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Experimental and theoretical multipole mixing ratios in transitions of ^{208}Pb

F. T. Avignone, III and S. M. Blankenship
Department of Physics, University of South Carolina, Columbia, South Carolina 29208

William W. True
Department of Physics, University of California, Davis, California 95616
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γ-γ directional correlations of the 277-583, 511-583, 722-583, 763-583, and 861-2615 keV cascades have been measured. The data support the spin and parity assignments of $(J\pi) = (6-)$ and $(5-)$ to the 3920 and 3961 keV levels, respectively. The following experimental multipole mixing ratios were extracted from the data: $\delta(277) = +0.0080 \pm 0.011$, $\delta(511) = -0.052 \pm 0.045$ or -0.68 ± 0.08, $\delta(722) = +0.31 \pm 0.07$, $\delta(763) = -0.01 \pm 0.06$, and $\delta(861) = +0.015 \pm 0.012$. These mixing ratios were also calculated in the framework of the particle-hole model with the following results: $\delta(277) = +0.0098$, $\delta(511) = +0.0196$, $\delta(722) = +0.1915$, $\delta(763) = -0.0653$ or $+0.0219$, and $\delta(861) = +0.0154$. The two possible values of $\delta(763)$ correspond to the two theoretically predicted $(5-)$ states at 4.00 and 4.18 MeV, respectively.

RADIOACTIVITY ^{228}Th; measured $\gamma\gamma(\theta)$; deduced δ for γ rays in ^{208}Pb.
NUCLEAR STRUCTURE ^{208}Pb; calculated δ for same γ rays in ^{208}Pb. Particle-hole model.

I. INTRODUCTION

Doubly-magic ^{208}Pb is probably the best nucleus in the Periodic Table to use as a core in shell model calculations. This core appears to retain its "integrity" in single or multiple particle-hole, in multiple hole, and in multiple particle excitations, as shell model calculations have shown. (For example, see Refs. 1–7 as well as references contained in these papers.)

These shell model calculations produce energies and wave functions which can then be used to compare quantities predicted with them to the corresponding experimental values. Within the approximations used, the calculated energies of the ground state and excited states are usually in fairly good agreement with the experimental observations. A far more stringent test of the model is the prediction of observables which depend on the details of the nuclear wave functions. These wave functions in shell model calculations are usually expressed as linear combinations of the basis states of the model space used. Some experiments, stripping reactions[8] for example, may depend on the magnitude of the amplitudes of the various components of the wave functions. On the other hand, experiments measuring electric and magnetic moments, electric transition rates, $E2$ and $M1$ branching ratios, and $E2/M1$ mixing ratios[9,10] are sensitive to both the amplitudes and phases of the various components of the wave functions. This paper deals with the comparison of experimental and theoretical $E2/M1$ mixing ratios.

The goal of the present investigation is the direct comparison of five theoretical $E2/M1$ multipole mixing ratios calculated using the wave functions of True, Ma, and Pinkston[1] with those measured in γ-γ directional correlation experiments. Unfortunately, this could not be done without further experimental effort because such measurements involve some fairly weak transitions following the β^- decay of ^{208}Tl and there are many conflicting results in the literature. The experimental results presented here should clarify some of these issues as well as represent values which can be directly compared to the theoretical predictions in a meaningful way.

An early compilation of experimental data concerning ^{208}Pb up to 1971 is presented by Lewis,[11] while a recent extensive bibliography is given by Wagner *et al.*[12]; hence, we shall not attempt to present discussion of those data, except where it directly pertains to the present investigation. One of the currently accepted decay schemes and a presentation of earlier γ-γ directional correlation measurements involving mainly the stronger transitions is given by Jagam and Murty.[13] In addition, we have carefully considered the spin and parity assignments proposed by Igo, Barnes, and Flynn[14] based on data from the reaction ^{210}Pb-$(p,t)^{208}$Pb, those proposed by Nellis and Morgan[15] based on data from ^{208}Pb$(n,n',\gamma)^{208}$Pb reactions, and those proposed independently by Heusler and von Bretano[16] and by Wagner *et al.*[12] based on data from (p,p') and (p,p) reactions, respectively.

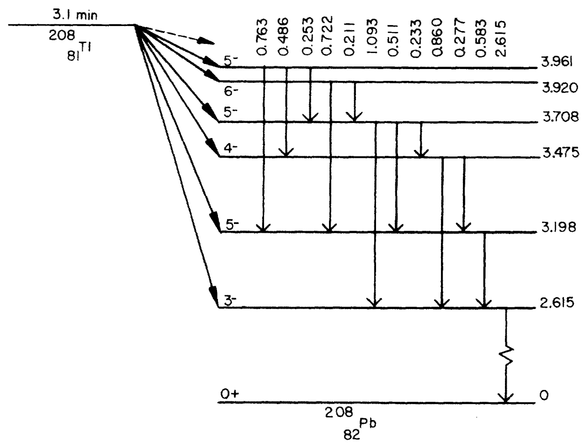

FIG. 1. Current decay-scheme of $^{208}_{82}$Pb from the β decay of $^{208}_{81}$Tl.

Combining these earlier assignments with the results of the present investigation we have sufficient decay scheme information in order to interpret the directional correlation data and to extract the multipole mixing ratios. The decay scheme is shown in Fig. 1.

II. EXPERIMENTAL PROCEDURE AND RESULTS

The directional correlation experiments were performed using an automated Ge(Li)-Na(Tl) coincidence spectrometer. The 33 cm^3 Ge(Li) detector was fixed and the 7.6 × 7.6 cm NaI(Tl) detector was rotated about an axis through the radioactive source. Standard coincidence techniques were employed and the coincidence pulse was used to gate a split-memory multichannel pulse-height analyzer whose input was the Ge(Li) detector energy spectrum. In this way, the pulse-height spectrum from the Ge(Li) detector, which is in coincidence with a given γ-ray observed in the NaI(Tl) detector, is stored in sections of the memory which each correspond to a given angle between detector axes. The moving NaI(Tl) detector was powered with a gain stabilized power supply and its angle was changed every 15 min. In addition, singles counting rates as well as the coincidence rate were printed every 15 min as a running stability check.

The radioactive source was a ~150 μC source of ^{228}Th which decays through a series of four α decays, a β decay followed by another α decay to 3.1 min ^{208}Tl which then decays by β^- emission to the excited levels of ^{208}Pb. The source was electrodeposited onto a fine gold wire 1.5 mm in length and placed in a small hole in a 2 mm diam cylindrical Lucite source holder. Earlier measurements of the strong correlation of the 583-2615 keV cascade, which has a well known 5(2)3(3)0 spin sequence, strongly indicate that no extranuclear perturbations of the correlation would be observable. In addition, the tiny wire source offers the strong advantage of good geometry over that possible with a liquid source. The fine wire and Lucite holder were also chosen to minimize the interference due to pair creation by the 2615 keV γ ray which might otherwise contaminate other coincidences involving the 511 keV γ ray. Auxiliary measurements of 511-511 keV coincidences indicate that these interferences are negligible compared to the strong 511-583 γ-γ cascade. In addition an upper limit was placed on the interference by calculating the number of 511 keV photons produced in the wire and in the Lucite by the 2615 keV γ ray using theoretical pair creation cross sections and this was found to be on the order of 3%.

The γ-ray lines in the coincidence data were stripped from the continuum, corrected for chance coincidences, and fitted by a method of least squares to a function of the usual form $W = 1 + A_{22}P_2(x) + A_{44}P_4(x)$, where $x = \cos\theta$. The coefficients A_{22} and A_{44} were then corrected for finite solid angle effects using the methods and results of Refs. 17 and 18.

Samples of the coincidence spectra are given in Figs. 2–4, while the resulting corrected correlation coefficients are presented in Table I.

III. INTERPRETATION OF THE EXPERIMENTAL RESULTS

In this section we shall discuss the interpretation of the directional correlation results in terms of spin sequences and extract the multipole mixing ratios. This effort is somewhat complicated by the fact that there are conflicting spin and parity assignments in the literature while at the same time the present directional correlation data, in some cases, can be interpreted in terms of several of the possible spin sequences. Recent high resolution measurements of the internal conversion electron spectrum,[19] coupled with the above directional correlation data, allow unambiguous interpretation for all but one of the five cascades investigated, namely the 511-583 keV cascade. Preliminary values for three of the conversion coefficients of interest are: $\alpha_k(277) \simeq 0.40$, $\alpha_k(511) \simeq 0.08$, and $\alpha_k(763) \simeq 0.04$. All three of these coefficients are consistent with an almost pure $M1$ assignment to these transitions which is in strong disagreement with the multipole mixing ratio of $\delta(277) = +4.8$ and to a lesser degree also in disagreement with the value $\delta(511) = -0.77$ given by Jagam and Murty in Ref. 13. Accuracies of between 8% and 12% are projected for the final values of α_k, hence they are most useful in as-

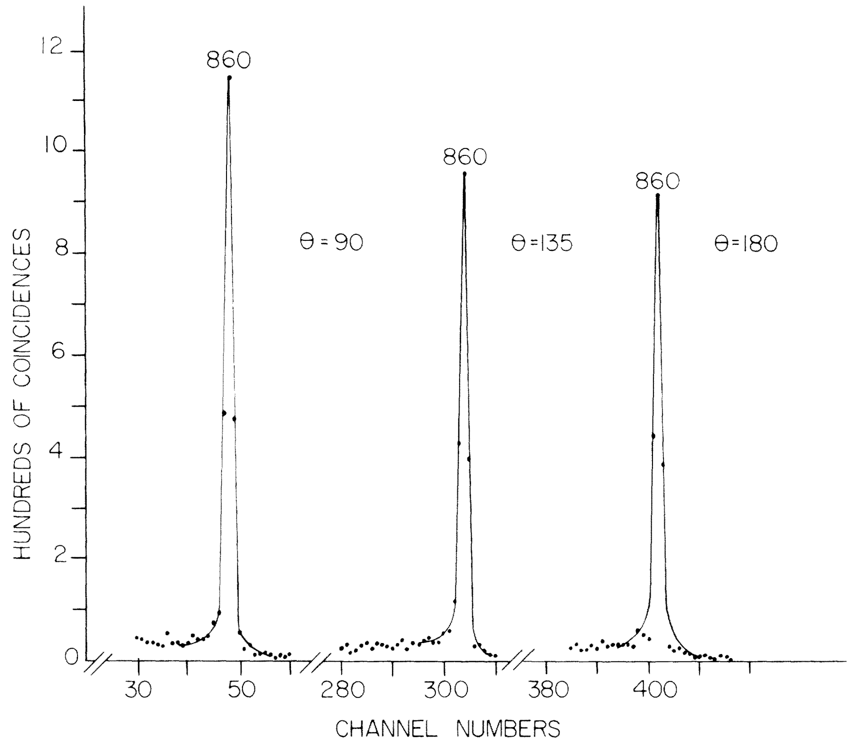

FIG. 2. The 860 keV γ ray in coincidence with the 2615 keV γ ray. The 90° and 270° data as well as the 135° and 225° data were averaged since no asymmetries in the data were observed.

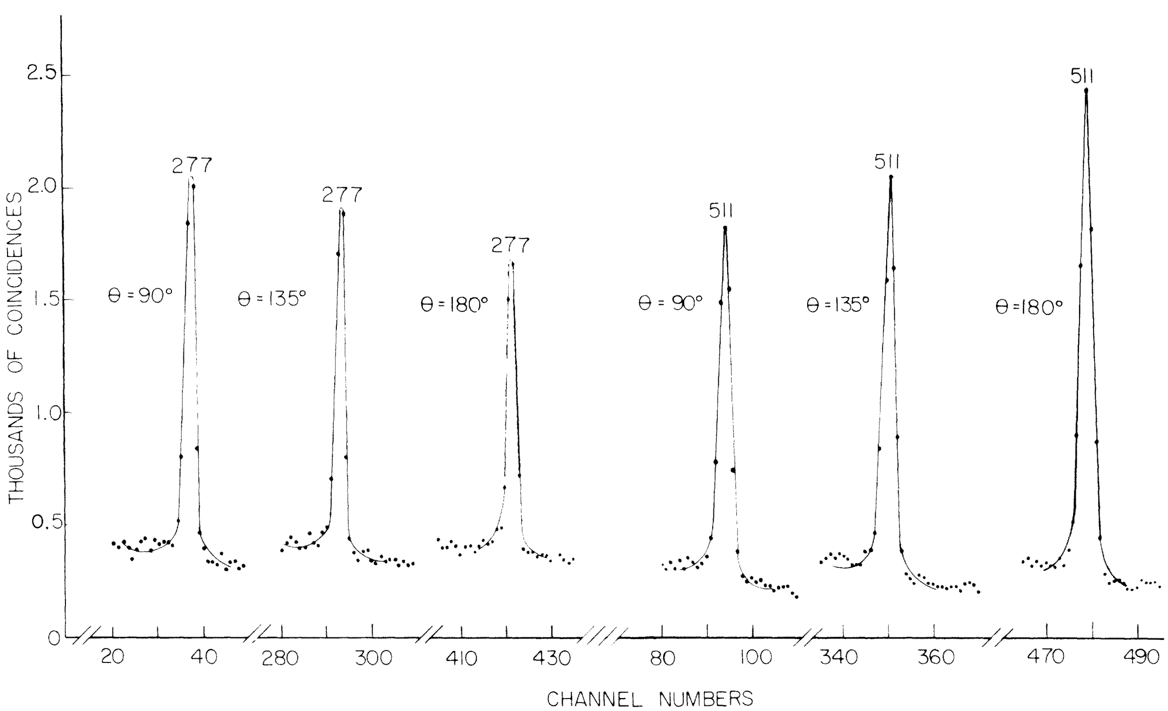

FIG. 3. The 277 and 511 keV γ rays in coincidence with the 583 keV γ ray. The 90° and 270° data as well as the 135° and 225° data were averaged since no asymmetries in the data were observed.

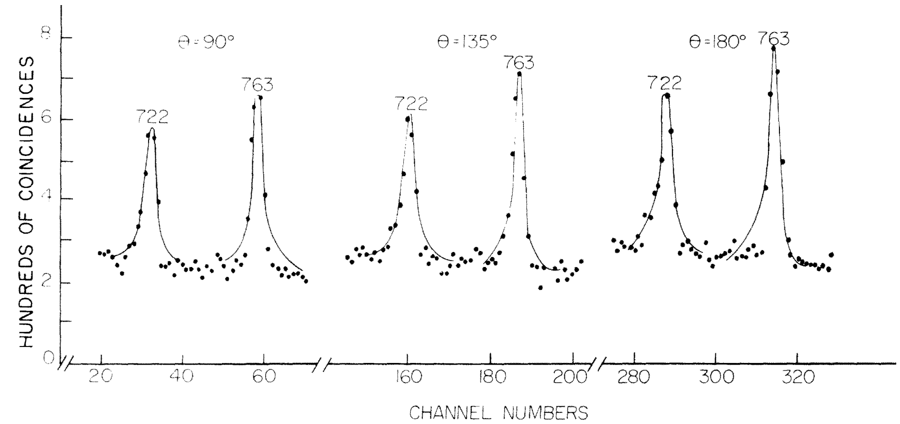

FIG. 4. The 722 and 763 keV γ rays in coincidence with the 583 keV γ ray. The 90° and 270° data as well as the 135° and 225° data were averaged since no asymmetries in the data were observed.

sisting in the interpretation of the directional correlation data.

The interpretation of the 277-583 keV cascade is reasonably straightforward especially since the spin sequence is well established as 4(1, 2)5(2)3.[11-16] The values of A_{22} and A_{44} given in Table I imply $\delta(277) = +0.008 \pm 0.011$ which is consistent with the preliminary $\alpha_k(277)$ given above. The large mixing ratio $\delta(277) = +4.8 \pm 0.4$ deduced by Jagam and Murty is not only in disagreement with the present results but, as pointed out in their article, is also in disagreement with the earlier internal conversion measurements of Emery and Kane and with those of Krisyuk *et al.* References to these measurements can be found in Ref. 13. We cannot directly compare our A_{kk} coefficients with those given in Ref. 13 because $\delta(277)$ was deduced from their measurement of the triple correlation of the 277(583)2614 keV cascade rather than the 277-583 keV cascade as measured in the present investigation.

The interpretation of the results for the 511-583 keV cascade should also be reasonably straightforward since the spin sequence is well established as 5-5-3. The fact that there are two values of $\delta(511)$ possible, coupled with the possibly large A_{44} coefficient does complicate the issue since this slightly favors the selection of the value $\delta(511) = -0.68 \pm 0.08$ which is in agreement with the value $\delta(511) = -0.77 \pm 0.41$ given by Jagam and Murty. A variety of values of $\delta(511)$ have been reported earlier, for example Elliot *et al.* report $|\delta| = 1.7 \pm 0.3$, Wood and Jastrom report $\delta = -0.18 \pm 0.03$, Emery and Kane report $|\delta| = 0.18 \pm 0.15$, and Wolfson reports $|\delta| = 0.4$. References to these measurements can be found in Ref. 13. The conversion coefficient measurement given above as a preliminary result implies a most probable value of $|\delta(511)| \simeq 0$, with a limiting value $|\delta(511)| \leq 0.4$, which favors the second possible solution, namely $\delta(511) = -0.052 \pm 0.045$. While there is evidence in the form of the present A_{44} and the earlier measurements to support the larger mixing ratio, we feel that there is equally strong evidence to support the smaller absolute value or $\delta(511) = -0.052$. We shall not be able to eliminate either value with the available data, hence we shall present both results for comparison to theory.

The interpretation of the data in the case of the 722-583 keV cascade depends on clarification of the spin of the level at 3920 keV. Jagam and Murty[13] give no assignment of $(J\pi)$ to this level; however, Lewis[11] tentatively assigned (6 −) to this level, based on information available until

TABLE I. Directional correlation coefficients of the present investigation.

Cascade E_γ [a] (keV)	Spin sequence	A_{22}	A_{44}
277-583	4-5-3	−0.130 ± 0.009	−0.03 ± 0.03
511-583	5-5-3	+0.197 ± 0.009	+0.09 ± 0.08
722-583	6-5-3	+0.11 ± 0.03	−0.02 ± 0.02
763-583	5-5-3	+0.188 ± 0.020	−0.07 ± 0.07
861-2615	4-3-0	−0.106 ± 0.025	−0.02 ± 0.02

[a] Mixing ratios quoted for the first γ ray.

1971. Igo and his co-workers[14] observed particle angular distributions in the reaction ^{210}Pb(p,t)-^{208}Pb and have given (6−) and (7−) as two possible ($J\pi$) assignments consistent with their data. The assignment of (7−) to the 3920 keV level is doubtful, as stated in Ref. 14, because of the absence of yields from the (p,t) and (t,p) reactions; however, the assignment (6−) is consistent with earlier (p,p) and (p,p') data.[18] In addition, this assignment is also consistent with recent (p,p) data[12] as well as (p,p') data.[16]

The directional correlation coefficients $A_{22} = +0.11 \pm 0.03$ and $A_{44} = -0.02 \pm 0.02$ are consistent with the spin sequence 6(1, 2)5(2)3 with two possible $E2/M1$ mixing ratios: $\delta(722) = +0.31 \pm 0.07$ and $\delta(722) = +2.64 \pm 0.055$. It should also be pointed out, however, that the results of the correlation experiment are also consistent with the spin sequence 7(2, 3)5(2)3. A preliminary conversion coefficient of the 722 keV transition has been obtained from high resolution singles counting data, by stripping the small 722 K peak from the higher energy side of the K peak from the stronger 727 keV transition in ^{212}Po. The preliminary value obtained is $\alpha_k(722) \simeq 0.05$. The theoretical conversion coefficients $\alpha(E1)$, $\alpha(E2)$, and $\alpha(M1)$ for this transition are (0.00381), (0.00891), and (0.0307), respectively, and the above result appears to favor the predominantly $M1$ multipolarity assignment for this transition which strongly supports the assignment of (6−) to the 3920 keV level. In addition, the larger possible value $\delta(722) = +2.64$ would be consistent with $\alpha_k(722) = 0.013$: Hence, all of the data considered together strongly favor the spin sequence 6(1, 2)5(2)3 and the mixing ratio $\delta(722) = +0.31 \pm 0.07$. The accurate measurement of $\alpha_k(722)$ may be possible but will involve a long tedious coincidence experiment. This possibility is presently being studied because the result would be of value in strengthening the present conclusion.

The analysis of the 763-583 cascade is complicated by the fact that the spin and parity assignment of the 3961 keV level is to date not a completely settled issue. The data compilation by Lewis[11] lists the 3961 keV level as (4−) where it was indicated in Ref. 11 that this was an uncertain assignment. The spin and parity of this level is given as (4−) in the decay scheme of Nellis and Morgan[15] as a definite assignment; however, the 763 keV γ ray was too weak to perform angular distributions during their study of the ^{208}Pb($n,n'\gamma$)-^{208}Pb reaction. Igo *et al.*,[14] on the other hand, give a definite assignment of (5−) to this level. Their assignment is mainly based on the fact that their angular distribution data from the (p,t) reaction delimit the consistent ($J\pi$) assignments to (5−) or (6+). In the analysis of their ^{208}Pb(p,p') data, Moore *et al.*[20] assign a negative parity to the 3961 keV level; however, that assignment was made largely on the grounds of theoretical interpretation and is not based on conclusive data. The preliminary value of the internal conversion coefficient $\alpha_k(763) \pm 0.04$ given above can be compared to the theoretical values for $\alpha(E1)$, $\alpha(E2)$, and $\alpha(M1)$ which are (0.00343), (0.00891), and (0.0307), respectively. This implies that this transition is very probably predominantly $M1$ with a possible $E2$ mixture and the parity can be fixed as (−) since the transition occurs to the well known (5−) state at 3198 keV. In addition, the more recent (p,p') data of Ref. 16 and the (p,p) data given in Ref. 12 were also interpreted in both cases as implying that the correct ($J\pi$) assignment to the 3961 keV level is (5−). Based on these facts we shall interpret the directional correlation to be that of a 5(1, 2)5(2)3 spin sequence. The measured correlation coefficients $A_{22} = +0.188 \pm 0.020$ and $A_{44} = -0.07 \pm 0.07$ imply $\delta(763) = -0.01 \pm 0.06$.

Finally, in the interpretation of the directional correlation of the 861-2615 keV γ-ray cascade, the question of the possibility of extranuclear perturbations of the correlation was raised because of the consistent difference between A_{22} measured in a solid source and those measured in a liquid source by Jagam and Murty (see Table I, Ref. 13). These differences were not taken seriously in the final analysis since similar differences were not observed in their measurements of the 583-2614 keV directional correlation which involves the same intermediate state. We also made a careful measurement of this correlation in order to obtain a correction for the NaI(Tl) detector finite solid angle effects in the case of the 2615 keV γ ray. The resulting correlation coefficients for the 861-2615 keV cascade are $A_{22} = -0.106 \pm 0.025$ and $A_{44} = +0.02 \pm 0.02$. These values imply a multipole mixing ratio of $\delta(861) = +0.015 \pm 0.012$.

Our correlation coefficients for this cascade are in good agreement with those of the earlier measurement, and the present value of the mixing ratio is also in agreement with that given by Jagam and Murty, namely $\delta(861) = +0.014 \pm 0.012$.

IV. THEORETICAL CALCULATIONS

In this section, the observed $E2/M1$ multipole mixing ratios, called δ, will be compared with the theoretical predictions based on the calculations of True, Ma, and Pinkston.[1]

In Ref. 1, all the one-hole one-particle neutron and proton excitations in the major shells adjacent to ^{208}Pb were taken into account. For a transition between two excited levels in ^{208}Pb, the final state will be written as

$$|I_f M_f\rangle = \sum \alpha_f(\bar{j}_1 j_2)\,|\bar{j}_1 j_2 I_f M_f\rangle\ , \qquad (1a)$$

where the sum is over all pairs of $j_1 j_2$ which can couple to form an angular momentum of I_f and the basis states can be either neutron or proton one-hole one-particle states. The bar over j_1 indicates that it represents a hole while j_2 represents a particle and $\alpha_f(\bar{j}_1 j_2)$ is the amplitude or configuration mixing coefficient for this component. Similarly, the initial state will be written as

$$|I_i M_i\rangle = \sum \alpha_i(\bar{j}_3 j_4)\,|\bar{j}_3 j_4 I_i M_i\rangle\ . \qquad (1b)$$

Following Krane and Steffen,[9] the $E2/M1$ multipole mixing ratio δ, in natural units ($\hbar = m = c = 1$), is defined by

$$\delta = \frac{\sqrt{3}\ E\langle I_f \| M(E2) \| I_i\rangle}{10\langle I_f \| M(M1) \| I_i\rangle}\ , \qquad (2)$$

where E is the energy of the transition measured in natural units. The multipole operators are those defined by Bohr and Mottelson[10] as follows:

$$M(E2) = \sum_i \epsilon_i r_i^2 Y_{2m}(\theta_i, \phi_i) \qquad (3a)$$

and

$$M(M1) = \sum_i \left(\frac{e\hbar}{2M}\right)[g_l l_{lm}(i) + g_s s_{lm}(i)] \qquad (3b)$$

in terms the effective charge ϵ, the nuclear Bohr magneton $\mu_N = e\hbar/2Mc$, the orbital and spin g factors g_l and g_s, and the rank one tensor operators l_{lm} and s_{lm}.

If the transition energy E were measured in units of MeV, the $E2$ reduced matrix elements in units of eF^2, and the $M1$ reduced matrix elements in units of l_N, the δ in Eq. (2) becomes

$$\delta = 0.008346E\,\frac{\langle I_f \| M(E2) \| I_i\rangle}{\langle I_f \| M(M1) \| I_i\rangle}\ . \qquad (4)$$

The reduced matrix elements are given by

$$\langle I_f \| M(Q_L) \| I_i\rangle = \hat{I}_i \hat{I}_f \sum \alpha_f(\bar{j}_1 j_2)\alpha_i(\bar{j}_3 j_4)\,[\,\delta_{j_2 j_4}\theta(j_1 j_2 I_f)\langle j_3 \| Q_L \| j_1\rangle W(I_f I_i j_1 j_3; L j_2) - \delta_{j_1 j_3}\theta(j_1 j_2 I_i L)\langle j_2 \| Q_L \| j_4\rangle W(I_f I_i j_2 j_4; L j_1)]\ , \qquad (5)$$

where $\hat{I} = (2I+1)^{1/2}$, $\theta(abc) = (-1)^{a+b+c}$, and $W(abcd; ef)$ is a Racah coefficient. The sum is over all pairs $j_1 j_2$ and $j_3 j_4$ as in Eq. (1) and Q_{LM} is $\epsilon r^2 Y_{2m}(\theta, \phi)$ and $\mu_N(g_l l_{lM} + g_s s_{lm})$ for $E2$ and $M1$ reduced matrix elements, respectively.

Because shell model calculations are normally done with a truncated set of basis states, one expects to be required to use effective charges for the protons and neutrons and effective g values for neutrons and protons. Unfortunately the "state of the art" of shell model calculations has not reached the point where one can deduce precisely what effective charges and effective g values should be used.

Experimental data will be used as a guide in determining ϵ_p and ϵ_n. References 1 and 2 used $\epsilon_p = 1.5e$ and $\epsilon_n = 0.5e$ for several nuclei in the lead region and obtained reasonably good fits to the experimental data. Bohr and Mottelson[21] give $\epsilon_p = 1.6e$ from the ^{209}Bi quadrupole moment and $\epsilon_p = 4 \pm 1.5e$ from a ^{209}Bi $E2$-transition probability. No ϵ_p is given for a proton hole. A value of $\epsilon_p = 4e$ appears to be about a factor of 2 too large when other $E2$-transition probabilities and quadrupole moments in the lead region are considered. $\epsilon_p = 1.6e$ is not much larger than the ϵ_p used in Refs. 1 and 2 and as it gives a slightly better fit to the $E2/M1$ mixing ratios, we adopt $\epsilon_p = 1.6e$ here. Bohr and Mottelson[21] also give $\epsilon_n = 0.9e$ and $0.85e$ from two ^{207}Pb neutron-hole $E2$-transition probabilities and $\epsilon_n = 0.42e$ from a ^{209}Pb neutron-particle $E2$-transition probabilitity. We shall adopt an "average" value of $\epsilon_n = 0.65e$, which is slightly larger than the ϵ_n of $0.5e$ used in Refs. 1 and 2.

Unfortunately, there is very little experimental information which can be used unambiguously to determine the effective g values. Consequently, free g values of $g_l(p) = 1.0$, $g_l(n) = 0$, $g_s(p) = 5.59$, and $g_0(n) = -3.83$ were adopted.

With these effective charges and g values, the $E2/M1$ mixing ratio δ can be calculated using Eqs. (4) and (5) and the wave functions of Ref. 1. These calculated δ's are compared with the experimentally measured δ's in Table II.

The $E2/M1$ mixing ratios are very sensitive to the details of the wave functions and therefore are a stringent test of them. As can be seen in Table II, all of the theoretical mixing ratios for the transitions investigated are in reasonably good agreement with the experimental mixing ratios, unless we are in error in our conclusion that the experimental value $\delta(511) = -0.052(45)$ is more probable than the value $\delta(511) = -0.68(8)$. In this case there is one serious disagreement; however, we feel that the preliminary internal conversion data are sufficient to favor the smaller value of $|\delta|$. We have investigated the feasibility of improving the accuracy of both the $\alpha_k(511)$ and 583-511 keV $\gamma\gamma(\theta)$ measurements sufficiently to be

TABLE II. Comparison between the experimental and theoretical $E2/M1$ mixing ratios in ^{208}Pb. All energies are in MeV and the energies in parentheses are those calculated in Ref. 1. See the text for further details.

Transition energy	Initial state ($J\pi$) energy	Final state ($J\pi$) energy	δ_{exp}	δ_{theor}
0.277	(4−) 3.475 (3.51)	(5−) 3.198 (3.35)	+0.008(11)	+0.0098
0.511	(5−) 3.708 (3.68)	(5−) 3.198 (3.35)	−0.052(45)	+0.0196
			−0.68(8)	
0.722	(6−) 3.920 (3.98)	(5−) 3.198 (3.35	+0.31(7)	+0.1915
0.763	(5−) 3.961 (4.00)	(5−) 3.198 (3.35)	−0.01(6)	−0.0653
0.763	(5−) 3.961 (4.18)	(5−) 3.198 (3.35)	−0.01(6)	+0.0219
0.861	(4−) 3.475 (3.51)	(3−) 2.615 (2.49)	+0.015(12)	+0.0154

able to determine δ(511) unambiguously. We have concluded that efforts to improve the accuracy of these measurements, using the present techniques, would probably not result in the required accuracy. A more fruitful effort might be spent in attempting internal conversion L-subshell measurements of the 511 keV transition; however, these will also be very difficult since the L-shell electrons will fall very near the strong 583 K-shell line.

The fourth 5^- level was calculated in Ref. 1 at 4.18 MeV and cannot be completely ruled out as a candidate for the experimentally observed 5^- level at 3.961 MeV. The 763 keV transition from this level has a calculated $E2/M1$ mixing ratio of +0.0168 which is still within the experimental error. However, one then can ask why the third 5^- level was not observed since it would lie lower in energy. On this basis and the fact that the third 5^- level gives a slightly better fit to the experimental data, the 3.961 MeV level is favored to be the third 5^- level in ^{208}Pb.

As seen in Table II, the 0.277, 0.722, and the 0.861 MeV transitions are fitted quite well. It is interesting to note that the calculated $E2/M1$ mixing ratios for these three transitions depend almost completely on the neutron particle-hole components of the wave functions and are essentially independent of the proton particle-hole components of the wave functions. In contrast, the 0.511 and 0.763 MeV transitions depend more sensitively on the proton particle-hole components and, in addition, there is also some cancellation between the neutron and proton components.

V. CONCLUSIONS

The directional correlation coefficients have been measured for five γ cascades in ^{208}Pb. In addition, the $E2/M1$ mixing ratio for the first γ ray in each cascade has also been measured. These experimentally measured mixing ratios are compared with theoretical mixing ratios based on a particle-hole shell model calculation of the excited states of ^{208}Pb. In general, the agreement between the experimental values and the calculated values is very good although there still remains a non-negligible probability that the more favored value we selected for the experimental mixing ratio of the 0.511 MeV transition is not correct. This would constitute a serious disagreement between theory and experiment.

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