U. S. Department of Commerce
National Bureau of Standards

Research Paper RP1781
Volume 38, April 1947

Part of the Journal of Research of the National Bureau of Standards

Disintegration of Scandium[46]

By Irving Feister and Leon F. Curtiss

The beta and gamma radiations of scandium[46] have been studied by means of a magnetic-lens spectrometer. The beta-ray spectrum was found to be simple, with the maximum energy at 0.36 Mev. No indications were found of any other group of beta rays having energies above this value. The gamma-ray spectrum consists of two gamma rays, with energies 0.88 Mev and 1.12 Mev. These two gamma lines appear to be of equal intensity, and are therefore very probably in cascade.

I. Introduction

Several investigations have been made of the radioactivity induced in scandium by slow neutrons. The latest of these reported in the literature by Walke [1][1] states that there are two groups of disintegration electrons, the main group having a maximum energy of 0.26 Mev, and the other group, less than 5 percent as abundant as the main group, having a maximum energy of 1.5 Mev. Walke also reports a single gamma ray of energy 1.25 Mev. These values of beta- and gamma-ray energies were obtained by means of absorption measurements in Al and in Pb, respectively.

Recently a table of radioactive isotopes was issued by the Manhattan District [2]. According to this table, the maximum energy of the beta rays from Sc^{46} is 0.4 Mev, and the gamma-ray spectrum consists of only one gamma ray of energy 1.4 Mev. The table does not indicate how these values were obtained.

The beta- and gamma-ray energies for Sc^{46} reported in the present paper were obtained by means of a spectrometer of the thin magnetic-lens type developed by Deutsch, Elliott, and Evans [3]. This instrument is described by Miller and Curtiss [4]. The results obtained are completely at variance with those reported by Walke. The maximum energy of the beta rays agrees fairly well with that given in the Manhattan District table [2], but the number and energies of the gamma rays do not agree with the data in that table.

II. Preparation of Sources

Sc^{46} was prepared for the present experiments by the reaction $Sc^{45}(n, \gamma)$. A sample of scandium oxide was irradiated with slow neutrons for over 2 months in the Clinton pile. The half-life of Sc^{46} has been accurately determined by Walke [1] as 85 ± 1 days.

The beta-ray source for the spectrometer is shown in figure 1, B. A thin Al foil mounted on a Lucite holder provided the backing for the source. The foil was moistened with a very thin layer of dilute glyptal solution, on which a small amount of the radioactive scandium oxide powder was deposited. The holder was designed to reduce back-scattering to a minimum.

Figure 1, A, shows the gamma-ray source used in the spectrometer. The active sample was placed in a small brass container whose walls were thick enough to absorb all the beta radiation emitted. A uranium radiator was used because both the photoelectric yield and the difference between the K- and L-electron binding energies are greatest in uranium, thus giving the most intense K- and L-photolines and the greatest separation between these lines (see fig. 4).

[1] Figures in brackets indicate the literature references at the end of this paper.

734742—47——2

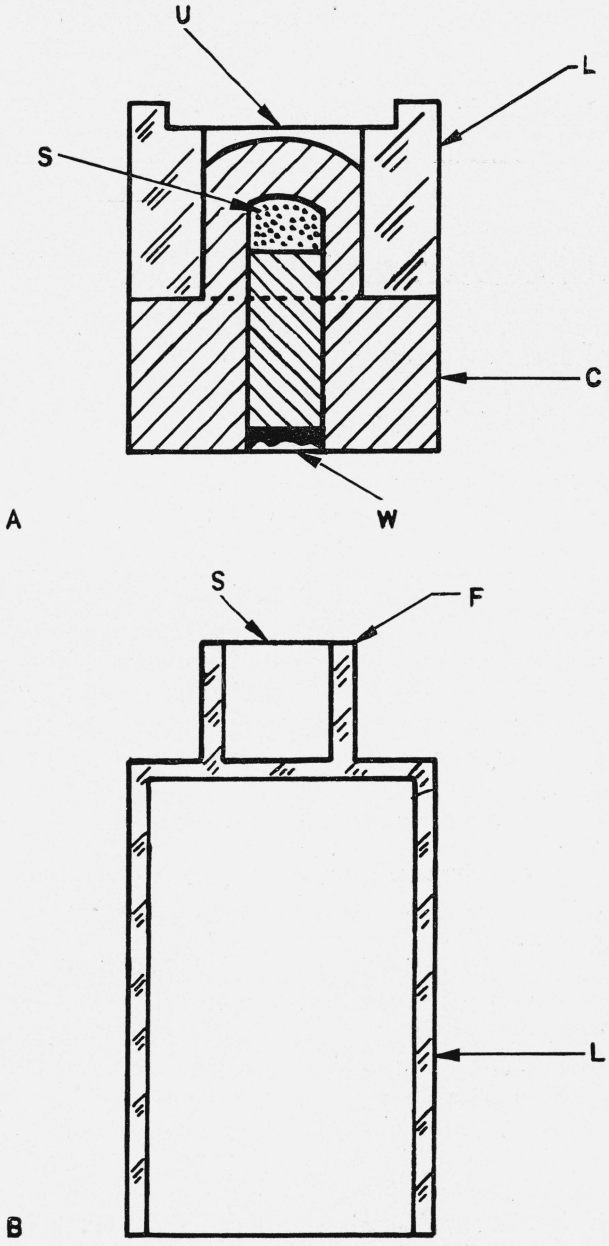

FIGURE 1.—*Section of source holders.*

A, For producing secondary photoelectrons from a uranium radiator by Sc^{46} gamma rays: *U*, thin uranium foil; *L*, Lucite collar; *S*, radioactive Sc^{46}; *C*, brass capsule; *W*, wax seal. *B*, For introducing Sc^{46} into the spectrometer for measurement of primary beta rays: *S*, thin deposit of Sc^{46} on aluminum foil, *F*; *L*, Lucite support.

III. Beta-Ray Spectrum of Sc^{46}

The beta-ray spectrum of Sc^{46} is shown in figure 2. The quantity N is equal to $P/H\rho$, where P is the number of pulses per minute in the Geiger-Müller counter; N represents the relative intensity over equal intervals of $H\rho$ [3, 5]. The symmetry of the beta-ray distribution indicates that the beta-ray spectrum is simple and consists of only a single group of electrons, which is confirmed by the Fermi plot (fig. 3). This is contrary to the results reported by Walke [1], who indicated the presence of two groups of electrons, the second being less than 5 percent as abundant as the main group. The absence of low-energy electrons with $H\rho < 670$ is due to absorption in the source and mica window (2.8 mg/cm^2) of the counter.

The Fermi plot for Sc^{46} is shown in figure 3. The departure from linearity of the Fermi plot in the low-energy range is very probably due to the distortion of the beta-ray spectrum at low energies because of scattering in the source and absorption in the mica window of the counter. The maximum energy of the beta rays, as obtained from figure 3, is 0.358 ± 0.008 Mev. This is in

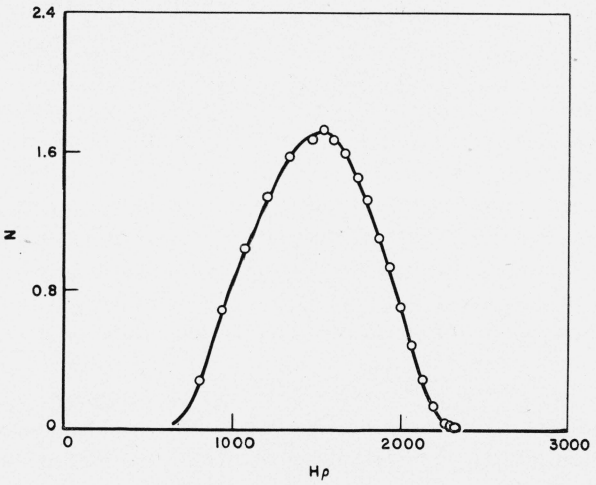

FIGURE 2.—*Primary beta-ray spectrum of Sc^{46} showing the intensity plotted against $H\rho$.*

Sc^{46} (85 days); beta-ray spectrum.

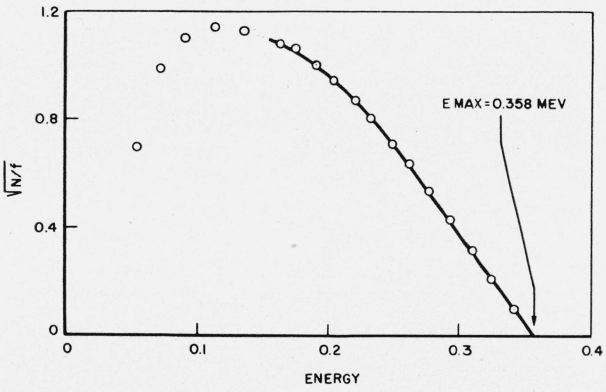

FIGURE 3.—*A Fermi plot of the data shown in figure 2.*

Sc^{46} (85 days); Fermi plot.

fairly good agreement with the value 0.4 Mev reported by the Manhattan Project [2]. No indication was found of any other group of disintegration electrons having a maximum energy of 1.5 Mev, as reported by Walke [1].

IV. Gamma Rays of Sc^{46}

The energies and approximate relative intensities of the gamma rays from Sc^{46} are deduced from the photoelectric conversion spectrum shown in figure 4. Here, again, N is equal to $P/H\rho$. The curve shows the spectrum of secondary electrons ejected from a uranium radiator (and from the brass capsule containing the source) by the gamma rays of Sc^{46}. The continuous distribution is due to Compton recoil electrons, mostly from the brass capsule, whereas the peaks are due to K- and L-electrons expelled from the U-radiator by the gamma rays from Sc^{46}. Figure 4 shows the presence of two gamma rays. Their energies may be determined from the K-photoconversion lines by adding the K-binding energy of uranium (0.118 Mev) to the K-electron energies observed. We thus obtain 0.883 $\pm$0.01 and 1.116 $\pm$0.02 Mev, respectively, for the two gamma-ray energies. As a further check on these results, the same gamma energies are also determined from the less intense L-photoconversion lines in figure 4, using the L-binding energy of uranium

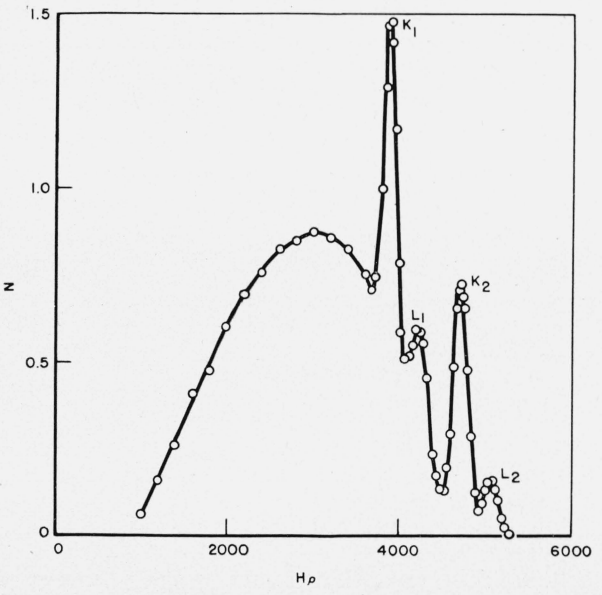

FIGURE 4.—*Seconondary electron spectrum produced by Sc^{46} gamma rays in uranium.*

K_1, L_1 are conversion lines of a 0.883-Mev gamma ray. K_2, L_2 are from a 1.116-Mev gamma ray. Sc^{46} (85 days); gamma rays; uranium radiator.

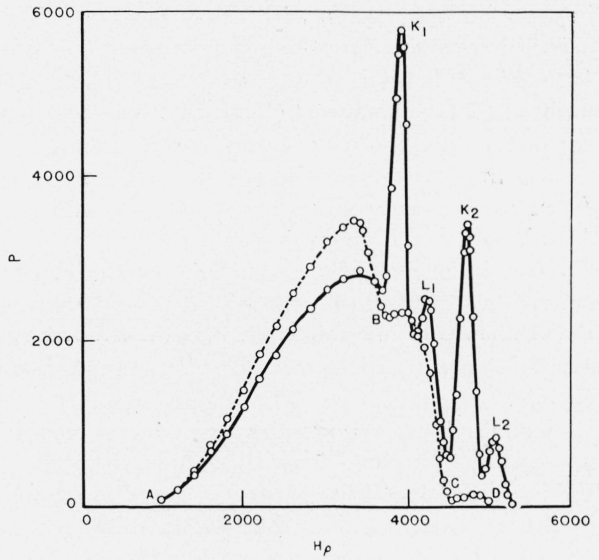

FIGURE 5.—*Comparison of secondary electron distributions produced by Sc^{46} gamma rays with and without uranium radiator.*

Sc^{46} (85 days); gamma rays;——gamma spectrum, uranium radiator; ------- without uranium radiator.

(0.022 Mev). The values thus obtained, 0.882 and 1.117 Mev, agree very closely with those given above.

These results are completely at variance with those of Walke [1], who reports only a single gamma ray from Sc^{46} with 1.25-Mev energy. They also disagree with the table recently published by the Manhattan District [2], according to which Sc^{46} emits only one gamma ray with 1.4-Mev energy.

The relation between the continuous Compton distribution and the photoelectric conversion spectrum of figure 4 is clearly shown in figure 5. Here P, the number of pulses per minute in the Geiger-Müller counter, is plotted against $H\rho$ instead of N. The full curve is the distribution obtained with the U-radiator in place (see fig. 1, A). The broken curve is the distribution obtained from the same source without the U-radiator. The broken curve has three distinct parts: A to B is due to Compton electrons expelled from the brass capsule by both gamma rays of Sc^{46}; B to C is due to Compton electrons expelled by the 1.12-Mev gamma ray alone; and C to D is very probably due to photoelectrons ejected from the brass capsule by the 1.12-Mev gamma ray.

It is seen from figure 5 that the number of Compton electrons obtained without the U-radiator

in place is greater than with the U-radiator. This is readily explained by the fact that the U-radiator (42 mg/cm^2) is thick enough to stop a considerable number of the Compton electrons from the brass capsule, especially in the lower energy region.

The broken curve in figure 5 shows that the K_1-photoelectron peak lies just beyond part A to B and the K_2 peak just beyond part B to C. This is in accord with what we would expect, since the maximum energy of the Compton recoil electrons from gamma rays in this energy range is only about 80 percent of the gamma-ray energy.

Siegbahn [5] has shown that the gamma energies may also be obtained from the inflection points of the Compton distribution curve. This was likewise done here, and the values thus obtained are in good agreement with the values as determined above. This latter method, however, is less accurate than the above, so that it is of use here primarily as an approximate check on the gamma energies obtained from the photolines.

V. Disintegration Scheme of Sc^{46}

A rough estimate of the relative intensities of the two gamma rays may be obtained from the relative heights of the K_1 and K_2 photoelectron peaks in figure 4. As a first approximation, the photoelectric absorption coefficient may be said to vary according to a law intermediate between E^{-2} and E^{-3}, where E is the gamma-ray energy; probably nearer E^{-2} for gamma rays in this energy range [6]. If we take the photoelectric absorption coefficient to be approximately proportional to E^{-2} and assume that the gamma rays are of *equal intensity*, then the ratio of the photoelectron intensities expelled from the uranium radiator by the two gamma rays of Sc^{46} is

$$\frac{I_{k1}}{I_{k2}} \cong \frac{1.12^2}{0.88^2} \cong 1.6. \tag{1}$$

Figure 4 shows that the ratio of the heights of the K_1 and K_2 peaks is about 1.5. The effect of finite radiator thickness (42 mg/cm^2) on the heights of the K_1 and K_2 photoelectron peaks is to reduce the height of the K_1 peak more than that of the K_2 peak, since the latter consists of more energetic electrons less likely to be absorbed in the radiator. Therefore, the observed relative heights of the K_1 and K_2 peaks in figure 4 are seen to be in approximate agreement with the ratio of equation 1, which is based on the assumption that the two gamma rays are of equal intensity.

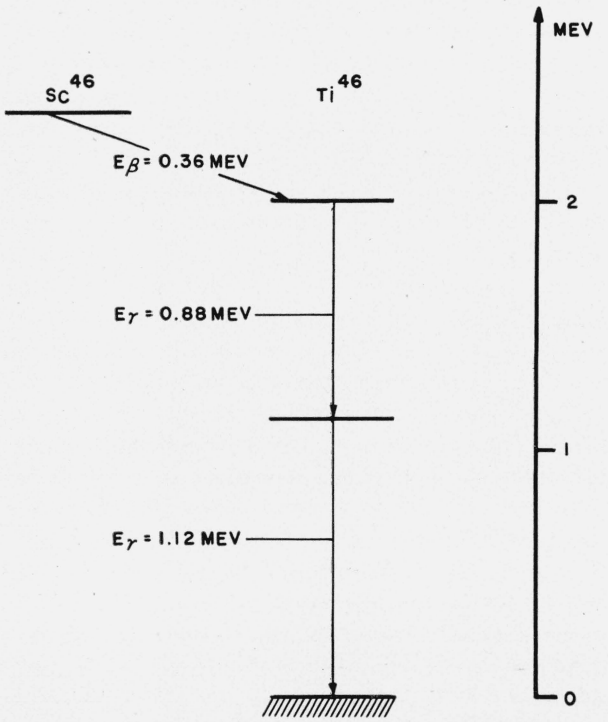

FIGURE 6.—*Suggested disintegration scheme for Sc^{46} based on the measured beta- and gamma-ray spectra.*

The above considerations do not, of course, definitely prove that the two gamma rays emitted by Sc^{46} are of equal intensity, but they do suggest strongly that such is actually the case. It seems very likely that the two gamma rays are in cascade, and that the disintegration scheme is as shown in figure 6. The order of emission of the two gamma rays is not determined by the present experiment.

In conclusion, we express our appreciation to Leonard C. Miller,[2] who set up and calibrated the spectrometer used in these experiments.

VI. References

[1] H. J. Walke, Phys. Rev. **57,** 163 (1940).
[2] Rev. Sci. Instr. **17,** 348 (1946).
[3] M. Deutsch, L. G. Elliott, and R. D. Evans, Rev. Sci. Instr. **15,** 178 (1944).
[4] L. C. Miller and L. F. Curtiss, J. Research NBS **38,** (1947) RP1778.
[5] K. Siegbahn, Phys. Rev. **70,** 127 (1946).
[6] L. H. Gray, Proc. Camb. Phil. Soc. **27,** 103 (1931).

WASHINGTON, February 13, 1947.

[2] Now at Clinton Laboratories, Oak Ridge, Tenn.