The Characteristic Radiations of Praseodymium (142)*

C. E. MANDEVILLE
Bartol Research Foundation of the Franklin Institute, Swarthmore, Pennsylvania
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The nineteen-hour Pr^{142} emits 2.22-Mev nuclear beta-rays (aluminum absorption) and gamma-rays having a maximum energy of 1.74 Mev as determined by coincidence absorption. Evidence is considered which leads to a somewhat lower value for the energy of this gamma-ray. Lead absorption indicated a soft component at 0.17 Mev. Beta-gamma-coincidence data revealed the presence of a soft beta-ray spectrum of low intensity having an end point at 215 kev. The hard beta-rays are non-coincident with gamma-radiation and are thus considered to be associated with a ground state transition. Gamma-gamma-coincidences, denoting cascade emission of gamma-rays by the excited residual nucleus, were observed, but no beta-beta-coincidences were found.
See note added in proof.

INTRODUCTION

IT seems well established[1–3] that slow neutron bombardment of praseodymium gives rise to a 19.3-hour period. This activity has been assigned to Pr^{142}, since Pr^{141} appears to be the only stable isotope of praseodymium. Recent measurements[3] seem to indicate the presence of long lived activities. These would have no effect upon the results of the present investigation, since PrO_2 was irradiated for only two hours in the Oak Ridge pile, and the measurements were completed within five days after removal of the irradiated material from the pile. The data herein reported were compiled with the use of absorption and coincidence counting methods which have been previously described.[4] No chemical separations were performed. However, the effects of impurities were thought to be small because of the short exposure time. The ordinates of all of the curves presented in the text of the paper were observed to decay with the nineteen-hour period.

RESULTS

The absorption in aluminum of the beta-rays of Pr^{142} is shown in Fig. 1 where the upper limit is seen to occur at 1.04 g/cm² or 2.22 Mev as calculated by Feather's equation.[5] This value is in good agreement with earlier reports.[1,2]

Coincidence absorption of the secondary electrons of the gamma-rays of Pr^{142} is shown in Fig. 2. The end point, according to the calibration curve of the coincidence counting set,[4] corresponds to a quantum energy of 1.74 Mev. Lead absorption measurements have previously indicated a value of 1.9 Mev[2] and 2.1 Mev.[3] The presence of this gamma-ray was also noticed by the writer in 1943.[6] The momentum distribution of the recoil electrons ejected by this gamma-ray from a thick aluminum radiator in a magnetic spectrograph was found to have a curve shape and extrapolated end point[7] identical with that of the 1.61-Mev[8] gamma-ray of La^{140}. The energy value obtained by this com-

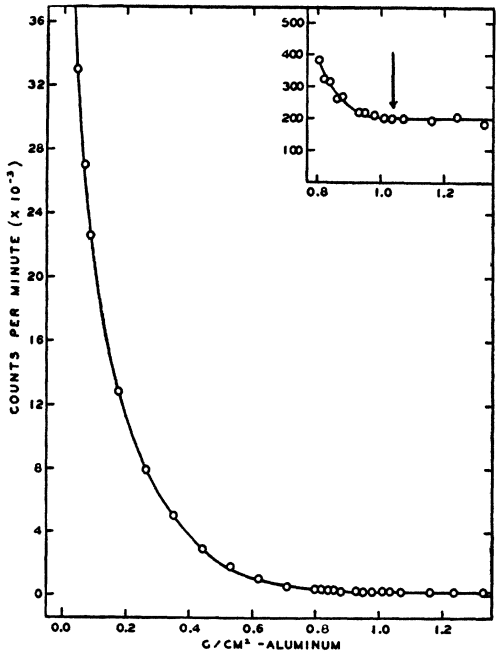

FIG. 1. Absorption in aluminum of the beta-rays of Pr^{142}. The absorption limit occurs at 2.22 Mev.

* Assisted by the Joint Program of the ONR and the AEC.
[1] C. S. Wu and E. Segrè, Phys. Rev. **61**, 203 (1942).
[2] J. W. DeWire, M. L. Pool, and J. D. Kurbatov, Phys. Rev. **61**, 544 (1942).
[3] J. M. Cork, R. G. Shreffler, and C. M. Fowler, Phys. Rev. **74**, 1657 (1948).
[4] C. E. Mandeville and M. V. Scherb, Nucleonics **3** (No. 4), 2 (1948).
[5] N. Feather, Proc. Camb. Phil. Soc. **34**, 599 (1938).
[6] C. E. Mandeville, unpublished data, 1943.
[7] The momentum distribution of the recoil electrons of the gamma-rays of lanthanum (140) [Phys. Rev. **63**, 387 (1943)] exhibits a high energy "tail" arising from the presence of gamma-rays of energy greater than 2 Mev and probably also from scattering. However, extrapolation at the point of maximum slope as recommended by Itoh [Proc. Phys. Math. Soc. Japan **23**, 605 (1941)] and by Siegbahn [Proc. Roy. Soc. **A189**, 527 (1947)] gives identical end points for the recoils of the high energy gamma-rays of La^{140} and Pr^{142}.
[8] R. K. Osborne and W. C. Peacock, Phys. Rev. **69**, 679 (1946).

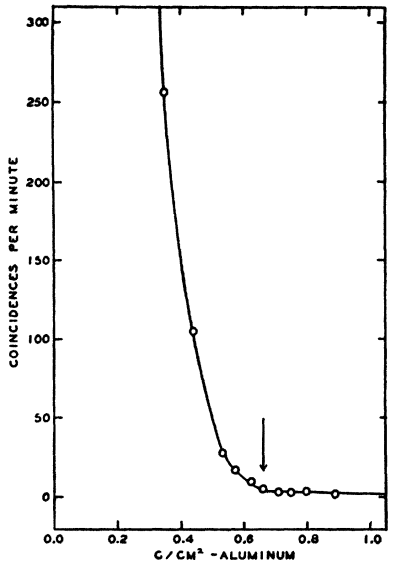

FIG. 2. Coincidence absorption of the recoil electrons of the gamma-rays of Pr^{142}. The end point corresponds to a quantum energy of 1.74 Mev.

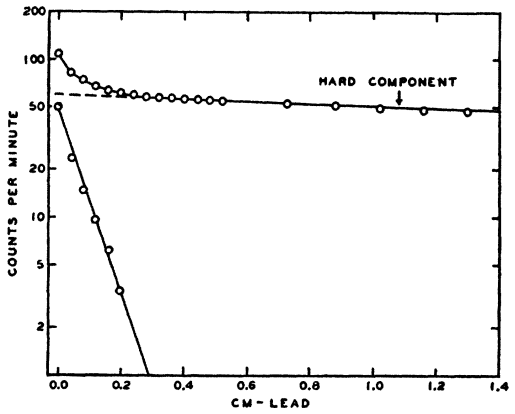

FIG. 3. Absorption in lead of the gamma-rays of Pr^{142}. The curve gives evidence of a soft component in addition to the well-known hard radiation.

parison method seems preferable to all others, since Wattenberg[9] reported no photo-neutrons from a Pr^{142}+Be source.** The lead absorption curve of Fig. 3 gives evidence of soft gamma-rays having an energy of about 0.17 Mev as well as the previously discussed hard radiation. Cork *et al.*[3] have reported conversion lines from Pr^{142} corresponding to gamma-ray energies of 133.7, 328.9, 489.6, and 623.6 kev.

The beta-gamma-coincidence rate of Pr^{142} is shown in Fig. 4, where it is seen to decrease from an extrapolated value of 0.05×10^{-3} coincidence

[9] A. Wattenberg, Phys. Rev. **71**, 497 (1947).

** Other reports of the energy of the intense gamma-ray of La^{140} are 1.63 Mev [L. C. Miller and L. F. Curtiss, Phys. Rev. **70**, 983 (1946)] and 1.65 Mev [W. Rall and R. G. Wilkinson, Phys. Rev. **71**, 321 (1947)]. Lens type spectrometers were employed in both cases.

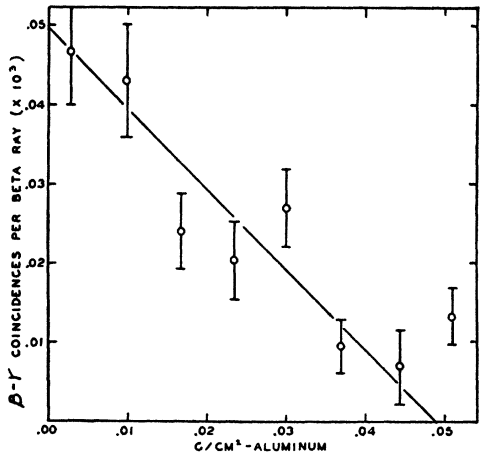

FIG. 4. The beta-gamma-coincidence rate of Pr^{142} as a function of the surface density of aluminum placed before the beta-ray counter. This curve shows that a soft spectrum is present having an end point at 215 kev and that the 2.22-Mev beta-rays lead to the ground state of the residual nucleus.

per beta-ray at zero absorber thickness to zero at 0.049 g/cm² in aluminum placed before the beta-ray counter.[10] This shows that a soft spectrum, coupled with gamma-rays, having an end point at 215 kev is present in the decay of Pr^{142}. It follows also that the 2.22-Mev beta-rays lead to the ground state of the Nd^{142} residual nucleus. A source of Pr^{142} was placed between two gamma-ray counters each shielded by 1.5 g/cm² of aluminum. A gamma-gamma-coincidence rate of 0.25×10^{-3} coincidence per gamma-ray was observed. The data of Cork *et al.*[3] also suggest cascade emission of gamma-rays. The conversion lines reported by them also sug-

[10] The "low Z" gamma-ray counter of the beta-gamma-coincidence counting arrangement was calibrated with the beta-gamma-coincidence rate of Sc^{46} (2 Mev of de-excitation energy, 2.66×10^{-3} coincidence per beta-ray). Knowing this, the difficulties related to detection of the small coincidence rate of Pr^{142} can be understood. To detect small beta-gamma-coincidence rates, counting rates as high as two-hundred thousand counts per minute have been used in the beta-ray counter. The beta-gamma-coincidences per beta-ray are unaffected as long as dead-time losses in the *gamma-ray counter* remain inappreciable. This more or less obvious fact has been verified by observing that the number of beta-gamma-coincidences per beta-ray recorded in the beta-ray counter remained unchanged for many different radioactive elements when the beta-ray counting rate was varied from twenty thousand to two-hundred thousand counts per minute.

If it is assumed that the soft spectrum of Pr^{142} is followed by about 2 Mev of gamma-ray energy, the beta-gamma-coincidence rate at zero absorber thickness, 0.05×10^{-3} coincidence per beta-ray, shows that the soft spectrum has an intensity about one-fiftieth as great as the 2.22-Mev spectrum. This estimate is in reasonably good agreement with the findings of the Ohio State group (reference 2) who report one high energy gamma-ray per twenty-five nuclear beta-rays.

It was stated in a footnote of a previous paper concerning Cd^{115}, Phys. Rev. **75**, 221 (1949), that the calculated intensity of the softer spectrum constitutes a lower limit, since the low energy beta-rays are heavily absorbed and scattered in the thin window of the beta-ray counter. This comment was without meaning, since at *zero absorber thickness*, all correction factors are unity and the estimate of relative intensity should be exact.

gest the possible existence of beta-beta-coincidences. A search was made for them, but after carefully eliminating all scattering effects arising from the 2.22-Mev beta-rays, none were found. This is not surprising, because the conversion electrons and associated soft nuclear beta-rays are very few in number as compared to the 2.22-Mev nuclear beta-rays.

Note added in proof: The "Table of Isotopes" compiled by G. T. Seaborg and I. Perlman [Rev. Mod. Phys. **20**, 585 (1948)], has appeared since this paper was presented for publication. In the table, reference is made to a report having only a restricted distribution by W. C. Peacock, J. W. Jones, and R. T. Overman [Plutonium Project Report Mon N-432, p. 56 (Dec. 1947)]. Their value of 1.65 Mev is quoted in the isotopic table as the energy of the hard gamma-ray of Pr^{142}. This is in agreement with the deductions of the present paper.

ACKNOWLEDGMENTS

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Radioactive Isotopes of Platinum and Gold

GEOFFREY WILKINSON

Radiation Laboratory and Department of Chemistry, University of California, Berkeley, California

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Using the 60-inch Crocker Laboratory cyclotron, bombardments have been made of iridium and platinum with 19-Mev deuterons, of iridium with 38-Mev α-particles, and of platinum and gold with fast and thermal neutrons. Radioactive isotopes of iridium, platinum, and gold were chemically separated and the radiation characteristics studied.

THE results of a survey of the radioactive isotopes of platinum and gold have been reported previously.[1] Table I summarizes present knowledge of these isotopes. The present paper describes in more detail the experimental techniques used and the radiation characteristics of the radioactive isotopes observed.

I. EXPERIMENTAL

A. Bombardment

Using the 60-inch cyclotron at the Crocker Laboratory, bombardments were made of iridium with 38-Mev helium ions and 18-Mev deuterons, of platinum with 18-Mev deuterons, fast and thermal neutrons, and of gold with fast neutrons.

In all bombardments, reagent quality metals were used. Platinum and gold were bombarded as 2- and 5-mil foils. Iridium was bombarded as the powdered metal, in order to facilitate subsequent solution; in short bombardments where no chemical separations were made, iridium foil was used. The metal powder was tamped into the trough of a water-cooled copper "interceptor" target, which received about one-third of the total beam from the cyclotron. The iridium was protected by wrapping the target with 0.2-mil tantalum foil.

After bombardment, platinum and gold targets were dissolved in boiling aqua regia. Iridium was dissolved by the procedure of Wichers *et al.*[2] The metal powder (100 mg) was transferred to a thick-walled glass tube, and an equal weight of sodium chlorate was added. While the tube was cooled in liquid air to prevent chemical reaction, 5 ml of fuming hydrochloric acid were added. After sealing, the tube was allowed to warm and then heated at 300°C for about three hours.

B. Chemical Separations

The chemical methods used in both the initial separations and in the separation of daughter activities were variants on the procedures outlined below. The steps were carried out in the given order, the usual radiochemical techniques being employed with milligram amounts of carriers present. "Holdback" and "scavenger" carriers were used at appropriate points, and separations were repeated until acceptable radiochemical purity was obtained.

[1] Geoffrey Wilkinson, Phys. Rev. **73**, 252 (1948).

[2] E. Wichers, W. G. Schlect, and C. L. Gordon, J. Nat. Bur. Stand. Research **33**, 363 (1944).