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Level Structure of Cr(52)

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Two additional positive-parity bands are suggested by the energy separations of the well-known 0+ and 2+ levels at 6.75 and 7.46 Mev and at 7.23 and 7.86 Mev, respectively.

The presence of a 3− level at 5.63 Mev, together with the recently assigned[9] 2− level at 4.97 Mev, and a possible 5− level at 8.84 Mev, has led to the discovery[4] of a new level at 7.02 Mev whose properties[3,4] are consistent with it being the third member of a $K=2$ negative-parity band. Similarly, the 1− level at 5.80 Mev may form a band with the 3− level at 7.19 Mev. It is interesting to note that if a rotational band is associated with these levels no evidence for a 2− member near 6.3 Mev is present. The absence of 2− and 4− members of this band requires a K quantum number of 0 and implies an octopole shape deformation or vibration of the nucleus. Such octopole motion giving rise to $K=0$ and 2 negative-parity bands has recently been considered by Lipas and Davidson.[25] Similar low-lying negative-parity bands are also expected on the shell model when particle excitation to $2p$ and $1f$ orbits as well as core excitation are included.[26]

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CONCLUSIONS

The alpha-particle angular correlation measurements described above allow unambiguous assignments of 3− and 1−, respectively, to be made to the 5.63- and 5.80-Mev levels of Ne^{20}. The value of $(2l+1)\Gamma_\gamma\Gamma_\alpha/\Gamma$ for the 5.63-Mev level is known to be sufficiently large for this level to contribute significantly to Ne^{20} formation in supernova explosions via the $O^{16}(\alpha,\gamma)Ne^{20}$ reaction. The observed assignments together with other data suggest the presence of negative-parity rotational bands in Ne^{20} and thus imply an octopole vibration of this nucleus.

ACKNOWLEDGMENTS

The author is indebted to Dr. E. Almqvist and Dr. A. E. Litherland for stimulating discussions concerning these measurements.

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Level Structure of Cr^{52}†

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The low excited states of Cr^{52} have been investigated by studying the decay of Mn^{52} using scintillation spectrometers and a double-focusing beta-ray spectrometer. In addition to the three strong lines at 0.74, 0.94, and 1.43 Mev, a number of weak transitions have been observed that require the addition of at least one new level at 3.614 Mev and which yield information on the spins and parities of the various levels. The following gamma rays have been observed: 1.434 Mev (100%), 1.332 Mev (5.7%), 1.246 Mev (5.8%), 1.214 Mev (2.9%), 0.935 Mev (83.9%), 0.847 Mev (2.6%), 0.744 Mev (81.9%), and 0.346 Mev (0.9%), in addition to several weaker and more uncertain lines. A decay scheme has been constructed which consists of levels at 1.434 Mev (2+), 2.369 Mev (4+), 2.648 Mev, 2.766 Mev (4+), 3.112 Mev (6+), 3.161 Mev (1,2,3), 3.614 Mev (5+, 6+), and 3.832 Mev (5+, 6+). A comparison has been made between the experimentally determined level structure and several theoretical calculations. Mn^{54} (290 day) was present in the Mn^{52}. The energy of the Mn^{54} gamma-ray transition was determined to be 834.9±1.1 kev.

I. INTRODUCTION

FOR the past several years a program has been underway at this laboratory to investigate the level structure of even-even nuclei in the vicinity of the $f_{7/2}$ shell (N or Z from 20 to 28 nucleons). There have been several calculations made for nuclei in this region, based on both the independent-particle model[1–4] and the collective model,[5–7] and each seems to offer only partial success. It is clear, however, that more complete experimental information is needed for a satisfactory

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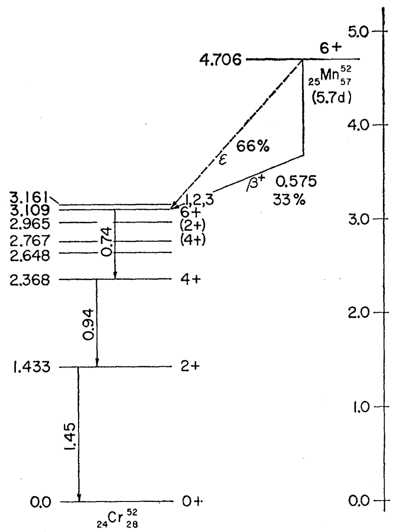

FIG. 1. Decay scheme of Mn[52] as previously reported.

comparison with any particular theory. While decay scheme studies have limitations, they do help in determining gamma-ray branching ratios, and often high spin states are populated that are missed in inelastic particle scattering.

The level structure of Cr[52] is of interest mainly because there are four $f_{7/2}$ protons outside of a closed shell, while the neutron shell is closed at $N=28$. The existing information on the decay of Mn[52] and the levels of Cr[52] at the time this study was begun is summarized in Fig. 1. The main features of the decay scheme are as listed in Way *et al.*[8] The energies of all of the levels (except the 3.109-Mev 6+ state) are taken from the inelastic proton measurements of Mazari, Buechner, and Sperduto.[9] It is evident from published work[10] that the level at 3.109 Mev is populated in the decay from Mn[52] and is distinct from the 3.161-Mev level which is seen in reaction studies and presumably has a spin no higher than 3 or 4. The three prominent gamma rays of 1.43, 0.94, and 0.74 Mev all appear to be $E2$ transitions between the levels with spins of 0+, 2+, 4+, and 6+.[8,11,12]

The four levels at 2.648, 2.767, 2.965, and 3.161 Mev first reported by Mazari *et al.*[9] have also been observed in inelastic neutron scattering by Van Patter[13] who indicated spins of 0, ≥ 4, 2, and 1, 2, or 3, respectively, for these levels. There have been a number of experiments[14–16] concerning the ground state of Mn[52] which establish a spin of 6 for that level, and a positive parity is required because of the allowed nature of the beta branch to the 3.109-Mev level in Cr[52].

After the completion of the experiments reported here, the results of Katoh, Nozawa, Yoshizawa, and Koh[17] on the decay of Mn[52] (5.7 day) and Mn^{52m} (21 min) were received. In summary, their work supports the decay scheme shown in Fig. 1. They also made precise measurements of gamma-ray energies and observed some weak transitions in the decay of Mn[52] and Mn^{52m} that have not been reported before. The relationship of their results to the present work will be discussed in more detail later.

It seemed likely from the calculations of Raz[5] and from the systematics of even-even nuclei around Cr[52] that another 6+ state should be present above the 3.109-Mev level but low enough in energy that it could be appreciably populated by an allowed electron capture branch. It appeared also that a careful search for weak gamma-ray transitions would be fruitful, since it could be expected that either the 2.648-, the 2.767-, or the 2.965-Mev level would be a 4+ state and hence be populated from the 3.109-Mev 6+ level or from a higher lying 6+ state.

Sources of 5.7-day Mn[52] were obtained from a commercial supplier[18] who used a $Cr+p$ reaction. Carrier-free manganese was then chemically separated from the chromium. Besides the 290-day Mn[54] no other radioactivity was detected in the three sources received. In the scintillation counter work the 0.835-Mev peak of Mn[54] was not in evidence for about 20 days.

II. GAMMA-RAY SCINTILLATION COUNTER MEASUREMENTS

A. Singles Measurements

A ($3\frac{3}{4}$ in. diam$\times$3 in.) NaI(Tl) crystal, integrally mounted on a 5-inch phototube, was used in conjunction with a 200-channel pulse height analyzer to obtain the various spectra. The sources were placed in a lucite capsule with 0.1-in. wall thickness which was more than sufficient to stop all of the positrons. Both the large singles NaI(Tl) crystal and the 2 in. $\times$2 in. coincidence NaI(Tl) crystal were calibrated empirically by constructing intrinsic photopeak efficiency versus gamma-ray energy curves using standard calibration sources.

Figure 2 shows a typical singles spectrum. The four

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[18] Nuclear Science and Engineering Corporation, Pittsburgh, Pennsylvania.

TABLE I. Gamma-ray intensities in the decay of Mn^{52}.

Gamma-ray energy (kev)[a]	Singles	1.43 Coin.	1.33 Coin.	0.935 Coin.	0.744 Coin.	Internal conver.[b]	External conver.	Weighted average
1433.6 ±0.4	100	100	Present	Present	Present	100	···	100
1332 ±1	···	5.7±0.3	···	···	···	5.7 ±0.9	4.1±3.5	5.7 ±1.0
1245.6 ±0.4	···	6.1±2.1	···	···	···	5.1 ±1.3	6.0±2.0	5.8 ±0.5
1214 ±1	···	···	···	···	···	$E2$:2.9±1.8	···	$E2$:2.9±1.8
						$E1$:6.0±3.6	···	$E1$:6.0±3.6
935.1 ±0.4	81.5±4.0	85.0±2.5	···	83.2±3.4[c]	Present	85.2 ±9.0	···	83.9 ±1.9
847.4 ±0.6	···	5.9±1.6	2.8±0.3	···	···	2.5 ±0.2	···	2.6 ±0.3
743.8 ±0.3	83.2±5.8	81.9±1.6[d]	···	81.9±1.6[d]	···	81.0 ±8.0	···	81.9 ±1.6[d]
345.74±0.08	···	···	0.6±0.3	···	···	0.88±0.08	1.0±0.2	0.89±0.2
Annihilation radiation	63.6±6.1	58.4±5.8	Present	60.3±1.0	65.8±1.2	···	···	62.5 ±3.2
Weak transitions								
2650±30 [e]	0.08±0.05	···	···	···	···	···	···	···
1463±2	···	···	···	···	···	0.3 ±0.2	···	···
1180±20 [e,f]	···	<2	···	···	···	···	···	···
1070±20 [e]	···	<4	<1	···	···	···	···	···
630±60 [e]	···	<3	<1	<3	<5	···	···	···

[a] Beta-ray spectrometer results.
[b] Based on $E2$ conversion coefficient.
[c] From intensity of 1.43-Mev gamma ray.
[d] Used for normalization.
[e] Gamma-ray spectrometer results.
[f] This gamma ray is believed to be the same as the 1.21-Mev line seen in internal conversion.

prominent peaks are due to annihilation radiation and to the main triple gamma-ray cascade. Weaker gamma rays have also been resolved at 1.33 and 1.25 Mev. There are four coincidence sum peaks (1.68, 1.94, 2.19, and 2.37 Mev) in evidence with energies higher than the 1.43-Mev line. To help search for weaker transitions in this region, the source was moved from 14 to 30 cm from the crystal, which had the effect of reducing the ratio of coincidence summing to normal gamma rays. There was no evidence of any gamma rays from about 1.6 to 2.4 Mev with an intensity greater than 0.5%. It is apparent that above 2.4 Mev the spectrum taken at 30 cm has a counting rate relative to the 1.43-Mev peak nearly equal to the spectrum at 14 cm, indicating the possible presence of a gamma ray. There are two weak coincidence sum peaks at 2.68 and 2.77 Mev due to the summing of the 1.43- with the 1.25- and 1.33-Mev gamma rays, respectively. From a knowledge of the relative intensities of these gamma rays and the coincidence summing efficiencies, sum peaks were constructed at the appropriate energies and subtracted from the 30-cm spectrum. The difference indicated a possible weak transition at 2.65 Mev of intensity less than 0.1%. Table I presents the results of the singles investigations. Of immediate interest are the intensities of the 0.744- and 0.935-Mev transitions since they are less intense than the 1.434-Mev gamma ray. All three gamma rays were previously reported as being of equal intensity.

The 1.72-Mev gamma ray seen by Katoh *et al.*[17] was not observed in these studies. Their estimated intensity for it is 0.5%; the present measurements indicate that if it is present it must be less than 0.5%.

The 1.25- and 1.33-Mev gamma rays were barely resolvable in the singles measurements. In order to look more sensitively for weak transitions, a series of coincidence spectra were taken.

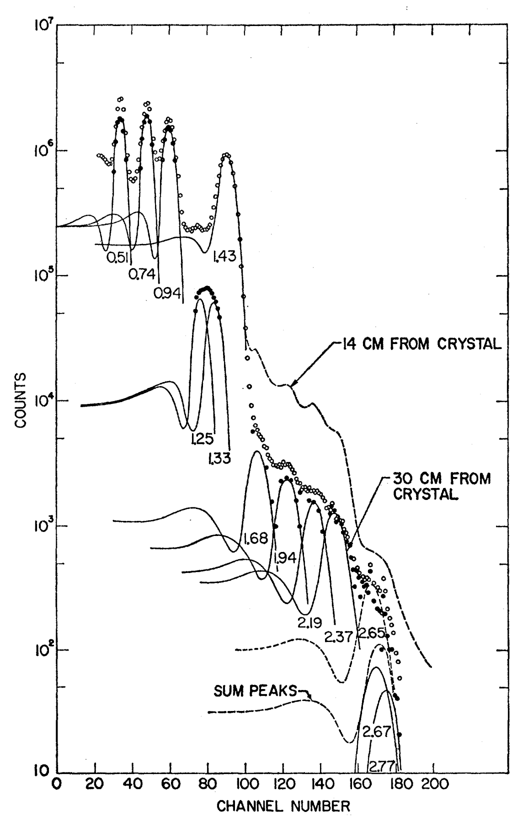

FIG. 2. Spectrum of the decay of Mn^{52} using a $3\frac{3}{4}$-in. diam×3 in. NaI(Tl) single crystal.

B. Coincidence Measurements

The coincidence arrangement used has been previously described.[19] NaI(Tl) crystals of 2-in. diam×2 in., and $1\frac{3}{4}$-in. diam×2 in. were used with RCA 6810 A photomultipliers and a fast-slow coincidence circuit ($2\tau=35$ mμsec) to gate the 200-channel pulse-height analyzer.

The Lucite source cup had sufficient wall thickness to stop all of the positrons. The counters were positioned at 90° with a 0.5-in. lead plate separating them. A number of coincidence spectra were run with the source counter separation at $1\frac{1}{2}$ in. and 3 in. There is a coincidence sum peak at 1.255 (0.744+0.511) Mev and at 1.446 (0.935+0.511) Mev. Changing the source-to-counter distance helped to untangle the coincidence sum peaks from the real gamma rays that happen to fall very near the sum peaks. All of the coincidence spectra shown were taken at 3 in. where only a very small correction had to be applied for the coincidence sum peak contribution.

Figure 3 shows a 1.43-Mev gamma-ray coincidence spectrum. This particular run had a duration of 4000 minutes live time. The gating discriminator was positioned to cover the 1.41- to 1.50-Mev energy range. Two gamma rays are distinct at 1.33 and 1.25 Mev, in addition to the strong lines at 0.51, 0.74, and 0.94 Mev. In the region from 1.25 to 0.94 Mev the analysis of the spectra consistently showed the presence of two additional lines; one at 1.07 Mev, and the other at about 1.18 Mev. Likewise, two other weak lines at 0.85 and around 0.60 Mev appeared in the lower energy portion.

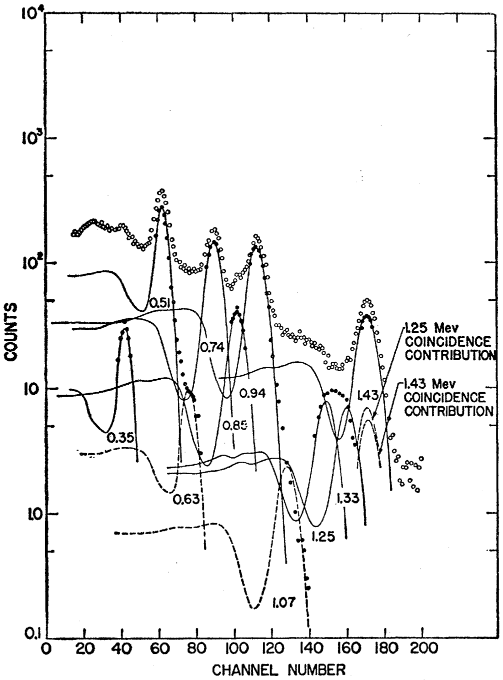

FIG. 4. Gamma-ray spectrum of $Mn^{52}\rightarrow Cr^{52}$ in coincidence with the 1.332-Mev radiation. Open circles are experimental points and solid circles are the result of subtracting gamma rays. Dashed curves at 0.63 and 1.07 Mev represent weak transitions. The dashed curves under the 1.434-Mev gamma-ray photopeak represent the respective contributions as labeled.

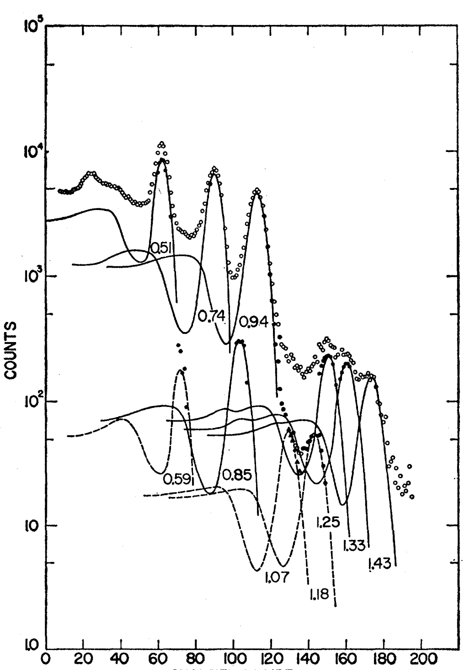

FIG. 3. Gamma-ray spectrum of $Mn^{52}\rightarrow Cr^{52}$ in coincidence with the 1.434-Mev radiation. Open circles are experimental points. Solid circles and triangles are the result of subtracting gamma-rays. Dashed curves represent weak transitions.

The intensity and energy of the four weak lines (0.60, 0.84, 1.07, and 1.18 Mev) depends very sensitively on the shapes of the single gamma-ray spectra used in the subtraction process. A number of 1.43-Mev coincidence spectra were analyzed with varying approximations in the subtraction process and all four seemed to consistently manifest themselves. Further evidence is presented later for these lines. The appearance of the peak at 1.43 Mev is partly due to the coincidence sum peak at 1.45 Mev but mostly due to the discriminator being positioned on the Compton distribution of the 1.679- (0.935+0.744) Mev sum peak which is in coincidence with the real 1.43-Mev gamma ray.

In order to normalize the coincidence intensities, the intensity of the 0.744-Mev gamma ray was taken to be $81.9\pm1.6\%$ (relative to the 1.43-Mev line being 100%) based on a combination of the results of the scintillation and beta-ray spectrometers. Combining the results of the four best 1.43-Mev coincidence spectra yields the results presented in Table I. The rms errors quoted are based solely on internal consistency. The intensity of the 1.25-Mev gamma ray has been corrected for a

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small contribution from the coincidence sum peak at 1.25 Mev (0.74+0.51 Mev).

The 1.33-Mev coincidence runs were particularly helpful in the analysis of the weak transitions and a typical run is shown in Fig. 4. The discriminator was carefully positioned to cover the energy range from 1.31 to 1.35 Mev so that a minimum contribution from the 1.25- and 1.43-Mev gamma rays was realized. Obviously a large portion of the spectrum shown in Fig. 4 is due to the Compton distribution but clearly resolved are the weak transitions at 0.847 and 0.346 Mev with intensities of $2.8\pm0.3\%$ and $0.6\pm0.3\%$, respectively. The weak transitions at 1.07 and 0.63 Mev are dashed because they are less certain than the others. The run shown in Fig. 4 was for 5000 minutes of live time. Because of the multiple triggering and low intensity of the 1.33-Mev gamma ray, no attempt was made to determine the intensity of the annihilation quanta in the 1.33-Mev spectrum.

A substantial amount of information was obtained from the 0.935- and 0.744-Mev gamma-ray coincidence spectra presented in Figs. 5 and 6, respectively. The gating discriminators were set to cover the energy range of 0.88 to 1.02 Mev for the 0.935-Mev coincidence runs, and 0.71 to 0.80 Mev for the 0.744-Mev coincidence runs.

In order to be able to subtract the coincident contribution from the Compton distribution beneath the 0.935-Mev peak, a second coincidence spectrum was measured for the same length of time as for the 0.935-Mev run but with the discriminator positioned from 1.02 to 1.16 Mev. The resulting spectrum, shown as the dashed curve in Fig. 5, was then subtracted from the original data and the solid points shown were the results. The spectrum was then analyzed and yielded gamma rays at 1.43, 1.25, 0.74, and 0.51 Mev. The intensities are again given in Table I. The presence of the 1.25-Mev gamma ray in the 0.935-Mev spectrum clearly shows that it is in coincidence with the 0.935-Mev transition and the absence of the 1.33-Mev gamma ray indicates that both the 0.935- and 1.33-Mev gamma rays feed the first excited state.

A different approach was used to analyze the 0.744-Mev spectrum. There was no convenient Compton distribution on either side of the photopeak in this case as was the case for the 0.935-Mev spectrum. The dashed curve shown in Fig. 6 is one which was constructed utilizing the best intensities of the 1.43-Mev coincidence runs for the 1.33-, 1.25-, and 0.935-Mev gamma rays. A coincidence spectrum, with multiple triggering included, for each of the above transitions, was constructed. These three spectra, along with the 1.43-Mev gamma-ray coincidence spectrum, were combined according to their Compton intensities under the 0.744-Mev gamma ray. The resulting dashed curve was then subtracted, leaving ostensibly the 0.744-Mev spectrum which was analyzed. The absence of the 1.33-, 1.25-, and 0.84-Mev gamma rays supports the results of the 0.935-Mev runs in that the assumed feeding of the levels at 2.766 and 2.369 Mev seems to be correct. The results of the 0.744-Mev coincidence runs are displayed in Table I.

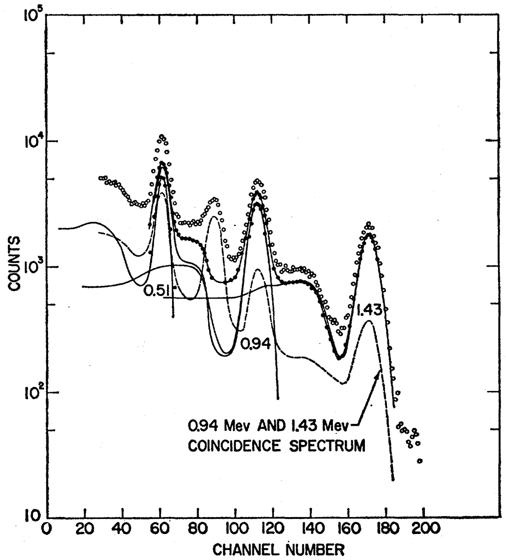

FIG. 6. Gamma-ray spectrum of $Mn^{52}\rightarrow Cr^{52}$ in coincidence with the 0.744-Mev radiation. Open circles are experimental points and solid circles are the result of subtracting gamma-rays. The continuous series of solid circles represents the result of subtracting the Compton contributions of the 1.43-, 1.33-, 1.25-, and 0.935-Mev radiations (dashed curve). Note the elimination of the 0.744-Mev photopeak.

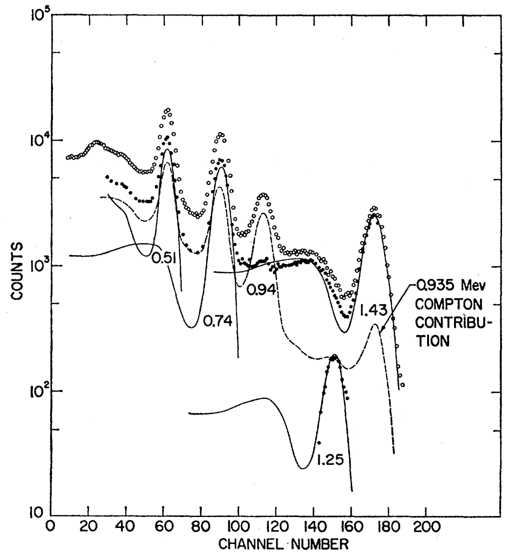

FIG. 5. Gamma-ray spectrum of $Mn^{52}\rightarrow Cr^{52}$ in coincidence with the 0.935-Mev radiation. Open circles are experimental points and solid circles are the result of subtracting gamma rays. The continuous series of solid circles represents the result of subtracting the Compton contributions of the 1.43-, 1.33-, and 1.25-Mev radiations (dashed curve). Note the elimination of the 0.935-Mev photopeak.

III. BETA RAY SPECTROMETER MEASUREMENTS

A. Description of the Spectrometer

Manganese 52 was the first isotope studied in detail with the University of Colorado's new double focusing electron spectrometer.[20] The spectrometer is of the Siegbahn-Svartholm type[21] in which the magnetic field has cylindrical symmetry, with the field in the equatorial plane varying as $(r)^{-\frac{1}{2}}$. It is constructed of iron in the inside-out configuration[22–25] and has a mean radius of 30 cm with a maximum design transmission of 5% of 4π. The detector is a Geiger-Mueller counter with a window of 0.00025-in. aluminized Mylar. The measurement of the momenta of the focused electrons is made with a peaking strip[26] which has a present limit of sensitivity of approximately 0.3 gauss cm.

Studies of the line profiles as a function of the field shape, transmission, source dimensions, and detector slit dimensions were in progress but were incomplete at the time these Mn^{52} studies were undertaken. Because of the possibility of errors due to line shifts as transmission or as other parameters are changed, all measurements, including calibrations, were made with the geometrical parameters of the spectrometer remaining unchanged.

B. Experimental Method

Two separate sources of Mn^{52} were studied. The Mn^{52} came dissolved in $1N$ HC1 which was evaporated to dryness on a ribbon of 0.00025-in. gold-coated Mylar film. This first source proved to be quite weak. The internal conversion electrons corresponding to the three main transitions were observed several times, as were the external conversion electrons from a uranium foil. The results of these measurements consisted primarily of the following energy determinations for the three main gamma-ray transitions: 1432.4 ± 1.1 kev, 934.3 ± 1.0 kev, and 743.3 ± 0.7 kev. The probable errors quoted are determined from the averages of several runs as well as from calibrations using electrons from the thorium active deposit. The intensities of the internal and the external conversion lines were measured, but with low accuracy due to the weak source. These intensities were consistent with the three gamma rays being $E2$ transitions of approximately equal intensity.

The second source of Mn^{52} was prepared in the same way as the first and was deposited on an area 6.35 mm wide and 38.1 mm long. The evaporated deposit was visible and was estimated to be less than 1 mg/cm. At the time the measurements were begun, the gamma-ray activity of the source was approximately 1500 mr/hr at two inches, which was several order of magnitude stronger than the first source.

Throughout these measurements, the beam-defining slits of the spectrometer were set to allow a geometrical transmission of two and one-half percent of 4π, corresponding to a luminosity of 6×10^{-2} cm^2. The width of the detector slit was 3.2 mm, and under these conditions the resolution was somewhat better than one percent. Previous experience with this spectrometer had suggested that under conditions of unchanged geometry, it was reliable to use the peaking strip current at the half-height point of the high-energy side of a peak of monoenergetic electrons as a measure of the momentum of that group of electrons.

1. The Internal Conversion Spectrum

The internal conversion spectrum of Mn^{52} is shown in Fig. 7, which shows the most complete of three detailed examinations of the spectrum as well as some of the portions of the spectrum as they appeared when re-examined. Representative statistical probable errors are approximately the diameter of the plotted points. The points on the graph are shown without correction for decay. In addition to the region shown, the region from 1000 to 500 gauss cm was examined. No electron groups of intensity greater than ten percent of the intensity of the 0.346-Mev group were observed in this scan. All peaks decayed with the 5.7-day half-life except for one of the two closely spaced peaks near 0.84 Mev as shown in Fig. 8. The higher energy peak decayed with the 5.7-day half-life and was thus attributed to Mn^{52}, while the lower energy peak decayed with a much longer half-life. It was attributed to the 290-day Mn^{54}.

2. The External Conversion Spectrum

The spectrum of the gamma rays converted externally in a foil of uranium approximately 20 mg/cm^2 thick was studied. The uranium converter was 6.35 mm wide and 38.1 mm high. It was deposited as uranium oxide on aluminum 0.040 in. thick by the method described by Novakov *et al.*[27] The internal conversion electrons from the source were stopped by Lucite 4 mm thick, so that the uranium was approximately 5.0 mm from the source.

Portions of this spectrum are shown in Fig. 9. The three main transitions are clearly visible from their K, L, and M conversion electrons, although the resolution, was not sufficient to allow separation of the

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[27] T. Novakov, S. Hultberg, and B. Andersson, Arkiv Fysik **13**, 117 (1958).

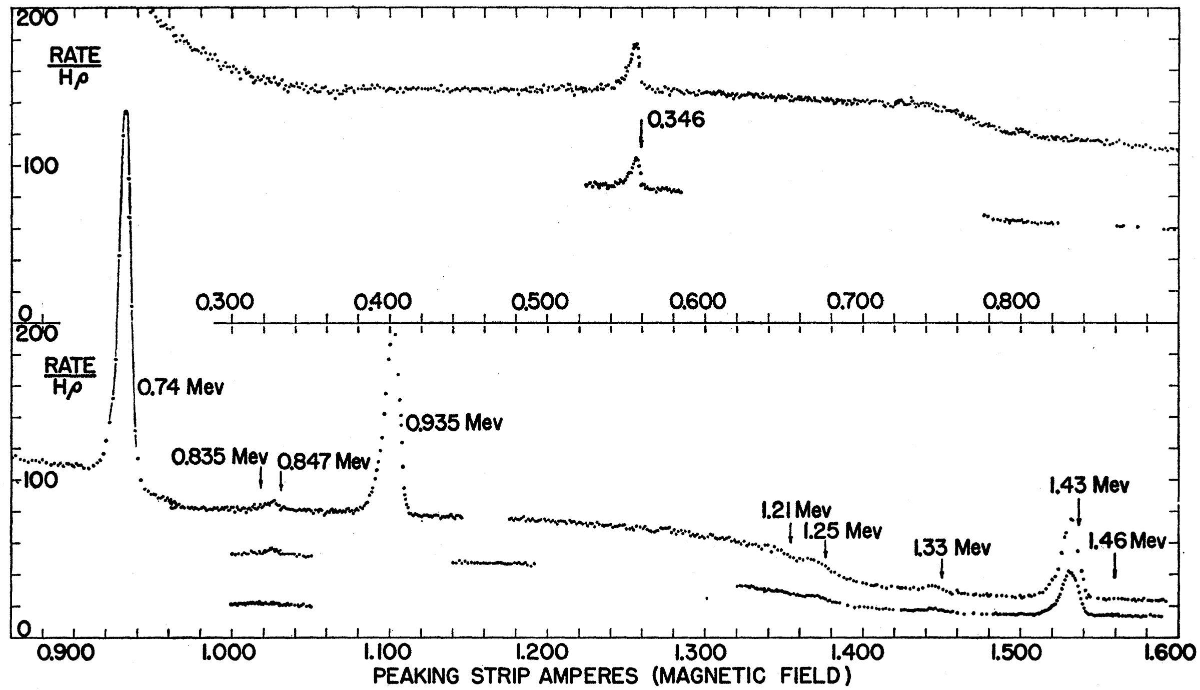

FIG. 7. Internal conversion spectrum from the decay of Mn^{52}. No decay corrections have been made.

several L subshell and the several M-subshell conversion electron groups. In addition to the conversion electrons from the three main transitions, those from some of the weaker transitions were seen in the examinations of the external conversion spectrum. Also visible is a prominent peak corresponding to the conversion in uranium of the annihilation quanta from the positrons from the Mn^{52} decay. The appearance of this peak of a known energy allowed accurate determinations of the momenta and energies of the other transitions.

C. Results

1. *Energy Measurements*

The energy of the two photon annihilation quanta was taken as $m_0c^2=510.976\pm0.007$ kev.[28] The binding energy of the K-shell electrons in uranium was taken as 115.601 ± 0.005 kev from the work of Nordling and Hagstrom.[29] These gave 2496.97 gauss cm as the momentum of the conversion electrons. It has been shown experimentally[30] that the center-of-mass motion of the annihilating positron-electron system can give rise to approximately 1 kev spread in the energy of the annihilation radiation. A detailed comparison of the shapes of the high-energy edges of the conversion lines from the main gamma rays and from the annihilation radiation in this work showed these shapes to be the same to within the experimental error, which would indicate that the Doppler broadening was masked by the effects of the resolution and the straggling from the thick converter. Detailed understanding of the line profiles under the conditions of these measurements is not yet sufficient to allow an evaluation to be made of the extent of the need for a Doppler correction in these

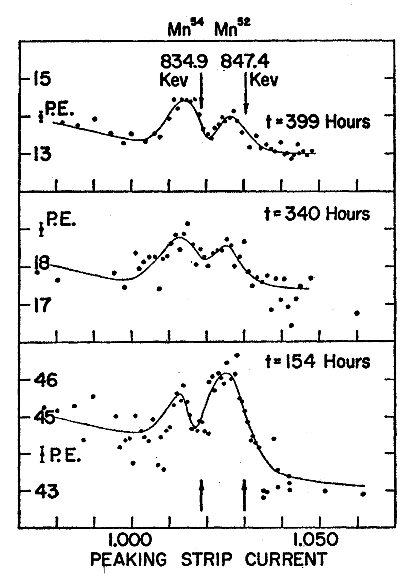

FIG. 8. Internal conversion spectrum from the decay of Mn^{52} and Mn^{54}. Three successive examinations without decay corrections are shown of the region around 0.84 Mev. The more rapid decay of the higher energy peak is evident.

[28] E. R. Cohen, K. M. Crowe, and J. W. M. DuMond, *The Fundamental Constants of Physics* (Interscience Publishers, Inc., New York, 1957).
[29] C. Nordling and S. Hagstrom, Arkiv Fysik **15**, 431 (1959).
[30] D. A. Lind and A. Hedgran, Arkiv Fysik **5**, 38, (1952).

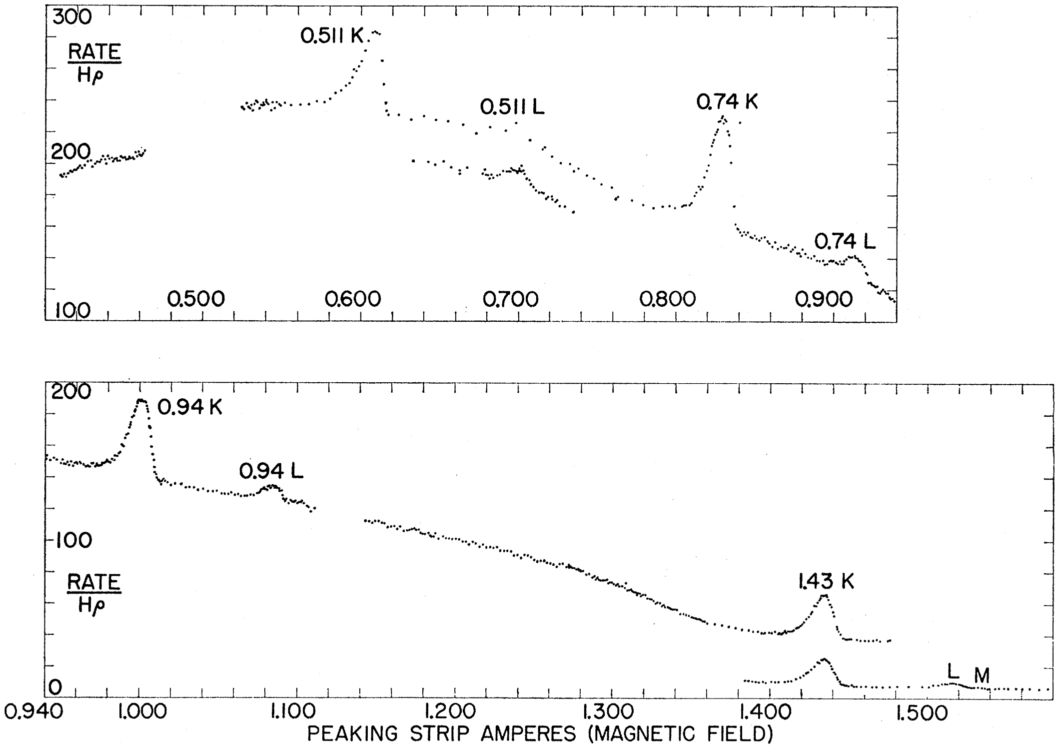

FIG. 9. External conversion spectrum of the decay of Mn^{52}. The converter used was 20 mg/cm² of uranium. No decay corrections have been made.

measurements. The similarity of the shapes of the high-energy edges of the various lines (which were the basis for the momentum comparisons) suggests that the correction, if needed, is small.

The reproducibility of the internal conversion measurements of peaking strip readings corresponding to conversion electron groups was better than the value of absolute calibrations which would be done with the spectra of separate sources of a standard such as the thorium active deposit because the standard and the unknown would have to have identical distributions over their areas and would have to be identically placed in the spectrometer. For these reasons it was felt that relative electron momenta, as determined from peaking strip measurements during periods when the source was not moved, would be reliable to a few parts in 10^4 while absolute calibrations through the use of a comparison thorium source could not achieve this accuracy. Consequently, the energies of the transitions seen in external conversion were determined by comparison with the annihilation peak. The relative momenta of the internal conversion electrons were used to check the consistency of this procedure and to determine the energies of the low-intensity transitions not seen in external conversion. The probable errors quoted are based on the internal consistency of several determinations of the same quantity, and are therefore believed to be reliable guides to the precision of these determinations. These data are summarized in Table II, where, for comparison, the recent work of Katoh *et al.*[17] is cited.

Two columns of errors are given for the present work. The first represents the probable error derived from internal consistency of several measurements, and the second is the larger, to include the uncertainties in the Doppler broadening of the annihilation radiation. The reason for the discrepancies between this work and that of Katoh *et al.* is not known.

2. *Intensity Measurements*

The method of Hultberg and Stockendal[31] was applied to the determination of the relative gamma-ray intensities and to the calculation of the internal conversion coefficients from the internal and external conversion data (see Appendix B). The relative gamma-ray intensities are listed in Table I. The experimental internal conversion coefficients for three of the less intense transitions are $e_K(1.33)=(10\pm10)\times10^{-5}$, $e_K(1.25)=(7\pm4)\times10^{-5}$, and $e_K(1.21)\geq(8\pm5)\times10^{-5}$. These are in agreement with the respective tabulated values[32] for $E2$ transitions of 7.4×10^{-5}, 8.6×10^{-5}, and 9.2×10^{-5}.

[31] S. Hultberg and R. Stockendal, Arkiv Fysik 14, 565 (1958).

[32] M. E. Rose, G. H. Goertzel, B. I. Spinrad, J. Harr, and P. Strong, Phys. Rev. 83, 79 (1951).

TABLE II. Gamma-ray transitions observed in Mn^{52} and Mn^{54}.

Isotope	This work (kev)		Katoh *et al.*[a] (kev)
Mn^{52}	1463 ±2 [b]	±2.5 [c]	
	1433.6 ±0.4	±0.8	1434.7±0.8
	1332 ±1	±1.4	
	1245.6 ±0.4	±0.8	
	1214 ±1	±1.4	
	935.1 ±0.4	±0.8	937.1±0.4
	847.4 ±0.6	±1.0	
	743.8 ±0.3	±0.6	746.8±0.2
	345.74±0.08	±0.15	
Mn^{54}	834.9±1.1		

[a] See reference 17.
[b] Probable errors based on internal consistency only.
[c] Estimated errors including uncertainties in Doppler corrections in the annihilation radiation.

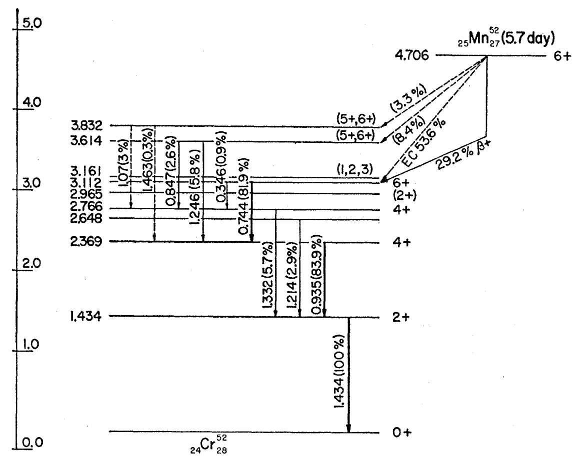

FIG. 10. Revised level scheme of the decay of Mn^{52}. Energies opposite the levels are those from the beta-ray spectrometer which are reported in this paper. The energies of 3.161 and 2.965 Mev are from Mazari *et al.* (see reference 9).

IV. SUMMARY OF EXPERIMENTAL RESULTS

The last column of Table I shows the weighted averages and rms errors of all the determinations of the intensities of the various gamma rays. The energies given in the left-hand column are the results of the beta-ray spectrometer as shown in Table II. The weaker and more uncertain transitions are shown at the bottom of Table I with limits on the intensities.

The revised decay scheme of Mn^{52} is shown in Fig. 10. The three main transitions are shown as before, although the intensities of the 0.744- and 0.935-Mev gamma rays are significantly less than the 1.434-Mev transition in contrast to previously reported work. The 1.332-Mev transition is shown from the 2.766- to the 1.434-Mev levels. The basis for this assignment is energetics and the fact that the gamma ray is in coincidence with the 1.434- but not in coincidence with the 0.935- or the 0.744-Mev gamma rays.

The 0.847- and 1.246-Mev transitions are shown as originating from a new level at 3.614 Mev. The energy match with these transitions going to the 2.766- and 2.369-Mev levels is very good and these assignments are completely consistent with the coincidence studies. The 1.33-Mev coincidence spectrum indicates the 0.346-, as well as the 0.847-Mev gamma ray, to be present; hence the 0.346- is shown between the 3.112- and 2.766-Mev levels, which is also in good agreement with energetics. The 1.07-Mev transition was shown to be in coincidence with the 1.332- and the 1.434-Mev transitions; hence it seems reasonable to show it originating from a new level at 3.832 Mev. The 1.463-Mev gamma ray could not be resolved in the scintillation work but it was in the beta-ray spectrometer measurements. Its assignment is based solely on energetics and the fact that a transition from the 3.832- to the 2.369-Mev levels is to be expected on the basis of the spin assignments. Because of the low intensities of these two transitions from the 3.832-Mev level they are shown as dashed lines, and the existence of the 3.832-Mev level is regarded as much less certain than the 3.614-Mev level.

It will be noticed in Table I that the 1.21-Mev gamma ray was not reported in the scintillation studies. A 1.18-Mev gamma ray was found whereas such a gamma ray was not seen in the beta-ray spectrometer work. The 1.43-Mev coincidence spectrum was re-analyzed to test the compatibility of a gamma ray at 1.21 Mev at the intensity reported in the beta-ray spectrometer studies. As seen in Fig. 3 there would be then a little overlap with the 1.25-Mev gamma ray. It was found that the 1.434-Mev coincidence spectrum was compatible with a line at 1.21 Mev at 2.9%. In the process the 1.18-Mev line was completely removed and the intensity of the 1.25-Mev transition was reduced to 4.9%. The alternate choice of intensity of 6.0% from the beta-ray spectrometer measurements for an $E1$ transition of 1.214 Mev is not compatible with the coincidence measurements. The combined scintillation and beta-ray spectrometer results speak then for a gamma ray at 1.214 Mev that is in coincidence with the 1.434-Mev line and is most likely an $E2$ or $M1$ transition. In spite of the lack of any observed feeding of the 2.648-Mev level, the 1.214-Mev transition from it is shown in Fig. 10. The sum of the energies, 1.4336 and 1.214 Mev, from the beta-ray spectrometer measurements, agrees with the energy 2.648 Mev as reported by Mazari *et al.* to within the quoted probable errors.

Table I shows that a 0.63-Mev gamma ray appeared consistently but its placement in the decay scheme is in doubt. Its presence in various coincidence runs implies that it is a transition between a new level at 3.74 Mev and the 3.112-Mev level. The revised decay scheme does not reflect this level since the evidence for it is not strong.

The state at 3.161 Mev reported by Mazari *et al.*[9] is conspicuous by the absence of measurable gamma rays which would feed that level or issue from it.

TABLE III. Energy levels of Cr^{52}.

This work (kev)	Mazari *et al.* [a] and Konijn *et al.* [b] (kev)	Katoh *et al.* [c] (kev)
3831.7±2.5	...	...
3613.8±0.8	...	...
...	3161±8.0	...
3112.1±0.8	3109±7.0[b]	3119.6±0.5
...	2965±8.0	...
2766.2±1.1	2767±8.0	...
2647.6±1.5	2648±8.0	...
2368.7±1.3	2368±8.0	2372.8±0.6
1433.6±0.8	1433±4.0	1434.7±0.8

[a] See reference 9.
[b] See reference 10.
[c] See reference 17.

Katoh *et al.*[17] reported a gamma ray from their singles measurements of 1.72-Mev energy and estimated its intensity as 0.5% of that of the 1.434-Mev transition. They suggest it may be the transition from the 3.161-Mev level to the 1.434-Mev level. From our singles studies, as mentioned earlier, and also our 1.434-Mev coincidence spectra, we can set an upper limit of 0.5% for a 1.73-Mev gamma ray, but we have found no evidence pointing to its existence. If such a transition to the 1.434-Mev level exists at this low intensity, an odd-parity state of low spin may be indicated for the 3.161-Mev level. A 3− state could be fed from a higher lying 5− state which, in turn, could be fed by a first-forbidden beta-decay branch. Systematics show that the first odd-parity state in even-even nuclei has predominantly a spin of 3. The energy of 3.161 Mev corresponds fairly well with the calculated value of 3.47 Mev using Morinaga's semi-empirical formula[33] for the first odd-parity level in even-even nuclei.

The energies of the various levels are shown in Table III along with the estimated errors. Also shown in Table III are energy values for the same levels as reported by others. The agreement with Mazari *et al.*[9] and Konijn *et al.*[10] is in general excellent.

In order to help in discussing spins of the proposed decay scheme the logft values were calculated using Moszkowski's nomogram,[34] and computing the theoretical EC/β^+ ratio. The latter computation was obtained by using the K/β^+ ratio for Mn^{52} as found in standard tables[35] and then adding appropriate terms for the L and higher shells.[35] The result was $EC/\beta^+ = (1.095)$. Having the net feeding of a level and the EC/β^+ ratio we can then obtain the logft value for either the EC or the β^+ transitions. For the 3.832-Mev level a logft of 6.2 for electron capture is obtained for a net feeding of 3.3%. For the level at 3.614 Mev with a net feeding of about 8.4% a logft value of electron capture 6.0 is obtained. A logft value of 5.5 is obtained for a net feeding of 82.8% for the 3.112-Mev level. Since higher energy positrons than those to the 3.112-Mev level were not found in these measurements, logft values were not calculated for other levels. It is felt that logft values of 6.2 and 6.0 are more representative of allowed rather than first-forbidden transitions. This calls for spins of 5+, 6+, or 7+ for the 3.614- and 3.832-Mev levels. Because both of these levels depopulate by transitions to 4+ states rather than 6+ states, it is assumed that the 7+ assignment should be excluded for the upper two levels. The positron branch to the 3.112-Mev level has a logft value characteristic of an allowed transition which is consistent with previously reported results since it has been clearly established that the ground state of Mn^{52} has a spin and parity of 6+ and that the 3.112-Mev level in Cr^{52} is also 6+.

Van Patter[36] has concluded from his inelastic neutron scattering data that the 2.766-Mev level must have a spin ≥ 4. From the transitions shown to and from this level in Fig. 10 it is apparent that 4+ is the only assignment consistent with any reasonable assumptions about the various transition probabilities.

It is impossible at the present time to make a definite spin and parity assignment to the level at 2.648 Mev.

It appears that the inelastic neutron data[37] most closely supports a spin of 0, but a 3− assignment cannot be ruled out. The fact that a 1.214-Mev transition has been observed without any observed population of the level at 2.648 Mev makes it difficult to understand either choice. On the basis that the 1.214-Mev transition is present to a few percent as shown in Fig. 10 in the decay of Mn^{52}, a 0+ assignment for the 2.648-Mev level is excluded. A 3− assignment likewise does not appear satisfactory since the conversion coefficient does not support an $E1$ multipolarity for the 1.214-Mev transition, and the problem of the feeding of the 2.648-Mev level still exists. While the feeding is better understood (a weak positron branch that might have been missed) for a 5− assignment, the transition to the 2.369-Mev level (a 0.279-Mev gamma ray) would be greatly favored over the existing transition to the 1.434-Mev level. The internal conversion electrons from a 0.279-Mev transition have not been observed and are at most less than one tenth the intensity of the electrons from the 0.346-Mev transition. Likewise the expected transition from the 3.112-Mev level to the 2.648-Mev level has not been observed and again the internal conversion electrons are experimentally less than one tenth the intensity of those from the 0.346-Mev transition. This fact in itself speaks strongly against any spin and parity between 4+ and

[33] H. Morinaga, Phys. Rev. **103**, 503 (1956).
[34] S. A. Moszkowski, Phys. Rev. **82**, 35 (1951).
[35] A. H. Wapstra, G. J. Nijgh, and R. van Lieshout, *Nuclear Spectroscopy Tables* (Interscience Publishers, Inc., New York, 1959).
[36] D. M. Van Patter (private communication, 1961).
[37] R. Sehr, Physik **137**, 523 (1954).

8+ and to a somewhat lesser extent against a 5− to 7− assignment for the 2.648-Mev level.

As mentioned previously, there was evidence for a weak gamma ray at 2.65 Mev in the scintillation spectrometer singles. If such a transition does in fact exist, a 2+ assignment for the 2.648-Mev level would be reasonable. The feeding of the level in this case could be by a weak 0.118-Mev gamma ray from the 2.766-Mev level. However, systematics of even-even nuclei and the inelastic neutron data would furnish arguments against a 2+ assignment.

From the intensity of the annihilation radiation relative to the 1.43-Mev gamma ray, the electron capture to positron ratio can be computed for the beta branch to the 3.112-Mev level. A net feeding of $(82.8\pm1.6)\%$ is required to this level based on gamma-ray intensities. It is felt that the most accurate determination of the intensity of the annihilation quanta was that found in the 1.43-Mev coincidence runs, which yielded a value of $(58.4\pm5.8)\%$. The error is based on an overall estimate of the accuracy of the intensities. Using the above values the EC/β^+ ratio becomes 1.84 ± 0.20. This is not inconsistent with the theoretical value of 2.04 obtained from the *Nuclear Spectroscopy Tables*.[35] Konijn *et al.*[10] reported an experimental value of 1.99 ± 0.06 to the 3.112-Mev level. Sehr[37] reported an experimental value of 2.01 ± 0.22 whereas Good, Peaslee, and Deutsch[38] got 1.86 ± 0.17.

Katoh *et al.*[17] reported the following low-intensity gamma rays from their study of the decay of Mn^{52m} 0.70 (3%), 0.94 (4%), 1.02 (3%), 1.15 (2%), 1.37 (missing %), and 1.52 (2%), all Mev. They suggested that a new level at 3.67 Mev might exist. A better fit is had with their data if two new levels were hypothesized at 3.48 and 3.80 Mev with the 1.15- and 1.02-Mev transitions leaving the 3.80-Mev level and the 0.70-Mev gamma ray leaving the 3.48-Mev level. Rough logft values for the transitions to the 3.80-, 3.48-, 2.965-, and 1.434-Mev levels are 3.8, 4.4, 5.5, and 5.4, respectively. While the first two values are very low it is apparent that all four transitions are allowed. Taking the 21-minute isomeric state of Mn^{52} as having a spin and parity of 2+, an allowed transition to the 2.965-Mev level would tend to support Van Patter's[13] assignment of 2+ to this level. In the present experiment no transitions were observed going to or from the 2.965-Mev level, which would also be consistent with a low spin assignment.

A study of the decay of V^{52} should offer some information on the location of states around 3.0 Mev with a spin and parity of 2+. Such a state should be populated by an allowed beta transition to a few percent and should be discernable. An experiment to detect weak transitions in the V^{52} decay is currently underway in this laboratory.

[38] W. M. Good, D. Peaslee, and M. Deutsch, Phys. Rev. **69**, 313 (1946).

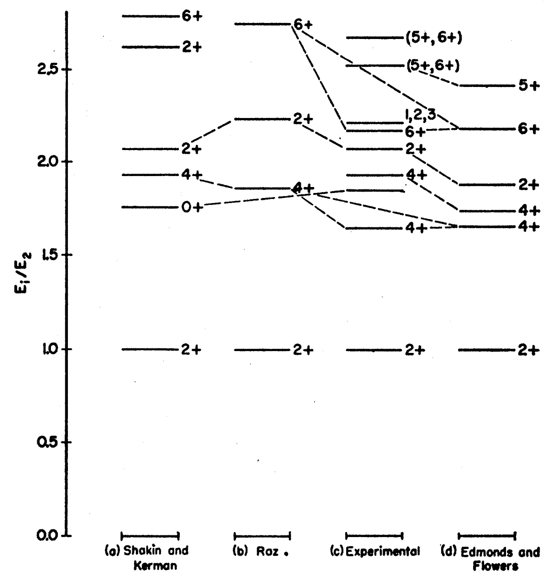

FIG. 11. The following theoretical calculations are compared to experimental results in a level scheme arrangement in which the level position represents the ratio of the energy of the level in question to the energy of the first excited level: (a) Shakin and Kerman (see reference 7), (b) Raz (see reference 5), (c) experimental results reported in this paper, and (d) Edmonds and Flowers (see reference 4). Dashed lines represent a correspondence between states of assumed similar configurational character.

V. DISCUSSION

The theoretical calculations of the levels of Cr^{52} can be divided into two general classifications: the extreme shell model viewpoint, which considers the level structure to be that of a pure $(f_{7/2})^4$ configuration; and the extreme vibrational picture, which ignores single-particle interactions and treats only the vibrational excitation of the nucleus as a whole. In this section each of the two will be considered in the light of the revised decay scheme. It should be pointed out that, because of uncertainties involved in the calculations, complete agreement is not to be expected; the models are capable only of correlating regularities in structure. In this sense, each model has some success.

The shell-model level structure for an $(f_{7/2})^4$ configuration consists of an $I=0, 2, 4, 6$ sequence of states, in which the $I=2, 4, 6$ states have seniority-quantum-number 2, and states with $I=2, 4, 5, 8$ and seniority 4. The relative positions of these levels depend on the nature of the interparticle interaction. In particular, the seniority-4 and seniority-2 states can lie quite closely together. Figure 11d shows an example of a $(f_{7/2})^4$ level scheme taken from a paper of Edmonds and Flowers,[4] in which the high-seniority $I=2$ and $I=4$ states lie below the 6+ state. They have computed the ordering of levels to be expected for the j-j coupling approximation. Oscillator wave functions of the form $\phi_l \exp[-\frac{1}{2}(r/a_0)^2]$ and a residual two-body interaction of a Gaussian shape $V(r)=D\exp[-(r/a)^2]$ were used. Their results are presented in terms of a range parameter

(a/a_0), which appears to have a value between 1.0 and 1.4 for the best fit to the levels of Cr^{52}. In Fig. 11d (a/a_0) was taken to be 1.4 with the experimental results plotted in Fig. 11c for comparison. There is excellent agreement with the first 4+ (2.369-Mev) and the first 6+ (3.112-Mev) levels, both of which have seniority 2 in the Edmonds-Flowers scheme. Their seniority-4 levels (4+ at 2.766 Mev, 2+ at 2.965 Mev, and 5+ at 3.614 Mev) are somewhat too low; this is due to the rather high value of (a/a_0). Choosing a value of (a/a_0) about 1.2 will raise these levels relative to the first 2+ state. This will destroy the fit to the 4+ (2.369-Mev) state, but will have little effect on the 6+ (3.112-Mev) state, and a better over-all agreement can probably be reached. The theory, however, says nothing about states at 2.648 or 3.161 Mev.

Independent of the interparticle interactions, the shell model makes specific predictions in Cr^{52} which can be tested by these data. In the first place, it states that the $I=0$, 2, 4, 6 seniority-2 level should be spaced the same in Cr^{52} as in Ca^{42}, Ca^{44}, and Ti^{50}. The correlation of these levels has been shown by Talmi.[39] It is not clear which of the 4+ levels in Cr^{52} should be regarded as being of seniority 2; since they are separated by only about 0.4 Mev; however, the choice is not critical.

Secondly, it is a consequence of the pure j-j coupling that, in a j^n configuration of identical nucleons, $M1$ transitions are forbidden.[40] With the assignments as given in Fig. 10, the Weisskopf single-particle estimate[41] would predict a 0.397-Mev $M1$ transition between the two 4+ states with a rate about 200 times greater than that of the 1.332-Mev $E2$ transition. Our upper limit on the intensity of an internal conversion electron group corresponding to the 0.397-Mev gamma ray places an upper limit of 7% on the intensity of a 0.397-Mev $M1$ transition relative to the 1.332-Mev transition. Thus, with respect to what is predicted by the Weisskopf single-particle estimate,[41] the $M1$ transition is hindered by a factor of at least 2500. Hence the $E2$ transition rate for the 1.332-Mev gamma ray may be considerably enhanced, as is usually the case, and there could still be a strong indication of the forbiddenness of the $M1$ transition.

Thus the shell model has considerable success in accounting for many features of the Cr^{52} structure. The major fact left unexplained is the enhancement of $E2$ transition rates. The collective model, on the other hand, accounts for such enhancement in a natural way. A calculation in the collective spirit has recently been made by Shakin and Kerman.[7] These authors treat the nucleus in terms of collective vibrations, carrying the expansion of the Hamiltonian to cubic terms, and thereby predicting deviations from the familiar oscillator spectrum. They have obtained expressions which give the relative positions of the one-phonon (2+), two-phonon (0+, 2+, 4+), and three-phonon (0+, 2+, 3+, 4+, 6+) states in terms of two constants α and B'. In order to evaluate these constants we have assumed that the 1.434-Mev level is the one-phonon state and that the levels at 2.965 and 2.766 Mev are the 2+ and 4+ states of the two-phonon triplet, respectively. While this interpretation is open to question, it seemed the only choice, since Shakin and Kerman's theory requires that the 0+ state of the triplet always be less in energy than the 4+ state. In Cr^{52} there is no evidence for a 0+ state below the 2.369-Mev level. It is possible, although difficult to understand from our data, that the level at 2.648 Mev is the 0+ state in question. In Fig. 11a are shown the levels predicted by their theory, based upon our choice of $\alpha=-0.21$ and $B'^2=0.024$. The 2+ and 4+ states of the triplet were used to evaluate α and B'^2 and are therefore fitted exactly to experimental results. The position of the 0+ level was calculated on this basis, and it is seen that the agreement is qualitatively all right but the state is depressed a little. This theory does not account for the levels at 2.360 or 3.112 Mev. Therefore, in this interpretation no comment about the $M1$ transition between the 4+ levels can be made.

It is probably true that collective effects should be considered in some degree for a complete theory of the spectra of nuclei such as Cr^{52}. The emphasis to be placed on such effects, however, is not at all clear. Kisslinger and Sorenson[6] have made a general calculation of the spectra to be expected when pairing forces (short-range forces analogous to the residual interactions) and two-body forces of the form $P^{(2)}(\cos\theta)$ (which give rise to spectra similar to collective motion) predominate. Their calculations are made for single-closed-shell nuclei, so that the neutron-proton interactions need not be considered. Because of simplifying assumptions made by them, the fine details of any given spectrum cannot be expected to fit their predictions. The importance of their work, and its relevance to the present spectrum, lies in its indication that collective effects may be explained in terms of a two-body force, and that these effects occur even fairly close to closed-shell nuclei.

In this light, then, the work of Raz[5] becomes more plausible. He has taken the same Hamiltonian used by Edmonds and Flowers,[4] with $a/a_0=1.0$, and has added a surface term of the usual form. He has then diagonalized the energy matrix for various choices of the strength D of the two-body force and the surface interaction parameter x. Fig. 11b shows the results of his calculations, with a somewhat arbitrary choice of D and x ($D=0.2\hbar\omega$, $x=0.5$). The calculation has been made for a configuration of two $f_{7/2}$ particles; pre-

[39] I. Talmi, *Proceedings of the Rehovoth Conference on Nuclear Structure* (North-Holland Publishing Company, Amsterdam, 1958).

[40] I. Talmi and I. Unna, Ann. Rev. Nuclear Sci. **10**, 353 (1960). We thank Professor Talmi for pointing out this result to us.

[41] D. H. Wilkinson, *Nuclear Spectroscopy* (Academic Press, Inc., New York, 1960), p. 852.

sumably the low seniority states of Cr^{52} will behave in somewhat the same manner.

The fit is not particularly good; the splittings have been expanded appreciably by the collective term. However, a different choice of D and x may bring about a better quantitative agreement, and still preserve the salient feature of this calculation: namely, the lowering of the one-phonon 2+ state to about the energy of the 6+ state. This may be the most reasonable explanation of the observed low-spin 3.16-Mev level.

In spite, then, of partial explanation, the degree to which collective effects contribute in Cr^{52} is not at all clear. If the 2.648-Mev level is proved to be a 0+ level by future experiments, the Shakin-Kerman arguments will be strengthened. The general success of the shell model is impressive; to date it is probably the best picture available for nuclei in this region.

ACKNOWLEDGMENTS

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APPENDIX A

The energy of the gamma ray from Mn^{54} was determined from a total of eight observations of the region around 0.84 Mev. In the internal conversion spectrum the presence of a group of conversion electrons was indicated whose half-life was appreciably greater than that of Mn^{52}. This group of electrons is shown three times in Fig. 8. It decayed with a half-life estimated to be greater than 100 days. The momentum of this group of electrons was measured to be 4131 ± 5 gauss cm, which corresponds to the conversion in chromium of a gamma ray whose energy is 834.9 ± 1.1 kev. This is to be compared with other measurements of the energy of the gamma ray of Mn^{54} of[42] 834.7 ± 1.1 kev and 837.9 ± 0.3 kev.[43]

APPENDIX B

Following the method of Hultberg and Stockendal[31] the internal conversion coefficient of a gamma-ray transition may be written:

$$e_K=(A_\beta/A_\gamma)(\tau_K fbd),$$

where A_β is the recorded intensity (peak area) of a single group of internal conversion electrons, A_γ is the recorded intensity (peak area) of the K-shell photoelectrons from the uranium converter; τ_K is the photoelectric cross section for the K shell of uranium; f is an energy-dependent factor which accounts for the fact that at different energies, different fractions of the photoelectrons from the uranium converter will enter the acceptance solid angle of the spectrometer; b is a constant of proportionality; and d is the thickness of the uranium converter.

Numerical calculations of the factor f as a function of energy can be made for any particular source—converter—spectrometer geometry, but this was not done in this case because of uncertainties in the exact geometry. Instead, an empirical determination of the relative values of the product $(\tau_K fbd)$ was made from the three principal gamma rays in the particular geometry used, and this was then used to determine the relative values of the internal conversion coefficients for the weak transitions.

The three main gamma rays were assumed to be $E2$ transitions whose internal conversion coefficients could be determined from the tables of Rose *et al.*[32] The recorded internal conversion electron intensities of these three transitions were divided by the corresponding internal conversion coefficients to give the gamma-ray intensities which were expressed relative to the intensity of 100 assigned to the 1.43-Mev transition. The intensities of the weak transitions could be determined in the same way for any assumed multipolarity. These are the intensities given in the column "Internal Conversion" of Table I. For the three main transitions A_γ and A_β are known, and tabulated values of e_K are used to determine relative values of the product $(\tau_K fbd)$ for the three main gamma rays. Relative values of $(\tau_K fbd)$ may be interpolated for other gamma ray energies for which both A_β and A_γ are measured, thus allowing a determination of e_K for those gamma rays. The results of these calculations are the internal conversion coefficients given in the text. The intensities I_γ of these transitions are determined from

$$A_\gamma=I_\gamma(\tau_K fbd)$$

and are listed in the column "external conversion" of Table I. Intensities of two weak transitions of 0.847 and 1.21 Mev are not given in this column because of inability to measure A_γ for these transitions. The 0.847-Mev uranium K photoelectrons were not resolved from the 0.74-Mev uranium L_{III} conversion electrons. The 1.21-Mev gamma ray was not evident in external conversion. Only an upper limit could be placed on its A_γ, giving a corresponding lower limit to its internal conversion coefficient. The errors are large because of the low intensities of these transitions.

[42] R. W. Peele, and T. A. Love, Oak Ridge National Laboratory Report ORNL-2790, 1959 (unpublished).
[43] T. Katoh, M. Nozawa, and Y. Yoshizawa, J. Phys. Soc. Japan **13**, 1419 (1958).