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III-18 Single Particle Transitions near ^{208}Pb

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§1. Experiments

We have recently studied the gamma decay between single-particle (-hole) states in the Pb region with the purpose of determining the renormalization of E2 and M1 matrix elements. The experimental techniques used in this study have been described in detail elsewhere[1] and will be summarized only briefly.

Absolute cross sections for Coulomb excitation of the lowest states in ^{207}Pb and ^{209}Bi have been measured with beams of ^{4}He(15–18 MeV) and ^{16}O(69–80 MeV). The specific energy loss of ^{4}He and ^{16}O in Pb has been measured by a novel method. B(E2) values accurate to at best $\pm 5\%$ have been obtained.

The Doppler-shift attenuation method (DSAM) was employed to derive mean lifetimes following the ^{207}Pb (^{16}O, ^{16}O$'\gamma$), ^{208}Pb(^{7}Li, ^{6}Liγ)^{209}Pb and ^{208}Pb(^{7}Li, $\alpha 2n\gamma$)^{209}Bi reactions. The mean lifetimes of a number of single-particle (-hole) states have been obtained (in ps): 0.19 ± 0.04 ($3p_{\bar{1}/2}^{-1}$ at 897.7 keV in ^{207}Pb); >3($1i_{11/2}$ at 779 keV in ^{209}Pb); 0.47 ± 0.13 ($3d_{5/2}$ at 1567 keV in ^{209}Pb); <0.02($2f_{5/2}$ at 2826 keV in ^{209}Bi), 0.03 ± 0.02 ($3p_{3/2}$ at 3120 keV in ^{209}Bi).

§2. E2 Transitions

The B(E2) values between single-particle (-hole) states in mass 209 (207) nuclei are summarized in Table I. Effective charges, $\beta_{\rm eff}$, extracted with the quoted harmonic oscillator radial integrals, are seen to differ appreciably for both protons and neutrons.

Impressive agreement can be obtained[1] if an intermediate coupling approach[2,3] is followed in which the core states in ^{208}Pb are considered to be the ground state and the quadrupole phonon state at 4.07 MeV (B(E2; $0^+ \to 2^+$) $= 0.30 \pm 0.02$ e^2b^2, ref. 4. The results in column 3 correspond to a unique value of the intermediate coupling parameter which, after a suitable choice of unperturbed single-particle energies, also accounts for the observed level scheme. The collective components in the lowest single-particle (-hole) states are typically $\sim$15% in intensity and give a fair indication of the quality of the shell closure in the ^{208}Pb ground state. The success of

Table I. Single particle E2 transitions.

	Orbitals	B(E2)$_{\rm exp}$ (e^2fm^4)	Intermediate coupling (e^2fm^4)	$\lvert\langle r^2\rangle\rvert$ fm^2	$\beta_{\rm eff}/e$[c]
ν	$2f_{5/2} \to 3p_{1/2}$	71 ± 3	71	31.95	0.94 ± 0.02
	$3p_{3/2} \to 3p_{1/2}$	61 ± 3	65	34.61	0.80 ± 0.02
	$2f_{7/2} \to 2f_{5/2}$		16	34.61	
	$3d_{5/2} \to 2g_{9/2}$	185 ± 50	214	35.32	0.89 ± 0.10
	$4s_{1/2} \to 3d_{5/2}$	154 ± 8[a]	142	39.13	0.65 ± 0.02
π	$2f_{7/2} \to 1h_{9/2}$	30 ± 3	31	24.97	2.36 ± 0.12
	$2f_{5/2} \to 1h_{9/2}$	480 ± 170[b]	645	24.97	0.89 ± 0.17
	$3p_{3/2} \to 2f_{7/2}$	500^{+1000}_{-200}	764	31.95	$1.55^{+1.12}_{-0.35}$

a) P. Salling: Phys. Letters **17** (1965) 139.
b) R. A. Broglia *et al.*: Phys. Rev. **C1** (1970) 1508.
c) $\beta_{\rm eff}$ (free nucleon) = 0.

Table II. Single particle M1 transitions.

	Orbitals	$B(\mathrm{M1})_{\mathrm{exp}}$ (μ_n^2)	$B(\mathrm{M1})_{\mathrm{theory}}$ [a] (μ_n^2)	$B(\mathrm{M1})$ (free nucleon)	δg_s	δg_l
ν	$3p_{3/2} \to 3p_{1/2}$	0.41 ± 0.07	0.30(0.14)	1.16	1.76	−0.072
	$2f_{7/2} \to 2f_{5/2}$	0.49 ± 0.16	0.14(0.03)	1.50	2.67	−0.024
	$1i_{11/2} \to 2g_{9/2}$	<0.04	0.01	*l*-forbidden		
π	$2f_{5/2} \to 2f_{7/2}$	0.76 ± 0.15	0.90	2.86	−3.90	−0.734
	$2f_{7/2} \to 1h_{9/2}$	$(4.3 \pm 0.7) \times 10^{-3}$ [b]	0.025	*l*-forbidden		

a) numbers in brackets include second order corrections.
b) $\delta^2 = 0.37$ assumed; M. R. Schmorak and R. L. Auble: Nuclear Data **B5** (1971) 207; M. J. Martin, *ibid.*, p. 87.

Table III. Magnetic moments (in μ_n).

	Orbitals	μ_{exp}	μ_{theory} [a]	$\mu_{(\mathrm{free\ nucleon})}$	δg_s	δg_l
ν	$3p_{1/2}$	0.59	0.61(0.60)	0.64	0.19	−0.0002
	$2f_{5/2}$	0.65 ± 0.05	0.88(0.98)	1.37	1.32	−0.003
	$3p_{3/2}$		−1.07(−0.78)	−1.91	1.38	+0.032
	$2f_{7/2}$		−1.08(−0.88)	−1.91	1.59	+0.009
	$2g_{9/2}$	~ -1.33	−1.16	−1.91	1.47	+0.004
	$1i_{13/2}$	~ -0.89	−0.79	−1.91	2.27	−0.002
π	$1h_{9/2}$	4.08	3.76	2.62	−1.52	−0.055
	$1i_{13/2}$	~ 7.9	7.51	8.79	−3.12	+0.047

a) Numbers in brackets include second order corrections.

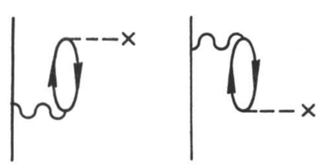
the simple intermediate coupling picture suggests that the renormalization of E2 transitions is mainly caused by $2\hbar\omega$ excitations.

§3. M1 Transitions

The $B(\mathrm{M1})$ values between single particle states in mass 209 (207) are shown in Table II. The three allowed transitions are hindered by a factor of 3–4. The remaining two M1 are *l*-forbidden and have a small magnitude. They should be particularly sensitive to renormalization effects. Table III gives the experimental information on the magnetic moments of single-particle (-hole) states.

First of all it may be remarked that the intermediate coupling wave functions are quite inadequate to explain the M1 transitions[1] since they are constructed to correlate $B(\mathrm{E2})$ values in neighboring nuclei.

We have used perturbation theory to calculate the renormalization[5,6] due to particle-hole (p-h) excitations. In first order the two such contributions are shown in Figs. 1(a) and 1(b). The two-body reaction matrix elements are obtained from a separable two-body interaction[7] (with $\hbar\omega = 7.8$ MeV). The first order renormalization is due to the particle-hole excitations of $h_{9/2} - h_{11/2}$ (for protons) and $i_{11/2} - i_{13/2}$ (for neutrons) with energy separations of 4.89 MeV and 5.22 MeV respectively. The renormalized and the experimental numbers are in fairly good agreement though the *l*-forbidden $B(\mathrm{M1}; 7/2^- \to 9/2^-)$ in ^{209}Bi is overestimated by a large factor (see Table II). Several comments can be made with regard to these calculations.



(a) (b)

Fig. 1(a) and 1(b)

i. The proton p-h contributes a larger amount to the renormalized M1 matrix elements than the neutron p-h.

ii. δg_s and δg_l are strongly state dependent and their magnitudes vary widely. In particular, $|\delta g_l|$ is much larger for M1 transitions than for magnetic moments. This partly explains the difficulty experience by Maier *et al.*[8] in fitting both transitions and moments with state-independent δg_s and δg_l.

iii. No account has been taken of the pion exchange currents which have recently been estimated by Arima[9] to be quite large. Phenomenologically such effects might be simulated by including an operator $g_p[Y^2 \times \sigma]^1$ and an additional $\delta g_l^{(mes)}$ in the usual M1 operator. We were able to fit all the existing data on magnetic moments and M1 transitions with a reasonable χ^2; the first order contributions were slightly readjusted by varying $\hbar\omega$, and the following 'mesonic' parameters were obtained for protons (neutrons): $\delta g_l^{(mes)} \sim 0.10(-0.03)$; $g_p \sim 0.8(0)$. These results are not very different from previous fits[8,10] obtained only from magnetic moment data and assuming state independence. The merit of the present fitting procedure is perhaps doubtful in view of the inadequacy of the first order renormalization as will be discussed in the following.

iv. With such a large contribution from the first order terms it seems appropriate to estimate the second order effects. We have evaluated the contribution to the single particle states in ^{207}Pb from the second order diagrams shown in Figs. 1(c)–1(f). The diagrams in Figs. 1(c) and 1(d) include effects of 1p–2h excitations while the diagrams in Figs. 1(e) and 1(f) take into account some of the 2p–3h contributions. Contributions from $2\hbar\omega$ and $1\hbar\omega$ proton and neutron p-h states have been taken into account. The contributions due to proton p-h states are quite large. Magnetic moments and B(M1)'s after including the second order corrections are shown in the Tables II and III. The magnetic moments change up to $\sim$0.2 nuclear magnetons. The total effect is to worsen the agreement with experiment. Details of these calculations will be published soon.[11] It may be remarked that *a priori* there is no reason to pick these four second order diagrams except that these are convenient for calculation. In addition these are the type of diagrams that will contribute in the renormalization of single-particle magnetic moments and M1 transitions in the neighbourhood of ^{16}O (*i.e.* mass 17 and 15) or ^{40}Ca(*i.e.* mass 41 and 39).

v. Since the one-body renormalization effects are large, it is natural to ask if the two-body effects will be completely negligible. From previous experience with the two-body operator for E2 transitions[6] it appears that such effects for M1 transitions may be as large as $\sim$10% of the one-body effects. Such a calculation is being undertaken since it will have a strong influence on the question of additivity which is frequently used to estimate some of the single-particle magnetic moments.

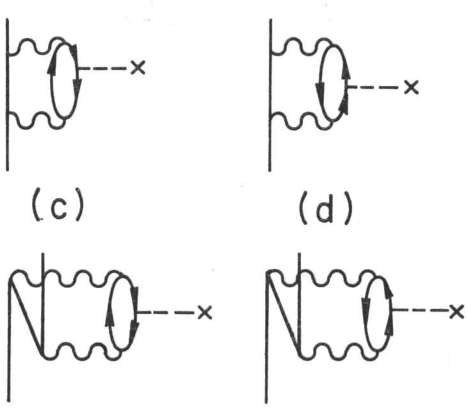


Fig. 1(c)–1(f)

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