Measurements of the number of beta-gamma-coincidences as a function of the energy of the beta-rays is shown in Fig. 1. Since the number of beta-gamma-coincidences per disintegration does not change with energy, it can be concluded that the beta-ray spectrum is simple. The average number of beta-gamma-coincidences per recorded beta-particle is 3.1×10^{-3}. Gamma-gamma-coincidences were also found, the number per recorded gamma-ray being 1.7×10^{-3}. Gamma-gamma-coincidence measurements were made over a period of about one month and were found to decay with essentially the same half-life as do the singles. The above evidence leads one to believe that positron emission leaves the resulting nucleus in an excited state from which one or more gamma-rays follow. Whether more than one gamma-ray follows the positron cannot be definitely stated at the present time. The fact that the number of recorded gamma-rays is so large in comparison to the number of recorded positive particles (a ratio of about one to three) leads one to suspect a process competing with the positron decay. Thus we are led to the conclusion that perhaps the K-capture process is also present.

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Artificial Radioactivity of Cr^{49}

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A radioactive isotope of half-life 41.9 ± 0.3 minutes has been produced by alpha-particle bombardment of titanium and by fast neutron bombardment of chromium. Evidence presented shows that the activity should be assigned to Cr^{49}. Absorption measurements indicate the presence of gamma-rays of energies 0.19 and 1.55 Mev. The end point of the positron spectrum is 1.45 Mev. The 33-minute activity in vanadium is assigned to V^{47}.

INTRODUCTION

MANY radioactive isotopes have been reported in the region of chromium and vanadium. Of particular interest in the present discussion are the 600-day,[1] 16-day,[2] 33-minute,[2] and 3.7-hour[2] periods of vanadium and the 26.5-day[3] period of chromium. In Fig. 1 are shown these and other adjoining isotopes exactly as they have been reported with the exception of the 33-minute period which has been changed from V^{49} to V^{47}. The data necessitating this change will be discussed later.

The present study of this region was begun in an effort to determine the position and characteristics of a newly observed 41.9-minute positron emitter which was obtained after activation of titanium with alpha-particles. Bombardments were made with the cyclotron at The Ohio State University which furnishes approximately 20-Mev alpha-particles, 10-Mev deuterons, and 5-Mev protons. Fast neutrons were obtained from deuteron bombardment of lithium. Decay and absorption measurements were made by means of a Wulf quartz fiber electrometer connected to a Freon filled ionization chamber. The length of bombardment was always adjusted to discriminate against a long period. The substances bombarded include chemically pure TiO_2, Sc_2O_3, Cr_2O_3, and V_2O_5.

[1] H. Walke, E. J. Williams, and G. R. Evans, Proc. Roy. Soc. **A171**, 360 (1939).
[2] H. Walke, Phys. Rev. **51**, 1011 (1937) and **52**, 777 (1937).
[3] H. Walke, F. C. Thompson, and J. Holt, Phys. Rev. **57**, 171 (1940).

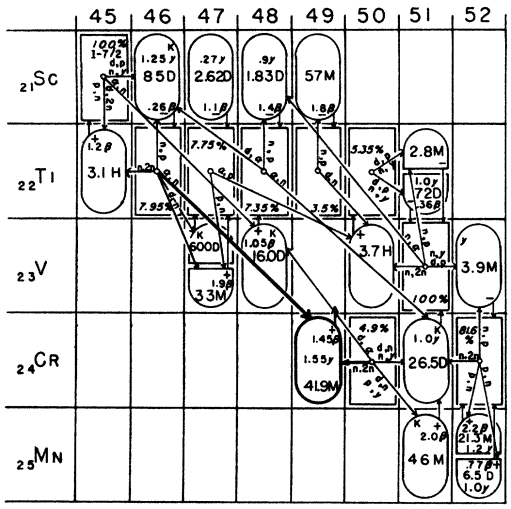

FIG. 1. Chart of region investigated. Abscissas represent mass numbers. Ordinates represent atomic numbers. Oblongs represent stable nuclei. Ovals represent artificial radioactive nuclei. Arrows represent nuclear reactions leading to radioactive nuclei.

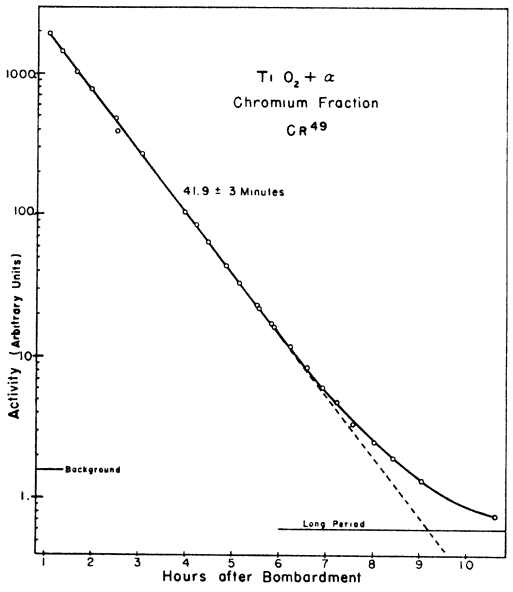

FIG. 2. Decay curve of Cr^{49} obtained from alpha-particle bombardment of titanium.

ACTIVATION OF TITANIUM WITH ALPHA-PARTICLES

The bombardment of titanium with alpha-particles produces a strong activity which decays by positron emission and with a period of 41.9 ± 0.3 minutes. Possible products of the bombardment include $V^{49,50}$ by the (α, p) reaction, $Cr^{49,51}$ by the (α, n) reaction, and Cr^{48} by the $(\alpha, 2n)$ reaction. V^{49} may also be formed as a decay product of Cr^{49}.

Since the accepted methods for the chemical separation of chromium and vanadium require several hours, a short and accurate procedure was worked out after several activations of titanium dioxide with alpha-particles.

In the (α, n) and (α, p) reactions the radioactive isotopes of vanadium and chromium are present in minute concentrations, undiluted by the bulk of the corresponding stable elements. Therefore inactive vanadium and chromium may be added in optimum quantities for precision separation. The method described below can be accomplished in about forty minutes.

Vanadium pentoxide and chromium trioxide were added as carrier to the activated titanium dioxide, and the mixture was fused with sodium carbonate-nitrate. The melt was extracted with water and filtered. Any undissolved titanium

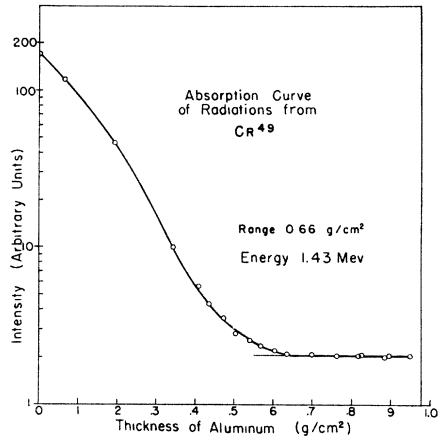

FIG. 3. Aluminum absorption curve for Cr^{49} gives an end point of the positron spectrum at 1.43 Mev.

dioxide was rejected, and the solution containing all the sodium vanadate and chromate was made acid and reduced. Vanadium was precipitated with cupferron and filtered off. The chromium in solution was neutralized, oxidized to chromate, and precipitated as barium chromate.

This method has been tested with two different relative quantities of chromium and vanadium carrier. In one case 10 milligrams of chromium and 200 milligrams of vanadium were used. In another, 200 milligrams of chromium and 10 milligrams of vanadium were added. In both

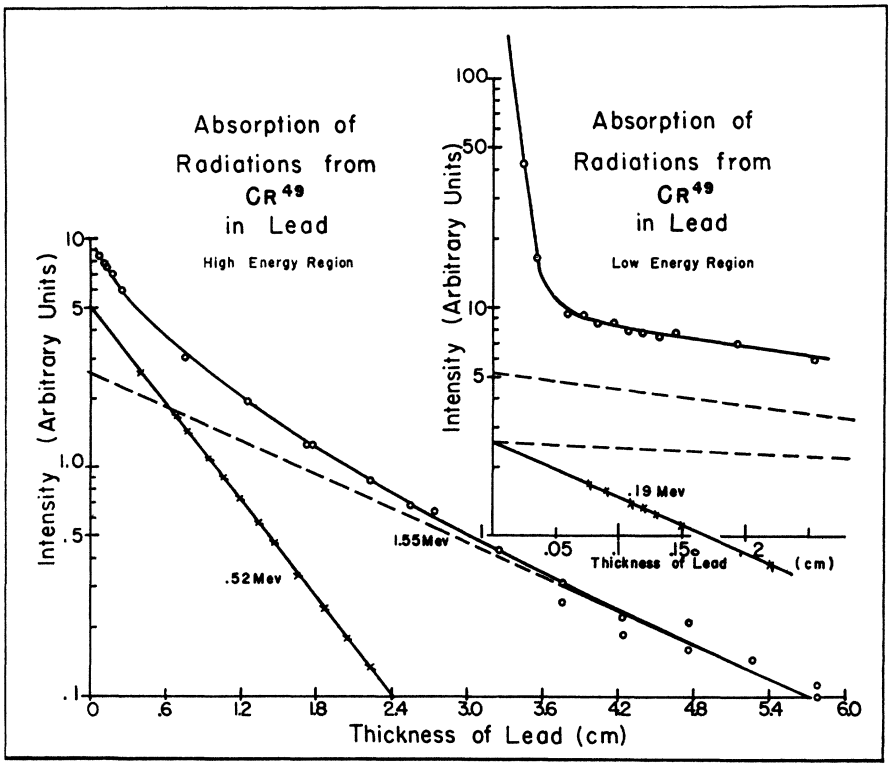

FIG. 4. Lead absorption curve for Cr^{49}. Three gamma-ray energies are evident, 0.19, 0.52, and 1.55 Mev.

cases it was found that the activity of 41.9 minutes was present in the chromium precipitate. The intensity of the activity of the vanadium precipitate was about one-thousandth that of the chromium activity and also decreased with longer half-life. Thus it was established that the 41.9-minute period belonged to chromium. The decay of the activity in the chromium fraction is shown in Fig. 2.

ASSIGNMENT TO Cr^{49}

Only three possibilities remain in the assignment of the activity produced in chromium by alpha-particle bombardment of titanium. These are $Cr^{49,51}$ by (α, n) and Cr^{48} by $(\alpha, 2n)$. Fast neutron bombardment of chromium has been found to produce the 41.9-minute period in chromium by the $(n, 2n)$ reaction. This limits the possibilities to $Cr^{49,51}$.

If the period belongs to Cr^{51}, it should be producible by a (p, n) reaction from V^{51}. Vanadium was bombarded with protons and no 41.9-minute activity was detected.

As an additional check, chromium was bombarded with deuterons. Cr^{51} should be produced by (d, p) reaction; and isotopes of manganese should also be expected by (d, n) or $(d, 2n)$ reactions. A strong 46-minute activity was found in the manganese fraction, but no period of the order of 41.9 minutes was observed in the chromium fraction. The 46-minute manganese period has previously been reported.[4]

Since chemical separation shows that the 41.9-minute activity, produced by alpha-particle bombardment of titanium and by fast neutron bombardment of chromium is an isotope of chromium and since this period has not been found by proton bombardment of vanadium or deuteron bombardment of chromium, the activity must evidently be due to Cr^{49}.

It is interesting to note that on a Konopinski plot[5] (log period *vs.* atomic number), 3.1-hour

[4] J. J. Livingood and G. T. Seaborg, Phys. Rev. **54**, 391 (1938).
[5] G. R. Dickson and E. J. Konopinski, Phys. Rev. **58**, 949 (1940).

Ti^{45}, 41.9-minute Cr^{49}, and 8.9-minute Fe^{53} fall almost on a straight line.

RADIATIONS EMITTED BY Cr^{49}

Since even without chemical separation, the 41.9-minute activity produced by alpha-particle bombardment was found to go through six or more half-lives before any appearance of other activity was noticeable in the decay curve, absorption determinations were made on the activated titanium oxide without chemical separation.

Aluminum absorption measurements, shown in Fig. 3, give an end point at 0.66 g/cm^2. According to the Sargent equation,[6] this corresponds to a positron energy of 1.43 Mev. A value of 1.48 Mev was obtained by cloud-chamber measurements. The weighted average is 1.45 Mev. On a Sargent diagram this energy together with the value of the period indicates that Cr^{49} decays by an allowed transition.

As shown in Fig. 4 absorption measurements in lead give gamma-rays of three distinct energies. One of these gamma-rays has an energy of 0.5 Mev, probably due to the annihilation radiation. The other two are of about equal intensity and have energies of 1.55 and 0.18 Mev. By measuring the decay through various thicknesses of lead, it has been shown that all three gamma-energies belong to the 41.9-minute period.

33-MINUTE VANADIUM

A 33-minute vanadium period, produced by deuteron and alpha-particle bombardment of titanium has been previously reported.[2] Since the activity could not be produced by fast neutrons on vanadium, the assignment was made to V^{49}. Aluminum absorption measurements gave a value of 0.82 g/cm^2, which corresponds to 1.8 Mev by the Sargent equation.

A 33-minute activity assigned to V^{49} is inconsistent with the assignment of the 41.9-minute activity to Cr^{49}. In addition several bombardments of titanium with alpha-particles have failed to reveal the 33-minute period.

However, deuteron bombardment of titanium and proton bombardment of titanium produce the 33-minute vanadium period with strong activity. The range of positrons from this isotope was measured and found to be approximately 0.82 g/cm^2, which agrees sufficiently well with the reported value of 0.86 g/cm^2. If positrons of such energy and activity existed at V^{49}, the aluminum absorption taken on the 41.9-minute Cr^{49} should have given an end point of 0.86 g/cm^2 instead of the 0.66 g/cm^2 which was found.

If the 33-minute period belonged to V^{48}, it should be produced by bombardment of scandium with alpha-particles. This reaction has been tried, but no 33-minute activity was observed. This period therefore seems to belong to V^{47} or V^{46}. If it belongs to V^{47}, then it is produced from titanium by (p, n) and (d, n) reactions and possibly by (p, y) and $(d, 2n)$ reactions. The 33-minute activity has been tentatively assigned to V^{47}.

The period of V^{49} is now undetermined. It is either very short (less than a minute) or else very long. Arguments[7] have been recently presented for placing the 600-day period at V^{49} instead of at V^{47}. Such a change of position would not be inconsistent with the results discussed in this article.

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[6] B. W. Sargent, Can. J. Research **A17**, 82 (1939).

[7] L. A. Turner, Phys. Rev. **58**, 679 (1940).