

Promethium

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Promethium, originally **prometheum**, is a chemical element with the symbol **Pm** and atomic number 61. All of its isotopes are radioactive; it is one of only two such elements that are followed in the periodic table by elements with stable forms, a distinction shared with technetium. Chemically, promethium is a lanthanide, which forms salts when combined with other elements. Promethium shows only one stable oxidation state of +3; however, a few +2 compounds may exist.

In 1902 Bohuslav Brauner suggested there was an element with properties intermediate between those of the known elements neodymium (60) and samarium (62); this was confirmed in 1914 by Henry Moseley who, having measured the atomic numbers of all the elements then known, found there was no element with atomic number 61. In 1926, an Italian and an American group claimed to have isolated a sample of element 61; both "discoveries" were soon proven to be false. In 1938, during a nuclear experiment conducted at Ohio State University, a few radioactive nuclides were produced that certainly were not radioisotopes of neodymium or samarium, but there was a lack of chemical proof that element 61 was produced, and the discovery was not generally recognized. Promethium was first produced and characterized at Oak Ridge National Laboratory in 1945 by the separation and analysis of the fission products of uranium fuel irradiated in a graphite reactor. The discoverers proposed the name "prometheum" (the spelling was subsequently changed), derived from Prometheus, the Titan in Greek mythology who stole fire from Mount Olympus and brought it down to humans, to symbolize "both the daring and the possible misuse of mankind's intellect." However, a sample of the metal was made only in 1963.

There are two possible sources for natural promethium: rare decays of natural europium-151 (producing promethium-147), and uranium (various isotopes). Practical applications exist only for chemical compounds of promethium-147, which are used in luminous paint, atomic batteries and thickness measurement devices, even though promethium-145 is the most stable promethium isotope. Because natural promethium is exceedingly scarce, it is typically synthesized by bombarding uranium-235 (enriched uranium) with thermal neutrons to produce promethium-147.

Properties

Promethium, ⁶¹Pm



Spectral lines of promethium

General properties

Name, symbol promethium, Pm

Appearance metallic

Promethium in the periodic table

Atomic number (*Z*) 61

Group, block group n/a, f-block

Period period 6

Element category ☐ lanthanide

Standard atomic weight (*A*_r) [145]

Electron configuration [Xe] 4f⁵ 6s²

per shell 2, 8, 18, 23, 8, 2

Physical properties

Phase solid

Melting point 1315 K (1042 °C, 1908 °F)

Boiling point 3273 K (3000 °C, 5432 °F)

Density near r.t. 7.26 g/cm³

Heat of fusion 7.13 kJ/mol

Heat of vaporization 289 kJ/mol

Physical properties

A promethium atom has 61 electrons, arranged in the configuration $[\text{Xe}]4f^56s^2$.^[3] In forming compounds, the atom loses its two outermost electrons and one of the 4f-electrons, which belongs to an open subshell. The element's atomic radius is the third largest among all the lanthanides but is only slightly greater than those of the neighboring elements.^[3] It is the only exception to the general trend of the contraction of the atoms with increase of atomic radius (caused by the lanthanide contraction^[4]) that is not caused by the filled (or half-filled) 4f-subshell.

Many properties of promethium rely on its position among lanthanides and are intermediate between those of neodymium and samarium. For example, the melting point, the first three ionization energies, and the hydration energy are greater than those of neodymium and lower than those of samarium;^[3] similarly, the estimate for the boiling point, ionic (Pm^{3+}) radius, and standard heat of formation of monatomic gas are greater than those of samarium and less than those of neodymium.^[3]

Promethium has a double hexagonal close packed (dhcp) structure and a hardness of 63 kg/mm^2 .^[5] This low-temperature alpha form converts into a beta, body-centered cubic (bcc) phase upon heating to 890°C .^[6]

Chemical properties and compounds

Promethium belongs to the cerium group of lanthanides and is chemically very similar to the neighboring elements.^[7] Because of its instability, chemical studies of promethium are incomplete. Even though a few compounds have been synthesized, they are not fully studied; in general, they tend to be pink or red in color.^{[8][9]} Treatment of acidic solutions containing Pm^{3+} ions with ammonia results in a gelatinous light-brown sediment of hydroxide, $\text{Pm}(\text{OH})_3$, which is insoluble in water.^[10] When dissolved in hydrochloric acid, a water-soluble yellow salt, PmCl_3 , is produced;^[10] similarly, when dissolved in nitric acid, a nitrate results, $\text{Pm}(\text{NO}_3)_3$. The latter is also well-soluble; when dried, it forms pink crystals, similar to $\text{Nd}(\text{NO}_3)_3$.^[10] The electron configuration for Pm^{3+} is $[\text{Xe}] 4f^4$, and the

Atomic properties

Oxidation states	3, 2 (a mildly basic oxide)
Electronegativity	Pauling scale: 1.13 (?)
Ionization energies	1st: 540 kJ/mol 2nd: 1050 kJ/mol 3rd: 2150 kJ/mol
Atomic radius	empirical: 183 pm
Covalent radius	199 pm

Miscellanea

Crystal structure	double hexagonal close-packed (dhcp)
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Thermal expansion	$9.0 \mu\text{m}/(\text{m}\cdot\text{K})$ ^[11] (at r.t.)
Thermal conductivity	$17.9 \text{ W}/(\text{m}\cdot\text{K})$
Electrical resistivity	est. $0.75 \mu\Omega\cdot\text{m}$ (at r.t.)
Magnetic ordering	paramagnetic ^[2]
Young's modulus	α form: est. 46 GPa
Shear modulus	α form: est. 18 GPa
Bulk modulus	α form: est. 33 GPa
Poisson ratio	α form: est. 0.28
CAS Number	7440-12-2

History

color of the ion is pink. The ground state term symbol is 5I_4 .^[11] The sulfate is slightly soluble, like the other cerium group sulfates. Cell parameters have been calculated for its octahydrate; they lead to conclusion that the density of $Pm_2(SO_4)_3 \cdot 8 H_2O$ is 2.86 g/cm³.^[12] The oxalate, $Pm_2(C_2O_4)_3 \cdot 10 H_2O$, has the lowest solubility of all lanthanide oxalates.^[13]

Unlike the nitrate, the oxide is similar to the corresponding samarium salt and not the neodymium salt. As-synthesized, e.g. by heating the oxalate, it is a white or lavender-colored powder with disordered structure.^[10] This powder crystallizes in a cubic lattice upon heating to 600 °C. Further annealing at 800 °C and then at 1750 °C irreversibly transforms it to a monoclinic and hexagonal phases, respectively, and the last two phases can be interconverted by adjusting the annealing time and temperature.^[14]

Promethium forms only one stable oxidation state, +3, in the form of ions; this is in line with other lanthanides. According to its position in the periodic table, the element cannot be expected to form stable +4 or +2 oxidation states; treating chemical compounds containing Pm^{3+} ions with strong oxidizing or reducing agents showed that the ion is not easily oxidized or reduced.^[7]

Isotopes

Promethium is the only lanthanide and one of only two elements among the first 83 that has no stable (or even long-lived) isotopes. This is a result of a rarely occurring effect of the liquid drop model and stabilities of neighbor element isotopes; it is also the least stable element of the first 84.^[16] The primary decay products are neodymium and samarium isotopes (promethium-146 decays to both, the lighter isotopes generally to neodymium via positron decay and electron capture, and the heavier isotopes to samarium via beta decay). Promethium nuclear isomers may decay to other promethium isotopes and one isotope (^{145}Pm) has a very rare alpha decay mode to stable praseodymium-141.^[16]

The most stable isotope of the element is promethium-145, which has a specific activity of 940 Ci (35 TBq)/g and a half-life of 17.7 years via electron capture.^{[16][17]} Because it has 84 neutrons (two more than 82, which is a magic number which corresponds to a stable neutron configuration), it may emit an alpha particle (which has 2 neutrons) to form praseodymium-141 with 82 neutrons. Thus it is the only promethium isotope with an experimentally observed alpha decay.^[18] Its partial half-life for

Discovery	Chien Shiung Wu, Emilio Segrè, Hans Bethe (1942)
First isolation	Charles D. Coryell, Jacob A. Marinsky, Lawrence E. Glendenin, Harold G. Richter (1945)
Named by	Grace Mary Coryell (1945)

Most stable isotopes of promethium					
iso	NA	half-life	DM	DE (MeV)	DP
¹⁴⁵Pm	syn	17.7 y	ε	0.163	¹⁴⁵ Nd
¹⁴⁶Pm	syn	5.53 y	ε	1.472	¹⁴⁶ Nd
			β [−]	1.542	¹⁴⁶ Sm
¹⁴⁷Pm	trace	2.6234 y	β [−]	0.224	¹⁴⁷ Sm

alpha decay is about 6.3×10^9 years, and the relative probability for a ^{145}Pm nucleus to decay in this way is $2.8 \times 10^{-7}\%$. Several other promethium isotopes (^{144}Pm , ^{146}Pm , ^{147}Pm etc.) also have a positive energy release for alpha decay; their alpha decays are predicted to occur but have not been observed.

The element also has 18 nuclear isomers, with mass numbers of 133 to 142, 144, 148, 149, 152, and 154 (some mass numbers have more than one isomer). The most stable of them is promethium-148m, with a half-life of 43.1 days; this is longer than the half-lives of the ground states of all promethium isotopes, except only for promethium-143 to 147 (note that promethium-148m has a longer half-life than the ground state, promethium-148).^[16]

Source

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