Energies of the Radiations from Co^{57} and Co^{58}†

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(Received March 28, 1955)

Using magnetic and scintillation spectrometers the energies of the radiations from Co^{57} and Co^{58} have been evaluated. Several gamma rays not previously reported have been observed. Co^{57} decays mainly by K capture but also to a slight extent by positron emission with an upper energy limit of about 300 kev, followed by gamma rays with energies 14.6, 29, 99.8, 122.8, 137.4, and 700 kev. Co^{58} decays by K capture and with positron emission of upper energy 485 ± 10 kev. Gamma rays with energies of 814 and 500 and possibly 1300 kev accompany the decay.

As early as 1937 it was found[1] that iron bombarded with deuterons in the cyclotron yielded several long-lived cobalt radioactivities. Subsequent investigations[2] resulted in the assignment of activities with half-lives of 270 and 72 days to Co^{57} and Co^{58}, respectively. The reports on the energies of the radiations show considerable disagreement indicating a need for further study.

In the present investigation magnetic photographic, and scintillation spectrometers were employed to study gamma rays, and the double-focusing, magnetic spectrometer was used to observe the positron spectrum of Co^{58}. In addition to the gamma energies previously recorded certain gamma transitions not previously reported are observed. The Co^{57} source was obtained from the Oak Ridge National Laboratory and was produced by a $p,2n$ reaction on Ni^{58} in a target of ordinary nickel. The resulting Cu^{57} in turn decays by positron emission through Ni^{57} to Co^{57} and thence to Fe^{57}. The Co^{58} specimen was from the same source but produced in the reactor by the (n,p) reaction on Ni^{58}. It decays mainly by K capture but also by weak positron emission to Fe^{58}.

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Some of the previously reported energies for the three well-known gamma rays, together with the results of the present investigation, are shown in Table I. In addition to these three gamma rays, others appear with energies of 700, 99.8, and 29 kev. These additional gamma rays are observed with the scintillation spectrometer. Of them, only the 99.8-kev gamma appears by conversion and this with a single line assumed to be due to Fe K-electrons.

For the three gamma rays shown in Table I, many electron lines are observed whose energies and relative intensities are shown in Table II. The relative intensities for the lines due to the 14.6-kev gamma ray are from visual estimates of the photographic densities, corrected for variation in radius and sensitivity of the emulsion with energy. The intensities for the other two gamma rays were obtained both by microphotometer traces of the photographic plates and by comparing the resolved peaks obtained with the source in the double-focusing spectrometer. The 14.6-kev in Fe^{57} has been reported[3] to have a half-life of 1.1×10^{-7} sec and the transition to the ground state was assumed[4] to be $M1$. The Z^2/W for this radiation is 46.2. From the empirical summary of Goldhaber and Sunyar, the observed K/L ratio of 3 appears to be somewhat lower than expected for an $M1$ transition. It would seem to be more compatible with an $E1$ or an $M2$ transition. The lifetime for the $M2$ transition at this energy would be of the order of seconds and this designation is thus improbable.

The large values of the K/L ratios for the 122.8- and 137.4-kev gamma rays suggest $E1$, $E2$, $M1$, or $M2$ transitions. The half-life of the $M2$ transition would

Table I. Gamma energies of Co^{57} as reported, in kev.

Observer	P[a]	ED[b]	DW[c]	AG[d]	CM[e]	Present work
γ_1	117	119		122.8	119	122.8
γ_2	130	131		137.6	133	137.4
γ_3			14			14.6

[a] E. H. Plesset, Phys. Rev. 62, 181 (1942).
[b] E. Elliott and M. Deutsch, Phys. Rev. 64, 321 (1943).
[c] M. Deutsch and W. Wright, Phys. Rev. 77, 139 (1950).
[d] D. Alburger and M. Grace, Proc. Phys. Soc. (London) A67, 280 (1954).
[e] B. Craseman and D. Manley, Phys. Rev. 98, 279 (A) (1955).

Table II. Energy and relative intensity of electron conversion lines from Co^{57}.

Designation	Electron energy, kev	Relative intensity	Energy sum, kev
K_1	7.3	3	14.4
L_1	13.7	1	14.6
M_1	14.5	0.25	14.6
K	92.7		99.8
K_2	115.7	10	122.8
L_2	121.8	0.9	122.7
M_2	122.7	0.15	122.8
K_3	130.3	8	137.4
L_3	136.6	0.8	137.5

† This investigation received the joint support of the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Livingood, Seaborg, and Fairbrother, Phys. Rev. 52, 135 (1937).
[2] Hollander, Perlman, and Seaborg, "Table of Isotopes," Berkeley (1952).
[3] M. Deutsch and W. Wright, Phys. Rev. 77, 139 (1950).
[4] M. Goldhaber and A. Sunyar, Phys. Rev. 83, 906 (1951).

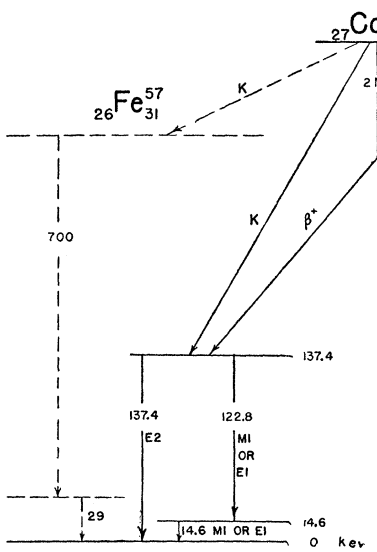

FIG. 1. Nuclear level scheme for Fe^{57}.

still be of the order of a thousandth of a second and hence should probably be excluded. While the K-conversion lines for the two gamma rays are of the same order of darkness and their K/L ratios are about the same, it is observed that the unconverted peak at 122.8 kev is many times[5] stronger than the peak at 137.4 kev. Hence, if the absolute conversion coefficient for the 137-kev gamma ray is ten times that for the 123-kev gamma ray, then the former is probably due to an $E2$ and the latter to an $E1$ or $M1$ transition. The positron spectrum was found to be extremely weak, with an upper limit of about 300 kev. It was not resolved into the two components reported.[6]

The 29-kev peak was found to be in coincidence with both the 100- and 700-kev radiations but not with the 123- or 137-kev gammas. No coincidences could be observed between the 700- and the 100-, 123-, or 137-kev radiations. It should be noted that coincidences as observed might result from the iodine x-ray (28 kev) escaping from one crystal back to the opposite crystal, resulting in an apparent peak due to the true peak energy minus the x-ray energy. Evidence that the low-energy peak is a gamma ray comes from the fact that it appears in the "singles" curve when there is no idoine or other scatterer back of the source. When iodine is intentionally placed directly back of the source the peak shifts slightly toward lower energy. Moreover, the 100-kev gamma ray yields a conversion line. The weak 700-kev transition probably follows K capture, and from the coincidence observation it might be concluded that it terminates at a level other than the ground state although this evidence is not incontrovertible. The escape peak is less likely to be significant at this high energy. The well-established transitions are shown as heavy lines in the nuclear level scheme of Fig. 1. The 99.8-kev transition is not included.

The half-life of the Co^{57} sample observed over a period of 8 months appears to be 267 days.

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Co^{58} decays by both K capture and positron emission to Fe^{58}. A single gamma ray of energy 0.81 Mev had been reported.[2] In the present investigation this gamma ray is observed both by electron conversion and by the scintillation spectrometer. The K-conversion line has an energy of 807 kev, indicating a gamma energy of 814 kev. The L line is very weak so that the K/L ratio is exceedingly large. It is impossible to infer from this ratio the type of multipole radiation, since at this small Z^2/W (0.8), the K/L ratio is large for all types of radiation. However, the ground state for the even-even ${}_{26}Fe^{58}$ nucleus is undoubtedly a level of even parity and zero spin. In such nuclei the first excited state is usually one of even parity and spin 2, so that an $E2$ transition is expected.

The Co^{58} source also contains some Co^{60} with its long-lived radiation at 1.17 and 1.33 Mev. With the scintillation spectrometer, strong peaks are obtained at 500 and 800 kev, and a weaker peak at 1.3 Mev. The 500-kev peak was at first assumed to be annihilation radiation. On observing coincidences between all betas in an anthracene crystal, and the gamma distribution in a NaI crystal, the 500- and 800-kev peaks were present in about the same relative intensity. On observing gamma-gamma coincidences with one crystal

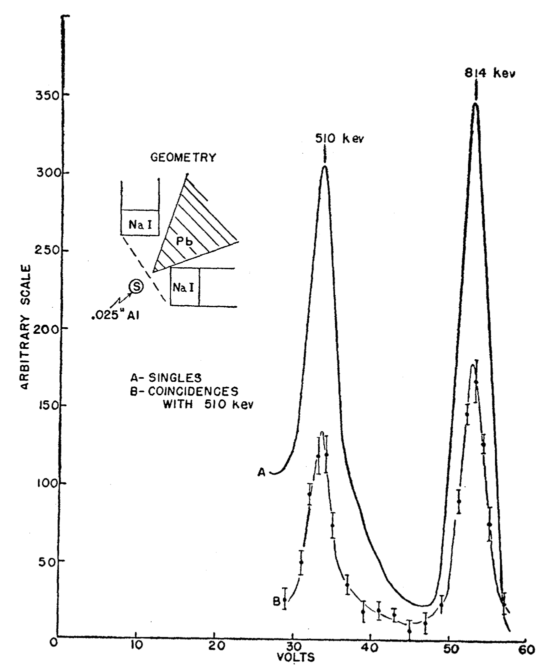

FIG. 2. Coincidence data for Co^{58}, with crystals at right angles.

[5] D. Alburger and M. Grace, Proc. Phys. Soc. (London) **A67**, 280 (1954).
[6] B. Craseman and D. Manley, Phys. Rev. **98**, 279 (1955).

set to receive the 500-kev peak, again the other crystal noted the two peaks in the same relative intensity. Since the annihilation photons travel in opposite directions and could yield 500–500 kev coincidences, the crystals were arranged at right angles with the source as shown in Fig. 2. The singles and coincidence curves are represented by solid and dotted lines, respectively, strongly indicating the existence of a gamma ray of about 500-kev energy. The peak at 1.3 Mev could be a summation peak for the other gamma rays or represent a crossover transition, or be in part due to the slight amount of Co^{60} that is known to be present. On inserting about 2 cm of lead between source and crystal the intensity is reduced much more than would be the case if it were all 1.3-Mev radiation, with its absorption coefficient of 0.66 cm^{-1}. This indicates that it is largely a summation peak, but in part it may be due to a cross-over transition.

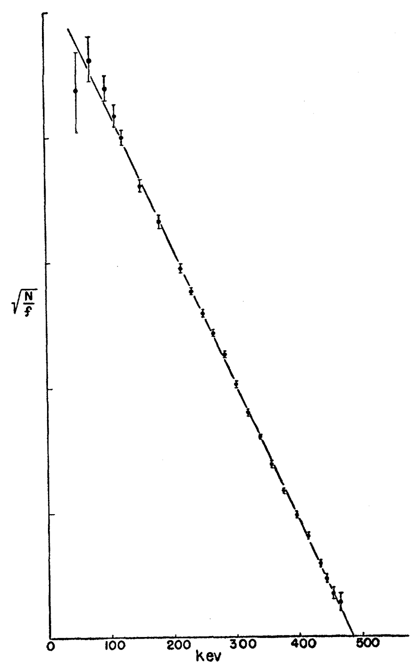

FIG. 3. The Fermi plot for the positron spectrum of Co^{58}.

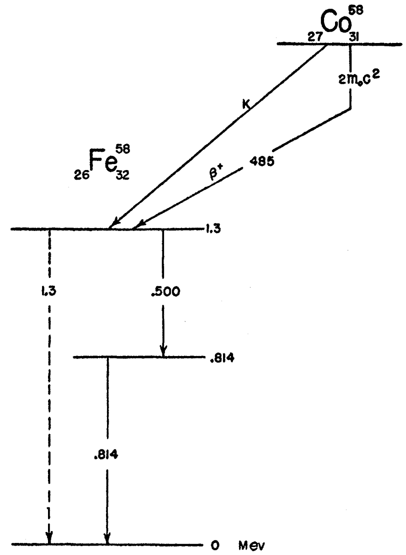

FIG. 4. Nuclear level scheme for Fe^{58}.

The positron spectrum was investigated in the double-focusing spectrometer and was found to have only one component. The almost massless source consisted of a line of the carrier-free material ruled on a conducting zapon film. The spectrometer window, also of zapon, was of minimum thickness (about 15 micrograms per cm^2) to withstand a pressure difference of 6 or 7 cm of Hg. The linearity of the Fermi plot, shown in Fig. 3, down to very low energies, indicates the very small stopping power of the film. The upper energy limit is 485±10 kev. If the positron decay occurs for about 15 percent of the decays, then the $\log ft$ value is about 6.5, which indicates a first forbidden transition. The simple decay scheme is shown in Fig. 4. The half-life of the Co^{58} source corrected for the presence of a slight amount of longer-lived activity is found to be 71.0 days.