Gadolinium

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Gadolinium is a chemical element with symbol **Gd** and atomic number 64. It is a silvery-white, malleable and ductile rare-earth metal. It is found in nature only in combined (salt) form. Gadolinium was first detected spectroscopically in 1880 by de Marignac who separated its oxide and is credited with its discovery. It is named for gadolinite, one of the minerals in which it was found, in turn named for chemist Johan Gadolin. The metal was isolated by Paul Emile Lecoq de Boisbaudran in 1886.

Gadolinium metal possesses unusual metallurgic properties, to the extent that as little as 1% gadolinium can significantly improve the workability and resistance to high temperature oxidation of iron, chromium, and related alloys. Gadolinium as a metal or salt has exceptionally high absorption of neutrons and therefore is used for shielding in neutron radiography and in nuclear reactors. Like most rare earths, gadolinium forms trivalent ions with fluorescent properties. Gadolinium(III) salts have therefore been used as green phosphors in various applications.

The gadolinium(III) ion occurring in water-soluble salts is quite toxic to mammals. However, chelated gadolinium(III) compounds are far less toxic because they carry gadolinium(III) through the kidneys and out of the body before the free ion can be released into tissue. Because of its paramagnetic properties, solutions of chelated organic gadolinium complexes are used as intravenously administered gadolinium-based MRI contrast agents in medical magnetic resonance imaging. However, in a small minority of patients with renal failure, at least four such agents have been associated with development of the rare nodular inflammatory disease nephrogenic systemic fibrosis. This is thought to be due to the gadolinium ion itself, since gadolinium(III) carrier molecules associated with the disease differ.

Gadolinium, $_{64}$Gd

General properties	
Name, symbol	gadolinium, Gd
Appearance	silvery white
Gadolinium in the periodic table	
Atomic number (*Z*)	64
Group, block	group n/a, f-block
Period	period 6
Element category	□ lanthanide
Standard atomic weight (±) (A_r)	157.25(3)[1]
Electron configuration	[Xe] $4f^7$ $5d^1$ $6s^2$
per shell	2, 8, 18, 25, 9, 2
Physical properties	
Phase	solid
Melting point	1585 K (1312 °C, 2394 °F)
Boiling point	3273 K (3000 °C, 5432 °F)
Density near r.t.	7.90 g/cm^3
when liquid, at m.p.	7.4 g/cm^3

Characteristics

Physical properties

A sample of gadolinium

Gadolinium is a silvery-white malleable and ductile rare-earth metal. It crystallizes in hexagonal, close-packed α-form at room temperature, but, when heated to temperatures above 1235 °C, it transforms into its β-form, which has a body-centered cubic structure.[2]

Gadolinium-157 has the highest thermal neutron capture cross-section among any stable nuclides: 259,000 barns. Only xenon-135 has a higher cross section, 2 million barns, but that isotope is unstable.[3]

Gadolinium is generally believed to be ferromagnetic at temperatures below 20 °C (68 °F)[4] and is strongly paramagnetic above this temperature. There is some evidence that gadolinium may be a helical antiferromagnet, rather than a ferromagnet, below 20 °C (68 °F).[5] Gadolinium demonstrates a magnetocaloric effect whereby its temperature increases when it enters a magnetic field and decreases when it leaves the magnetic field. The temperature is lowered to 5 °C (41 °F) for the gadolinium alloy $Gd_{85}Er_{15}$, and the effect is considerably stronger for the alloy $Gd_5(Si_2Ge_2)$, but at a much lower temperature (<85 K (−188.2 °C; −306.7 °F)).[6] A significant magnetocaloric effect is observed at higher temperatures, up to 300 K, in the $Gd_5(Si_xGe_{1-x})_4$ compounds.[7]

Individual gadolinium atoms have been isolated by encapsulating them into fullerene molecules and visualized with transmission electron microscope.[8] Individual Gd atoms and small Gd clusters have also been incorporated into carbon nanotubes.[9]

Chemical properties

Gadolinium combines with most elements to form Gd(III) derivatives. It also combines with nitrogen, carbon, sulfur, phosphorus, boron, selenium, silicon and arsenic at elevated temperatures, forming binary compounds.[10]

Heat of fusion	10.05 kJ/mol
Heat of vaporization	301.3 kJ/mol
Molar heat capacity	37.03 J/(mol·K)

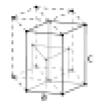
Vapor pressure *(calculated)*

P (Pa)	**1**	**10**	**100**	**1 k**	**10 k**	**100 k**
at T (K)	1836	2028	2267	2573	2976	3535

Atomic properties

Oxidation states	1, 2, **3** (a mildly basic oxide)
Electronegativity	Pauling scale: 1.20
Ionization energies	1st: 593.4 kJ/mol 2nd: 1170 kJ/mol 3rd: 1990 kJ/mol
Atomic radius	empirical: 180 pm
Covalent radius	196±6 pm

Miscellanea

Crystal structure	hexagonal close-packed (hcp) 
Speed of sound thin rod	2680 m/s (at 20 °C)
Thermal expansion	α poly: 9.4 µm/(m·K) (at 100 °C)
Thermal conductivity	10.6 W/(m·K)
Electrical resistivity	α, poly: 1.310 µΩ·m
Magnetic ordering	ferromagnetic-paramagnetic transition at 293.4 K
Young's modulus	α form: 54.8 GPa
Shear modulus	α form: 21.8 GPa

Unlike other rare earth elements, metallic gadolinium is relatively stable in dry air. However, it tarnishes quickly in moist air, forming a loosely adhering gadolinium(III) oxide (Gd_2O_3), which spalls off, exposing more surface to oxidation.

$$4\ Gd + 3\ O_2 \rightarrow 2\ Gd_2O_3$$

Gadolinium is a strong reducing agent, which reduces oxides of several metals into their elements. Gadolinium is quite electropositive and reacts slowly with cold water and quite quickly with hot water to form gadolinium hydroxide:

$$2\ Gd + 6\ H_2O \rightarrow 2\ Gd(OH)_3 + 3\ H_2$$

Gadolinium metal is attacked readily by dilute sulfuric acid to form solutions containing the colorless Gd(III) ions, which exist as $[Gd(H_2O)_9]^{3+}$ complexes:[11]

$$2\ Gd + 3\ H_2SO_4 + 18\ H_2O \rightarrow 2\ [Gd(H_2O)_9]^{3+} + 3\ SO_4^{2-} + 3\ H_2$$

Gadolinium metal reacts with the halogens (X_2) at temperature about 200 °C:

$$2\ Gd + 3\ X_2 \rightarrow 2\ GdX_3$$

Bulk modulus	α form: 37.9 GPa
Poisson ratio	α form: 0.259
Vickers hardness	510–950 MPa
CAS Number	7440-54-2
History	
Naming	after the mineral Gadolinite (itself named after Johan Gadolin)
Discovery	Jean Charles Galissard de Marignac (1880)
First isolation	Lecoq de Boisbaudran (1886)

Most stable isotopes of gadolinium

iso	NA	half-life	DM	DE (MeV)	DP
^{148}Gd	syn	75 y	α	3.271	^{144}Sm
^{150}Gd	syn	1.8×10^{6} y	α	2.808	^{146}Sm
^{152}Gd	0.20%	1.08×10^{14} y	α	2.205	^{148}Sm
^{154}Gd	2.18%	is stable with 90 neutrons			
^{155}Gd	14.80%	is stable with 91 neutrons			
^{156}Gd	20.47%	is stable with 92 neutrons			
^{157}Gd	15.65%	is stable with 93 neutrons			
^{158}Gd	24.84%	is stable with 94 neutrons			
^{160}Gd	21.86%	is stable with 96 neutrons			

Chemical compounds

In the great majority of its compounds, Gd adopts the oxidation state +3. All four trihalides are known. All are white except for the iodide, which is yellow. Most commonly encountered of the halides is gadolinium(III) chloride ($GdCl_3$). The oxide dissolves in acids to give the salts, such as gadolinium(III) nitrate.

Gadolinium(III), like most lanthanide ions, forms complexes with high coordination numbers. This tendency is illustrated by the use of the chelating agent DOTA, an octadentate ligand. Salts of $[Gd(DOTA)]^-$ are useful in magnetic resonance imaging. A variety of related chelate complexes have been developed, including gadodiamide.

Reduced gadolinium compounds are known, especially in the solid state. Gadolinium(II) halides are obtained by heating Gd(III) halides in presence of metallic Gd in tantalum containers. Gadolinium also form sesquichloride Gd_2Cl_3, which can be further reduced to GdCl by annealing at 800 °C. This gadolinium(I) chloride forms platelets with layered graphite-like structure.[12]

Isotopes

Naturally occurring gadolinium is composed of 6 stable isotopes, ^{154}Gd, ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd and ^{160}Gd, and 1 radioisotope, ^{152}Gd, with ^{158}Gd being the most abundant (24.84% natural abundance). The predicted double beta decay of ^{160}Gd has never been observed (the only lower limit on its half-life of more than 1.3×10^{21} years has been set experimentally[13]).

Twenty-nine radioisotopes have been characterized, with the most stable being alpha-decaying ^{152}Gd (naturally occurring) with a half-life of 1.08×10^{14} years, and ^{150}Gd with a half-life of 1.79×10^{6} years. All of the remaining radioactive isotopes have half-lives of less than 74.7 years. The majority of these have half-lives of less than 24.6 seconds. Gadolinium isotopes have 4 metastable isomers, with the most stable being ^{143m}Gd ($t_{1/2}$=110 seconds), ^{145m}Gd ($t_{1/2}$=85 seconds) and ^{141m}Gd ($t_{1/2}$=24.5 seconds).

Isotopes with atomic masses lower than the most abundant stable isotope, ^{158}Gd, primarily decay via electron capture to Eu (europium) isotopes. At higher atomic masses, the primary decay mode is beta decay, and the primary products are Tb (terbium) isotopes.

Source

- Wikipedia: Gadolinium (https://en.wikipedia.org/wiki/Gadolinium)