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Absorption and Emission Spectra of Promethium

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Five milligrams of promethium ($^{147}_{61}$Pm) separated from fission products at the Oak Ridge National Laboratory, were loaned by the United States Atomic Energy Commission for this investigation. The absorption spectrum of this sample in solution was plotted between 3500 and 10000 angstroms; the principal bands have wavelengths 494.5, 548.5, 568.0, 685.5, 735.5 millimicrons (±0.5 millimicrons). Small portions of the sample were dried on copper electrodes employed in photographing alternating-current arc and spark spectra with a concave grating of 22-foot radius. Excepting Sm, into which Pm decays, no other rare earths could be detected in this sample, but common chemical contaminants were troublesome. Between 2200 and 6900 angstroms the wavelengths and relative intensities of more than 2,200 new spectral lines were determined, but it was not possible to differentiate Pm I and Pm II lines with the light sources employed. The strongest Pm lines have wavelengths 3892.16, 3910.26, 3919.09, 3957.74, and 3998.96 ±0.02 angstroms. Hyperfine structure is suspected in some Pm lines, indicating that the nuclei of $^{147}_{61}$ Pm atoms possess mechanical and magnetic moments. Confirming the findings of the Oak Ridge National Laboratory, both the absorption and the emission spectrum identify this fission product as a new element of rare-earth type; they provide positive proof that the long-sought element with atomic number 61 has been discovered.

I. Introduction

In a paper read before the Bohemian Academy and the Russian Association of Scientists in 1902, Brauner [1] [1] came to the conclusion that only seven elements remained to be discovered. One of these, he said, must lie between neodymium and samarium because the atomic weights of these two elements differed by 6.1 units, whereas the average difference between the atomic weights of two neighboring rare earths is only 3 units. This was undoubtedly the first prediction of a missing rare earth, which ever since has been the object of search and controversy. Moseley's [2] discovery in 1913 of a quantitative relation between Röntgen frequencies and atomic numbers confirmed Brauner's prediction and fixed the atomic number of the unknown rare earth as 61.

In 1926 reports of the concentration and identification of the element with atomic number 61 came practically simultaneously from three different sources. A neodymium concentrate from Brazilian monazite was submitted to X-ray examination by Cork, James, and Fogg [3], who reported that seven L-series lines corresponded to predicted lines of element 61. Harris, Yntema, and Hopkins [4] claimed that the fractionation of cerium group material as double magnesium nitrate concentrated element 61 between 60 Nd and 62 Sm. They based their claim to the discovery of this element on three different lines of evidence: five arc-spectrum lines (3305.8, 3329.1, 3342.5, 3378.0 and 3379.2 A) common to pure Nd and Sm and to intermediate fractions, the presence in intermediate fractions of absorption bands (5,816 and 5,123 A), which became stronger as those of Nd and Sm became weaker, and the presence of two lines (2.2781 and 2.0070 A) in the X-ray spectrum near the theoretical positions for $L\alpha_1$, and $L\beta_1$, of element 61 for which they proposed the name illinium. Rolla and Fernandes [5] reported that experiments with commercial didymium oxide yielded fractions showing variations in absorption spectra and X-ray lines proving the presence of element 61, for which they proposed the name florentium. Up to the present time none of these "discoverers" has substantiated their claims, nor have any other scientists succeeded in separating element 61 from natural sources. Recent application of Mattauch's rule [6] and of considerations [7, 8] on nuclear instability lead to the conclusion that element 61 is either nonexistent in nature or could occur only with extremely low abundance.

Following the discovery of artificial radioactivity in 1934, several attempts have been made to produce isotopes of element 61 by bombarding other rare earths with particles accelerated in cyclotrons. Thus, indications were obtained [9, 10] that an unstable isotope of element 61 may be produced by bombarding praseodymium with alpha particles, but the amounts made in this manner were too small to investigate the atomic weight and properties other than radioactive. The first positive identification of isotopes of element 61 came in 1946 when Marinsky, Glendenin, and Coryell [11] separated and chemically identified 47-hour and 3.7-year half-life isotopes found among uranium fission products. From a fission yield of 1.4 percent the former was judged [12] to have an integral mass of 149, and the latter with a fission yield of 2.6 percent was found [12] with the mass spectrometer to have atomic weight 147. The discoverers of element 61 proposed [13] that this new element be named prometheum (symbol Pm).

The separation of milligram quantities of element 61 from fission was described in 1948 by Parker and Lantz [14]. Portions of this sample were used by Burkhart, Peed, and Spitzer [15] for the measurement of four lines in the Röntgen K spectrum, and by Peed, Spitzer, and Burkhart [16] for the measurement of six lines in the Röntgen L spectrum, thus obtaining evidence that the material was element 61. Three milligrams of sample recovered from the X-ray

[1] Figures in brackets indicate the literature references at the end of this paper.

tube were then applied to investigations of optical emission and absorption spectra. Part of this sample was used by Feldman [17] to photograph a portion of the arc spectrum in the ultraviolet; seven lines (3366.05, 3377.64, 3391.25, 3418.67, 3427.42, 3441.09, 3449.81 A) characteristic of element 61 were reported, but the five lines previously presented by Yntema [18] were not confirmed. The remainder of this sample was used by Parker and Lantz [19] for an investigation of the absorption spectrum of element 61 in which they found ten principal bands with wavelengths 459.5, 493.5, 548.5, 568.0, 629.0, 685.0, 702.7, 737.2, 785.0, and 810.0 mμ. The spark spectrum of element 61 was first investigated by Timma [20], who published approximate intensities and wavelengths for 59 lines ranging from 3629.8 to 4381.9 A.

At the request of the National Bureau of Standards, the United States Atomic Energy Commission supplied on loan 5 mg of $^{147}_{61}$Pm for the purpose of studying the optical spectra of this fission product in some detail. The sample was delivered in March 1949, and a preliminary report on the absorption and emission spectra of promethium [21] was given at a meeting of the Optical Society of America on March 11, 1950. In the present paper the authors present the methods and results of their investigations of spectroscopic properties of the last discovered rare-earth element, now called promethium [22].

II. Absorption Spectrum of Promethium

The 5-mg sample of Pm was received in the form of the nitrate; this was dissolved in 0.5 ml (H_2O+ HNO_3) to make a concentration of 10 mg Pm/ml, that is, 0.030-molar Pm $(NO_3)_3$ solution. This pink-colored Pm solution was transferred to a 1-cm quartz cell of a Model DU Beckman Quartz spectrophotometer for the observation of absorption bands. A diaphragm limiting the exit light beam to a height of 2 mm was mounted in the filter slide ahead of the solution, and the absorption cell was elevated in its holder so that the light beam could pass unobstructed through the solution. Transmittance measurements were made relative to a blank cell containing water. Before making observations on Pm the instrument was checked with a 0.076-molar solution of $Nd(NO_3)_3$, and then the wavelength scale was carefully calibrated from 253.6 to 1128.7 mμ by using Hg, Ne, and H lines. During the run on Pm, transmittance measurements were made at intervals of 5 mμ or less. The results were plotted, and a curve drawn to represent the absorption spectrum of Pm is reproduced in figure 1. From this curve the wavelengths of at least eight absorption bands characteristic of Pm were estimated with an uncertainty of less than 1 mμ. The wavelengths representing maximum absorption in each band are shown in table 1, where they are compared with similar values (and molar extinction coefficients) reported by Parker and Lantz [19]. The agreement is exceedingly good. In addition to the eight principal bands given in table 1, our absorption observations suggest the existence of five faint bands with approximate wavelengths 403, 450, 590, 628, and 803 mμ. The first of these coincides with 402.5 mμ reported by Parker and Lantz [19], and ascribed to Sm because this is the strongest absorption characteristic of Sm and because Pm naturally transmutes

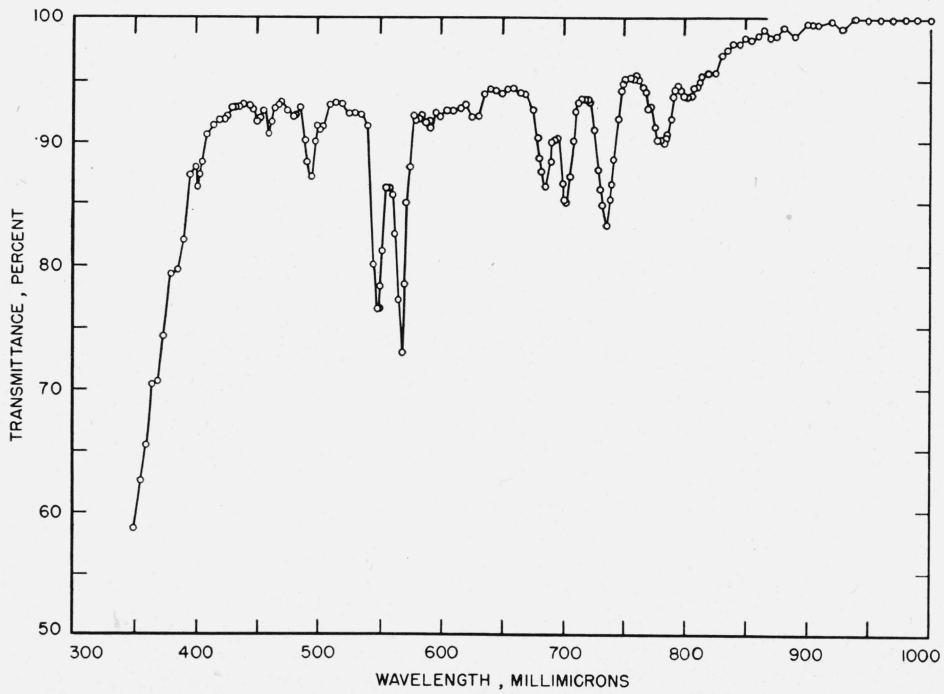

FIGURE 1. *Absorption spectrum of 0.030-molar promethium nitrate solution (10 mg* Pm/*ml).*

to Sm. The faint bands at 450 and 590, although not mentioned by Parker and Lantz [19], are also discernible in their absorption curves, while the last two may correspond to the faintest bands reported by them to have wavelengths 629.0 and 810.0 mμ, respectively. These weak bands probably deserve further investigation to prove that they belong to Pm. These descriptions of the absorption spectrum prove that Pm is a rare earth, resembling Nd or Sm in possessing strong, relatively sharp, bands. These bands are uniquely characteristic of Pm; they cannot be confused with bands belonging to other rare earths, least of all with those reported for illinium [4].

TABLE 1. *Principal absorption bands of promethium*

NBS	Parker and Lantz	
Wavelength	Wavelength	Molar extinction coefficient
mμ	mμ	
459.5±0.5	459.5±0.5	0.7
494.5±0.5	493.5±0.5	1.2
548.5±0.5	548.5±0.5	2.3
568.0±0.5	568.0±0.2	2.3
----------	629.0±1.0	0.5
685.5±0.5	685.0±0.2	1.3
702.5±1.0	702.7±0.3	1.6
735.5±0.5	737.2±0.2	1.9
784.0±1.0	785.0±0.2	1.1
----------	810.0±0.1	0.6

III. Arc and Spark Spectra of Promethium

Because Pm is a typical rare earth, like Nd or Sm, its arc and spark spectra could be expected to consist of thousands of lines of moderate to weak intensity. Furthermore, because all rare earths are easily ionized, the second spectrum is strongly excited in arcs as well as in sparks and the first spectrum can be generated strongly in arcs only if ionization can be restrained in some way. In all complex spectra, especially those of rare-earth elements, it is highly desirable to differentiate the first and second spectrum; otherwise it is hopeless or meaningless to find regularities among the spectral lines. Before making any arc or spark spectrograms of Pm, some preliminary tests were made with Sm to determine if two different excitation conditions afforded by the Applied Research Laboratory Multisource unit, and successfully employed by Meggers and Scribner [23] in separating the first two spectra of Tc, could be applied to rare earths. The answer was no.

Previous experience with arc spectra of rare earths on copper and on carbon electrodes showed that the second spectra were somewhat enhanced in carbon spectrograms, but this method was not applied to Pm because the sample was too small and the cyanogen bands would interfere seriously.

Finally, experiments were made to restrain the ionization in the alternating-current arc by adding sufficient cesium to a rare earth. Trials with pure Sm samples admixed with 20, 10, 5, or 2 percent of Cs showed that the addition of Cs actually weakened both Sm spectra, but Sm II more than Sm I. By comparing relative intensities of Sm lines in spark spectrograms with alternating-current arc spectrograms obtained by adding 5 percent of Cs to the sample, it was indeed possible to distinguish between Sm I and Sm II lines. When the same conditions were imposed on Pm, the results were disappointing; the Pm I lines could not be distinguished from Pm II lines by comparing line intensities in juxtaposed spectrograms made with oscillatory arc and spark discharges, even when 5 percent of Cs was added to the arc sample. It was suspected that these efforts to sort Pm I and Pm II were frustrated by the abundance of common chemical impurities, which probably equalized ionization in all the light sources that were tried.

The light sources consisted of oscillatory arc or spark discharges between ¼-in. copper rods bearing 50 to 400 μg of Pm on clean machined ends. These electrodes were mounted in a stainless-steel cylindrical cell provided with a quartz window at one end and with an air exhuast through a glass-wool filter designed to trap the vaporized Pm for future recovery. Although the first electrodes were circular in cross section, the later ones were machined with rectangular ends about 3 mm wide to reduce lateral fluctuations of the discharge and concentrate more light on the spectrograph slit. After the copper electrodes were cut, a thin layer of wax (one drop of a solution of 0.1 g of Apiezon *M* in 100 ml of petroleum ether) was dried on the machined ends. Then with the aid of a remote control pipette, Pm solution was transferred to the electrodes and dried with an infrared heat lamp. The duration of exposure for spectrum photography was limited to 30 or 40 seconds, because successive use of the same loaded electrodes showed that nearly all of the added material was burned off in this time, and a longer time of exposure only enhanced the spectrum of copper.

Spectrograms were made with a concave grating of 22-feet radius and 15,000 lines per inch. In the first order spectrum the resolving power is nearly 50,000 and the reciprocal linear dispersion about 5 A/mm. A slit width of 22 μ was used.

Three positions of the grating and 20-in. plate holder recorded the spectrum between 2,200 and 9,000 A with successive exposures on three types of photographic plates. The region 2,200 to 4,700 A was photographed on Eastman 103-uv sensitized plates, the region 4,400 to 6,900 A on II F sensitized plates, and 6,500 to 9,000 A on I N hypersensitized plates. In the long-wave region, the ARL Multisource unit strongly excited the spectra of atmospheric nitrogen and oxygen, and the spectrum of Pm was disappointingly weak. For that reason we are restricting this report to observations on Pm spectra between the limits 2,200 and 6,900 A.

Because Pm decays by β^- emission to Sm, a spectrogram of pure Sm was recorded beside each Pm spectrogram. By sliding a slotted diaphragm in front of the slit, a series of adjacent spectrograms was made as follows: iron arc, copper spark, samarium spark on copper, promethium spark on copper, iron arc as shown in figure 2. On some spectrograms, exposures to promethium arc on cop-

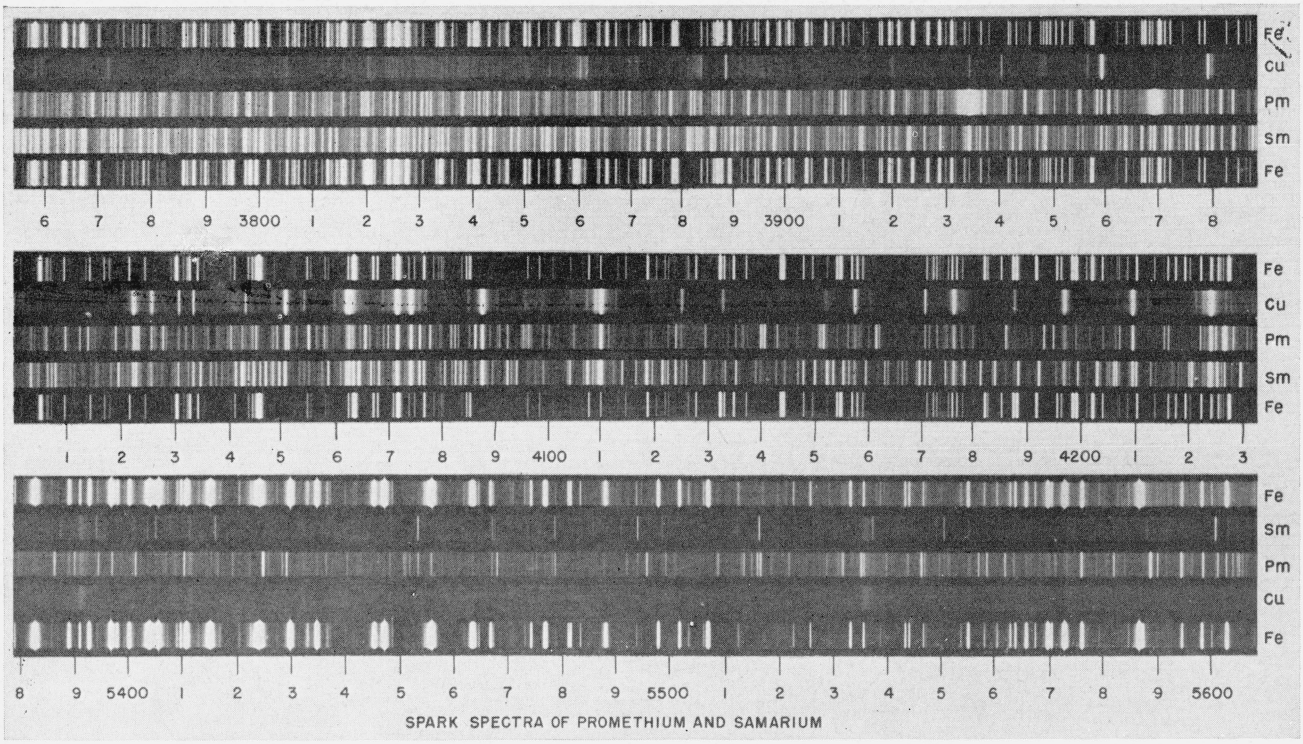

FIGURE 2. *Spark spectra of promethium and samarium.*

per and to copper arc were inserted before the final iron. At least two satisfactory spectrograms were made for each of the first two spectral ranges mentioned above, and the best ones were measured twice. This gave at least six determinations for lines appearing in the overlapping portions of these ranges. The positions of Pm lines relative to iron standards were measured to 0.001 mm with an excellent 50-cm comparator constructed by the Gaertner Scientific Corp. All lines appearing in the Cu plus Pm spectrograms that were not duplicated or masked in the Cu comparison spectra were measured, even though many were easily recognized as impurities. The principal lines of Sm appeared in the Pm spectrograms with about 1 or 2 percent of their intensity in the Sm comparison spectra, and many such lines were measured as internal standards to check the final wavelengths. Incidentally, it appears that accurate measurements of intensity ratios of Pm:Sm lines at intervals of several years could lead to an independent determination of the half life of Pm. These Sm lines are omitted from our Pm table, but a few approximate coincidences are retained because intensity ratios indicate that real Pm lines are present.

Table 2 contains the measured wavelengths and estimated relative intensities of 2,249 new spectral lines believed to belong to Pm atoms and ions. It is most likely that a majority of these lines are characteristic of Pm^+ ions, but some, especially in the visible spectrum, may belong to neutral Pm atoms. Unfortunately, it was not possible with the available sample to differentiate the Pm I and Pm II lines with the light sources employed. Whether or not the impurities in this first sample can be blamed for equalizing excitation in different sources remains an open question. Excepting a trace of Sm, no other rare earths could be detected spectroscopically in this Pm sample, but common chemical impurities were abundant and troublesome. In all, nearly double the number of lines reported in table 2 were measured on Pm spectrograms, but those not reported were identified as belonging to Mg, Ca, Sr, Ba, Li, Na, K, Cr, Mn, Fe, Co, Ni, Si, Zn, Pb, and Al. It is possible that some real Pm lines have been masked by impurity lines, or atmospheric lines, and it is certain that in such a rich spectrum some Pm lines have been obscured by the principal lines of copper, 3248, 3274, 5106, 5153, 5218, 5700 and 5782 A. The agreement of wavelength values derived from different spectrograms, and also the agreement with the wavelengths of impurities, indicates that the values presented in table 2 are rarely uncertain by more than ± 0.02 A.

TABLE 2. *Emission spectra of promethium*

λ=Wavelength; *c*=complex; *d*=double; *h*=hazy; *H*=very hazy; *l*=shaded to longer waves; *s*=shaded to shorter waves; *w*=wide

λ	Intensity	λ	Intensity
6872. 76	2	6661. 25	10
6858. 58	5	6659. 05	40
6857. 21	2	6653. 34	2
6843. 07	2	6652. 50	6
6840. 19	2	6649. 97	8
6837. 08	1	6643. 72	3*h*
6832. 45	3*h*	6639. 55	2*h*
6831. 09	6*h*	6637. 34	2*h*
6824. 06	2	6635. 32	4
6822. 47	1	6635. 07	1
6818. 18	3	6628. 17	1
6811. 68	20	6625. 54	10*h*
6810. 55	2*h*	6623. 14	5*h*
6809. 47	1	6622. 08	3
6802. 95	4*h*+Sm	6614. 45	4*h*
6798. 92	8	6613. 93	5*h*
6798. 25	2*h*	6613. 27	3
6797. 22	2*h*	6598. 11	8
6796. 87	10	6592. 29	10
6793. 56	6	6586. 39	10
6787. 81	2	6576. 03	8
6783. 50	1	6567. 27	10?
6783. 09	10	6558. 48	10*h*
6776. 07	5*h*	6554. 47	4*h*
6774. 06	2*h*	6553. 24	4*h*
6773. 21	2	6550. 58	4
6772. 29	30	6546. 74	1
6771. 00	4*h*	6545. 08	3*h*
6767. 00	1	6544. 33	5*h*
6763. 14	2	6536. 68	6*h*
6762. 01	4	6529. 89	1
6761. 65	3	6529. 49	6
6761. 45	2	6524. 32	3
6758. 91	3	6523. 05	7
6756. 45	20	6522. 03	3
6755. 78	2	6520. 37	5
6755. 11	6	6519. 43	20
6749. 91	5	6518. 18	3*h*
6744. 81	1	6517. 13	3*h*
6742. 30	1	6514. 15	2
6732. 17	4	6509. 74	2
6729. 40	4	6507. 74	2*h*
6727. 93	2*h*	6501. 12	2*h*
6726. 95	8	6490. 36	1*h*
6722. 87	2	6488. 65	1
6720. 30	3	6488. 22	1
6714. 81	5*h*	6475. 93	4
6712. 14	1+Sm	6474. 31	8
6709. 09	2	6469. 91	2*h*
6706. 27	10	6469. 35	1
6698. 82	3	6468. 84	2
6698. 63	4	6467. 36	7
6696. 39	4	6464. 59	2
6692. 65	7	6453. 78	1*h*
6691. 82	3	6452. 20	3
6690. 09	15	6451. 72	1
6686. 2	5*wc*	6450. 98	3*h*
6680. 89	20	6448. 90	2
6668. 94	9	6446. 97	1
6665. 00	2*h*	6446. 05	5

TABLE 2. *Emission spectra of promethium*—Continued

λ	Intensity	λ	Intensity
6443. 27	2*h*	6322. 39	2*hd*
6442. 49	2*h*	6318. 06	2
6440. 74	2*h*	6316. 04	1
6438. 04	4	6314. 20	10
6436. 57	10	6311. 45	2
6433. 98	1	6309. 68	2
6430. 92	5	6306. 77	3
6429. 65	10	6306. 56	5
6428. 61	6	6304. 17	5*l*
6427. 85	2	6302. 42	2
6426. 00	8	6300. 67	2
6425. 71	4	6298. 03	3
6424. 85	5	6294. 20	2
6422. 59	5	6289. 93	8+Sm
6420. 83	6	6287. 31	1
6418. 53	3	6286. 01	2*h*
6416. 25	2	6284. 03	1
6415. 98	5	6280. 65	2*h*
6415. 23	1	6274. 51	4
6413. 15	4	6266. 71	1
6412. 63	2	6264. 54	1*h*
6411. 46	1*h*	6263. 25	10
6409. 99	4	6261. 1	3*Hl*
6401. 53	2	6259. 29	1
6401. 28	6	6257. 94	2
6400. 89	3	6257. 43	2
6399. 87	2*h*	6252. 85	1
6395. 86	1	6251. 64	4*c*
6390. 22	2	6248. 83	3*h*[1]
6389. 51	2	6244. 52	1
6386. 52	4	6242. 95	3*h*
6383. 74	6	6236. 88	1*h*
6383. 48	3*h*	6234. 32	4*hc*
6379. 89	2	6232. 06	3*hc*
6378. 98	1	6230. 42	2*h*
6378. 24	4	6228. 75	2*h*
6375. 88	2	6226. 58	1
6375. 17	2	6225. 68	2
6373. 62	2	6224. 38	3*h*
6372. 18	2*h*	6223. 01	1
6371. 22	1*h*	6220. 24	1
6369. 47	1	6219. 00	1
6366. 00	5*ld*	6217. 10	1
6360. 57	3	6215. 96	1
6359. 14	2*h*	6211. 97	2*h*
6356. 57	1	6208. 91	20
6356. 01	4	6207. 47	2
6352. 74	1	6206. 53	2*h*
6351. 22	2*h*	6202. 80	2*h*
6348. 79	2*h*	6201. 82	6
6343. 63	2*h*	6201. 13	2
6341. 52	3*c*	6199. 44	1*h*
6339. 14	1	6194. 82	2*h*
6334. 02	6*c*	6191. 81	3
6333. 55	1	6188. 77	1
6332. 99	3	6186. 31	1
6329. 32	3	6184. 52	10
6326. 93	3	6183. 63	2*h*
6323. 74	2*h*	6180. 01	2
6323. 55	3*h*	6179. 36	3*h*

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
6177. 85	3*h*	6027. 11	20
6175. 35	3	6025. 70	8*c*
6173. 41	2*h*	6022. 74	4
6171. 74	2*h*	6022. 12	2*h*
6159. 53	10	6018. 29	5
6156. 14	3*c*	6015. 15	1
6152. 00	4*hc*	6014. 16	1
6151. 70	4	6013. 68	1
6147. 65	1*h*	6012. 73	3*hc*
6134. 64	2*h*	6009. 09	2*h*
6133. 99	2*h*	6008. 04	3
6133. 35	1*h*	6006. 10	1
6132. 05	1	6003. 50	4
6126. 79	3	5997. 74	1
6121. 08	3	5997. 09	15+Ba
6120. 70	1*h*	5996. 03	1
6119. 38	2	5995. 24	1*h*
6117. 35	3	5994. 24	1
6116. 67	2	5992. 44	4
6114. 90	10	5988. 59	2*hl*
6109. 72	2	5987. 13	10*c*
6107. 27	1*h*	5983. 06	3*c*
6101. 10	6	5982. 40	4*c*
6100. 16	6	5981. 71	1
6097. 84	2*h*	5979. 09	3*d*
6097. 23	3	5978. 41	2
6096. 04	2*h*	5977. 44	1*h*
6094. 69	2	5974. 98	1*h*
6094. 11	3*h*	5973. 52	1*h*
6090. 41	2	5972. 19	2
6089. 27	1*h*	5967. 83	6*h*
6087. 41	1	5967. 17	1
6085. 41	20	5963. 00	15
6081. 62	2*h*	5960. 08	10*c*
6079. 64	3	5959. 15	1
6076. 40	10	5956. 65	1
6074. 68	7*dc*	5956. 39	3
6073. 81	4	5955. 33	3
6072. 92	3*c*	5954. 48	2
6070. 09	3+Sm	5950. 82	7
6069. 84	5*c*	5949. 37	1
6069. 00	1	5946. 49	40*c*
6067. 52	1	5943. 29	1*H*
6067. 00	10*c*	5941. 94	3
6060. 96	2*h*	5941. 60	1
6060. 45	1	5939. 62	2
6055. 20	1	5937. 21	1
6054. 31	2	5935. 90	4
6053. 85	2	5934. 99	2*h*
6053. 29	4	5934. 33	2*h*
6052. 57	15*c*	5933. 09	2
6050. 15	8*c*	5930. 85	1
6047. 22	4*c*	5928. 03	3*c*
6043. 33	2*h*	5927. 72	4*c*
6042. 07	2	5927. 17	25*c*
6039. 71	1*h*	5925. 87	1
6038. 31	5*hc*	5925. 08	1
6030. 08	7	5923. 84	2*c*
6028. 69	1*h*	5922. 02	1
6027. 86	3*c*	5917. 39	6*c*

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
5915. 73	1	5806. 29	5
5914. 89	2	5804. 13	2
5910. 62	1	5802. 01	1
5907. 42	1	5801. 85	1*h*
5905. 87	1*H*	5801. 38	1
5905. 48	1	5800. 91	1*h*
5904. 67	4	5800. 69	2*h*
5904. 16	4	5798. 26	1
5901. 87	8	5794. 59	1*h*
5899. 76	15	5794. 07	1*h*
5884. 85	1	5793. 32	3
5882. 16	1	5792. 17	1
5881. 24	1	5790. 78	1*h*
5880. 58	1	5789. 30	2
5878. 76	10*c*	5789. 15	3
5876. 51	1*H*	5788. 89	6
5875. 31	20*c*	5785. 74	1
5873. 09	4*h*	5784. 70	1
5872. 56	1*h*	5783. 50	2
5869. 51	1*h*	5780. 75	4
5868. 79	30*c*	5778. 19	3
5868. 14	1	5777. 18	3
5867. 72	2	5774. 03	2
5866. 13	2	5773. 68	3
5863. 65	3	5772. 19	10*c*
5862. 80	2*h*	5769. 32	3
5862. 05	4	5769. 12	2
5861. 16	1*H*	5768. 11	20
5853. 04	1*h*	5766. 92	2
5849. 64	3	5765. 73	2
5844. 67	1	5765. 36	6*c*
5841. 71	1	5764. 73	1*h*
5841. 00	8	5760. 86	3
5837. 32	1	5758. 15	2
5836. 65	1	5756. 80	1*h*
5835. 70	4	5755. 82	2*h*
5834. 96	5*c*	5754. 91	1*h*
5833. 58	1*h*	5753. 72	5*c*
5833. 05	3*c*	5752. 46	1
5831. 54	1	5751. 74	2
5830. 23	1	5749. 75	1
5827. 84	8*c*	5748. 98	1*h*
5825. 90	2	5747. 96	3*c*
5825. 60	1	5747. 36	3
5823. 91	50	5747. 12	4
5823. 52	3*h*	5746. 80	2
5822. 39	1	5746. 17	3*h*
5822. 03	1	5744. 29	1
5821. 72	1	5742. 39	1
5820. 83	2	5740. 81	5
5820. 03	1	5739. 74	2
5818. 31	1	5735. 58	1
5817. 92	1	5734. 75	2
5816. 04	2*h*	5733. 48	1
5815. 92	1	5731. 52	2
5813. 65	1*h*	5730. 79	2
5812. 82	2*h*	5729. 83	2*h*
5812. 01	2*h*	5726. 41	1*h*
5810. 14	6	5725. 05	1
5809. 85	3	5723. 41	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
5721. 01	3*cd*	5604. 92	3*h*
5719. 38	3	5604. 07	3
5718. 46	1*h*	5596. 58	2*hd*
5714. 62	2	5596. 22	1
5713. 00	2*hd*	5595. 74	2*hc*
5712. 42	8*s*	5594. 87	2*h*
5709. 65	2*h*	5591. 75	2
5708. 83	4	5584. 08	2
5704. 92	1*H*	5582. 62	1*H*
5704. 32	1	5580. 68	1*h*
5704. 12	1*h*	5578. 82	3
5702. 00	1	5576. 46	1
5699. 64	2	5576. 01	80
5697. 06	2*cd*	5573. 31	2
5693. 28	1	5572. 87	1
5692. 01	1	5571. 03	4*c*
5691. 00	1	5569. 72	1
5687. 34	1	5569. 27	1*h*
5686. 95	2*h*	5566. 56	1
5685. 99	2	5565. 64	2
5684. 92	1*h*	5563. 32	4
5681. 37	2	5561. 72	20
5679. 88	1	5560. 15	1*h*
5676. 23	2	5558. 38	15
5674. 20	1	5557. 61	2*h*
5673. 23	2	5556. 86	12
5672. 57	1*h*	5555. 21	1*h*
5671. 01	2	5551. 28	2*h*
5670. 54	1	5549. 47	2
5669. 45	1	5546. 76	5
5668. 72	3	5546. 09	80
5667. 79	2*h*	5543. 70	3*h*
5664. 95	1*h*	5540. 69	1
5662. 36	1	5539. 75	3
5660. 16	2	5539. 09	1
5659. 70	2	5537. 35	1
5657. 55	4*c*	5534. 95	18
5655. 83	1	5531. 61	8
5655. 04	2	5531. 33	3
5654. 50	3*c*	5530. 70	4*cd*
5651. 04	1	5528. 59	4
5649. 72	6	5528. 01	1*h*
5649. 07	1*h*	5527. 27	1
5645. 31	1	5524. 91	1
5644. 45	1	5524. 12	1
5642. 83	1*h*	5521. 61	5
5641. 28	20	5520. 84	1
5639. 46	4	5518. 22	3
5638. 32	5	5516. 41	10
5636. 00	1	5515. 79	8
5635. 36	1	5514. 75	3
5634. 45	7	5513. 30	6*c*
5634. 29	1	5510. 21	1
5632. 41	1	5508. 53	4
5630. 72	1	5508. 26	2*c*
5616. 74	2	5500. 84	1
5610. 90	7	5500. 49	2
5606. 50	1*h*	5498. 86	4
5605. 84	3*c*	5496. 21	1
5605. 25	3	5495. 44	15

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
5491. 65	5*wc*	5390. 48	5
5487. 52	2	5389. 46	2
5478. 36	4	5386. 99	4
5477. 77	2	5386. 79	5
5476. 45	2	5382. 91	1
5474. 85	2	5380. 77	1*wh*
5474. 16	1	5380. 29	2
5473. 84	1	5374. 27	1
5473. 29	1*h*	5371. 34	4
5472. 14	1*h*	5370. 63	1
5471. 30	1	5369. 06	1*h*
5470. 02	1*c*	5365. 87	4
5469. 45	1*h*	5361. 13	2*w*
5468. 75	1	5364. 65	1
5468. 36	1	5362. 80	3
5467. 62	10	5358. 65	1*h*
5466. 64	3*h*	5357. 67	1*h*
5464. 19	1*h*	5354. 56	6*sd*
5463. 04	2*wc*	5352. 28	1*h*
5462. 27	1	5351. 33	1*h*
5457. 45	2	5351. 05	1
5456. 98	1*h*	5348. 26	8
5456. 10	1*h*	5347. 03	2
5455. 50	4	5346. 12	8
5453. 03	5+*Sm*	5344. 83	1
5451. 52	3	5344. 40	2
5450. 81	3	5342. 43	1
5450. 45	4*cd*	5341. 29	2+*Sm*
5447. 81	2	5339. 18	2*h*
5445. 79	1	5335. 55	2*h*
5442. 44	1	5334. 73	2*h*
5441. 93	1	5334. 02	2
5440. 01	3	5333. 47	1*h*
5437. 38	1	5331. 53	1*h*
5436. 21	3	5330. 50	1
5434. 54	2	5327. 89	2*wh*
5431. 26	1	5320. 84	1*h*
5429. 03	15	5319. 80	8
5428. 21	4	5318. 58	15
5425. 66	1	5314. 24	4*hc*
5424. 76	18	5311. 78	1
5424. 52	20	5310. 63	1
5422. 32	2*h*	5308. 84	10
5421. 50	1	5305. 25	1
5420. 33	1*h*	5302. 01	8
5419. 14	3	5299. 89	2
5416. 54	2*h*	5296. 96	1
5415. 29	2	5295. 09	2
5414. 58	1	5294. 62	1
5413. 71	1	5293. 91	20
5411. 30	2*h*	5291. 08	1
5410. 43	20	5290. 79	1
5408. 79	2	5289. 41	1
5407. 06	2*c*	5287. 00	1*h*
5406. 58	2	5281. 40	4
5402. 54	1	5280. 42	1
5401. 60	7	5279. 51	1*h*
5398. 98	1	5277. 26	1
5397. 32	8	5276. 45	2
5394. 83	6	5274. 93	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
5270. 62	50	5119. 83	1
5263. 10	1	5119. 36	1
5262. 40	15	5116. 92	2*w*
5257. 50	2	5111. 56	1
5257. 09	4	5107. 87	2
5251. 84	5	5100. 73	5
5250. 19	1	5097. 26	15
5249. 27	1	5096. 14	1
5246. 93	2*h*	5094. 80	6
5246. 31	40	5092. 35	1
5242. 35	2*h*	5089. 32	15
5238. 95	1	5085. 79	4
5236. 64	30	5081. 34	1
5236. 25	50	5080. 50	15
5229. 35	1	5074. 99	2
5228. 53	1	5072. 12	1
5225. 10	25	5067. 32	10
5224. 84	8	5060. 68	1
5215. 95	15	5058. 29	15
5214. 67	1	5057. 54	1
5208. 08	50	5054. 93	1
5203. 76	1	5050. 70	1
5203. 24	1	5045. 28	6
5196. 19	1	5044. 84	2*h*
5194. 03	30	5044. 30	5+Sm
5192. 36	1	5039. 58	1
5189. 81	1	5035. 30	1
5188. 16	2	5030. 80	2
5187. 57	1	5028. 75	1
5185. 92	1	5026. 69	1
5185. 01	10	5021. 66	3*c*
5180. 19	1	5016. 14	10
5173. 26	2*h*	5015. 05	2
5171. 57	50	5010. 33	4
5170. 77	1	5007. 50	1
5169. 69	30	5005. 79	1
5165. 65	2	4999. 14	1
5165. 32	3*hc*	4998. 25	2
5164. 62	2	4997. 10	15
5162. 79	2	4993. 63	1
5161. 12	1	4990. 31	2
5158. 74	2	4987. 18	1
5153. 82	40	4984. 47	3
5150. 98	3	4982. 91	1
5150. 30	2	4979. 53	2
5148. 93	1	4975. 36	8
5147. 58	1	4974. 74	3
5146. 27	10	4974. 27	2
5145. 11	8	4972. 44	1
5142. 52	1*h*	4971. 41	10
5140. 53	1*h*	4959. 45	8
5136. 22	1*hc*	4956. 84	1
5135. 38	1	4954. 04	3
5134. 28	1	4950. 80	1
5129. 68	1	4946. 89	3
5127. 33	15	4945. 04	2*d*
5125. 39	2	4943. 28	8
5122. 48	1	4939. 11	1
5121. 44	25	4937. 21	1
5120. 60	4*c*	4932. 99	5

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
4918. 29	1	4728. 65	2
4917. 20	1	4728. 37	4
4915. 23	2	4726. 32	1
4913. 18	5*d*	4724. 21	1
4904. 27	1	4720. 98	1
4903. 07	1	4718. 64	1
4902. 05	1	4716. 99	2
4901. 25	2	4714. 90	1
4900. 28	2	4710. 76	2
4892. 51	5	4707. 02	3
4890. 62	2	4703. 93	1
4887. 01	1	4703. 21	1
4882. 60	1	4702. 53	1
4872. 43	2	4697. 48	2
4870. 41	2	4696. 80	1
4869. 80	1	4695. 71	3
4868. 33	1	4694. 64	1
4866. 23	2	4694. 26	1*h*
4865. 72	4	4692. 80	1
4865. 32	3	4691. 02	1
4860. 73	10	4690. 48	1
4858. 89	1	4682. 93	3
4852. 72	2	4682. 24	1
4847. 76	2	4678. 14	1
4846. 59	4	4677. 93	1
4840. 69	5	4675. 98	1
4837. 66	5	4675. 47	1
4831. 14	1	4671. 24	2
4829. 70	2	4666. 85	2*hd*
4829. 48	5*d*	4665. 20	4
4827. 68	1	4663. 47	2
4824. 15	8*c*	4663. 17	1
4813. 44	2	4661. 48	2*h*
4811. 94	5	4660. 76	1
4810. 21	3	4658. 31	2
4809. 54	3	4656. 85	1
4801. 33	7	4656. 10	2
4799. 86	3	4653. 39	2
4798. 97	8	4653. 23	2
4798. 09	3	4651. 90	3*h*
4789. 51	1	4649. 51	1+Sm
4789. 26	4	4647. 03	1
4781. 29	3	4645. 04	1
4779. 36	1	4643. 75	1
4773. 46	6	4643. 35	2
4769. 86	2	4641. 02	2*d*
4764. 46	2	4640. 14	1
4762. 57	15	4638. 34	2
4759. 00	10	4637. 47	3
4758. 36	2	4635. 81	1
4757. 72	2	4633. 46	2
4753. 80	1	4632. 79	2
4745. 12	2	4632. 03	1
4744. 84	1	4630. 17	1
4739. 76	1	4628. 70	7
4739. 08	10	4627. 59	1
4738. 23	1	4625. 97	1
4737. 97	1	4625. 29	3
4734. 26	5	4624. 42	1
4732. 79	1	4623. 68	3

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
4623. 11	1*h*	4511. 57	2
4621. 57	1	4509. 37	10+Cu
4620. 30	1	4502. 12	1
4619. 75	1	4500. 14	60
4618. 61	1*h*	4498. 24	3
4617. 01	2	4496. 82	3
4615. 85	10	4492. 05	25
4611. 96	1	4490. 45	1*h*
4609. 83	1	4489. 56	1
4607. 76	1	4485. 02	1
4605. 70	3	4481. 58	2
4602. 07	3	4479. 35	1
4601. 83	1	4477. 46	20
4601. 09	1*h*	4475. 96	1
4600. 24	1	4475. 31	5
4598. 92	2*h*	4475. 05	7
4597. 55	1	4473. 23	30
4591. 29	1	4471. 50	20
4590. 23	3	4470. 61	2
4589. 42	1+Sm	4468. 14	1
4589. 13	1	4465. 80	5*h*
4586. 29	3	4464. 53	2
4585. 49	1	4461. 55	1
4583. 31	1	4459. 95	20
4579. 48	1	4458. 94	5
4578. 60	5	4456. 87	1
4575. 27	2	4453. 96	80
4573. 99	1	4452. 84	10+Sm
4573. 05	1	4451. 81	5
4572. 15	1	4451. 05	1
4570. 37	1	4450. 65	1
4569. 46	2*h*	4450. 26	1
4568. 14	1	4446. 90	60
4565. 58	1	4445. 41	50
4564. 85	10	4443. 67	15
4563. 42	1	4438. 69	1
4560. 35	2	4432. 51	40
4559. 21	1	4430. 58	2
4558. 58	3	4427. 17	1
4557. 02	1	4425. 11	3
4556. 60	4	4423. 99	5
4556. 01	1	4422. 28	1
4549. 80	1	4421. 15	15+Sm
4547. 54	1	4419. 35	10+Sm
4546. 00	1	4418. 15	8
4545. 41	4*h*	4417. 98	100
4538. 51	3	4417. 63	2
4535. 69	3*d*	4414. 09	10
4534. 15	1	4412. 48	1
4531. 70	1	4411. 77	4*d*
4529. 20	80	4406. 73	1
4527. 68	2	4404. 78	1
4526. 07	1	4404. 26	10
4525. 61	1	4403. 07	1+Sm
4525. 19	60	4402. 31	4
4522. 65	8	4401. 97	1
4519. 08	3	4401. 58	1
4517. 92	1	4400. 29	2
4514. 63	2	4400. 17	2
4513. 54	10	4396. 83	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
4396 26	1*h*	4310. 36	3
4391. 62	1	4306. 11	3
4389. 68	4	4305. 49	5
4389. 25	2	4303. 86	20
4388. 76	20	4303. 51	5
4388. 51	2	4300. 63	2
4387. 05	5	4300. 32	1
4381. 87	20	4298. 65	1
4381. 17	18+Ca	4295. 70	1
4374. 90	2	4295. 11	7
4374. 41	1	4294. 12	3
4373. 82	1	4293. 38	4
4372. 88	6	4291. 78	2
4372. 52	4	4288. 77	2
4369. 87	1	4287. 78	6
4369. 63	2	4287. 56	1
4367. 23	3	4284. 59	2
4365. 99	5*l*	4281. 97	2
4365. 07	10	4279. 07	1*h*
4364. 58	1	4278. 48	1*h*
4363. 87	1*h*	4277. 83	1
4362. 06	4+Sm	4277. 52	10
4360. 79	5*h*	4275. 54	4
4359. 90	4*h*	4273. 29	2
4359. 49	1	4270. 83	1
4356. 97	2	4270. 30	2*h*
4356. 59	2	4265. 32	1
4354. 16	6	4264. 59	3
4353. 48	1*h*	4264. 30	1
4349. 27	1	4263. 33	3
4348. 74	1	4260. 23	3
4346. 92	1	4259. 12	4
4346. 35	3	4254. 93	4
4342. 11	30	4254. 78	6
4340. 52	15	4254. 13	1
4337. 45	20	4249. 38	3*w*
4336. 53	30	4247. 10	1
4334. 87	2	4242. 98	2
4334. 64	2	4241. 93	1
4333. 73	1	4240. 29	5
4333. 40	3	4239. 98	3
4332. 04	20	4238. 26	20*h*
4330. 60	5	4234. 14	15
4330. 06	10	4233. 39	4
4329. 59	1	4231. 74	3
4328. 29	6	4231. 41	1
4327. 41	2	4230. 87	4
4325. 88	25	4228. 74	2
4325. 04	1	4228. 35	10
4324. 84	1	4226. 25	3
4323. 86	1	4225. 06	8
4320. 63	1	4223. 02	2
4319. 46	1	4222. 15	20
4317. 82	1	4219. 08	2
4317. 28	2*h*	4218. 24	1
4315. 65	2	4216. 30	10
4315. 36	10	4214. 61	1
4314. 20	1	4213. 96	2
4313. 12	5	4210. 97	2
4311. 57	2*h*	4208. 42	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
4207. 63	1	4129. 33	4
4207. 21	10	4128. 26	1
4206. 37	2	4127. 83	1
4205. 39	1	4125. 46	1
4204. 10	5	4124. 89	2
4201. 56	3	4124. 63	1
4194. 70	20	4123. 97	15+Sm
4192. 92	30	4122. 45	5
4190. 63	3	4119. 97	2
4189. 49	1	4119. 36	2
4188. 96	2	4119. 16	1
4186. 03	2	4116. 16	2*h*
4185. 74	20	4114. 34	1
4180. 06	1	4112. 19	1
4179. 66	5	4111. 32	3
4179. 31	1	4109. 62	2
4178. 93	2	4108. 73	2
4177. 99	1	4108. 27	1
4177. 47	4	4104. 83	6
4174. 74	3	4101. 76	2
4174. 06	1	4100. 55	1
4172. 79	7	4100. 03	5
4171. 46	6	4098. 87	4*h*
4169. 18	1	4096. 72	2*h*
4168. 33	1	4096. 40	2
4167. 69	1	4096. 19	5
4162. 61	1	4095. 72	2*d*
4162. 03	6	4095. 33	3
4161. 50	15	4095. 11	3
4161. 21	10	4094. 76	2
4159. 99	4	4092. 25	3+Sm
4158. 57	2	4090. 79	5
4158. 20	2	4090. 37	3
4157. 45	1	4088. 95	3
4156. 90	1	4086. 10	50*w*
4156. 07	5	4085. 10	3*h*
4155. 67	1	4083. 07	6
4154. 06	3	4082. 49	10
4151. 60	10	4081. 74	10*d*
4151. 40	8	4079. 91	2
4151. 04	3	4079. 56	3
4150. 74	3	4078. 84	2
4149. 45	2	4078. 30	1
4147. 43	1	4075. 85	60
4146. 54	3*l*	4075. 06	2
4143. 85	1	4073. 60	1
4142. 87	10	4070. 48	1
4142. 33	2	4069. 90	10
4140. 46	25*d*	4069. 08	5
4140. 08	3	4067. 92	3
4139. 72	15	4066. 45	5
4137. 98	1	4065. 90	3
4137. 26	2	4065. 65	15
4136. 48	4	4065. 36	2
4136. 16	3	4064. 79	2
4135. 11	9	4063. 27	1
4133. 66	3	4060. 66	2
4131. 87	1*h*	4060. 32	2
4131. 15	1*h*	4059. 72	4
4129. 53	2	4058. 61	3

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
4058. 28	1	4000. 83	1
4058. 07	6	4000. 39	1
4057. 07	2	3998. 96	100
4056. 64	3*d*	3997. 83	3
4056. 46	2	3996. 71	3
4055. 20	60*l*	3995. 05	30+N
4053. 63	1	3992. 99	5
4052. 93	4	3987. 90	10
4052. 00	1	3987. 41	1+Sm
4051. 50	30	3987. 10	1
4049. 36	7	3986. 09	2*h*
4048. 55	3	3985. 73	3
4048. 22	2	3983. 71	1
4046. 49	2*h*	3983. 10	10
4045. 37	20	3982. 81	3
4044. 75	4	3982. 23	3
4044. 49	1	3980. 73	50*l*
4042. 89	3+Sm	3980. 41	2
4042. 00	2	3979. 38	2
4040. 74	15*d*	3978. 12	3
4040. 07	4	3976. 98	3*d*
4039. 47	1	3975. 65	4
4038. 94	1	3974. 95	2
4038. 69	1	3974. 38	1
4038. 17	3	3973. 49	5
4036. 48	5	3973. 18	3
4035. 93	2	3972. 63	1
4034. 26	1	3972. 13	6
4032. 45	7	3969. 61	2
4029. 98	1	3965. 64	2
4029. 46	1	3964. 59	1
4028. 84	5*h*	3963. 82	1
4028. 20	25	3961. 98	1
4027. 79	2*h*	3961. 07	2*h*
4026. 98	2	3959. 96	6
4026. 60	4	3959. 74	7
4026. 00	10	3957. 74	100
4023. 70	15	3957. 18	1*h*
4023. 28	5	3955. 88	1
4022. 90	8	3954. 61	3
4021. 75	1	3954. 29	8
4021. 34	5*l*	3953. 97	1
4019. 34	20	3952. 91	2
4018. 68	3	3952. 13	6
4016. 78	1	3950. 65	1*h*
4016. 33	2	3949. 69	10
4015. 54	3	3948. 50	2
4015. 08	1	3947. 79	1+Sm
4014. 81	1	3947. 22	15
4014. 20	25	3946. 85	10
4012. 71	20	3945. 53	1
4010. 55	2	3944. 23	30*h*
4009. 97	50	3943. 95	3+Al
4006. 48	3	3941. 35	2*d*
4006. 31	2	3940. 60	10
4005. 94	4	3940. 13	8
4004. 96	1	3939. 23	1
4004. 22	2	3938. 35	2+Cr
4003. 64	3	3936. 47	80*l*
4002. 86	1	3935. 46	2

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3931. 96	3	3877. 24	3
3931. 55	10	3876. 48	2
3929. 50	1*h*	3876. 15	2
3928. 55	2	3875. 50	2+Sm
3927. 88	2	3875. 34	8
3927. 75	2	3874. 76	2*h*
3926. 81	1*h*	3872. 69	3
3925. 82	2*h*	3871. 84	5
3925. 26	4	3870. 79	2*h*
3924. 99	1	3869. 83	7
3924. 44	2*h*	3869. 62	4
3923. 81	1	3868. 55	6*l*
3922. 33	2	3867. 94	8
3921. 80	15	3866. 79	1
3921. 39	3*h*	3866. 33	4
3919. 09	100*l*	3864. 24	4
3918. 45	2	3863. 62	12*d*
3917. 12	7	3863. 16	8
3915. 94	2	3862. 72	4
3915. 69	1	3861. 15	1
3913. 76	2	3860. 88	1
3913. 48	4	3860. 20	1
3911. 66	1	3857. 98	3*d*
3911. 13	2	3856. 90	1
3910. 76	1	3856. 41	2*h*
3910. 26	100	3854. 62	4*h*
3909. 51	25	3853. 90	3
3907. 83	8	3852. 15	5
3907. 25	5	3850. 84	2*h*
3906. 35	2	3850. 57	2
3904. 40	3	3850. 08	2
3901. 93	3	3849. 46	1
3901. 22	1	3848. 74	15
3900. 99	1	3847. 29	3
3900. 55	1	3846. 30	2*h*
3899. 78	40	3845. 36	25
3899. 36	4	3845. 00	1
3897. 62	2	3844. 33	4*d*
3897. 12	3	3842. 93	40
3896. 35	2*h*	3842. 35	3
3895. 74	6*h*	3842. 22	2
3894. 46	2	3841. 58	2
3894. 11	4*l*	3841. 40	2
3892. 16	100	3841. 21	2
3891. 40	2	3840. 52	8
3889. 71	2	3839. 79	2
3887. 86	1	3835. 76	4
3887. 35	5	3835. 22	3
3886. 56	15	3831. 53	15*d*+Sm
3885. 99	3	3830. 73	9
3885. 69	2	3830. 46	8
3884. 66	2	3829. 08	5
3884. 14	1	3828. 34	8
3883. 05	1	3827. 41	2
3882. 07	10	3825. 90	5+Fe
3881. 37	18*d*+Sm	3824. 83	10
3880. 03	1	3823. 52	8+Cr
3879. 52	1	3823. 00	1
3878. 77	2	3822. 68	2
3877. 63	80*c*	3821. 44	4

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3820. 51	30	3779. 62	2*h*
3820. 07	5	3778. 75	6*l*
3819. 62	5	3777. 35	3
3819. 26	20	3777. 13	5
3818. 26	2*h*	3776. 62	10*h*
3817. 74	1	3776. 02	5
3817. 31	4	3775. 65	6
3816. 36	1	3775. 03	4
3815. 82	10	3774. 58	10*h*
3815. 33	2	3774. 05	3
3813. 73	10	3773. 01	4*d*
3812. 70	2	3772. 61	2+Sm
3812. 36	3	3772. 41	1
3811. 99	2	3771. 98	12
3811. 54	2	3770. 97	9
3811. 33	1	3769. 21	4
3810. 74	2	3768. 97	20
3810. 27	7*h*	3768. 51	2
3810. 05	2	3768. 15	3
3809. 04	5	3767. 49	5
3808. 42	1	3765. 03	1
3806. 92	2*w*	3764. 92	2
3806. 55	1	3764. 62	4
3806. 06	25	3764. 10	3
3805. 78	2	3763. 46	7
3805. 17	1*h*	3762. 32	3
3803. 61	1	3761. 58	3
3802. 99	3*d*	3759. 55	4*h*
3802. 48	15	3758. 98	3*h*
3802. 28	7	3758. 37	5
3802. 08	2	3757. 85	2
3801. 75	1	3756. 55	2+Sm
3801. 31	1	3755. 36	3*d*
3800. 68	2	3754. 88	4*d*+Sm
3800. 30	3	3754. 47	3*h*
3799. 49	5	3753. 76	10*d*
3798. 39	10*h*	3753. 25	10
3798. 17	15	3752. 45	1
3797. 66	2	3751. 59	6
3795. 66	40	3750. 64	1*h*
3794. 54	4	3750. 08	50
3793. 60	3	3748. 54	4
3792. 73	1	3747. 64	3+Sm
3791. 20	15	3747. 10	30
3789. 53	4	3745. 86	50
3788. 46	3	3744. 36	1
3787. 60	1	3743. 90	4*d*+Cr
3787. 33	3	3743. 42	4
3786. 07	2*d*	3742. 51	30
3785. 29	1	3741. 98	2
3785. 03	1	3741. 40	4
3784. 71	4	3740. 56	3
3784. 20	6	3739. 81	2
3783. 82	3	3739. 44	2
3782. 99	1	3735. 53	2
3782. 39	5	3734. 31	10
3781. 98	2*h*	3733. 62	1*h*
3781. 57	6	3733. 03	3
3781. 38	2	3732. 79	3
3780. 40	3	3732. 51	10

TABLE 2 *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3730. 46	5*h*	3673. 08	4
3728. 97	2	3670. 02	1
3728. 26	10*d*	3669. 86	6
3727. 79	4	3669. 11	1*h*
3727. 11	2	3668. 47	1
3725. 62	1*h*	3667. 31	7
3724. 87	6+Sm	3667. 04	3
3723. 11	10	3666. 26	10
3722. 71	1	3665. 50	9
3721. 96	8	3664. 94	3
3721. 72	20	3664. 57	1
3719. 62	1	3662. 59	2
3719. 35	2	3661. 08	2
3718. 88	10+Sm	3660. 71	3
3718. 39	1	3660. 54	3
3715. 73	20	3660. 03	4
3714. 54	2	3659. 39	30
3713. 60	1	3658. 63	2
3713. 28	2*h*	3658. 40	10
3712. 59	3	3658. 04	4
3711. 72	80	3657. 59	8
3709. 02	2	3657. 08	2
3708. 34	15*sd*	3655. 80	8
3706. 68	2*h*	3654. 87	2
3705. 22	2*h*	3653. 78	2
3704. 90	1	3652. 13	8
3704. 53	15	3651. 76	2
3704. 21	2	3651. 25	10
3702. 64	40	3650. 54	1
3702. 38	4	3649. 98	10
3701. 65	4	3648. 75	2
3699. 00	15	3648. 35	2
3698. 39	4	3647. 72	2
3697. 50	30	3647. 23	5
3695. 70	1	3646. 29	3
3694. 78	10	3644. 99	2
3693. 49	1	3643. 84	2*h*
3692. 52	30	3643. 58	2*h*
3691. 70	10	3642. 50	1
3691. 11	5	3642. 26	4
3689. 78	40	3641. 65	10+Sm
3689. 47	7	3641. 22	1
3688. 76	1	3640. 74	3*s*
3687. 65	20	3637. 40	2
3687. 26	10	3636. 96	2
3686. 77	8	3636. 48	1
3685. 62	3	3634. 26	30+Sm
3685. 41	5	3632. 25	4*d*
3684. 43	1	3630. 86	3
3683. 67	6	3629. 85	20
3681. 73	6+Sm	3628. 53	3
3680. 89	4	3628. 03	1
3680. 41	10	3626. 28	3
3679. 59	3*h*	3625. 84	1
3679. 14	3	3625. 31	1*h*
3678. 63	18	3622. 94	3*h*
3678. 49	20	3622. 28	5
3675. 86	3	3621. 79	4
3675. 16	1	3620. 90	2
3673. 79	3*h*	3620. 14	15

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3619. 19	1	3574. 52	3
3619. 02	2	3573. 86	4
3618. 13	3	3572. 99	5
3617. 95	1	3572. 45	1
3617. 52	2*d*	3571. 46	1
3615. 58	1	3570. 85	1
3613. 86	2	3570. 54	1
3613. 29	15	3569. 75	2
3612. 15	1	3569. 25	1
3611. 80	6	3569. 02	2
3611. 21	4*d*	3568. 70	1
3610. 74	20	3567. 77	2
3610. 21	4	3567. 01	2
3608. 59	1	3566. 05	1
3608. 09	3	3565. 65	1
3607. 79	2	3565. 32	20
3607. 00	8	3562. 99	8
3606. 73	1	3562. 13	7
3606. 46	1	3561. 62	6
3605. 86	3	3560. 11	1*h*
3604. 09	8	3559. 47	10
3602. 75	2*d*	3557. 83	1
3602. 33	2	3557. 13	3
3601. 43	2	3556. 95	1
3600. 56	5	3555. 89	1*h*
3600. 16	1	3554. 60	1
3598. 79	1	3553. 82	2
3598. 58	2	3553. 61	4
3598. 34	2	3552. 81	1
3598. 26	2	3551. 97	2
3597. 87	2	3551. 63	2
3596. 20	1	3551. 13	5
3595. 50	1	3550. 38	2
3595. 11	5	3550. 17	2
3594. 20	3	3549. 74	1
3592. 93	3	3548. 97	1
3592. 32	2	3547. 52	1*h*
3591. 94	1	3546. 81	1
3591. 65	3	3546. 59	3*d*
3591. 17	3	3546. 33	1
3589. 98	1	3545. 78	3
3589. 56	3	3544. 91	6*d*
3589. 31	2	3544. 03	5*d*
3588. 44	1	3543. 72	1
3587. 81	2	3541. 70	6
3587. 65	1	3540. 72	1
3587. 10	1*h*	3540. 31	1*h*
3586. 42	1	3539. 99	2*h*
3585. 70	6*d*	3538. 80	4
3583. 90	2	3537. 52	2
3583. 04	4	3536. 64	4
3582. 41	3	3532. 26	1
3581. 51	2	3528. 84	2
3580. 11	15	3528. 47	3
3578. 36	1	3528. 01	1
3578. 06	4	3525. 93	1
3577. 43	2	3525. 65	1*h*
3576. 47	1	3525. 00	1
3576. 15	5	3522. 88	3
3575. 94	2	3522. 35	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3521. 04	2*h*	3412. 30	1
3519. 14	1	3411. 70	1
3518. 75	1	3408. 67	8+Sm
3517. 82	1	3408. 06	10
3516. 59	1	3404. 29	1
3514. 84	10	3404. 04	2
3512. 97	2*d*	3401. 32	2
3511. 42	3	3400. 88	1
3510. 88	3*h*	3400. 16	1
3509. 78	1	3399. 81	3
3509. 07	1	3398. 42	1
3508. 58	2*h*	3397. 65	2
3508. 30	1	3396. 67	1
3505. 90	3	3396. 26	3*d*
3502. 47	3*h*	3395. 85	2
3501. 50	2*h*	3395. 15	3
3501. 06	2*hd*	3394. 17	1
3499. 42	2*h*	3393. 44	1
3494. 06	1	3392. 56	2
3490. 08	2	3391. 28	10
3487. 41	3+Sm	3390. 66	1
3482. 65	4	3387. 34	1
3482. 14	1	3386. 97	1
3481. 97	8	3386. 76	1
3480. 62	20	3386. 14	2
3478. 62	15+Ca	3384. 68	6+Sm
3478. 13	3	3383. 15	1
3471. 98	1	3381. 10	2
3471. 84	1	3380. 23	1
3468. 62	1	3379. 67	1
3467. 20	5*h*	3377. 68	9
3462. 91	20	3377. 02	2
3462. 25	2	3376. 56	2
3460. 25	25	3374. 47	2*h*
3456. 81	1	3374. 17	2*h*
3454. 06	1	3371. 20	2
3449. 81	40	3367. 06	2
3448. 57	1	3366. 05	5
3447. 52	1	3364. 44	8
3446. 89	1	3363. 33	1
3442. 80	2*h*	3363. 02	2
3441. 97	1	3360. 21	8
3441. 16	12	3359. 65	3
3439. 02	2	3359. 29	1
3435. 85	3*h*	3359. 00	1
3433. 21	1	3358. 14	10
3432. 12	1	3355. 84	2
3431. 64	2	3354. 46	1
3431. 19	1	3352. 23	4
3430. 88	3*h*	3350. 48	2
3430. 34	1	3345. 99	3
3429. 49	1	3340. 88	4
3428. 89	1	3339. 18	1
3427. 40	50	3336. 80	1
3426. 99	1	3333. 79	3*h*
3422. 24	2*h*	3331. 73	2
3420. 12	1	3331. 22	1
3419. 06	1	3330. 47	1
3418. 71	5	3327. 64	1
3417. 53	1	3327. 03	2

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3325. 30	3+Sm	3194. 64	2
3321. 70	1	3192. 25	4
3321. 21	15+Sm	3187. 20	8+Sm
3319. 97	1	3186. 82	1
3318. 85	2	3185. 18	6
3318. 44	1	3183. 88	8+Sm
3314. 85	1	3182. 54	6
3314. 48	3	3174. 51	6
3313. 40	1	3172. 77	10
3311. 76	6	3171. 47	1
3310. 66	8+Sm	3170. 58	1
3308. 46	1	3169. 08	6
3307. 05	20+Sm	3167. 59	1
3305. 39	4	3162. 89	3
3304. 53	1	3161. 48	1
3304. 08	1	3161. 10	3*w*
3300. 42	1	3158. 39	4
3299. 04	1	3157. 27	6
3296. 69	1	3145. 51	1
3295. 65	1	3144. 54	4*h*
3294. 98	2	3139. 34	3
3291. 21	1	3133. 47	2
3289. 68	2	3131. 85	1
3287. 84	3	3129. 53	1
3284. 41	1	3126. 55	3
3278. 79	4	3122. 81	1
3271. 96	1	3118. 76	10
3271. 71	1	3117. 22	10
3269. 59	1	3115. 36	10
3268. 79	1	3114. 36	1
3268. 66	2	3108. 11	15
3266. 39	1	3104. 24	6
3265. 69	2	3099. 46	4
3265. 24	1	3096. 21	2
3253. 00	2	3091. 86	15
3252. 04	1	3090. 19	12
3251. 49	1	3089. 61	2
3249. 98	1	3088. 37	4
3241. 43	1	3087. 83	3
3240. 46	3	3086. 02	15
3239. 86	1	3085. 08	4
3239. 62	6	3077. 70	1
3238. 57	4	3077. 52	1
3237. 29	1	3074. 25	4*w*
3236. 63	6+Sm	3072. 41	30
3232. 79	1	3070. 08	1
3219. 92	1	3067. 99	2
3218. 61	5	3066. 34	5
3211. 79	5	3064. 05	1
3211. 38	2*w*	3061. 20	6
3210. 37	2*w*	3060. 48	8
3207. 89	4	3056. 06	1
3205. 67	4	3054. 14	7
3204. 51	3	3052. 01	1
3203. 00	1	3050. 59	1
3202. 15	3	3050. 20	1
3200. 79	1	3049. 68	1
3200. 08	3	3049. 53	2
3198. 77	1	3047. 99	8
3197. 95	2	3047. 16	1

TABLE 2. *Emission spectra of promethium*—Con.

λ	Intensity	λ	Intensity
3046. 07	2	2843. 90	4*w*
3042. 12	1	2841. 86	15*w*
3041. 88	2	2840. 82	10*w*
3036. 94	1	2839. 05	2
3035. 50	1	2830. 99	5*h*
3033. 72	2	2829. 63	1
3030. 79	1	2826. 63	1
3029. 52	2	2825. 32	3
3029. 34	2	2822. 15	8*h*
3027. 21	3	2820. 10	10*h*
3026. 23	1	2811. 95	2*h*
3025. 43	1	2808. 05	4
3024. 66	1	2794. 02	3*w*
3023. 54	3	2787. 72	5*w*
3019. 58	3	2723. 17	1
3018. 47	8	2671. 05	10
3010. 31	1	2642. 38	1
3008. 85	10	2641. 93	1
3007. 85	2	2638. 46	7
3004. 59	10	2632. 00	15
2990. 24	1	2628. 87	2
2982. 84	6	2610. 20	1*h*
2979. 58	1	2608. 24	4
2963. 10	3	2596. 04	3
2959. 22	2	2589. 50	1*h*
2952. 25	5	2581. 20	1
2946. 73	3*h*	2556. 18	1
2927. 33	2	2502. 12	4*w*
2919. 36	2	2471. 94	3*h*
2916. 38	2	2460. 86	1
2900. 92	1	2453. 94	1*h*
2898. 02	1*w*	2437. 90	2
2889. 56	1	2437. 45	1
2888. 02	1	2429. 66	1
2886. 89	1	2428. 30	2
2885. 08	5	2428. 16	1
2879. 07	2	2420. 96	1
2871. 78	3	2419. 59	1
2860. 97	12*d*+Cr	2402. 39	2*h*
2857. 46	20*c*	2397. 44	1
2850. 80	5	2385. 82	1
2848. 21	8*w*	2379. 68	1
2846. 96	2*c*	2341. 17	1*h*
2845. 82	1*c*	2337. 28	1
2844. 99	2*c*		

It is highly desirable that the arc and spark spectra of promethium be reobserved in a greater range with a purer sample, with greater spectrographic dispersion and resolving power, and with a guarantee that Pm I and Pm II lines can be sorted. Until this is accomplished, all attempts to find regularities and recognize atomic energy levels in these spectra will be futile. In the meanwhile, the data presented in table 2 may be regarded as a preliminary description of the spark spectrum of promethium providing positive proof, in addition to that previously obtained at the Oak Ridge National Laboratory [17, 20], that the long-sought element with atomic number 61 has been truly discovered [11]. Although Röntgen spectra were thrice reported as proof of earlier discovery [3, 4, 5] they were never supported by convincing evidence of optical spectra. Both the absorption and the emission spectral data here presented for promethium not only identify this fission product as a new element, but also as one that possesses unmistakable characteristics of a "rare-earth". The strongest emission lines, probably Pm II, have wavelengths 3892.16, 3910.26, 3919.09, 3957.74, and 3998.96 A. These will be important for spectrochemical identification and for testing whether or not Pm can be detected in nature before fission products become abundant and widespread. Hyperfine structure is suspected in some Pm lines, namely, 5868.89, 5875.31, 5927.17, and 5946.49 A, indicating that the nuclei of $^{147}_{61}$Pm atoms possess appreciable mechanical and magnetic moments. This hyperfine structure will be investigated with interferometers at this Bureau.

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