tudes are all interfering constructively, the exchange amplitudes will also be almost entirely in phase. As a check we have calculated the cross section for the ^{118}Sn(p,p') scattering to the collective 2^+ excited state using Yoshida's random-phase-approximation wave functions.[7] The calculation, which again used a Serber interaction, was done with and without the exchange terms. 46 single-particle transitions having 90% of the $E2$ transition strength were included in the amplitudes. The inclusion of the knockout exchange amplitudes increases the cross section by a factor of 2.0 compared with the direct cross section alone. Thus, the exchange contribution even to collective states is large.

If we take the even force seriously and take this result as a rough measure of the contribution of exchange to collective transitions, realizing that the many calculations of inelastic scattering using the nuclear collective model do not explicitly include exchange, we might expect that values of the deformation parameter β obtained from such a model should be reduced by a factor of $\sqrt{2}$. Such values would be out of line with those obtained by other means.[8] Apparently the optical model contains in its parametrization of elastic scattering the effect of exchange, and the interaction for inelastic transitions, which is obtained by taking the derivative of the optical potential with respect to radius, also must contain somehow the effect of the exchange contribution.

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1^- NEUTRON PARTICLE-HOLE STATES IN ^{208}Pb POPULATED BY PROTON DECAY OF ANALOG RESONANCES*

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Gamma rays from the decay of neutron particle-hole states in ^{208}Pb populated by analog resonances in ^{209}Bi have been measured with a Ge(Li) crystal. 12 states are found to have observable ground-state transitions. States at 5.27, 5.50, 5.94, 6.32, 6.49, and 7.09 MeV have been assigned $J^\pi = 1^-$ on the basis of ground-state branching fractions and angular distributions.

An isobaric analog resonance formed by the proton bombardment of an even closed-neutron-shell nucleus may be considered as a superposition of a single-particle state and a set of two-particle, one-hole states. If the resonance decays through the inelastic proton channel, a neutron particle-hole state is formed,[1-3] and since the particle and the hole lie in different major shells, this usually results in negative-parity states. The formation of such states by analog resonances has been found to be strong and selective.[4]

The neutron particle-hole states formed in this way are usually bound and will decay by gamma-ray transitions to lower lying states. Because of the usual spin and parity selection rules,[5] states of angular momentum greater than one are most likely to cascade through lower lying 2^+ and 3^- states. However, 1^- neutron particle-hole states are strongly favored to make $E1$ ground-state transitions.[6]

Thus, 1^- neutron particle-hole states may be identified by exciting them through (p,p') reactions on an analog resonance and observing their ground-state gamma-ray decays. We have previously identified 1^- states in ^{140}Ce by this method, using p-γ coincidences,[6] and a similar coincidence method has been employed in (d,p) reactions.[7] If the gamma rays are detected with good resolution, no proton coincidence is required since the resonant behavior and relatively large transition energies identify the states of interest. This procedure, which was used in the present work, has several experimental advantages: One can take advantage of the good resolution now available with Ge(Li) gamma-ray detectors, and, because of the large widths of the analog resonances (~250 keV), one can use fairly thick targets, thereby reducing effects due to surface contaminants. (In fact, accelerators with poor beam energy resolution could be used very effectively in these experiments.)

The angular-momentum relations in a reaction of this type are particularly simple and greatly simplify the interpretation of gamma-ray angular distributions: (1) The total angular momentum carried in by the incident proton is determined by the spin of the analog resonance; (2) the total angular momentum of the neutron particle of the particle-hole state is equal to the spin of the analog resonance; (3) the total angular momentum carried away by the outgoing proton is characteristic of the neutron hole and is unique if the particle-hole state has a single-hole configuration; (4) since the outgoing proton is unobserved, the contributions of different neutron-hole configurations to the gamma-ray angular distribution will add incoherently; (5) in the case of overlapping resonances, e.g., $g_{7/2}$ and $d_{3/2}$, the different particle configurations will interfere in the gamma-ray angular distribution only when they have the same hole configuration. Gamma-ray angular distributions have been calculated[8] for the relevant particle and hole configurations in ^{208}Pb assuming 1^- or 2^- particle-hole states. These angular distributions are given in Table I.

In the present work we have used the approach outlined above to study the high-lying neutron particle-hole states in ^{208}Pb populated by inelastic proton scattering on the $g_{9/2}$(14.92 MeV), $d_{5/2}$ (16.50 MeV), $s_{1/2}$ (16.97 MeV), and $d_{3/2}$ (17.47 MeV) analog resonances in ^{209}Bi. A 20.7-cm^3 coaxial Ge(Li) detector having an energy resolution of about 15 keV for the gamma rays of interest (5-8 MeV) was placed about 15 cm from the ^{208}Pb target. The target was bombarded with protons from the University of Washington High Voltage Engineering Corp. Model FN three-stage tandem accelerator, and gamma-ray spectra were recorded with an on-line computer. Figure 1 shows a portion of the gamma-ray spectra measured at the $d_{5/2}$, $s_{1/2}$, and $d_{3/2}$ resonances. Five prominent peaks (labeled b, c, e, g, and $^{16}O_{6.13}$) and a number of weaker ones are visible in these spectra. The strongest peak is due to oxygen contamination in the target and comes from the ground-state decay of the 3^- (6.131-MeV) states in ^{16}O. This peak together with one from the 3^- (2.609-MeV) state in ^{208}Pb was used for energy calibration. Table II summarizes the analysis of peaks found in these spectra. The criteria for inclusion of a peak in this table were the following: (a) It must be apparent in at least two independent experimental runs, (b) it must show resonant behavior, and (c) it must correspond closely in energy and in resonant behavior to a state observed in (p,p') measurements,[4] if such data are available.

Table I. Calculated gamma-ray angular distributions for ground-state transitions from neutron particle-hole states.

Configuration Particle	Configuration Hole	Spin and Parity of Particle-Hole State 1^-	Spin and Parity of Particle-Hole State 2^-
$d_{5/2}$	$p_{1/2}$	. . .	$1+\frac{4}{7}P_2-\frac{4}{7}P_4$
$d_{5/2}$	$f_{5/2}$	$1+\frac{16}{35}P_2$	$1-\frac{10}{49}P_2-\frac{18}{49}P_4$
$d_{5/2}$	$p_{3/2}$	$1-\frac{2}{35}P_2$	$1+\frac{10}{49}P_2+\frac{32}{49}P_4$
$s_{1/2}$	$p_{1/2}$	1	. . .
$s_{1/2}$	$f_{5/2}$	. . .	1
$s_{1/2}$	$p_{3/2}$	1	1
$g_{7/2}$	$f_{5/2}$	$1-\frac{5}{14}P_2$	$1+\frac{25}{294}P_2+\frac{32}{49}P_4$
$g_{7/2}$	$p_{3/2}$	. . .	$1+\frac{25}{49}P_2-\frac{18}{49}P_4$
$d_{3/2}$	$p_{1/2}$	$1-\frac{1}{2}P_2$	$1+\frac{1}{2}P_2$
$d_{3/2}$	$f_{5/2}$	$1-\frac{1}{10}P_2$	$1-\frac{5}{14}P_2$
$d_{3/2}$	$p_{3/2}$	$1+\frac{2}{5}P_2$	1

At the $d_{3/2}$ resonance, which populates most of the states observed, measurements were made at 55°, 90°, 110°, and 125° to obtain crude angular distributions of the gamma rays. These points were fitted with a distribution of the form $W(\theta)=a_0[1+a_2P_2(\cos\theta)]$ and the coefficients a_0 and a_2 were evaluated.

Table II summarizes the results of these measurements. The energies, ground-state branching fractions $F_{\text{g.s.}}$, and a_2 coefficients of the observed peaks are given. The ground-state branching fractions $F_{\text{g.s.}}$ were calculated using the extracted coefficient a_0 [except in the case of peak (d) where it was not available] and 90° cross section obtained from Ref. 4. This procedure neglects the effects of the inelastic proton angular

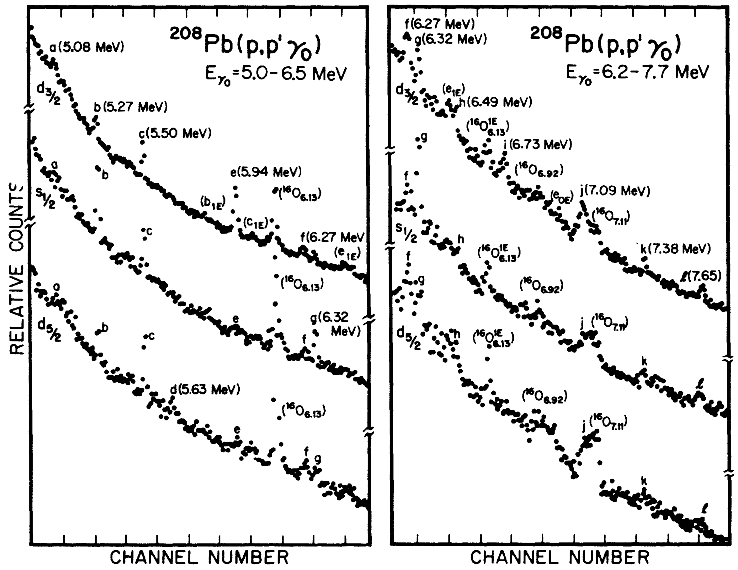

FIG. 1. High-energy portion of the gamma-ray spectra observed with a 20.7 cm^3 Ge(Li) detector at proton bombarding energies corresponding to analog resonances in ^{209}Bi. The peaks labeled a-k are identified as second-escape peaks from ground-state transitions in ^{208}Pb.

distribution. However, recent measurements of some of the angular distributions[9] indicate that the relative error thereby incurred is less than 10%. There is also an absolute error of about 25% on the branching fraction normalization due to the uncertainty in the detection efficiency of the Ge(Li) detector.

Table II also lists the energies of states observed in (p,p'), (d,p) and resonant gamma-ray absorption (γ,γ) reaction measurements[10] which we have associated with the states observed in the present work. The (d,p) reaction would be expected to select only states with $p_{1/2}$-hole configurations, and both of the states observed in that reaction have been found to have strong ground-state transitions[11] and are seen in Table II to have negative a_2 values, which is consistent, according to Table I, with a $(d_{3/2},p_{1/2}^{-1})_1$ configuration. The (γ,γ) reaction populates spin-one states via $E1$ or $M1$ transitions.[10] The states given in this column in parentheses are known to come from lead but not necessarily from ^{208}Pb. Since the particle-hole states we expect to populate have the particle and the hole in different major shells, they are likely to be negative parity.

There is a possibility that a high-lying 2^- neutron particle-hole state can have an observable $M2$ ground-state branch if its reduced nuclear matrix elements with low-lying collective states

Table II. Prominent gamma rays observed in ^{208}Pb$(p,p'\gamma_0)$.

Peak label	γ-ray energy (MeV)	Relative transition strength on resonance $d_{5/2}$	$s_{1/2}$	$d_{3/2}$	$F_{\text{g.s.}}$ (%)	a_2	Comparison with other data (p,p') State (Ref. 4) (MeV)	(d,p) State (Refs. 7 and 9) (MeV)	(γ,γ) State (Ref. 11) (MeV)	Assigned J^π	Footnotes
a	5.08	0.08	0.08	0.15	67 ± 12	0.46 ± 0.52	5.071	...	...	(1^-)	a
b	5.27	0.26	1.00	0.27	80 ± 8	−0.10 ± 0.38	5.284	5.28	...	1^-	
c	5.50	0.46	0.57	0.33	78 ± 7	−0.64 ± 0.38	5.505	...	5.52	1^-	b
d	5.63	0.15	...	...	45 ± 20	...	5.679	...	...	$(1,2)^-$	c
e	5.94	0.10	...	0.50	60 ± 2	−0.41 ± 0.16	5.936	5.93	(5.91)	1^-	d
f	6.27	0.14	0.13	0.14	45 ± 5	−0.18 ± 0.36	6.255		(6.25)	$(1,2)^-$	d
g	6.32	0.12	0.45	0.12	73 ± 12	−0.02 ± 0.49	6.304		...	1^-	
h	6.49	0.07	0.07	0.11	60 ± 8	0.21 ± 0.40	6.480		...	1^-	e
i	6.73	...	...	0.11	6.7 ± 0.8	0.14 ± 0.47	6.730		6.72	$(1,2)^-$	f
j	7.09	0.11	0.09	0.12	50 ± 4	0.21 ± 0.25	7.072		7.06	1^-	
k	7.38	0.04	0.07	0.06	...	0.52 ± 0.47			7.32	(1^-)	
l	7.65	0.02	0.05	0.04	...	0.93 ± 0.52			...		g

[a] (p,p') state at 5.071 resonates at the $i_{11/2}$ analog resonance (see text).
[b] (p,p') state at 5.505 shows considerable nonresonant strength (see text).
[c] (p,p') state at 5.679 was selected over state at 5.646 because the former resonantes only at the $d_{5/2}$ resonance.
[d] Parentheses around energies in (γ,γ) column indicate states not established to be from ^{208}Pb in Ref. 9.
[e] Plate gap in (p,p') data on $d_{3/2}$ resonance.
[f] Branching fraction is $\frac{1}{10}$ of other states observed (see text).
[g] Excitation energy of this state is about 300 keV above neutron binding energy in ^{208}Pb (see text).

are small. Such a branch has been observed in ^{16}O.[12] However, the ratio of the Weisskopf widths in ^{208}Pb for neutron single-particle transitions from a 2^- state at 6.3 MeV to the ground state and the 3^- (2.609-MeV) state is only $\Gamma(M2)_{6.3}/\Gamma(M1)_{3.7}=6\times10^{-4}$.

In Table II we have assigned $J^\pi=1^-$ in those cases where there is a large ground-state branching fraction, a definitely negative a_2, or a state also definitely observed in resonant gamma absorption. In several cases the data bear further comment, which will be given below.

State *a*.—Although this state has a sizeable ground-state branch it has been observed in (p,p') to resonate at the $i_{11/2}$ resonance. The latter behavior is unlikely for a 1^- state. Thus the state is either an unresolved doublet or the association of this gamma ray with the 5.071 (p,p') state is incorrect.

State *c*.—This state has considerable nonresonant strength in (p,p') and is presumably collective. Therefore the angular distribution considerations given above do not apply to this state.

State *i*.—This state has a small ground-state branch and was only observed because it was strong in (p,p'). This suggests that the ground-state branch is inhibited for reasons of structure or spin or that the (p,p') state is an unresolved doublet.

State *l*.—The excitation energy of this state is about 300 keV above the neutron binding energy in ^{208}Pb, and thus there is some question as to whether it could come from ^{208}Pb. It is apparently at the proper energy to arise from the first escape peak of the 7.115-MeV gamma ray from ^{16}O. However, this is unlikely because the expected second escape peak is not present in sufficient strength.

The present work could be substantially improved by using a Ge(Li) detector with better resolution. More careful angular distributions could provide specific information about the hole configurations of the states. In addition, it should be possible to apply the technique to a wide variety of nuclei.

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