

Uranium



Uranium ore(USGS)

Uranium is a radioactive element that occurs naturally in low concentrations (a few parts per million) in soil, rock, and surface and groundwater. It is the heaviest naturally occurring element, with an atomic number of 92. Uranium in its pure form is a silver-colored heavy metal that is nearly twice as dense as lead and is pyrophoric when finely divided.

Uranium exhibits three crystallographic modifications as follows: alpha \rightarrow beta \rightarrow gamma. It is a little softer than steel, and is attacked by cold water in a finely divided state. It is malleable, ductile, and slightly paramagnetic. In air, the metal becomes coated with a layer of oxide. Acids dissolve the metal, but it is unaffected by alkalis.

History

Previous Element: <u>Protactinium</u>	92 U 238.03
Next Element: <u>Neptunium</u>	
Physical Properties	
Color	Silvery
Phase at Room Temp.	Solid
Density (g/cm ³)	19.05
Hardness (Mohs)	---
Melting Point (K)	1405.2
Boiling Point (K)	4203
Heat of Fusion (kJ/mol)	12.6
Heat of Vaporization (kJ/mol)	417
Heat of Atomization (kJ/mol)	490
Thermal Conductivity (J/m sec K)	27.5
Electrical Conductivity (1/mohm cm)	33.333
Source	Uranite (oxide)
Atomic Properties	
Electron Configuration	[Rn]7s ² 5f ⁶ d ¹
Number of <u>Isotopes</u>	3
Electron Affinity (kJ/mol)	---
First Ionization Energy (kJ/mol)	584

Second Ionization Energy (kJ/mol)	Not applicable
Third Ionization Energy (kJ/mol)	Not applicable
Electronegativity	1.7
Polarizability (Å ³)	27.4
Atomic Weight	238.03
Atomic Volume (cm ³ /mol)	12.5
Ionic Radius ²⁻ (pm)	---
Ionic Radius ¹⁻ (pm)	---
Atomic Radius (pm)	156
Ionic Radius ¹⁺ (pm)	---
Ionic Radius ²⁺ (pm)	---
Ionic Radius ³⁺ (pm)	116.5
Common Oxidation Numbers	+6
Other Oxid. Numbers	+3, +4, +5
Abundance	
In Earth's Crust (mg/kg)	2.7
In Earth's Ocean (mg/L)	3.2×10 ⁻³
In Human Body (%)	Near 0%
Regulatory / Health	
CAS Number	7440-61-7 metal, pyrophoric
OSHA Permissible Exposure Limit (PEL)	TWA: 0.25 mg/m ³
OSHA PEL Vacated 1989	TWA: 0.2 mg/m ³ STEL: 0.6 mg/m ³
NIOSH Recommended Exposure Limit	TWA: 0.2 mg/m ³ STEL: 0.6 mg/m ³ IDLH: 10 mg/m ³ (Potential carcinogen)
Sources: Mineral Information Institute Jefferson Accelerator Laboratory EnvironmentalChemistry.com	

The name derives from the planet Uranus, which in Roman mythology was "Father Heaven". Uranium was found to be first used in yellow-colored glass, which contained more than 1% uranium oxide, dating back to 79 A.D. found near Naples, Italy. The metal was first isolated in 1841 by the French chemist Eugene-Melchior Peligot, who reduced the anhydrous chloride with potassium. The German chemist Martin Heinrich Klaproth discovered the element in 1789 when he recognized an unknown element in the mineral pitchblende, following the German/English astronomer William Hershel's discovery of the planet in 1781.

Uranium was apparently formed in super novae about 6.6 billion years ago, a decay product of elements with higher atomic weight, which may have once been present on Earth or elsewhere in the universe. It occurs in most rocks in concentrations of 2 to 4 parts per million, and in much lower concentrations in seawater. Its radioactive decay provides the main source of heat inside the Earth, causing convection and continental drift.

Sources

Uranium, not as rare as once thought, is now considered to be more plentiful than mercury, antimony, silver, or cadmium, and is about as abundant as molybdenum or arsenic. It occurs in numerous minerals such as pitchblende, uraninite, carnotite, autunite, uranophane, and tobernite. It is also found in phosphate rock, lignite, monazite sands, and can be recovered commercially from these sources.

The United States Department of Energy purchases uranium in the form of acceptable triuranium octaoxide (U₃O₈) concentrates. This incentive program has greatly increased the known uranium reserves. Uranium can be prepared by reducing uranium halides with alkali or alkaline earth metals or by reducing uranium oxides by calcium, aluminum, or carbon at high temperatures. The metal can also be produced by electrolysis of KUF₃ or uranium tetrafluoride (UF₄), dissolved in a molten mixture of calcium chloride (CaCl₂) and sodium chloride (NaCl). High-purity uranium can be prepared by the thermal decomposition of uranium halides on a hot filament.

Uses

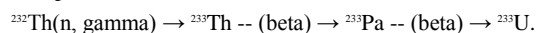
Uranium is of great importance as a nuclear fuel. Uranium-238 (²³⁸U) can be converted into fissionable plutonium by the following reactions:



This nuclear conversion can be brought about in breeder reactors where it is possible to produce more new fissionable material than the fissionable material used in maintaining the chain reaction.

Uranium-235 (²³⁵U) is of even greater importance because it is the key to utilizing uranium. ²³⁵U, while occurring in natural uranium to the extent of only 0.71%, is so fissionable with slow neutrons that a self-sustaining fission chain reaction can be made in a nuclear reactor constructed from natural uranium and a suitable moderator, such as heavy water or graphite, alone.

Uranium-235 can be concentrated by gaseous diffusion and other physical processes, if desired, and used directly as a nuclear fuel, instead of natural uranium, or used as an explosive. Natural uranium, slightly enriched with ²³⁵U by a small percentage, is used to fuel nuclear power reactors to generate electricity. Natural thorium can be irradiated with neutrons as follows to produce the important isotope ²³³U:



While thorium itself is not fissionable, ²³³U is, and in this way may be used as a nuclear fuel. One pound of completely fissioned uranium has the fuel value of over 1500 tons of coal.

The uses of nuclear fuels to generate electrical power, to make isotopes for peaceful purposes, and to make explosives are well known. The estimated world-wide capacity of the 429 nuclear power reactors in operation in January 1990 amounted to about 311,000 megawatts. Uranium in the U. S. is controlled by the U. S. Nuclear Regulatory Commission. New uses are being found for depleted uranium, i.e., uranium with the percentage of ²³⁵U lowered to about 0.2%.

Uranium is used in inertial guidance devices, in gyro compasses, as counterweights for aircraft control surfaces, as ballast for missile reentry vehicles, and as a shielding material. Uranium metal is used for X-ray targets for production of high-energy X-rays; the nitrate has been used as a photographic toner, and the acetate is used in analytical chemistry.

Crystals of uranium nitrate are triboluminescent. Uranium salts have also been used for producing yellow "vaseline" glass and glazes. Uranium and its compounds are highly toxic, both from a chemical and radiological standpoint.

Isotopes

Uranium has sixteen isotopes, all of which are radioactive. Naturally occurring uranium nominally contains 99.28305% by weight ²³⁸U, 0.7110% ²³⁵U, and 0.0054% ²³⁴U. Studies show that the percentage weight of ²³⁵U in natural uranium varies by as much as 0.1%, depending on the source. The U. S. Department of Energy has adopted the value of 0.711 as being their official percentage of ²³⁵U in natural uranium. Natural uranium is sufficiently radioactive to expose a photographic plate in an hour or so. Much of the internal heat of the Earth is thought to be attributable to the presence of uranium and thorium.

Radioactive Properties of Key Uranium Isotopes				
Isotope	Half-Life	Natural Abundance (%)	Specific Activity (Ci/g)	Decay Energy (MeV)
²³⁴ U	248,000 yr	0.0055	6.2×10^{-3}	4.8 α
²³⁵ U	700 million yr	0.72	2.2×10^{-6}	4.4 α 0.21 γ

Uranium is naturally radioactive, ^{238}U	4.5 billion yr	99.27	3.3×10^7	4.2 α
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which means that atoms of uranium are unstable and decay by emitting particles and energy. Uranium decays very slowly by emitting an alpha particle. The half-life of uranium-238 is about 4.5 billion years, which means it is not very radioactive. In fact, its very long half-life (and thus low radioactivity) is the reason uranium still exists on the Earth. Three additional isotopes of uranium are not naturally present but can be produced by nuclear transformations. These are uranium-232, uranium-233, and uranium-236. Like the natural uranium isotopes, these three also decay by emitting an alpha particle.

The isotope ^{235}U is important because under certain conditions it can readily be split, yielding a lot of energy. When the nucleus of a ^{235}U atom captures a neutron it splits in two (fissions), releases energy in the form of heat, and emits two or three neutrons. If enough of these expelled neutrons cause the nuclei of other ^{235}U atoms to split, releasing further neutrons, a fission ‘chain reaction’ can be achieved. This is the process that occurs in a nuclear reactor where the heat is used to make steam to produce electricity. Each fission of a ^{235}U atom releases about 200 MeV (3.2×10^{-11} joule)—about 50 million times as much energy as burning an atom of carbon. In other terms, a kilogram of natural uranium used in a typical reactor yields around 20,000 times as much energy as a kilogram of coal, and a kilogram of enriched nuclear fuel yields 160,000 times as much. Fission produces hundreds of different kinds of fission products (isotopes of much lighter elements), most of which are radioactive. In addition, a uranium atom may capture a neutron without splitting, leading the formation of a number of radioactive transuranic elements. These byproducts comprise nuclear waste.

Physical Characteristics of Uranium Compounds				
Compound	Melting Point (°C)	Crystal Particle (Density (g/cm ³))	Bulk (Density (g/cm ³))	Solubility in Water at Ambient Temperature
UF ₆	64.1	4.68	4.6	Decomposes to UO ₂ F ₂
UF ₄	960 ± 5	6.7	2.0 - 4.5	Very slightly soluble
UO ₂ F ₂	Decomposes to U ₃ O ₈ at 300	6.37	~2.6	Soluble
U ₃ O ₈	Decomposes to UO ₂ at 1,300	8.30	1.5 - 4.0	Insoluble
UO ₂	2,878 ± 20	10.96	2.0 - 5.0	Insoluble
Uranium metal	1,132	19.05	19	Insoluble

Chemical forms of uranium

Uranium can take many chemical forms. In nature, uranium is generally found as an oxide, such as in the olive-green-colored mineral pitchblende, which contains triuranium octaoxide (U₃O₈). Uranium dioxide (UO₂) is the chemical form most often used for nuclear reactor fuel. Uranium-fluorine compounds are also common in uranium processing, with uranium hexafluoride (UF₆) being the form used in the gaseous diffusion enrichment process. Uranium tetrafluoride (UF₄) is frequently produced as an intermediate in the processing of uranium. As noted above, in its pure form, uranium is a silver-colored metal. Because several of these compounds might be used or produced during the conversion process, a brief description of the physical and chemical properties of each is provided below.

Uranium Oxides (U₃O₈ and UO₂)

The most common forms of uranium oxide are U₃O₈ and UO₂. Both oxide forms are solids that have low solubility in water and are relatively stable over a wide range of environmental conditions. Triuranium octaoxide (U₃O₈) is the most stable form of uranium and is the form most commonly found in nature. Uranium dioxide (UO₂) is the form in which uranium is most commonly used as a nuclear reactor fuel. At ambient temperatures, UO₂ will gradually convert to U₃O₈. Because of their stability, uranium oxides are generally considered the preferred chemical form for storage or disposal.

Uranium Hexafluoride (UF₆)

Uranium hexafluoride (UF₆) is the chemical form of uranium that is used during the uranium enrichment process. Within a reasonable range of temperature and pressure, it can be a solid, liquid, or gas. Solid UF₆ is a white, dense, crystalline material that resembles rock salt. Uranium hexafluoride does not react with oxygen, nitrogen, carbon dioxide, or dry air, but it does react with water or water vapor (including humidity in the air). When UF₆ comes into contact with water, such as water vapor in the air, the UF₆ and water react, forming

corrosive hydrogen fluoride (HF) and a uranium-fluoride compound called uranyl fluoride (UO_2F_2). For this reason, UF_6 is always handled in leak-tight containers and processing equipment. Although very convenient for processing, UF_6 is not considered a preferred form for long-term storage or disposal because of its relative instability.

Uranium Tetrafluoride (UF_4)

Uranium tetrafluoride (UF_4) is often called green-salt because of its characteristic color. It is generally an intermediate in the conversion of uranium hexafluoride (UF_6) to either uranium oxide (U_3O_8 or UO_2) or uranium metal, because it can be readily converted to any of these forms. UF_4 is a solid composed of agglomerating particles with a texture similar to baking soda. It is non-volatile, non-hygroscopic, but only slightly soluble in water. After exposure to water, UF_4 slowly dissolves and undergoes hydrolysis, forming several possible uranium compounds and hydrogen fluoride (HF). The time for hydrolysis can be significant. Although not as stable as the uranium oxides, several recent studies have indicated that UF_4 may be suitable for disposal.

Uranium Metal

Uranium metal is a heavy metal, which is silvery white, malleable, ductile, and softer than steel. It is one of the densest materials known (19 g/cm^3), being 1.6 times more dense than lead. Uranium metal is not as stable as the molecule triuranium octaoxide (U_3O_8) or uranium dioxide (UO_2) because it is subject to surface oxidation. It tarnishes in air, with the oxide film preventing further oxidation of massive metal at room temperature. Water attacks uranium metal slowly at room temperature and rapidly at higher temperatures. Uranium metal powder or chips will ignite spontaneously in air at ambient temperature.

Handling

Finely divided uranium metal, being pyrophoric, presents a fire hazard. Working with uranium requires the knowledge of the maximum allowable concentrations that may be inhaled or ingested. Recently, the natural presence of uranium in many soils has become of concern to homeowners because of the generation of radon and its daughters.

Further reading

- [WNA Education Paper on Uranium](#)
- [World Energy Council, Survey of Energy Resources](#)
- [Uranium data at the U.S. Department of Energy](#)

Source:

<http://www.eoearth.org/view/article/51cbef217896bb431f69c952/?topic=51cbfc78f702fc2ba8129e5f>