n} + \delta\mu^{pn}$ scarcely depend on which forces are adopted.

Reference

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