from the region of the continuum populated following the last neutron evaporation. The absence of fast side feeding to the 10^+ and 12^+ states suggests that at the peak of the $4n$ reaction the probability for entering ^{158}Er with initial angular momentum in the range $(9-13)\hbar$ is small, presumably because of the preferential evaporation of a fifth neutron in low-angular-momentum collision.[11]

If one interprets the "backbending" of the curve of the nuclear moment of inertia versus the square of the rotational frequency for the ^{158}Er ground band (Ref. 3) as indicative of the nucleus undergoing a phase change, then the 18^+ and 16^+ levels should belong to the "normal phase," whereas the 12^+ level (and down) should belong to the "superconducting phase." One would expect that the $B(E2;16^+\rightarrow 14^+)$ and $B(E2;14^+\rightarrow 12^+)$ would be inhibited relative to the rotational value, but this is not the case according to the present measurements. We hope that these results will stimulate detailed calculations of $B(E2)$ values in the neighborhood of the "phase change" in ^{158}Er.

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Mixing of Two-Particle, Two-Hole States in ^{208}Po†

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States of ^{208}Po up to an excitation energy of 2 MeV have been investigated via the two-neutron pickup reaction ^{210}Po$(p,t)^{208}$Po. We have extracted angular distributions for the five observed states of ^{208}Po and have made J^π assignments. These states are discussed in terms of the excitation of simple modes observed in ^{206}Pb and ^{210}Po. Matrix elements have been extracted for the interaction between the two-neutron-hole 2^+ excitations and the two-proton-particle 2^+ excitations and compared with simple theoretical estimates.

A well-known feature of the excitation spectra of spherical even-even nuclei is the low-energy collective 2^+ state. It is usually the first excited state and is strongly excited in both inelastic scattering and two-nucleon transfer reactions. Its properties have been discussed extensively in the literature[1,2] both in terms of microscopic wave functions resulting from some residual interactions and also as an elementary excitation mode or "building block" of the nuclear excitation scheme. Both these approaches have been applied successfully in the lead region. In the present paper we address ourselves to the question of what role the neutron-proton force plays in the generation of these states. In the vicinity of a doubly magic nucleus, as ^{208}Pb, some of the elementary excitations may be characterized as specifically particle or hole type as well as neutron or proton type, and the question becomes, to what extent are neutron- and proton-type build-

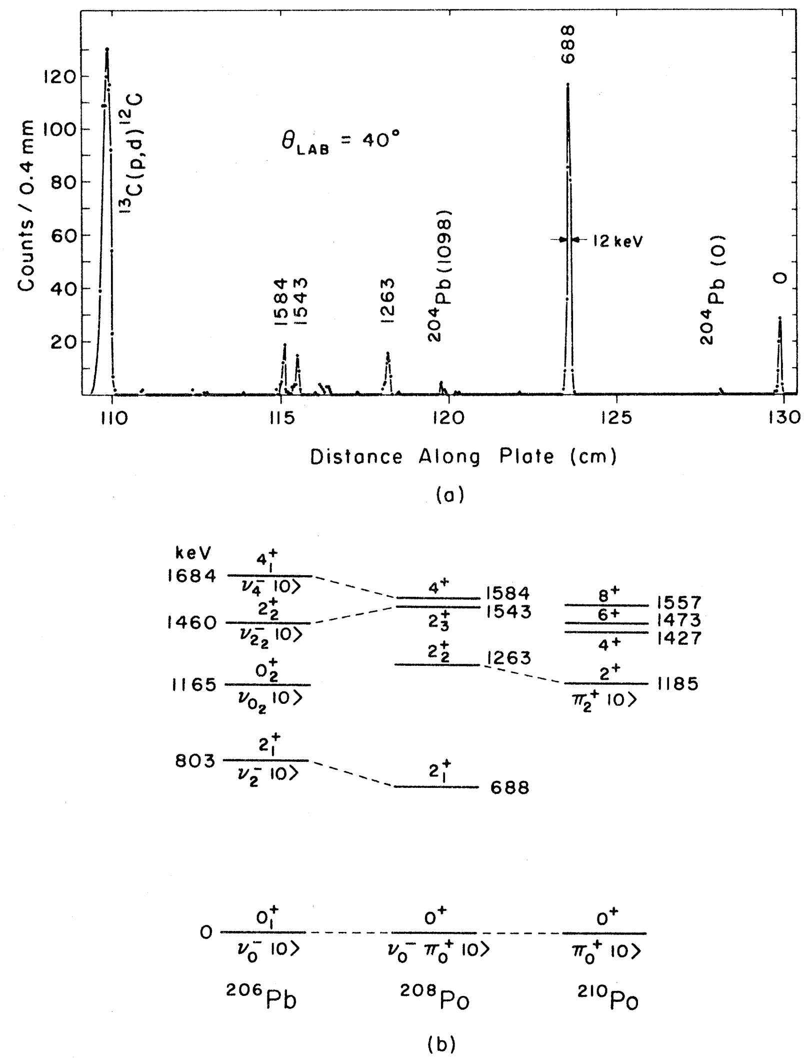

FIG. 1. (a) Triton spectrum observed for the reaction ^{210}Po$(p,t)^{208}$Po at 17.8 MeV proton energy at 40°. (b) Comparison of the level schemes of ^{206}Pb, ^{208}Po, and ^{210}Po. Only natural-parity states are shown.

ing blocks independent? Noting that the two-neutron-hole 2^+ state in ^{206}Pb is at 803 keV and the two-proton-particle 2^+ state in ^{210}Po is at 1185 keV, we focus our attention on ^{208}Po where both modes could exist independently but where any coupling between the two modes would cause a mixing of the wave functions with a consequent shift in energies. In the present experiment these shifts have been determined and interpreted in terms of matrix elements connecting these two excitation modes.

The two-proton-particle, two-neutron-hole states in ^{208}Po have been studied via the two-neutron pickup reaction ^{210}Po$(p,t)^{208}$Po using a 17.8-MeV proton beam from the University of Pittsburgh three-stage tandem accelerator. The tritons were momentum analyzed and recorded on photographic emulsions placed along the focal plane of the Enge split-pole spectrograph. The overall energy resolution was about 12 keV full width at half-maximum. Angular distributions were obtained for states in ^{208}Po for the angular range $10° < \theta < 58°$. The details of the experimental setup and of the fabrication technique for this radioactive target have been given elsewhere.[3] Figure 1(a) shows a triton spectrum at $\theta_{\rm lab} = 40°$. Because ^{210}Po (138.4 days) decays by α emission to ^{206}Pb, the triton groups leading to the ground state and the 1.098-MeV state of ^{204}Pb were also observed [see Fig. 1(a)]. The angular distribution of tritons from the reaction ^{210}Po$(p, t)^{208}$Po are shown in Fig. 2(b). Figure 2(a) shows

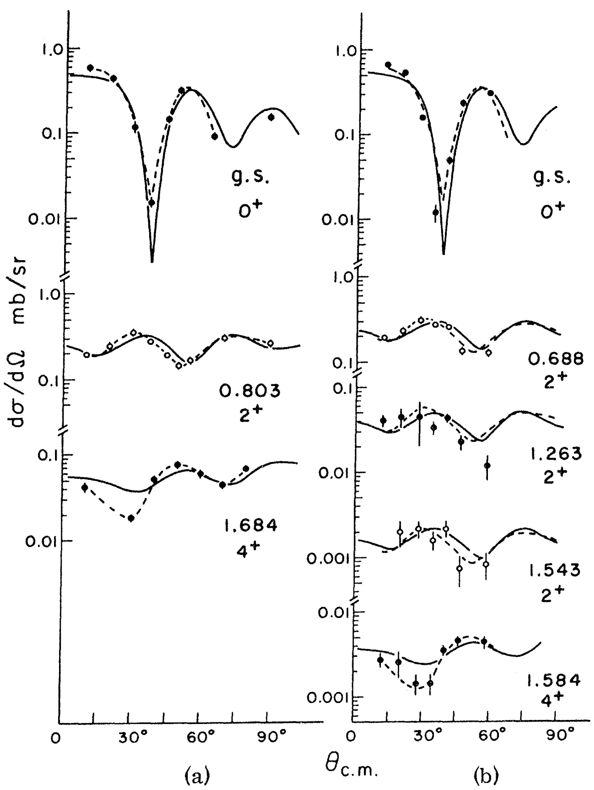

FIG. 2. Angular distributions of tritons from the reactions (a) ^{208}Pb$(p,t)^{206}$Pb and (b) ^{210}Po$(p,t)^{208}$Po, both at 17.8 MeV beam energy. The solid curves are the distorted-wave Born-approximation predictions; for the reaction ^{208}Pb$(p,t)^{206}$Pb, the dashed curves are drawn through the ^{206}Pb data points and serve as the empirical $l=0$, 2, and 4 templates. The Po data are compared with these templates in (b).

the angular distribution of tritons from the reaction ^{208}Pb$(p,t)^{206}$Pb to the known 0^+, 2^+, and 4^+ states of ^{206}Pb measured[4] under identical conditions. The solid curves are the predictions of the distorted-wave analyses for the (p,t) reactions on ^{208}Pb and ^{210}Po. The dashed lines connect the data points for the ^{208}Pb(p,t) experiment and serve as empirical $l=0$, 2, and 4 curves. These curves have been used as templates for the ^{210}Po(p,t) case, and, by comparison, values of the l transfer (and hence J^π) for the states of ^{208}Po have been assigned.

The five observed states of ^{208}Po are compared with the levels of ^{206}Pb and ^{210}Po in Fig. 1(b). The dashed lines connect states we interpret as having similar character. This is based primarily on the analogy with the two-neutron pickup reaction ^{208}Pb$(p,t)^{206}$Pb. Thus levels corresponding to the ground state and the first two 2^+ and the first 4^+ states of ^{206}Pb are seen. A level corresponding to the first excited 0^+ state in ^{206}Pb at 1165 keV is not seen in ^{208}Po. The weak level at 1263 keV we identify with the proton-correlated 2^+ state of ^{210}Po at 1185 keV. The total intensity of the $l=0$ transition and the sum of the intensities of the three $l=2$ transitions observed in ^{208}Po are equal (within $\pm 10\%$) to those observed for the ^{206}Pb ground state and two 2^+ states, respectively. The 1584-keV 4^+ state in ^{208}Po has only about 75% of the 1684-keV 4^+ state in ^{208}Pb.

We interpret the observation of the 1263-keV state in ^{208}Po in this two-neutron pickup reaction as an indication of mixing of the neutron and proton 2^+ excitation modes. (In the following discussion, the contributions arising from two-step processes are assumed to be negligible.) In order to extract the matrix element implied by the level shifts, we adopt the obvious notation for the levels in ^{206}Pb and ^{210}Po indicated in Fig. 1(b). The unperturbed states in ^{208}Po are denoted: 0_1 as $\nu_0^-\pi_0^+|0\rangle$, 2_1 as $\nu_2^-\pi_0^+|0\rangle$, 2_2 as $\nu_0^-\pi_2^+|0\rangle$, and 2_3 as $v_{2_2}^-\pi_0^+|0\rangle$. Here v_J^- and v_J^+ refer to neutron-hole pairs and proton-particle pairs coupled to angular momentum J. In the simplest model, where these 2^+ states are independent excitation modes and no mixing of wave function occurs, the reaction ^{210}Po(p,t) would only excite two 2^+ states in ^{208}Po, 2_1 and 2_3, at the unperturbed energies of 803 and 1460 keV, respectively. The state 2_2 involves excited proton configurations and should not be excited. Thus the observation of three 2^+ states is an indication of a partial breakdown of this model.

By simple perturbation calculations, we have estimated the matrix elements connecting the unperturbed levels. First, in a model involving only two levels, i.e., ignoring the 1.543-MeV state of ^{208}Po, we obtain from the observed energy shifts a value of $|V_{12}|\simeq 217$ keV, where V_{12} denotes the matrix element between the two levels. This predicts that the (p,t) reaction should populate the 2_1^+ and 2_2^+ states with relative intensities of 0.83 and 0.17, respectively. The sum of these two intensities should equal the intensity for the 2_1^+ state in ^{206}Pb for the reaction ^{208}Pb$(p,t)^{206}$Pb. The experimental results (see Table I) support these predictions.

For the three-level perturbation calculation, we assume there is no interaction between the 2_1^+ and 2_3^+ unperturbed levels, i.e., $V_{13}=0$. This is justified since the locations of the corresponding states in ^{206}Pb, which we are using as the un-

TABLE I. Intensities (μb/sr) for the 2^+ states of ^{206}Pb and ^{208}Po observed in the (p,t) reaction.

	^{208}Pb(p,t)^{206}Pb		^{210}Po(p,t)^{208}Po		
	2_1^+(0.803)	2_2^+(1.465)	2_1^+(0.688)	2_2^+(1.263)	2_3^+(1.543)
Observed Intensities	380	29	310	60	22
Calculated Intensities for the 2-level model assuming that the 2_3^+(1.543) state of ^{208}Po does not mix. This gives V_{12}=217 keV.			315	65	22
Calculated Intensities for the 3-level model but assuming V_{13} = 0. This gives V_{12} = 250 keV V_{23} = 120 keV.			300 ± 10	77 ± 40	33 ± 28

perturbed energies for the three-level calculation, already include the effects of such an interaction. Under this constraint the calculation gives $|V_{12}|\simeq 250$ keV and $|V_{23}|\simeq 120$ keV. The predicted intensities for the 2^+ levels of ^{208}Po on the basis of both the two-level model as well as the three-level model are summarized in Table I together with the experimental results. The errors in the predicted intensities are due to the uncertainties of the phases of the wave functions.

It is interesting to estimate the matrix element V_{12} connecting two-neutron-hole and two-proton-particle 2^+ excitation modes. We follow a procedure used[5-7] for the interaction of two-neutron-hole and two-neutron-particle 2^+ modes observed in ^{208}Pb. In that case the two ^{208}Pb states are $[^{206}\text{Pb}(2^+)\otimes {}^{210}\text{Pb}(0^+)]$ and $[^{206}\text{Pb}(0^+)\otimes {}^{210}\text{Pb}(2^+)]$ which in our notation are $\nu_2^-\nu_0^+|0\rangle$ and $\nu_0^-\nu_2^+|0\rangle$, respectively. Here the interaction matrix element, $V_{12}(^{208}\text{Pb})$, extracted from the observed shifts,[5] is ~125 keV. This matrix element has been estimated[6,7] by using a standard microscopic particle-vibration coupling Hamiltonian, namely $H_c = k_2(r)\sqrt{5}\,\sum_i[a_2Y_2(i)]_0$. The resulting matrix element is

$$V_{12}(^{208}\text{Pb}) = \frac{\langle k_2\rangle[b_2(210)b_2(206)]^{1/2}}{5Ze_{\text{eff}}(206)}$$

$$\simeq 0.012\,\langle k_2\rangle \quad (e_{\text{eff}}=1).$$

Here the quantity $b_2(A) = B(E2,A;0^+\to 2^+)/B(E2)_{\text{sp}}$. With a value of $\langle k_2\rangle = 50$ MeV, $V_{12}(^{208}\text{Pb})$ becomes ~600 keV. In order to explain this large overestimate, Broglia, Parr, and Bes[6] have introduced a coupling to an isovector quadrupole mode which reduces the above result.

This treatment (without the isovector quadrupole mode) is directly applicable to the ^{208}Po case. The only difference in the expression for V_{12} is that $b_2(^{210}\text{Pb})$ must be replaced by the $b_2(^{210}\text{Po})$. The two b_2 values have been measured[3,8] and have both been determined relative to the b_2 of ^{206}Pb. Thus the ratio of the b_2's is well determined and is

$$b_2(^{210}\text{Po})/b_2(^{210}\text{Pb}) = \tfrac{1.4}{3.5}.$$

Therefore the predicted matrix element for ^{208}Po becomes

$$V_{12}(^{208}\text{Po}) = [\tfrac{1.4}{3.5}]^{1/2}V_{12}(^{208}\text{Pb}) \simeq 380 \text{ keV}.$$

This may be compared with the value of 250 keV derived above from the experimental data. Thus, in the present ^{208}Po case the experimentally determined value is somewhat smaller than the simple estimate, but the discrepancy is not nearly so large as in ^{208}Pb.

It may be concluded from this investigation that there is a coupling between the neutron and proton excitation modes in ^{208}Po which may be represented by a matrix element of approximately

250 keV. The estimate of this matrix element with a simple model yields a value which is just 50% larger than this experimentally determined value, whereas a similar comparison in ^{208}Pb showed a factor of ~5 difference. There is, therefore, no *a priori* need to introduce the isovector mode in the ^{208}Po case. It is, however, not clear what the effect of the isovector mode would be in this case, since the coupling is between protons and neutron holes, whereas in ^{208}Pb the coupling is between neutrons and neutron holes. It will be important to determine whether the introduction of the isovector quadrupole mode can explain simultaneously the large deviation from the simple model in ^{208}Pb and the near agreement in ^{208}Po.

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Test of *CP* Noninvariance in the Decay $K^{\pm} \to \pi^{\pm}\pi^0\gamma$†

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A careful search has been made for possible *CP*-nonconserving differences between $K^+ \to \pi^+\pi^0\gamma$ and $K^- \to \pi^-\pi^0\gamma$ decays. In a sample of over 4000 completely reconstructed decays in the charged-pion kinetic-energy interval of 51 to 100 MeV, the asymmetry is 0.005 ± 0.020, with a systematic uncertainty of ± 0.022, indicating no evidence for a *CP*-invariance violation. This result, combined with that obtained from the sum spectrum, suggests that the direct emission is largely magnetic dipole.

In a previous paper,[5] we presented evidence for direct emission in this decay which confirmed the possibility that a *CP*-invariance violation could be observed. In particular, if the direct emission of the magnitude observed were largely due to a *CP*-nonconserving electric-dipole transition, we could expect an asymmetry $(R^+ - R^-)/(R^+ + R^-)$ in the decay rates $R^{\pm}$ up to approximately 0.06 in the charged-pion kinetic-energy interval of 51 to 1000 MeV. Furthermore, in some region of the Dalitz plot an asymmetry as large as approximately 0.2 could be observed. In the present paper we compare $K^+ \to \pi^+\pi^0\gamma$ with $K^- \to \pi^-\pi^0\gamma$ decays and set limits on the asymmetry.

The $\pi^{\pm}\pi^0\gamma$ decay mode was studied from kaon decays in flight in an experiment performed in a 1.8-GeV/c partially separated beam at the Brookhaven National Laboratory alternating gradient synchrotron. The incident kaon and its charged decay pion were recorded with a core read-out wire-spark-chamber spectrometer. The conversion points of the three γ's were recorded in a γ detector[6] which consisted of eight layers of lead, an optical spark chamber, and