by He^3 more closely follow the theoretical curves obtained, based on the Serber interaction.

These experimental results suggest that the influence of the charge exchange reaction, $n+He^3 \leftrightarrow p+T$, is indeed important. Inclusion of this and the $n+He^3 \leftrightarrow D+D$ reaction in the theory may bring the $n-He^3$ and $p-T$ results to as close agreement with the theoretical distributions based on the Serber exchange force as is found for the $p-He^3$ and $n-T$ results. A study of the effect of the charge exchange reaction and the $He^3(n,d)D$ reaction on the theoretical distributions expected for elastic scattering is reported to be in progress.[22]

[22] B. H. Bransden (private communication).

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Decay of I^{132}

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The decay of I^{132} has been investigated by means of scintillation spectrometers. Energies (and relative intensities) of the gamma rays which were observed are 0.240(1.3), 0.518(15), 0.667(100), 0.72(5), 0.775(63), 0.953(15), 1.14(1.2), 1.142(2.7), 1.30(2.4), 1.392(6.4), 1.45(1.1), 1.75(0.3), 1.91(0.7), 1.99(0.8), 2.08(0.18), 2.18(0.13), and 2.39(0.11) Mev. Our data indicate that the gamma-ray peak at 0.667 Mev actually consists of four gamma rays with energies between 0.62 and 0.68 Mev. An energy level diagram of Xe^{132} based on the present spectral studies and gamma-gamma angular correlation measurements has been proposed. Energies (and spins) of the levels are 0.673(2+), 1.32, 1.448(4+), 1.81, 1.966(3), 2.10(3 or 4), 2.401(4), 2.59(3), and 2.84(3, 4, or 5) Mev.

I. INTRODUCTION

During the past few years several nuclear models have been developed to explain the experimentally observed properties of low-lying levels in even-even, medium-weight nuclei. To determine the range of applicability of these different models and to provide information which can be used to guide future development of nuclear models, additional experimental studies of these nuclei are needed. In the present work, levels of the even-even nucleus Xe^{132} which are populated by the decay of 2.3-hr I^{132} have been studied by means of scintillation spectrometers. An energy-level diagram which incorporates the results of this study has been proposed.[1]

The most extensive previous investigation of the decay of I^{132} was made by Finston and Bernstein.[2] Their decay scheme is illustrated in Fig. 1. The first excited state of Xe^{132} has also been observed in Coulomb excitation studies.[3] A value of four has been measured for the ground-state spin of I^{132} by Sherwood, Ovenshine, and Parker,[4] and by Lipworth, Garvin, and Nierenberg.[5]

[1] A brief account of some of these measurements was presented at the 1960 Conference of the Southeastern Section of the American Physical Society [R. L. Robinson, E. Eichler, and N. R. Johnson, Bull. Am. Phys. Soc. **5**, 448 (1960)].
[2] H. L. Finston and W. Bernstein, Phys. Rev. **96**, 71 (1954).
[3] G. F. Pieper, C. E. Anderson, and N. P. Heydenburg, Bull. Am. Phys. Soc. **3**, 38 (1958).
[4] J. E. Sherwood, S. J. Ovenshine, and G. W. Parker, Bull. Am. Phys. Soc. **4**, 386 (1959).
[5] E. Lipworth, H. L. Garvin, and W. A. Nierenberg, Bull. Am. Phys. Soc. **4**, 353 (1959).

II. EXPERIMENTAL PROCEDURE AND RESULTS

A. Source Preparation

Fission-product Te^{132} was obtained from Brookhaven National Laboratory. Tellurium and iodine carrier was added to an aliquot and the solution made strongly basic. Sodium hypochlorite was added to oxidize the tellurium and iodine to insure good exchange of activity and carrier. The solution was then acidified and Te metal precipitated by treatment with SO_2 gas. After the precipitate was washed, it was dissolved in a small amount of concentrated HNO_3. Iodine carrier was added and extracted into CCl_4. This CCl_4 solution contained the long-lived iodine isotopes—I^{131} and I^{133}—that had grown in during processing and shipment of the source material.

After an adequate growth period, more iodine carrier was added and a CCl_4 extraction performed. Next the CCl_4 phase was removed and washed with water, and the I^{132} activity was back-extracted into the aqueous phase by addition of sodium metabisulfite. Finally, $AgNO_3$ solution was added to precipitate AgI. Sources of AgI mounted on 6.5 mg/cm² Mylar tape were used for singles spectra and most gamma-gamma coincidence spectra. Sources of tellurium metal containing Te^{132}–I^{132} equilibrium mixture mounted on Mylar tape were used for beta-gamma and gamma-gamma-gamma coincidence spectra.

B. Gamma-Ray Spectra

The gamma rays were detected with 3 in.×3 in. NaI crystals which were mounted on 6363 DuMont photo-

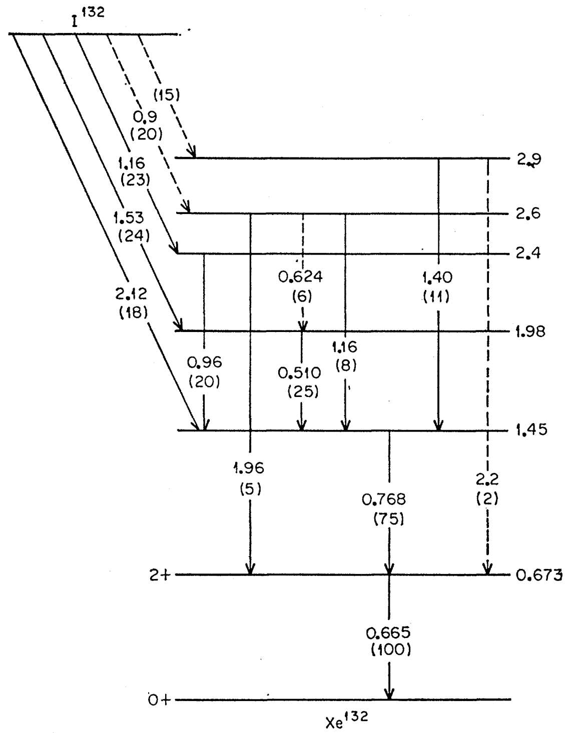

FIG. 1. Decay scheme of I^{132} proposed by Finston and Bernstein (see reference 2). The pair of numbers associated with each transition gives its energy in Mev and relative intensity.

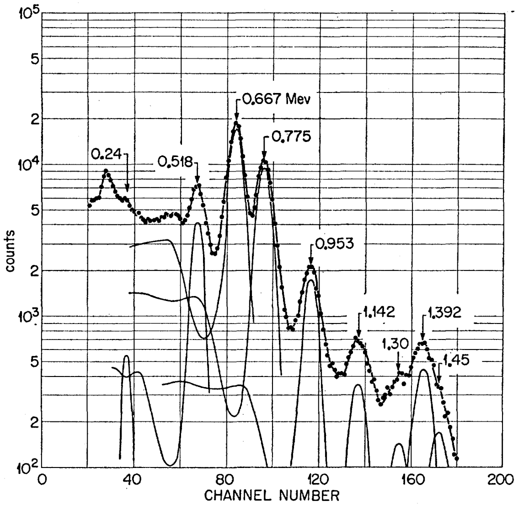

FIG. 2. I^{132} low-energy gamma-ray spectrum.

multiplier tubes. The resolution of each detector was ~8% for the 662-kev gamma-ray peak in Cs^{137}. Data were taken with either a 200- or 256-channel analyzer.

The singles spectra of I^{132} are given in Figs. 2 and 3. A 0.7-g/cm^2 polystyrene absorber was placed between source and detector to absorb beta rays. The low-energy and high-energy spectra were observed for source-to-detector distances of 9.3 and 20 cm, respectively. Since the corrections for gamma-ray summing in the crystal applied to several of the high-energy gamma rays were large, a measurement was also made of the high-energy spectrum with a source-to-detector distance of 40 cm. In order to determine gamma-ray intensities, the spectra were decomposed as illustrated in the figures. The spectral distributions were deduced from the spectra of Na^{24}, Y^{88}, Na^{22}, Zn^{65}, Mn^{54}, Cs^{137}, and Cr^{51}. Relative gamma-ray intensities, which are normalized to a value of 100 for the intensity of the composite gamma-ray peak at 0.667 Mev, are given in Table I.

Energies of the more intense gamma-ray peaks were determined by simultaneous measurement of standards

TABLE I. I^{132} gamma-ray energies and relative intensities.

		Relative intensity							
		Spectra in coincidence with gamma rays of energies (Mev):							
E_γ (Mev)	Singles spectrum	0.518	0.667	0.775	0.953	1.142	1.392	0.667 and 0.667[a]	0.667 and 0.775[a]
0.240±0.007	1.0 ±0.5	0.4±0.2	1.8 ±0.4	1.2± 0.4		0.4±0.3			
0.518±0.007	16.8 ±1.8		20 ±3	13 ± 2				12± 5	16 ±5
0.667±0.007	100 ±7[b]	21 ±6[b]	38 ±4[b]	80 ±10[b]	14±2	4.0±1.6	6.2±1.7		32 ±9
0.72 ±0.02				2 ± 1				9± 4	5 ±4
0.775±0.007	63 ±6	13 ±3	72 ±8		14±2	3.6±1.0	7.1±1.3	35±13	
0.953±0.009	14.6 ±1.0		13.9 ±1.6	14 ± 2					13 ±4
1.142±0.015	3.7 ±0.5		4.1 ±0.5	2.5± 0.4					2.8±1.4
1.30 ±0.02	2.4 ±0.6		2.6 ±0.6					} 3± 2	
1.392±0.014	6.4 ±0.7		6.8 ±0.8	5.2± 0.7					3.3±1.1
1.45 ±0.03	1.1 ±0.4		1.4 ±0.6						
1.75 ±0.03	0.3 ±0.1		0.3 ±0.1						
1.91 ±0.03	0.7 ±0.2		0.8 ±0.2						
1.99 ±0.03	0.8 ±0.3								
2.08 ±0.04	0.18±0.06		} 0.11±0.06						
2.18 ±0.04	0.13±0.06								
2.39 ±0.04	0.11±0.04		<0.09						
2.54 −2.7	<0.03								
2.7 −2.9	<0.01								

[a] Gamma-gamma-gamma coincidence spectra.
[b] Full-energy peak is wider than that expected for a single gamma ray.

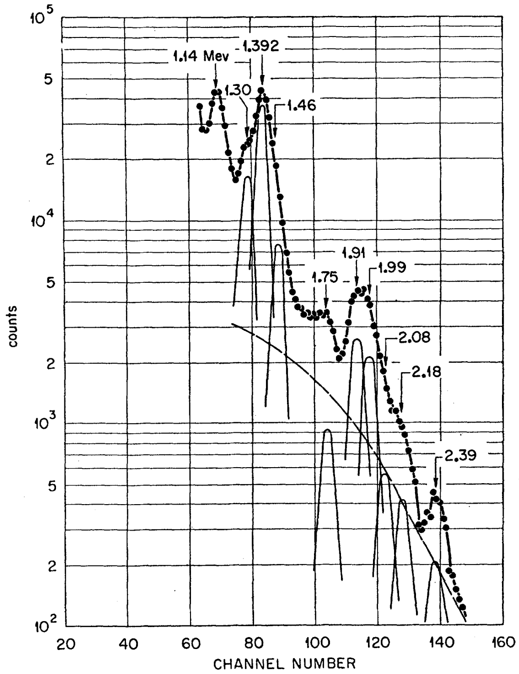

FIG. 3. I^{132} high-energy gamma-ray spectrum. The dashed line represents a continuum which is believed to result from gamma-ray summing in the crystal and from bremsstrahlung produced by electrons from the high-energy beta-ray groups.

and I^{132}. The standards were Au^{198}(0.412 Mev), Be^7(0.477 Mev), Bi^{207}(0.570 and 1.064 Mev), Mn^{54}(0.838 Mev), Y^{88}(0.899 and 1.832 Mev), Zn^{65}(1.114 Mev), Na^{22}(1.276 Mev), and Tl^{208}(2.614 Mev). The intense gamma-ray peaks of I^{132} were then used as internal energy standards. Table I lists the energies that were obtained.

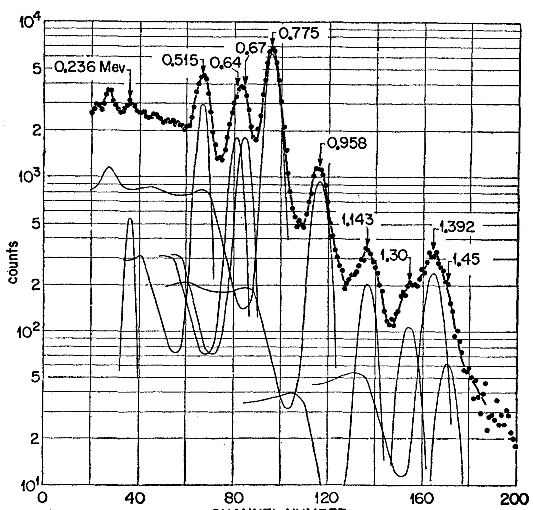

FIG. 4. I^{132} low-energy gamma-ray spectrum in coincidence with the 0.667-Mev gamma-ray peak. The single-channel window width was 40 kev.

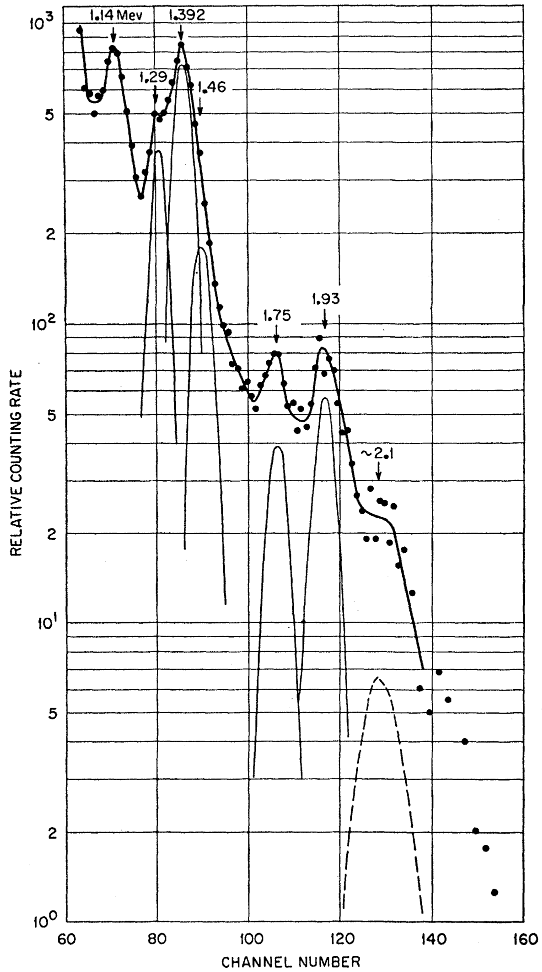

FIG. 5. I^{132} high-energy gamma-ray spectrum in coincidence with the 0.667-Mev gamma-ray peak. The source was a Te^{132}–I^{132} equilibrium mixture. The single-channel window width was 40 kev.

C. Gamma-Gamma Coincidence Spectra

The spectra in coincidence with the 0.518-, 0.667-, 0.775-, 0.953-, 1.142-, and 1.392-Mev gamma-ray peaks were investigated. The fast-slow coincidence circuit that was used had a resolving time 2τ of 0.17 μsec. The spectra are shown in Figs. 4–7. Chance counts have been subtracted. For these runs the angle between the two detectors was 180°, and the distance between the source and each detector was 9.3 cm. Intensities which were determined are included in Table I. Corrections have been applied for the angular correlation between the coincident gamma rays and for coincidences with Compton scattered, higher-energy gamma rays.

The peak at 0.512 Mev in the spectrum in coincidence with the 0.518-Mev gamma ray is partially due to annihilation radiation (presumably produced by high-energy gamma rays). This was indicated by a reduction of the intensity of this peak when the spectrum was re-examined with an angle of 125° between the two de-

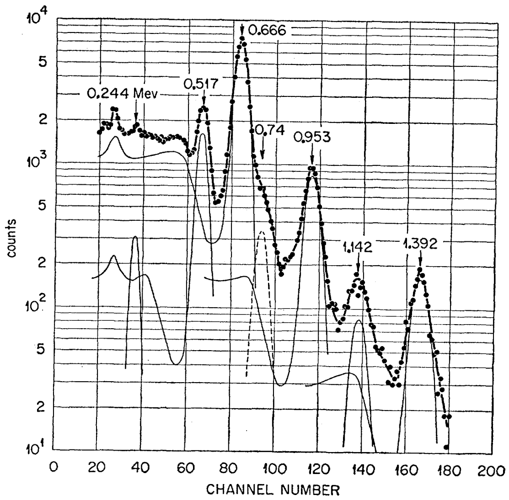

FIG. 6. I^{132} gamma-ray spectrum in coincidence with the 0.775-Mev gamma ray. The single-channel window width was 50 kev.

tectors. The remainder of this peak and also the unlabeled peaks in Fig. 7 can be attributed to coincidences with events in the single-channel window which do not result from the gamma ray of interest.

The peaks at ~0.67 Mev in the singles spectrum and in the spectra in coincidence with the 0.518- and 0.775-Mev gamma rays appear to be 10–15% wider than that expected for the full-energy peak of a single gamma ray.

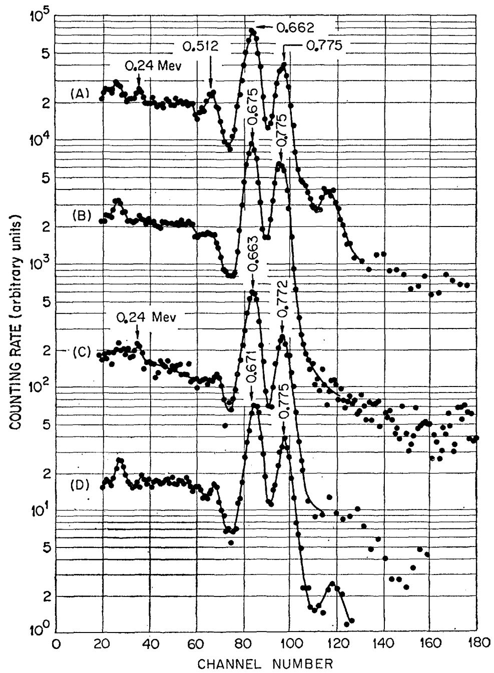

FIG. 7. I^{132} gamma-ray spectra in coincidence with the (A) 0.518-, (B) 0.953-, (C) 1.142-, and (D) 1.392-Mev gamma rays. The single-channel window widths of the four spectra were 30, 75, 60, and 100 kev, respectively. The source used for the spectrum in coincidence with the 1.142-Mev gamma ray was a Te^{132}–I^{132} equilibrium mixture.

This suggests that there is more than one gamma ray with approximately this energy. Such a suggestion is borne out by the spectrum in coincidence with the 0.667-Mev gamma-ray peak in which gamma rays were resolved with energies of 0.64 and 0.67 Mev. Because of the uncertainty in the individual intensities of these two gamma rays, only the sum of their intensities is given in Table I.

D. Gamma-Gamma-Gamma Coincidence Spectra

Two gamma-gamma-gamma coincidence spectra which were measured are illustrated in Fig. 8. Chance counts have been subtracted. For both spectra the distance between the source and each of the three 3 in.×3 in. NaI crystals was 8–10 cm. As in the gamma-gamma coincidence spectra, the resolving time 2τ was 0.17 μsec. The gamma-ray intensities are listed in Table I. No correction has been applied to them for angular correlation between the coincident gamma rays. The intensities of the gamma rays in Table I obtained when the two single-channel windows were both set on the 0.667-Mev peak need to be divided by two for comparison with the other intensities. Doubling of the intensities is a consequence of both windows accepting the same region of the spectrum.

E. Beta-Gamma Coincidence Spectra

For beta-gamma coincidence studies the beta rays were detected with a $1\frac{1}{4}$ in.-diam×$\frac{1}{2}$ in.-thick anthracene crystal which was coupled to a 6292 DuMont photomultiplier tube. The resolution of the detector for the

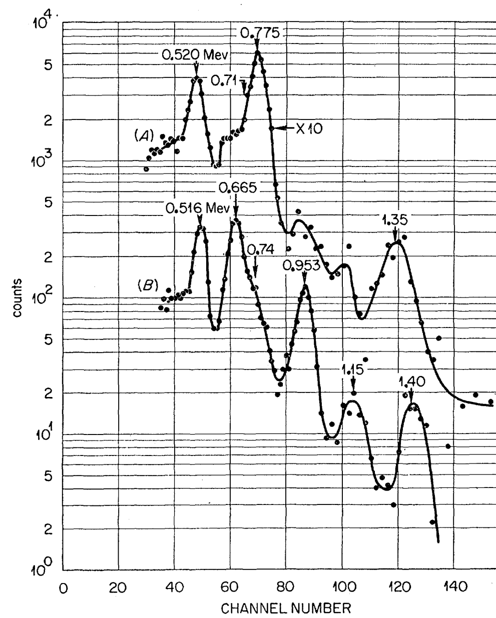

FIG. 8. I^{132} gamma-gamma-gamma coincidence spectra obtained with the two 50-kev wide single-channel windows set to accept the peaks at (A) 0.667 and 0.667 Mev and (B) 0.667 and 0.775 Mev.

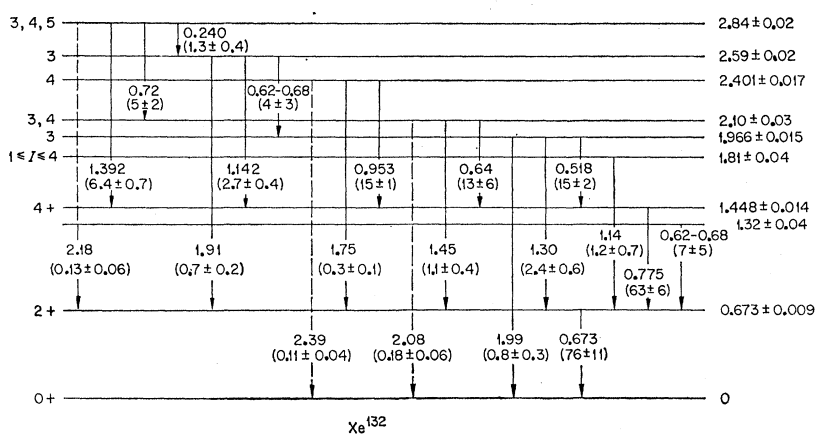

FIG. 9. Proposed energy-level diagram for Xe^{132}. The pair of numbers associated with each transition gives its energy in Mev and relative intensity.

624-kev internal-conversion electron line in Cs^{137} was ~11%. The end-point energies of the beta-ray spectra which were observed in coincidence with the 0.667- and 0775-Mev gamma-ray peaks are 2.13±0.05 and 2.16 ±0.06 Mev, respectively. These values are in agreement with the maximum beta-ray energy reported for I^{132},[2] and thus suggest that the highest energy beta-ray group terminates at the third excited level in Xe^{132} (see Fig. 9). Finston and Bernstein[2] reported a similar position for the maximum-energy beta-ray group on the basis of their beta-gamma coincidence studies. From the spectrum in coincidence with the 0.667-Mev gamma-ray peak, an upper limit for the intensity of a beta-ray group which populates the first excited level of Xe^{132} is established as less than 0.2% of the total beta-ray intensity.

F. Gamma-Gamma Angular Correlations

For the investigation of gamma-gamma angular correlations, the source was ~50 microliters of a solution of Te^{132}–I^{132} mixture in dilute HNO_3 contained in a $\frac{1}{8}$-in. diam fluorothene cylinder. It was placed 15 cm from each detector and was surrounded by a 0.7-g/cm² polystyrene absorber. Data were taken every 10° between 90° and 180°. The distance between the source and the movable detector was constant to within 0.2%. A least-squares fit of the data was made on an IBM 704 computer to the function $W(\theta)=1+A_2P_2(\cos\theta)+A_4P_4(\cos\theta)$, where P_2 and P_4 are Legendre polynomials. The results were corrected for the finite angular resolution of the detectors.[6] This correction was approximately 8% for A_2 and 30% for A_4. The corrected experimental values for A_2 and A_4 are given in Table II. Errors include not only statistical errors but also those which are introduced in the process of analyzing the data.

III. ENERGY-LEVEL DIAGRAM

An energy-level diagram based on the results of our studies is given in Fig. 9. This scheme includes all levels proposed by Finston and Bernstein[2] (see Fig. 1) and new levels at 1.32, 1.81, and 2.10 Mev. Coincidences found between the 0.667-Mev gamma-ray peak and the 1.75- and 1.30-Mev gamma rays give additional evidence for the 2.401- and 1.966-Mev levels, respectively. The 1.99-Mev gamma ray, which was observed only in the singles spectrum, is placed as a ground-state transition from the 1.966-Mev level. Because of their weak intensities, the assignments of the 2.08- and 2.18-Mev gamma rays should be considered as only tentative. The position given to the 0.240-Mev gamma ray in the level scheme is consistent with the energy difference of the 2.84- and 2.59-Mev levels and with the coincidence data.

TABLE II. Experimental angular correlation coefficients.

Angular correlation between gamma rays of energies (Mev)[a]	A_2	A_4
0.518−~0.65 } 0.518−0.673 }	+0.152±0.029	−0.023±0.018
0.64−0.673 } ~0.65−0.673 }	−0.168±0.021	+0.106±0.028
0.953−0.673	+0.206±0.014	+0.010±0.015
1.14−0.673 } 1.142−0.673 }	+0.008±0.033	−0.009±0.045
1.30−~0.65 } 1.30−0.673 }	+0.081±0.043	−0.070±0.061
1.392−0.673	−0.030±0.021	−0.026±0.030
0.518−0.775	+0.173±0.026	+0.022±0.030
0.64−0.775 } ~0.65−0.775 } 0.673−0.775 }	+0.047±0.012	+0.018±0.017
0.953−0.775	+0.223±0.017	+0.008±0.023
1.142−0.775	−0.194±0.036	+0.012±0.050
1.392−0.775	−0.023±0.015	+0.031±0.020

[a] The presence of several gamma rays between 0.62 and 0.68 Mev and of two gamma rays with energies 1.14 and 1.142 Mev is discussed in Sec. III.

[6] M. E. Rose, Phys. Rev. **91**, 610 (1953).

Four transitions with energies between 0.62 and 0.68 Mev are shown in the energy-level diagram. The most intense is the 0.673-Mev ground-state transition. Its energy is obtained from the spectra in coincidence with the 0.953- and 1.392-Mev gamma rays. The second transition in this energy region is given in Fig. 9 between the 2.59- and 1.966-Mev levels. It is inferred from the presence of the 0.520- and 1.35-Mev gamma rays in the triple coincidence spectrum for which both single-channel windows were set to accept the 0.667-Mev peak [see Fig. 8(A)]. This inference is based on the assumption that the 1.35-Mev peak is due to the 1.30-Mev gamma ray which is found in the singles spectrum and the spectrum in coincidence with the 0.667-Mev gamma-ray peak. The fact that no 1.35-Mev gamma ray was observed in these latter two spectra provides evidence for this assumption. The difference between the intensities obtained for the 0.518-Mev gamma ray in coincidence with the 0.667- and 0.775-Mev gamma-ray peaks also favors placement of a transition between the 2.59- and 1.966-Mev levels. The third transition with an energy between 0.62 and 0.68 Mev is shown in the level scheme as populating the 1.448-Mev level. It is needed to explain part of the intensity obtained for the 0.666-Mev gamma-ray peak in coincidence with the 0.775-Mev gamma ray. Inclusion of this transition requires a new level with energy of 2.10 Mev. Additional evidence for this level is given by the presence of a 1.45-Mev gamma ray in the spectrum in coincidence with the 0.667-Mev gamma-ray peak and an $\sim$0.72-Mev gamma ray in both of the gamma-gamma-gamma coincidence spectra.

It is inconsistent with our results to give the remaining intensity of the composite 0.667-Mev gamma-ray peak to the transition which de-excites the 0.673-Mev level. If this is done, the total intensities of transitions which populate the 0.673-Mev level are less than the intensity of the transition which de-excites it. To remedy the situation it appears necessary to include a fourth gamma ray with an energy between 0.62 and 0.68 Mev which is not in coincidence with the 0.775-Mev gamma ray. The only reasonable position for such a transition is between a level at 1.32 Mev and that at 0.673 Mev.

TABLE III. Intensities and comparative half-lives of the I^{132} beta-ray groups.

Terminating level (Mev)	Relative intensity	Logft
0.673	<0.15	>10.0
1.32	7	8.0
1.448	11	7.6
1.81	1.2	8.3
1.966	14	7.1
2.10	9	7.2
2.401	15	6.5
2.59	6	6.6
2.84	13	5.8

This gamma ray is probably the 0.62-Mev gamma ray which has been observed by Whyte, Sharma, and Taylor[7] in the decay of Cs^{132}. Since no direct observation was made of this gamma ray or of the gamma ray between the 2.59- and 1.966-Mev levels in the present study, we can only put limits on their energies. The energy of 0.64±0.02 Mev for the transition between the 2.10- and 1.448-Mev levels in Fig. 9 is taken from the spectrum in coincidence with the 0.667-Mev gamma-ray peak.

The difference in the observed intensity of the 1.14-Mev gamma ray in coincidence with the 0.667- and 0.775-Mev gamma-ray peaks suggests there are two gamma rays of approximately this energy. The intensity of the transition between the 2.59- and 1.448-Mev levels is a weighted average of two intensity values obtained from (a) the 0.775-Mev gamma ray seen in the spectrum in coincidence with the 1.142-Mev gamma ray and (b) the 1.142-Mev gamma ray seen in the spectrum in coincidence with the 0.775-Mev gamma ray. The remaining 1.14-Mev gamma-ray intensity is attributed to a transition between the 1.81- and 0.673-Mev levels.

Values of the relative intensities and comparative half-lives for the beta-ray groups of I^{132} are given in Table III. The intensity of the transition which terminates at the 0.673-Mev level was determined from the beta-ray spectrum in coincidence with the 0.667-Mev gamma-ray peak. For the other beta-ray transitions, these values were deduced from the energy-level diagram shown in Fig. 9. The comparative half-lives for the beta-ray groups which terminate at the 1.81- and 1.32-Mev levels should not be considered significant because of the large errors in the intensities of the gamma rays de-exciting these levels and the possibility of undetected gamma rays feeding these levels. For example, our data are not inconsistent with a 0.5-Mev gamma ray between the 1.81- and 1.32-Mev levels if its intensity is less than 4. Except for the group which populates the 0.673-Mev level, the remaining groups have comparative half-lives which are characteristic of once-forbidden, nonunique transitions or of allowed transitions. Since the ground-state spin of I^{132} is 4,[4,5] the levels populated by these groups are each expected to have a spin of 3, 4, or 5. The large value obtained for the comparative half-life of the transition which terminates at the 2+, 0.673-Mev level

TABLE IV. Angular correlations of the 1.392–0.775 Mev and the 1–3, 1.392–0.673 Mev cascades.

Sequence	δ	A_2	A_4
Experimental		−0.025±0.012	+0.013±0.017
$2(Q)4(Q)2(Q)0$		+0.200	+0.093
$3(D+Q)4(Q)2(Q)0$	+0.14	−0.025	−0.003
$4(D+Q)4(Q)2(Q)0$	−0.62	−0.025	+0.042
$5(D+Q)4(Q)2(Q)0$	−0.069	−0.025	0.000
$6(Q)4(Q)2(Q)0$		+0.102	+0.009

[7] G. N. Whyte, B. Sharma, and H. W. Taylor, Can. J. Phys. **38**, 877 (1960).

favors even parity for the ground state of I^{132}. Ground-state spins of nuclei in this region also indicate that the parity is even; i.e., for the ground states of neighboring odd-A nuclei, the odd proton is in the $d_{5/2}$ or $g_{7/2}$ orbital and the odd neutron is in the $d_{3/2}$ orbital.

From the systematics of even-even nuclei, the Xe^{132} level at 1.448 Mev is expected to have spin and parity 2+, 4+, or possibly 0+. Only 4+ is compatible with the comparative half-life of the beta-ray group which populates this level. Another argument against a 2+ assignment is the failure to observe a ground-state transition from the 1.448-Mev level. For example, from the spectrum in coincidence with the 0.953-Mev gamma ray, the ratio of the cascade to crossover gamma rays from the 1.448-Mev level is >160. This is considerably larger than values of 2–10 which have been found for ratios of the cascade to crossover gamma rays from the second 2+ levels of neighboring even-even nuclei.

Since the correlation functions for the sequence $I(D+Q)4(Q)2$ and the 1–3 sequence $I(D+Q)4(Q)2(Q)0$ are identical, the experimental coefficients obtained from the angular correlations of the 1.392–0.775-Mev and the 1–3, 1.392–0.673-Mev cascades were combined. These values are compared in Table IV with the theoretical correlation coefficients which occur for different spins of the 2.84-Mev level. Only dipole and quadrupole radiations are considered. The value of the mixing ratio δ, where $\delta=(Q/D)^{\frac{1}{2}}$ in the notation of Biedenharn and Rose,[8] was chosen to give best agreement between the theoretical and experimental coefficients. A spin assignment of 3, 4, or 5 for the 2.84-Mev level is consistent with the measured correlations. These correlations do indicate that the 1.392-Mev transition consists of greater than 72% dipole radiation.

The coefficients obtained for the angular correlations of the 0.953–0.775-Mev and the 1–3, 0.953–0.673-Mev cascades, which were also combined, are given in Table V along with the theoretical coefficients for sequences with different spins for the 2.401-Mev level. The theoretical coefficients for the sequence $4(99.7\%\ D+0.3\%\ Q)4(Q)2(Q)0$ are in best agreement with the experimental coefficients. However, the sequence $5(73\%\ D+27\%\ Q)4(Q)2(Q)0$ does give an acceptable although poorer fit. A transition which fits energetically between this 2.401-Mev level and the ground state was observed in the singles spectrum, but it is unlikely that a transition between levels with spins 4 (or 5) and 0 would have sufficient intensity to be seen. Thus, this position for the gamma ray or the spin assignment of the 2.401-Mev level is questionable.

TABLE V. Angular correlations of the 0.953–0.775 Mev and the 1–3, 0.953–0.673 Mev cascades.

Sequence	δ	A_2	A_4
Experimental		$+0.213\pm0.011$	$+0.009\pm0.013$
$2(Q)4(Q)2(Q)0$		$+0.200$	$+0.093$
$3(D+Q)4(Q)2(Q)0$	$+0.47$	$+0.213$	-0.034
$4(D+Q)4(Q)2(Q)0$	$+0.059$	$+0.213$	$+0.001$
$5(D+Q)4(Q)2(Q)0$	-0.61	$+0.213$	-0.015
$6(Q)4(Q)2(Q)0$		$+0.102$	$+0.009$

[8] L. C. Biedenharn and M. E. Rose, Revs. Modern Phys. **25**, 729 (1953).

TABLE VI. Angular correlation of the 1.142–0.775 Mev cascade.

Sequence	δ	A_2	A_4
Experimental		-0.194 ± 0.036	$+0.01\pm0.05$
$2(Q)4(Q)2$		$+0.200$	$+0.09$
$3(D+Q)4(Q)2$	-0.064	-0.194	0.00
$4(D+Q)4(Q)2$	-2.5	-0.179	$+0.13$
$5(D+Q)4(Q)2$	$+0.18$	-0.194	0.00
$5(D+Q)4(Q)2$	$+10$	-0.194	-0.06
$6(Q)4(Q)2$		$+0.102$	$+0.01$

The angular correlation of the 1.142–0.775-Mev cascade suggests the spin of the 2.59-Mev level is 3 or 5 (see Table VI). The presence of two 1.14-Mev gamma rays, as indicated in the coincidence spectra, is corroborated by the difference in the 1.142–0.775-Mev and 1.14–0.673-Mev correlation functions. From these two correlations and the intensities of the two 1.14-Mev gamma rays given in Fig. 9, the correlation coefficients of the 1.14–0.673-Mev cascade, which originates at the 1.81-Mev level, have been deduced. These coefficients are compatible with the theoretical coefficients obtained for any reasonable spin assignment of the 1.81-Mev level except 0 (see Table VII).

Spin assignments of 5 for the 2.59-, 2.401-, 2.10-, and 1.81-Mev levels, which are consistent with the angular correlation measurements and the comparative half-lives of the beta-ray groups, are not probable in view of the relative gamma-ray intensities. If the spin for any of these levels were 5, the ratio of the single-particle transition probabilities for transitions from that level to the 4+, 1.448-Mev level and to the 2+, 0.673-Mev level would be 10^6 to 10^8. The observed branching ratios, which are all $\leqslant 50$, would require that relative to the single-particle estimates the transitions to the 4+ levels be hindered, or the transitions to the 2+ levels be enhanced, by factors which are larger than usually found.

The angular correlation of the 0.518–0.775-Mev cascade is consistent with a spin assignment of 3, 4, or 5 for

TABLE VII. Angular correlation of the 1.14–0.673 Mev cascade.

Sequence	δ	A_2	A_4
Experimental		$+0.46\pm0.31$	-0.06 ± 0.19
$0(Q)2(Q)0$		$+0.36$	$+1.14$
$1(D+Q)2(Q)0$	$+0.79$	$+0.46$	-0.29
$2(D+Q)2(Q)0$	$+0.41$	$+0.46$	$+0.05$
$2(D+Q)2(Q)0$	$+0.95$	$+0.46$	$+0.16$
$3(D+Q)2(Q)0$	-0.85	$+0.26$	-0.03
$4(Q)2(Q)0$		$+0.10$	$+0.01$
$5(O)2(Q)0$		$+0.18$	0.00

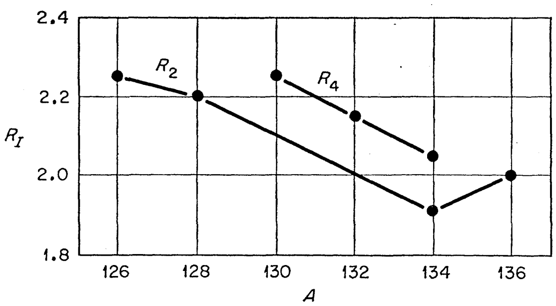

FIG. 10. Systematics of low-lying levels of even xenon nuclides. R_2 and R_4 are ratios of the energies of the second 2+ levels and of the first 4+ levels, respectively, to the energies of the first 2+ levels. Levels for Xe^{134} are from data obtained by N. R. Johnson, E. Eichler, G. D. O'Kelley, J. W. Chase, and J. T. Wasson, Phys. Rev. **122**, 1546 (1961). The others are taken from the *Nuclear Data Sheets* (National Academy of Sciences, National Research Council, Washington, D. C.).

the 1.966-Mev level (see Table VIII). However, spin 3 is favored by the presence of the 1.99-Mev ground-state transition. For spin 3, the 0.518-Mev gamma ray would consist of 86% dipole radiation and 14% quadrupole radiation.

Other angular correlations were measured (the coefficients are included in Table II) but they were each composed of two or more correlations. Because of this, it was not possible to obtain any useful information from them about the spins of levels and multipolarities of transitions.

IV. DISCUSSION

Our results give no definite information about the spin of the 1.32-Mev level shown in Fig. 9. However, systematics of even-even medium-weight nuclei indicate that its spin and parity is 2+. More specifically, systematics of even xenon nuclides indicate that the second 2+ level is below the first 4+ level. A plot of the ratios of the energies of the second 2+ levels and first 4+ levels to the energies of the first 2+ levels of xenon nuclides are given in Fig. 10. This plot suggests the energy of the second 2+ level of Xe^{132} should be about twice the energy of the first 2+ level. Such a value is in good agreement with the energy of the 1.32-Mev level.

In Fig. 11 the levels of Xe^{132} are compared with levels predicted by nuclear models which have been developed to account for the properties of low-lying levels in even-

TABLE VIII. Angular correlation of the 0.518–0.775 Mev cascade.

Sequence	δ	A_2	A_4
Experimental		$+0.173\pm0.026$	$+0.022\pm0.030$
$2(Q)4(Q)2$		$+0.200$	$+0.093$
$3(D+Q)4(Q)2$	$+0.40$	$+0.173$	-0.026
$4(D+Q)4(Q)2$	-0.073	$+0.173$	$+0.001$
$4(D+Q)4(Q)2$	$+1.1$	$+0.173$	$+0.083$
$5(D+Q)4(Q)2$	-0.45	$+0.173$	-0.010
$6(Q)4(Q)2$		$+0.102$	$+0.009$

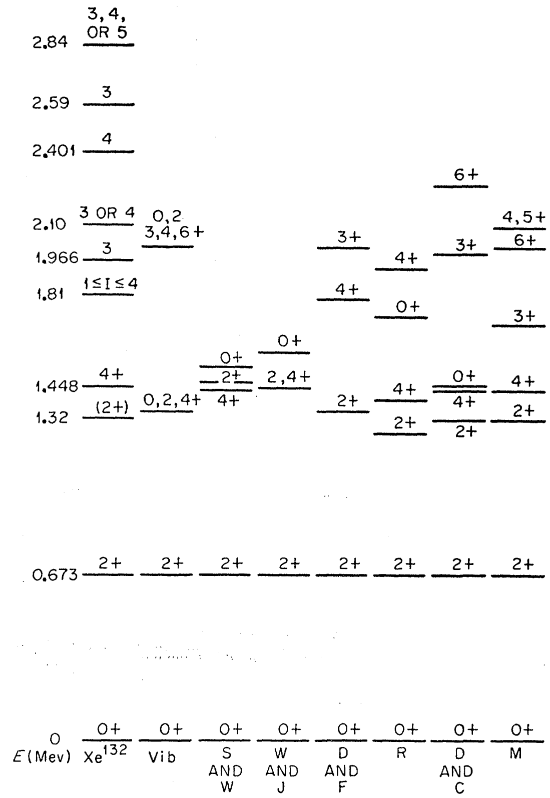

FIG. 11. Comparison of the Xe^{132} levels with levels predicted by the following nuclear models: Vib—Pure vibrational model. S and W—Model of Scharff-Goldhaber and Weneser. Levels taken from Fig. 3 of reference 9 with $K=1.2$. W and J—Model of Wilets and Jean. Levels taken from Fig. 2 of reference 10 with $x_0=1.8$. D and F—Model of Davydov and Filippov (see reference 11). Levels taken from Fig. 1 ($\gamma=30°$) of the reference: G. R. DeMille, T. M. Kavanagh, R. B. Moore, R. S. Weaver, and W. White, Can. J. of Phys. **37**, 1036 (1959). R—Model of Raz. Levels taken from Fig. 3 of reference 12 with $D=1.00$ and $x=0.3$. D and C—Model of Davydov and Chaban. Levels taken from Figs. 1–3 of reference 13 with $\gamma=24°$ and $\mu=0.7$. M—Model of Mallmann. Levels determined from reference 14 with $k=1.0$, $b=5.66\times10^{-3}$, $A/C=5.703$, and $hC=47.8$ kev.

even medium-weight nuclei.[9–14] Values of parameters which were used to obtain the levels for each model are given in the figure caption. Failure to observe levels in Xe^{132} with spins and parities 0+ and 6+, as proposed in several models, probably has no significance. In view of the I^{132} ground-state spin of 4,[4,5] levels of spins 0 and 6 would not be expected to be populated sufficiently to be observed. The 2+ and 4+ levels with energies approximately twice the energy of the first 2+ level are predicted by all models given in Fig. 11 except the axially asymmetric model of Davydov and Filippov.[11]

[9] G. Scharff-Goldhaber and J. Weneser, Phys. Rev. **98**, 212 (1955).
[10] L. Wilets and M. Jean, Phys. Rev. **102**, 788 (1956).
[11] A. S. Davydov and G. F. Filippov, Nuclear Phys. **8**, 237 (1958).
[12] B. J. Raz, Phys. Rev. **114**, 1116 (1959).
[13] A. S. Davydov and A. A. Chaban, Nuclear Phys. **20**, 499 (1960).
[14] C. A. Mallmann (preprint).

The first 4+ level of the axially asymmetric model is, instead, very near the 1.81-Mev Xe^{132} level, which could have spin 4. This model, as well as the extension of this model presented by Davydov and Chaban,[13] does predict a 3+ level which has an energy similar to that of the proposed spin 3, 1.966-Mev level. It might be noted that this 1.966-Mev level and the 1.81- and the 2.10-Mev levels appear to group around an energy which is three times that of the first 2+ level. This is the energy that the pure vibrational model predicts for five degenerate levels. The three levels of Xe^{132} could have spins of three of these levels; i.e., 2, 3, and 4.

In many even-even nuclei a 3- level, which can be explained as due to octupole surface vibrations,[15] has been observed with an energy between 2 and 3 Mev. There are three possible levels with spin 3 in this energy region in Xe^{132}. Unfortunately, it is not possible to say which one if any of these levels arises from octupole surface vibrations, since our results do not establish their parities.

[15] A. M. Lane and E. D. Pendlebury, Nuclear Phys. **15**, 39 (1960).

The gamma-gamma angular correlation measurements indicate the 1.392-, 0.953-, and 0.518-Mev transitions consist of a large amount of dipole radiation. Since a transition between levels of even-even nuclei which arise from collective types of nuclear motion is expected to have a predominantly electric quadrupole character, this suggests that the 2.84-, 2.401-, and 1.966-Mev levels may be excitations of the intrinsic structure or at least strongly influenced by it.

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Half-Life of B^{12}, Na^{24m}, and As^{75m}†*

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The following half-lives were measured: B^{12}, $(20.31\pm0.20)\times10^{-3}$ sec; the 472-kev level of Na^{24}, $(19.9\pm0.3)\times10^{-3}$ sec; and the 305-kev level of As^{75}, $(16.8\pm0.4)\times10^{-3}$ sec. The activities were made with a pulsed beam from a Van de Graaff generator. The data were taken with gated radiation-detection circuits in conjunction with a 9-channel time-delay analyzer, and the half-lives were determined by least-squares analysis.

INTRODUCTION

THE need for accurate half-life measurements in the millisecond range has been apparent for some time. The theory of weak interactions is sufficiently advanced to be able to interpret very accurate values for the half-life of some of the light nuclei such as B^{12}. The demand on accuracy for gamma-transition half-lives are not yet as severe; however, in several restricted classes, where empirical systematics have been observed, accuracy of the order of a few percent is significant. The state of experimental half-life determinations just a few years ago may be illustrated with B^{12}, where published values ranged from 18.5 ± 1 msec[1] to 27 ± 2 msec,[2] or with As^{75m}, where values ranged from 12 ± 3 msec[3] to 21 ± 2 msec.[4]

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* A preliminary report covering a part of this work appeared in Bull. Am. Phys. Soc. 4, 56 (1959).
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[1] E. Norbeck, Jr., Bull. Am. Phys. Soc. **1**, 329 (1956).
[2] J. V. Jelley and E. B. Paul, Proc. Cambridge Phil. Soc. **44**, 133 (1946).
[3] S. H. Vegors, Jr., and P. Axel, Phys. Rev. **101**, 1067 (1956).
[4] E. C. Campbell and P. H. Stelson, Oak Ridge National Laboratory Report ORNL-2076, 1956 (unpublished), p. 32.

Nuclei or nuclear states with half-lives in this time range are generally produced by activating a sample with the pulsed beam of an accelerator. The activity is then studied between beam pulses. It would appear that many of the earlier measurements were less accurate than had been claimed because of difficulties encountered in measuring the background on which the activity of interest was superimposed. In the work to be described, special precautions were taken to minimize the background due to the accelerator as well as the buildup of activities with intermediate half-lives. By analyzing the same data with different values for the background, an attempt was made to arrive at a realistic estimate of the accuracy of the reported half-lives.

EXPERIMENTAL PROCEDURE

The activities were produced either with the proton or with the deuteron beam of the large Los Alamos electrostatic accelerator. The type of information that could be obtained about these activities depended on the timing of the irradiation-counting cycle. Where the amount of activity was limited or where for background reasons the beam current had to be limited, an efficient