Radiations from Scandium[46] and Titanium[51] *

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Sc^{46} and Ti^{51} have been prepared in the Clinton pile. The characteristic radiations of these isotopes have been investigated by absorption and coincidence methods.

Sc^{46} was found to emit beta-rays having a range of 0.076 gram/cm² in aluminum and gamma-rays having a maximum energy of 1.0 Mev as determined by coincidence absorption. No hard beta-rays having an end point in the vicinity of 1.5 Mev were observed to be emitted by Sc^{46}. The beta-gamma-coincidence rate was found to be 1.4×10^{-3} coincidence per beta-particle and independent of the beta-ray energy, while the gamma-gamma-coincidence rate was $(0.62\pm0.06)\times10^{-3}$ coincidence per gamma-ray. These coincidence rates suggest that each beta-ray is followed by two gamma-rays.

The 72-day isomer of Ti^{51} emitted beta-rays having a range of 0.09 gram/cm² in aluminum and gamma-rays having a maximum energy of 1.0 Mev by coincidence absorption. The beta-gamma-coincidence rate was 0.9×10^{-3} coincidence per beta-ray and was independent of the beta-ray energy. The gamma-gamma-coincidence rate was $(0.35\pm0.03)\times10^{-3}$ coincidence per gamma-ray. These coincidence rates indicate that the beta-transition leads to an excited state of the V^{51} residual nucleus and that some or all of the residual nuclei de-excite with the emission of two or more gamma-rays in cascade.

1. INTRODUCTION

THE isotopes of scandium and titanium of long half-period have been the subject of several investigations.[1–6] The half-periods of scandium[46] and titanium[51] have been established as 85 ± 1 days and 72 ± 2 days, respectively.[1,2] The radioactive materials with which the experiments of this paper were carried out were prepared at the Clinton pile. The energies of the beta-rays and gamma-rays were measured by absorption in aluminum, and coincidence rates were observed in order to obtain some information as to the disintegration schemes.

2. APPARATUS

Thin-walled Geiger counters of two types were used. For measuring the energy of beta-rays, aluminum foils were placed between the radioactive source and a glass bubble counter having a window thickness of 0.0013 cm. For coincidence absorption measurements wherein the gamma-ray energies were determined, two Geiger counters in coincidence, each having a wall thickness of 0.013 cm, were used. The cathodes of the two counters were of Aquadag, the thickness of the Aquadag layer being 0.0006 cm.

Two identical Aquadag counters were placed with axes parallel, as in Fig. 1, when gamma-gamma-coincidences were to be observed. Aluminum blocks were placed between the counters and the source so that no primary beta-rays would be recorded. The block before C_2 was then removed, and the beta-gamma-coincidence rate was observed. The wires of the counters were attached to the input grids of a conventional coincidence circuit of the Rossi type. The output

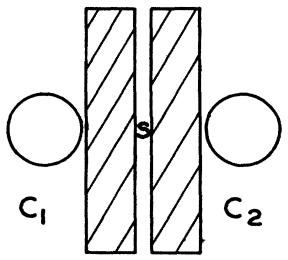

FIG. 1. Counter arrangement for gamma-gamma-coincidences. The counters are denoted by C_1 and C_2, and the radioactive source is placed at S.

* Supported by the Office of Naval Research.

[1] H. Walke, E. J. Williams, and G. R. Evans, Proc. Roy. Soc. **171A**, 360 (1939).
[2] H. Walke, Phys. Rev. **57**, 163 (1940).
[3] H. Walke, communication to G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944).
[4] Lise Meitner, Arkiv. f. Mat. Astron. och Fysik, **28B**, No. 14 (1942); *ibid.*, **32A**, No. 6 (1945).
[5] I. Feister and L. F. Curtiss, J. Research Nat. Bur. Stand. **38**, 411 (1947).
[6] A. E. Miller and M. Deutsch, Bul. Am. Phys. Soc. 22, 7 (1947).

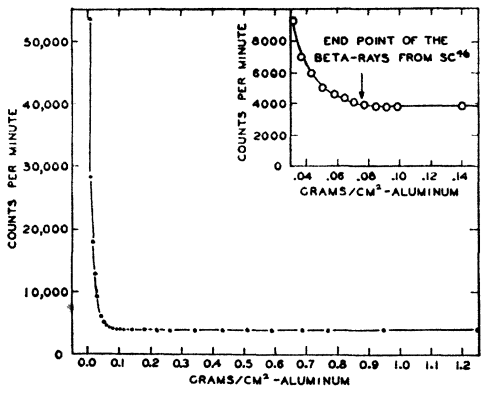

FIG. 2. Absorption of the beta-rays from Sc^{46}. The constant counting rate beyond the beta-ray group arises from the gamma-ray background.

tube of this circuit fed a scale of sixty-four and mechanical recorder.

When the beta-gamma-coincidence rate was computed, corrections were made for gamma-gamma-coincidences, accidentals, and gamma-ray counts in the beta-ray counter. The accidental correction was calculated from the usual equation

$$A = N_1 N_2 (K\tau),$$

where N_1 and N_2 were the single counting rates in either counter, and $K\tau$ was 2.5 microseconds. The coincidence rates of the two identical counters of Fig. 1 were used to form an estimate of the number of gamma-rays following each beta-particle. For obtaining beta-gamma-coincidences as a function of the beta-ray energy, C_2 was replaced by a thin bubble counter.

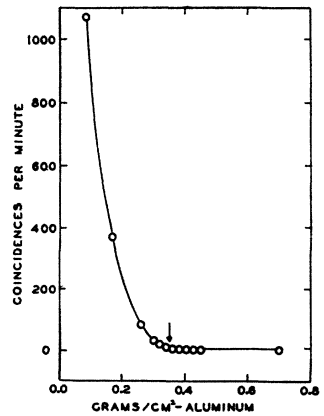

FIG. 3. Coincidence absorption of the Compton secondaries of the gamma-rays from Sc^{46}.

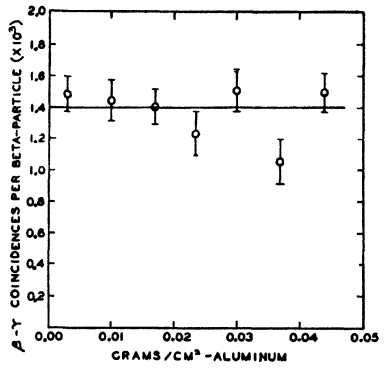

FIG. 4. Genuine beta-gamma-coincidences in the disintegration of Sc^{46}.

3. SCANDIUM[46]

The beta-rays from Sc^{46} have been measured with conflicting results. Walke[2] has reported two groups of beta-rays having energies of 0.26 Mev and 1.5 Mev. Meitner[4] found the group of low energy but attributed Walke's group of hard beta-rays to secondary effects. More recently, Feister and Curtiss[5] have verified that only the low energy group is present, whereas Peacock and Wilkinson[7] have reported the presence of a beta-ray group having an end point at 1.49 Mev and of about the same intensity relative to the main group as that of Walke's initial report.

The absorption curve for the beta-rays from Sc^{46} is given in Fig. 2. The end point occurs at 0.076 gram/cm² in aluminum. According to these measurements, only one group of beta-rays is present. The counting rate is seen to be constant over the entire region where contributions from the 1.5 Mev group might be found. Every effort was made to eliminate scattering and secondary effects as described by Deutsch[8] and Meitner.[9] This absorption curve certainly does not resemble that given by Walke on the interval beyond the main group of low energy beta-rays. The end point of Fig. 2 corresponds to a beta-ray energy of about 0.29 Mev.[10]

[7] Charles Peacock and R. G. Wilkinson, Phys. Rev. **72**, 251 (1947).
[8] M. Deutsch, Phys. Rev. **61**, 672 (1941).
[9] Lise Meitner, Phys. Rev. **63**, 73 (1943).
[10] Following Walke's convention, this energy has been estimated from the range-energy relation for homogeneous beta-rays, since the equations of Feather and Sargent do not apply for beta-ray energies below 0.7 Mev. The value 0.36 Mev obtained by Feister and Curtiss, Miller and Deutsch, and Peacock and Wilkinson, using spectrometer techniques, is naturally more desirable than that computed from the absorption limit.

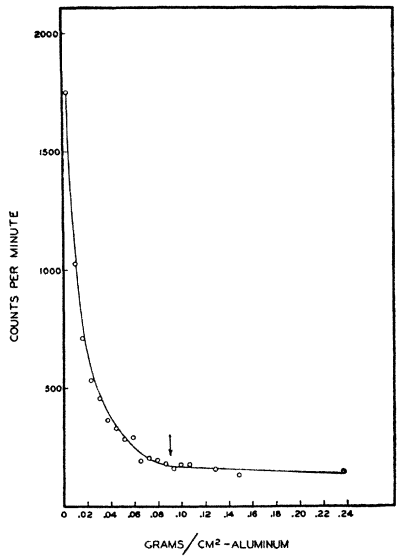

FIG. 5. Absorption of the beta-rays from Ti^{51}.

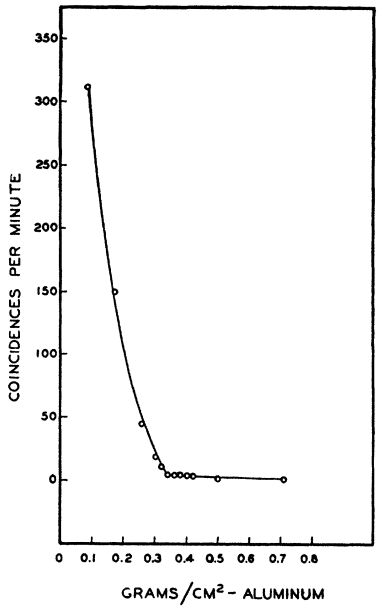

FIG. 6. Coincidence absorption of the Compton secondaries of the gamma-rays from Ti^{51}.

The maximum energy of the gamma-rays emitted by Sc^{46} was measured by coincidence absorption. The curve for these data is given in Fig. 3, where the end point occurs at 0.345 gram/cm². This corresponds to a quantum energy of 1.0 Mev.[11]

Using a thin bubble counter on the "beta-ray side," beta-gamma-coincidences were investigated. These data are given in Fig. 4. The genuine beta-gamma-coincidence rate was found to be 1.4×10^{-3} coincidence per beta-ray recorded in the beta-ray counter, and from the curve it is seen that the coincidence rate is independent of the beta-ray energy, suggesting that only one beta-ray spectrum is present. Corrections were made for gamma-gamma-coincidences in the beta-gamma-counting arrangement.

The two identical Aquadag counters of Fig. 1 gave coincidence rates of $(1.40\pm0.05)\times10^{-3}$ beta-gamma-coincidence per beta-ray and $(0.62\pm0.06)\times10^{-3}$ gamma-gamma-coincidence per gamma-ray. According to these coincidence rates, each beta-ray is followed by two gamma-rays.[12]

4. TITANIUM[51]

The absorption curve for the beta-rays from Ti^{51} is given in Fig. 5. The end point occurs at 0.09 gram/cm² in aluminum. This corresponds to a beta-ray energy of about 0.32 Mev. The value reported by Walke *et al.*[1] was 0.36 Mev. The data for coincidence absorption of the gamma-rays from Ti^{51} are given in Fig. 6, where the end point is found to correspond to a gamma-ray energy of 1.0 Mev.[11]

Using the thin bubble counter as the beta-ray counter, a genuine beta-gamma-coincidence rate of 0.9×10^{-3} coincidence per beta-ray was observed. These data are given in Fig. 7. This coincidence rate was independent of the beta-

[11] In arriving at 1.0 Mev for the gamma-ray energy, the maximum energy of the Compton secondaries was obtained from the range-energy relation for homogeneous beta-rays, and an appropriate amount of energy was added for collisions in the forward direction. The curve of H. Maier-Leibnitz (Physik. Zeits. **43**, 333 (1942)) also gives 1.0 Mev, so that the coincidence arrangement may in a sense be regarded as calibrated.

[12] This estimate is based upon the assumption that the gamma-ray efficiency of the two identical Aquadag counters is the same for all quanta emitted in the disintegration. The general formulation of the Indiana University group has been followed (Phys. Rev. **56**, 962 (1939)); that is,

$$\frac{K}{K-1}=\frac{\alpha}{\beta},$$

where

α = beta-gamma coincidence rate $= 1.4\times10^{-3}$,
β = gamma-gamma-coincidence rate $= 0.62\times10^{-3}$,
K = number of gamma-rays per disintegration.

Then $K = 1.8$ for Sc^{46}.

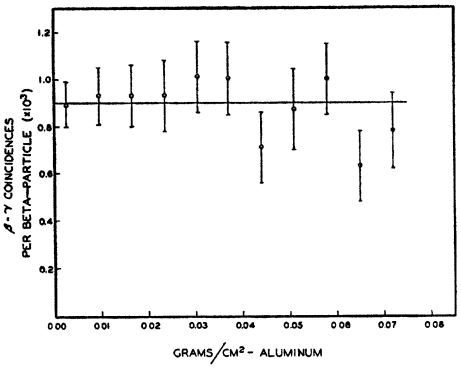

FIG. 7. Genuine beta-gamma-coincidences in the disintegration of Ti^{51}.

ray energy. The counters of Fig. 1 gave a beta-gamma-coincidence rate of $(0.90\pm0.03)\times10^{-3}$ coincidence per beta-ray and a gamma-gamma-coincidence rate of $(0.35\pm0.03)\times10^{-3}$ coincidence per gamma-ray. These coincidence rates suggest that 1.6 quanta are emitted per disintegration.[12] Ti^{51} cannot emit two gamma-rays of energy about 1.0 Mev since, for the same counters and geometry, its coincidence rates differ too greatly from that of Sc^{46}. The disintegration diagram of Fig. 8 then seems probable. About two-thirds of the disintegrations would occur by the alternate mode rather than by the emission of a single gamma-ray of energy 1.0 Mev to the ground state of V^{51}. Of course, it may be that de-excitation of the V^{51} residual nucleus occurs by only one mode with a gamma-ray of low energy in cascade with the 1.0-Mev radiation. The low detection efficiencies of the counters for the low energy quantum would then explain the coincidence rates.

5. ACKNOWLEDGMENTS

The writers are indebted to Mr. Willis E. Ramsey for many helpful discussions and to Mr. A. G. Nester who made the counters. They wish to express their particular appreciation to Professor W. B. Keighton of Swarthmore College for having carried out the chemical separations. They wish also to acknowledge the interest of Dr. W. F. G. Swann, Director of the Bartol Research Foundation.

Note added in proof: The coincidence rates of Sc^{46} have been redetermined with high statistical accuracy, and the net gamma-ray efficiency of the aquadag counters has been calculated in the usual manner.* It was assumed that Sc^{46} emits two gamma-rays in cascade of energies 0.88 and 1.12 Mev respectively. For a gamma-ray energy of 1 Mev, the net efficiency is about 0.7×10^{-3}. The coincidence rates of Ti^{51} suggest that gamma-rays having an energy of 1 Mev are in cascade with gamma radiation of low energy and having a net efficiency of about 0.2×10^{-3}. This would seem to be a more plausible disintegration scheme than that of Fig. 8.

APPENDIX I: CHEMICAL PROCEDURE FOR SCANDIUM

Two milligrams of Sc_2O_3 contained in a glass ampoule were irradiated by neutrons in the pile. The crushed ampoule was washed first with warm $6N-HNO_3$ and then with water. About fifty milligrams of aluminum were added in the form of a solution of aluminum nitrate. The solution was then diluted to ten milliliters. After the addition of 250 mg of NH_4Cl, the solution was heated to boiling, and the hydroxides of scandium and aluminum were precipitated together with ammonia. The hydroxides were washed with hot 2 percent NH_4NO_3 solution, dissolved in concentrated HCl, water was added, and the hydroxides were again precipitated.

This second hydroxide precipitate was dissolved in HCl, evaporated nearly to dryness, and dissolved in water and a few drops of HCl. To the resulting solution was added about fifty milligrams of inactive calcium as calcium nitrate solution. Calcium and scandium oxalates were precipitated together from the hot solution by adding an equal volume of saturated oxalic acid solution. After standing over night, the pre-

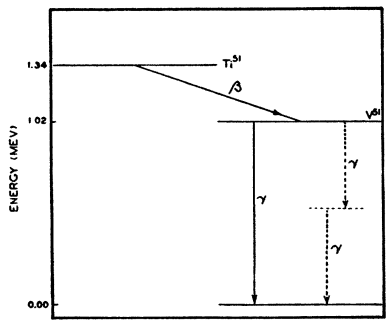

FIG. 8. Tentative disintegration scheme for Ti^{51}.

* J. V. Dunworth, Rev. Sci. Inst. 11, 167 (1940).

cipitate was washed with 1 percent oxalic acid solution, dried, and ignited at 800–1000°C. The product weighed 74 mg and consisted of CaO and practically the entire quantity (2 mg) of Sc_2O_3. The calcium was added as a carrier to assure complete recovery of the radioactive scandium.

By this procedure it was intended to obtain scandium free of radioactive phosphorus, calcium, and iron.

APPENDIX II: CHEMICAL PROCEDURE FOR TITANIUM

Chemically pure TiO_2 was irradiated by neutrons in the pile. The titanium dioxide was fused in platinum with ten times its weight of sodium carbonate. The melt was then boiled with water and filtered. The insoluble residue of titania was well washed with boiling water, and the filtrate and washings were rejected. This procedure should have removed phosphorus and part of any scandium impurity. The partly purified titania was then fused in platinum with potassium acid sulfate, and the melt was dissolved in cold $6N-H_2SO_4$. Orthotitanic acid was precipitated, at room temperature, with dilute ammonium hydroxide. The precipitate was dissolved in concentrated HCl and the solution diluted to $2N$. One volume of saturated oxalic acid solution was added to three volumes of the warm solution. After standing four hours, a trace of precipitate, which may have been calcium or scandium oxalate, was filtered out.

The filtrate was again made ammoniacal, and the orthotitanic acid precipitate was filtered out, washed, and dissolved in HCl. After dilution to $2N$, sufficient tartaric acid was added to prevent precipitation of titanium. The solution was neutralized with ammonia, made about $0.3N$ in H_2SO_4, and saturated with H_2S. Ammonia was added in decided excess, and the solution was again saturated with H_2S. The precipitate, probably iron and platinum sulfides, was filtered out. The filtrate, made strongly acid with H_2SO_4, was boiled to expel H_2S, diluted, and cooled. The titanium was precipitated with a 4 percent solution of cupferron added in excess, and the precipitate was ignited to TiO_2. The procedure outlined gave a sample of TiO_2 free of phosphorus, scandium, calcium, and iron.

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The Propagation of a Pulse in the Atmosphere. Part II

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The previous investigation of the dispersion of long waves in the atmosphere has been extended to shorter periods of the order of one minute. Both the phase velocity and group velocity have been determined. The results are applied to the interpretation of the pressure wave produced by the Great Siberian Meteor and to the pressure oscillations recorded by microbarographs in England.

1. INTRODUCTION AND SUMMARY

FOR the purpose of interpreting the observed features of the pressure wave produced by the explosion of the Great Siberian Meteor in 1908,[1] the previous investigation by the author[2] of the dispersion of long waves in the atmosphere (Krakatoa wave, period of one hour) has been extended to shorter periods of the order of a minute. Two model atmospheres have been treated, one (*a*) having a finite height in which the temperature gradient is constant and equal to 7/11 of the adiabatic, and another (*b*) in which the same temperature gradient prevails in the troposphere, but a constant temperature is assumed above 10.3 km. The variation of phase

* This work was carried out while the writer served as consultant to project N6-ori-139, task order #1, sponsored by the O.N.R.

[1] F. J. W. Whipple, Q. J. Roy. Meteor. Soc. **56**, 287 (1930).

[2] C. L. Pekeris, Proc. Roy. Soc. **A171**, 434 (1939); this paper will be referred to as I.