

Curium

From Wikipedia, the free encyclopedia

Curium is a transuranic radioactive chemical element with symbol **Cm** and atomic number 96. This element of the actinide series was named after Marie and Pierre Curie – both were known for their research on radioactivity. Curium was first intentionally produced and identified in July 1944 by the group of Glenn T. Seaborg at the University of California, Berkeley. The discovery was kept secret and only released to the public in November 1945. Most curium is produced by bombarding uranium or plutonium with neutrons in nuclear reactors – one tonne of spent nuclear fuel contains about 20 grams of curium.

Curium is a hard, dense, silvery metal with a relatively high melting point and boiling point for an actinide. Whereas it is paramagnetic at ambient conditions, it becomes antiferromagnetic upon cooling, and other magnetic transitions are also observed for many curium compounds. In compounds, curium usually exhibits valence +3 and sometimes +4, and the +3 valence is predominant in solutions. Curium readily oxidizes, and its oxides are a dominant form of this element. It forms strongly fluorescent complexes with various organic compounds, but there is no evidence of its incorporation into bacteria and archaea. When introduced into the human body, curium accumulates in the bones, lungs and liver, where it promotes cancer.

All known isotopes of curium are radioactive and have a small critical mass for a sustained nuclear chain reaction. They predominantly emit α -particles, and the heat released in this process can potentially produce electricity in radioisotope thermoelectric generators. This application is hindered by the scarcity, high cost and radioactivity of curium isotopes. Curium is used in production of heavier actinides and of the ^{238}Pu radionuclide for power sources in artificial pacemakers. It served as the α -source in the alpha particle X-ray spectrometers installed on several space probes, including the Sojourner, Spirit, Opportunity and Curiosity Mars rovers and the Philae lander on comet 67P/Churyumov-Gerasimenko, to analyze the composition and structure of the surface.

Characteristics

Physical

Curium, $_{96}\text{Cm}$



General properties

Name, symbol	curium, Cm
Appearance	silvery metallic, glows purple in the dark

Curium in the periodic table

Atomic number (<i>Z</i>)	96
Group, block	group n/a, f-block
Period	period 7
Element category	☐ actinide
Standard atomic weight (<i>A</i> _r)	(247)
Electron configuration	[Rn] 5f ⁷ 6d ¹ 7s ²
per shell	2, 8, 18, 32, 25, 9, 2

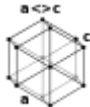
Physical properties

Phase	solid
--------------	-------

A synthetic, radioactive element, curium is a hard dense metal with silvery-white appearance and physical and chemical properties resembling those of gadolinium. Its melting point of 1340 °C is significantly higher than that of the previous transuranic elements neptunium (637 °C), plutonium (639 °C) and americium (1173 °C). In comparison, gadolinium melts at 1312 °C. The boiling point of curium is 3110 °C. With a density of 13.52 g/cm³, curium is significantly lighter than neptunium (20.45 g/cm³) and plutonium (19.8 g/cm³), but is heavier than most other metals. Between two crystalline forms of curium, the α-Cm is more stable at ambient conditions. It has a hexagonal symmetry, space group P6₃/mmc, lattice parameters *a* = 365 pm and *c* = 1182 pm, and four formula units per unit cell.^[18] The crystal consists of a double-hexagonal close packing with the layer sequence ABAC and so is isotypic with α-lanthanum. At pressures above 23 GPa, at room temperature, α-Cm transforms into β-Cm, which has a face-centered cubic symmetry, space group Fm $\bar{3}$ m and the lattice constant *a* = 493 pm.^[18] Upon further compression to 43 GPa, curium transforms to an orthorhombic γ-Cm structure similar to that of α-uranium, with no further transitions observed up to 52 GPa. These three curium phases are also referred to as Cm I, II and III.^{[19][20]}

Curium has peculiar magnetic properties. Whereas its neighbor element americium shows no deviation from Curie-Weiss paramagnetism in the entire temperature range, α-Cm transforms to an antiferromagnetic state upon cooling to 65–52 K,^{[21][22]} and β-Cm exhibits a ferrimagnetic transition at about 205 K. Meanwhile, curium pnictides show ferromagnetic transitions upon cooling: ²⁴⁴CmN and ²⁴⁴CmAs at 109 K, ²⁴⁸CmP at 73 K and ²⁴⁸CmSb at 162 K. Similarly, the lanthanide analogue of curium, gadolinium, as well as its pnictides also show magnetic transitions upon cooling, but the transition character is somewhat different: Gd and GdN become ferromagnetic, and GdP, GdAs and GdSb show antiferromagnetic ordering.^[23]

In accordance with magnetic data, electrical resistivity of curium increases with temperature – about twice between 4 and 60 K – and then remains nearly constant up to room temperature. There is a significant increase in resistivity over time (about 10 μΩ·cm/h) due to self-damage of the crystal lattice by alpha radiation. This makes uncertain the absolute resistivity value for curium (about 125 μΩ·cm). The resistivity of

Melting point	1613 K (1340 °C, 2444 °F)					
Boiling point	3383 K (3110 °C, 5630 °F)					
Density near r.t.	13.51 g/cm ³					
Heat of fusion	13.85 kJ/mol					
Vapor pressure						
P (Pa)	1	10	100	1 k	10 k	100 k
at T (K)	1788	1982				
Atomic properties						
Oxidation states	6, ^[1] 4, 3 , 2 (an amphoteric oxide)					
Electronegativity	Pauling scale: 1.3					
Ionization energies	1st: 581 kJ/mol					
Atomic radius	empirical: 174 pm					
Covalent radius	169±3 pm					
Miscellanea						
Crystal structure	double hexagonal close-packed (dhcp) <div></div>					
Electrical resistivity	1.25 μΩ·m ^[2]					
Magnetic ordering	antiferromagnetic-paramagnetic transition at 52 K ^[2]					
CAS Number	7440-51-9					
History						
Naming	named after Marie Skłodowska-Curie					

curium is similar to that of gadolinium and of the actinides plutonium and neptunium, but is significantly higher than that of americium, uranium, polonium and thorium.^{[2][24]}

Under ultraviolet illumination, curium(III) ions exhibit strong and stable yellow-orange fluorescence with a maximum in the range about 590–640 nm depending on their environment.^[25] The fluorescence originates from the transitions from the first excited state ⁶D_{7/2} and the ground state ⁸S_{7/2}. Analysis of this fluorescence allows monitoring interactions between Cm(III) ions in organic and inorganic complexes.^[26]

Chemical

Curium ions in solution almost exclusively assume the oxidation state of +3, which is the most stable oxidation state for curium.^[27] The +4 oxidation state is observed mainly in a few solid phases, such as CmO₂ and CmF₄.^{[28][29]} Aqueous curium(IV) is only known in the presence of strong oxidizers such as potassium persulfate, and is easily reduced to curium(III) by radiolysis and even by water.^[30] The chemical behavior of curium is different from the actinides thorium and uranium, and is similar to that of americium and many lanthanides. In aqueous solution, the Cm³⁺ ion is colorless to pale green,^[31] and Cm⁴⁺ ion is pale yellow.^[32] The optical absorption of Cm³⁺ ions contains three sharp peaks at 375.4, 381.2 and 396.5 nanometers and their strength can be directly converted into the concentration of the ions.^[33] The +6 oxidation state has only been reported once in solution in 1978, as the curyl ion (CmO₂²⁺): this was prepared from the beta decay of americium-242 in the americium(V) ion ²⁴²AmO₂⁺.^[1] Failure to obtain Cm(VI) from oxidation of Cm(III) and Cm(IV) may be due to the high Cm⁴⁺/Cm³⁺ ionization potential and the instability of Cm(V).^[30]

Curium ions are hard Lewis acids and thus form most stable complexes with hard bases.^[34] The bonding is mostly ionic, with a small covalent component.^[35] Curium in its complexes commonly exhibits a 9-fold coordination environment, within a tricapped trigonal prismatic geometry.^[36]

Isotopes

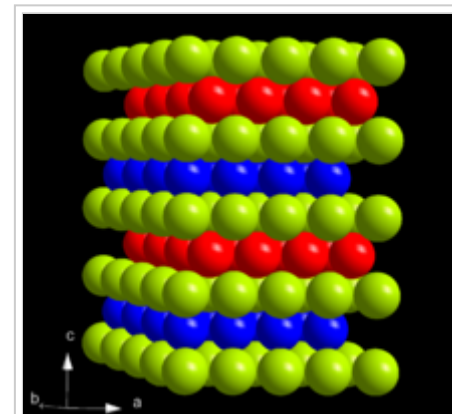
Discovery	and Pierre Curie				
	Glenn T. Seaborg, Ralph A. James, Albert Ghiorso (1944)				
	Most stable isotopes of curium				
iso	NA	half-life	DM	DE (MeV)	DP
²⁴² Cm	syn	160 d	SF	–	–
			α	6.1	²³⁸ Pu
²⁴³ Cm	syn	29.1 y	α	6.169	²³⁹ Pu
			ε	0.009	²⁴³ Am
			SF	–	–
²⁴⁴ Cm	syn	18.1 y	SF	–	–
			α	5.8048	²⁴⁰ Pu
²⁴⁵ Cm	syn	8500 y	SF	–	–
			α	5.623	²⁴¹ Pu
²⁴⁶ Cm	syn	4730 y	α	5.475	²⁴² Pu
			SF	–	–
²⁴⁷ Cm	syn	1.56×10 ⁷ y	α	5.353	²⁴³ Pu
²⁴⁸ Cm	syn	3.40×10 ⁵ y	α	5.162	²⁴⁴ Pu
			SF	–	–
²⁵⁰ Cm	syn	9000 y	SF	–	–
			α	5.169	²⁴⁶ Pu
			β [−]	0.037	²⁵⁰ Bk

About 20 radioisotopes and 7 nuclear isomers between ^{233}Cm and ^{252}Cm are known for curium, and no stable isotopes. The longest half-lives have been reported for ^{247}Cm (15.6 million years) and ^{248}Cm (348,000 years). Other long-lived isotopes are ^{245}Cm (half-life 8500 years), ^{250}Cm (8,300 years) and ^{246}Cm (4,760 years). Curium-250 is unusual in that it predominantly (about 86%) decays via spontaneous fission. The most commonly used curium isotopes are ^{242}Cm and ^{244}Cm with the half-lives of 162.8 days and 18.1 years, respectively.^[10]

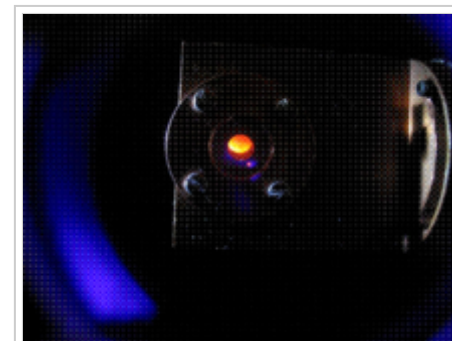
All isotopes between ^{242}Cm and ^{248}Cm , as well as ^{250}Cm , undergo a self-sustaining nuclear chain reaction and thus in principle can act as a nuclear fuel in a reactor. As in most transuranic elements, the nuclear fission cross section is especially high for the odd-mass curium isotopes ^{243}Cm , ^{245}Cm and ^{247}Cm . These can be used in thermal-neutron reactors, whereas a mixture of curium isotopes is only suitable for fast breeder reactors since the even-mass isotopes are not fissile in a thermal reactor and accumulate as burn-up increases.^[41] The mixed-oxide (MOX) fuel, which is to be used in power reactors, should contain little or no curium because the neutron activation of ^{248}Cm will create californium. This is strong neutron emitter, and would pollute the back end of the fuel cycle and increase the dose to reactor personnel. Hence, if the minor actinides are to be used as fuel in a thermal neutron reactor, the curium should be excluded from the fuel or placed in special fuel rods where it is the only actinide present.^[42]

The table to the right lists the critical masses for curium isotopes for a sphere, without a moderator and reflector. With a metal reflector (30 cm of steel), the critical masses of the odd isotopes are about 3–4 kg. When using water (thickness ~20–30 cm) as the reflector, the critical mass can be as small as 59 gram for ^{245}Cm , 155 gram for ^{243}Cm and 1550 gram for ^{247}Cm . There is a significant uncertainty in these critical mass values. Whereas it is usually of the order 20%, the values for ^{242}Cm and ^{246}Cm were listed as large as 371 kg and 70.1 kg, respectively, by some research groups.^{[41][43]}

Currently, curium is not used as a nuclear fuel owing to its low availability and high price.^[44] ^{245}Cm and ^{247}Cm have a very small critical mass and therefore could be used in portable nuclear weapons, but none have been reported thus far. Curium-243 is not suitable for this purpose because of its short half-life and strong α emission which would result in excessive heat.^[45] Curium-247 would be highly suitable, having a half-life 647 times that of plutonium-239.



Double-hexagonal close packing with the layer sequence ABAC in the crystal structure of α -curium (A: green, B: blue, C: red)



Orange fluorescence of Cm^{3+} ions in a solution of tris(hydrotris)pyrazolylborato-Cm(III) complex, excited at 396.6 nm.

Occurrence

The longest-lived isotope of curium, ^{247}Cm , has a half-life of 15.6 million years. Therefore, any primordial curium, that is curium present on the Earth during its formation, should have decayed by now. Curium is produced artificially, in small quantities for research purposes. Furthermore, it occurs in spent nuclear fuel. Curium is present in nature in certain areas used for the atmospheric nuclear weapons tests, which were conducted between 1945 and 1980.^[46] So the analysis of the debris at the testing site of the first U.S. hydrogen bomb, Ivy Mike, (1 November 1952, Enewetak Atoll), beside einsteinium, fermium, plutonium and americium also revealed isotopes of berkelium, californium and curium, in particular ^{245}Cm , ^{246}Cm and smaller quantities of ^{247}Cm , ^{248}Cm and ^{249}Cm . For reasons of military secrecy, this result was published only in 1956.^[47]

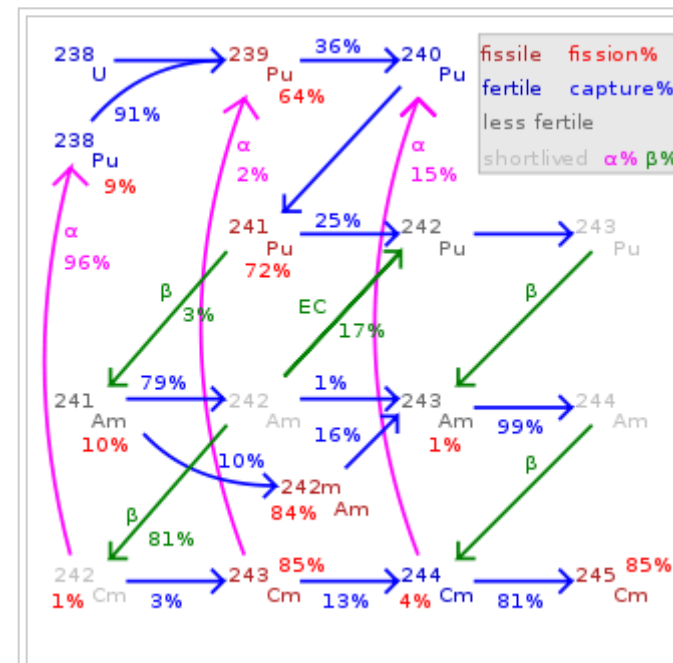
Atmospheric curium compounds are poorly soluble in common solvents and mostly adhere to soil particles. Soil analysis revealed about 4,000 times higher concentration of curium at the sandy soil particles than in water present in the soil pores. An even higher ratio of about 18,000 was measured in loam soils.^[48]

The transuranic elements from americium to fermium, including curium, occurred naturally in the natural nuclear fission reactor at Oklo, but no longer do so.^[49]

Exceedingly minute amounts of the isotope ^{244}Cm may be produced naturally from the theoretically predicted extremely rare double beta decay of the trace primordial isotope ^{244}Pu , but this has not yet been observed.^[50]

Source

- Wikipedia: Curium (<https://en.wikipedia.org/wiki/Curium>)



Transmutation flow between ^{238}Pu and ^{244}Cm in LWR.^[40]

Fission percentage is 100 minus shown percentages.

Total rate of transmutation varies greatly by nuclide.

^{245}Cm – ^{248}Cm are long-lived with negligible decay.