Radioisotope P^{33}†

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Radioactive phosphorus has been obtained by an *n*, *p* reaction on sulfur which had been electromagnetically enriched in S^{33}. The beta spectrum of this phosphorus showed an increase in the low energy beta group approximately proportional to the isotopic enrichment. This confirms the previous identification of this activity with P^{33}. The maximum beta energy was determined from several Kurie plots and found to be 0.249 ± 0.002 Mev. The half-life was found to be 24.4 ± 0.2 days. The spectrum appears to have an allowed shape as is expected from theoretical considerations.

I. INTRODUCTION

A LOW-ENERGY beta group has been reported in P^{32} samples[1,2] and identified with P^{33}. For a further study of this activity, radioactive phosphorus was obtained from a neutron irradiation of sulfur which had been electromagnetically enriched in S^{33}. An increase in yield of the low-energy activity approximately proportional to the enrichment of S^{33} was interpreted as confirmation of the isotopic assignment. The increased amount of P^{33} also served to facilitate more accurate measurement of half-life and energy characteristics.

II. EXPERIMENTAL RESULTS

A half gram of sodium sulfate which had been enriched in S^{33} by a mass separation was obtained from Oak Ridge. This sample, along with a control sample of ordinary sodium sulfate, was irradiated in the Chalk River pile for 128 hours. Carrier-free phosphorus sources were prepared from these samples by use of an exchange column.[2]

The initial spectra from these sources were obtained with a thin-lens spectrometer[3] which had been modified to incorporate ring focusing.[4] Figure 1 shows a comparison of the beta spectra of the control and the enriched phosphorus about $3\frac{1}{2}$ weeks after removal from the pile. The spectra have been normalized at the peak region of the P^{32} spectra. The ordinate values are for the spectrum of the enriched phosphorus. The increased yield of the low-energy beta group supports the previous conclusion[2] that it is the activity of P^{33}.

Additional spectra were obtained periodically of the P^{33}-enriched phosphorus source for half-life and end-point energy determinations of P^{33}. When the source had become too weak for the thin-lens spectrometer, an intermediate image spectrometer[5] was used to extend the investigation. This increased the counting rate approximately 150 times due to a fiftyfold increase in transmission and an increase in half-width of about three.

Kurie plots of the P^{33} component obtained from earlier samples[2] did not appear to be linear, but low statistics and thick source effects precluded any definite conclusions about the experimental spectral shape. The first Kurie plot from the P^{33}-enriched source is shown in Fig. 2 as it appeared 68 days after irradiation. A least squares calculation of the Kurie line yielded a value of 0.248 Mev for the maximum beta energy. The straight line indicates an allowed spectral shape. However, the Kurie plots from later spectra were increasingly nonlinear with the line convex toward the energy axis, as shown by the crosses in Fig. 3. This changing shape suggested the presence of another longer-lived activity of slightly lower energy, perhaps the activity previously reported[2] in half-life data from an old phosphorus source. This activity had a half-life of about 90 days.

A spectrum was taken 279 days after the neutron irradiation. At this time the P^{32} activity was negligible in the energy range of P^{33}. The spectrum was definitely distorted in such a way as to indicate the presence of another beta group of slightly lower energy than that of P^{33}. This may be seen in the total spectrum of Fig. 4. In this case the Kurie plot appeared linear above 175 kev. A least squares line through these points gave a maximum energy value of 0.250 Mev. An S^{35} Kurie

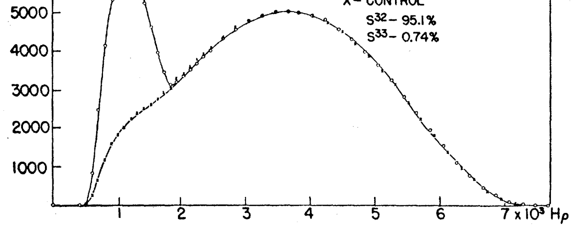

FIG. 1. Beta spectra of phosphorus samples 20 days after irradiation.

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[1] Sheline, Holtzman, and Fan, Phys. Rev. **83**, 919 (1951).

[2] Jensen, Nichols, Clement, and Pohm, Phys. Rev. **85**, 112 (1952).

[3] Jensen, Laslett, and Pratt, Phys. Rev. **75**, 458 (1949).

[4] Pratt, Boley, and Nichols, Rev. Sci. Instr. **22**, 92 (1951); Keller, Koenigsberg, and Paskin, Rev. Sci. Instr. **21**, 713 (1950).

[5] Nichols, Pohm, Talboy, and Jensen (to be published).

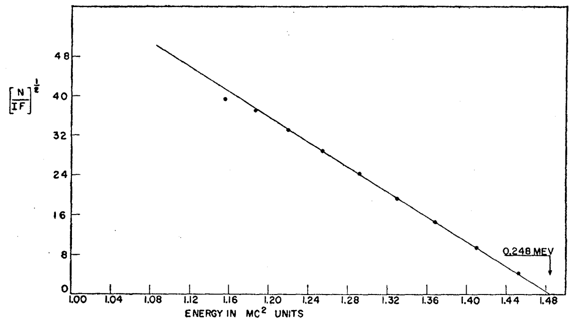

FIG. 2. Kurie plot of P^{33} 68 days after irradiation.

plot of the remainder of the spectrum gave an end-point energy of 0.170 Mev which agrees reasonably well with previous values[6] for S^{35}. These two Kurie plots are shown in Fig. 5. The half-life of the activity remaining in the sample 416 days after removal from the pile was found to be about 85 days. It is estimated that the activity due to P^{33} was less than three percent of the total activity. The components of the total beta spectrum are indicated in Fig. 4.

Earlier spectra from the P^{33}-enriched source were corrected for S^{35} activity by calculating the relative change of these components and normalizing the calculated S^{35} activity by matching the P^{33} components in the region above the maximum energy of S^{35}. A value of 24.4 days was used for the half-life of P^{33} and a value of 87.5 days was used for the half-life of S^{35}. After the calculated S^{35} activity was subtracted, the Kurie plots were linear as shown by the circles in Fig. 3.

The relative growth of P^{33} to P^{32} over a period of 191 days was determined from five spectra. The area of the P^{33} and P^{32} spectrum components was compared in each spectrum using only the region above 120 kev to insure no change in transmission efficiency due to window absorption in the Geiger counters or pulse discrimination in the scintillation counter. A logarithmic plot of the relative activities gave an excellent straight line

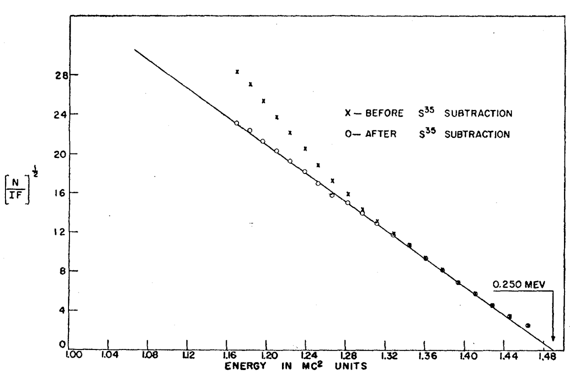

FIG. 3. Kurie plot of P^{33} 211 days after irradiation.

[6] Hollander, Perlman, and Seaborg, Revs. Modern Phys. **25**, 469 (1953).

and yielded a half-life value of 24.3 days for P^{33} using a value of 14.3 days for the half-life of P^{32}.

By extension of the Kurie plots of P^{32} and P^{33}, the total ratio of the activities was found for one spectrum and calculated back to the time of removal of the sample from the pile. The relative cross section for the n, p reaction on S^{33} compared to that of S^{32} for the neutron distribution in the Chalk River pile was found to be about 2.6. This increase may be expected since the $S^{32}(n,p)P^{32}$ reaction is endoergic, requiring neutron energies of about 1 Mev, while the $S^{33}(n,p)P^{33}$ reaction is exoergic and may be induced by slower neutrons.

III. SUMMARY

The results of this investigation confirm the previous conclusion that the low energy beta group in P^{32} samples formed by an n, p reaction on sulfur is due to P^{33}. With revaluation of previous half-life data in light of

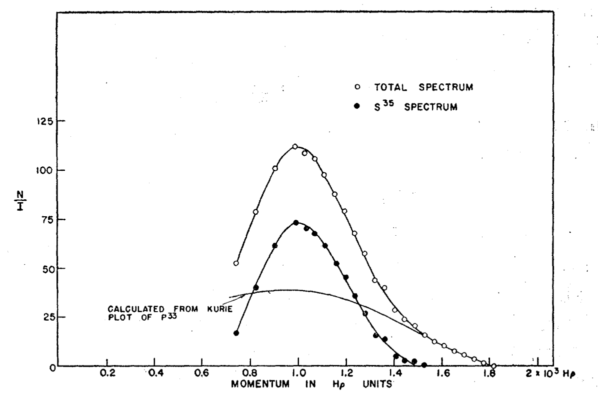

FIG. 4. Beta spectrum of phosphorus from S^{33}-enriched sulfur 279 days after irradiation.

the observed S^{35} in the phosphorus samples, the mean value of the half-life of P^{33} is now found to be 24.4 ± 0.2 days. The maximum beta energy, taken from four linear Kurie plots and both spectrometers, is calculated to be 0.249 ± 0.002 Mev.

Using these values, an f value of 0.055 is obtained from the graphs of Feenberg and Trigg[7] and a log ft value of 5.1 is found for P^{33}. According to Nordheim[8] this is a normal allowed transition. The spin of S^{33} is known to be $\frac{3}{2}$.[9,10] The magnetic moment of S^{33} indicates a $d_{\frac{3}{2}}$ state.[10] According to the nuclear shell model,[11] a regular filling of the levels would give a $d_{\frac{3}{2}}$ state to the P^{33} nucleus. The decay of P^{32} would then be a normal allowed transition in which the orbital momentum and spin are unchanged. For such a transition the values of

[7] E. Feenberg and G. Trigg, Revs. Modern Phys. **22**, 399 (1950).
[8] L. W. Nordheim, Phys. Rev. **78**, 294 (1950).
[9] C. H. Townes and S. Geschwind, Phys. Rev. **74**, 626 (1948).
[10] Eshbach, Hillger, and Jen, Phys. Rev. **80**, 1106 (1950).
[11] M. G. Mayer, Phys. Rev. **78**, 16 (1950).

log ft range mostly from 4.8 to 5.5.[8] The experimental value of 5.1 thus agrees well with these values and the experimental spectral shape is consistent with these considerations. However, P^{31} is known to have a spin of $\frac{1}{2}$ and an $s_{\frac{1}{2}}$ state. On the basis of the nuclear shell model one would expect P^{33} to have an $s_{\frac{1}{2}}$ state also. The decay of P^{33} would then involve an orbital momentum change of two and a spin change of one. This type of transition has log ft values mostly in the range of 6.5 to 7.5,[8] but with some stragglers. The experimental value of 5.1 for log ft is not in agreement with these values. These considerations add confirmation to the $d_{\frac{3}{2}}$ state for P^{33}.

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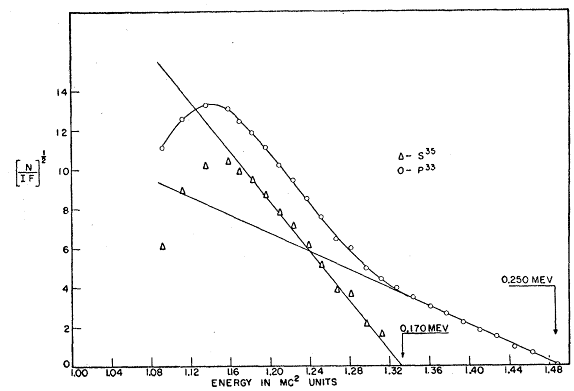

FIG. 5. Kurie plots of P^{33} and S^{35} 279 days after irradiation.

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A New Isotope of Palladium, 1.5-Minute Pd^{113}†

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A new isotope, 1.5-minute Pd^{113}, has been isolated from the fission products of natural uranium bombarded with 190-Mev deuterons. The mass assignment and half-life were determined by successive milkings of the 5.3-hour Ag^{113} daughter.

EXAMINATION of the neutron excess isotopes of palladium led the authors to speculate that Pd^{113} may have a half-life which could be determined by milking the well-known 5.3-hour Ag^{113} daughter.

A strip of uranium foil was bombarded with 190-Mev deuterons for two minutes in the circulating beam of the Berkeley 184-in. cyclotron using a "rabbit-type" target. After bombardment the target was transported in a pneumatic tube to the chemistry laboratory and dissolved in aqua regia with palladium holdback agent added. Two silver chloride scavenges were performed, the second scavenge was complete 4.5 minutes after the beam was turned off. The supernatant liquid from the second scavenge was decanted into a centrifuge cone containing a measured amount of silver nitrate solution. The mixture was maintained at about 90°C and stirred vigorously. The precipitate was centrifuged so that the time of separation of the precipitate from the solution was, as nearly as possible, one minute after the separation of the silver chloride scavenge. Twelve milkings were made at one minute intervals. The silver chloride precipitate was washed as soon as possible after decantation. Less than two percent of the supernatant liquid remained with the decanted precipitate.

After all the milkings and washings were complete, silver was purified radiochemically to remove radionuclides that had adsorbed on the silver chloride. The purified samples were counted with a standard chlorine-quenched Geiger tube. The 7.5-day Ag^{111} activity milked from the 22-minute Pd^{111} was resolved from the decay of the silver samples and used to determine the efficiency of each milking. The 3.2-hour Ag^{112} and 5.3-hour Ag^{113} activities were resolved analytically[1] after subtraction of the 7.5-day Ag^{111} activity. The resultant half-life of the Pd^{113} parent was 1.5 minutes.

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[1] W. F. Biller (private communication).