in Sr^{88}. Then

$$\Delta E_d = \{\alpha^2 \langle d_{5/2}0^+|T_+[H,T_-]|d_{5/2}0^+\rangle + \beta^2\langle s_{1/2}2^+|T_+[H,T_-]|s_{1/2}2^+\rangle + 2\alpha\beta\langle d_{5/2}0^+|T_+[H,T_-]|s_{1/2}2^+\rangle\}/2T.$$

The nondiagonal element is evaluated to be 4 keV by using the experimentally known $B(E2)$ value for the transition $2^+ \to 0^+$. The difference between the two diagonal elements in ΔE_d cannot be calculated without further assumptions concerning the structure of the 0^+ and 2^+ states.

[10]A contribution $-\epsilon^2|\Delta E|/T(2T+1)$ arising from the compound mixing of the analog state with the state $T_-|T+1\rangle$ has been added to Eq. (10).

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COULOMB EXCITATION OF THE COLLECTIVE SEPTUPLET AT 2.6 MeV IN ^{209}Bi†

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Beams of 18-MeV α particles and 70-MeV ^{16}O were used for $E3$ Coulomb excitation of the weak-coupling $3^-|h_{9/2}\rangle$ septuplet $J^\pi = \frac{3}{2}^+, \cdots, 15/2^+$ at 2.6 MeV in ^{209}Bi. A complete decay scheme was obtained and short lifetimes were determined from observed Doppler effects. We deduce several absolute transition probabilities for both excitation and decay involving the multiplet and low-lying single-particle states.

The ^{209}Bi septuplet originating from the weak coupling of the $1h_{9/2}$ proton to the octupole vibration in ^{208}Pb has been studied by many authors[1,2] by means of inelastic particle scattering. Hafele and Woods[2] were the first to resolve all states but two of this multiplet, and in this way were able to assign spins by exploiting the $(2J+1)$ dependence of the cross section. The details of the weak-coupling model for this multiplet and admixtures therein were discussed by Mottelson,[3] Broglia, Damgård, and Molinari,[4] and Hamamoto.[5]

The gamma rays following Coulomb excitation of this multiplet by 18-MeV α particles and 70-MeV oxygen ions were the subject of the present experiment. The target consisted of a thick piece of zone-purified ^{209}Bi which was machined, degreased, and mounted shortly before the evacuation of the target chamber; in this way impurity lines could be reduced to a great extent. Oxygen was the principal contaminant. Figure 1 shows relevant sections of the 4096-channel gamma spectra observed with an Oak Ridge Technical Electronics Corporation 32-cm^3 Ge(Li) detector at 90°. The energy resolution was 4.5 keV. A level diagram is shown in Fig. 2. Errors are ±0.5 keV for the 896.5-, 1608.9-, and 2741.4-keV states and ±1 keV for the others.

With alpha particles, spectra were obtained in five steps from 0° to 90°. The angular distributions were isotropic within the experimental error of ~15%. Intensities were obtained from the alpha-particle spectra, although the ^{16}O-induced yield at 90° gives virtually the same results.

Lifetimes for the $\frac{3}{2}^+$, $\frac{5}{2}^+$, and $\frac{15}{2}^+$ members of the multiplet were determined from a combination of Coulomb-excitation yields and branching ratios; those for the $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{11}{2}^+$, and $\frac{13}{2}^+$ members were determined from the Doppler broadening observed in the ^{16}O-induced spectra, and partially from the Doppler shifts seen in the α-induced spectra.[6] The rather large errors reflect the necessity of a decomposition of the overlapping Doppler broadening (shifted) lines in the ^{16}O case (see Fig. 1) in order to extract widths (average shifts). Such a decomposition was feasible because of the good energy and intensity information extracted from the α-induced spectra where all the lines were well separated. The 992-keV transition from the $\frac{11}{2}^+$-$\frac{13}{2}^+$ doublet to the 1609-keV $i_{13/2}$ state in the ^{16}O-induced spectrum could be decomposed into two lines with a (2 ± 1)-keV separation because of the appreciable Doppler shift observed in the presumed $\frac{11}{2}^+$ member of the doublet. A $(15\pm5)\%$ $\frac{11}{2}^+ \to i_{13/2}$ $M1$ branch was observed, which has to be considered as tentative, since it could also originate from a small background peak located at the same position. The $\frac{13}{2}^+$ level decays almost entirely to the $i_{13/2}$ state, but a 1% branch to the ground state is required in order to agree with the lifetime extracted from the $E3$ Coulomb-excitation yield.

The absolute value of the $B\uparrow(E3)$ to the multi-

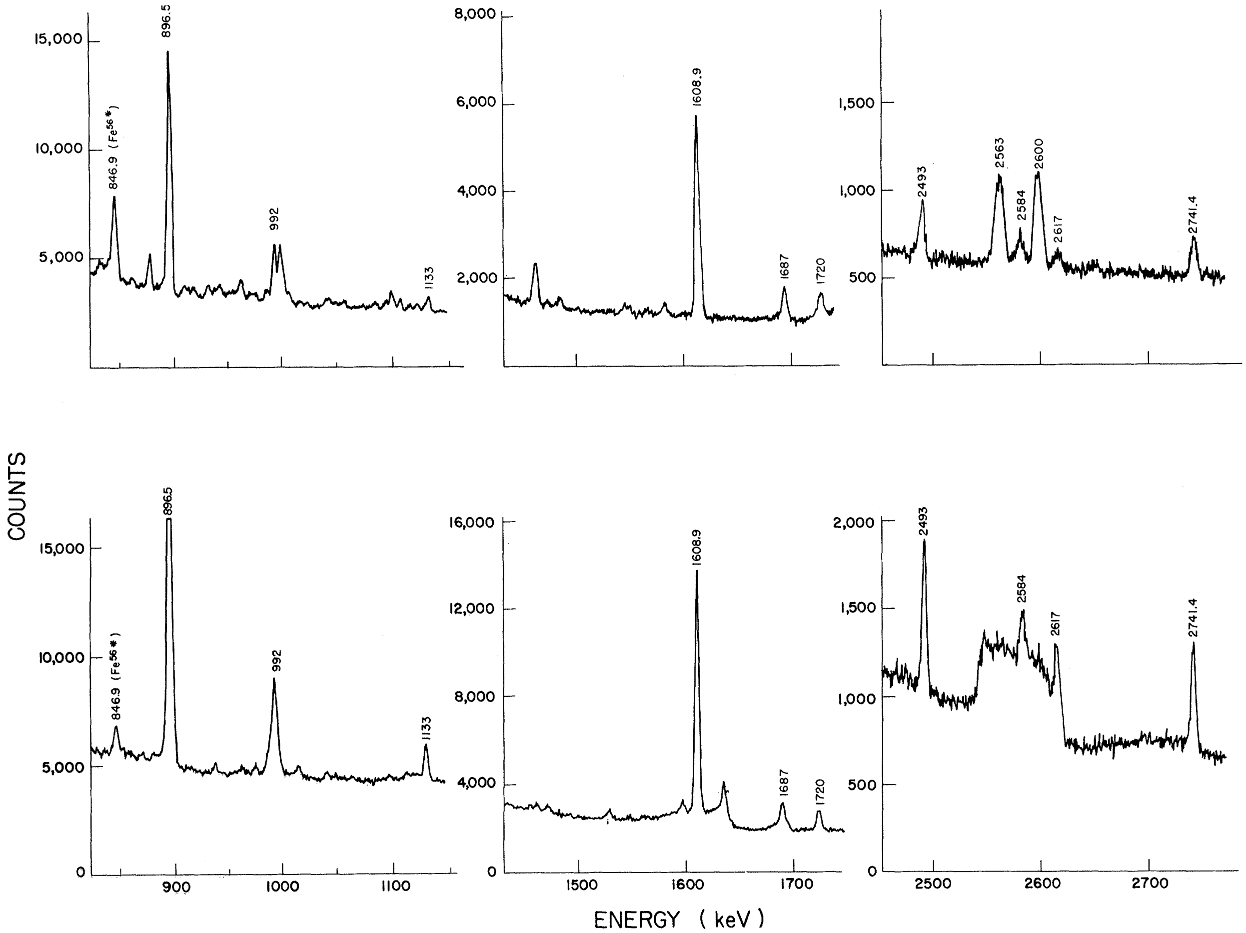

FIG. 1. The relevant energy spectra of de-excitation gamma rays following Coulomb excitation of ^{209}Bi at 90°. The top spectrum is for 18-MeV α and the bottom for 70-MeV ^{16}O particles. The peak just above 992 keV in the upper left section is caused by an impurity.

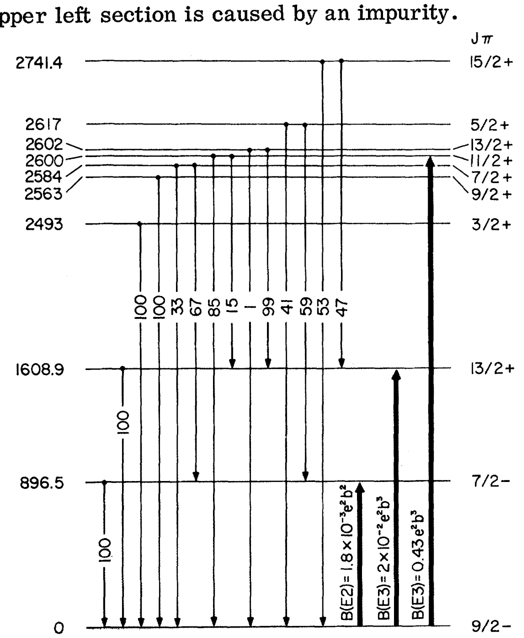

FIG. 2. Energy-level diagram showing the octupole septuplet in ^{209}Bi and the de-excitation gamma rays. The branching ratios are accurate to ±15%.

plet is found to be $(0.45\pm 0.15)e^2$ b^3,[7] and that to the 1609-keV $i_{13/2}$ state is $(0.022\pm 0.008)e^2$ b^3, which is 0.2 times the $B\uparrow(E3)$ to the $\frac{13}{2}^+$ member of the multiplet. (The arrow denotes transitions upwards or downwards.) This implies a larger admixture than reported from proton transfer reactions on ^{208}Pb.[8] The value of $B\uparrow(E3)$ to the 1609-keV level is about 100 times that predicted by a single-particle calculation, and was included in the total $B\uparrow(E3)$ to the multiplet. The measured $B\uparrow(E2)$ to the 896-keV $\frac{7}{2}^-$ state is $(1.8\pm 0.6)\times 10^{-3}e^2$ b^2, which is about three times the single-particle estimate made with the appropriate statistical factor and assuming a uniform density with a radius of $1.2A^{1/3}$ and an effective charge of unity.

A summary of our results is given in Table I. Branching ratios and excitation energies are given in Fig. 2. The observed transitions and the $B\downarrow(E3)$ values derived from the Coulomb-excitation yields to the multiplet are consistent with the spin assignments of Hafele and Woods.[2] With-

Table I. Measured lifetimes and reduced transition probabilities for ^{209}Bi.

J^π	Mean life[a] (psec)	$B(E3, J_i \to g.s.)\downarrow$[b] ($e^2 b^3$)	$B(\lambda)\downarrow(e^2b^\lambda)$[c] $\frac{9}{2}^-$ (g.s.)	$\frac{7}{2}^-$ (896.5)	$\frac{13}{2}^+$ (1608.9)
$\frac{3}{2}^+$	55 ± 16	.053 ± .007			
$\frac{9}{2}^+$	$0.02\ ^{+0.03}_{-0.015}$	.074 ± .011	B(E1) = 1.9(5)	B(E1) ≤ 3.4(6)	
$\frac{7}{2}^+$	$0.4\ ^{+0.25}_{-0.15}$	.065 ± .010	B(E1) = 3.0(7)	B(E1) = 2.2(6)	
$\frac{11}{2}^+$	$0.10\ ^{+0.1}_{-0.05}$	.078 ± .012	B(E1) = 3.0(6)		B(M1) = 1.0(5)
$\frac{13}{2}^+$	$0.35\ ^{+0.20}_{-0.15}$	.072 ± .011			B(M1) = 1.8(5)
$\frac{5}{2}^+$	15 ± 5	.057 ± .009		B(E1) = 4.9(8)	
$\frac{15}{2}^+$	17 ± 5	.048 ± .007			B(M1) = 1.2(7)

[a]Mean lives measured from Coulomb excitation yield for 896.5-keV ($\frac{7}{2}^-$) and 1608.9-keV ($\frac{13}{2}^+$) states are 64 ±20 and 3900 ± 1200 psec, respectively.
[b]The value for the $\frac{13}{2}^+$ level includes the $B\downarrow(E3)$ from the 1609 state.
[c]$B\downarrow(\lambda)$ values show negative power of 10 in parenthesis.

in the framework of the weak-coupling model the $B\downarrow(E3)$ values should all be the same, and moreover, should be equal to the $B\downarrow(E3)$ of the 3^- state in ^{208}Pb.[7] Our results for the $\frac{5}{2}^+$, $\frac{7}{2}^+$, $\frac{9}{2}^+$, $\frac{11}{2}^+$, and $\frac{13}{2}^+$ states are the same within experimental error (absolute errors are ±30%) as expected, but the $B\downarrow(E3)$ values for the $\frac{3}{2}^+$ and $\frac{15}{2}^+$ states are somewhat lower. This may be related to the fact that the $\frac{3}{2}$ and $\frac{15}{2}$ states are the ones displaced most from the centroid of the multiplet. It seems unlikely that the missing $\frac{15}{2}^+$ intensity can be explained by an unobserved, highly converted intraband $M1$ transition.

The $E1$ transitions are generally quite weak, consistent with systematics.[9] It is interesting to note that an admixture of as little as 10^{-6} Weisskopf unit can give a branch comparable with the $E3$ decay. Of the six possible $E1$ transitions, the $\frac{9}{2}^+ \to \frac{9}{2}^-$ is the strongest; it also has no observable branch (≤5%) to the 896-keV state. The $E1$ decays are reproduced well by recent calculations of Hamamoto[5] under the assumption of an effective charge of $0.3e$. Our lifetimes for the $\frac{11}{2}^+$, $\frac{9}{2}^+$, and $\frac{7}{2}^+$ $E1$ decays are also in reasonable agreement with the recent resonant fluorescence results of Metzger.[10]

Although magnetic dipole transitions are generally expected to be strong between members of a weak-coupling multiplet,[11] in the case of ^{209}Bi they are too weak to compete with other transitions. The approximately 20% collective admixture into the 1609-keV $i_{13/2}$ level together with the E_γ^3 dependence of $M1$ transition probabilities, however, result in observable $M1$ branches to this state from the $\frac{11}{2}^+$, $\frac{13}{2}^+$, and $\frac{15}{2}^+$ members of the septuplet. The $M1$ transitions are generally in poor agreement with the calculated values of Hamamoto.[5]

Using our measured lifetimes and branching ratios and taking the magnetic moment of the ^{209}Bi ground state as $4.08\mu_N$, weak-coupling calculations[12] of these transitions can be used to derive a magnetic moment of the 3^- octupole vibrational state in ^{208}Pb. The $\frac{15}{2}^+$ decay samples only the collective admixture in the 1609-keV state, but for the $\frac{13}{2}^+$ decay one must also include the appropriate magnetic moment of the $i_{13/2}$ single-particle state, which was taken to be the "quenched" value of $7.0\mu_N$. From the $\frac{13}{2}^+ \to i_{13/2}$ transition we get $1.6 \pm 0.6\mu_N$, whereas the $\frac{15}{2}^+ \to i_{13/2}$ decay yields $2.3 \pm 0.3\mu_N$, leading to a weighted average of $2.2 \pm 0.3\mu_N$. This value is based on the 20% collective admixture in the 1609-keV state obtained in the present experiment and is consistent with the recently reported value of $1.74 \pm 0.42\mu_N$.[13] A 10% admixture yields a magnetic moment not significantly different. Using $\mu(3^-) = 2.2\mu_N$ and the 15% $M1$ branch, the pure-weak-coupling model predicts a lifetime for the $\frac{11}{2}^+$ member which is an order of magnitude longer than the observed value. A small admixture of the $i_{11/2}$ single-particle state into the $\frac{11}{2}$ member of the multiplet, of the same order as that expected theoretically,[3-5] could account for the observed transition.

In conclusion, the gamma decay information on the weak-coupling multiplet in ^{209}Bi confirms earlier results that the weak-coupling model works extremely well here. It would therefore be of great interest to attempt to understand quantitatively the small deviations observed.

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OBSERVATION OF "PERIPHERAL" BACKWARD MULTIPION PRODUCTION AT 2.15 BeV/c *†

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Using the Princeton-Pennsylvania Accelerator rapid-cycling bubble chamber in a flash-lamp triggered mode we have observed backward $(\pi^+\pi^-)$ and $(\pi^+\pi^-\pi^0)$ multipion production in the reaction $\pi^+n \rightarrow pm(\pi)$ at 2.15 BeV/c. The main characteristics of the data are a sharp forward peaking of the proton relative to the incident π^+ direction for all multipion masses below 1100 MeV/c and the strong production of the ω meson. Backward ω production is observed to be more probable than backward ρ production. The sharp forward peaking of the proton in these reactions is suggestive of the dominance of baryon exchange.

The existence of inelastic hadron-induced reactions that are mediated by meson exchanges is well established. Correspondingly, very little information presently exists concerning inelastic reactions mediated by baryon exchange. In this note we present data on the reactions

$$\pi^+n \rightarrow \pi^+\pi^-p, \quad (\pi^+d \rightarrow \pi^+\pi^-pp); \tag{1}$$

$$\pi^+n \rightarrow \pi^+\pi^-\pi^0p, \quad (\pi^+d \rightarrow \pi^+\pi^-\pi^0pp), \tag{2}$$

with the outgoing proton restricted to kinematic configurations with a low momentum transfer between the incident π^+ and the outgoing proton. The selection of such a configuration is expected to enhance the probability of baryon-exchange dominance of these reactions. The overall purpose of this experiment was to select and study the small class of all π^+d interactions which result in a forward-produced proton having momentum comparable with that of the incident π^+ beam. Reactions (1) and (2) are a subset of this class of events.

The data on Reactions (1) and (2) were collect-