states of energies

$$E_I=\frac{\hbar^2}{2\mathcal{I}}[I(I+1)+a(-1)^{I+\frac{1}{2}}(I+\tfrac{1}{2}) -\{I_0(I_0+1)+a(-1)^{I_0+\frac{1}{2}}(I_0+\tfrac{1}{2})\}], \quad (2)$$

where I and I_0 are the excited-state and ground-state nuclear spins respectively, and $\mathcal{I}$ is the nuclear moment of inertia. The decoupling parameter, a, reflects the structure of the wave function of the last odd nucleon. Values of a found using Eq. (2) and the energies of the first two excited states are given in Table I. It is of interest to note the trends exhibited in the odd isotopes of even-Z nuclei near closed shells in the light of the unified model. In tellurium, a particularly good example, the spin and parity of the first excited states of the odd isotopes near $A=121$ is $\frac{3}{2}^+$. The position of these states starting at $A=121$ decreases monotonically with increasing A until the ground state spin becomes $\frac{3}{2}^+$ instead of $\frac{1}{2}^+$. Equation (2) is consistent with this behavior if a decreases as A increases. If this equation applies, competition in the filling of the $3s_{\frac{1}{2}}$ and $2d_{\frac{3}{2}}$ independent-particle neutron shells should be reflected in the values of a for the odd Te isotopes because a depends on the amount of admixture of the competing states.

We are greatly indebted to Dr. E. H. Geer for valuable aid and many helpful discussions. We are also grateful to Dr. N. P. Heydenburg and Dr. G. M. Temmer for several enlightening discussions.

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Neutron-Capture Gamma-Ray Spectra of V, Co, Ti, Fe, Cr, Au, Mn, and I†*

MELVIN REIER,‡§ *Brookhaven National Laboratory, Upton, New York*

AND

MORRIS H. SHAMOS, *Washington Square College, New York University, New York, New York*

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An experiment has been performed on the neutron-capture gamma spectra of eight elements in the region of about 100 kev to 2.5 Mev using NaI crystals. Wherever possible, the data have been compared with the results of previous experiments and existing energy level schemes.

I. INTRODUCTION

THE study of energy levels in nuclei by measuring the prompt gamma rays resulting from thermal neutron capture is a relatively recent approach to the problem of nuclear spectroscopy. The techniques used in some of the early measurements[1–3] limited the information obtained to a general picture of the decay scheme. However, structural details were rarely obvious. A very fruitful technique using a pair spectrometer[4] has given excellent information in the region from about 3 Mev up to the binding energy. The low-energy component of the spectrum has generally been investigated by the use of NaI crystals.[5–9] Motz[10–11] used a lens spectrometer to measure the energy of the electrons emitted by a photoelectric converter exposed to the capture gamma-ray beam in the region from 300 kev to 3 Mev.

Although the construction of a level scheme is most easily performed with the high-energy data, low-energy information is needed not merely as supplementary data, but to remove the ambiguities inherent when there are more than one capturing isotope and to give a more complete picture regarding the multiplicity of the decay. The experiment reported here covers the region from about 100 kev to 2.5 Mev.

II. APPARATUS

The target and spectrometer were located opposite an experimental hole which yielded a flux of about 10^6 n/cm^2 sec, on the west face of the Brookhaven reactor. Figure 1 shows a schematic of the experiment. The upper surface of those targets for which the capture cross section is not large compared with the scattering cross section was covered with an aluminum box containing lithium fluoride in order to prevent neutrons which are scattered from the target from being captured in the surrounding equipment and detectors.

Spectroscopy was performed by means of a 3 cm ×3

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‡ Submitted in partial fulfillment of the requirements for the Ph.D. degree at New York University.

§ Now at Westinghouse Atomic Power Division, Pittsburgh, Pennsylvania.

[1] C. D. Moak and J. W. T. Dabbs, Phys. Rev. **74**, 1249 (1948), and Phys. Rev. **75**, 1770 (1949).

[2] H. D. Kubitschek and S. M. Dancoff, Phys. Rev. **76**, 531 (1949).

[3] B. Hamermesh, Phys. Rev. **76**, 182 (1949); **80**, 415 (1950); **81**, 487 (1951).

[4] See B. B. Kinsey, in *Beta and Gamma-Ray Spectroscopy*, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 795.

[5] Pringle, Taylor, and Roulston, Phys. Rev. **87**, 1016 (1952).

[6] B. Hamermesh and V. Hummel, Phys. Rev. **88**, 916 (1952).

[7] T. Braid, Phys. Rev. **90**, 355(A) (1953).

[8] T. Braid, Phys. Rev. **91**, 442(A) (1953).

[9] Reardon, Krone, and Stump, Phys. Rev. **91**, 334 (1953).

[10] H. T. Motz, Phys. Rev. **90**, 355(A) (1953).

[11] H. T. Motz, Phys. Rev. **93**, 925(A) (1954).

cm NaI(Tl) crystal (crystal A in Fig. 1) in contact with a DuMont K 1186 photomultiplier tube. This combination had a resolution of 7.5% for the 662-kev gamma ray of Cs^{137}. Four NaI crystals B were mounted in a ring with their outputs connected in parallel. These served as a detector for the scattered gamma rays when the apparatus was used as a Compton spectrometer.

The experiment was designed so that data could be obtained by two methods:

(*1*) *Singles.*—In this case, all gamma rays interacting in crystal A would be measured. This method suffers from the fact that the lower energy photopeaks are superimposed upon the Compton-scattered spectrum of the higher energy gamma rays.

(*2*) *Coincidences.*—In this case, the equipment was operated as a Compton spectrometer in a fashion similar to that suggested by Hofstadter and McIntyre.[12]

A block diagram of the electronics is shown in Fig. 2. If a pulse from A and a pulse from B occur within the fast-coincidence time (0.1 μsec), an output results which lasts about 2 μsec. If, during this time, the pulse from B passes through an electronic window which has been adjusted at about 200 kev, depending on the region of the capture spectrum being observed, an output is derived from the slow-coincidence circuit which results in the generation of a sweep pulse. This permits the pulse from A to be stretched and displayed on a gray-wedge oscilloscope,[13] which was photographed through a Wratten $C5$ blue filter on 35 mm Eastman-Kodak Spectroscopic IV–O or IV–F film. During the time the sweep is in operation, a "clamp" circuit prevents any additional pulses in A from entering the stretching circuit and distorting the spectrum. If the B side of the fast and slow coincidence circuits are appropriately biased, all pulses[14] in the A channel are displayed and a singles spectrum results.

III. NATURE OF MEASUREMENTS

The capture spectrum of each target was obtained by taking a series of exposures at different gain settings and in the singles and coincidence positions. Au^{198}, Cs^{137}, Co^{60}, and Na^{24} sources were used for the purpose of

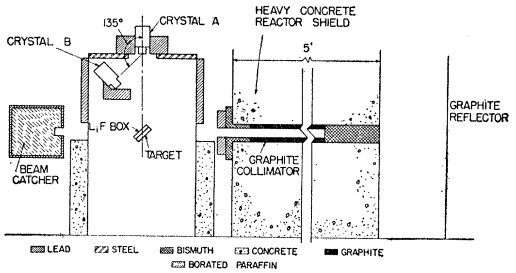

FIG. 1. Schematic drawing of capture gamma-ray experiment.

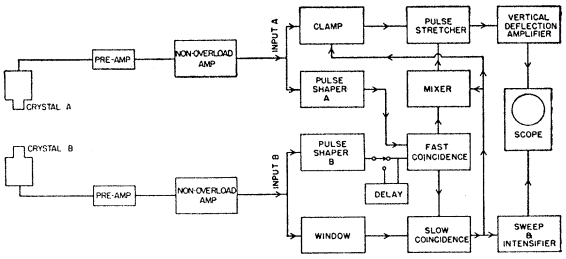

FIG. 2. Block diagram of Compton spectrometer.

energy calibration lines at 411 kev; 662 kev; 1.17 Mev and 1.33 Mev; and 1.38 Mev and 2.76 Mev, respectively. In all cases an artificial pulser was used to establish the low-energy side of an exposure so that in all pictures the energy range is from zero to some arbitrarily set value.

Singles counting rates varied from about 1.5×10^5 per minute to about 2.5×10^5 per minute, depending upon the capture cross section and complexity of the capture spectrum of the target. Singles pictures required about two minutes exposure time using IV–O film for the low-energy part of the spectrum, and about six minutes when photographing the spectrum up to 3 Mev. The reason for this difference in exposure time will become apparent in the description of the general features of all pictures.

The counting rates of the coincidence pictures varied from about 60 per minute to about 160 per minute. This depended upon the capture cross section of the target and the region of the spectrum being examined.

The window in the B channel was set at the energy of the recoil photons corresponding to the energy of the primary gamma rays which were of interest in the particular exposure. Since the gamma-ray intensity from all sources incident upon the B crystals rose sharply in the low-energy region, the coincidence counting rate was higher when the low-energy part of the spectrum was being examined.

The coincidence pictures were taken with a sweep speed about ten times slower than the singles pictures and required an exposure of about 12 to 20 hours.

Background

The following three distinct mechanisms could account for a background contribution to the coincidence spectrum of about 35%. It is believed that there are other factors which make the background still higher.

(*1*) *Ordinary accidentals.*—This accounted for about 10% of the total coincidence rate and could be determined quite accurately by switching in the delay line shown in the B channel of Fig. 2. It can be shown that the accidental counting rate is $2\beta N_A N_{B(\text{random})}\tau_f \times(1+2N_{B(\text{total})}\tau_s)$, where β is that fraction of the events in B which get through the window, N_A is the counting rate in A channel, $N_{B(\text{random})}$ is the total counting rate in B minus those counts in B which originate in the same excited nucleus as a pulse in A,

[12] R. Hofstadter and J. A. McIntyre, Phys. Rev. **78**, 619 (1950).
[13] Bernstein, Chase, and Schardt, Rev. Sci. Instr. **24**, 437 (1953).
[14] Actually, a bias of about 0.4 volt was put on the input of the A and B channels to reduce photomultiplier noise.

τ_f is the fast-coincidence time, τ_s is the slow-coincidence time. Since $N_{B(\text{total})}\tau_s$ is approximately 0.001, the slow-coincidence time has little effect upon the accidental counting rate and the expression for the random counting rate may be reduced to $2\beta N_A N_{B(\text{random})}\tau_f$.

(2) *Cascade coincidences.*—These are true coincidences which arise by the following mechanism. An excited compound nucleus usually reaches the ground state via other lower excited states. This means that, in general, the loss of the excitation energy due to the absorption of a neutron results in the emission of more than one gamma ray. One of these gamma rays may strike the spectrometer crystal A while another strikes the detector crystal B. Unlike the accidentals, these are true coincidences and therefore cannot be reduced by a reduction of the coincidence time. The shape of the spectrum arising by this mechanism very nearly resembles that of a singles spectrum and was obtained by placing a lead collar about 4 inches long with walls about $\frac{3}{4}$ inch thick, directly beneath crystal A to exclude all Compton coincidences. It can easily be seen why the shape of the spectrum deviates from that of a singles spectrum by the following consideration. The intensity of a gamma ray which arises from a transition in a chain in which there are many excited states, will be exaggerated in comparison with the intensity of a gamma ray which comes from a chain involving only one intermediate level. Efforts were made to reduce this cascade coincidence effect by placing as much lead as possible between the target and crystal B. The contribution from the cascade effect was about 15% of the total coincidence rate. It should be noted that it is the presence of the target which produces the high accidental and cascade coincidence rates. These two effects are practically negligible when there is no target in place.

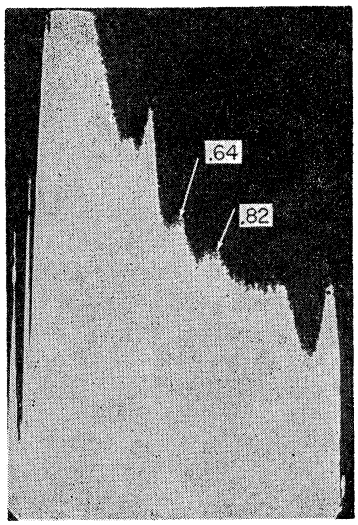

FIG. 4. Vanadium singles capture spectrum.

(3) *Compton coincidences from stray gamma radiation not originating in the target.*—This is due to the high level of gamma activity at the equipment, even when the neutron beam is shut off, and is estimated by placing a LiF shutter in front of the experimental hole. Its contribution to the total coincidence rate was about 10%.

There is also a background to all singles exposures. The counting rate in crystal A with no target in place was about 4×10^4 per minute. The shape is a continuum rising very rapidly in the region of about 200 kev.

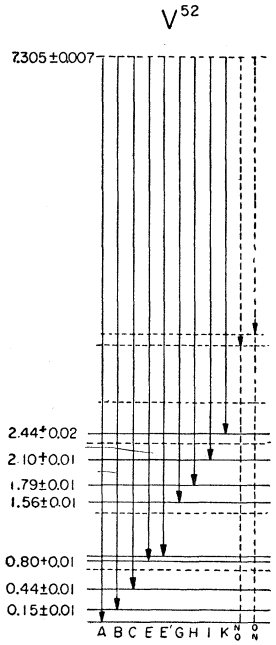

FIG. 3. Proposed decay scheme for the capture gamma rays from vanadium.[15]

IV. RESULTS

A. General Features of Photographs

Before presenting a detailed analysis of the data, it would seem worthwhile to list those features which all pictures have in common.

(1) *Singles.*—(a) A rapidly rising background in the low-energy region because of the buildup of the Compton scattered gamma rays of higher energy capture gamma rays, and because of the very sharp rise in intensity of the pile background in the low-energy region. (b) A prominent annihilation peak. Below this peak the intensity rises much more rapidly than above the annihilation peak. (c) A sharp drop in the background at about 140 kev. (d) An x-ray peak at about 75 kev.

(2) *Coincidences.*—(a) A background which rises more slowly in the low-energy region compared with singles photographs. (b) A small peak at 510 kev due to annihilation gamma rays feeding through as accidentals and by the cascade coincidence process. (c) A peak at about 320 kev due to Compton coincidences of the annihilation gamma rays.

In general, the buildup in the singles photographs below about 600 kev was not as rapid as the increase in

the photoelectric cross section of NaI. In addition, the coincidence spectrum below 600 kev was complicated by two peaks due to the annihilation gamma rays. These two facts combined to make the singles photographs in the region below about 600 kev superior to the coincidence pictures. Several representative photographs of the data will be shown below.

B. Intensity Measurements

Unfortunately, precise intensity measurements of peaks were not made because of the high background upon which the peaks normally were superimposed. A very small error in the measurement of the height of a peak on a large background would be greatly magnified compared to the same error on a peak with a much smaller background. This difficulty became particularly apparent in the gray wedge method of intensity analysis because of the logarithmic response of the wedge, so that a relatively intense transition may appear only as a slight peak if it is superimposed upon a high background.

C. Analysis of Data

(*1*) *Vanadium.*—A solid block of vanadium one-half inch thick was irradiated. Because there is only one isotope, there is no ambiguity regarding the origin of the observed lines. Level schemes for the capturing isotope V^{52} were obtained by Bartholomew and Kinsey[15]

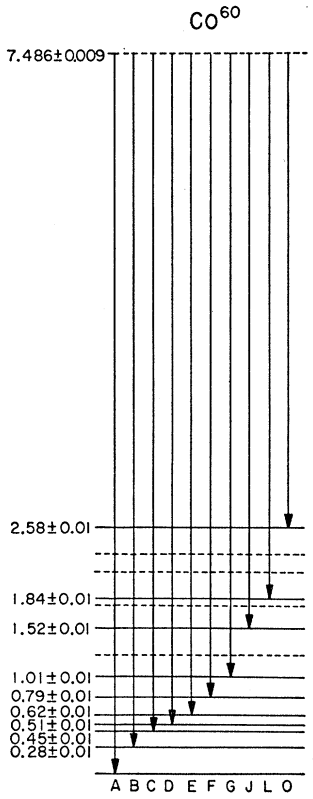

FIG. 5. Proposed decay scheme for the capture gamma rays from cobalt.[15]

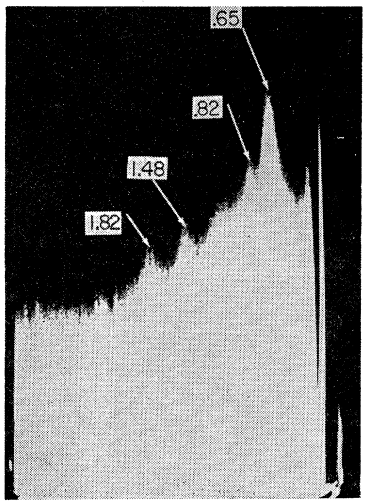

FIG. 6. Coincidence spectrum of cobalt.

using the reaction $V^{51}(n,\gamma)V^{52}$ and by Schwager and Cox[16] using the $V^{51}(d,p)V^{52}$ reaction. That proposed in the (n,γ) experiment is reproduced in Fig. 3. In addition to the 1.46-Mev radioactive decay line, several additional lines were observed in the present experiment. One of these at about 0.82 Mev is shown in Fig. 4. It seems too broad for a single line and probably corresponds to the transition of E and E' to the ground state of Fig. 3. The line at 0.64±0.02 Mev cannot be accounted for on the basis of any transitions in the decay scheme shown in Fig. 3. Another line at 0.43±0.02 was observed which indicates a transition from C to the ground state of the V^{52} level scheme shown in Fig. 3.

(*2*) *Cobalt.*—Cobalt shavings packed in a thin aluminum can were irradiated. Since there is only one stable isotope, the entire spectrum must be attributed to Co^{60}. The low-energy part of the spectrum was investigated by Reardon, Krone, and Stump[9] and by Hamermesh and Hummel.[6] The high-energy part was done by Bartholomew and Kinsey.[15] The results of this investigation agree reasonably well with the decay scheme (Fig. 5) proposed by the latter. There is almost a complete lack of agreement with the results of the first two papers. Figure 6 shows peaks at β energies of 1.56, 1.23, 0.60, and 0.44 Mev corresponding to gamma rays of 1.82±0.04, 1.48±0.04, 0.82±0.02, and 0.65±0.02 Mev. These are in agreement with transitions from lines L, J, S, and E to the ground state. In addition, singles spectra of the low-energy region show peaks at 0.289±0.010 and 0.237±0.005 Mev. The peak at 0.289 is consistent with a transition from the first excited state B to the ground state. Inasmuch as the intensity of the 0.237 peak is very difficult to estimate, its origin is doubtful. However, there is no indication in any of the data of a transition from the state G at 1.01 Mev to the ground state. A transition from G to S would result in a gamma ray of about 220 kev which would be consistent with the 237-kev line

[15] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. 89, 386 (1953).

[16] J. E. Schwager and L. A. Cox, Phys. Rev. 92, 102 (1953).

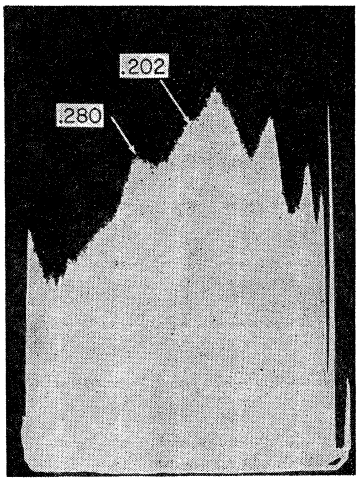

FIG. 7. Singles spectrum of copper.

observed. However, it should be noted that the intensity of the 237-kev peak does appear greater than that which could be accounted for by a transition from G to F. There is also a slight indication of a line at about 430 kev.

(*3*) *Copper.*—A target composed of 26 plates of about 0.065 inch thick copper was irradiated. The only gamma rays observed were in the very low-energy region and were detected in singles pictures, one of which is shown in Fig. 7. The lines are at 208±10 kev and 202±10 kev. Although the latter one is very weak, it is evident in all exposures. Copper consists of two stable isotopes, Cu^{63} and Cu^{65}. Bartholomew and Kinsey[15] report a number of high-energy capture gamma rays, three of which are of interest in connection with the data presented here and are shown in Table I. It seems fairly well established that A is the direct transition to the ground state of Cu^{64}. Because of discrepancies in the neutron binding energy of Cu^{66}, they were unable to say whether B represented a transition to the first excited state of Cu^{64} or the ground state of Cu^{66}. The 280-kev line reported here lends very strong support to the first possibility. Also, it is believed that C is due to the transition to the ground state of Cu^{66}. If it represented another excited state of Cu^{64}, the transition C to B or C to A would most probably have been observed. Very little can be said about the origin of the very weak 202-kev line.

(*4*) *Titanium.*—Titanium shavings packed in a thin aluminum box were irradiated. Titanium consists of five stable isotopes. From a knowledge of isotopic abundance and cross section,[17] Ti^{48} contributes 95% to the total cross section. The next highest is Ti^{47} with 2.1%. From the intensity found in the experiment reported here, it may be assumed every observed peak is due to capture in Ti^{48}. The decay scheme of titanium has been investigated in all regions of the spectrum. Motz[11] measured the capture gamma spectrum in the low-energy region using a β-ray spectrometer. Figure 8 shows a decay scheme for Motz's data based on one proposed by Pieper[18] and Kinsey and Bartholomew.[19] The numbers in parentheses of Motz's data give relative intensities. The numbers to the left of the decay scheme are the energy levels inferred from the five gamma rays found by Motz. Two gamma-rays found by Braid[7] are also shown. A singles photograph showed an intense peak at 334±6 kev. Figure 9 is a coincidence picture of the spectrum up to about 2.2 Mev. Peak A is a beta peak at 1.50 Mev corresponding to a gamma ray of 1.75±0.04 Mev. Peak B seems too broad for a single line and probably results from two or more gamma rays between about 1.53 and 1.58 Mev. Peak C is at a beta energy of 1.095 Mev, corresponding to a gamma ray of 1.39±0.02 Mev. The above mentioned lines are in good agreement with the data on Fig. 8. Peak D also appears to be due to two or more unresolved gamma rays between about 1.06 and 1.10 Mev. In view of the proposed decay scheme the origin of D is very uncertain.

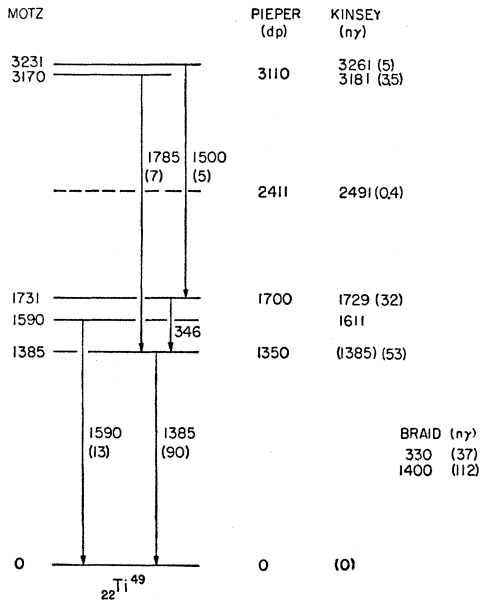

FIG. 8. Ti^{49} decay scheme.[18,19]

(*5*) *Iron.*—A sample of very pure iron two inches

TABLE I. A partial list of the capture gamma-rays from copper from Bartholomew and Kinsey.[a]

γ ray	Energy in Mev	Intensity in photon per 100 captures
A	7.914±0.006	20
B	7.634±0.006	9
C	7.296±0.009	5.5

[a] See reference 15.

[17] H. Pomerance, Phys. Rev. **88**, 412 (1952).
[18] G. F. Pieper, Phys. Rev. **87**, 215 (1952).
[19] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **89**, 375 (1953).

thick was irradiated. Iron consists of four stable isotopes, of which Fe^{56} contributes 92% to the capture cross section. The line structure found in the present experiment has been attributed entirely to the compound nucleus Fe^{57}. Kinsey and Bartholomew[19] investigated the high-energy components of the spectra using the pair spectrometer. Their data show a very strong ground-state transition in Fe^{57} and a probable excited state at 354 kev in Fe^{57}, inferred from a gamma peak 354 kev below the binding energy of Fe^{57}. J. A. Harvey, using the (d,p) reaction, inferred an excited state at 0.36 Mev from an exceptionally wide proton group. A singles exposure of the low-energy region of the iron capture spectra showed a gamma-ray peak at 355±8 kev. The intensity is estimated at under 5%. A coincidence exposure revealed a peak probably due to two unresolved gamma rays, which have been estimated to be at about 1.55 and 1.68 Mev. This agrees reasonably well with Kinsey's data, from which he infers two excited states in Fe^{57} at 1.62 and 1.72 Mev.

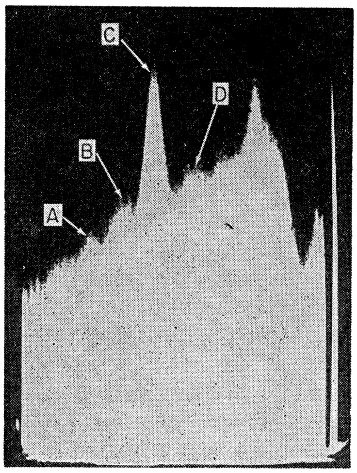

FIG. 9. Coincidence spectrum of titanium.

(6) *Chromium.*—About 1400 grams of very pure chromium were irradiated. Chromium consists of three staple isotopes, Cr^{50}, Cr^{52}, and Cr^{53}, whose contributions to the cross section are 24.5%, 20.5%, and 55%, respectively. The contribution of another staple isotope Cr^{54} is negligible. Kinsey and Bartholomew[19] have investigated the high-energy region of the capture spectrum of this element. The two most energetic gamma rays (9.716 and 8.88 Mev) they found are attributed by them to the transition to the ground state and first excited state of the compound nucleus Cr^{54}. The energy difference is 835 kev, which is in excellent agreement with the decay gamma ray of Mn^{54} found by Deutch and Elliot[20] and the capture gamma data of Braid.[8] A singles photograph of the capture spectrum of chromium showed a peak at 815±16 kev. Kinsey estimates the neutron binding energy in Cr^{51} at 9.07±0.09 Mev, although the intensity is too weak for them to detect it. They also find a gamma ray at 8.499±0.007 Mev. They interpret this as due to the first excited state of Cr^{51}. In addition to the one at 815±16 kev, one at 740±20 kev was found. This is interpreted as being due to the transition from the first excited state to the ground state of Cr^{51}. Some support for this is lent by the first excited state at 755±50 kev found in Cr^{51} by Stelson, Preston, and Goodman,[21] using the $V^{51}(p,n)Cr^{51}$ reaction. Adding 0.740 to 8.499 Mev gives a neutron binding energy of 9.24 Mev for Cr^{51}. This is somewhat higher than that estimated by Kinsey. Coincidence capture spectra of Cr^{51} showed a peak at 2.13±0.05 Mev and a probable one at 1.07±0.06 Mev. Neither of these can be placed into possible decay schemes with any degree of certainty. It should be noted that Stelson *et al.* report additional excited states at 1.165, 1.420, and 1.530 Mev, none of which were observed in the experiment reported here.

TABLE II. High-energy capture gamma rays from Kinsey and Bartholomew.[a]

Gamma ray	E (in Mev)	Intensity in photons per 100 neutron captures
A	6.494±0.008	1.5
B	6.453±0.011	2.1
C	6.310±0.008	2.8
D	6.249±0.009	6
E	6.146±0.013	1.8
F	5.976±0.011	1.8
G	5.702±0.016	1.6
H	5.52 ±0.03	1.3
I	5.20 ±0.03	1.7
J	4.59 ±0.04	3

[a] See reference 22.

(7) *Gold.*—About 90 grams of high-purity gold were irradiated. The high-energy region of gold was investigated by Bartholomew and Kinsey[22] and found to be very complex. A list of gamma rays found by them is shown in Table II. *H*, *I*, and *J* refer to the highest energy of an unresolved group. A singles photograph of the capture spectrum of the low-energy region of gold revealed a gamma ray at 248±13 kev. This is interpreted as a transition from level *D* to *A* in Table II. While the gamma ray *A* was the highest one found and agrees with the neutron binding energy of 6.35±0.15 Mev found by Harvey[23] for Au^{198}, Bartholomew and Kinsey claim that the intensity of line *A* is much too high for an $M2$ transition based on a spin of one[24] and an even parity for the compound nucleus and the spin of 3 and odd parity[25] for the ground state of Au^{198}. However, a more recent measurement by Wood[26]

[20] M. Deutch and L. G. Elliot, Phys. Rev. **65**, 211 (1944).

[21] Stelson, Preston, and Goodman, Phys. Rev. **80**, 287 (1950).
[22] B. B. Kinsey and G. A. Bartholomew, Can. J. Phys. **31**, 1025 (1953).
[23] J. A. Harvey, Phys. Rev. **81**, 353 (1951).
[24] J. Titman and C. Sheer, Phys. Rev. **83**, 746 (1951).
[25] Elliot, Preston, and Wolfson (to be published).
[26] R. E. Wood, Phys. Rev. **95**, 453(A) (1954).

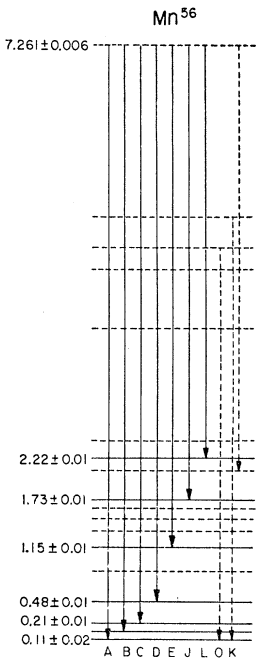

FIG. 10. Decay scheme for the capture gamma rays from manganese proposed by Kinsey and Bartholomew.[15]

gives a value of 2 for the spin of the 4.91-ev resonance of the compound nucleus of Au^{198}. This results in an $E1$ transition from the capture state to the ground state which is consistent with the intensity of gamma-ray A. (See Table II.)

(*8*) *Manganese.*—A solid block of very pure manganese was irradiated. Since manganese has only one stable isotope, all the lines observed must be due to capture in Mn^{55}. The level scheme proposed by Bartholomew and Kinsey[15] is shown in Fig. 10. A singles photograph of the low-energy region of the manganese capture spectrum showed peaks at 98±5 kev, 206±10 kev, 266±15 kev, and 308±15 kev. The first two gamma rays are probably transitions from the first two excited states of Mn^{58} to the ground state as shown on Fig. 10. These are in agreement with gamma rays of 90 kev and 190 kev found by Hamermesh and Hummel.[6] The origin of the 266 and 308 kev gamma-rays cannot be inferred by the decay scheme with any reliability. In addition to the low-energy capture lines three other gamma rays were observed at 2.05, 1.77, and 0.82 Mev, which are presumed to be the decay radiation of the 2.6 hr Mn^{56}.

(*9*) *Iodine.*—About 700 grams of very pure iodine were irradiated. Very little structure could be observed. A weak peak was seen at about 255 kev although a strong possibility exists that there may be several very weak lines in that region. The fluorescent radiation in iodine was exceptionally broad. It is believed that this is due to a very intense capture gamma ray at about 85 kev.

D. Summary

Table III lists the gamma rays observed in this experiment.

TABLE III. Gamma rays observed in this experiment.

Element	Energy in Mev
Vanadium	0.64, 0.43, two unresolved lines at about 0.82.
Cobalt	1.82, 1.48, 0.82, 0.65, 0.289, 0.237.
Copper	0.280, 0.202.
Titanium	1.75, two unresolved lines between 1.53 and 1.58, 1.39, two unresolved lines between 1.06 and 1.10, 0.334.
Iron	two unresolved lines between 1.55 and 1.68, 0.355.
Chromium	2.13, 1.07, 0.815, 0.740.
Gold	0.248.
Manganese	0.308, 0.266, 0.206, 0.098.
Iodine	0.255, 0.085.

V. CONCLUSIONS

Virtually all the lines observed are consistent with the previously proposed decay schemes and with the high-energy data. In most cases they represent a transition from an excited state directly to the ground state. In spite of this fact, one would have to be extremely cautious in constructing a decay scheme for an element on the basis of the low-energy data alone. A conclusion which seems justified on the basis of the data presented here is that the average number of gamma rays per neutron capture is only slightly more than two. However, even this statement must be made with a great deal of caution; for each element may decay by a number of three- or four-step processes which involve the emission of gamma rays in the region of 2 to 3.5 Mev, which are too weak to be detected by the Compton spectrometer used in this experiment or by the pair spectrometer used by Kinsey *et al.*

VI. ACKNOWLEDGMENTS

It is a pleasure to express our thanks to Dr. Robert D. Schamberger for many valuable discussions. Dr. Alois Schardt "canned" a number of crystals for us and Mr. Robert D. Chase of the Electronics Division of Brookhaven National Laboratory built the Compton spectrometer. The members of the photography and duplicating division were extremely cooperative during the entire course of the research. Finally, but by no means least, we would like to express our indebtedness to Dr. Marvin Fox, Chairman of the Reactor Department of Brookhaven National Laboratory, without whose assistance this research could not have been undertaken.

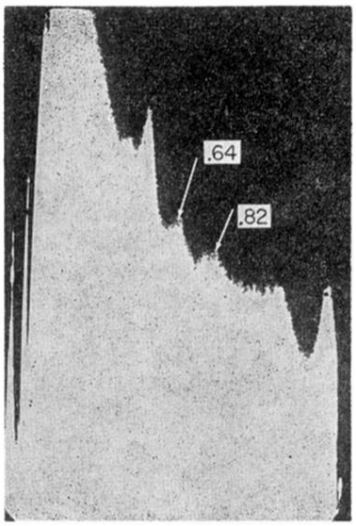

FIG. 4. Vanadium singles capture spectrum.

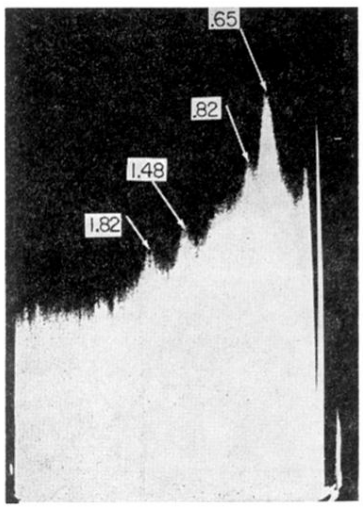

FIG. 6. Coincidence spectrum of cobalt.

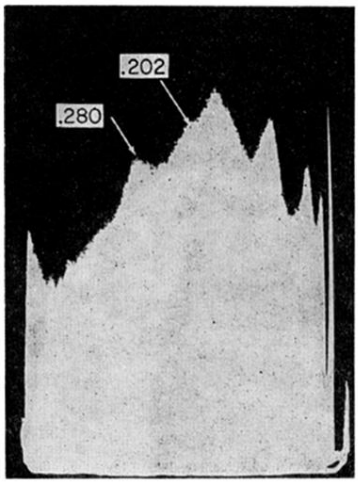

FIG. 7. Singles spectrum of copper.

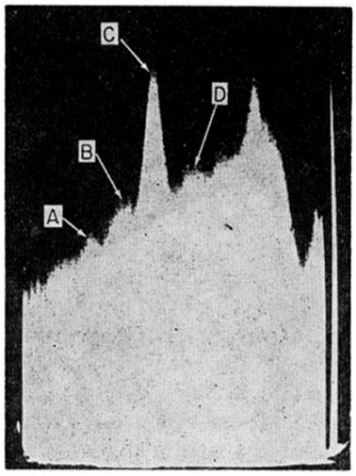

FIG. 9. Coincidence spectrum of titanium.