SEARCH FOR ISOBARIC ANALOGUES OF M1 STATES AND GIANT SPINFLIP RESONANCES IN THE $^{208}\text{Pb}(p,n)$ REACTION

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This study was initiated to search for isobaric analogues of magnetic dipole radiating states in ^{208}Pb , and to determine the feasibility of using the (p,n) reaction to aid in locating M1 strength in medium to heavy nuclei. The experimental situation pertaining to M1 ground-state radiative strength has been summarized¹ recently with the conclusion that little definitive information is available for nuclei with $A > 40$. In ^{208}Pb it is known that thirty-four resonances between 7.38-7.79 MeV contain $\Sigma B(M1) \approx 2.6 \mu_0^2$, with about half of this localized³ within a narrow doorway state at ~ 7.5 MeV. The analogue resonances would lie at an excitation energy of ~ 22.7 MeV in ^{208}Bi , and would have $T=22$. If these do not strongly admix with background states, they might be observed in the $^{208}\text{Pb}(p,n)$ reaction. The same experiment is also expected to yield information on the giant Gamow-Teller (GT) resonance for which little information is available for targets with $A > 90$.

A zero degree spectrum taken at $E_p = 120$ MeV is shown in Fig. 1. Zero degree cross sections and excitation energies are given in Table I. Our

measured excitation energy for the IAS of ^{208}Pb g.s. is 15.0 ± 0.3 MeV which is in good agreement with the value of 15.17 ± 0.02 MeV reported⁴ by Crawley et al.

Figure 1. Time-of-flight neutron spectrum for $^{208}\text{Pb}(p,n)^{208}\text{Bi}$ at $\theta=0^\circ$ for $E_p=120$ MeV. Fits to the peaks (with the exception of that at 21.5 MeV) discussed in this paper with the assumed background are shown.

We have therefore normalized our energy scale to that work. Macroscopic DWBA calculations (optical model parameters⁵ from Schwandt et al.) were used to assign ℓ -transfer. The 2.8 MeV peak is assigned as $\Delta\ell=1$ whereas those at 15.2 and 15.6 MeV are $\Delta\ell=0$. The peaks at 22.9 and 24.6 MeV also fall off rapidly with angle and, hence, are $\Delta\ell=0$. In this preliminary study, we were unable to obtain an angular distribution for the 21.5 MeV peak. However, it is clear from the 160 MeV data, that it behaves similarly to the 2.8-MeV peak and thus also involves $\Delta\ell=1$.

The cross section for the neutron group at 15.6 MeV increases relative to that for the IAS in going from 120 to 160 MeV. The increase in the ratio of the relative cross sections by a factor of ~ 2.2 at 160 MeV is in good agreement with the predictions⁶ of Love

Table I. Energies and cross sections for resonances observed in $^{208}\text{Pb}(p,n)^{208}\text{Bi}$ reaction at $E_p=120$ MeV

$E_x(^{208}\text{Bi})^a$ (MeV)	$d\sigma/d\Omega(0^\circ)$ (mb/sr)	$\Gamma(\text{FWHM})^b$ (MeV)	J^π
2.8	0.86 ± 0.15		2^-
15.2	9.0 ± 1.5		0^+ (IAS)
15.6	41 ± 12	4.1	1^+ (GT)
21.5 ± 1.0	c	10 ± 3	$(1)^{-d}$
22.9	0.9 ± 0.4		1^+
24.6	1.0 ± 0.5	1.2	1^+

a) Excitation energies normalized to 15.2 MeV for the g.s. IAS. Uncertainties in excitations of other resonances relative to the IAS are ± 0.2 MeV, except where noted.

b) Where not given, Γ was found to be equal to the experimental resolution ~ 0.67 MeV.

c) Cross section only determined at $\sim 5^\circ$. At 160 MeV, the 5° cross section is about 80% of that for the GT at 0° .

d) $J=2$ cannot be ruled out.

for the increase of $(J_{\sigma\tau}/J_\tau)^2 \sim 1.5$. Hence, we conclude that the peak at 15.6 MeV corresponds to the giant GT resonance. The peaks at 22.9 and 24.6 MeV, as well as parts of the spectrum between threshold and the ground-state IAS, behave similarly to the 15.6-MeV peak. Hence, these represent additional GT strength.

Assigning the isospin of the target as T_0 , the cross sections to states with (T_0-1) , T_0 and (T_0+1) should be proportional to $(2T_0-1)(2T_0+1)^{-1}$, $(T_0+1)^{-1}$ and $[(2T_0+1)(T_0+1)]^{-1}$, respectively. Thus, for nuclei with large T_0 (such as ^{208}Pb , $T_0=22$), one should mainly observe states in the final nucleus with isospin $T=(T_0-1)$. For the reaction $^{208}\text{Pb}(p,n)^{208}\text{Bi}$, the strength to $T=22$ states in ^{208}Bi should have approximately 4% of the strength to $T=21$ states.

The peak at $E_x=22.9$ MeV has a FWHM which is comparable to the energy resolution and, within experimental uncertainties, occurs near the energy expected for the analogues of the M1 resonances near 7.5 MeV in ^{208}Pb . In addition, the cross section for this peak is approximately 2% that of the 15.6 MeV peak as expected. Hence, we assign the 22.9 MeV peak as $T=T_0$ and suggest it represents the analogue of the M1 strength observed in ^{208}Pb . The peak at $E_x=24.6$ MeV is also suggested to have $T=T_0$ and to represent IAS of M1 strength as yet unidentified in ^{208}Pb . The photoneutron polarization measurements on ^{208}Pb by Holt et al.⁷ have found tentative evidence for M1 strength near 9 MeV.

The GT matrix elements have been deduced from the zero degree cross sections using the procedure described elsewhere in this report. We use $|J_\tau|=89$ MeV-fm³ and $|J_{\sigma\tau}|=168$ MeV-fm³ in reasonable agreement with the impulse approximation. With this value of $|J_\tau|$ and $\langle F \rangle^2=44$, we can use the experimental cross section for the g.s. IAS to deduce $N_\tau^D=0.049$

which is in reasonable agreement with a calculated value of 0.038 ± 0.01 . Calculations indicate $N_{\sigma\tau}^D$ is about 20% greater than N_{τ}^D . With this assumption and the above value for the volume integral we find for the 15.6-MeV peak $\langle GT \rangle^2 \approx 48$.

For $^{208}\text{Pb}(p,n)^{208}\text{Bi}$, Ikeda⁸ predicted a total GT strength of 132 with about 90% concentrated within a broad resonance, $T=(T_0-1)$, ($\Gamma \sim 5$ MeV) located near the g.s. IAS. Our data are in good agreement with these calculations and seem to disagree with a recent suggestion⁹ that the GT strength should be highly fragmented in heavy nuclei. Inclusion of the lower lying $\Delta I=0$ cross section and reduction of the "assumed" backgrounds could raise our "observed" GT strength to $\sim 65\%$. However, it must be remembered that the deduced matrix elements are sensitive to the distortion factors, and these must be more fully explored for heavy nuclei such as lead before a final conclusion can be made as

to whether there is "missing" GT strength.

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