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M1 Transitions in ^{208}Bi

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We have recently measured the gamma widths of some low-lying states in ^{208}Bi by the Doppler shift attenuation method (DSAM) using the reaction ^{207}Pb(^{7}Li, α2n)^{208}Bi. This heavy ion reaction is necessary to impart sufficient velocity to the recoils so that DSAM can be used. A more detailed account of this experiment has been submitted elsewhere for publication.[1] These results are given in Table I. Here we propose to discuss the implications of these measurements regarding configuration mixing.

The low-lying levels of ^{208}Bi, shown in Fig. 1, consist of an $h_{9/2}(p_{1/2})^{-1}$ ground state doublet, an $h_{9/2}(f_{5/2})^{-1}$ sextuplet at 500–900 keV, and an $h_{9/2}(p_{3/2})^{-1}$ quartet and $f_{7/2}(p_{1/2})^{-1}$ doublet at 900–1100 keV.[2] We have measured gamma widths of states belonging to the latter two configurations. Theoretical calculations have been done by Kim and Rasmussen[3] using a phenomenological interaction, and by Kuo[4] using an effective interaction derived from the Hamada-Johnson potential. These calculations exhibit good agreement with the experimental level energies. Kuo calculates that configuration admixtures in these states are rather small.

Magnetic moments and B(M1)'s have been measured for most of these single particle states and good estimates are available for the unmeasured values.[5] These may be related through Racah algebra to M1 matrix elements of the particle-hole configuration. By using experimental single particle matrix elements we automatically take core polarization and mesonic effects into account. This calculation neglects core polarization induced jointly by the valence particle and hole.

The sensitivity of B(M1)'s to small admixtures in

Table I. ^{208}Bi widths and branching ratios.

Ex MeV	Initial Spin	Final Spin	E_γ MeV	Calculated widths Γ_{M1} a) meV	Γ_{M1} b) meV	Γ_{M1} c) meV	Γ_{E2} meV	Γ_{exp} meV	Branching ratios calc	exp. d)
1.0950	6^+	5^+	1.0950	17.8	6.15	5.64		$3.5^{+1.2}_{-0.9}$		1
0.8862	5^+	5^+	0.8862	5.58	1.95	2.16		$1.22^{+0.49}_{-0.36}$	0.55	0.48 (0.031)
	5^+	4^+	0.8231	3.00	1.05	1.77		$1.32^{+0.53}_{-0.39}$	0.45	0.52 (0.027)
1.0694	3^+	4^+	1.0067	13.7	4.77	2.74		$0.86^{+0.31}_{-0.28}$	0.88	0.830(0.031)
		5^+	1.0694				0.059	$0.024^{+0.009}_{-0.008}$	0.019	0.023(0.005)
		4^+	0.4677			0.263		$0.094^{+0.034}_{-0.031}$	0.085	0.091(0.006)
		3^+	0.4361			0.050		$0.054^{+0.019}_{-0.017}$	0.016	0.052(0.005)
1.0330	4^+	5^+	1.0330		0.056	0.084 e)	0.027	$0.39^{+0.12}_{-0.10}$	0.99	0.614(0.023)
		4^+	0.9703		0.0011	0.00002 f)	0.0006	$0.158^{+0.047}_{-0.042}$	0.006	0.249(0.011)
		5^+	0.4058			0.00003	0.000001	$0.020^{+0.006}_{-0.005}$	0.0003	0.032(0.002)
		3^+	0.4002			0.000004	0.0000002	$0.0051^{+0.0015}_{-0.0014}$	0.00003	0.008(0.002)
		5^+	0.1467			0.00016		$0.062^{+0.018}_{-0.016}$	0.0014	0.097(0.012)
0.9363	3^+	4^+	0.8731		0.035	0.0044		$0.17^{+0.10}_{-0.17}$		1
1.5393	(2^+)	3^+	0.9061		0.032	0.050	0.00015	$0.22^{+0.17}_{-0.22}$		≥ 0.74

a) Pure configuration and bare nucleon g-factors.
b) Pure configuration experimental single particle matrix elements.
c) Kuo wavefunctions experimental single particle matrix elements.
d) From ref. 3.
e) With 10% $h_{9/2}(3p_{3/2})^{-1}$ configuration admixed into initial state $\Gamma_{M1} = 0.35$ meV.
f) Under assumption of note e), $\Gamma_{M1} = 0.19$ meV.

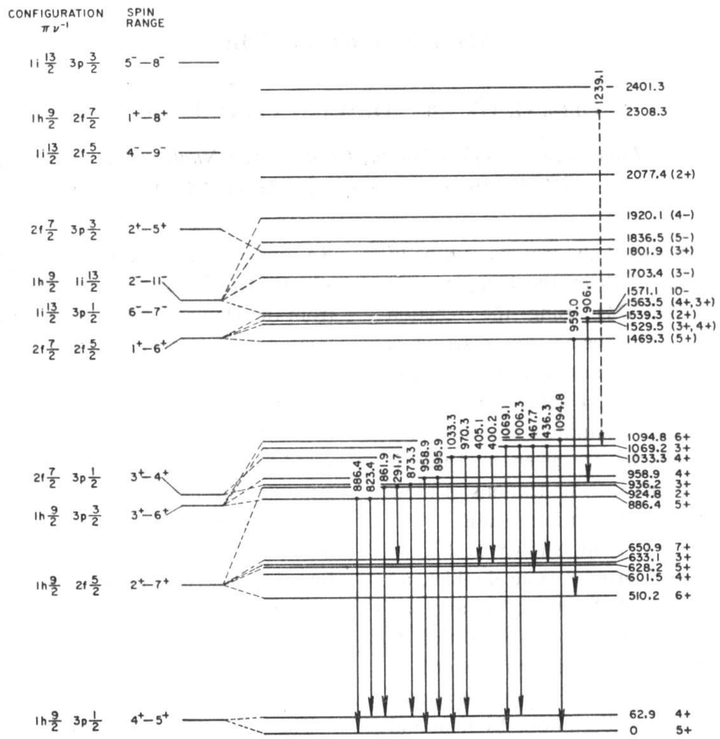

Fig. 1. Partial decay scheme of ^{208}Bi (from ref. 3). Only gamma rays relevant to our lifetime measurements are shown.

the ^{208}Bi wavefunctions may be seen from the following considerations:

a) the transition rate varies as the squared amplitude of the admixture in the wavefunction.

b) the decay $f_{7/2} \to h_{9/2}$ is hindered by a factor of 100 relative to $(p_{3/2})^{-1} \to (p_{1/2})^{-1}$ and a factor of 1000 relative to $h_{9/2} \to h_{9/2}$, so the gamma width of the $f_{7/2}(p_{1/2})^{-1}$ configuration is dominated by admixtures of $h_{9/2}(p_{1/2})^{-1}$ and $h_{9/2}(p_{3/2})^{-1}$.

c) for decays of the $h_{9/2}(p_{3/2})^{-1}$ quartet, the large value of $B(\mathrm{M1};\ h_{9/2} \to h_{9/2})$ makes the gamma width sensitive to admixtures of $h_{9/2}(p_{1/2})^{-1}$ in the excited state, and of $h_{9/2}(p_{3/2})^{-1}$ in the ground state. An example of this sensitivity is shown in Table II for the $h_{9/2}(p_{3/2})^{-1}5^+ \to h_{9/2}(p_{1/2})^{-1}4^+$ and $f_{7/2}(p_{1/2})^{-1}4^+ \to h_{9/2}(p_{1/2})^{-1}5^+$ transitions.

The errors involved in these calculations come from errors in the experimental B(M1)'s that we use. In the best case, this is dominated by the 15% error in $B(\mathrm{M1};\ (p_{3/2})^{-1} \to (p_{1/2})^{-1})$. In cases where considerable cancellation of the matrix elements occur these errors may be larger.

Signs of the M1 matrix elements have been determined from the shell-model calculations. However an ambiguity exists for $\langle f_{7/2} \| \mathrm{M1} \| h_{9/2} \rangle$; we have chosen a negative sign for this matrix element to agree with the core-polarization calculation of Khanna.[6)]

Our DSAM measurements have even larger errors than this, 30–40%. In some cases we can compare with our calculations branching ratios measured by Proetel *et al.*[7)] to an accuracy of about 5%.

The measured widths of the 6^+ and 5^+ members of the $h_{9/2}(p_{3/2})^{-1}$ quartet are in satisfactory agreement with the calculations when we consider the 15% error in $B(\mathrm{M1};\ (p_{3/2})^{-1} \to (p_{1/2})^{-1})$. The excellent agreement of the branching ratios for the 5^+ and 3^+ states is a rather sensitive test of the Kuo wavefunction.

There remains a discrepancy in the width of the 3^+ member of the quartet; moreover, this calculated width is about the same as for the other quartet members, so this discrepancy is independent of the stopping power assumed in our DSAM analysis. We

Table II. Contributions to the M1 matrix element from configuration admixtures.

Transition	Configuration	Mixing coefficient[a)]	Contribution to matrix element (arb. units)
$h_{9/2}(p_{3/2})^{-1}5^+ \rightarrow h_{9/2}(p_{1/2})^{-1}4^+$	$h_{9/2}(p_{3/2})^{-1} \rightarrow h_{9/2}(p_{1/2})^{-1}$	0.954	3.46
	$h_{9/2}(p_{3/2})^{-1} \rightarrow h_{9/2}(p_{3/2})^{-1}$	0.183	1.31
	$h_{9/2}(p_{1/2})^{-1} \rightarrow h_{9/2}(p_{1/2})^{-1}$	0.040	−0.04
	$h_{9/2}(p_{1/2})^{-1} \rightarrow h_{9/2}(p_{3/2})^{-1}$	0.008	−0.02
$f_{7/2}(p_{1/2})^{-1}4^+ \rightarrow h_{9/2}(p_{1/2})^{-1}5^+$	$f_{7/2}(p_{1/2})^{-1} \rightarrow h_{9/2}(p_{1/2})^{-1}$	0.945	−0.51
	$h_{9/2}(p_{3/2})^{-1} \rightarrow h_{9/2}(p_{1/2})^{-1}$	−0.04	−0.11
	$f_{7/2}(p_{3/2})^{-1} \rightarrow f_{7/2}(p_{3/2})^{-1}$	−0.0029	0.02
	$f_{7/2}(f_{5/2})^{-1} \rightarrow f_{7/2}(f_{5/2})^{-1}$	−0.014	0.02
	$h_{9/2}(p_{1/2})^{-1} \rightarrow h_{9/2}(p_{1/2})^{-1}$	−0.014	−0.01

a) Product of the amplitudes of the configurations in the Kuo wavefunctions.

observe in our spectra a gamma ray at 1.239 MeV which was found by Proetel[7)] to be in coincidence with the 1.007 MeV gamma ray deexciting the 3^+ state. Thus we attribute the discrepency in the 3^+ width to feeding from a higher long-lived state.

The decay of the $f_{7/2}(p_{1/2})^{-1}3^+$ state is observed to be highly hindered in agreement with the calculation. Both the gamma width and the branching ratio of the 4^+ state disagree with the calculation. Alford *et al.*[2)] have found evidence for a 10% admixture of $h_{9/2}(p_{3/2})^{-1}$ in the spectroscopic strength of this state in the ^{209}Bi(d, t) reaction. From Table II we see that the width is quite sensitive to admixtures of this type. The sensitivity to an $h_{9/2}(p_{1/2})^{-1}$ admixture is rather low in this case because of a cancellation in the $\langle h_{9/2}\|M1\|h_{9/2}\rangle$ and $\langle p_{1/2}\|M1\|p_{1/2}\rangle$ contributions to the matrix element. Assuming a 10% mixture of $h_{9/2}(p_{3/2})^{-1}$ we calculate M1 widths of 0.35 meV for the $4^+ \rightarrow 5^+$ transition and 0.19 meV for the $4^+ \rightarrow 4^+$ transition, in excellent agreemen twith the observed width and branching ratios.

Conclusion

We have measured the lifetimes of a number of levels in ^{208}Bi to an accuracy of about 30–40%. These lifetimes depend sensitively on small admixtures in the wavefunctions of these states, and thus are a good test of nuclear structure calculations for ^{208}Bi. The ^{208}Bi wavefunctions calculated by Kuo give generally good agreement with our observed lifetimes and branching ratios. However, our results also confirm the 10% admixture of $1h_{9/2}(3p_{3/2})^{-1}$ configuration in the 1.033 MeV level, as reported by Alford.[2)]

Because of the large uncertainties of our lifetime measurements we cannot draw conclusions about the existence of additional renormalizations in the particle-hole system. The data for this experiment was collected in 32 hours of running. However, even if considerably longer running times and more counters are used to increase the statistics, large errors will still remain in the extracted Doppler shifts because of the complexity of the spectra.

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