Converted Gamma-Radiation from Silver, Cadmium, Indium, Praseodynium, and Rhenium

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By use of beta-spectrometers and absorption methods the half-lives and energy characteristics of radioactive isotopes of silver, cadmium, indium, praseodymium, and rhenium have been determined. The activities studied were induced by neutron capture in the pile.

Silver of half-life 282 days had gamma-rays of energy 114.2, 655, 880 kev and 1.38 Mev. Cadmium appears to yield several radioactivities; one of which is a positron emitter and converted gamma-rays of 86.3 and 336.9 Kev are observed. The well known 48-day activity in indium has a converted gamma-ray whose energy is more closely determined as 190.9 Kev. Praseodymium also displays a complex decay curve, but associated with a short half-life previously reported as 19.2 hours are gamma-rays of 133.7, 328.9, 489.6, and 624 Kev, and by absorption a high energy gamma-ray of 2.1 Mev. Rhenium is strongly activated in the pile, yielding two radioactivities, of half-lives 16 hours and 91 hours. A converted gamma-ray of 153.6 Kev is found for the short-lived activities, and gamma-energies of 122.7, 135.8, 127.5, and 640 Kev exist for the longer-lived activity.

OXIDES of silver, cadmium, indium, praseodymium, and rhenium were irradiated in the pile for periods of two months and four months. The irradiated samples were studied by the use of electrometers to determine the half-lives and absorption coefficients and more particularly in semicircular-focusing, magnetic spectrometers by the photographic method to observe the electrons resulting from internal conversion. Three spectrometers of the "Alnico" type, previously described,[1] were employed. These magnets were excited so as to provide uniform fixed fields of approximately 200, 300, and 400 gauss, thus giving a variation in resolving power at different energies.

Most of these elements have been studied previously, but with the longer bombardments now available certain new radioactivities are observed. The energies of the gamma-rays displaying internal conversion are definitely evaluated for the first time.

SILVER

Silver exists in nature as two stable isotopes of mass 107 (52 percent), and 109 (48 percent). By neutron capture, isotopes of mass 108 and mass 110 should be produced. The half-life of Ag 108 has been reported[2] as 2.3 minutes, and Ag 110 has been reported as consisting of isomers of half-lives of 22 seconds and 225 days.

In this investigation with the longer bombardment the half-life of the long-lived emitter is shown to be greater than previously reported, namely 282 days. Three internally converted gamma-rays were found, corresponding to energies of 114.2, 655, and 880 kev. This calculation is based upon the apparent agreement of the $K-L$ lines when the difference in silver, instead of cadmium is used. This would indicate that the gamma-emission precedes the beta-radiation. In addition a gamma-ray of 1.38 Mev was found by absorptions in lead.

The beta-spectrum has been studied in an electron lens spectrometer. Some electrons are found with energies well above 1 Mev. If these electrons are assumed to be due to high energy gamma-rays, then the remainder of the electrons define a Fermi plot whose upper limit is at 0.58 Mev.

CADMIUM

Cadmium has 8 stable isotopes with masses lying between 106 and 116. Previous investigations[3] have indicated that by neutron capture it might be possible to produce an isotope of mass 107 (from 106, 1.4 percent) whose half-life has been reported from 6.7 hours to 1.4 days, or mass

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[1] J. M. Cork, Phys. Rev. **72**, 581 (1947).

[2] Amaldi, D'Agostino, Fermi, Ponticorvo, Rasetti, and Segrè, Proc. Roy. Soc. **149**, 522 (1935); M. Pool, Phys. Rev. **53**, 116 (1938); M. Deutch, A. Roberts, and L. Elliott, Phys. Rev. **61**, 389 (1942); and others.

[3] Delsasso, Ridenour, Sherr, and White, Phys. Rev. **55**, 113 (1939); J. Cork and J. Lawson, Phys. Rev. **56**, 291 (1939); A. Helmholz, Phys. Rev. **60**, 160 (1941); Isotope Committee, Science **103**, 697 (1946).

TABLE I.

Element At. No.	Element Name	Beta-limit (absorption)	Gamma-energies By absorption	Gamma-energies By conversion	Half-life	Probable mass
47	Silver	0.58 Mev	1.38 Mev	114.2, 655, 880 kev	282 days	110
48	Cadmium	1.20	0.61		64 hours	115
		—	—	86.3, 336.9	∼75 days	107 or 115
49	Indium	1.98	0.81	190.9	48 days	114
59	Praseodymium	—	2.1	133.7, 328.9, 489.6, 624	19.2 hours Others	142
75	Rhenium	0.70	0.64	122.7, 135.8,	91 hours	186
		—	—	137.5		
		—	—	153.6	∼16 hours	188

115 (from 114, 28 percent) reported as having isomeric emitters of half-lives 2.5 days and 43 days.

The resolution of the decay curves of the irradiated specimens here studied indicated half-lives of 75 days, and 64.0 hours. Two different chemical specimens were observed and found to agree in this respect. Longer lived emitters may be ultimately found to exist but four months after the bombardment there is no indication as yet of their presence.

Internally converted gamma-rays are associated with the 75-day activity and their energies are found to be 86.3 and 336.9 kev. There is no evidence for the existence of a gamma-ray of greater energy, by absorption measurements.

An analysis of the radiation by a strong resolving magnetic field showed that shortly after the bombardment some few positrons, some gamma-rays, and intense negative electrons were emitted. Three months after the bombardment the relative number of positrons to electrons had greatly increased. The presence of positrons indicates that the isotope 107 has been produced, although the reported half-life of 158 days has not been observed. Additional time will be necessary to affirm this. The negative electrons associated with the 64-hour half-life appear by their absorption in aluminum to have an upper limit of 1.19 Mev. Gamma-radiation is also present in the freshly bombarded specimen, with an absorption coefficient in lead indicating an energy of 0.61 Mev.

INDIUM

Indium has been the subject of many previous reports. Only two stable isotopes of mass 113 (4.5 percent) and mass 115 (95.5 percent) exist in nature, yet at least 12 radioactive indium emitters are believed to be possible. By neutron capture it should be possible to observe only one of the previously reported radioactivities, since the others all have a life too short or are produced by reactions not possible in the pile.

The activity to be expected has been reported[4] as resulting from mass 114, and having a half-life of 48 days. It is also reported to decay by the emission of a gamma-ray, followed by a beta-particle. In this decay the $K-L$ difference of the observed converted electron lines should be characteristic of the element indium, rather than of the next element tin which would have been the case had the beta emission occured first. The $K-L$ difference here observed confirms this assignment. The value of the gamma-ray is more precisely given as 190.9 Mev.

Other shorter-lived activities did exist in the irradiated indium several hours after it was received from the pile, but their characteristics were not precisely determined.

PRASEODYMIUM

Praseodymium exists in nature only as the isotope of mass 141. By neutron capture it should be possible to excite a radioactivity in the mass 142 previously reported[2, 5] as having a half-life of 19.3 hours. An analysis of the decay curve shows that the activity of this irradiated sample is more complicated.

[4] J. Lawson and J. Cork, Phys. Rev. **57**, 983 (1940).

[5] M. Pool, J. Cork, and R. Thornton, Phys. Rev. **52**, 239 (1937); J. de Wire, M. Pool, and J. Kurbatov, Phys. Rev. **61**, 544 (1942).

Internally converted gamma-rays, associated with the short-lived activity, are found to have energies of 133.7, 328.9, 489.6, and 623.6 kev.

It can be observed that the sum of the energies of the first and third gamma-rays is almost identical to that of the highest value. An analysis of the decay curve indicates that certain longer lived activities are present. The correct solution must await further aging of the specimen.

By lead absorption there appears to be a high energy gamma-ray at about 2.1 Mev.

RHENIUM

Rhenium exists as two stable isotopes, of mass 185 (38.2 percent) and mass 187 (61.8 percent). Neutron capture should produce Re 186 reported[6] as having a half-life of 90 hours and Re 188 with a half-life of 18 hours. The pile irradiated specimen was exceedingly active, indicating a large capture cross section particularly for Re 185. A specimen with minimum usable mass gave good spectrograms, with an exposure of 20 minutes instead of several days as required for many other elements.

An analysis of the half-life curve showed the principle decay to have a 91-hour half-life, together with an additional initial activity whose half-life is determined as approximately 16 hours.

Both emitters yield conversion electrons from which the gamma-rays are evaluated. A single converted gamma-ray of energy 153.6 kev is observed for the shorter half-life. For the 91-hour activity gamma-rays of energy 122.7, 135.8, and possibly 137.5 kev are found. In each case the $K-L-M$ electron peaks are observed and the 'L' line appears in the 91-hour activity stronger than the 'K'. An additional gamma-ray of energy 0.64 Mev is indicated by absorption in lead. The upper limit of the beta-spectrum for the 91-hour activity appears by absorption in aluminum to be at 0.70 Mev.

The values of the energies and half-lives observed in this investigation are shown collectively in Table I. These studies were made possible by the support of the Atomic Energy Commission and the Office of Naval Research.

[6] K. Fajans and W. Sullivan, Phys. Rev. **58**, 276 (1940).

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Cosmic-Ray Bursts at Sea Level and under Thirty Meters of Clay

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Cosmic-ray bursts have been investigated by means of ionization chambers made of Duralumin, of volume 1.15 liter and wall thickness 12 mm, filled with argon to pressures of about 82 atmos. at 0°C. The bursts were registered with recording electrometers. The experiments were carried out in a hut with a thin roof at sea level and in an underground station under 30 meters of clay. At both levels runs were made with the chambers unshielded and also with sheets of aluminium (up to 33 cm) and of lead (up to 18 cm) placed above them. In all, about 3000 hours at the underground station and 1000 hours at sea level were successfully recorded. The results obtained underground are the first systematic investigation concerning bursts observed far below sea level. The air-lead transition curves there show a flat maximum which occurs at a greater thickness of lead than that observed at sea level.

1. INTRODUCTION

THE energy of the ionizing charged part of the cosmic radiation can be measured directly and individually in a strong electromagnetic field with a cloud chamber, or indirectly and integrally, from the total energy lost in

* This paper has been condensed by H. Carmichael, without significant changes of wording, from a paper published by C. N. Chou, under the same title, in *Collected Papers* (College of Science and Engineering, National University of Amoy, China, 1943), Vol. 1, pp. 1–36. It has been submitted for publication in The Physical Review in the belief that experimental results are of considerable interest. The experimental data has been replotted from the original tables. Further discussion of the results will be found in the following paper. Two of the experimental curves were previously published in a short note: H. Carmichael and C. N. Chou, Nature **144**, 325 (1939).