to come out around 80 keV when all five rates were used in the minimum-χ^2 program. The ratio of K^{0*} to K^{+*} rate was also roughly 4. This last feature did not change appreciably in solutions 2 and 3 of Table II where four and three decay rates were used, respectively, to fit the parameters. In solution 3 the ρ radiative width agrees with the experiment and K^{+*} width is well within the experimental bound. The ω radiative width comes out to be less than half the experimental width but is consistent with the value of $\Gamma(\omega\to\pi\gamma)/\Gamma(\rho\to\pi\gamma)$ obtained in solutions 1 and 2.

We feel that it would be very desirable to repeat the $\rho^-\to\pi^-\gamma$ measurement and, if possible, to measure this rate in an e^+e^- experiment. The measurement of K^{+*} rate is very important to provide a check of SU(3) violations by comparing it with the K^{0*}.

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Photoneutron Polarization Studies of the Giant $M1$ Resonance in ^{208}Pb†

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The photoneutron polarization from states near threshold was measured, for the first time, for the reaction $^{208}\mathrm{Pb}(\gamma,n_0)^{207}\mathrm{Pb}$ throughout the neutron energy range 500 to 1000 keV. Spin and parity assignments were made for these states. The giant $M1$ resonance in ^{208}Pb was found to be less fragmented than previously thought. The data suggest that there is some "missing" $M1$ strength in ^{208}Pb.

Although there has been nearly a decade of speculation[1] concerning the existence of a giant $M1$ resonance, data on the characteristics of the collective $M1$ strength in nuclei have remained sparse and inconclusive. In general, the $M1$ strength in photonuclear reactions should be enhanced at those energies corresponding to spin-flip transitions of nucleons between the filled and empty members of spin-orbit partners. An ideal nucleus for observation of such a collective $M1$ effect is ^{208}Pb. Theoretical calculations of the strength of the $M1$ resonance in ^{208}Pb have taken two distinct forms. Vergados[2] and Lee and Pittel[3] have followed the precedent of Arima and Horie[4] by employing the concept of configuration mixing and a free-nucleon $M1$ operator to the calculation of the $M1$ ground-state radiation width, whereas Ring and Speth[5] chose to renormalize the $M1$ operator in a phenomenological way in order to account for configuration mixing and mesonic effects.[6] The discrepancies between the results of the two theories are large. The ground-state radiation width of the isovector part of the $M1$ resonance was calculated to be 79 eV and located at 7.5 MeV in Ref. 2, but only 21.7 eV at 8.3 MeV in Ref. 5.

Clearly it is essential to know the resonance parameters of the states near threshold in ^{208}Pb if we are to understand the $M1$ giant resonance. Unfortunately, the parities of the states above 7.68 MeV could not be determined unambiguously from the photoneutron angular distributions measured in previous experiments.[7,8] In this Letter, we report the results of a threshold photoneutron experiment in which the polarization of the emitted photoneutrons has been measured throughout the neutron energy range 500 to 1000 keV. This work represents the first measurement of polarization of photoneutrons from resonances near threshold. Observations of the photoneutron polarization together with the angular-distribution measurements permit assignments of the spins and parities of these resonances.

The present work exploits the pulsed, high-current electron linac available at the Argonne National Laboratory. An energy-analyzed, 9-MeV electron beam with a peak current of 10 A, a pulse width of 4 nsec, and a rate of 800 sec^{-1} is focused onto a 0.2-cm-thick silver converter. The bremsstrahlung from this process then irradiates a plate (5 cm × 2.5 cm × 0.5 cm thick) of isotopically enriched ^{208}Pb (99.1% pure ^{208}Pb). Photoneutrons from this reaction travel through a well-collimated, 9-m flight path which is at an angle of either 90° or 135° with respect to the electron-beam axis. At the end of this flight path the neutrons scatter from a liquid ^{16}O target (7.5-cm-diam cylinder) which acts as a neutron polarization analyzer. The neutrons scatter from the ^{16}O target into two scintillation counters which are placed at angles of ±50° with respect to the neutron beam axis. The counters (12.5-cm × 10.0-cm × 3.8-cm-thick NE110 plastic scintillator) are located at 0.4 m from the center of the ^{16}O scatterer.

In the present work the shapes of the threshold photoneutron spectra were particularly sensitive to small shifts of the detector gains. False asymmetries in the neutron polarization measurements can arise from these gain shifts. Hence, it was necessary to hold the detectors fixed and precess the neutron spins with a solenoid in order to reduce these false asymmetries to negligible amounts. A solenoid, 1.5 m long and 10 cm i.d., is located 5 m along the flight path. The maximum axial field is 1.5 kOe, which is sufficient to precess a 1-MeV neutron through 180°. This solenoid was designed for use with a continuous spectrum of neutrons using the general method of Nath *et al.*[9] Since the spectrum of photoneutrons from ^{208}Pb is continuous, it was necessary to determine the angle of precession at each measured energy. The angles of precession were taken into account [see Eqs. (7) and (20) of Ref. 9] in extracting the final polarizations. The neutron time-of-flight spectra were recorded with and without the magnetic field. The spectra observed at 135° are shown in the lower half of Fig. 1. The power of the spin-precession technique can be seen by observing that the relative magnitudes of the spectra at ±50°

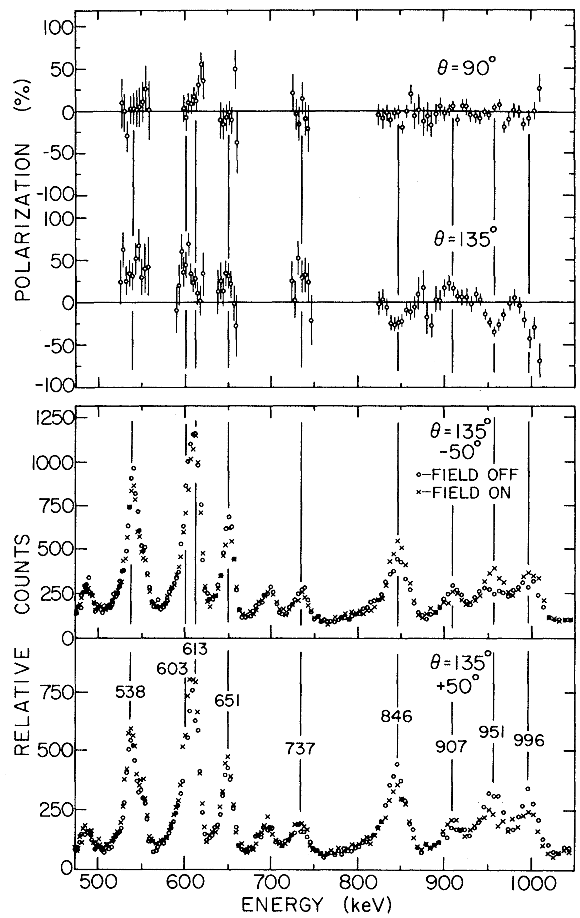

FIG. 1. Upper half: The measured photoneutron polarization in the energy range 500 to 1000 keV at angles of 90° and 135°. The error limits are primarily statistical in nature. Only the 613-keV resonance emits polarized neutrons at *both* 90° and 135°. Lower half: The raw time-of-flight spectra observed at 135° for neutron scattering angles of ±50° with and without the solenoidal field.

with the solenoid off are interchanged with those with the solenoid on for polarized neutrons. The analyzing power of ^{16}O is relatively high throughout the neutron energy range 300 to 1000 keV. The analyzing power was found by using the R-matrix parameters of Hickey *et al.*[10] The scattering angle of 50° was selected to give the highest analyzing power in this energy range. The analyzing power at 50° varies from 60% at 350 keV to −98% at 950 keV and passes through zero at 476 keV. The analyzing power of ^{16}O was corrected for finite-geometry effects and multiple-neutron-scattering effects using a modified version of the code of Stinson, Tang, and Sample.[11] These effects were found to be less than 10% of the analyzing power in the energy range 500 to 1000 keV.

Nearly all of the resonances below a neutron energy of 1 MeV in ^{208}Pb can be treated as isolated levels ($\langle D\rangle \approx 15$ keV). Hence, the expression for the photoneutron differential polarization for the reaction $^{208}Pb(\gamma, n_0)^{207}Pb$ is given[12] by

$$\frac{d\vec{p}}{d\Omega} = \hat{k}\lambda_\gamma^2\{(0.33a_s a_{p_0}\sin\Delta_{p_0 s} + 0.23a_s a_{p_1}\sin\Delta_{sp_1})\sin\theta + 0.20a_s a_d \sin\Delta_{ds}\sin 2\theta\}, \tag{1}$$

where a_s, a_p, and a_d are the amplitudes for s-, p-, and d-wave neutron emission, respectively, and, e.g., $\Delta_{sd} = \delta_s - \delta_d$ is the phase difference. The subscripts 0 and 1 refer to the p-wave channel spins. Here $\hat{k}$ is a unit vector whose direction is perpendicular to the reaction plane and λ_γ is the reduced wavelength. The term $-0.20\hat{k}\lambda_\gamma^2 a_{p_0}a_{p_1} \times\sin\Delta_{p_0p_1}\sin 2\theta$ was eliminated from the above expression. The phase Δ_{ij} for an isolated level is given, to the first order, by the difference between the potential scattering phase shifts. Hence, $\Delta_{p_0p_1} = \varphi_{p_0} - \varphi_{p_1} = 0$, to first order, for isolated resonances. This expression demonstrates the power of the photoneutron polarization measurement for defining the parities of states in ^{208}Pb. We assume that the relative orbital angular momentum of the emitted neutron is $l \leq 2$. A pure $E1$ resonance will decay by only s- and d-wave neutron emission. Hence, the shape of the differential polarization for $E1$ states is $\sin(2\theta)$ in form. An isolated $M1$ resonance gives no polarization. A resonance with $E1$-$M1$ interference decays by s- and p-wave neutron emission and gives rise to $\sin\theta$ dependence of the polarization. Therefore the polarization due to a pure $E1$ resonance will have a maximum value at 135°, but no contribution at 90°. A resonance with $E1$-$M1$ mixing will have a nonzero value of polarization at both angles. The possibility of $E2$ resonances occurring in this energy region has been eliminated on the basis of angular-distribution measurements.[7,8] In addition, an estimate was made for the amount of $E2$ strength one might expect in the energy region 7.56 to 8.38 MeV. It is believed[13] that a collective $E2$ resonance exists in ^{208}Pb at a mean excitation of 10.8 MeV. Using the total reduced transition probability (6000 fm^4) for the 10.2-, 10.6-, and 11.2-MeV resonances and a Lorentzian curve with a total width of 2.7 MeV, a ground-state radiation width of 3.9 eV was calculated for this energy region. This small amount of strength spread over 820 keV would have a negligible effect on the results. The results of the present measurements are also shown in Fig. 1. Here the 538-, 651-, 737-, 846-, 907-, 951-, and 996-keV states in ^{208}Pb emit neutrons with a zero polarization at 90° and a nonzero polarization at 135°. We conclude that these resonances are $E1$.

In the region of the 603–613-keV resonances, the nonzero polarization at 90° is due to $E1$-$M1$ interference. In order to determine which of the two overlapping levels is the $M1$ resonance, a calculation was made using Eq. (1) and a Breit-Wigner shape for the amplitudes,

$$|a_l|^2 = \Gamma_{\gamma_0}\Gamma_l/[(E_r - E)^2 + (\Gamma/2)^2],$$

where l refers to the relative orbital angular momentum of the outgoing neutron, and Γ_l and Γ are the partial and total widths, respectively. The phases $\Delta_{l_1 l_2}$ were chosen as hard-sphere phase-shift differences. The Γ_{γ_0} and Γ were taken from Ref. 8 and from Allen and Macklin.[14] The partial neutron widths were fixed using the angular-distribution measurements. A triangular resolution function was folded in with the calculated polarization. The results of this calculation are compared with the observed polarizations in Fig. 2. The assignments of 1^- to the 603-keV level and 1^+ to the 613-keV level provide the best representation of the observations.

This work is in disagreement with that of Bowman *et al.*[7] who assigned positive parities to the 651- and 846-keV states. From the present work, it is clear that Bowman *et al.*[7] underesti-

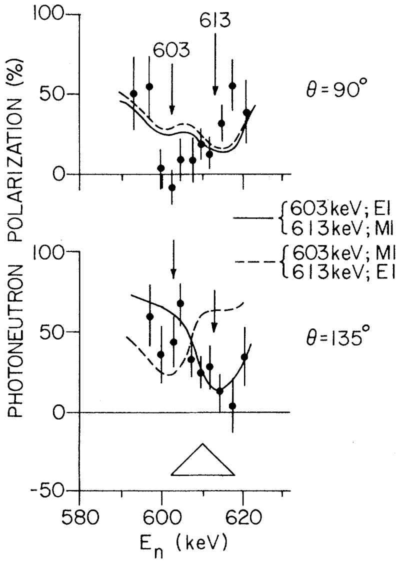

FIG. 2. The curves represent the calculated polarization using the isolated-level approximation [Eq. (1)] in the region of the 603–613-keV resonances. The triangle represents the energy resolution of the time-of-flight spectrometer.

mated the effect of the $l=2$ partial waves on the observed angular distributions. A summary of the present work is given in Table I. The ground-state radiation widths in Table I were taken from Ref. 8. In the neutron energy range 500 to 1000 keV the only observed $M1$ state is at 613 keV with a width of 19.7 eV. The only other possible unbound states which could be $M1$ are the 315- and 181-keV resonances. Harvey[15] determined that the 315-keV state may be an $E1$ excitation, while Toohey and Jackson[8] have shown that the 181-keV resonance is probably an $M1$ transition with a width of 9.9 eV. Together, the widths of the 181- and the 613-keV states ($\Gamma_\gamma = 29.6$ eV) account for less than half of the predicted[2,3] width ($\Gamma_{\gamma_0} = 79$ eV). Another consideration is that more than half of the $M1$ strength expected for ^{207}Pb was observed at 7.5 MeV by Medsker and Jackson.[16] These facts suggest that there is some missing $M1$ strength in ^{208}Pb. Of course, the expected $M1$ strength might be below the photoneutron threshold. Although Lindgren *et al.*[17] have reported evidence for the existence of bound $M1$ resonances in ^{208}Pb, the amount of $M1$ strength below threshold remains unknown. However, if we speculate that the 181- and the 613-keV resonances are the only $M1$ excitations in this energy region, then the results are in remarkable agreement with the calculations of Ring and Speth.[5]

TABLE I. Summary of results from the threshold photoneutron polarization experiment.

E_r (keV)	Polarization $\theta = 90°$	$\theta = 135°$	J^π	Γ_{γ_0}[a] (eV)
996	No	Yes	1^-	5.8
951	No	Yes	1^-	3.5
907	No	Yes	1^-	6.5
846	No	Yes	1^-	10.1
737	No	Yes	1^-	3.5
651	No	Yes	1^-	11.8
613	Yes	Yes	1^+	19.7
603	No	Yes	1^-	8.0
538	No	Yes	1^-	12.8

[a]Values of Γ_{γ_0} were taken from Ref. 4.

The predictions[5] are that $E_1 = 7.50$ (7.56) MeV, $\Gamma_{\gamma_{01}} = 9.47$ (9.9) eV, and $E_2 = 8.30$ (7.99) MeV, $\Gamma_{\gamma_{02}} = 21.67$ (19.7) eV. The numbers in parentheses are the measured[8] values.

In conclusion, the feasibility of using a high-current linac for the measurement of polarization of threshold photoneutrons from the reaction ^{208}Pb$(\gamma, n_0)^{207}$Pb has been demonstrated. In the region 500 to 1000 keV, $E_{exc} = 7.88$ to 8.38 MeV, only the 613-keV level, which corresponds to an excitation energy of 7.99 MeV, is 1^+. Hence, the giant $M1$ resonance in ^{208}Pb is not as fragmented in this energy region as previously believed.

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Intracollisional Interference in the Spectrum of HD Mixed with Rare Gases*

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We present the first observation and interpretation of an interference effect in the infrared absorption spectrum of HD–rare-gas mixtures. This effect, due to constructive or destructive interference between allowed and collision-induced dipoles during a collision, is referred to as "intracollisional interference." Is is manifested by the appearance of a narrow line at the $R_1(1)$ position which increases with rare-gas density. This interference has relevance to the determination of HD abundance in planetary atmospheres.

As was first pointed out by Wick[1] in 1935, the HD molecule has an allowed electric dipole vibration-rotation spectrum. Because the allowed dipole arises from the nonadiabatic breakdown of the Born-Oppenheimer approximation, it has a small magnitude of the order of 10^{-3} D. The infrared spectrum of HD was first observed by Herzberg[2] in 1950, and more recently by Trefler and Gush,[3] in the pure rotational, and by Bejar and Gush,[4] and by McKellar[5,6] in various vibrational bands.

Collision-induced spectra occur quite generally and are due to absorption by the transient dipole created in a pair of molecules during a collision (for a recent review see, e.g., Welsh[7]). Most work in this area has been done with molecules that do not have allowed infrared dipole spectra, e.g., H_2 and N_2. Mixtures of homonuclear diatomic molecules with inert gases have also been extensively studied. For the collision-induced spectrum of a dipolar gas, the possibility of an interference between the two types of dipoles (allowed and induced) discussed above should be considered. In the present paper we