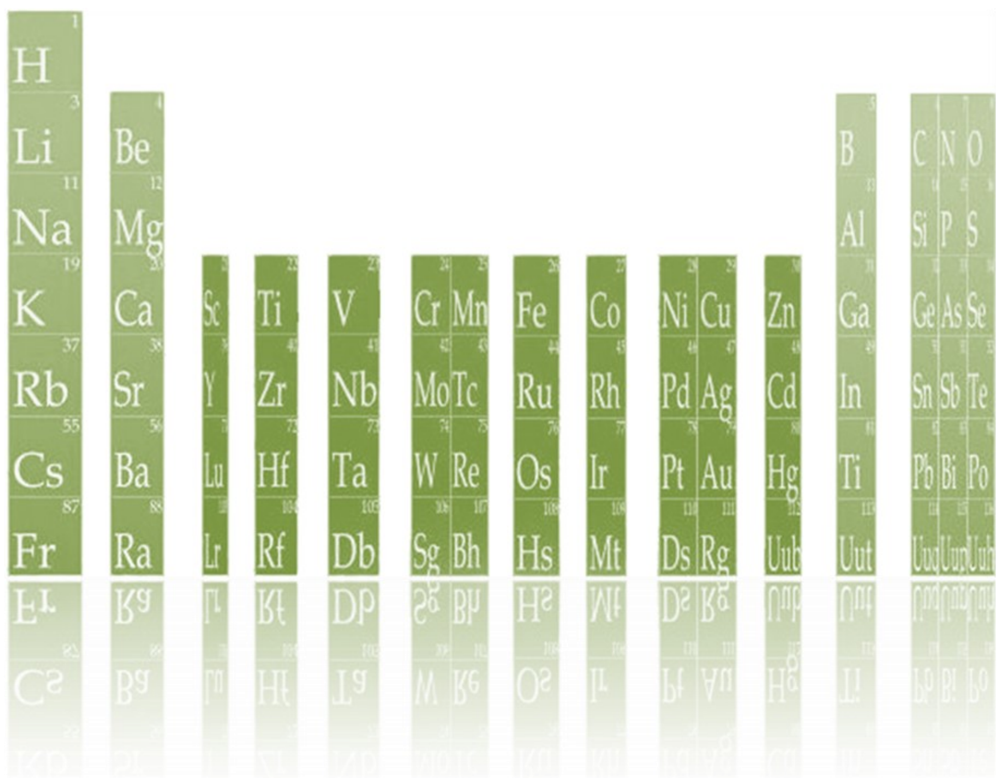
A UNEVERSE OF

ELEMENTS

An Encyclopedia of the Chemical Elements



ABDELRAHMAN ELBESHIR

ASSOCIATE PROFFESSOR

UNIVERSITY OF SHENDI

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

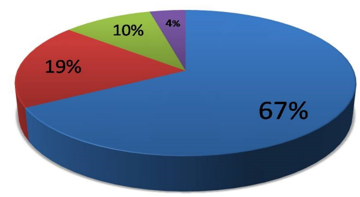
أَلَمْ تَرَ أَنَّ ٱللَّهَ أَنزَلَ مِنَ ٱلسَّمَآءِ مَآءً فَأَخْرَجْنَا بِهِۦ ثَمَرَٰتٍ مُّخْتَلِفًا أَلْوَٰنُهَا ۚ
وَمِنَ ٱلْجِبَالِ جُدَدٌۢ بِيضٌ وَحُمْرٌ مُّخْتَلِفٌ أَلْوَٰنُهَا وَغَرَابِيبُ سُودٌ
﴿٢٧﴾ وَمِنَ ٱلنَّاسِ وَٱلدَّوَآبِّ وَٱلْأَنْعَٰمِ مُخْتَلِفٌ أَلْوَٰنُهُۥ كَذَٰلِكَ ۗ
إِنَّمَا يَخْشَى ٱللَّهَ مِنْ عِبَادِهِ ٱلْعُلَمَٰٓؤُا۟ ۗ إِنَّ ٱللَّهَ عَزِيزٌ غَفُورٌ ﴿٢٨﴾

سورة فاطر (27 - 28)

To my family
with all my love

PREFACE

Diverse but in harmony … are the chemical elements ... the mysterious components of the earthly life and the building blocks of our universe are worthy of pondering. they make our bodies, our home, our food and the air that we take in or cast out. They make the burning sun and the cool moon. They are the components of everything seen or unseen, no matter how far or near, how small or huge…



90% of the of the human body mass is formed of 3 elements

My idea was to write an article dealing with the chemical elements as an essential subject for science students. Sources of information included textbooks, scientific journals, lectures, magazine articles, internet web cites and science and science history encyclopedias. The outcome was scientific facts as well as a broad general scientific knowledge that could not be withheld from the non-specialized reader. The project ended up with replacing the exclusive idea of the draft of a chemistry book by an Encyclopedia of the Chemical Elements hoping to meet the following objectives:

Goal I. To provide a concise reference dealing with the nature and the properties of the chemical elements for teachers, researchers and students in the fields of natural sciences, medical sciences and biology, and in the fields of chemistry, physics and geological sciences in particular.

Goal II. To provide the public library by a cognitive cultural dictionary of chemical elements presented as an important material related to the general public in a simple and logical sequence for a non-specialized reader(without chemical formulae or equations).

The study provides an opportunity to familiarize the reader with the general characteristics of chemical elements and their compounds and aims to extract (scientific) knowledge from documented sources that answer many questions such as: What are the essential elements for life and what are their role and their natural sources. It will give correct answers to queries like: what is the heaviest element or what is the hardest or costliest? and will answer questions like what is red mercury or yellow chromium, or what is the difference between white phosphorous and black phosphorous, or how enriched uranium differs from depleted uranium.

The Encyclopedia is presented according to the general classification of the chemical elements into three main groups: the metallic elements, the non-metallic elements and the metalloids. One hundred elements are presented according to their order in the periodic table (according to atomic number).

SUPPLEMENTS

The web site ***Alchemy.com*** is designed to provide students and researchers with important data including tables and graphical representations of different chemical and physical properties sorted in different manner. It includes maps of geographical sites of mineral ores and links to the most smart mineral photos and galleries.

Acknowledgments

With great pleasure I wish to thank my colleagues in the faculty of science and technology at the university of Shendi who reviewed the content and made helpful comments. My deepest appreciation goes to all friends and academic staff who assisted in preparation of materials or contributed in other ways to improve the text. I was extremely fortunate to have acquaintance with people like Dr. Nino Cutic who made an important contribution by his kind offer of copyright of all the assimilated atomic spectra presented in this book. I owe special thanks to Dr. John Bettes professor Rob Lavensky and Max Whiteby who contributed to this project by kindly permitting copyright of different mineral images.

Iam indebted to all photographers and researchers who provided smart mineral images in the Wikipedia under GNU Free Documentation License. In this respect I wish to thank Chris Ralph, Dave diet, Daniel Cewen, Andreas scalp (Andel), Tor Sevenson, Didier Descouens, Alchemist-hp, Stowarzyszenie Spirifer, Tillman, Tomihahndorf, Benjahbmm27, Didier Descouens, *Svdmolen,* Arpingstone, Skatebiker, Ondrej Mangl, Dennis, *Mstroeck,* Cory Doctorow, Hannes, Xvazquez, Jurii. *,* JJ Harrison, Skatebiker and Armatung whose work was important for students and researchers particularly in the field of Earth Sciences . I wish to thank my sons , Kamaleldin, Omer and Ahmed (Dido) who made a major contribution by undertaking the work of programming and designing of the book.

CONTENTS

Chapter 1

Introduction

THE MYSTERY OF MATTER

Starting from the material of this paper, and everything around you, ending with the perspective universe with all its consistent celestial bodies and constellations.... All this creation is made up of less than 90 chemical elements which are perfectly organized to give rise to the diverse components of our earthly life.

Concern with the nature of mater started since the dawn of history when Philosopher's and Middle Ages scientists carried out their search under the control of occultism and magic work. They were influenced by the Hellenistic philosophy and the assumption of Aristotle in the fourth century BC that defined the four components of matter as fire, air, water and soil and assumed that different materials were simply made of different ratios of these four elements. The idea of converting base metals such as iron and copper to gold and silver endeavored scientists and wealth seekers to continue the search in the nature of matter.

Of course no one succeeded in obtaining the precious metal, but, undoubtedly, those efforts paved the way for future efforts that continued throughout the ages to end up with the emergence of modern theories and scientific knowledge. It is worth mentioning that synthesis of elements or transference of an element into another (transmutation) presents no miracle after the development of modern nuclear physics and the implementation of particle accelerators. This finally fulfilled the dreams of scientists but not the hopes of wealth seekers that remain elusive as the cost of an artificially prepared element is many orders of the precious natural element.

THE ARAB EMPIRE

Towards the eighth century AD the Roman Empire was collapsing and the path of knowledge and scientific development was turned over towards the rising Arab State.

Arab scientists and philosophers continued the search for the origin of matter while still influenced by the theory of the four batters and by the overwhelming idea of the discovery of the Philosopher's Stone or elixir that heals diseases and turn base metals into gold and silver. The Arab assumption defined the three components of matter as sulfur, mercury and salt.

Jabir ibn Hayyan (721 - 815) was the first major alchemist. He opposed the old concepts and refused the Hellenistic theories. The idea of element transformation was thus ruled out. Jabir discipline is considered to be the foundation of modern scientific research. He was the first to call for extraction of information through practical trials, scientific reasoning and adoption of experimental methods. His address to disciples was (My son… you must use experiment to get knowledge). He developed the first steps to classify the elements in three main groups: “The Spirits” or volatile elements including arsenic, sulfur and mercury; “Metallic Bodies” like gold, silver and copper and “The stone bodies” or non-ductile elements (nonmetals).

Portrayed of Jabir

(The Father of chemistry)
815 -721

Jabir practiced extraction and distillation techniques and devised apparatus which are routinely used in today's chemical laboratories.

Research was continued by scientists like Al-Kindi (805 - 873) the author of (Refutation of the Claim of Those Who Claim the Artificial Fabrication of Gold and Silver) and Abu Bakr al-Razi (865—925), and the philosopher Avicenna (980-1037), who discredited the theory of transmutation of elements by saying (Despite of the apparent change, no change can be affected in different species of substances).

The ninth century witnessed the foundation of the contemporary scientific knowledge and the uprising of writing and translation work in different fields of science. More than 200 manuscripts were attributed to Abu Bakr al-Razi alone, the most famous is his chemistry book (The Secret of Secrets) which was translated to several languages and adopted as a reference in European universities until the seventeenth century.

THE RENAISANCE

The end of the thirteenth century AD was the beginning of what became known as the Renaissance in Europe, which coincided with the decline of the Arab states. A new civilization flourished and scientific development was to be redirected towards the west, but this time it was based on more solid scientific grounds and freed from acts of deceit, magic and myths of the Middle Ages.

The European countries were liberated and societies were freed from feudal laws and the pace of development increased due to economic growth and the discovery of the new world and with its rich quarries. Institutes and universities were established and research work was carried out by scientists and Philosopher's who were freed from Church restrictions.

The English Robert Boyle (1627-1691) put forward his 'modern theory' in which he concluded that matter contains indivisible components. Then the British scientist John Dalton (1766-1844) established the idea of individual units of matter (the atoms) in his atomic theory.

FROM CLASSICAL PHYSICS TO MODERN THEORIES

Towards the end of the nineteenth century it was revealed that the atom itself was composed of minute micro units and Michael Faraday (1791 -1867) had observed (during his experiments in electrolysis) the relationship between the amount of electricity and the amount of the precipitated matter from an element and suggested the relationship between atoms and units of electricity, which he named electrons. Subsequent studies of the cathode ray in vacuum tubes by Joseph Thompson (1856 -1940) also resulted in the identification of the electron and its properties. Then Millikan (1868 - 1953) succeeded to practically count the charge of a single electron for the first time and to prove that this charge is quantized (fixed quantities). In 1911 his student Rutherford suggested the nuclear model that described the atom to be made up of a central core (nucleus) containing protons that carry a positive charge and surrounded by electrons and that the nucleus represent 1 of 10,000 of the volume of the atom and more than 99.95% of its mass. In 1932 the neutron was discovered and described as an electrically neutral unit found in the nucleus and has the same mass of the proton, and that the number of protons in a nucleus is characteristic of the element (atomic number).

The discovery of the photoelectric effect and the atomic spectra and the knowledge of the relationship between the frequency of light and energy were the keys that opened the doors to understand the internal structure of the atom.

Max Planck (1858 - 1947) put forward the assumption of the dual character of light (wave-particle duality) which was confirmed by Albert Einstein (1905) who was studying the photoelectric effect and who named these entities of energy as quanta or photons. It was finally concluded that the distinction between matter and energy which is seen in the macroscopic world is not actually inherent in nature.

Scientists observed that if light energy emitted by a thermally or electrically excited body is passed through a prism of glass, it shows wavelengths (atomic spectra) specific for each element. Niels Bohr (1885-1962) was the first who presented a visualization of the internal structure of the atom by using the idea of electronic orbitals to explain the line spectrum in his quantum theory.

Einstein theories explained quantum mechanics , proved the existence of the atom and solved the puzzling wave-particle duality . The evolution of modern particle physics in the 1950s was followed by the invention of particle accelerators and particle analyzers which was the breakthrough that lead to important theories and great discoveries including subatomic particles, antimatter and cosmic background radiation.

Protons and neutrons (nucleons) as well as electrons are recognized as members of a class of matter known as fermions. Protons and neutrons are classified as "baryons" which are composite particles composed of three quarks.

Quarks are subatomic particles that differ in their charges and exist as two main types (up-quarks and down quarks) and held together by forces provided by virtual particles known as gluons. Quarks and gluons are thus, the basic building blocks of all known matter.

Leptons, on the other hand are elementary particles which are not composed of quarks. They include electrons as well as three types of extremely low mass neutral matter particles known as neutrinos. Neutrinos are produced in the sun and in other stars, and are also produced in beta decay processes but the majority of neutrinos are believed to be created in the first fractions of a second following the Big bang. These tiny particles, which travel at about light velocity are neutral and stable and have very week interaction with other matter. Billions of neutrinos are continuously reaching the surface of the earth with cosmic rays. It is believed that about 50 trillion neutrinos pass through the human body every second.

At least twenty two types of elementary particles and about twenty hypothetical elementary particles are now recognized. For every matter particle there is a corresponding antimatter particle that differ only in electrical properties. These antiparticles form what is known as the antimatter of the universe.

CREATION OF THE UNIVERSE

The creation of matter and the origin of life continue to be the enigma that puzzled scientists throughout the ages. Scientists wonder whether theoretical interpretations put forward by physics will ever be proved. They need to find out the nature of the cosmic microwave background radiation and to confirm that it is black-body radiation. Are neutrinos constitute dark matter and are Higgs Bosons will ever be detected are other questions waiting to be answered.

According to the *Standard Model Theory* all the known matter particles are composites of 6 quarks, 6 leptons and a number of force carrier particles such as photons and gluons.

The most accepted theory of creation is the Big Bang Theory which is based on studies of emissions from exploding stars (supernovas). Another theory is the Steady State theory which suggests that the universe is static (infinitely old and infinitely large).

The Big Bang theory assumes that more than ten billion years ago all (*available matter)* collapsed in a small unit with an imaginable high density and temperatures reaching tens of millions of degrees. The result was a massive explosion (Big Bang).

Within a fraction of a second a thermonuclear process started. The fuel involved included all available *matter, antimatter, photons and exotic (undefined) matter* available. The theory assumes that matter, energy, time and space were all created at that instant following the Big Bang. Cosmic background radiation and exotic matter are considered by astronomers as footprints of the Big bang.

The Space-Time Theorem of General Relativity, a product of recent solution of Einsteinium General Relativity theory, suggests an ultimate origin for creation, dimensions and even time and hence, supports the idea of a non-static universe. The detection of cosmic background radiation, the establishment of the existence of the exotic matter and the expansion of the universe which was confirmed by Einstein theory of relativity are disproves of the Steady State theory.

The Big Bang is believed to be responsible for providing hydrogen necessary for the formation of stars. Hydrogen isotopes are fused in the interior of stars to form helium nuclei which in turn fuse to form heavier elements.
The thermonuclear processes continues until the iron nucleus is formed and the star reaches an old age. Iron is characterized by the highest value of binding energy. At this stage the fusion process slows down. The star is running out of fuel and is reaching the end of its life.
A massive star may suddenly expand and undergo a violent explosion that produces –in a very short time tremendous energy and becomes a supernova. The explosion produces enough energy to overcome the energy barrier of higher mass elements which are born in the core of these supergiant stars. If a star is greater than thirty solar masses it might become a black hole.
This was the birth of the universe which started to expand and to gradually cool down as it was setting up clusters of galaxies, containing trillions of stars. Smaller stars and planets including our earth were unsewed. Together with other planets our earth orbits around the sun. Our sun is one of billions of stars that collect in the Milk Way galaxy which is one member of a cluster of galaxies.
It is believed that most stuff in these clusters is not yet detected and scientists conclude that most of the entire universe is made of an invisible *matter* which they simply call dark matter.
Chemical combinations took place to make conditions favorable on our planet. Dead stars and Supernova debris were responsible for the production of heavy elements found in the core and on the crust of the earth. The earthly life gradually started in a perfect order, with all forms of life chemistry including deserts, green forests, rivers, animals, and finally Adam and Eve!

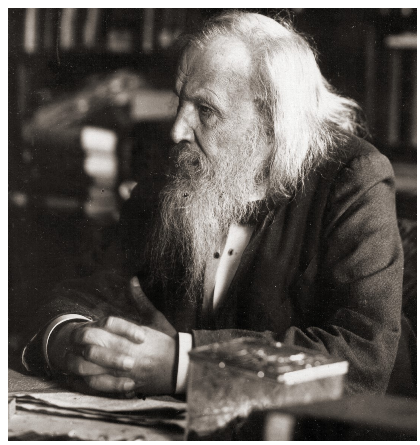
THE LARGE HADRON COLLIDER (LHC)

Continuous efforts to unlock some of the secrets of creation ended with the establishment of the Large Hadron collider (LHC) in the French-Swiss border. It is a huge particle accelerator housed in a 27- km- long underground tunnel. The aim of the project was to recreate conditions of the Big Bang and learn the consequences that lead to cosmic evolution in the first few microseconds that followed the Big Bang.
Collision of lead atoms which were accelerated at enormous speed and incredible temperatures exceeding ten trillion degrees resulted in smashing of atoms.

A melt of nuclear matter containing fundamental particles including quarks and gluons has been reported to be seen for the first time. Scientists also announced that a number of antihydrogen atoms (antimatter) were successfully prepared and preserved for some milliseconds before being annihilated with the surrounding normal matter and both to vanish in a flash of light..

THE PERIODIC TABLE OF THE ELEMENTS

In 1869 the Russian scientist Mendeleev arranged 63 known elements based on atomic mass in a table known as the Mendeleev periodic table of the elements. His table did not include noble gases but some spaces were left for yet-to-be discovered elements including elements 5 and 14 (boron and silicon).



Dmitri Mendeleev

1834—1907

Establishment of the quantum theory lead to more understanding of the nature of the internal structure of atoms and provided a theoretical foundation for the modern periodic table's arrangement in which the elements are arranged according to their atomic numbers (number of protons).

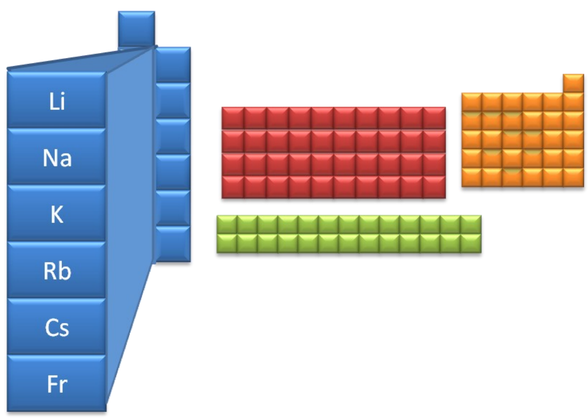
In 2007 the number of known chemical elements reached 117. Elements with atomic numbers 83 or more are unstable (radioactive). Those with atomic numbers higher than 95 are radioactive and do not exist naturally and are artificially synthesized from heavy elements through nuclear transformations. Elements from 83 to 94 are also radioactive and unstable, but are found in nature, either due to their long half-lives or because they are constantly being bread as a result of spontaneous decay of other radioactive elements. Elements of atomic numbers 83 or less are all stable except for the element number 43 (technetium) and the element number 61 (promethium).

Chemical compounds are the product of the union of two or more elements and most of the elements are found as compounds with the exception of the noble elements such as gold, platinum and the noble gases which usually exist naturally in their free elemental form. More than 10 million chemical compounds are now known.

Chapter 2

Alkali metals

The Alkali metals are the members of the first group in the periodic table. They are silver– white and their metallic characteristics increase down the the group (this is the usual trend in other groups of the Periodic Table). Thus, lithium (atomic number 3) shows the weakest metallic properties while francium (atomic number 87) is the most active alkali metal.



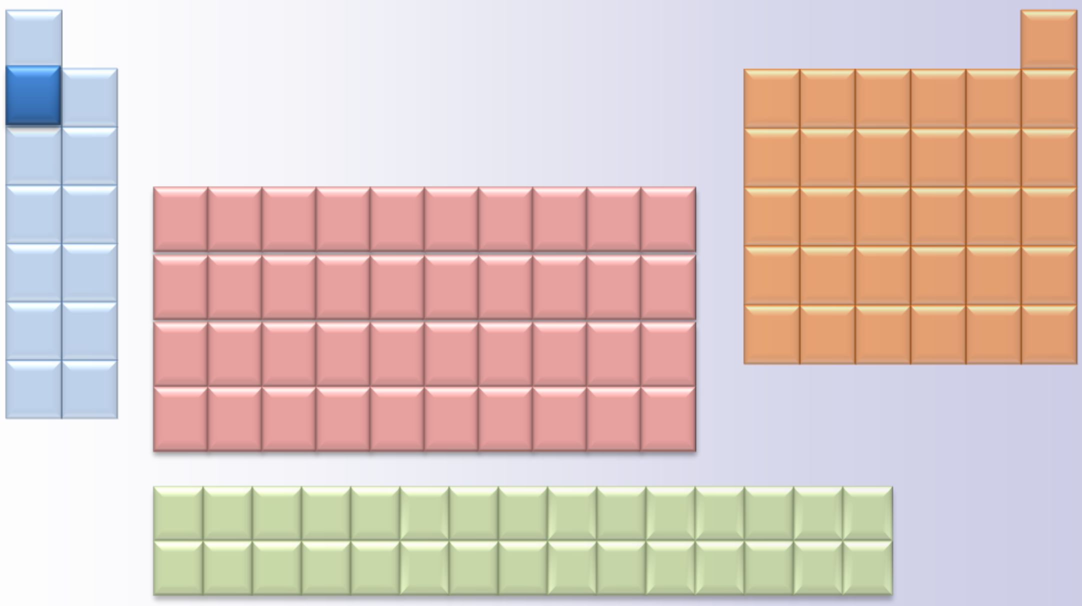
Hydrogen is a non-metallic element that belongs here by name only and is put on the top of this group only because of its atomic number.

Due to their chemical reactivity, the alkali metals are found naturally in the form of compounds such as sodium chloride (table salt) and never occur free in nature. They are rapidly oxidized in the air and explode in cold water with the evolution of hydrogen gas and the formation of highly alkaline solutions (to avoid hazards, alkali metals are handled carefully and are stored in very dry conditions, such as an atmosphere of an inert gas or dry kerosene).

Alkali metals are characterized by low values of density and low melting point temperatures. They show the lowest ionization energies among the elements of the periodic table.

Pure alkali metals are industrially prepared through the electrolysis of their molten salts.

Lithium Li



Lithium is a soft silvery-white alkali metal characterized by the highest specific heat and the lowest density among all the solid elements (lithium density is equivalent to half the density of water).

Lithium occurs naturally - only chemically combined - in volcanic rocks in lipidolite and patalite ores but the crude element is commercially obtained from spodummen ores and mineral water springs. The pure metal can be obtained through the electrolysis of the molten chloride.

Spodumine

(Lithium aluminum silicates)

-Afghanistan -

Lithium in paraffin oil

Lithium is chemically active. It reacts with cold water (but less vigorous than sodium and potassium) and is the only common metal that reacts with nitrogen at room temperature.

The freshly cut metal oxidizes rapidly in air to form a dark layer of the oxide and automatically ignites at a temperature of 200 **°C** (lithium should be stored submerged in dry mineral oil or kerosene or in an atmosphere of an inert gas). Lithium and its compounds are used in glass and grease formulations and in the manufacture of light and high performance alloys with aluminum, copper, manganese, and cadmium

Li Lithium , 3

Pure lithium metal is used in rechargeable lithium ion batteries.

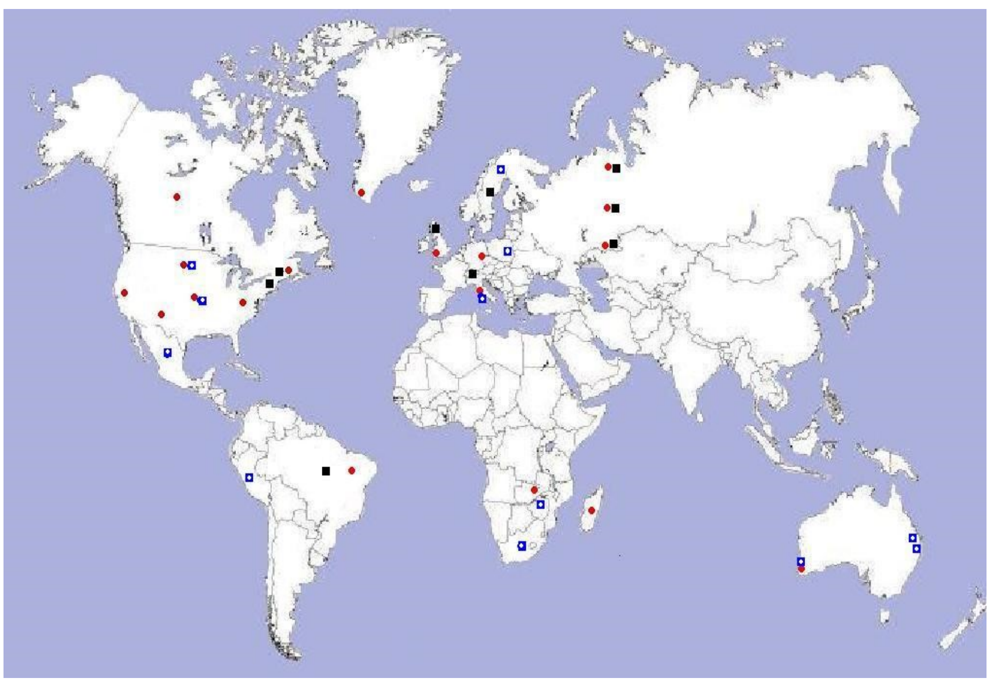
Lithium carbonate and lithium citrate are ingredients of anti-depression and mania drugs.

Lithium hydroxide is a strong alkaline material that reacts with fats and oils in the manufacture of lithium soap. It is also used to purify indoor air (inside aircraft, for example) by absorbing carbon dioxide resulting from breathing and tobacco smoke.

Lithium has a number of applications in the nuclear power field . It is used as a coolant in nuclear breeder reactors and is bombarded with neutrons in nuclear reactors to produce tritium and lithium deuteride. The latter compound is the fusion fuel in the thermonuclear weapon (Hydrogen bomb).

Methyl lithium and a number of alkyl lithium compounds are important organometallic reagents in the field of preparative organic chemistry.

Mineral ore locations



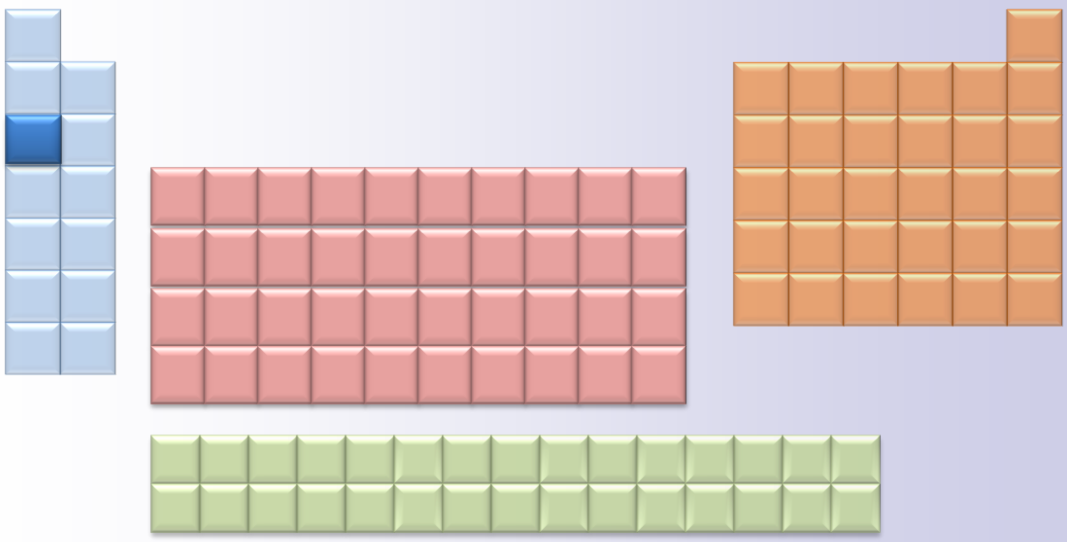
■ Lipidolite ▫ Patalite ● Spodumen

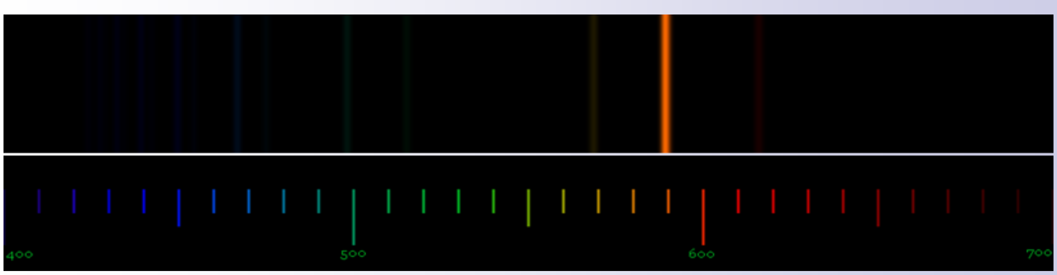
Li Lithium , 3

Physical and chemical properties

Symbol	Li	Relative atomic mass	6.941
Atomic number	3	Melting point (°C)	180.54
Group	1	Boiling point (°C)	1346.85
Period	2	Specific heat (J/g.K)	3.582
Family	Alkali metals	Oxidation numbers	+1
Physical state (20°C)	solid	Electronegativity (pouling)	0.98
Atomic radius (pm)	152	Thermal conductivity (W/m.K)	84.7
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	4.60
Electronic configuration	$[He]2S^1$	Heat of vaporization (kJ/mol)	134.7
Molar volume(cm3/ mole,273K)	13.00	Ist. ionization potential (kJ/mole)	513.3
Density (g/cm3)	0.534	2nd.Ionization potentia l(kJ/mole)	7298.0
Number of isotopes	5	3rd. ionization potential (kJ/mol)	11814.8

Sodium Na





Sodium is a soft, silvery- white metal with a bright luster that disappears on exposure to air. It is the most abundant alkali metal in nature and its abundance is estimated at about 8 .2% of the mass of the earth's crust. It occurs only in the form of compounds and the most common minerals are halite rocks (rock salt), cryolite and zeolite. Large quantities of the element are found in sea water in the form of sodium chloride.

Sodium is chemically very active. It explodes in cold water producing hydrogen gas which catches fire as a result of the high temperature of the reaction (sodium should be stored submerged in dry kerosene or mineral oil or in an atmosphere of an inert gas).

The most commercially important metal compound is sodium chloride. It is obtained from seawater, halite ores and from the deposits of salt lakes.

Sodium metal

Halite

The mineral form of sodium chloride

Crystals are usually blue, pink or yellow due to inclusion of impurities of copper, dead algae or defects on crystal lattice

Sodium chloride or table salt is used in human food since ancient history .It represents the chief raw material for the industrial production of the pure metal through the electrolysis of the molten chloride in Downs cell where chlorine gas is obtained as a by-product.

Due to its strong drying and antibacterial action sodium chloride is widely used in sterilization and in food preservation. It is also used in the process of 'salting' in the early stages of tanning to protect the animal leather from bacterial damage.

Sodium carbonate is used with sand (silica) in detergents and in glass industry. Sodium bicarbonate (baking soda) is used in food industry and the hydroxide (caustic soda) is reacted with oils and fats in the manufacture of soap.

Na Sodium , 11

The high intensity of sodium emission allowed the use of the element in the manufacture of incandescent lamps (sodium vapour lamps).

A sodium-potassium alloy which is liquid at room temperature is used as a heat transfer fluid in some nuclear reactors and other applications.

Sodium phosphate is used in detergents and in the pharmaceutical industry, and the sulphate is used in glass, detergents and paper industries.

The sodium ion has a vital role in nerve transmission, muscle contraction and maintenance of blood pressure and, together with potassium, sodium is responsible for the regulation of water balance inside the living cell.

Sodium vapor lamp

is more safe than the mercury vapor lamp

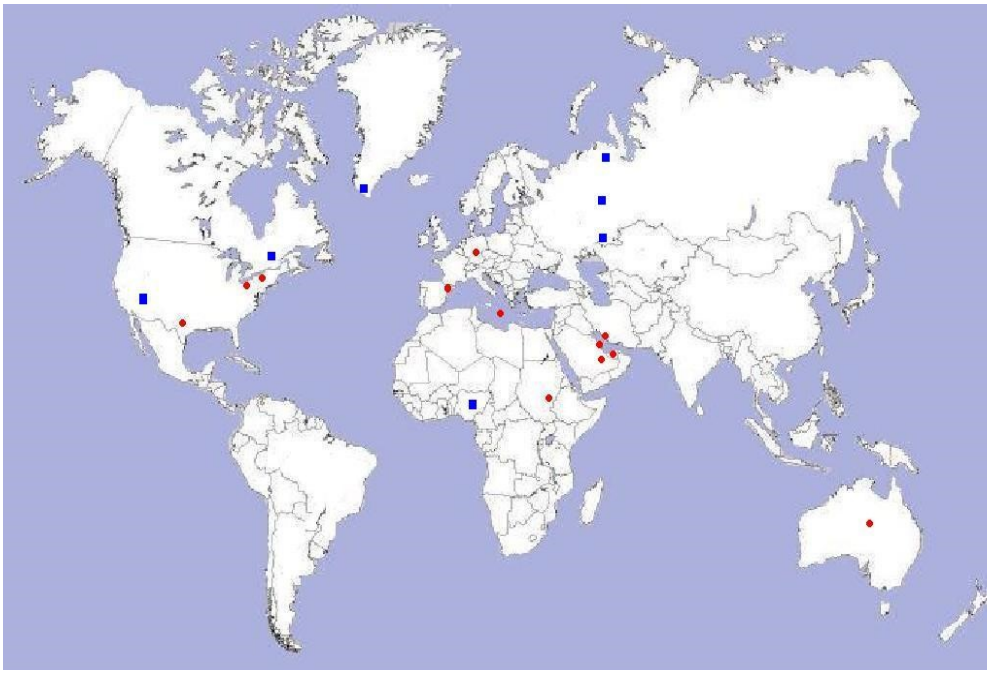
Sodium chloride

Na Sodium , 11

Physical and chemical properties

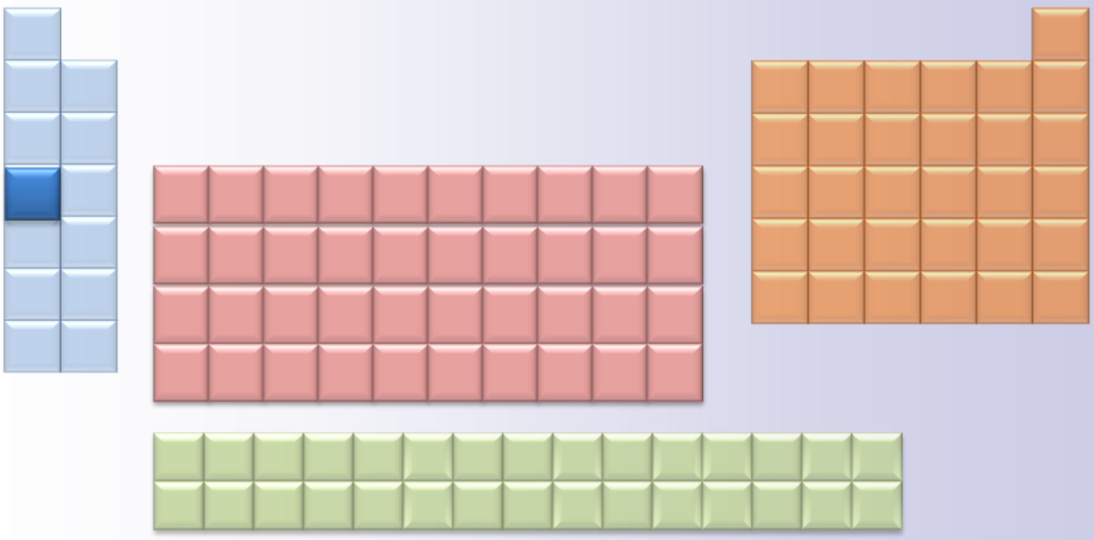
Symbol	Na	Relative atomic mass	22.990
Atomic number	11	Melting point (ºC)	97.81
Group	1	Boiling point (ºC)	882.95
Period	3	Specific heat (J/g.K)	1.228
Family	Alkali metals	Oxidation numbers	+1
Physical state(20°C)	solid	Electronegativity (pouling)	0.93
Atomic radius (pm)	153.7	Thermal conductivity (W/m.K)	141
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	2.64
Electronic configuration	$[Ne]3S^1$	Heat of vaporization (kJ/mol)	89.04
Molar volume(cm3/ mole,273K)	23.68	Ist. ionization potential (kJ/mole)	495.8
Density (g/cm3)	1.444	2nd.Ionization potential (kJ/mole)	4562.4
Number of isotopes	14	3rd. ionization potential (kJ/mol)	6912

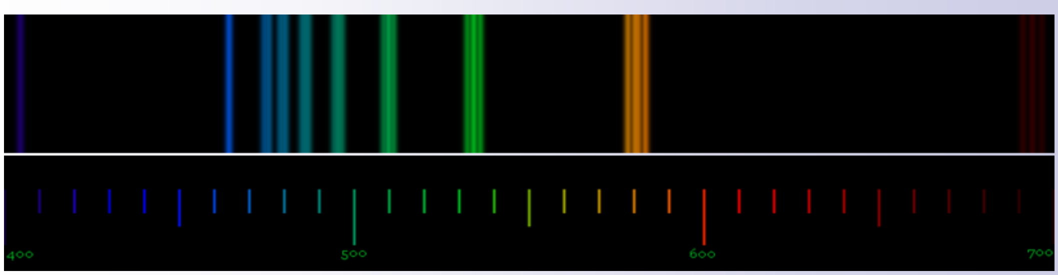
Mineral ore locations



■ Cryolite ● Halite

Potassium K





Potassium is a soft, silvery-white metal found naturally in the form of salts in karnalyte and sylvite rocks and in waters of mineral springs.

Potassium is chemically very active. It oxidizes rapidly in air and explodes in cold water forming the hydroxide and hydrogen gas which catches fire as a result of the high temperature of the reaction (the metal should be stored submerged in dry mineral oil or kerosene or in an atmosphere of an inert gas).

Potassium salts are components of a number of important industrial products: the nitrate, carbonate and the chloride are used in the manufacture of fertilizers. The bromide is used in photography and the iodide and citrate are used in the medical field.

Potassium cyanide , an extremely toxic substance, can dissolve noble metals and is widely used in gold mining. Potassium permanganate is a strong oxidizing agent and an effective bactericide. The chromate and the dichromate are strong oxidizing agents and color removers. They find use in different industries including leather tanning, dyes, fireworks and matches. Potassium chlorate and nitrate are also strong oxidizing agents and are used in the manufacture of ammunition and explosives.

Potassium is an essential mineral for both the animal and plant growth and is a prime factor in controlling the functions of nerve cells and muscles.

Sylvite

(Potassium chloride)

Potassium is available in most foods, particularly in vegetables and fruits

K Potassium , 19

Together with sodium, potassium is necessary for the regulation of water balance inside the living cell.
Potassium bromate is a white poisonous salt and a powerful oxidizing agent which has been widely used to improve the quality of bread and pastry. The compound is toxic and carcinogenic but is readily disintegrated if sufficient heat is applied.
Bromated bakery products were prohibited in Europe in 1990 and afterwards in most other countries of the world.

Mineral ore locations

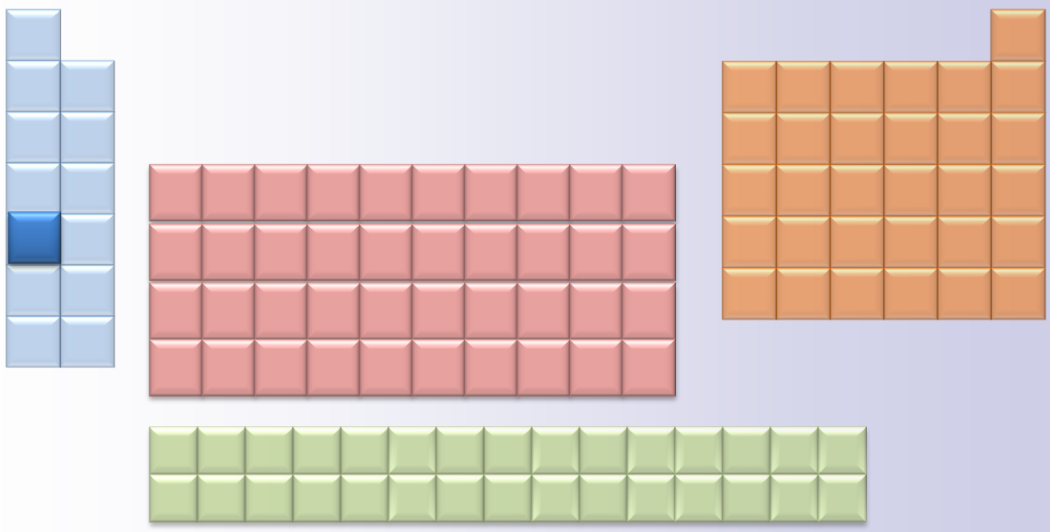
■ Sylvite •Karnalyte

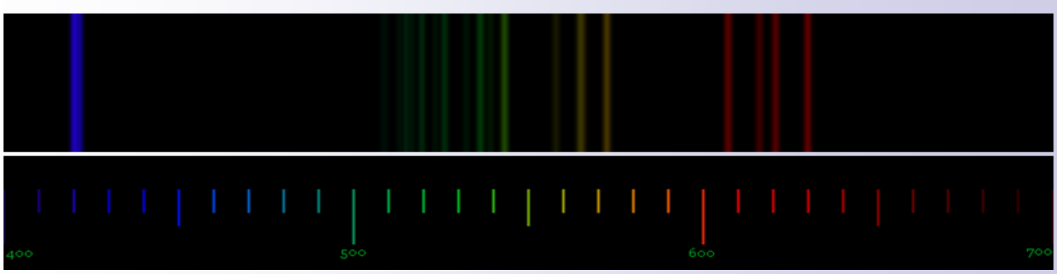
K Potassium , 19

Physical and chemical properties

Symbol	K	Relative atomic mass	39.098
Atomic number	19	Melting point (ºC)	63.65
Group	1	Boiling point (ºC)	773.85
Period	4	Specific heat (J/g.K)	0.757
Family	Alkali metals	Oxidation numbers	+1
Physical state (20°C)	solid	Electronegativity (pouling)	0.82
Atomic radius (pm)	227	Thermal conductivity (W/m.K)	102.4
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/ mol)	2.40
Electronic configuration	$[Ar]4S^1$	Heat of vaporization (kJ/mol)	77.53
Molar volume(cm3/ mole,273K)	45.36	Ist. ionization potential (kJ/mole)	418.8
Density (g/cm3)	0.862	2nd.Ionization potential (kJ/mole)	3051.4
Number of isotopes	18	3rd. ionization potential (kJ/mol)	4411

Rubidium Rb





Rubidium is a very soft , silvery-white metal that occurs naturally - in the form of the oxide - in the company of cesium ores (lepidolite and pollucite) and is commercially recovered from these ores. It also occurs in potassium ores and brines.
Rubidium is ranked second among the elements (after cesium) in terms of chemical activity, alkalinity and electropositivity. The metal spontaneously ignites in air and explodes in cold water with evolution of hydrogen gas, which catches fire as a result of the high heat of the reaction. It reacts with ice and with water at temperatures below -100 °C. (rubidium should be stored submerged in dry mineral oil or kerosene or in an atmosphere of an inert gas).

lepedolite

Lavender

California, USA

Lepedolite

Rose-red

- Brazil -

Lepedolite

Yellow

- Brazil -

Rb Rubidium , 37

Rubidium forms alloys with mercury (amalgam) and with gold, cesium, sodium and potassium. The element is important in designing of fiber optics components and in the processes of the eradication of oxygen and waste gas in vacuum tubes.

Rubidium salts are used in the manufacture of special types of glass and are utilized in fireworks to give the purple color.

The element is one of five metals that can be found in the liquid state near room temperature (together with gallium, cesium, mercury and francium).

Mineral ore locations

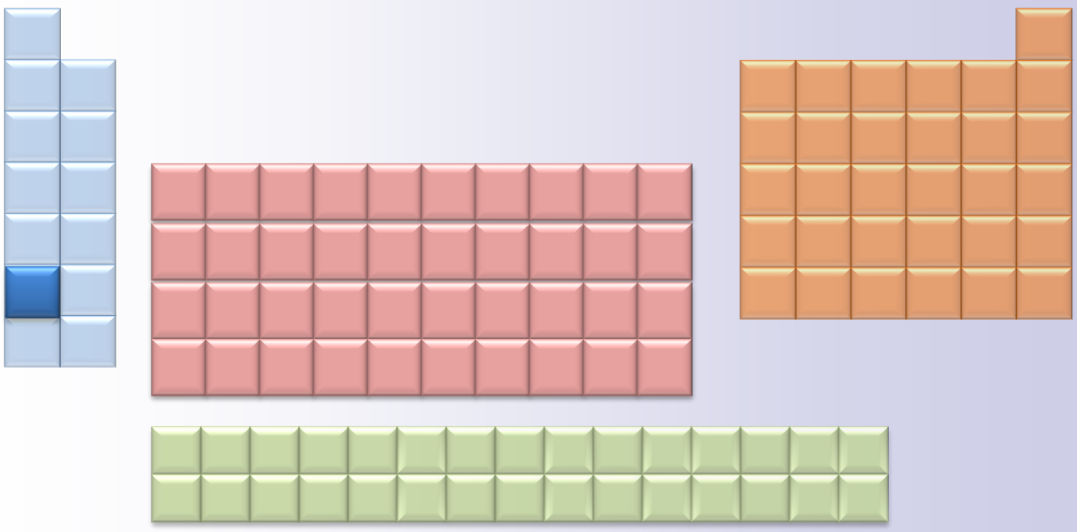
● Lepidolite

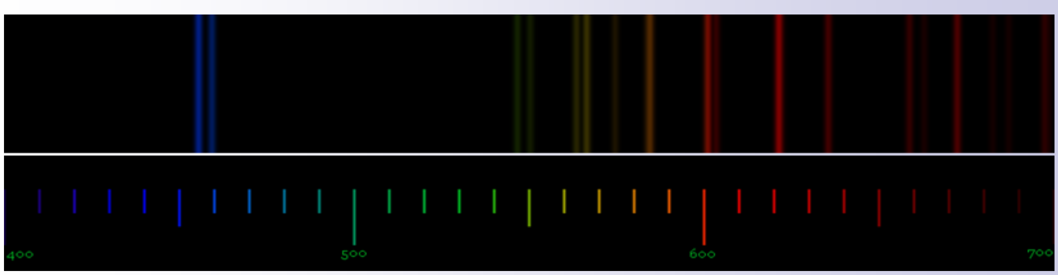
Rb Rubidium , 37

Physical and chemical properties

Symbol	Rb	Relative atomic mass	85.468
Atomic number	37	Melting point (ºC)	39.05
Group	1	Boiling point (ºC)	687
Period	5	Specific heat (J/g.K)	0.363
Family	Alkali metals	Oxidation numbers	+1
Physical state(20°C)	solid	Electronegativity (pouling)	0.82
Atomic radius (pm)	247.5	Thermal conductivity (W/m.K)	58.2
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	2.20
Electronic configuration	[Kr] $5S^1$	Heat of vaporization (kJ/mol)	69.2
Molar volume (cm3/mole,273K)	55.79	Ist. ionization potential (kJ/mole)	403.0
Density (g/cm3)	1.532	2nd.Ionization potential (kJ/mole)	2632
Number of isotopes	30	3rd. ionization potential (kJ/mol)	3900

Caesium Cs





Cesium is a soft and malleable silvery metal that occurs naturally in lepidolite and pollucite ores (aluminum and cesium silicates). The pure metal is usually obtained through the electrolysis of the molten cyanide.

Cesium is the most electropositive element after francium and is thus, one of the most chemically active elements. It spontaneously ignites in air and explodes in contact with cold water with evolution of hydrogen gas, which catches fire as a result of the high heat of the reaction . It even reacts with ice and with water at temperatures below -100 °C (Cesium should be stored submerged in dry mineral oil or kerosene or in an atmosphere of an inert gas).

Cesium is one of five metals that can be found in the liquid state at normal temperatures (together with gallium, rubidium, mercury and francium).

The most important compounds of cesium include the chloride, the nitrate and the hydroxide which is the strongest known alkali.

The element is used for the eradication of gases in closed electronic devices and is also used as a chemical intermediate (catalyst) in the hydrogenation process of vegetable oils.

Cesium is commonly used in the atomic clock which is characterized by very high-precision (precision within 5 seconds in every 300 years).

Time keeping here is based on the principle of oscillation (resonance) between the nucleus and the electrons in the outer orbits of atoms.

With the exception of francium, cesium is characterized by the largest number of isotopes among all the elements.

Pollucite

(Cesium Aluminum silicates)

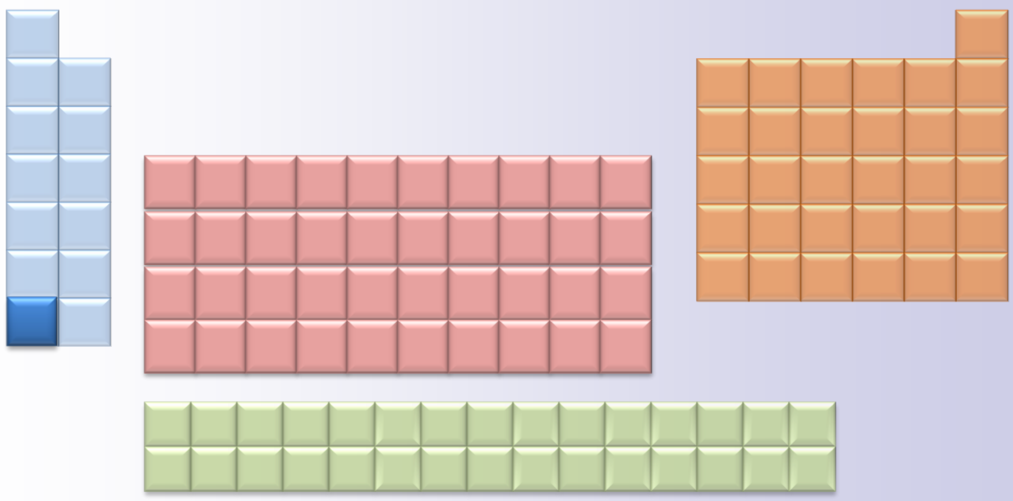
- Pakistan -

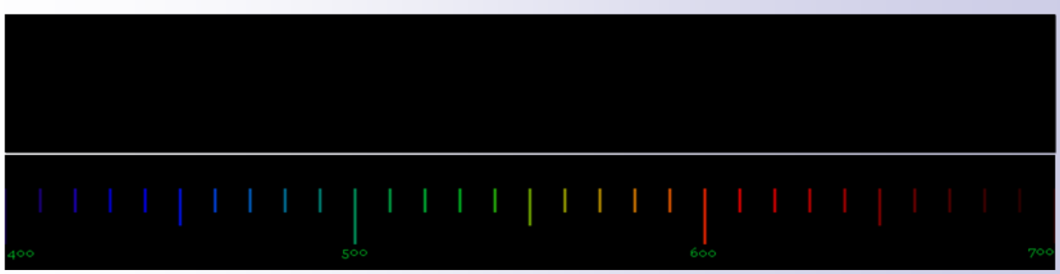
Cs Cesium , 55

Physical and chemical properties

Symbol	Cs	Relative atomic mass	132.905
Atomic number	55	Melting point (ºC)	28.33
Group	1	Boiling point (ºC)	678.33
Period	6	Specific heat (J/g.K)	0.242
Family	Alkali metals	Oxidation numbers	+1
Physical state (20°C)	solid	Electronegativity (pouling)	0.79
Atomic radius (pm)	265.4	Thermal conductivity (W/m.K)	35.9
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	2.09
Electronic configuration	[Xe]6S¹	Heat of vaporization (kJ/mol)	65.90
Molar volume(cm3/ mole,273K)	70.96	Ist. ionization potential (kJ/mole)	375.7
Density (g/cm3)	1.873	2nd.Ionization potential (kJ/mole)	2420
Number of isotopes	40	3rd. ionization potential (kJ/mol)	?

Francium Fr





Francium is a highly radioactive and one of the rarest elements in nature. It was predicted by Mendeleev (1870) but was only discovered in1939 to be the last natural element to be discovered.

Minute traces of francium occur in uranium and thorium minerals as a result of alpha disintegration of actinium-227 isotope which produces francium-223 that continues to decay into astatine, radium and radon.

Francium-223 is the longest lived isotope (half life 21.8 minutes) and the only isotope of francium occurring in nature. The element is artificially prepared through different pass ways but mostly by bombarding thorium with protons or radium with neutrons. However, no weighable quantity of the element has ever been prepared or isolated.

Francium is the heaviest alkali metal and the most electropositive element. It is characterized by the highest equivalent weight and is the least stable naturally occurring chemical element.

Because of its rarity and lack of stability there are no commercial applications for francium and the use of the element is limited to the fields of pure scientific research.

Francium is one of five metals that can be found in the liquid state near room temperature (together with gallium, rubidium, cesium, mercury).

Francium is the least stable element in the periodic table and the half –life of the most stable isotope is about 22 minutes

Fr Francium , 87

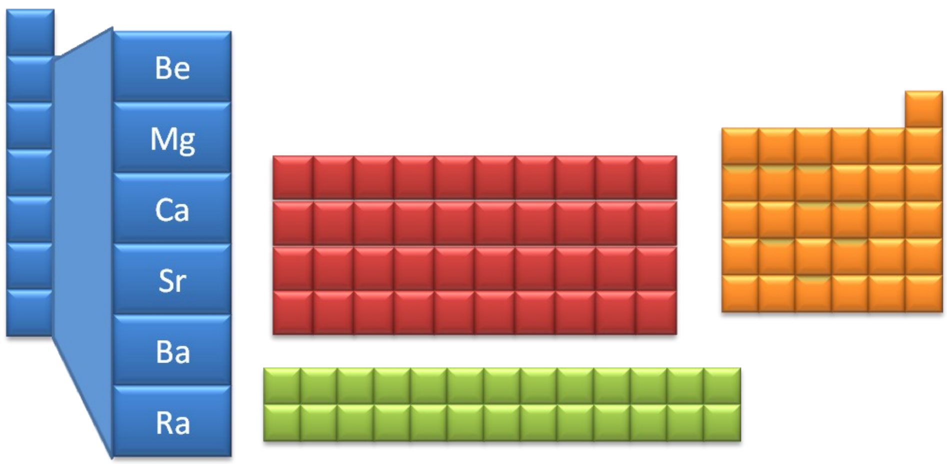
Physical and chemical properties

Symbol	Fr	Relative atomic mass	223
Atomic number	87	Melting point (ºC)	26.85
Group	1	Boiling point (ºC)	676.85
Period	7	Specific heat (J/g.K)	####
Family	Alkali metals	Oxidation numbers	+1
Physical state(20°C)	solid	Electronegativity (pouling)	0.7
Atomic radius (pm)	270	Thermal conductivity (W/m.K)	15
Crystal structure	Body centered cubic	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]7s^1$	Heat of vaporization (kJ/mol)	####
Molar volume (cm3/mole,273K)	####	Ist. ionization potential (kJ/mole)	392.96
Density (g/cm3)	1	2nd.Ionization potential (kJ/mole)	2100
Number of isotopes	34	3rd. ionization potential (kJ/mol)	3100

Chapter 3

Alkaline earth metals

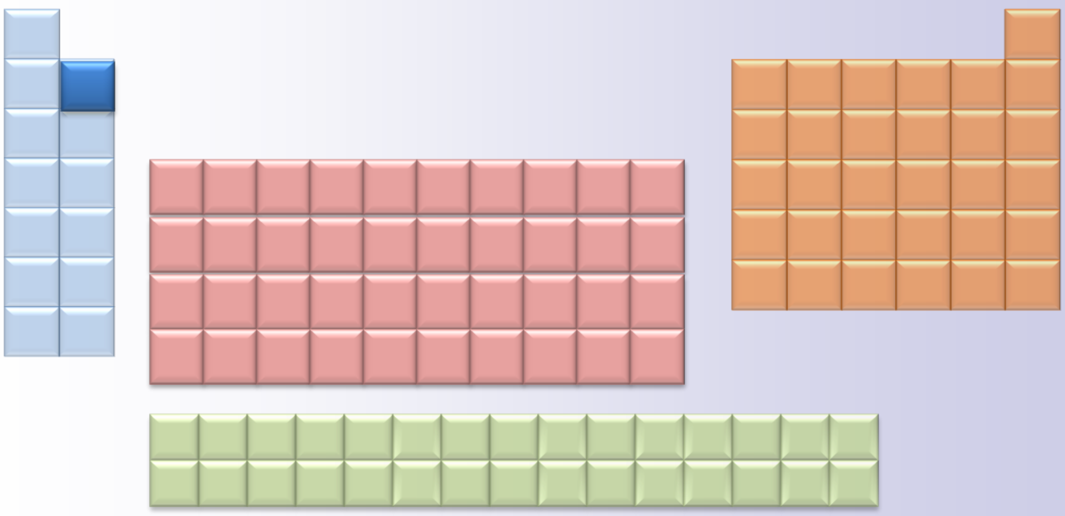
Alkaline earth elements are group 2 elements of the periodic table. They are silver-white metallic elements that are easily oxidized in moist air and generally, react with cold water (but less violently than alkali metals) to free hydrogen and yield highly alkaline solutions.

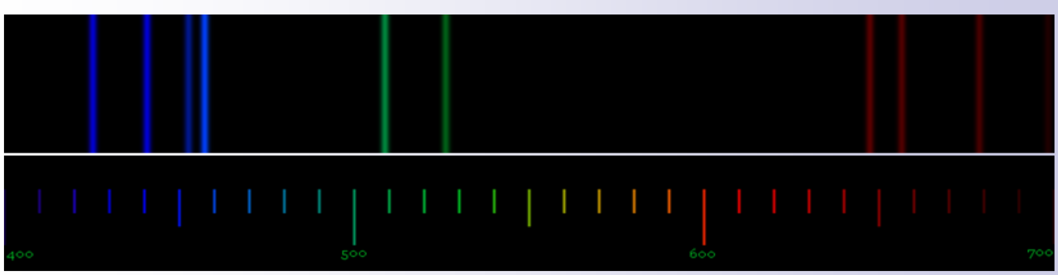


As in all groups in the periodic table, the metallic properties of the elements increase down the group .Thus barium and calcium dissolve in cold water and warm water respectively while magnesium interacts only with water vapor. Beryllium is not only resistant to water vapor but completely departs from the group and acquires properties of nonmetals such as solubility in alkalis.

Similar to alkali metals, alkaline earth metals are usually prepared by the electrolysis of the molten salts.

Beryllium Be





Beryllium is a hard, steel gray element found in beryl mineral (beryllium aluminum silicate). The pure metal is usually obtained through the reduction of the chloride or fluoride with calcium or magnesium, or by the electrolysis of the molten basic fluoride.

Beryllium is relatively inert compared with members of the group. It is not affected by water even at high temperatures and is protected from oxidation in air by a slow formation of a hard surface layer. However, the finely divided metal ignites spontaneously in air to form the oxide and the nitride.

Beryllium is one of the lightest elements and is an ideal material for X-ray windows. The element and its oxide (beryllia) are among the materials used in nuclear rods to slow neutrons and control the chain reaction in nuclear reactors.

Emerald is a form of beryl mineral which acquires a green color due to the presence of traces of iron and chromium. It is considered one of the most valuable gemstones known, and is used in decorations since the dawn of history.

Emerald
(on calcite)
- Colmbia -

Beryllium alloys with copper and a number of metals are characterized by light weight, corrosion resistance, durability and ability to withstand high heat. These alloys are used to manufacture electronic equipment and parts of aircraft and spacecraft.

Beryllium crystal

Be Beryllium , 4

A mixture of beryllium with an alpha- emitter such as polonium or radium is used to act as a neutron source to start the fission reaction in new nuclear reactors with new fuel.

Dust and fumes of beryllium as well as its compounds are highly toxic and have serious effects especially on the skin and the respiratory system. The element and a number of its compounds are usually classified as carcinogens.

Mineral ore locations

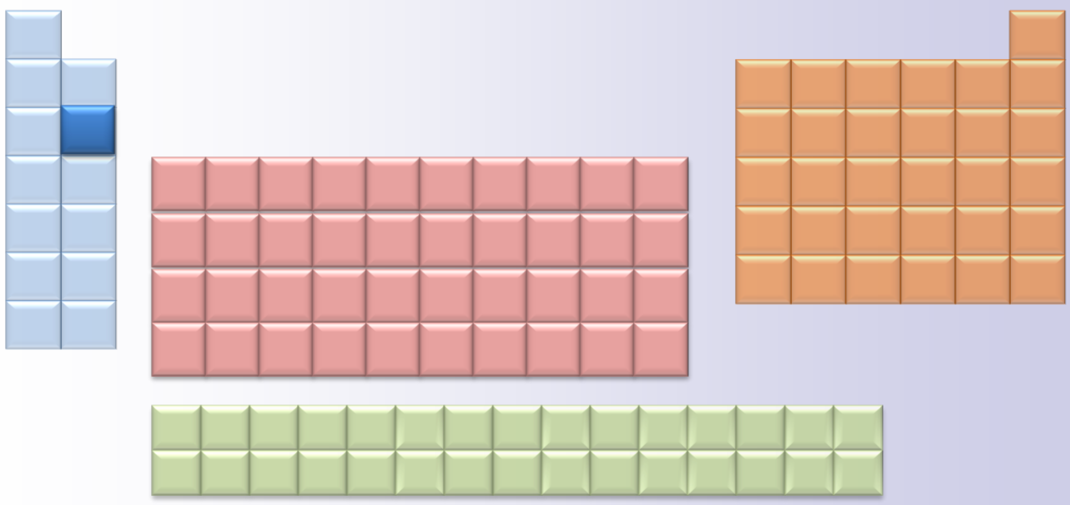
- Beryl

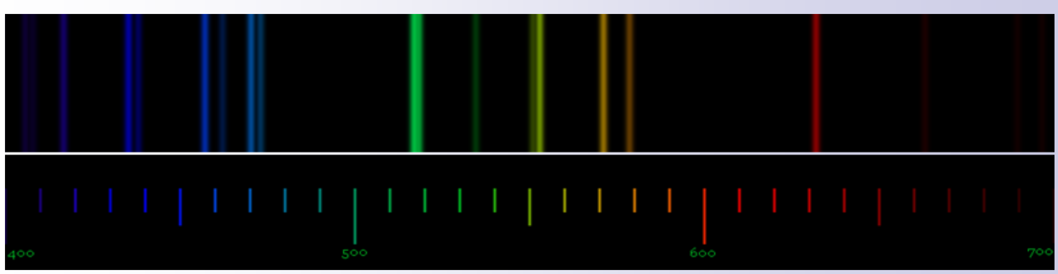
Be Beryllium , 4

Physical and chemical properties

Symbol	Be	Relative atomic mass	9.012182
Atomic number	4	Melting point (°C)	1277.85
Group	2	Boiling point (°C)	2969.85
Period	2	Specific heat (J/g.K)	1.825
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	1.57
Atomic radius (pm)	113.3	Thermal conductivity (W/m.K)	200
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	9.80
Electronic configuration	[He]$2S^2$	Heat of vaporization (kJ/mol)	308.8
Molar volume (cm3/mole,273K)	4.88	Ist. ionization potential (kJ/mole)	899.5
Density (g/cm3)	1.8548	2nd.Ionization potential (kJ/mole)	1757.1
Number of isotopes	6	3rd. ionization potential (kJ/mol)	14848

Magnesium Mg



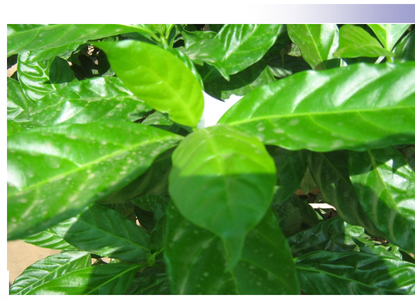


Magnesium is a light, silvery-white metal occurring (only chemically combined) in a number of mineral ores including dolomite and magnesite and constituting about 2% of the mass of the earth's crust

The pure metal is industrially obtained through the reduction of the oxide or through the electrolysis of the molten chloride (which is extracted from sea water and brackish wells).

Magnesium oxidizes slowly in air and reacts slowly with water vapor. It does not react with cold water, oxygen nor with alkalis at normal temperatures.

However, finely divided magnesium metal burns on heating with a brilliant bright light and magnesium is one of a few elements that combine directly with nitrogen.



Magnesium is the central element in chlorophyll protein in plant plastids where water and carbon dioxide combine to form glucose in the process of photosynthesis

The ability of magnesium metal to reduce oxides is utilized to obtain pure elements from their ores. This is the common industrial method in the commercial production of silicon, uranium, vanadium and titanium metals.

Magnesium is used for protecting iron and steel against corrosion (cathodic protection). It is also used in light bombs and optical photography.

A number of magnesium compounds are commercially important in different industrial fields: Hydrated magnesium sulfate (Epsom salt) is used in agriculture as a soil fertilizer and in the medical field for the treatment of some types of severe asthma attacks.

Dolomite

(Magnesium carbonate)

Mg Magnesium , 12

Magnesium chloride is used in the manufacture of fire retardants, textiles and paper industry. Magnesium citrate is used as a laxative and also as a magnesium supplement. Magnesium oxide (magnesia) occurs naturally as periclase mineral. It is a secondary source of magnesium and is used in antacids and laxatives formulae. The hydroxide (milk of magnesia), the sulfate (Epsom salt), the chloride and the citrate are all used in the field of pharmaceutical industry.

Magnesium is a vital element to both animals and plants. It is an essential mineral required for a number of biological processes within the living cell. It is important for building bones and teeth, and is responsible for the balance of sodium and potassium elements in the living cell and magnesium ion is required for muscle, nervous system and blood pressure control. Magnesium is the central element in chlorophyll protein which is found in plant plastids.

Magnesium is available in various types of foods but the main sources are meats, whole grains, brown rice, green vegetables, bananas, peanuts and dairy products.

Mineral ore locations

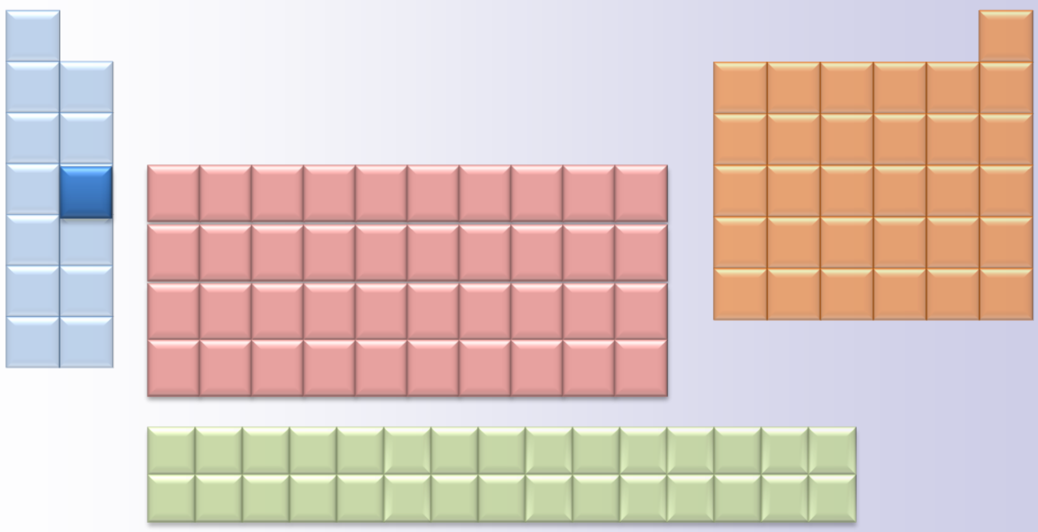
• Dolomite ■ Magnesite

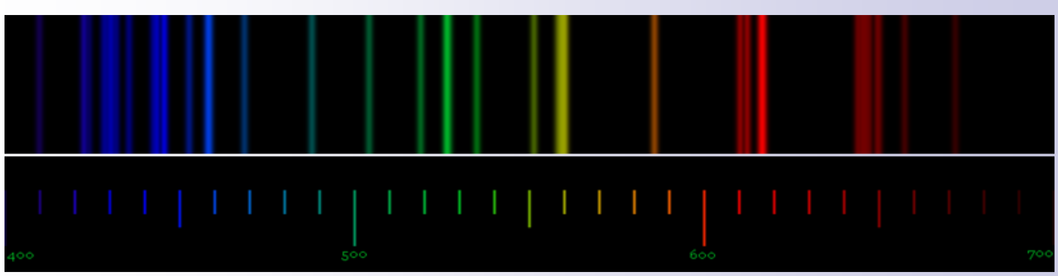
Mg Magnesium , 12

Physical and chemical properties

Symbol	Mg	Relative atomic mass	24.305
Atomic number	12	Melting point (°C)	648.85
Group	2	Boiling point (°C)	1089.85
Period	3	Specific heat (J/g.K)	1.023
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state(20°C)	solid	Electronegativity (pouling)	1.31
Atomic radius (pm)	160	Thermal conductivity (W/m.K)	156
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	9.04
Electronic configuration	$[Ne]3S^2$	Heat of vaporization (kJ/mol)	128.7
Molar volume (cm3/mole,273K)	13.98	Ist. ionization potential (kJ/mole)	737.7
Density (g/cm3)	1.738	2nd.Ionization potential (kJ/mole)	1450.7
Number of isotopes	12	3rd. ionization potential (kJ/mol)	7732.6

Calcium Ca





Calcium is a hard silvery-white metallic element that ranks fifth among the elements in the earth's crust of which it forms more than 3 % by weight and is the element with the highest concentration in fresh water.

Major ores of the element are the sedimentary rocks of gypsum, calcite and dolomite.

The pure metal is usually prepared by the electrolysis of the fused chloride to which calcium fluoride is added in order to lower the melting point.

Calcium is chemically very reactive. It reacts violently with cold water and quickly loses its luster in air to form a white coating of the nitride.

Gypsum

(Calcium sulfate)

- Mexico-

Calcite

(Calcium carbonate)

- Fluorida,USA -

Calcium is used as a reducing agent in the extraction of other metals such as thorium and uranium and is applied in the manufacture of alloys, especially with aluminum, copper, magnesium ,beryllium and lead. It is used as a "getter" for residual gases in vacuum tubes.

Calcium carbonate is the chief component of stalactites and stalagmites in limestone caves.

Important calcium compounds include quick lime (calcium oxide) and slaked lime (calcium hydroxide). Both compounds are important in building materials and in the processes of urban and waste water treatment.

Limestone and gypsum are the main components of Portland cement.

Ca Calcium , 20

Calcium hypochlorite is a strong bleaching agent and the carbide is treated with water in the industrial process of acetylene gas production.

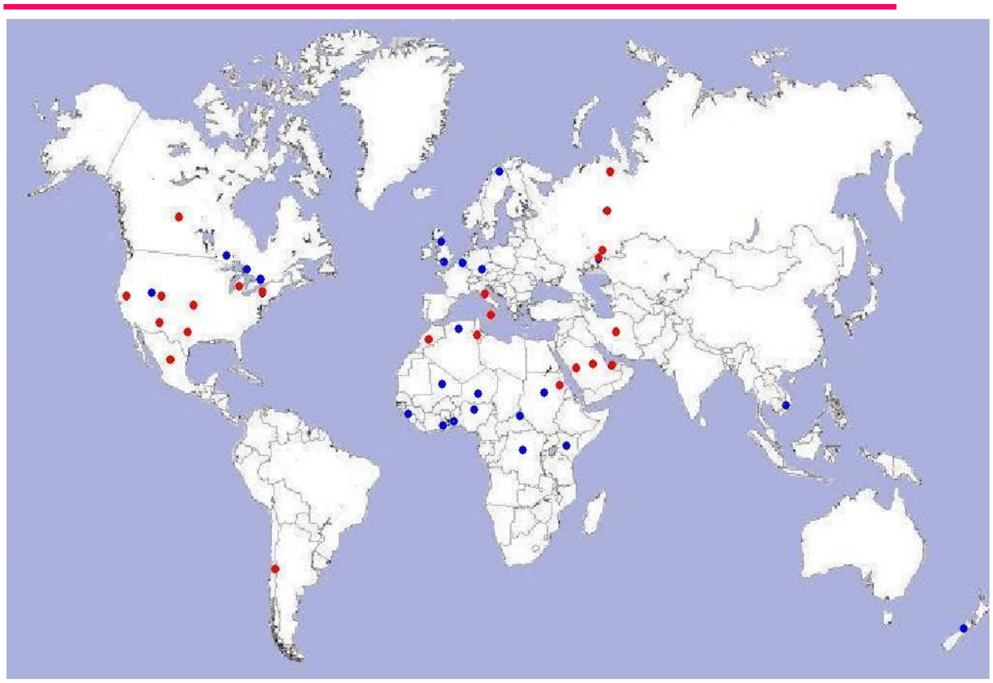
Calcium is an essential constituent of bones, teeth, shells and foliage and the calcium ion has a vital role in the function of the heart and blood clotting, and in the activity of the nervous system.

Milk and dairy products, almonds, hazelnuts and apricots are the major natural food sources of the element.

Lime stone

-Marianna, USA-

Mineral ore locations



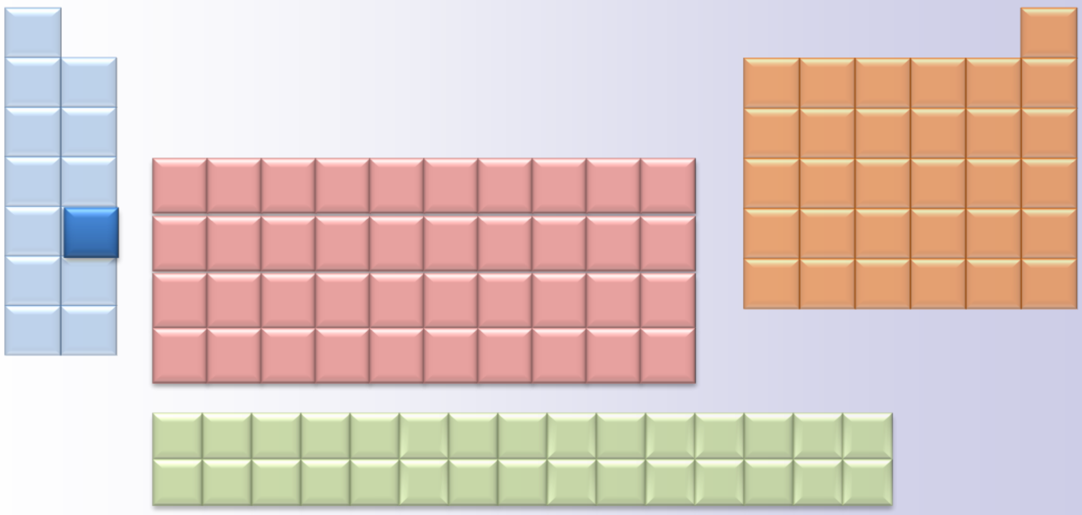
• Limestone • Gypsum

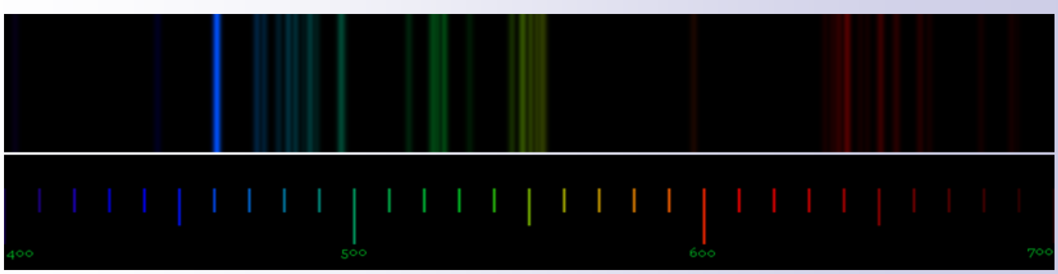
Ca Calcium , 20

Physical and chemical properties

Symbol	Ca	Relative atomic mass	40.078
Atomic number	20	Melting point (°C)	838.85
Group	2	Boiling point (°C)	1483.85
Period	4	Specific heat (J/g.K)	0.647
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	1.00
Atomic radius (pm)	197.3	Thermal conductivity (W/m.K)	200
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	9.33
Electronic configuration	$[Ar]4S^2$	Heat of vaporization (kJ/mol)	149.95
Molar volume(cm3/ mole,273K)	25.86	Ist. ionization potential (kJ/mole)	589.7
Density (g/cm3)	1.550	2nd.Ionization potential (kJ/mole)	1145
Number of isotopes	16	3rd. ionization potential (kJ/mol)	4910

Strontium Sr





Strontium is a shiny silvery-white metal which is abundant in nature and is ranked 15th among the elements of the earth's crust. It is found in volcanic and sedimentary rocks in the form of carbonates (strontianite) or sulfates (celestine). Strontium is chemically active and is readily oxidized in air to gain a yellow color. It reacts violently with water and dissolves in dilute acids with the evolution of hydrogen. At high temperatures it reacts with hydrogen, oxygen, nitrogen and the halogens (the element is usually stored in mineral oil or dry kerosene).

Strontianite
(Strontium carbonate)
-California -

Celestine
(Strontium sulfate)
- Malagasy -

Strontium and its compounds are used in fireworks and the hydroxide is used in the purification of sugar.

During the nuclear fission of uranium a number of the most important radioactive isotopes of strontium are generated. These isotopes are produced during atomic bomb testing and are distributed in large areas. The most important strontium isotopes in the nuclear fallout are strontium-89 (half–life 50 days) and strontium -90 (half-life 27.7 years). The latter represents a serious environmental hazard and is one of the most important factors of nuclear contamination. Falls of the isotope are dissolved in water to find its way to plants and animals and consequently to consumers of milk and other products. Strontium is chemically similar to calcium and in case of absorption it settles in bone tissue to act as a local source of damaging radiation.

On the other hand, stable strontium (nonadioactive strontium) is nontoxic and was found effective for the prevention and treatment of osteoporosis and other bone-related conditions. This nonradioactive strontium can be administered to people exposed to radiation in adequate doses to gradually replace and eliminate radioactive strontium from the body.

Mineral ore locations

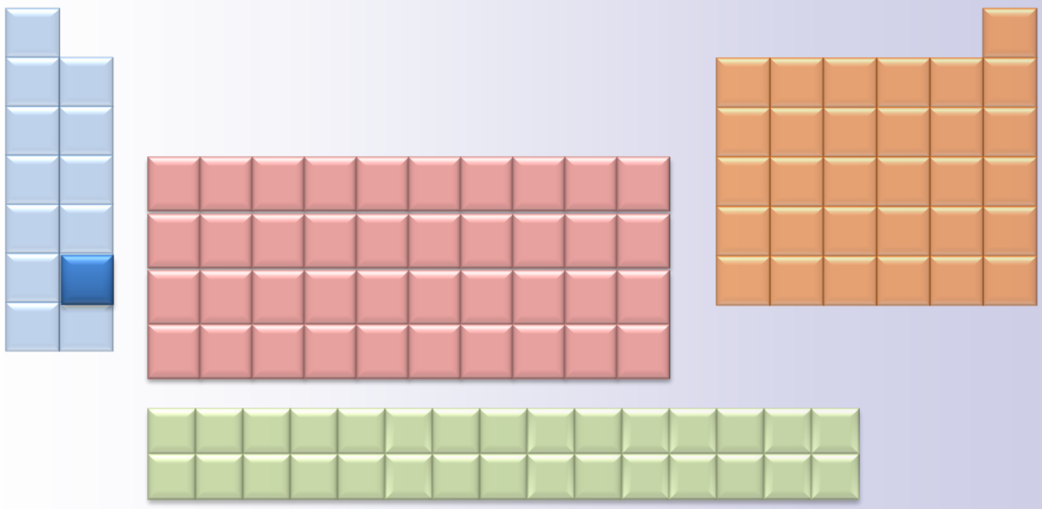
● Strontianite ■ Celestine

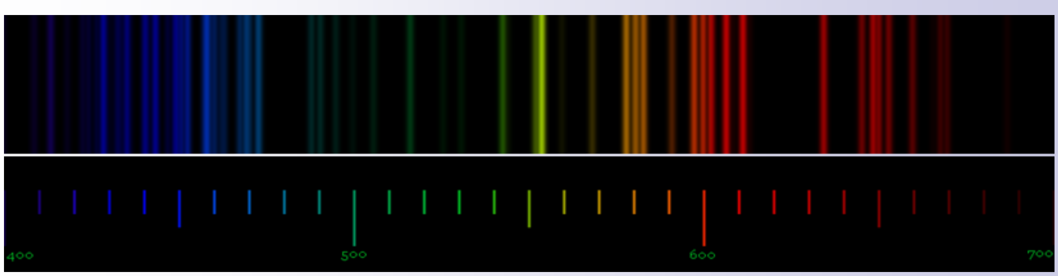
Sr Strontium , 38

Physical and chemical properties

Symbol	Sr	Relative atomic mass	87.62
Atomic number	38	Melting point (°C)	768
Group	2	Boiling point (°C)	1383
Period	5	Specific heat (J/g.K)	0.31
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	0.95
Atomic radius (pm)	215.1	Thermal conductivity (W/m.K)	35.3
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	9.16
Electronic configuration	[Kr] $5S^2$	Heat of vaporization (kJ/mol)	138.91
Molar volume (cm3/mole,273K)	34.50	Ist. ionization potential (kJ/mole)	549.5
Density (g/cm3)	2.540	2nd.Ionization potential (kJ/mole)	1064.2
Number of isotopes	23	3rd. ionization potential (kJ/mol)	4210

Barium Ba





Barium is a soft silvery-white metal with estimated natural abundance of about 0.04% of the mass of the earth's crust. It occurs naturally in a chemically combined form and is commercially extracted from barite ores (barium sulfate) and witherite ores (barium carbonate). The pure metal is usually obtained through the electrolysis of the molten chloride.

Barium is chemically very active. It reacts vigorously with cold water and is rapidly oxidized in moist air (the metal is usually stored in dry kerosene or mineral oil or in an atmosphere of an inert gas).

Barium metal is used in the manufacture of bearing alloys and in the eradication of oxygen in vacuum tubes and other closed electronic devices. Barite ore is widely used as a wetting agent in drilling fluids.

Commercially important barium compounds include the sulfate which is widely used in the manufacture of white paint, and as a water emulsion administered to patients prior to X-ray photography.

Barium carbonate (witherite) is used as an additive to the components of bricks, cements, ceramics and glass, and (being a toxic substance) is used for rat eradication.

Barium chloride is utilized in the purification of brine solutions for caustic soda- chlorine cells. It is an important ingredient in steel industry, manufacture of pigments and in fireworks to give the green color.

Barium nitrate , which is found in the rare mineral nitrobarite, is mixed with a number of compounds such as aluminum powder, thermite and TNT to give explosive formulations for pyrotechnics, grenades and other applications.

Barite

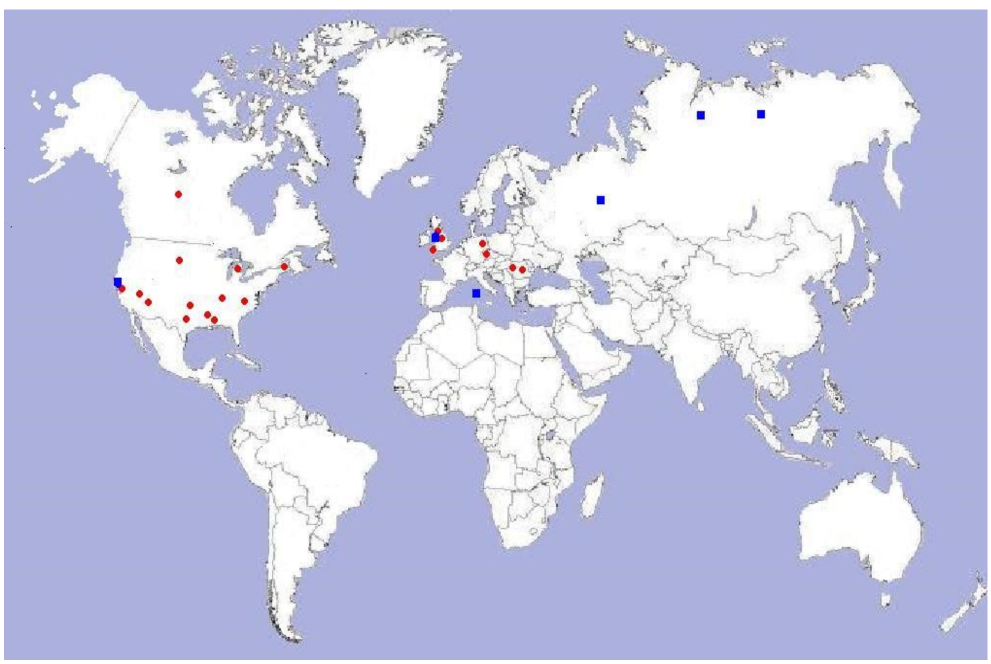
(Barium sulfate)

- South Dakota,USA -

Ba Barium , 56

Barium peroxide is used as a color remover in leather and textile industries.
All water and acid soluble barium salts are usually highly toxic, a fact which limits most applications of these compounds .

Mineral ore locations



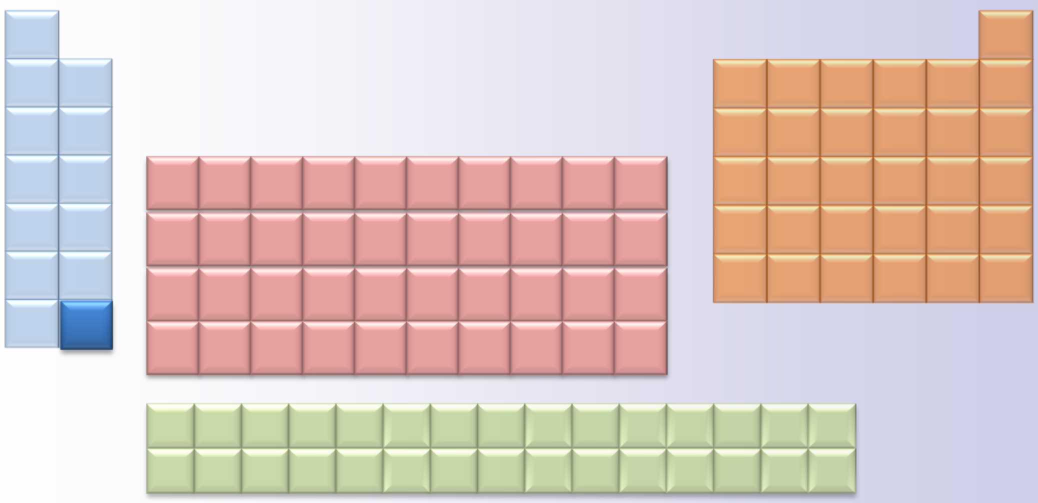
• Barite ■ Weatherite

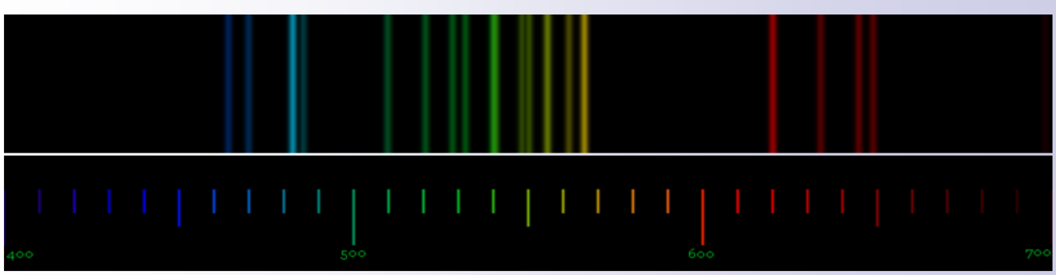
Ba Barium , 56

Physical and chemical properties

Symbol	Ba	Relative atomic mass	137.327
Atomic number	56	Melting point (°C)	728
Group	2	Boiling point (°C)	1636
Period	6	Specific heat (J/g.K)	0.204
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	0.89
Atomic radius (pm)	217.3	Thermal conductivity (W/m.K)	18.4
Crystal structure	Body centered Cubic	Heat of fusion (kJ/mol)	7.66
Electronic configuration	$[Xe]6S^2$	Heat of vaporization (kJ/mol)	150.9
Molar volume (cm3/mole,273K)	38.21	Ist. ionization potential (kJ/mole)	502.8
Density (g/cm3)	3.594	2nd.Ionization potential (kJ/mole)	965.1
Number of isotopes	35	3rd. ionization potential (kJ/mol)	?

Radium Ra





Radium is a bright silvery-white metal that occurs naturally as a result of the continuous disintegration of uranium isotopes.

The element was discovered in 1898 in pitchblende ore (uranium oxide) and the pure element was obtained in 1902 through the electrolysis of the chloride solution.

Radium is similar to barium and calcium in its chemical activity. It decomposes in cold water to liberate hydrogen and loses its luster in air to form a black layer of the oxide or the nitride.

Radium glows in the dark as a result of the high radiation activity. It is a hazardous alpha, beta and gamma emitter (the radioactivity of radium is one million times uranium activity). It decays to radon, which is a gaseous element and one of the most serious sources of natural radioactive pollution.

Radium is treated by the body as calcium and in case of ingestion it settles on bone tissues where its destructive radiations result in the destruction of bone marrow cells that produce red blood cells.

Utilization of radium is banned in a number of areas including medical irradiation, cosmetics formulations and automatic color paints.

Radium is chemically similar to calcium. It is precipitated on bone tissue where its destructive radiations affect bone morrow cells with consequent distortion of red blood cells

Radium—226

Ra Radium , 88

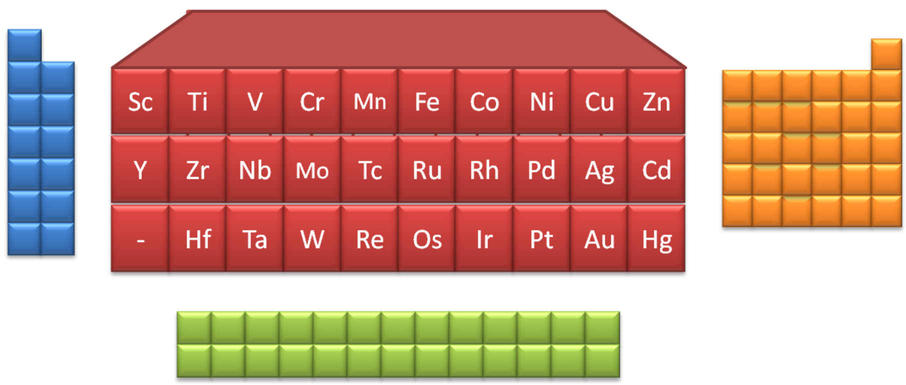
Physical and chemical properties

Symbol	Ra	Relative atomic mass	226.025
Atomic number	88	Melting point (°C)	699.85
Group	2	Boiling point (°C)	1139.85
Period	7	Specific heat (J/g.K)	####
Family	Alkaline earth metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	0.89
Atomic radius (pm)	223	Thermal conductivity (W/m.K)	18.6
Crystal structure	body Centered Cubic	Heat of fusion (kJ/mol)	7.15
Electronic configuration	$[Rn]7s^2$	Heat of vaporization (kJ/mol)	136.8
Molar volume(cm3/ mole,273K)	45.2	Ist. ionization potential (kJ/mole)	509.3
Density (g/cm3)	2	2nd.Ionization potential (kJ/mole)	979.0
Number of isotopes	25	3rd. ionization potential (kJ/mol)	3300

Chapter 4

Transition metals

These are the 38 elements occupying groups 3 to 12 in the periodic table. All are solid elements (except for mercury) and all acquire the metallic properties. They are ductile and malleable and are usually characterized by high melting points, thermal and electrical conductivity and high resistance to corrosion.



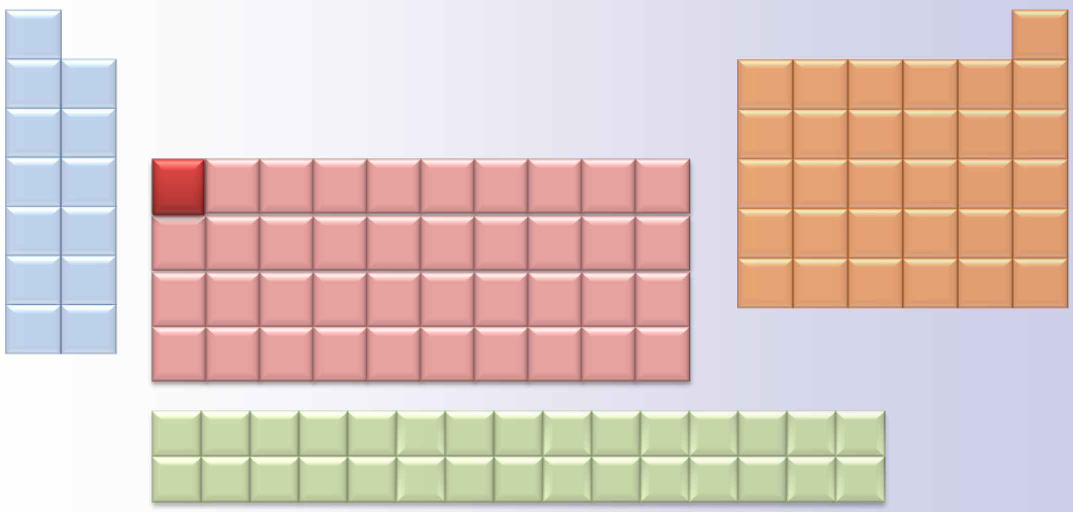
The transition metal group includes the most known and most important metallic elements.

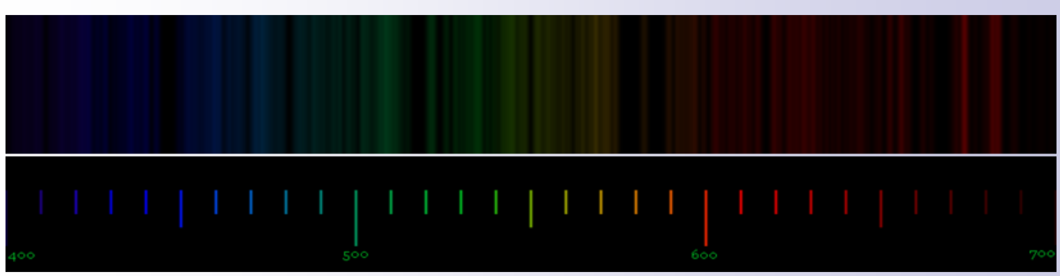
Thus, silver, copper and gold represent 3 noble elements in group 11. These elements (in the same order) are the best conductors of electricity among all the elements.

Transition metals include the heaviest natural elements (platinum, iridium and osmium) and the magnetic metals (iron, cobalt and nickel) . The group also includes the most widely used metal catalysts in different fields of industry.

With the exception of gold and copper, transition metals are characterized by pure silvery- white colors. On the other hand compounds of the transition metals are often colorful. This is a result of the existence of vacancies in the orbits of the outer electrons. Electrons are excited to these vacancies as a result of absorption of specific frequencies of the incident light. Unabsorbed waves are reflected in different frequencies and hence show different colors characteristic of the particular compound.

Scandium Sc





Scandium is a rare, soft, silvery-white metallic element similar in chemical characteristics to the rare earth metals and once classified within this group. It was predicted by Dmitri Mendeleev in 1869 who pointed out its position in his periodic table and described some of its properties.

Scandium is found naturally (only chemically combined) in minute amounts in a vast number of ores including thortveitite, euxenite, and gadolinite but, due to its low concentration the element is produced exclusively as a by-product of uranium ore refining and is recovered from mine tailings of iron and rare earth metal ores.

The pure metal was obtained for the first time in 1937 when the oxide was converted to scandium fluoride and then reduced with metallic calcium.

Scandium is chemically very active and is readily attacked by water or oxygen. It reacts vigorously with many acids and develops a yellowish or pinkish cast on exposure to air.

Scandium imparts unique characteristics to metal alloys and most of the commercial product is consumed in the manufacture of high-strength aluminum alloys which contain 0.1% to 0.5% of scandium. These alloys are characterized by high durability, light weight and high resistance to heat, and are particularly important in the manufacture of military and aerospace components.

Scandium oxide is used in high intensity discharge lamps and the iodide is added ,along with sodium iodide to mercury vapor lamps to increase light intensity and brilliance.

Some artificially produced radioactive isotopes of the element are used as tracers in the studies of oil wells and pipelines.

Thortveitite

(Scandium and yttrium silicates)

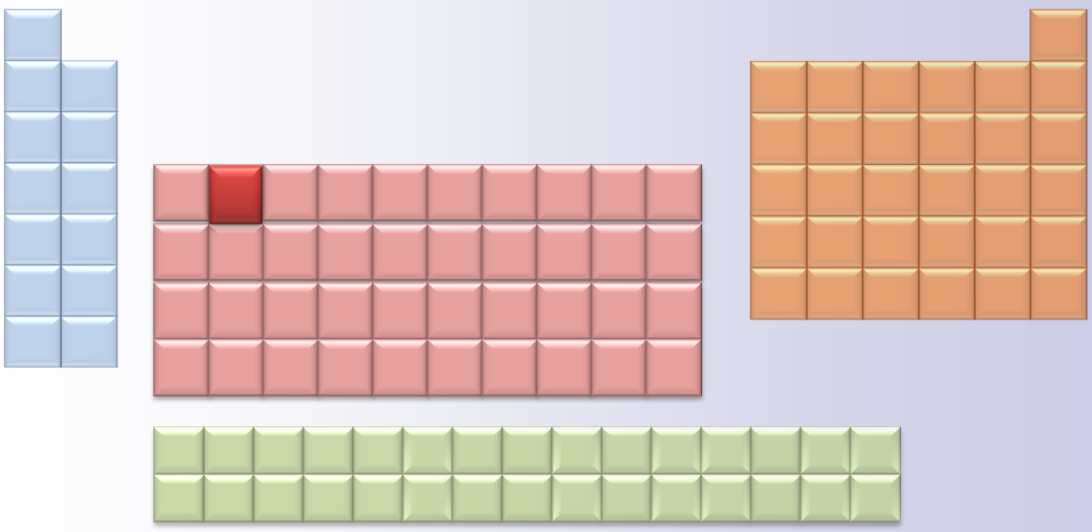
-Norway-

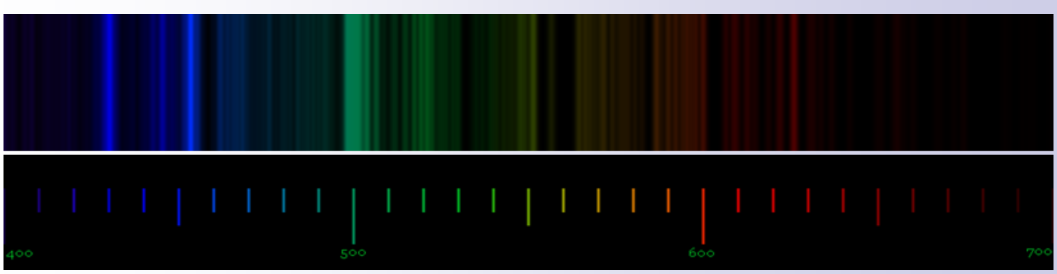
Sc Scandium , 21

Physical and chemical properties

Symbol	Sc	Relative atomic mass	44.956
Atomic number	21	Melting point (°C)	1540
Group	3	Boiling point (°C)	2830
Period	4	Specific heat (J/g.K)	0.568
Family	Transition metals	Oxidation numbers	+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.36
Atomic radius (pm)	160.6	Thermal conductivity (W/m.K)	15.8
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	15.9
Electronic configuration	$[Ar]3d^{1}4S^{2}$	Heat of vaporization (kJ/mol)	304.8
Molar volume(cm3/ mole,273K)	15.04	Ist. ionization potential (kJ/mole)	631
Density (g/cm3)	2.989	2nd.Ionization potential (kJ/mole)	1235
Number of isotopes	15	3rd. ionization potential (kJ/mol)	2389

Titanium Ti





Titanium is a bright- white, ductile and malleable metal that ranks ninth among the elements with respect to natural abundance in the earth's crust. It is abundant in volcanic and sedimentary rocks and is usually extracted from ilmenite (iron titanium oxide) and rutile (titanium dioxide) minerals .

Metallic titanium is industrially produced by Kroll process. The metal ore is reduced with coke at 1000°C. The mixture is then treated with chlorine gas to form the volatile tetrachloride which is then purified by distillation and finally reduced with magnesium to obtain the pure metal.

Titanium is characterized by light weight and high resistance to corrosion and chemical attack.

Titanium crystal bar
(purity 99.995)

Ilmenite
- iron titanium oxide
— Quebec, Canada—

The metal has the durability of steel but less than half its density. It is used as an alloying agent with metals including iron, aluminum, chromium, copper and manganese. These alloys are desirable for their light weight, durability and heat resistance. They are particularly important for manufacturing parts of aircraft and spacecraft, artificial joints for humans, sporting equipment and underpin dentures in the field of dental implants.

Because of its high resistance to the impact of salt water, titanium alloys are of the most viable materials for the design of desalination plants and other structures exposed to the sea.

Besides being the major sources of titanium metal, ilmenite is used in the manufacture of titanium dioxide for paint pigments while rutile is used as a coating on welding rods.

Ti Titanium , 22

Titanium nitride is highly resistant to corrosion and is extremely hard (9.0 on Mohs Scale) and is widely used in coating drill bits and other cutting tools.

Titanium and its compounds are used as catalysts in many chemical processes and most titanium production is used to make titanium dioxide (titania) which is a white ,nontoxic pigment with a high refractive index. It is considered as an ideal coloring material in the field of food, cosmetics and plastic industries.

Rutile
Needle - crystals
- Brazil -

Mineral ore locations

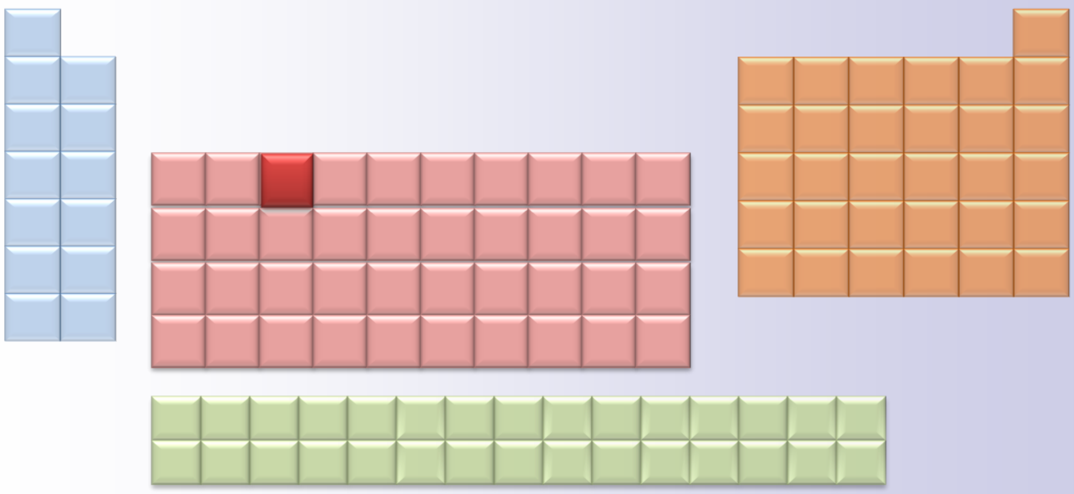
▪ Ilmenite • Rutile ▪Titanite

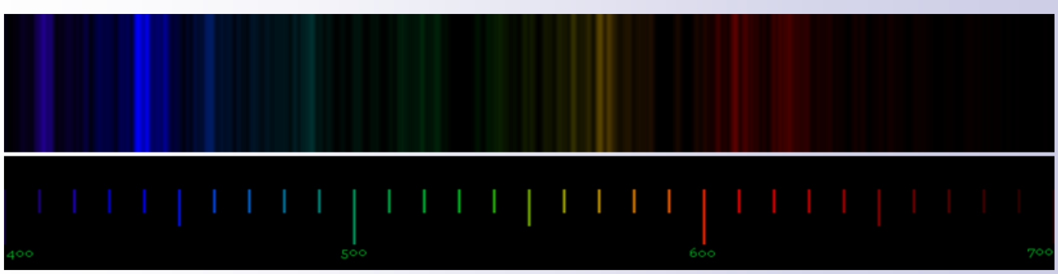
Ti Titanium , 22

Physical and chemical properties

Symbol	Ti	Relative atomic mass	47.867
Atomic number	22	Melting point (^oC)	1659
Group	4	Boiling point (^oC)	3286
Period	4	Specific heat (J/g.K)	0.523
Family	Transition metals	Oxidation numbers	+2,+3,+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.54
Atomic radius (pm)	144.8	Thermal conductivity (W/m.K)	21.9
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	20.9
Electronic configuration	$[Ar]3d^2 4S^2$	Heat of vaporization (kJ/mol)	428.9
Molar volume (cm3/mole,273K)	10.55	Ist. ionization potential (kJ/mole)	658
Density (g/cm3)	4.540	2nd.Ionization potentia (kJ/mole)	1310
Number of isotopes	18	3rd. ionization potential (kJ/mol)	2652

Vanadium V





Vanadium is a silvery, malleable and ductile metal which is characterized by high resistance to most mineral acids, alkalis and salt water (this is largely due to the formation of a hard oxide layer on the metal surface).

Vanadium is encountered in more than sixty mineral ores. The element is commercially obtained, as a by-product, of mining and purification processes of patronite (lead sulfide), vanadinite (lead chlorovanadate) and the radioactive uranium ore (carnotite).

The pure metal is obtained by reducing the oxide with calcium or magnesium metals.

Vanadinite

(lead chlorovanadate)

- Morocco -

Carnotite

(potassium uranium vanadate)

-Colorado, USA -

Most of the commercial product of vanadium is consumed in the manufacture of vanadium steel alloy (ferrovanadium) which is unique for high resistance to oxygen and nitrogen. The metal is also used in the manufacture of super conductive magnets.

Vanadium compounds are particularly effective as catalysts in oxidation processes (vanadium pentoxide is used for the industrial production of sulfuric acid).

Vanadium and its compounds are usually toxic. On the other hand the metal ion is necessary for the growth of chicks and poultry, and its deficiency affects the growth of bones and feathers.

V Vanadium , 23

Shellfish, parsley, horseradish and black pepper are the most important food sources of the element.

Minor concentrations of vanadium were reported by some medical researchers to help in reaching normal sugar levels in the body while other research centers are developing vanadium drugs that fight malignant cells in experimental animals.

Ferrovanadium

Mineral ore locations

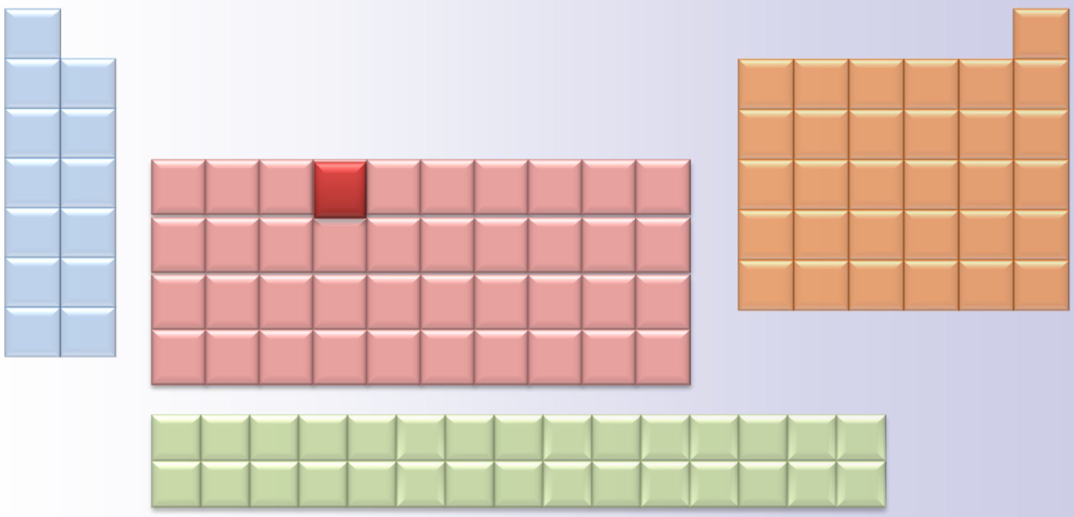
■ Disclozite ● Vanadinite ● Carnotite

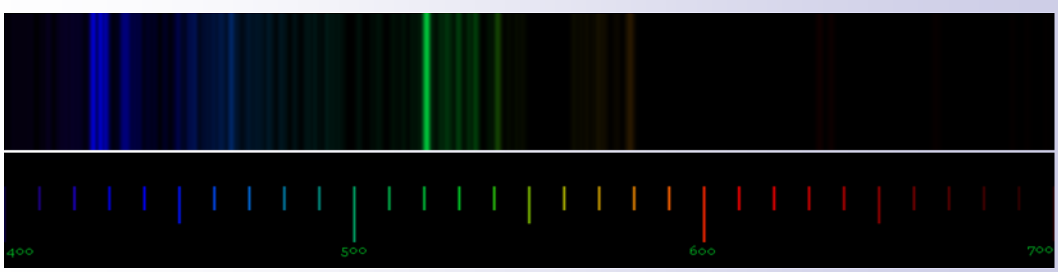
V Vanadium , 23

Physical and chemical properties

Symbol	V	Relative atomic mass	50.942
Atomic number	23	Melting point (°C)	1886
Group	5	Boiling point (°C)	3376
Period	4	Specific heat (J/g.K)	0.489
Family	Transition metals	Oxidation numbers	+2,+3,+4,+5
Physical state (20°C)	solid	Electronegativity (pouling)	1.63
Atomic radius (pm)	132.1	Thermal conductivity (W/m.K)	30.7
Crystal structure	body Centered Cubic	Heat of fusion (kJ/mol)	17.6
Electronic configuration	$[Ar]3d^3 4S^2$	Heat of vaporization (kJ/mol)	458.6
Molar volume(cm3/ mole,273K)	8.34	Ist. ionization potential (kJ/mole)	650
Density (g/cm3)	6.110	2nd.Ionization potential (kJ/mole)	1414
Number of isotopes	11	3rd. ionization potential (kJ/mol)	2828

Chromium Cr





Chromium is a hard, steel-bright metal characterized by good resistance to corrosion and by a high melting point temperature.

Chromium is mined (mainly in South Africa) from chromite ores (iron magnesium chromium oxide) and the pure metal is commercially produced by reducing the oxide with silicon or aluminum at high temperatures.

Chromium is added (with nickel) in the manufacture of hard and corrosion-resistant steel alloys. It is also used in metal plating where a hard thin layer of the oxide protects the chrome-plated metals.

All chromium compounds are colored and are usually classified as toxic.

Chromium chloride

(All chromium compounds are colored)

The most important compounds of the element are the chromates and dichromates of sodium and potassium which are strong oxidizing agents.

Chromium metal

Chromite

- Albania -

Cr Chromium , 24

Some chromium salts are utilized in the manufacture of paint, leather tanning and textile industry

Chromium is essential to human life and minor concentrations of the element are needed for a healthy body. It is the vital element that controls the movement of sugar from the blood into living cells, where energy is produced.

The major natural sources of chromium are yeast, meat (liver), cheese, whole grains, egg yolk, black pepper and vegetables.

Mineral ore locations

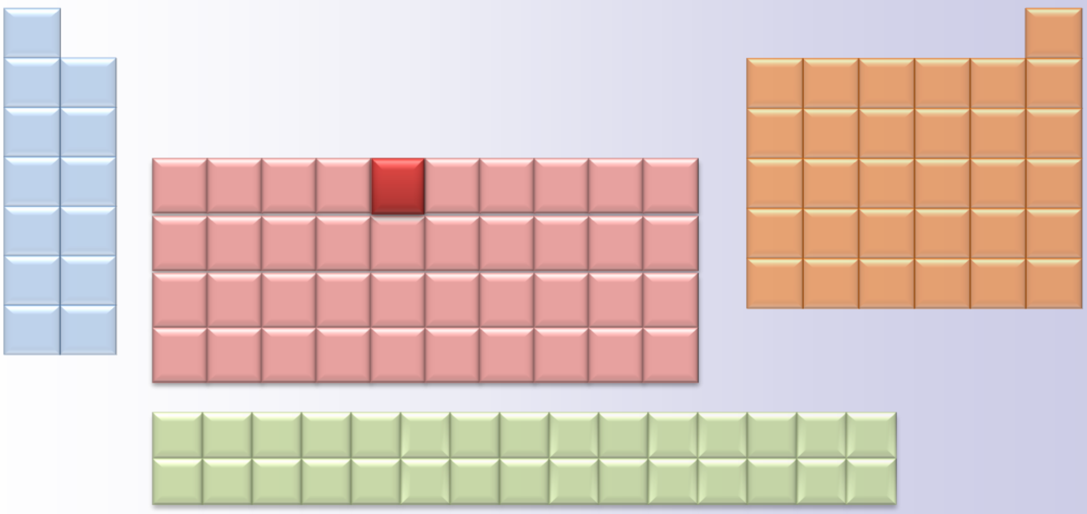
- Chromite

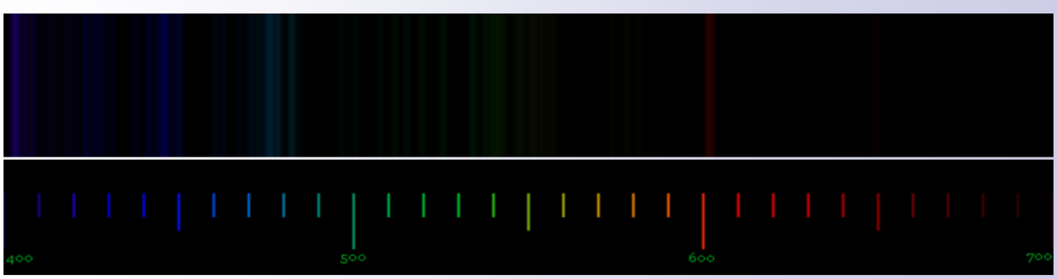
Cr Chromium , 24

Physical and chemical properties

Symbol	Cr	Relative atomic mass	51.996
Atomic number	24	Melting point (ºC)	1856
Group	6	Boiling point (ºC)	2671
Period	4	Specific heat (J/g.K)	0.449
Family	Transition metals	Oxidation numbers	+2,+3,+4,+5,+6
Physical state(20°C)	solid	Electronegativity (pouling)	1.66
Atomic radius (pm)	124.9	Thermal conductivity (W/m.K)	93.7
Crystal structure	body Centered Cubic	Heat of fusion (kJ/mol)	15.3
Electronic configuration	$[Ar]3d^5 4S^1$	Heat of vaporization (kJ/mol)	348.78
Molar volume (cm3/mole,273K)	7.23	Ist. ionization potential (kJ/mole)	652.7
Density (g/cm3)	7.190	2nd.Ionization potential (kJ/mole)	1592
Number of isotopes	13	3rd. ionization potential (kJ/mol)	2987

Manganese Mn





Manganese is a shiny, gray metal that exists in four allotropic forms and resembles iron but is harder and brittle. It is estimated to form about 0.1% by weight of the earth's crust .

Manganese compounds were known and have been utilized since ancient history. The element is found in a number of minerals, principally the oxide and hydroxide ores (pyrolusite and manganite). It is also encountered as a component in meteorite rocks and in the form of hydroxides in manganese nodules on the ocean floor.

Commercially, manganese is produced by roasting (oxidation) of its ores, followed by reduction of the resulting oxide with aluminum and the metal is further purified through the electrolysis of sulfate solutions. Manganese is chemically active. It tarnishes on exposure to air and, when heated, oxidizes to the oxide. It slowly decomposes cold water and readily reacts with carbon ,nitrogen, silicon, phosphorus, sulfur, and the halogens.

Manganite
-Manganese hydroxide-
- South Africa -

Manganese metal

Manganese is extensively used to produce a number of alloys such as magnetic alloys with iron, aluminum and antimony. It is also used to desulfurize and deoxidize steel.

Manganese dioxide is an inorganic pigment known and used for painting since the middle ages.

It is used as a depolarizer in dry batteries and is also used to eliminate undesired green colors resulting from the presence of iron compounds in glass.

Potassium permanganate is a strong oxidizing agent that is widely used in the field of analytical chemistry (volumetric analysis) . It is also used in the medical field as a bactericide.

Manganese is an essential trace element for both animals and plants. It is important for plant growth and is a component of a number of enzymes in the animal

Manganese nodules

Mineral ore locations

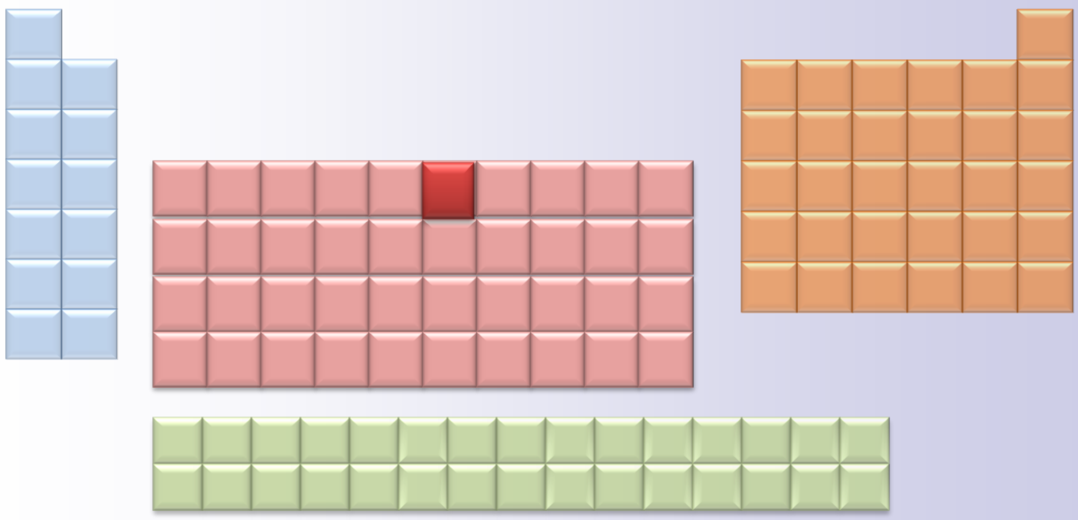
■ Manganite ◘ Rhodochrosite ● Pyrolusite

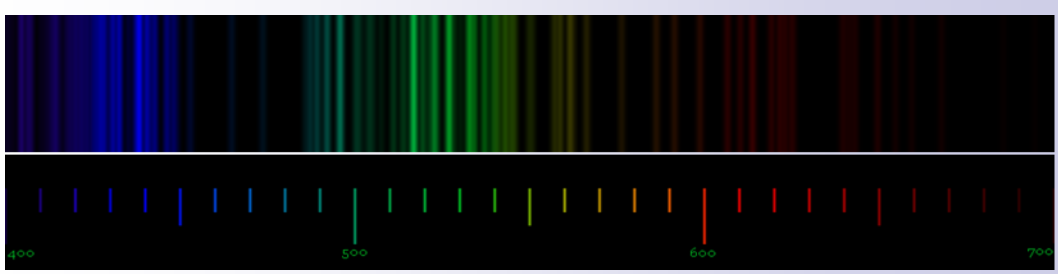
Mn Manganese , 25

Physical and chemical properties

Symbol	Mn	Relative atomic mass	54.938
Atomic number	25	Melting point (°C)	1243
Group	7	Boiling point (°C)	1961
Period	4	Specific heat (J/g.K)	0.479
Family	Transition metals	Oxidation numbers	+2,+3,+4,+6,+7
Physical state (20°C)	solid	Electronegativity (pouling)	1.55
Atomic radius (pm)	124	Thermal conductivity (W/m.K)	7.82
Crystal structure	Body Centered cubic	Heat of fusion (kJ/mol)	14.4
Electronic configuration	$[Ar]3d^5 4S^2$	Heat of vaporization (kJ/mol)	219.7
Molar volume (cm3/mole,273K)	7.38	Ist. ionization potential (kJ/mole)	717.4
Density (g/cm3)	7.440	2nd.Ionization potential (kJ/mole)	1509.0
Number of isotopes	21	3rd. ionization potential (kJ/mol)	3248.4

Iron Fe





Iron is a ductile and malleable metal which is silvery-gray in its pure form.

Iron is widespread in nature. It is ranked fourth among the elements and second among the metals in terms of natural abundance. Its principal ores are siderite (iron carbonate) , hematite, and the ferromagnetic mineral, magnetite (iron oxides).

Iron is chemically active. It readily rusts in moist air, dissolves in mineral acids and combines directly with sulfur, phosphorus, carbon, silicon and the halogens.

Commercially, iron is produced through the reduction (smelting) of hematite or magnetite with carbon at temperatures reaching 2,000 ^{o}C.

Iron forms its most important alloys with carbon: cast iron contains 2- 4 % carbon while steel alloys consist of less than 2 % carbon with small amounts of manganese, sulfur, phosphorus and silicon.

Iron is the cheapest and the most commonly used metal. It occupies the first place in the commercial production of metals (more than 90 percent of worldwide metal production)

Hematite
(Ferric oxide)
- Brazil -

and is a central component in the manufacture of most electronic equipment and electric motors.

Iron is a ferromagnetic element. It is attracted by magnets and can be readily magnetized or made a permanent magnet by adding metals such as nickel, aluminum and cobalt.

The element is the principal ingredient in the dye serving as oxygen carrier in blood (hemoglobin) and its deficiency causes anemia. It is also a component of a number of enzymes

Main food sources of the element include beans, wheat bran, liver, cocoa, sesame, and egg yolk.

Ferrous sulfate elixir is a pharmaceutical product used as an iron supplement for treatment of low levels of iron in the blood.

Fe Iron , 26

The major inhibitors of iron absorption in the body are coffee, tea and spinach (Although it contains an iron component but spinach also contains oxalic acid which is linked to the metal ion and prevents its absorption in blood). On the other hand, excessive amounts of iron are not recommended and studies of liver disease have shown a close relation between iron accumulation in the body and alcohol intake.

Astronomers and geologists believe that iron has no native origin on earth. It is assumed that a rocky planet, similar to earth, has exploded during the early stages of the formation of the solar system and began to rain the earth with an alloy of iron and nickel on a daily basis. Professor Armstrong of the U.S. space agency (NASA) pointed out that iron (and nickel) atoms are characterized by the highest binding energy among all the elements (this is the energy required to form an atom from the fundamental particles (protons, neutrons and electrons). Armstrong explained that the binding energy of the iron atom is much higher than the available energy in the solar system as a whole. He summarized (So scientists believe that iron is not composed on the earth and is not original in our planet but is delegated to it).

Magnetite

(Ferrous-ferric oxide)

-New York, USA -

The Hoba Meteorite

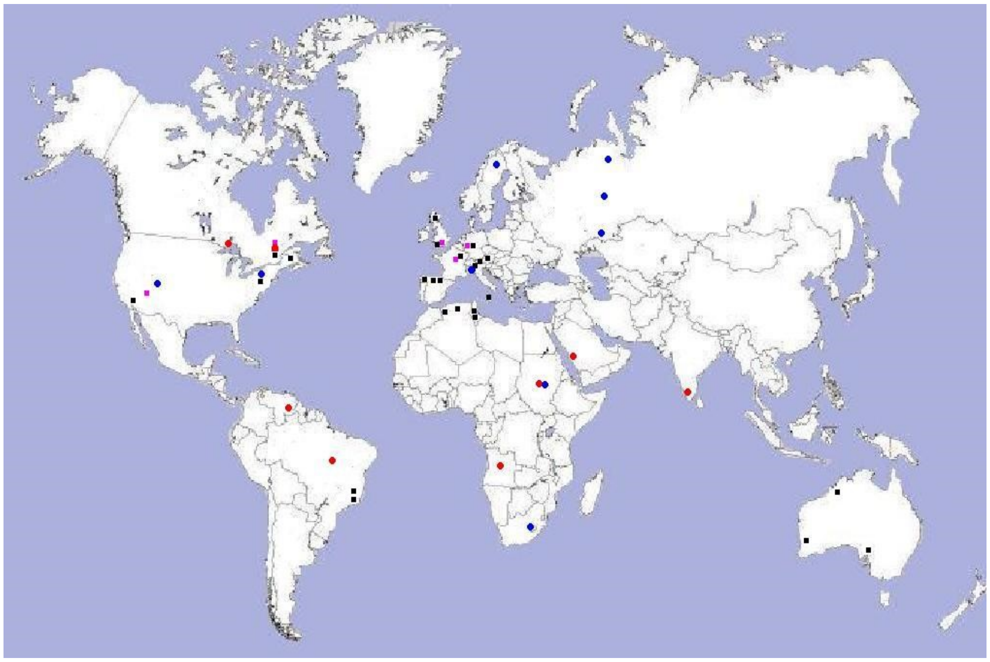
-Hoba region , Namibia -

An alloy of iron(84 %) and nickel (16 %)

It weighs about 60 tons and is the largest meteorite on the surface of the earth

Fe Iron , 26

Mineral ore locations



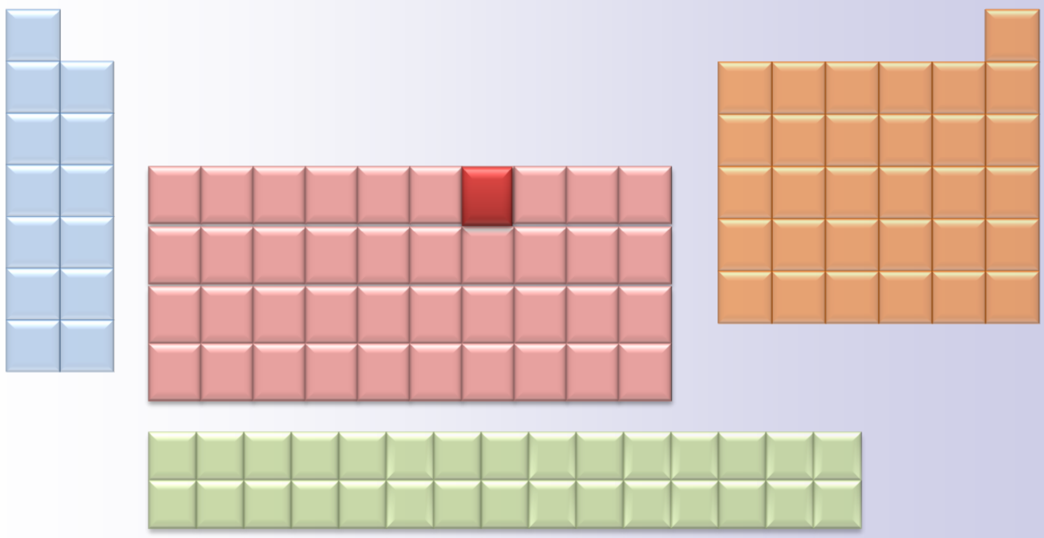
Gothite Siderite Magnetite Hematite

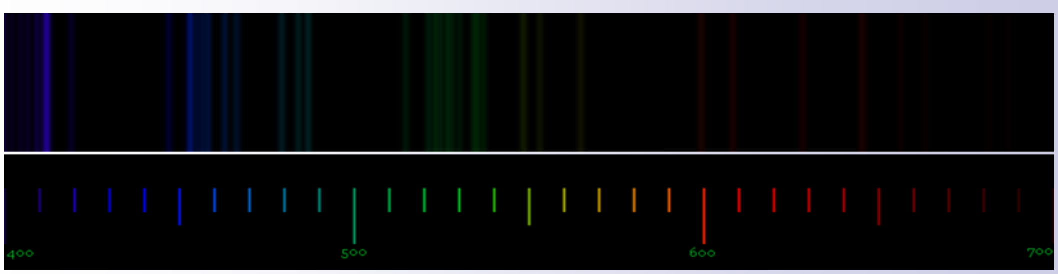
Fe Iron , 26

Physical and chemical properties

Symbol	Fe	Relative atomic mass	55.847
Atomic number	26	Melting point (°C)	1534
Group	8	Boiling point (°C)	2749
Period	4	Specific heat (J/g.K)	0.449
Family	Transition metals	Oxidation numbers	+2,+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.83
Atomic radius (pm)	124.1	Thermal conductivity (W/m.K)	80.2
Crystal structure	Body centeredCu-bic	Heat of fusion (kJ/mol)	14.9
Electronic configuration	$[Ar]3d^6 4S^2$	Heat of vaporization (kJ/mol)	351.0
Molar volume(cm3/ mole,273K)	7.09	Ist. ionization potential (kJ/mole)	759.3
Density (g/cm3)	7.874	2nd.Ionization potential (kJ/mole)	1561
Number of isotopes	24	3rd. ionization potential (kJ/mol)	2957

Cobalt Co





Cobalt is a silvery-white, hard and brittle ferromagnetic element which resembles iron and nickel in appearance. It does not occur as a free element in nature but small amounts of its compounds are common in a number of minerals usually associated with nickel , silver , lead , copper , and iron ores. It is principally found in cobaltite, linnaeite minerals. It also occurs in the secondary ore erythrite or red cobalt but cobalt is usually extracted, as a by-product, of the mining and purification processes of copper, lead and nickel ores.

Cobalt is rather stable in air due to the formation of a protective oxide film but is readily attacked by halogens and sulfur .

Erythrite

(Hydrated cobalt arsenate)

- Morocco -

Cobaltite

(cobalt sulfoarsenide)

-Hankansboda,Sweden -

The most important commercial uses of the metal are in the field of alloy manufacture. It is a component in iron, nickel and chromium alloys which are used in the manufacture of metal cutting equipment, permanent magnets, and other applications. Cobalt is also utilized in electroplating of metals, where a solid, shiny and rust-resistant layer is obtained.

Irradiation of cobalt with neutrons in a nuclear reactor generates the radioactive cobalt-60 isotope. Cobalt-60 isotope is a gamma and beta emitter and is widely used in many industrial applications including detection of cracks and flaws in metal parts of aircraft and turbines.

Co Cobalt , 27

Cobalt-60 isotope is also used in the field of agriculture as an anti-epidemic and in the medical field for the sterilization of drugs and medical devices. Cobalt element is vital to the animal life. It is the metallic component of vitamin B -12, which regulates different biological processes of carbohydrates, proteins and fats within the living cell.

Meat, dairy products and green leafy vegetables are the principal food sources of the element.

Cobalt metal
(A piece of cobalt cathode)

Mineral ore locations

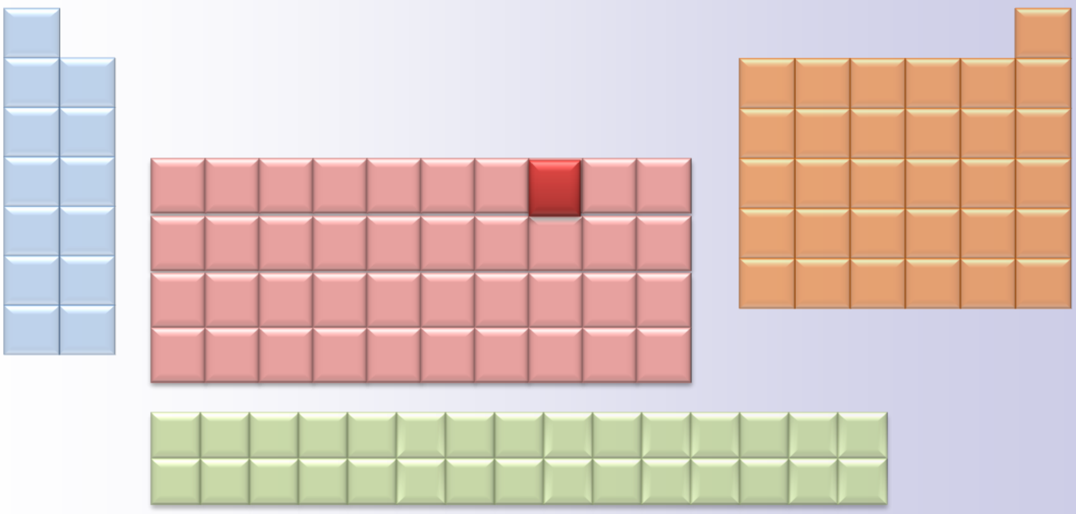
• Erythrite ■ Cobaltite

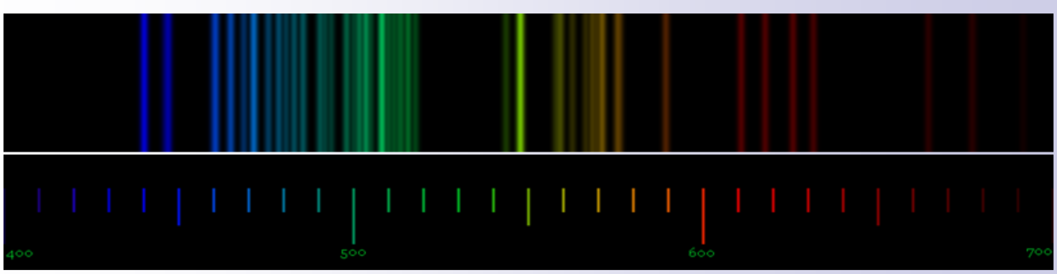
Co Cobalt , 27

Physical and chemical properties

Symbol	Co	Relative atomic mass	58.933
Atomic number	27	Melting point (°C)	1494
Group	9	Boiling point (°C)	2869
Period	4	Specific heat (J/g.K)	0.421
Family	Transition metals	Oxidation numbers	+2,+3,+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.88
Atomic radius (pm)	125.3	Thermal conductivity (W/m.K)	100
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	15.2
Electronic configuration	$[Ar]3d^7 4S^2$	Heat of vaporization (kJ/mol)	382.4
Molar volume(cm3/ mole,273K)	6.62	Ist. ionization potential (kJ/mole)	760.0
Density (g/cm3)	8.900	2nd.Ionization potential (kJ/mole)	1646
Number of isotopes	22	3rd. ionization potential (kJ/mol)	3232

Nickel Ni





Nickel is a silvery-white, ductile and malleable ferromagnetic metal that occurs naturally in silicate and sulfide ores (garnierite and pentlandite) in the company of iron, sulfur and arsenic ores.

The pure metal is usually extracted by roasting (oxidation) of sulfide ores followed by reduction (smelting) with cock. Further purification is conducted by passing carbon monoxide to form nickel carbonyl which volatilizes leaving the impurities in the solid state and finally decomposes to deposit high-purity nickel (99.9%).

Garnierite

(Nickel and magnesium silicates)
-New Caledonia -

Nickel chunk

Nickel is stable in air (mainly due to the formation of a rigid protective layer of the oxide). It is characterized by high resistance to corrosion by alkalis and is not affected by water in normal conditions. However, it readily dissolves in acids (except concentrated nitric acid).

Most commercial product of nickel is consumed by steel industry to make corrosion-resistant alloys. It is used in currency coins, metal plating and in the manufacture of dry accumulators (nickel cadmium batteries). It is also used as a catalyst in the industrial hydrogenation processes of vegetable oils.

Ni Nickel , 28

Nickel is one of the white metals (together with palladium and silver) that are used in the production of white gold alloy in jewelry industry.

The element and many of its compounds are classified as carcinogens. On the other hand it has been proved that nickel is an essential trace element for the human and plant life and is a component of a number of vital body enzymes.

Vegetables, fruits and cereals are the most important natural sources for nickel.

Mineral ore locations

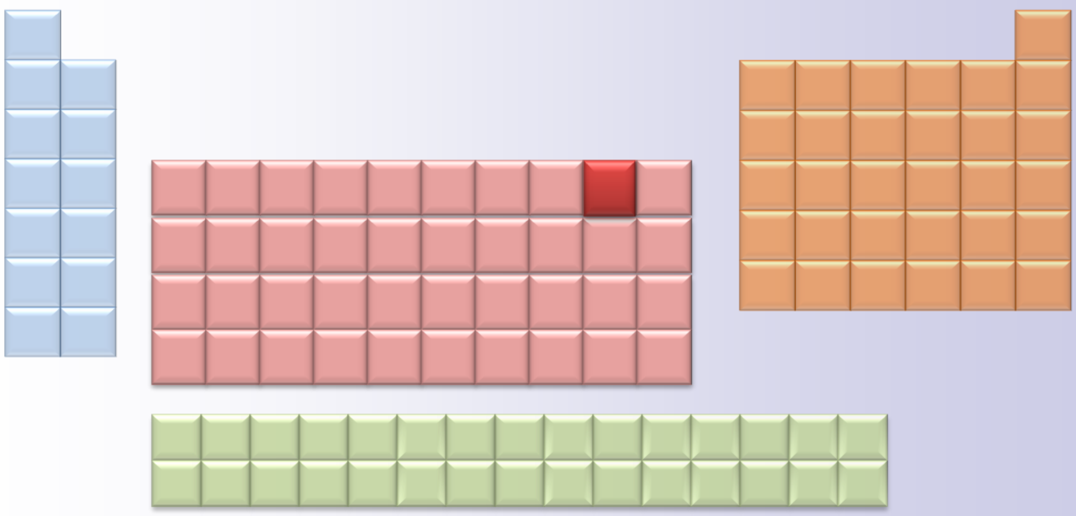
• Pentlandite ■ Garnierite

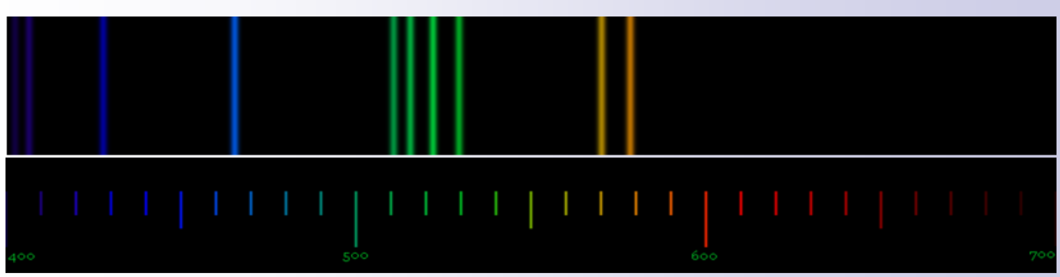
Ni Nickel , 28

Physical and chemical properties

Symbol	Ni	Relative atomic mass	58.693
Atomic number	28	Melting point (°C)	1452
Group	10	Boiling point (°C)	2731
Period	4	Specific heat (J/g.K)	0.444
Family	Transition metals	Oxidation numbers	+2,+3,+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.91
Atomic radius (pm)	124.6	Thermal conductivity (W/m.K)	90.7
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	17.6
Electronic configuration	$[Ar]3d^8 4S^2$	Heat of vaporization (kJ/mol)	371.8
Molar volume(cm3/ mole,273K)	6.59	Ist. ionization potential (kJ/mole)	736.7
Density (g/cm3)	8.902	2nd.Ionization potential (kJ/mole)	1753.0
Number of isotopes	14	3rd. ionization potential (kJ/mol)	3393

Copper Cu





Copper is a reddish-orange, malleable and ductile metal that takes a bright metallic luster and ranks third in the commercial production of metals (after iron and aluminum).

Together with gold and iron copper has been known and used in different parts of the world before 10,000 years.

The major commercial sources of the element are the sulfide ores (chalcopyrite ,Chalcocite and bournite) and the carbonate ore (malachite). Native copper is found in a number of regions but in limited quantities.

Major producers of copper are Chile, U.S and Indonesia.

Metallurgical operations of copper start with roasting the ore to form the oxide which is then reduced by cock in the process of smelting and finally subjected to electrolytic refining.

Copper refining electrolytic cells are composed of positive electrodes (anodes) of crude copper and negative electrodes (cathodes) which are made of sheets of very pure copper. An electric current of 200 A is passed through an electrolyte solution containing copper sulfate and sulfuric acid and pure copper is gradually built on cathodes that eventually turn into masses of high-purity copper (+99.99%).

A number of valuable metals such as gold, silver and platinum which are insoluble in the electrolyte fall from the anode to the bottom of the cell with the anode slime.

Copper is relatively inert and is only attacked by oxidizing acids such as nitric acid. It gradually tarnishes and loses its luster in moist air and slowly corrodes and develops a green layer of basic copper carbonate (verdigris) or green patina (a mixture of oxides and carbonates) that prevent further erosion.

Copper is characterized by a very high electrical conductivity (second only to silver) and will readily form an electrochemical cell when it comes in contact with another metal in the presence of moisture.

Native Copper

Cu Copper , 29

Malachite (with quartz)

-Tsumeb,Namibia-

The major commercial applications of copper are in the field of the electric industry. It is also used in plumping, heating and building construction.

Copper sulfate is a commercial product used as a fungicide and herbicide for cleaning freshwater pipes and swimming pools . It is also important in petroleum, leather and textile industries.

Two of the most famous and most important copper alloys which are known and used since ancient times are bronze (copper and tin alloy) and brass (copper and zinc alloy). The copper-nickel alloy is widely used in currency coins.

Copper oxide in Fehling's solution is used in tests for reducing sugars and is the traditional reagent for testing glucose in urine.

The metal is one of the most important constituents of silver and gold alloys in the jewelry industry. It is used in protective coatings and undercoats for metals such as nickel, chromium and zinc.

Chalcocite

- Bristol, USA -

Bournite

(Copper and iron sulfides)

-cornwall , England -

Cu Copper , 29

Copper is a principal component of several enzymes that organize and control many processes in the human cell. These include control of iron absorption in blood plasma, functioning of the central nervous system and formation of the dye that gives color to hair, skin and eyes (melanin).

The major food sources of copper are oysters, nuts and dry legumes.

All water soluble copper compounds are toxic.

Mineral ore locations

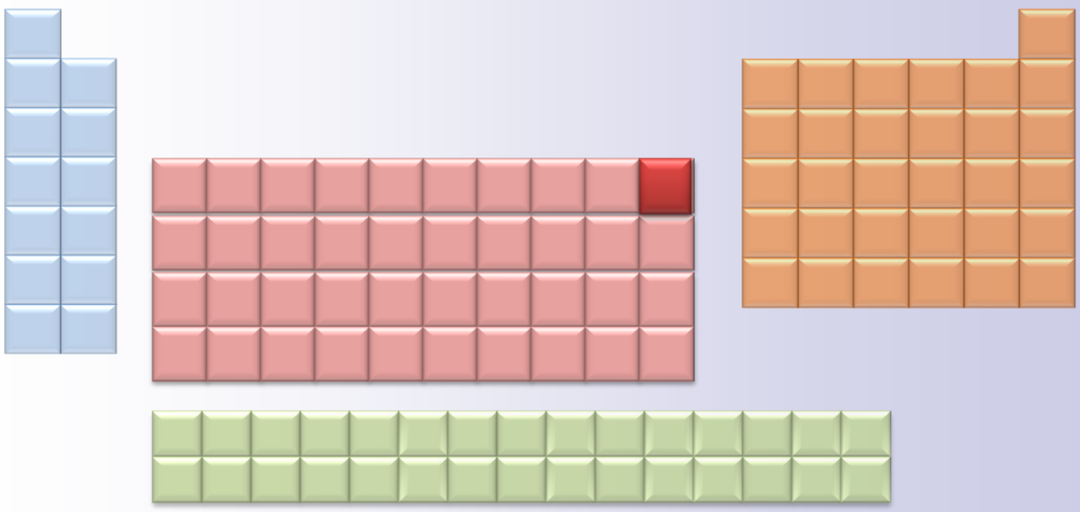
Chalcopyrite ■ bournite ● Native copper ● Chalcocite

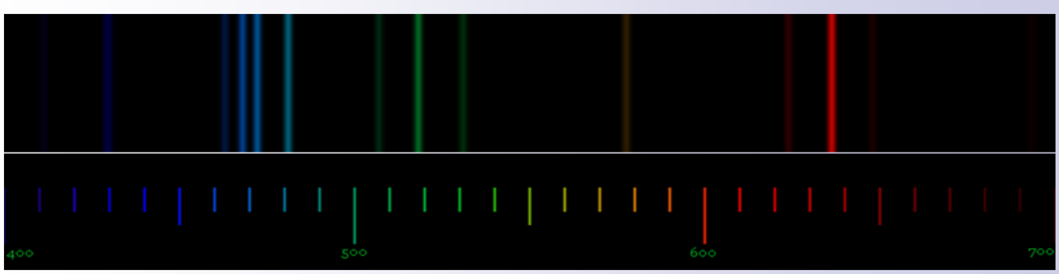
Cu Copper , 29

Physical and chemical properties

Symbol	Cu	Relative atomic mass	63.546
Atomic number	29	Melting point (ºC)	1083.45
Group	11	Boiling point (ºC)	2566
Period	4	Specific heat (J/g.K)	0.385
Family	Transition metals	Oxidation numbers	+1,+2,+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.90
Atomic radius (pm)	127.8	Thermal conductivity (W/m.K)	401
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	13.0
Electronic configuration	$[Ar]3d^{10}4S^1$	Heat of vaporization (kJ/mol)	304.6
Molar volume(cm3/ mole,273K)	7.09	Ist. ionization potential (kJ/mole)	745.4
Density (g/cm3)	8.960	2nd.Ionization potential (kJ/mole)	1658
Number of isotopes	29	3rd. ionization potential (kJ/mol)	3554

Zinc Zn





Zinc is a bright, bluish-white lustrous metal. It is brittle at normal temperatures but soft and malleable at temperatures above 100 °C. It is the 24th most abundant element in the earths crust and it ranks fourth in the commercial production of metals (after iron, aluminum and copper).

Mineral sources of zinc include willemite, smithsonite and sphalerite ores. The latter represents the principal commercial source of the element.

Ores are roasted to oxidize the zinc sulfide to zinc oxide which is then reduced to the metal by carbon or carbon monoxide. Further purification is conducted through electrolytic methods.

Sphalerite crystals
(with minor associated chalcopyrite)
-Colorado, USA -

Zinc is chemically active and readily reacts with nonmetals and with both acids and alkalis. It quickly tarnishes in moist air as it reacts with atmospheric carbon dioxide and produces a layer of zinc carbonate that protects the metal against further erosion. Zinc is used to make corrosion resistant alloys including soft solder (with lead and tin), German silver alloy (with copper and nickel). It has been used with copper for making brass since ancient times.

Iron and steel plating (galvanization) is an important traditional process widely used for protection against corrosion. Zinc is also utilized for protection of metal structures of ships and boats (cathodic protection). In this process zinc metal acts as a (sacrificial) anode to prevent the erosion of the steel structure (cathode).

The metal is utilized in zinc-carbon batteries to act as both the container and as an electrode.

Zinc oxide is an important material in the manufacture of paints and pharmaceutical products. It is the main ingredient in calamine lotion which is widely used as an antipruritic and antiseptic. It is also used in other industrial products including plastics, printing ink and textiles.

Zn Zinc , 30

Zinc is an essential trace element for animals and plants and is involved in numerous aspects of body metabolism. It is an antioxidant and is involved in many important biological activities such as the kidney function, the immune system and the synthesis of nucleic acids. It supports normal growth and controls the function of sensory organs and cell division.

The main food sources of zinc are oyster, salmon, meat, eggs, dairy products, almonds, whole grains, beans and sunflowers.

Pumpkin

A natural source of zinc

Mineral ore locations

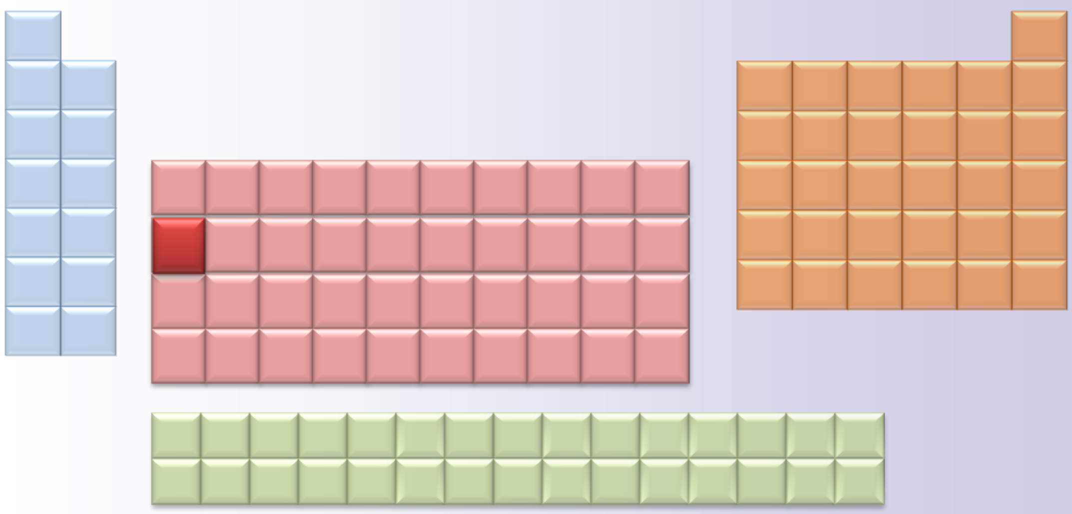
▪ Willemite • Sphalerite • Zincite

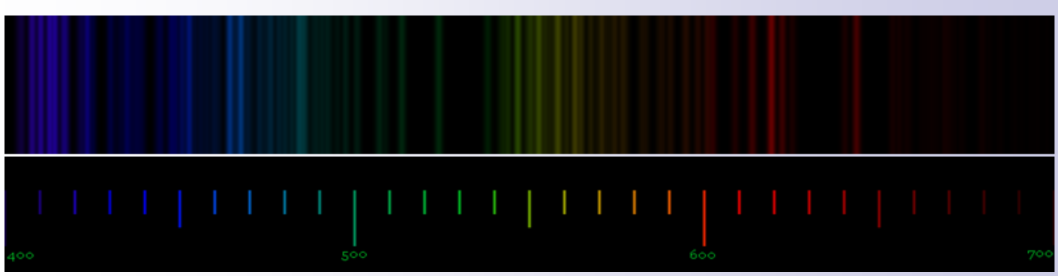
Zn Zinc , 30

Physical and chemical properties

Symbol	Zn	Relative atomic mass	65.39
Atomic number	30	Melting point (ºC)	419
Group	12	Boiling point (ºC)	906
Period	4	Specific heat (J/g.K)	0.388
Family	Transition metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	1.65
Atomic radius (pm)	133.2	Thermal conductivity (W/m.K)	116
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	6.67
Electronic configuration	$[Ar]3d^{10}4S^{2}$	Heat of vaporization (kJ/mol)	115.3
Molar volume(cm3/ mole,273K)	9.17	Ist. ionization potential (kJ/mole)	906.4
Density (g/cm3)	7.133	2nd.Ionization potential (kJ/mole)	1733.3
Number of isotopes	25	3rd. Ioniza tion potential (kJ/mol)	2832.6

Yttrium Y





Yttrium is a soft silvery and shiny metal which is very similar to scandium. It occurs (in the combined form only) in uranium and rare earth minerals and is usually recovered from monazite and bastnasite ores. The element is one of the decay products of uranium and hence, one of the major elements derived from the spent nuclear fuel in nuclear power plants.

Yttrium is common in both soil and sea water (its abundance in the earth's crust is about 400 times that of silver) and its existence in relatively high concentrations in lunar rocks has been proved.

Fergusonite

(A complex oxide of Rare earth Elements)

- Sweden -

Yttrium metal

Yttrium is chemically active and is readily soluble in water and mineral acids with evolution of hydrogen gas. At higher temperatures it combines with many non-metals such as carbon, silicon, phosphorus, sulfur, selenium and the halogens.

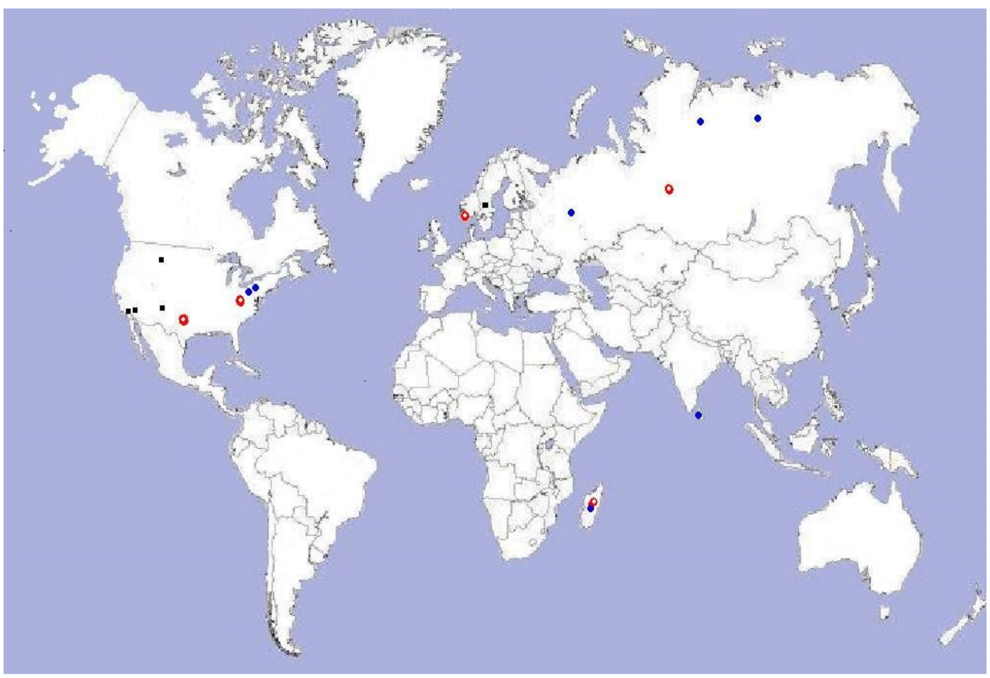
Owing to the formation of a protective oxide layer, yttrium acquires protection against corrosion and relative resistance to chemical attack. On the other hand, the finely divided metal automatically catches fire in air.

Y Yttrium , 39

Fields of commercial application of yttrium include the electronic industry, the production of synthetic gemstones, metal alloys and dentistry.

Yttrium oxide (yttria) is used as a catalyst for some polymerization processes. It is also used to make yttrium iron garnets which are characterized by special magnetic properties with iron, aluminum and gadolinium. It is doped with europium to make phosphors that give the red color in the color television tube.

Mineral ore locations



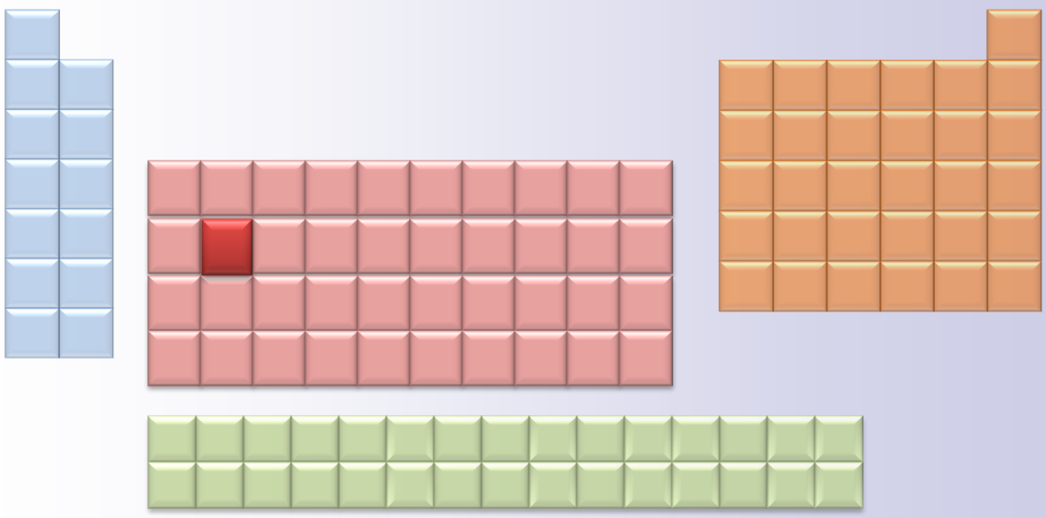
■ Fergusonite ● Monazite ● Bastnasite

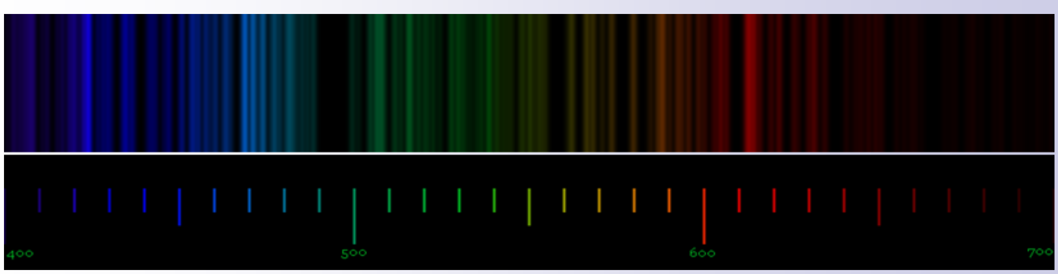
Y Yttrium , 39

Physical and chemical properties

Symbol	Y	Relative atomic mass	88.906
Atomic number	39	Melting point (°C)	1521
Group	3	Boiling point (°C)	3337
Period	5	Specific heat (J/g.K)	0.298
Family	Transition metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.22
Atomic radius (pm)	181	Thermal conductivity (W/m.K)	17.2
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	17.2
Electronic configuration	[Kr]$4d^1$ $5S^2$	Heat of vaporization (kJ/mol)	393.3
Molar volume(cm3/ mole,273K)	19.89	Ist. ionization potential (kJ/mole)	616
Density (g/cm3)	4.469	2nd.Ionization potential(kJ/mole)	1181
Number of isotopes	32	3rd. ionization potential (kJ/mol)	1980

Zirconium Zr





Zirconium is a silver-gray, lustrous, ductile and malleable metallic element. It is widely distributed in the earth's crust in the form of silicates (zircon) accompanying titanium and tin ores, and is usually isolated as a by-product of mining and purification processes of these metals. Zircon also contains hafnium which has extremely similar chemical properties and the two elements are separated through ion exchange processes.

Zirconium is commercially produced by Kroll process. The heated ore is treated with carbon and then with chlorine gas to form the volatile tetrachloride which is purified by sublimation and finally reduced to the pure metal by magnesium at temperatures reaching 1000 °C.

Zircon crystal

Zirconium metal

Zirconium has exceptional resistance to corrosion and is only attacked by aqua regia and hydrofluoric acid. It is extremely resistant to heat, but metal filings burn with a bright flame and a temperature reaching 4930 °C which is one of the highest temperatures known.

Important compounds of zirconium include the di-, tri- and tetrachloride which are strong reducing agents, and the carbonate which is a usual ingredient of printing inks and colors.

However, the most important compound of the metal is zirconium oxide which exists naturally as zirconia. It is a refractory material that melts at 2960 °C and which is not affected by acids (except hydrofluoric acid).

Zirconia is widely used in furnaces, high temperature crucibles, dentistry and jewelry industry.

Zirconium is used as a hardening agent in steel alloys and some zirconium compounds are utilized in a number of industrial applications. The hydride is a reducing agent and a vacuum tube getter and the carbide which is extremely hard and corrosion resistant is used in bits for cutting tools

Because of the low probability of neutron absorption in addition to the mechanical strength and the exceptional resistance to heat and corrosion, most of zirconium metal production is used in nuclear energy applications. Hafnium-free, high purity -zirconium (nuclear-grade zirconium) is used to make tubes that contain uranium oxide fuel in nuclear reactors (fuel rods).

Mineral ore locations

● Zircon

Zr Zirconium , 40

Physical and chemical properties

Symbol	Zr	Relative atomic mass	91.224
Atomic number	40	Melting point (°C)	1851
Group	5	Boiling point (°C)	4376
Period	4	Specific heat (J/g.K)	0.278
Family	إنتقالية Metals	Oxidation numbers	+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.33
Atomic radius (pm)	160	Thermal conductivity (W/m.K)	22.7
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	23.0
Electronic configuration	$[Kr]4d^2 5S^2$	Heat of vaporization (kJ/mol)	581.6
Molar volume(cm3/ mole,273K)	14.02	Ist. ionization potential (kJ/mole)	660
Density (g/cm3)	6.506	2nd.Ionization potential (kJ/mole)	1267
Number of isotopes	25	3rd. ionization potential (kJ/mol)	2218

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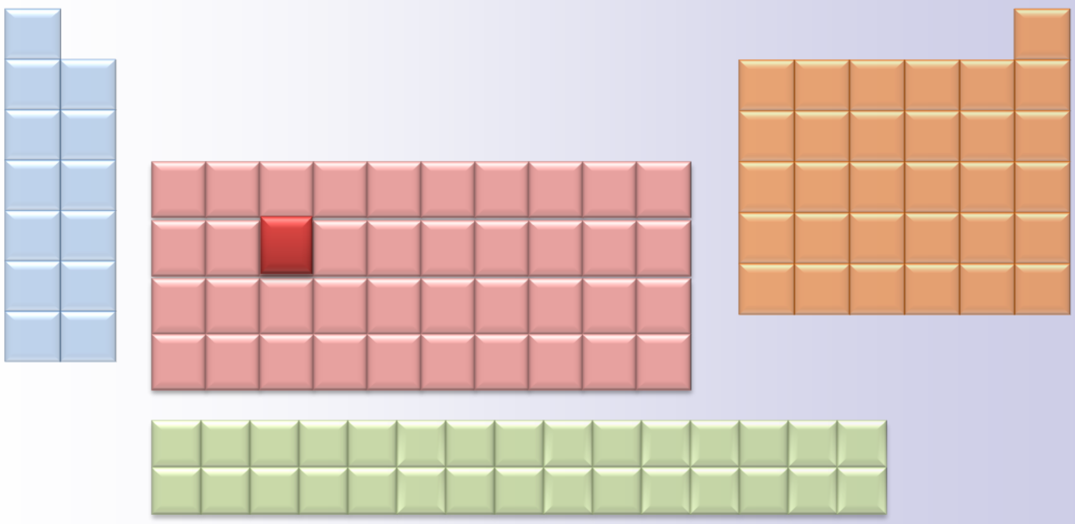
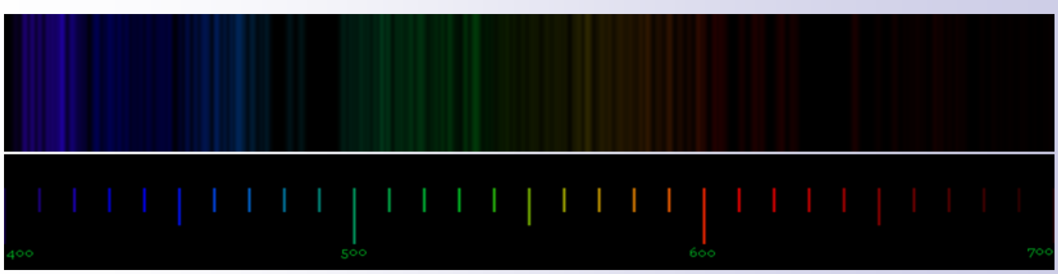
Niobium Nb





Niobium (also known as columbium) is a lustrous, ductile and malleable metallic element which is difficult to distinguish from tantalum due to the close similarity in both physical and chemical properties.

Niobium is rare and occurs naturally in week concentrations in a number of ores but principally in columbite ore. It substitutes for tantalum in a number of ores and in different proportions and columbite-tantalite ores are usually used as a source of both elements.

The metal is resistant to molten alkalis and most acids and is not affected by water or air at normal conditions (this is mainly due to the formation of a thin protective oxide layer on the surface of the metal).

Niobium bead

Columbite

Major applications of niobium are in the steel industry and particularly in making carbon steel which is used in gas and crude oil pipelines.

Niobium is also used in the manufacture of certain heat-resistant alloys (with nickel, iron and cobalt) for use in aircraft engines. It is alloyed with vanadium and technetium to produce super conductive magnets for use in magnetic resonance devices.

Niobium finds increasing importance in the electronic industry, laser materials and jewelry. It is preferred in medical industry branches that require an inert and easy to shape material as in the case of pacemakers.

Nb Niobium , 41

Important compounds of niobium include the crystalline and very rigid carbide, the super conductive hydride and the strong reducing agent di-iodide.

Mineral ore locations

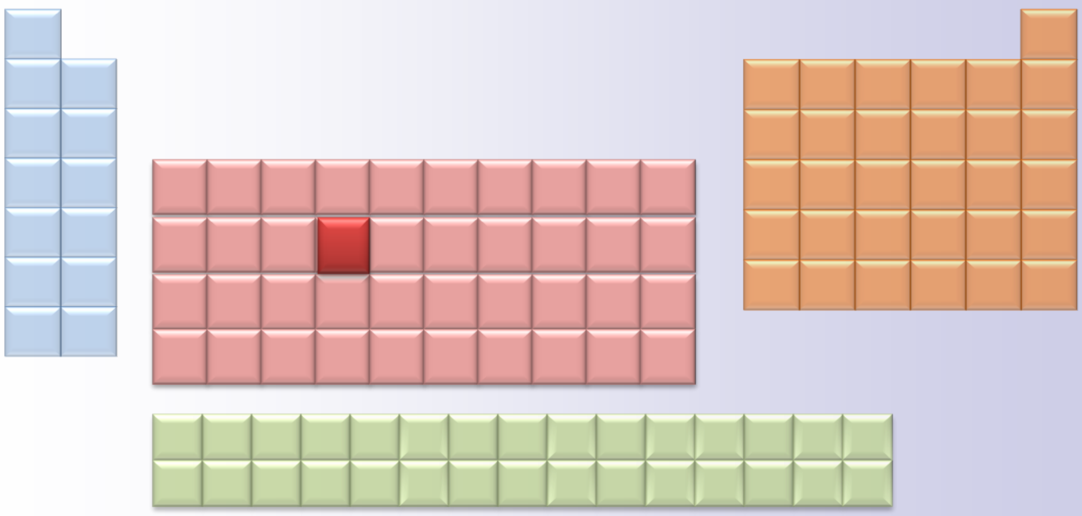
■ Columbite -Tantalite

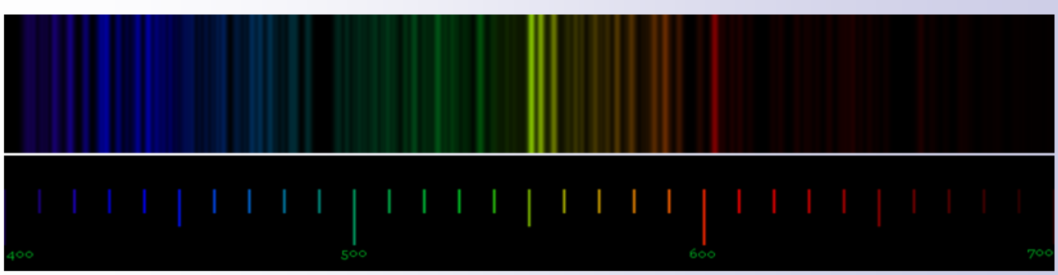
Nb Niobium , 41

Physical and chemical properties

Symbol	Nb	Relative atomic mass	92.906
Atomic number	41	Melting point (ºC)	2467
Group	5	Boiling point (ºC)	4741
Period	5	Specific heat (J/g.K)	0.278
Family	Transition metals	Oxidation numbers	+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.6
Atomic radius (pm)	142.9	Thermal conductivity (W/m.K)	53.7
Crystal structure	BodyCentered Cubic	Heat of fusion (kJ/mol)	27.2
Electronic configuration	$[Kr]4d^4\ 5S^1$	Heat of vaporization (kJ/mol)	696.6
Molar volume (cm3/mole,273K)	10.84	Ist. ionization potential (kJ/mole)	664
Density (g/cm3)	8.570	2nd.Ionization potential (kJ/mole)	1382
Number of isotopes	31	3rd. ionization potential (kJ/mol)	2416

Molybdenum Mo





Molybdenum is a silvery-white metallic element that usually occurs in the company of copper ores and is commercially produced from molybdenite (molybdenum sulfide) and wulfenite (lead molybdate) ores.

The element is also obtained, as a by-product, of mining and refining operations of copper and tungsten ores.

Molybdenum is stable in air and is only oxidized at temperatures above 600 °C . However, it is attacked by mineral acids and molten alkalis.

Crystalline Molybdenum

Wulfenite

(lead molybdate)

-North China -

The pure metal is obtained through the reduction of the oxide and is usually consumed in manufacturing steel alloys and electrodes for electric heating furnaces (molybdenum is identified by the highest melting point after tantalum and tungsten).

Molybdenum sulfide is widely used in high temperature lubricants where fats and oils are normally degraded.

The element is vital to animals and plants as it constitutes the primary element in the structure of many enzymes.

Major food sources of molybdenum include potatoes, cereals, legumes and grains of sunflowers.

Mo Molybdenum , 42

Molybdenite

(molybdenum sulfide)

Mineral ore locations

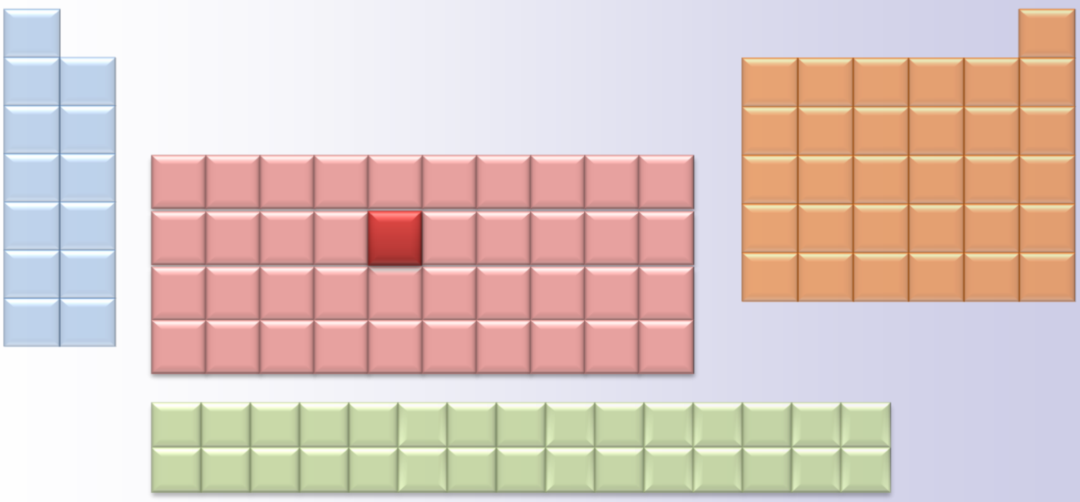
• Molybdenite

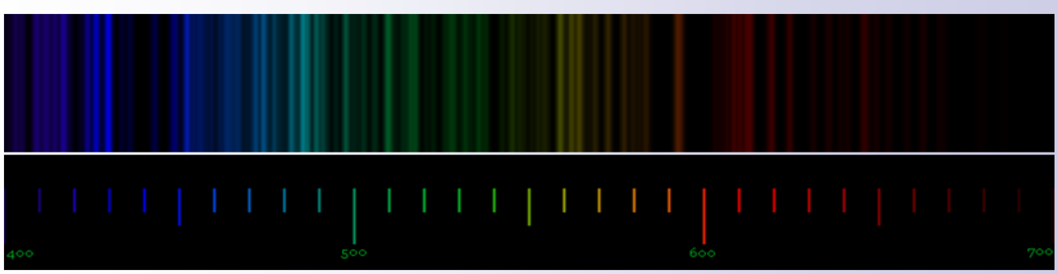
Mo Molybdenum , 42

Physical and chemical properties

Symbol	Mo	Relative atomic mass	95.94
Atomic number	42	Melting point (°C)	2616
Group	6	Boiling point (°C)	4611
Period	5	Specific heat (J/g.K)	0.251
Family	Transition metals	Oxidation numbers	+3,+4,+5,+6
Physical state(20°C)	solid	Electronegativity (pouling)	2.16
Atomic radius (pm)	136.2	Thermal conductivity (W/m.K)	138
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	27.6
Electronic configuration	$[Kr]4d^5\ 5S^1$	Heat of vaporization (kJ/mol)	594.1
Molar volume (cm3/mole,273K)	9.39	Ist. ionization potential (kJ/mole)	685.0
Density (g/cm3)	10.220	2nd.Ionization potential (kJ/mole)	1558
Number of isotopes	23	3rd. ionization potential (kJ/mol)	2621

Technetium Tc





Technetium is a radioactive element predicted by Mendeleev (1868) who described a number of its characteristics, and pointed out its location in the periodic table between the element 42 (molybdenum) and the element 44 (ruthenium). It was discovered in 1937 to be the first artificially synthesized element.

Technetium is a silvery - gray metal that gradually loses its luster in moist air. It dissolves in nitric acid, concentrated sulfuric acid and aqua regia, but is insoluble in all concentrations of hydrochloric acid.

Technetium has no stable isotope and its natural occurrence (as traces) is due to the continuous disintegration of uranium isotopes.

The main commercial product of the element is technetium - 99 isotope which is obtained, as a by- product, of spent nuclear fuel in nuclear power stations.

Addition of technetium offers high corrosion - resistance to steel alloys but, being radioactive, its applications are restricted to closed systems.

The metastable nuclear isomer, technetium -99m, is a gamma emitter and is characterized by a very short half -life (6 hours). This makes technetium an ideal element for imaging in the medical field.

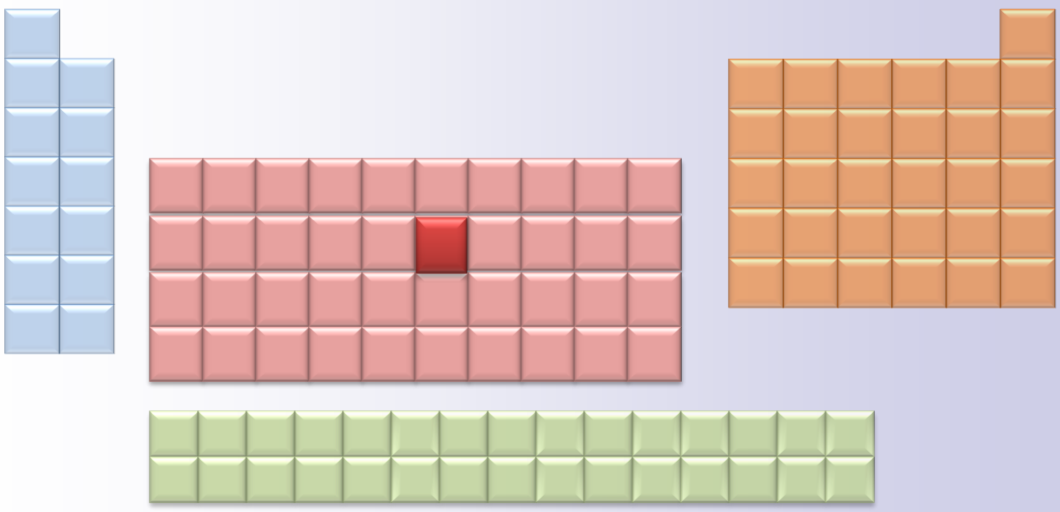
Technetium and promethium are distinguished by radioactivity among all light elements

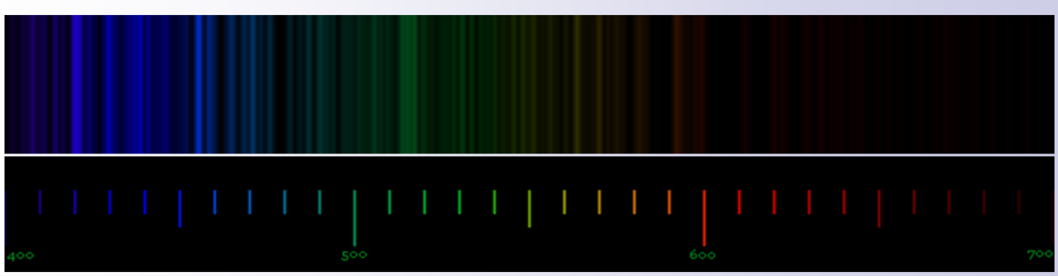
Tc Technetium , 43

Physical and chemical properties

Symbol	Tc	Relative atomic mass	98.906
Atomic number	43	Melting point (°C)	2171
Group	7	Boiling point (°C)	4876
Period	5	Specific heat (J/g.K)	####
Family	Transition metals	Oxidation numbers	+4, +6 , +7
Physical state (20°C)	solid	Electronegativity (pouling)	1.9
Atomic radius (pm)	135.8	Thermal conductivity (W/m.K)	50.6
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	23.81
Electronic configuration	$[Kr]4d^6\ 5S^1$	Heat of vaporization (kJ/mol)	585.22
Molar volume (cm3/mole,273K)	8.6	Ist. ionization potential (kJ/mole)	702
Density (g/cm3)	11.50	2nd.Ionization potential (kJ/mole)	1472
Number of isotopes	25	3rd. ionization potential (kJ/mol)	2850

Ruthenium Ru





Ruthenium is a white and hard platinum-group metal. It is highly resistant to atmospheric conditions and is not oxidized in air at temperatures below 800 °C . It does not dissolve in cold or hot acids or even in aqua regia. However, it is attacked by halogens and molten alkalis, and it explodes violently in a solution of potassium chlorate.

Ruthenium is one of the rarest elements in nature. It occurs, in the elemental pure form but in week concentrations along with ore deposits of platinum alloys (principally in osmiridium alloy). The element is usually obtained as a by-product of mining and refining of these ores and also as a by-product of nickel processing operations. It is isolated from spent nuclear fuel as it constitutes about 0.2% of the mass of depleted uranium.

Ruthenium is primarily used as an alloying agent and is added to platinum and palladium metals to obtain alloys with high durability and high resistance to corrosion (addition of 0.1% ruthenium makes titanium 100 times more resistant to corrosion).

Ruthenium is also added to the alloys of nickel, cobalt and molybdenum and to gold alloys in jewelry making.

The metal is important in the electronic industry (electrical resistors and conductors) and in the field of chemical industries (poles of electrolytic cells).

Ruthenium compounds are used as catalysts in many industrial operations including the production of ammonia from natural gas, acetic acid from methyl alcohol and elimination of hydrogen sulfide from oil in petroleum refining. Some ruthenium compounds are used for coloring glass and ceramics.

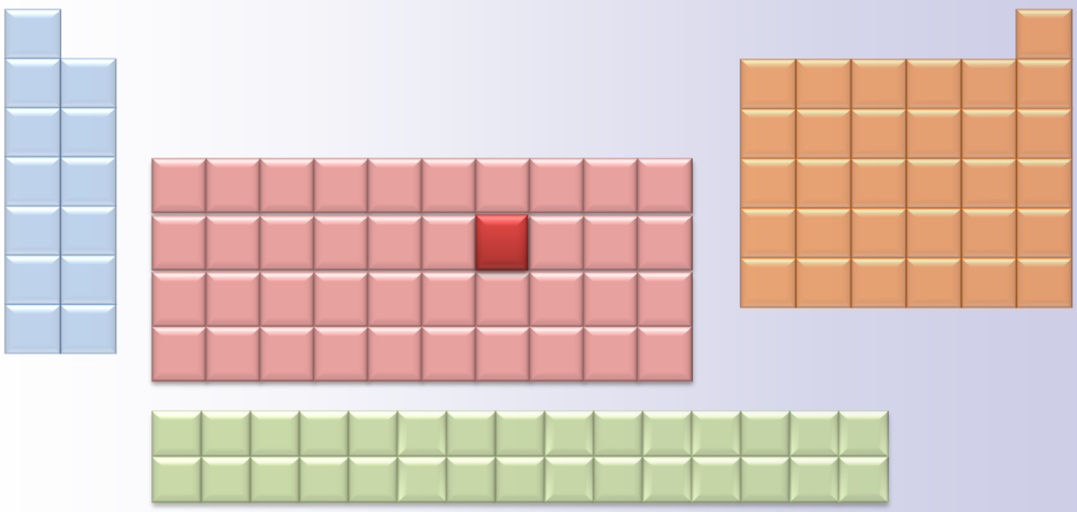
Ruthenium bar

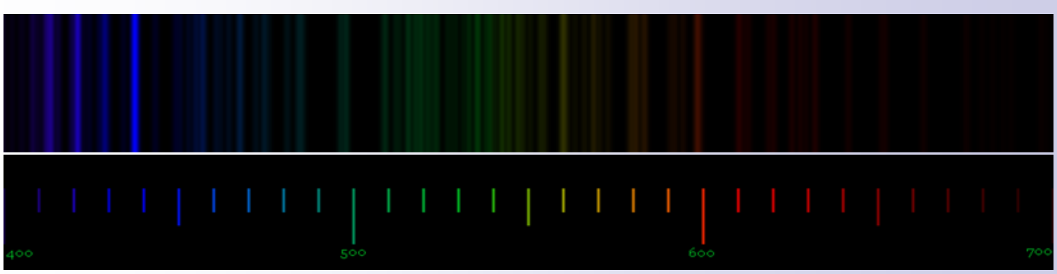
Ru Ruthenium , 44

Physical and chemical properties

Symbol	Ru	Relative atomic mass	101.07
Atomic number	44	Melting point (ºC)	2309
Group	8	Boiling point (ºC)	3899
Period	5	Specific heat (J/g.K)	0.238
Family	Transition metals	Oxidation numbers	+3, +4 , +5
Physical state (20°C)	solid	Electronegativity (pouling)	2.2
Atomic radius (pm)	134	Thermal conductivity (W/m.K)	117
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	23.7
Electronic configuration	$[Kr]4d^7 5S^1$	Heat of vaporization (kJ/mol)	567.8
Molar volume (cm3/mole,273K)	8.14	Ist. ionization potential (kJ/mole)	711
Density (g/cm3)	12.370	2nd.Ionization potential (kJ/mole)	1617
Number of isotopes	20	3rd. ionization potential (kJ/mol)	2747

Rhodium Rh





Rhodium is a hard, silvery-white platinum metal characterized by a high melting point and high resistance to corrosion. It occurs naturally—in low concentrations of the free elemental form – along with platinum deposits that constitute its chief commercial source. The element is also isolated from nuclear fuel (it constitutes about 0.4% of the mass of spent fuel).

Rhodium is classified as the most precious and the most noble natural element. It forms a protective superficial oxide layer in air and is insoluble in single acids and is only slightly affected by aqua regia.

The principal application of rhodium is in the automotive industry and most of the commercial product is consumed in the manufacture of catalytic converters that break harmful exhaust gases such as nitrogen oxides into eco friendly gases (nitrogen and oxygen).

Electrolytic deposition of rhodium on the surface of white gold and platinum offers glamorous reflectability to ornaments and decorations. The metal is also added to platinum and palladium alloys for hardening and improving corrosion resistance.

Rhodium is utilized as a chemical intermediate in the industrial hydrogenation processes of organic compounds. A platinum-rhodium catalyst is used in the manufacture of nitric acid from ammonia, and a rhodium metal complex is used in the manufacture of acetic acid by carbonylation of methyl alcohol.

Rhodium metal powder

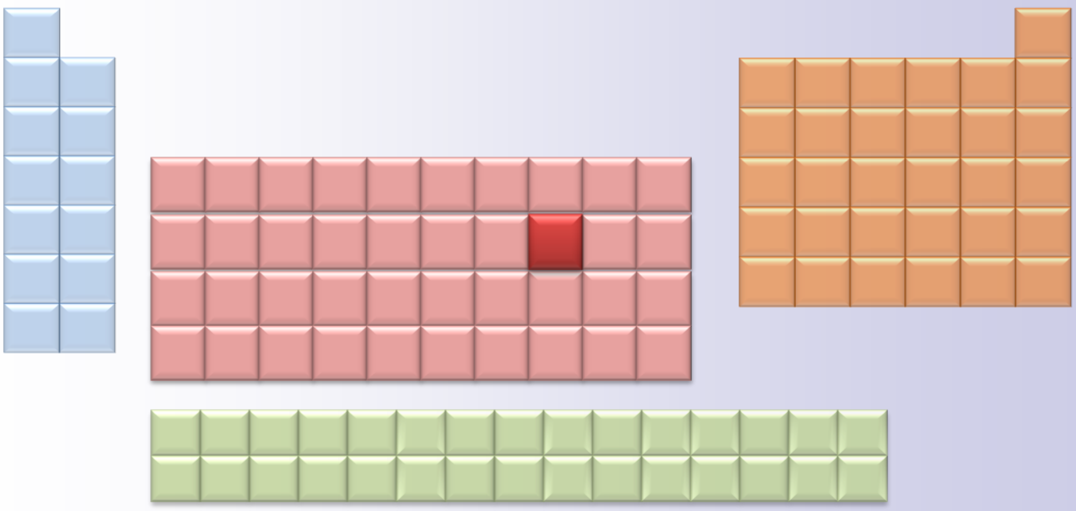
Rhodium cylinder

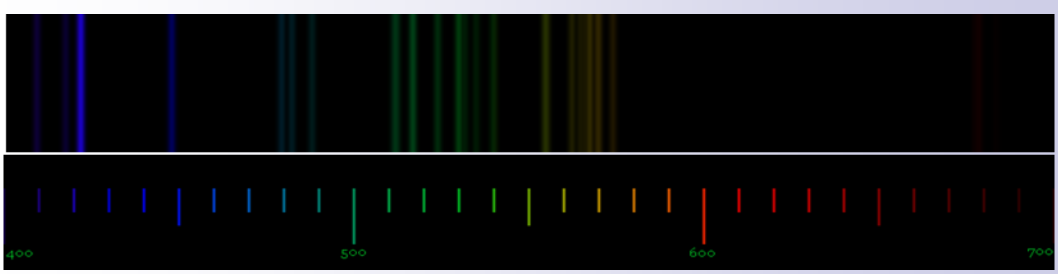
Rh Rhodium , 45

Physical and chemical properties

Symbol	Rh	Relative atomic mass	102.906
Atomic number	45	Melting point (ºC)	1965
Group	9	Boiling point (ºC)	3726
Period	5	Specific heat (J/g.K)	0.243
Family	Transition metals	Oxidation numbers	+3, +4 , +5
Physical state (20°C)	solid	Electronegativity (pouling)	2.28
Atomic radius (pm)	134.5	Thermal conductivity (W/m.K)	150
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	21.55
Electronic configuration	$[Kr]4d^8\ 5S^1$	Heat of vaporization (kJ/mol)	495.4
Molar volume(cm3/ mole,273K)	8.29	Ist. ionization potential (kJ/mole)	720
Density (g/cm3)	12.410	2nd.Ionization potential (kJ/mole)	1744
Number of isotopes	34	3rd. ionization potential (kJ/mol)	2997

Palladium Pd





Palladium is a silvery-white, ductile and malleable platinum metal. It is a rare element that occurs naturally in the free elemental form together with platinum alloys and is usually extracted, as a by-product, of mining of nickel and copper ores.

Palladium is characterized by the lowest density and the lowest melting point of a platinum metal and although it is the member of the least resistance to chemical change among the group, it is only slightly affected in atmosphere. However, it is readily dissolved in concentrated nitric acid and hot sulfuric acid.

Palladium is characterized by an ability to absorb 900 times its volume of hydrogen or acetylene gas at room temperature. Another unique characteristic of palladium is its strong catalytic power which is demonstrated by the oxidation of hydrogen to water at room temperature in the presence of the metal. These properties account for the important applications of palladium in the industrial field, particularly in dehydrogenation processes and in catalytic converters.

The metal is also important in other industrial fields including fabrication of medical equipment and electrical appliances.

Palladium is one of the white metals (together with nickel and silver) that are used to make white gold alloy in ornament and jewelry production factories.

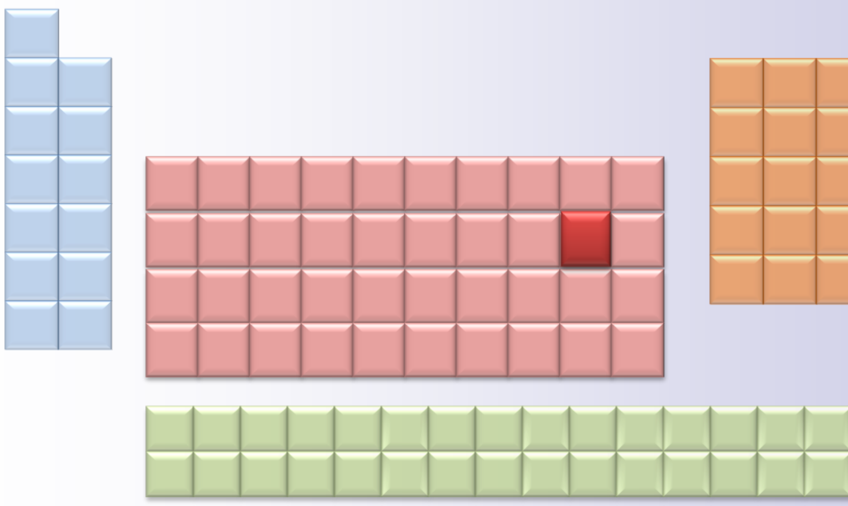
Palladium metal

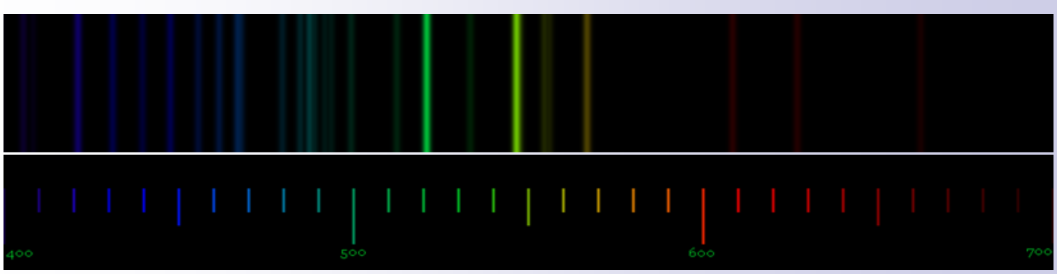
Pd Palladium , 46

Physical and chemical properties

Symbol	Pd	Relative atomic mass	106.42
Atomic number	46	Melting point (°C)	1551
Group	10	Boiling point (°C)	3139
Period	5	Specific heat (J/g.K)	0.244
Family	Transition metals	Oxidation numbers	+2, +3 , +4
Physical state (20°C)	solid	Electronegativity (pouling)	2.20
Atomic radius (pm)	137.6	Thermal conductivity (W/m.K)	71.8
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	17.2
Electronic configuration	$[Kr]4d^{10}$	Heat of vaporization (kJ/mol)	393.3
Molar volume(cm3/ mole,273K)	8.85	Ist. ionization potential (kJ/mole)	805
Density (g/cm3)	12.020	2nd.Ionization potential (kJ/mole)	1875
Number of isotopes	25	3rd. ionization potential (kJ/mol)	3177

Silver Ag





Silver is a precious element of the gold group which has been known since ancient times. The pure metal is highly ductile and malleable and is characterized by a brilliant white metallic luster.

Native silver occurs naturally, usually accompanying gold and copper metals. It also occurs, chemically combined , in a number of mineral ores including argentite (silver sulfide) and Chlorargyrite (silver chloride or horn silver). However most of the commercial product of the element is usually obtained, as a-by product, of refining processes of copper, gold, lead and zinc ores.

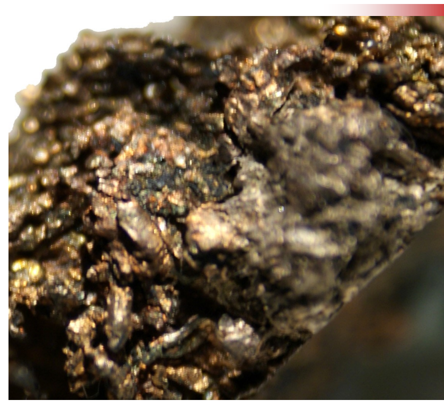
Silver is stable in pure air and water, but tarnishes on exposure to ozone or humid air containing sulfur or hydrogen sulfide. It dissolves in cold dilute nitric acid and in hot concentrated sulfuric acid, but is not affected (even by fused) alkalis.

Silver is characterized by the highest electrical conductivity of any element and by the highest thermal conductivity of any metal.

Sterling silver contains 92.5% by weight of silver and 7.5% by weight of another metal (usually copper). This alloy is used in jewelry, silverware, electrical contacts and was traditionally used in currency coins. The metal is also used in high-capacity silver-zinc and silver-cadmium batteries, and some silver compounds are utilized as catalysts in a number of chemical industry processes.

Argentite

(silver sulfide)



Native silver

Ag Silver , 47

Silver-indium-cadmium alloys containing about 80% silver are commonly used in control rod material for pressurized water reactors
Silver halides are extensively used in photography and silver nitrate has antiseptic properties and is applied as an external treatment in the medical field.
Silver azide and silver fulminate are powerful explosives.
Silver element is non-toxic, but most of its compounds are toxic due to the presence of the associated negative ions in solutions.
Silver is characterized by the most pure white color and is the best known reflector of visible light. It is electrically or chemically deposited on glass in the manufacture of mirrors and is the best material for coating solar reflectors .

Mineral ore locations

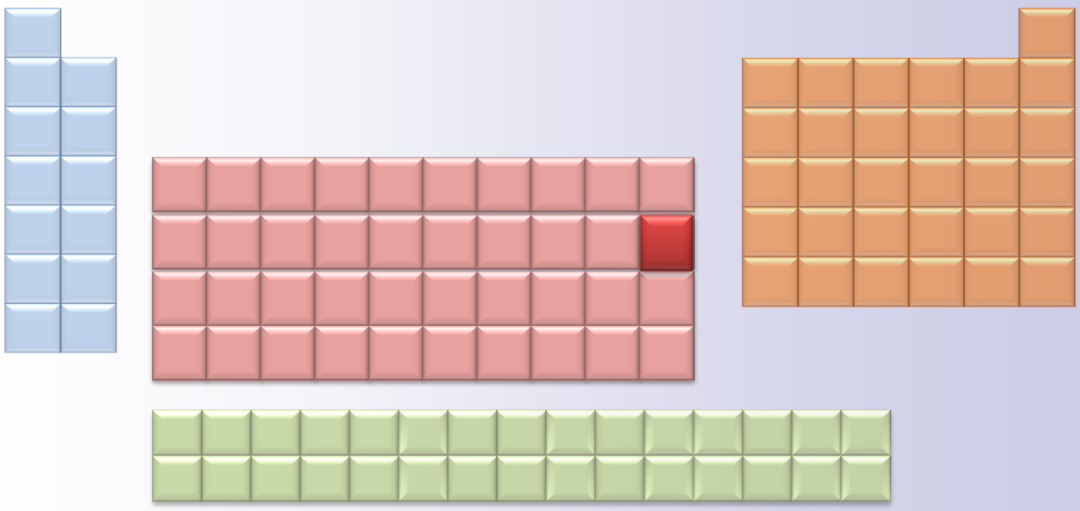
● Argentite ○ Horn silver

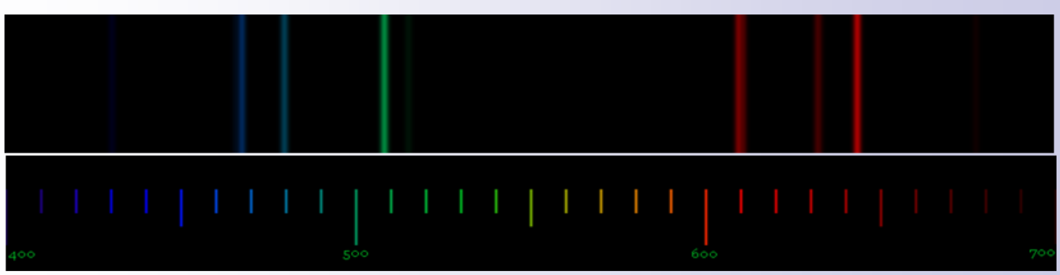
Ag Silver , 47

Physical and chemical properties

Symbol	Ag	Relative atomic mass	107.868
Atomic number	47	Melting point (°C)	961.95
Group	11	Boiling point (°C)	2211
Period	5	Specific heat (J/g.K)	0.235
Family	Transition metals	Oxidation numbers	+1, +2, +3
Physical state (20°C)	solid	Electronegativity (pouling)	1.93
Atomic radius (pm)	144.4	Thermal conductivity (W/m.K)	429
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	11.3
Electronic configuration	$[Kr]4d^{10}5S^{1}$	Heat of vaporization (kJ/mol)	255.1
Molar volume (cm3/mole,273K)	10.27	Ist. ionization potential (kJ/mole)	731.0
Density (g/cm3)	10.500	2nd.Ionization potential (kJ/mole)	2073
Number of isotopes	46	3rd. ionization potential (kJ/mol)	3361

Cadmium Cd





Cadmium is a soft, bluish-white , ductile and malleable metal which is chemically similar to zinc and is widespread in soil, air and sea.

Sulfide ores represent the principal commercial source of the metal. It is usually isolated as a by-product of mining and smelting of sphalerite ores (zinc sulfide) and the processing of lead and copper sulfide ores.

Most of the commercial product of cadmium is consumed in the manufacture of accumulators (rechargeable nickel–cadmium batteries).

Cadmium sulfide (cadmium yellow) is used as a pigment for glass and plastic products, fireworks and refractory materials.

The metal and its compounds are also utilized in metal alloys, jewelry, electroplating, television phosphors and laser materials.

Cadmium element and cadmium compounds are toxic and are usually classified as carcinogens.

Cadmium pollution is due to natural factors such as forest fires, volcanoes and erosion. It also results from man-made factors such as iron and zinc metallurgical operations, accumulators, phosphate fertilizers, household waste, and tobacco smoke. The latter is the principal source of the element in the human body.

Verbalizing international laws regarding cadmium pollution together with re-cycling operations are important factors that may help to prevent or limit the risks associated with cadmium pollution.

Silver-indium-cadmium alloys are utilized as control rod material for pressurized water reactors.

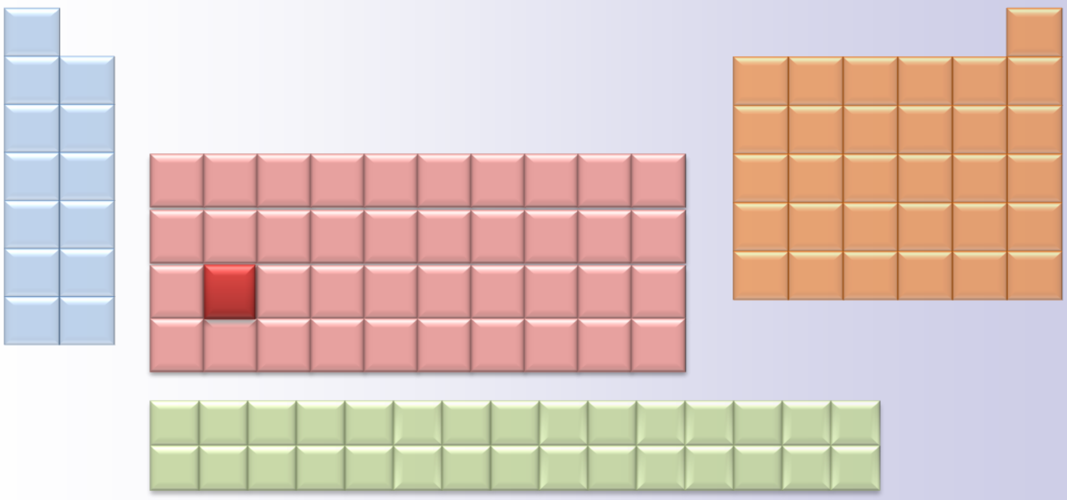
Nickel-Cadmium batteries

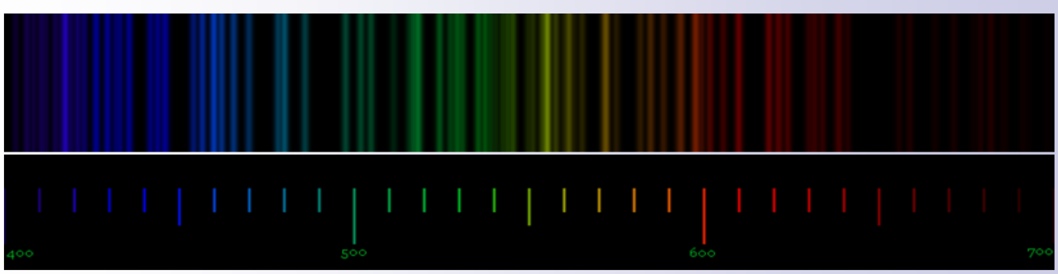
Cd Cadmium , 48

Physical and chemical properties

Symbol	Cd	Relative atomic mass	112.411
Atomic number	48	Melting point (°C)	320
Group	12	Boiling point (°C)	764
Period	5	Specific heat (J/g.K)	0.232
Family	Transition metals	Oxidation numbers	+2
Physical state (20°C)	solid	Electronegativity (pouling)	1.69
Atomic radius (pm)	148.9	Thermal conductivity (W/m.K)	96.8
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	6.11
Electronic configuration	$[Kr]4d^{10}5S^{2}$	Heat of vaporization (kJ/mol)	99.87
Molar volume(cm3/ mole,273K)	13.00	Ist. ionization potential (kJ/mole)	867.6
Density (g/cm3)	8.650	2nd.Ionization potential (kJ/mole)	1631
Number of isotopes	31	3rd. ionization potential (kJ/mol)	3616

Hafnium Hf





Hafnium is a steel- gray, ductile and malleable metal predicted by Mendeleev 50 years before its discovery in Denmark in 1923.

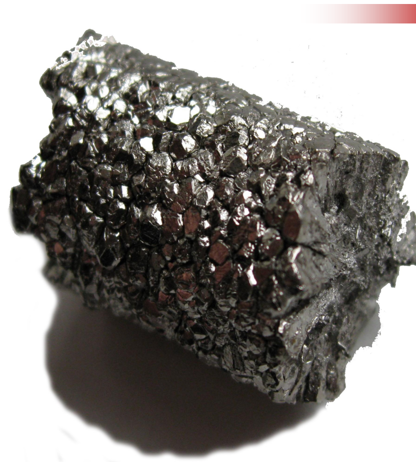
Hafnium is chemically very similar to zirconium and the two elements occur together in the form of silicates (zircon) usually in the company of titanium and tin ores . The two metals are isolated as by-products of refining processes of these elements and are separated by ion exchange processes .

Hafnium metal is corrosion-resistant and is stable in air due to the formation of a hard protective surface layer. However, the finely divided metal spontaneously ignites in air.

It is unaffected by concentrated alkalis but combines with the halogens at room temperature and with oxygen, nitrogen, sulfur and carbon at higher temperatures.

In spite of its scarcity and the difficulty of separation from zirconium, hafnium metal finds many important commercial applications. These include the manufacture of electrodes and integrated circuits in the electronic industry and the production of alloys with some metals such as tungsten, titanium, niobium and iron. However, the major commercial application of the element is in nuclear reactor control rods (Hafnium absorption cross section for thermal neutrons is about 600 times that of zirconium).

Hafnium carbide is one of the most heat-resistant materials known, and the metal nitride is an exceptionally hard refractory material characterized by one of the highest melting point temperatures known (°C).



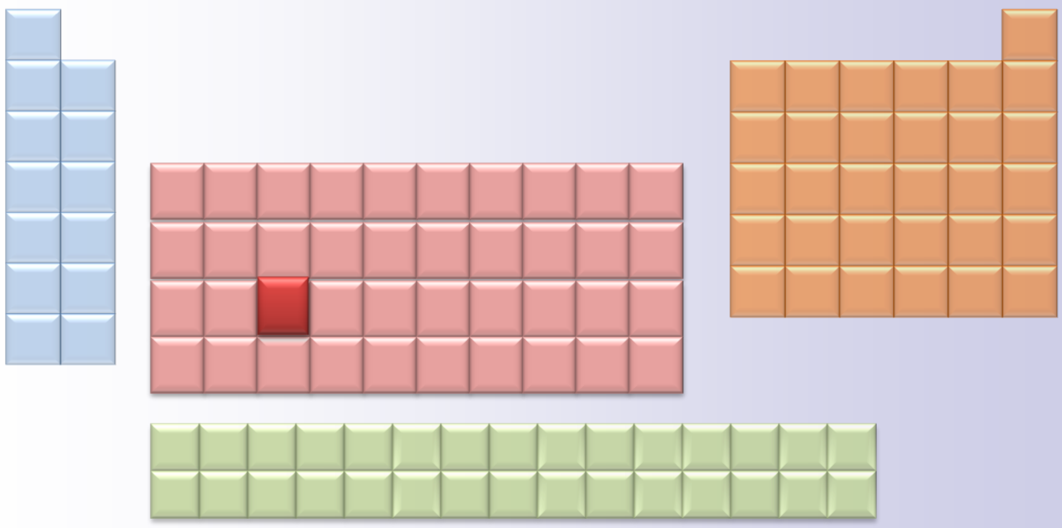
Hafnium metal

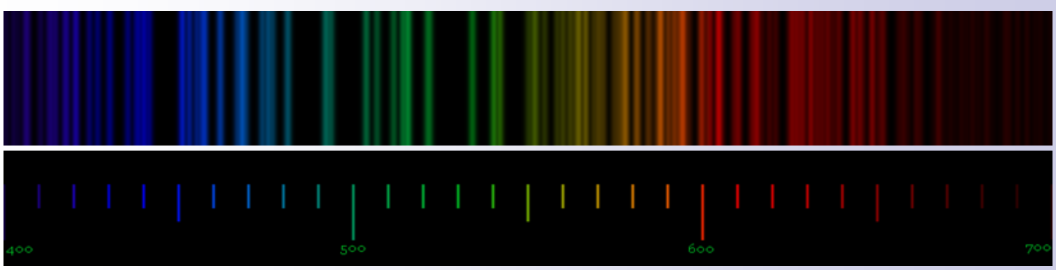
Hf Hafnium , 72

Physical and chemical properties

Symbol	Hf	Relative atomic mass	178.49
Atomic number	72	Melting point (°C)	2229
Group	4	Boiling point (°C)	5196
Period	6	Specific heat (J/g.K)	0.144
Family	Transition metals	Oxidation numbers	+4
Physical state (20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	156.4	Thermal conductivity (W/m.K)	23.0
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	25.5
Electronic configuration	$[Xe]4f^{14}5d^{2}6S^{2}$	Heat of vaporization (kJ/mol)	661.1
Molar volume(cm3/ mole,273K)	13.41	Ist. ionization potential (kJ/mole)	642
Density (g/cm3)	13.310	2nd.Ionization potential (kJ/mole)	1440
Number of isotopes	34	3rd. ionization potential (kJ/mol)	2250

Tantalum Ta





Tantalum is a shiny, gray and dense metal. It is hard , but is ductile and malleable.

The element, which is rather rare in nature, is extracted from different ores, but principally from tantalite which is an oxide ore of iron, manganese and tantalum. The element is also found in microlite ore and is obtained, as a by-product, of refining operations of tin ores.

Niobium, with very similar chemical properties, substitutes for tantalum in a number of ores and in different proportions and columbite-tantalite ores are usually used as a source of both elements.

Tantalum crystal

Tantalite

(An oxide of iron, manganese, and tantalum)

- Australia -

Tantalum is a good conductor of heat and electricity. It is highly resistant to corrosion due to the formation of a protective oxide film. It is not soluble in aqua regia or in any individual acid (except hydrofluoric acid).

Tantalum is a refractory metal. It is characterized by the highest melting point after tungsten and niobium (2995 °C). It is not oxidized in air at temperatures below 150 °C and is only slightly affected by alkalis.

Tantalum is used in the manufacture of electronic components especially in resisters and capacitors of electronic circuits (tantalum capacitors).

Ta Tantalum , 73

Tantalum is added to a number of metals such as platinum, copper and nickel to make durable, heat and corrosion resistant alloys. It is also used as a substitute for platinum in surgical equipment and prosthetics as it causes no immune resistance.

Tantalum carbide is one of the hardest and most durable man-made materials and is widely used in the manufacture of sharp edges of cutting tools.

Mineral ore locations

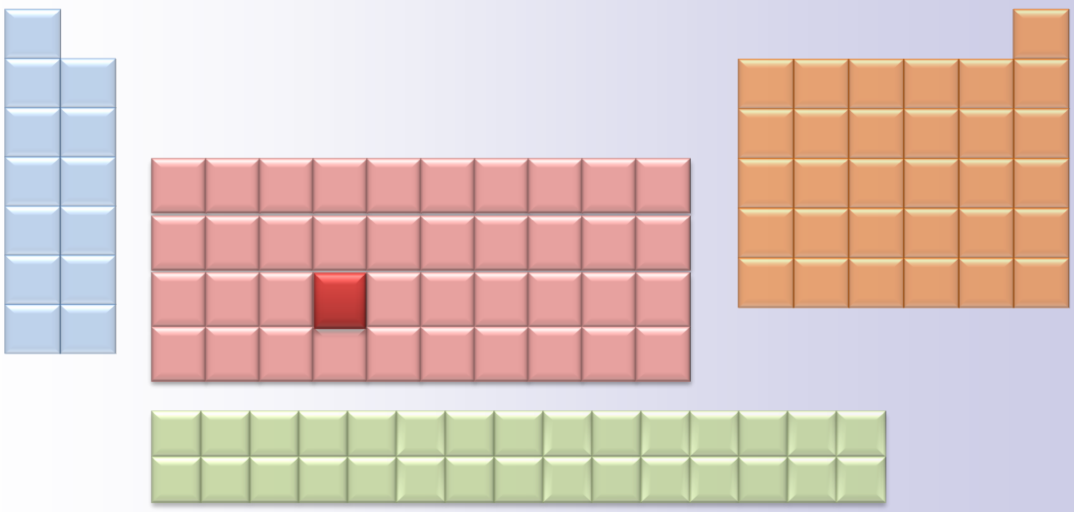
- Columbite - Tantalite

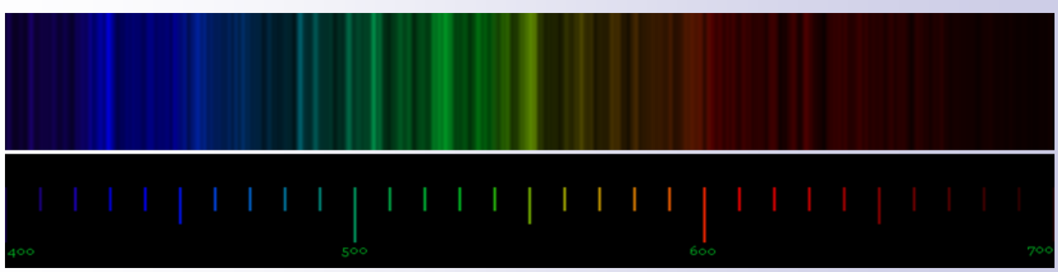
Ta Tantalum , 73

Physical and chemical properties

Symbol	Ta	Relative atomic mass	180.948
Atomic number	73	Melting point (°C)	2995
Group	5	Boiling point (°C)	5424
Period	6	Specific heat (J/g.K)	0.140
Family	Transition metals	Oxidation numbers	+3, +4, +5
Physical state (20°C)	solid	Electronegativity (pouling)	1.5
Atomic radius (pm)	143	Thermal conductivity (W/m.K)	57.5
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	31.4
Electronic configuration	$[Xe]4f^{14}5d^{3}6S^{2}$	Heat of vaporization (kJ/mol)	753.1
Molar volume (cm3/mole,273K)	10.87	Ist. ionization potential (kJ/mole)	761
Density (g/cm3)	16.654	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	31	3rd. ionization potential (kJ/mol)	####

Tungsten W





Tungsten (also called wolfram) is a steel-gray and dense metallic element. It occurs naturally as iron tungstates in wolframite and ferberite ores, but is principally mined from sheelite ore (calcium tungstate). The pure metal is commercially obtained by reducing tungsten oxide with hydrogen or carbon.

Crude tungsten is hard and brittle, but the pure metal is ductile and malleable. It is characterized by the highest melting point and the lowest vapor pressure among all metals and by the second highest melting point (after carbon) among all the elements.

Zone—refined Tungsten crystal

Sheelite
(Calcium tungstate)
- China -

Tungsten is highly resistant to corrosion. It is only slightly affected by most mineral acids or alkalis, and is only oxidized in the air at high temperatures.

Tungsten and its alloys are used in many industrial fields, especially those concerned with high temperature applications. Major industrial products of tungsten include filaments for electric lamps, fuses, electronic valves, electrodes of X-ray and television tubes, high temperature heating devices and radiation shields.

Tungsten carbide is one of the most rigid carbides (melting point 1770 °C). It is widely used in the manufacture of cutting and drilling tools in the fields of metal- working, mining and petroleum industries .

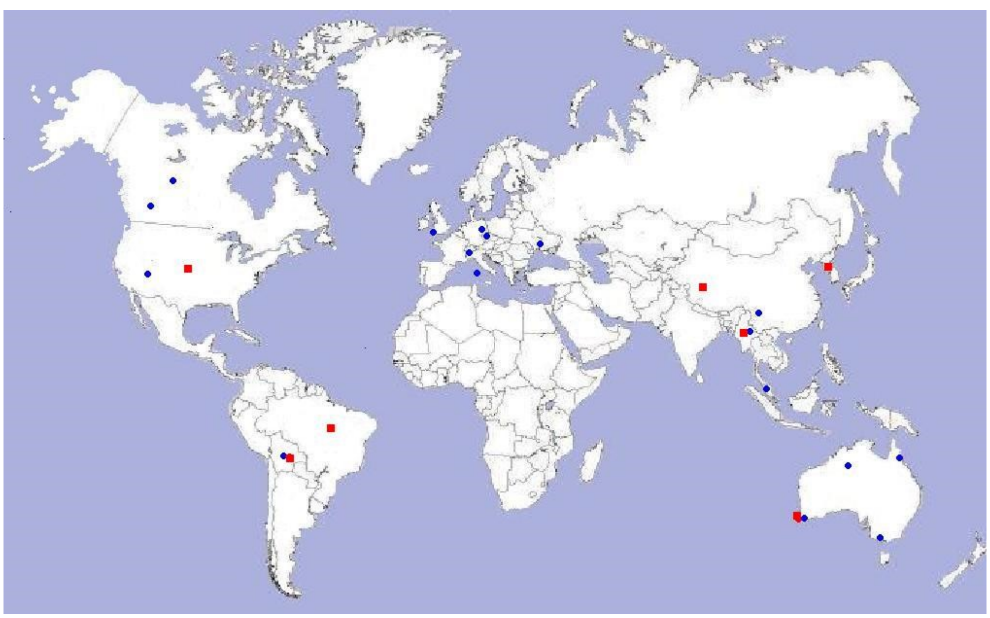
W Tungsten , 74

A number of tungsten compounds are used in the industrial field as catalysts, inorganic pigments and as high temperature lubricants (tungsten disulfide is a dry lubricant used at temperatures up to 500 °C).

Tungsten is used in the production of hard and heat resistant steel alloys (tungsten steel) and in the manufacture of highly rigid alloys with silicon and boron.

The filament of the incandescent light bulb is made of pure tungsten

Mineral ore locations



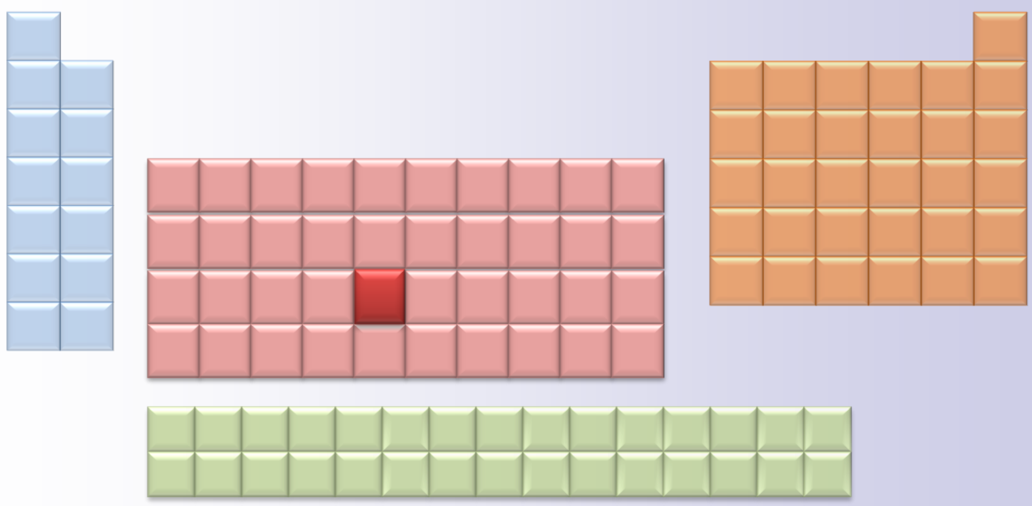
● Ferberite ■ Sheelite

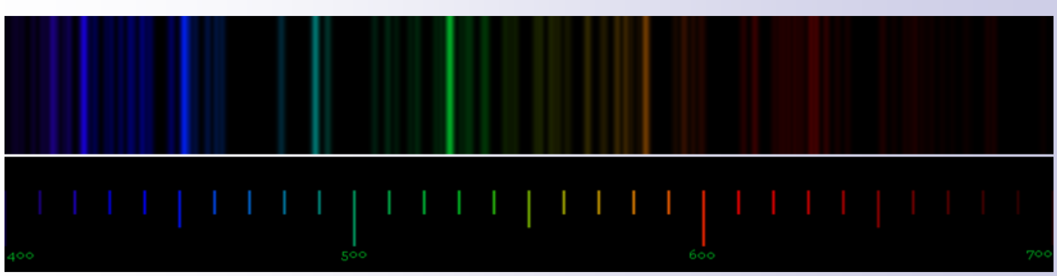
W Tungsten , 74

Physical and chemical properties

Symbol	W	Relative atomic mass	183.84
Atomic number	74	Melting point (ºC)	3406
Group	6	Boiling point (ºC)	5656
Period	6	Specific heat (J/g.K)	0.132
Family	Transition metals	Oxidation numbers	+4, +5,+6
Physical state (20°C)	solid	Electronegativity (pouling)	2.36
Atomic radius (pm)	137.0	Thermal conductivity(W/ m.K)	174
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/ mol)	35.2
Electronic configuration	$[Xe]4f^{14}5d^{4}6S^{2}$	Heat of vaporization (kJ/mol)	799.1
Molar volume(cm3/ mole,273K)	9.53	Ist. ionization potential (kJ/mole)	770
Density (g/cm3)	19.300	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	29	3rd. ionization potential (kJ/mol)	####

Rhenium Re





Rhenium is a lustrous silvery-white metallic element and the last of the natural elements to be discovered (1925). It is among the rarest elements in the earth's crust and one of the most precious. It is not found free in nature and is widely spread throughout the earth's crust but in extremely low concentrations . It occurs in the uncommon mineral rheniite (rhenium sulfide) but is commercially obtained, as a by-product, of mining and refining processes of molybdenum and copper ores in which its concentration reaches up to 0.2%.

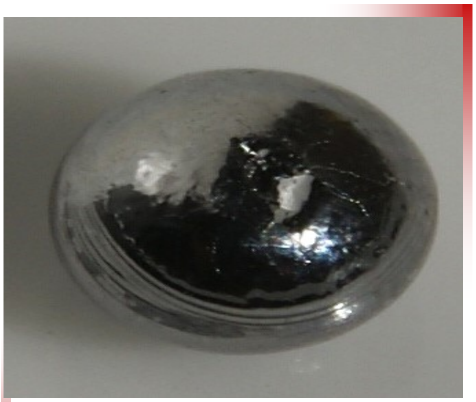
The powder which is the usual commercial form of rhenium can be consolidated by pressing and sintering to obtain a compact shape of the metal that becomes ductile and malleable after annealing.

Although rhenium is resistant to corrosion and oxidation in normal conditions, it is readily dissolved in dilute mineral acids and is gradually attacked in moist air. The metal dust is a fire and explosion hazard.

Rhenium element is characterized by an exceptionally high density, exceeded only by platinum, iridium, and osmium. It is also characterized by a very high melting point exceeded only by carbon and tungsten.

Rhenium is used in filaments and is added to molybdenum in the manufacture of superconductive alloys, and due to its high resistance to corrosion the metal is used in thermocouples (those made of rhenium -tungsten alloy are used to measure temperatures up to 2200 °C).

Rhenium catalysts are exceptionally resistant to poisoning from nitrogen, sulfur, and phosphorus. The finely divided metal is used in the oxidation of alcohols and in hydrogenation processes, and a rhenium-platinum alloy is used in petroleum cracking operations (restructuring) to convert the oil to petroleum derivatives of large octane number (more efficient gasoline).



Rhenium metal

Mineral ore locations

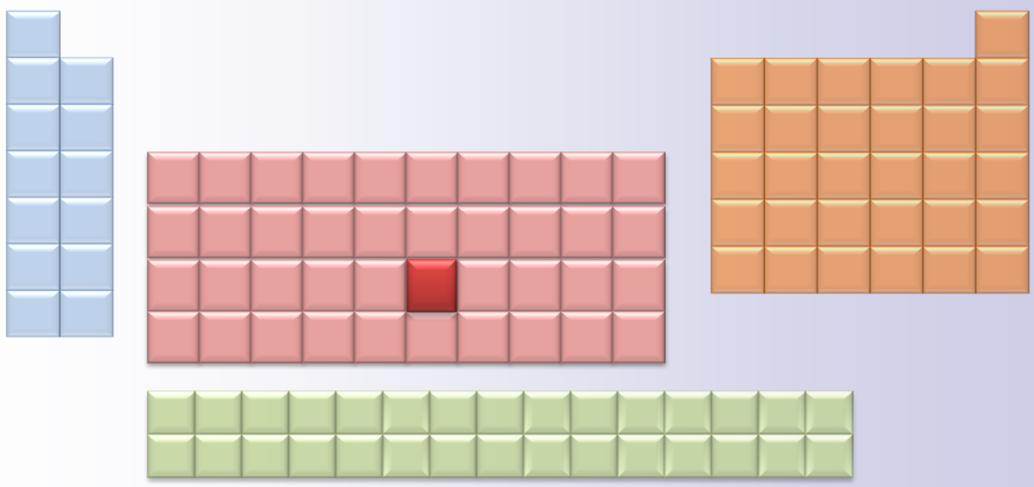
● Molybdenite ■ Columbite—Tantalite

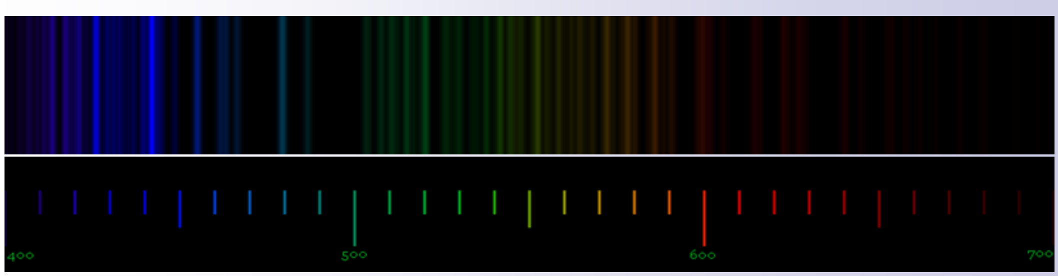
Re Rhenium , 75

Physical and chemical properties

Symbol	Re	Relative atomic mass	186.207
Atomic number	75	Melting point (°C)	3179
Group	7	Boiling point (°C)	5626
Period	6	Specific heat (J/g.K)	0.137
Family	Transition metals	Oxidation numbers	+4, +5,+6,+7
Physical state (20°C)	solid	Electronegativity (pouling)	1.9
Atomic radius (pm)	137.0	Thermal conductivity (W/m.K)	47.9
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	33.1
Electronic configuration	$[Xe]4f^{14}5d^{5}6S^{2}$	Heat of vaporization (kJ/mol)	707.1
Molar volume(cm3/ mole,273K)	8.86	Ist. ionization potential(kJ/mole)	760
Density (g/cm3)	21.020	2nd.Ionization potential (kJ/mole)	1260
Number of isotopes	34	3rd. ionization potential (kJ/mol)	2510

Osmium Os





Osmium is a bluish-white, hard and brittle platinum metal that shows no ductility even at high temperatures. It is found free in nature in igneous and in alluvial deposits in platinum ores and as a component of the mineral osmiridium (a scarce natural alloy of osmium and iridium). It is usually commercially recovered as a by-product of platinum and nickel refining operations.

Osmium is the densest of all the elements (osmium and iridium are the heaviest elements but osmium is slightly denser than iridium).

Osmium is characterized by the highest melting point temperature and the lowest vapor pressure in the platinum group. It is one of a few elements that acquire exceptionally high resistance to rust and corrosion and is unaffected by concentrated acids or even by aqua regia. However, it dissolves in molten alkalis and on exposure to air the metal powder forms osmium tetroxide which is a pungent, highly toxic and a powerful oxidizing agent.

Osmium is mostly utilized in the production of very hard and corrosion-resistant alloys with other metals in the platinum group. Osmiridium is artificially fabricated from osmium and iridium for use in the manufacture of smelting crucibles, dental equipment, micro-electronic devices and surgical implants such as pacemakers .

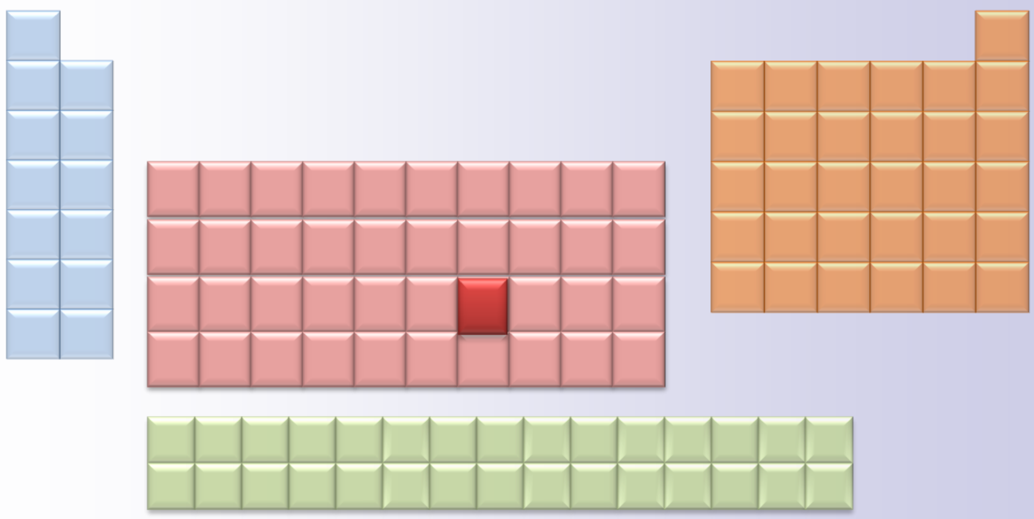
Pure osmium bead

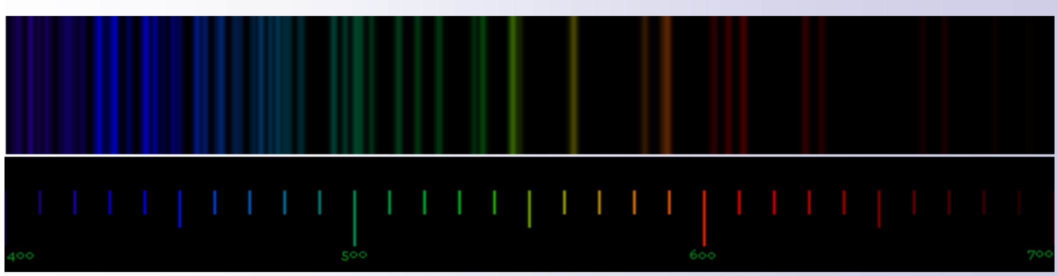
Os Osmium , 76

Physical and chemical properties

Symbol	Os	Relative atomic mass	190.23
Atomic number	76	Melting point (ºC)	3053
Group	8	Boiling point (ºC)	5026
Period	6	Specific heat (J/g.K)	0.130
Family	Transition metals	Oxidation numbers	+3, +4, +5, +6, +7
Physical state (20°C)	solid	Electronegativity (pouling)	2.2
Atomic radius (pm)	135	Thermal conductivity (W/m.K)	87.6
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	29.3
Electronic configuration	$[Xe]4f^{14}5d^{6}6S^{2}$	Heat of vaporization (kJ/mol)	627.6
Molar volume(cm3/ mole,273K)	8.43	Ist. ionization potential (kJ/mole)	814.17
Density (g/cm3)	22.590	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	37	3rd. ionization potential (kJ/mol)	####

Iridium Ir





Iridium is a rare, silvery-white, hard , brittle and very dense metal. It occurs naturally (in limited concentrations) in the pure elemental form, along with osmium and other platinum metals in alluvial sediments and meteorite rocks and is commercially recovered as a by-product of nickel and copper mining and processing.

Iridium and osmium are the densest elements, and iridium is the element which is most resistant to rust and corrosion. It does not dissolve in concentrated acids or aqua regia except in the granular form. However, it dissolves in some molten salts such as sodium chloride and potassium cyanide , and the powder form of iridium represents a fire hazard .

The most important application of the element is as a hardening agent for platinum alloys and the production of corrosion- resistant alloys with osmium (osmiridium). These alloys are used for special industrial purposes such as the manufacture of surgical implants and microelectronic devices.

Iridium is used in the manufacture of smelting crucibles and other equipment for high temperature applications. It is also used in heavy-duty electrical contacts and as a chemical intermediate (catalyst) in the manufacture of acetic acid from methyl alcohol.

An alloy of 90% platinum and 10% iridium was used to make the international standard kilogram.

Some radioactive isotopes of Iridium are used in radiotherapy.

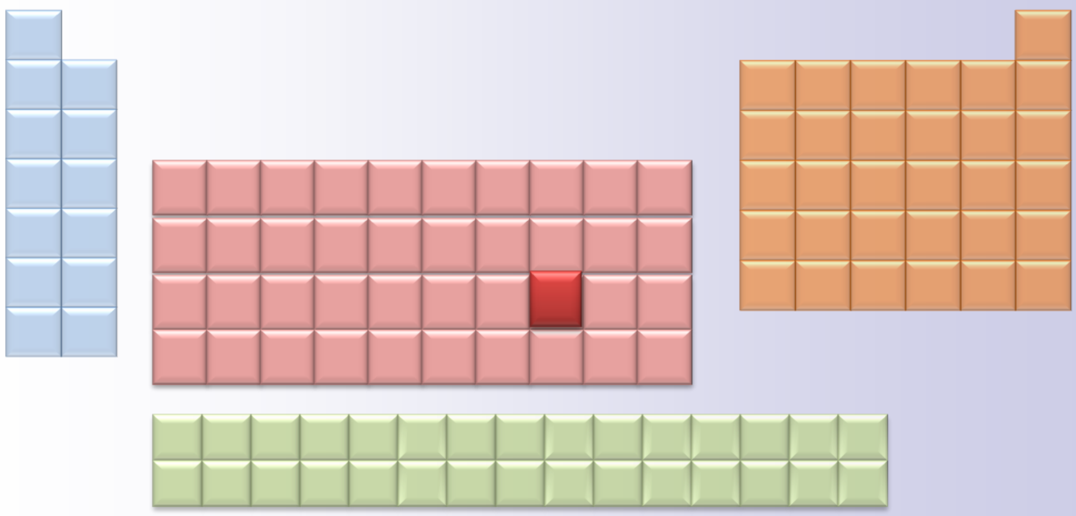
Pure iridium

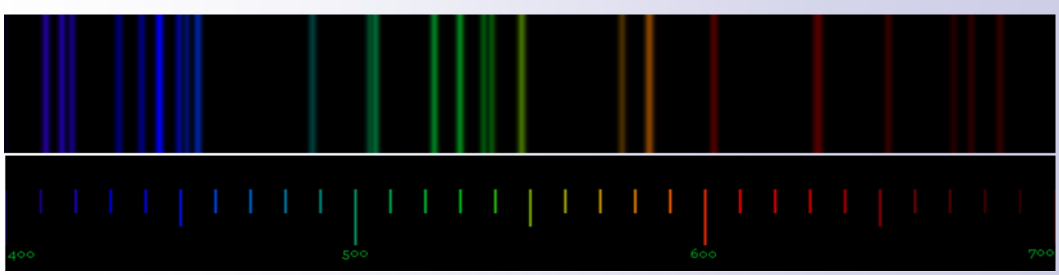
Ir Iridium , 77

Physical and chemical properties

Symbol	Ir	Relative atomic mass	192.22
Atomic number	77	Melting point (°C)	2409
Group	9	Boiling point (°C)	4129
Period	6	Specific heat (J/g.K)	0.031
Family	Transition metals	Oxidation numbers	+3, +4, +5,
Physical state (20°C)	solid	Electronegativity (pouling)	2.20
Atomic radius (pm)	135.7	Thermal conductivity (W/m.K)	147
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	26.4
Electronic configuration	$[Xe]4f^{14}5d^{7}6S^{2}$	Heat of vaporization (kJ/mol)	563.6
Molar volume(cm3/ mole,273K)	8.57	Ist. ionization potential (kJ/mole)	865.19
Density (g/cm3)	22.420	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	40	3rd. ionization potential (kJ/mol)	####

Platinum Pt





Platinum is a soft, lustrous, silvery-white precious metal. It is dense, ductile and malleable. It is extremely rare and occurs - in low concentrations- in the free elemental form along with nickel and copper ores with traces of iridium, osmium, ruthenium and palladium (platinum group metals).

Platinum is also encountered in a chemically combined form in cooperate mineral (platinum sulfide) and in sperrylite ore (platinum arsenide) which is a rare but an economically important mineral. The precious element is also produced commercially as a by-product of nickel refining operations.

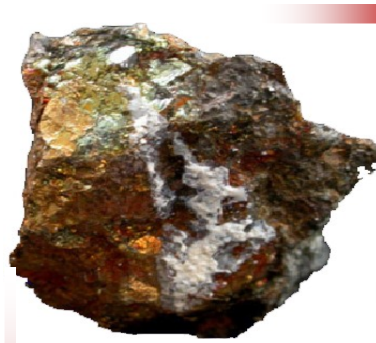
Platinum is not oxidized in air even at high temperatures. It is not dissolved by common acids and is not attacked by halogens below 300°C. However, it dissolves in aqua regia to form chloroplatinic acid. It is readily dissolved by cyanides and is attacked by sulfur and caustic alkalis.

Platinum is widely used in decorations and jewelry manufacture and in the electrical and electronic industry for thermocouples and electrodes.

The metal is also used to make corrosion resistant equipment and utensils for medical and laboratory applications and is mixed with cobalt to obtain a number of alloys with unusual magnetic properties.

Native platinum nugget

- Russia -



Sperrylite

(platinum arsenide)

- Ontario, Canada -

Pt Platinum , 78

Platinum is characterized by an exclusive ability to absorb large volumes of hydrogen at normal temperatures. It is also characterized by a unique catalytic activity. Thus, a mixture of hydrogen and oxygen gas will explode in the presence of platinum , a thin wire of the metal will automatically glow in contact with methyl alcohol vapor and a solution of hydrogen peroxide will readily decompose into water and oxygen in the presence of platinum.

Platinum metal is the chemical intermediate (catalyst) in the manufacture of sulfuric acid (Contact process). It is the common catalyst in the industrial manufacture of nitric acid (Ostwald process) and in the destructive distillation processes of petroleum. It is widely used as a catalytic converter in vehicles to facilitate the complete decomposition of the exhaust gases.

Mineral ore locations

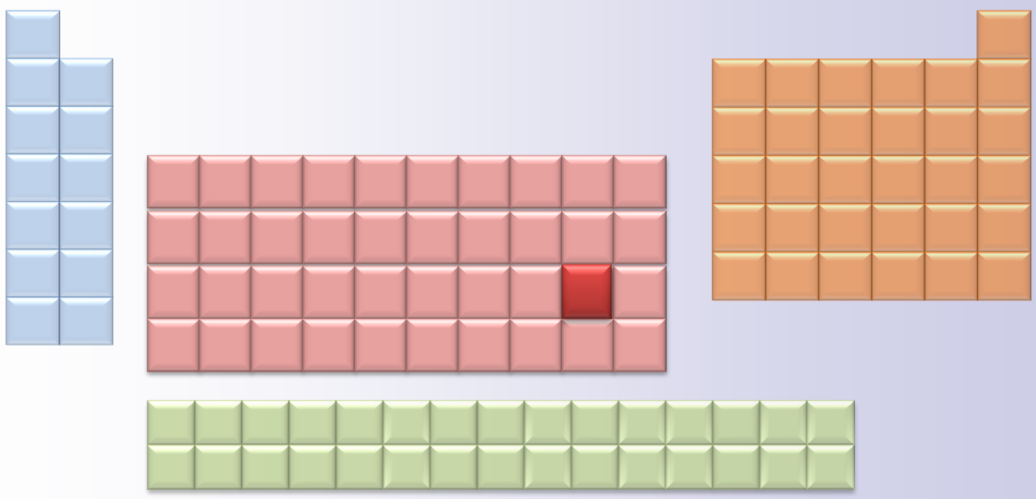
- Native platinum

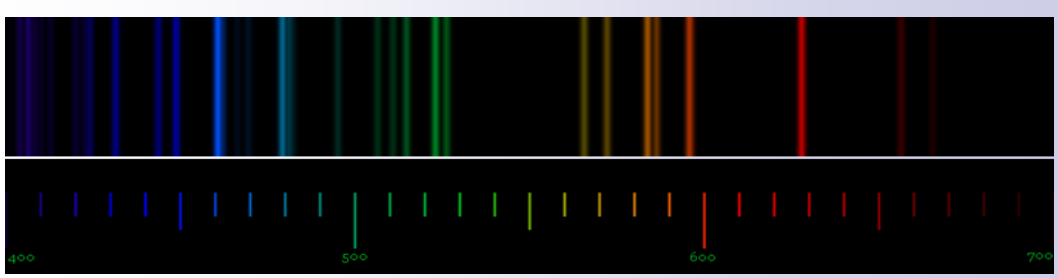
Pt Platinum , 78

Physical and chemical properties

Symbol	Pt	Relative atomic mass	195.078
Atomic number	78	Melting point (ºC)	1771
Group	10	Boiling point (ºC)	3826
Period	6	Specific heat (J/g.K)	0.133
Family	Transition metals	Oxidation numbers	+2, +4, +5,
Physical state (20°C)	solid	Electronegativity (pouling)	2.28
Atomic radius (pm)	138	Thermal conductivity (W/m.K)	71.6
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	19.7
Electronic configuration	$[Xe]4f^{14}5d^{9}6S^{1}$	Heat of vaporization (kJ/mol)	510.5
Molar volume (cm3/mole,273K)	9.10	Ist. ionization potential (kJ/mole)	864.39
Density (g/cm3)	21.450	2nd.Ionization potential (kJ/mole)	1791.07
Number of isotopes	36	3rd. ionization potential (kJ/mol)	####

Gold Au





Gold is a precious metal which has been known and highly valued since ancient history. It is dense and bright yellow when in a mass, and black or purple in the granular form.
Gold is the most ductile and malleable metal and the best conductor of heat and electricity after silver and copper. It is found naturally in the pure elemental form retaining its natural luster and pure color. It is widely distributed in the earth's crust, occurring - in very limited concentrations- usually associated with silver, copper and platinum metals.
Gold is resistant to oxidation and is not affected by air or attacked by individual acids (except selenic acid). However, it dissolves in solutions of chlorine, bromine and iodine and in alkaline cyanide solutions and aqua regia .
Various methods are used for gold extraction. The most simple method is the manual panning technique which is carried out by washing sand and gravel containing gold by running water, where light components of sand and other particulates will float and the heavy metal settles to the bottom of the pan.

Other operations use mercury metal to make a gold - mercury alloy (amalgam) in order to separate gold from sand and associated minerals. This is followed by distillation of mercury which easily volatilizes leaving pure gold.
Mercury is a toxic element and a cumulative poison that represents one of the most serious factors of pollution in the environment. Operations involving extraction of gold with mercury are still practiced in many areas without appreciation of its serious hazards.

Gold nugget
(Australia)

Au Gold, 79

The cyanide method is a modern commercial technique for gold extraction. Crude ores are treated with potassium cyanide solution in the presence of oxygen to form a gold cyanide complex which is reduced in a further step by zinc powder to recover gold.

Commercial amounts of gold are obtained as a by-product of roasting and smelting processes of galena (lead ore). It is also recovered from the anode slime of copper electrolytic refining cells.

Pure gold is too soft for fabrication and is usually alloyed with metals like silver, copper and nickel for different applications.

The purity of gold is recognized by parts of gold in 1000 parts of the alloy or by carat units where 24 carat means pure gold and 22-carat means 22 parts of gold in 24 parts of the ingot. The five legal standards are: 22, 18, 15, 12 and 9 carats.

Other elements are also added to gold to offer desirable colors. Iron is used to give the blue color and aluminum is added to offer the purple color. White gold alloy is made by adding a white metal such as nickel, palladium or silver. A common formulation consists of 90% by weight of gold and 10 % of nickel.

Gold is beaten into extremely thin sheets to obtain gold leaf. This is usually 22-karat gold commonly used in decorations to give a thin coating to different solid surfaces.

Native Gold

(on quartz)

- Italy -

Au Gold, 79

Gold is used in jewelry and coinage and is adopted as an international standard for monetary system. It is also used in the manufacture of parts of electrical and electronic equipments that require rust and corrosion resistance such as surgery and dentistry equipments.

The isotope gold - 198 is radioactive with a short half-life (2.7 days). It is considered as an ideal material for application as a radioactive tracer and for diagnostic and radiotherapy applications in the medical field.

Mineral ore locations

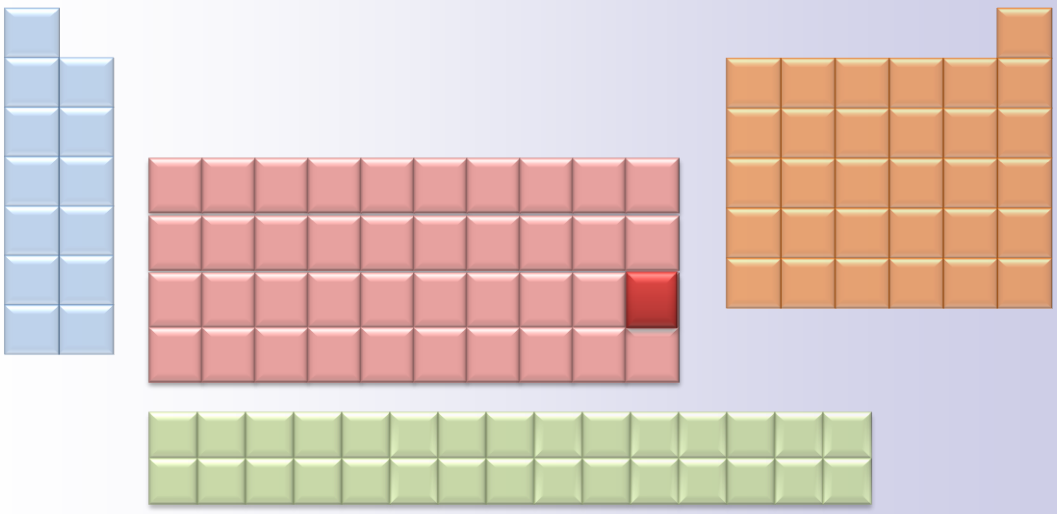
• Native gold

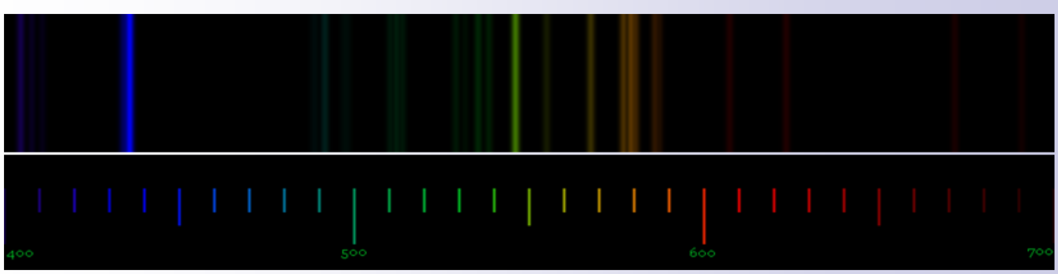
Au Gold, 79

Physical and chemical properties

Symbol	Au	Relative atomic mass	196.967
Atomic number	79	Melting point (°C)	1064.43
Group	11	Boiling point (°C)	2806
Period	6	Specific heat (J/g.K)	0.129
Family	Transition metals	Oxidation numbers	+1, +3, +5
Physical state (20°C)	solid	Electronegativity (pouling)	2.54
Atomic radius (pm)	144.2	Thermal conductivity (W/m.K)	317
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	12.7
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{1}$	Heat of vaporization (kJ/mol)	324.4
Molar volume (cm3/mole,273K)	10.19	Ist. ionization potential (kJ/mole)	890.13
Density (g/cm3)	19.320	2nd.Ionization potentia l(kJ/mole)	1977.96
Number of isotopes	39	3rd. ionization potential (kJ/mol)	####

Mercury Hg





Mercury

Mercury is a silvery-white metallic element and the only common metal found in the liquid state in normal conditions. It is rare in the earth's crust and is found - chemically combined - in cinnabar ore (mercury sulfide). It is also found as traces of the free element associated with silver metal.

The pure metal is usually extracted by roasting (oxidation) of cinnabar followed by condensation of the resulting mercury vapor to collect the liquid metal.

Mercury is a poor conductor of heat, but a good conductor of electricity. It is resistant to corrosion and is not oxidized in air below 300°C. However, it dissolves in mineral acids and reacts with sulfur at room temperature.

With the exception of iron and a limited number of elements, mercury combines-in normal conditions- with all the elements to form alloys known as amalgams.

Common applications of mercury include its use in light bulbs(mercury vapor lamps) and in the manufacture of barometers and thermometers (mercury is distinguished by the lowest melting point of a metal (-39°C)).

Cinnabar

- Nevada -

Mercury chloride (calomel) is a component of electrochemical electrodes, and mercury fulminate is an explosive with high sensitivity to shock and is used as trigger for other explosives.

Mercury and most of its compounds are highly toxic . The pure element is volatile and is easily absorbed through the respiratory system and through the skin to act as a cumulative poison inside the living body and as a factor of neurological problems.

The environmental impacts and the threat posed by mercury pollution are not recognized by many communities and many practices involving mercury are not regulated in the absence of serious national polices.

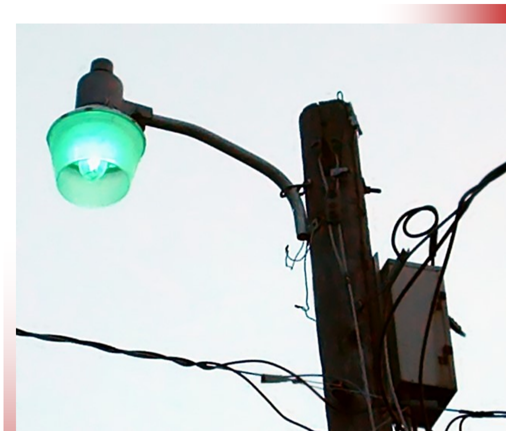
Hg Mercury , 80

The major sources of mercury pollution include the traditional processes of gold, platinum and silver extraction , the application of the mercury cathode in electrolytic cells for soda and chlorine production and the use of mercury amalgams in dentistry.

Other sources of mercury pollution include various compounds used in colors, fungicides, cosmetics (mascara) and the improper disposal of crashed thermometers, fluorescent and heavy discharge mercury lamps .

Red mercury has been a controversial name since the eighties of the twentieth century. Development of super high quality electronic equipment and use as a substitute for uranium and plutonium to obtain small destructive weapons and the ability to control missiles and radars are a few of the alleged characteristics of red mercury.

None of the extraordinary powers attributed to the so called red mercury approved to be realistic as no material can acquire such supernatural powers. It is believed that the high-prized stuff handled to customers as red mercury oxide or cinnabar (mercury sulfide) may or may not be related to mercury. These products could be marketed with attached misleading warning signs for illegal profits .



High pressure mercury- vapor lamp

Hg Mercury , 80

Mineral ore locations

Hg Mercury , 80

Physical and chemical properties

Symbol	Hg	Relative atomic mass	200.59
Atomic number	80	Melting point (ºC)	-38.87
Group	12	Boiling point (ºC)	356.58
Period	6	Specific heat (J/g.K)	0.140
Family	Transition metals	Oxidation numbers	+1, +2
Physical state (20°C)	Liquid	Electronegativity (pouling)	2.00
Atomic radius (pm)	160	Thermal conductivity (W/m.K)	8.34
Crystal structure	Rhombohedral	Heat of fusion (kJ/mol)	2.331
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{2}$	Heat of vaporization (kJ/mol)	59.15
Molar volume (cm3/mole,273K)	14.81	Ist. ionization potential (kJ/mole)	1007.07
Density (g/cm3)	13.546	2nd.Ionization potential (kJ/mole)	1809.69
Number of isotopes	37	3rd. ionization potential (kJ/mol)	3299.82

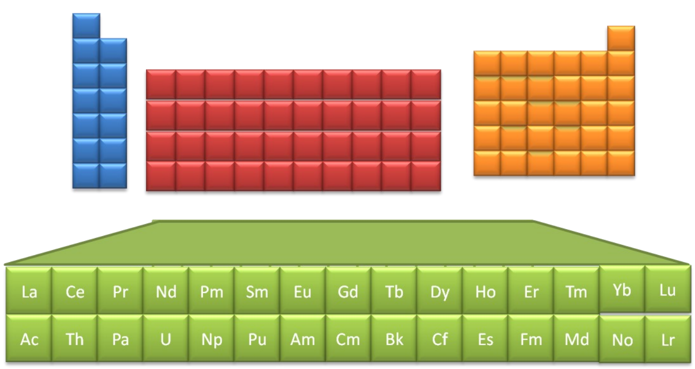
Chapter 5

Inner transition metals

Inner Transition Metals are the chemical elements occupying the two rows below the periodic table and include the lanthanide elements (rare earths) and the actinoids (actinide elements). These elements are very similar to the transition metals in their metallic properties and in most applications.

The lanthanide series is attributed to the element lanthanum (atomic number 57) and the actinoids are attributedto actinium (atomic number 89).

The reason for the offset arrangement of the two groups is partly because of the different electronic structure of atoms of the elements and also in order to avoid a broad periodic table.



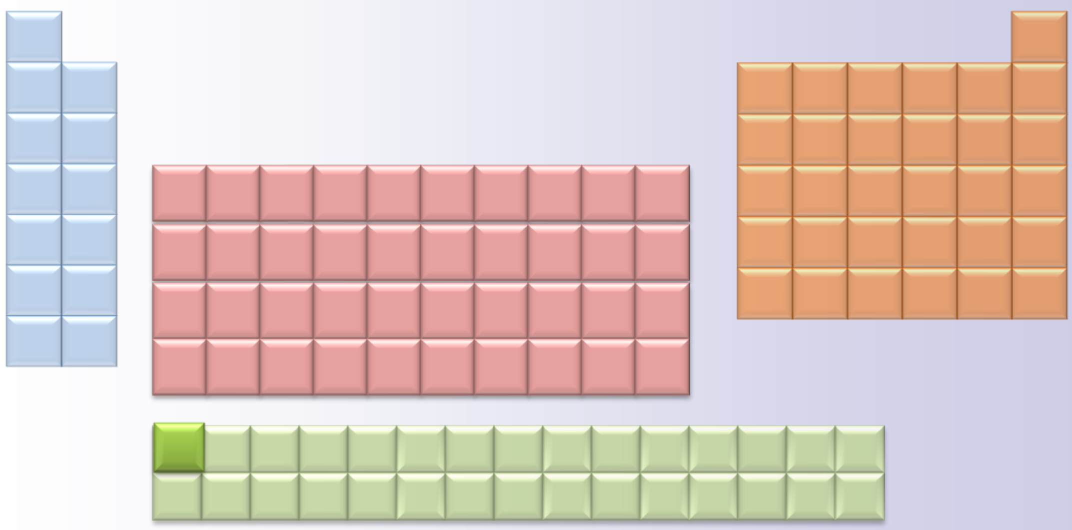
Promethium (atomic number 61) together with transuranium elements in the actinoid series do not exist naturally, and are artificially prepared in nuclear laboratories.

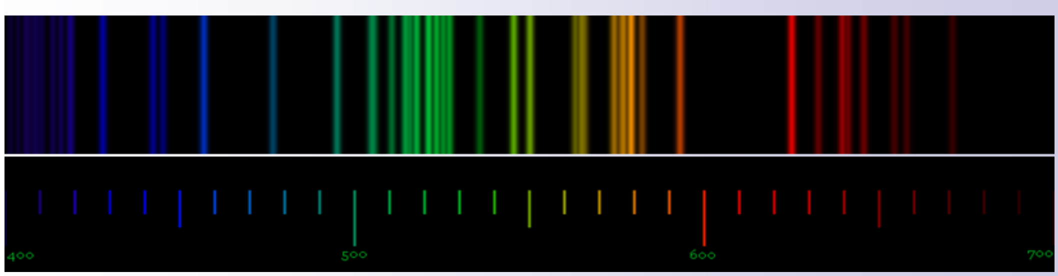
The lanthanide series include 14 elements: Lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium and lutetium.

Monazite and bastnasite are the principal ores for the rare earths and China republic is the major world producer.

The actinoids occupy the last row below the lanthanides and consist of all the radioactive elements proceeding actinium. Only four of these elements, namely actinium, thorium, protactinium and uranium are found naturally in the earth's crust (Actinium and protactinium occur as trace amounts resulting from the spontaneous decay of the heavier elements). The remaining members of the group are artificially synthesized and are called transuranium elements (elements with atomic numbers greater than 92).

Lanthanum La





Lanthanum is a rare earth element, and the first member of the lanthanide series to which its name is adopted. It is soft, silvery- white, ductile and malleable. It is commercially recovered from monazite and bastnasite minerals through solvent extraction techniques and the pure metal is usually obtained through the reduction of the fused chloride or fluoride with calcium.

Lanthanum is a major component of mischmetal which is a natural alloy composed of about 50% cerium and about 25% lanthanum with small amounts of neodymium and praseodymium.

Lanthanam metal

Lanthanum is one of the most chemically active rare earth metals. It oxidizes rapidly in moist air, slowly reacts with cold water to free hydrogen and readily combines with carbon, nitrogen, boron, selenium, silicon, phosphorus, sulfur and the halogens (the metal is usually stored submerged in dry mineral oil or in an atmosphere of an inert gas).

Lanthanum is added to steel alloys to improve malleability and ductility and lanthanum oxide is added to components of glass to improve the alkali resistance and to make special optical lenses for cameras and telescopes.

Lanthanum compounds are widely used as components of catalysts in refining processes of crude oil and other industrial processes. Other compounds are used in carbon lighting applications. lanthanum carbonate is used in the medical field to absorb excess phosphates resulting from renal failure.

A combination of misch alloy with iron oxide and magnesium oxide has the ability to give intense sparks on friction with a rough surface (pyrophoricity) and is widely used in lighter flints

La Lanthanum , 57

Mineral ore locations

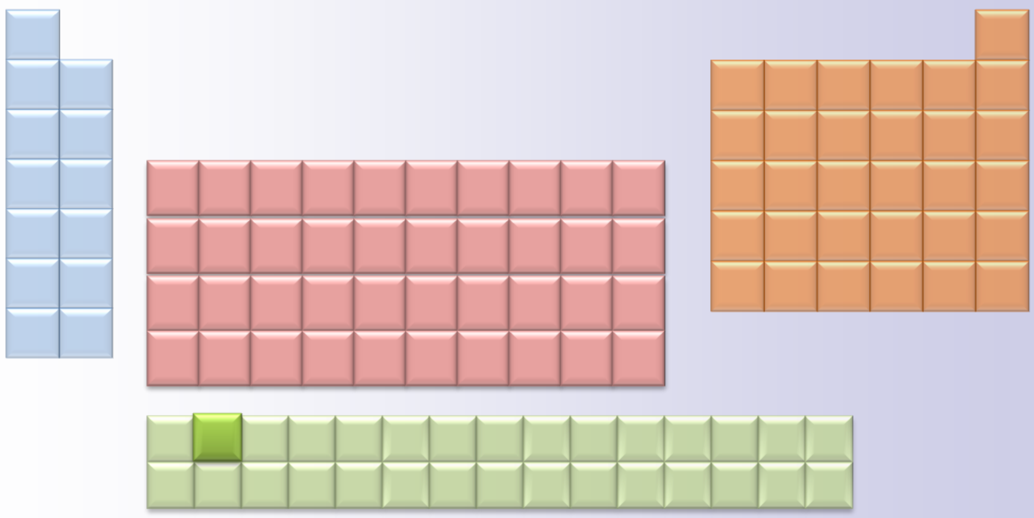
● Monazite ■ Bastnasite

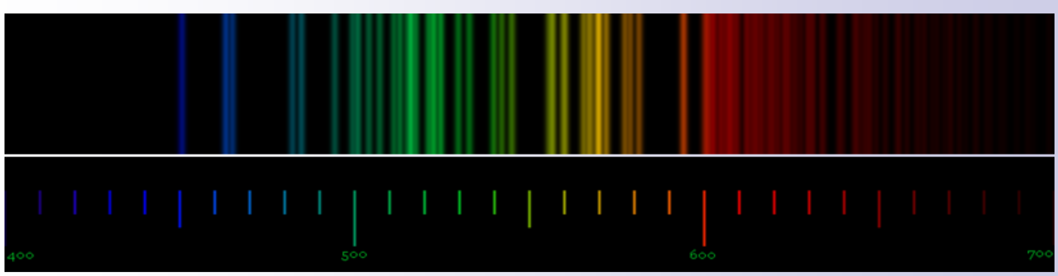
La Lanthanum , 57

Physical and chemical properties

Symbol	La	Relative atomic mass	138.906
Atomic number	57	Melting point (ºC)	920
Group	3	Boiling point (ºC)	3456
Period	6	Specific heat (J/g.K)	0.195
Family	Rare earth metals	Oxidation numbers	+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.1
Atomic radius (pm)	187.7	Thermal conductivity (W/m.K)	13.5
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	10.04
Electronic configuration	$[Xe]5d^1 6S^2$	Heat of vaporization (kJ/mol)	399.6
Molar volume (cm3/mole,273K)	22.60	Ist. ionization potential (kJ/mole)	538.1
Density (g/cm3)	6.145	2nd.Ionization potential (kJ/mole)	1067.14
Number of isotopes	31	3rd. ionization potential (kJ/mol)	1850.34

Cerium Ce





Cerium is a lustrous, steel-gray, soft and malleable metal that exists in a number of allotropic forms. It does not occur free in nature but is found, along with other lanthanide elements, in a number of minerals but mainly in monazite (phosphate mineral) and bastnasite (carbonate mineral).

The pure metal is usually obtained through the reduction of the fused fluoride with calcium or by the electrolysis of the chloride.

Cerium is the most abundant of the lanthanides and (after europium) is the most chemically active. It reacts with cold water to form cerium hydroxide and hydrogen gas and dissolves in alkalis and in all dilute and concentrated acids. It tarnishes in moist air at normal temperatures and spontaneously ignites at temperatures higher than 65 °C. The pure metal can be activated by scratching to catch fire at room temperature (cerium is usually stored submerged in dry mineral oil or in an atmosphere of an inert gas).

Cerium is used to enhance properties of aluminum and magnesium alloys. It is added to steel alloys to get rid of oxygen and other undesirable elements such as sulfur, lead and antimony.

Cerium compounds are used in a number of industrial fields, notably the glass and petroleum industries.

Cerium oxide (Syria) is used in the manufacture of ceramics and in glass polishing.

Cerium is a strong reducing agent and is used as an intermediate (catalyst) in the chemical industry and as a reducing agent in metallurgy. It is used in catalytic converters which are attached to the exhaust system of motor vehicles to absorb toxic emissions of carbon monoxide and convert them to (the less harmful) carbon dioxide.

Cerium metal

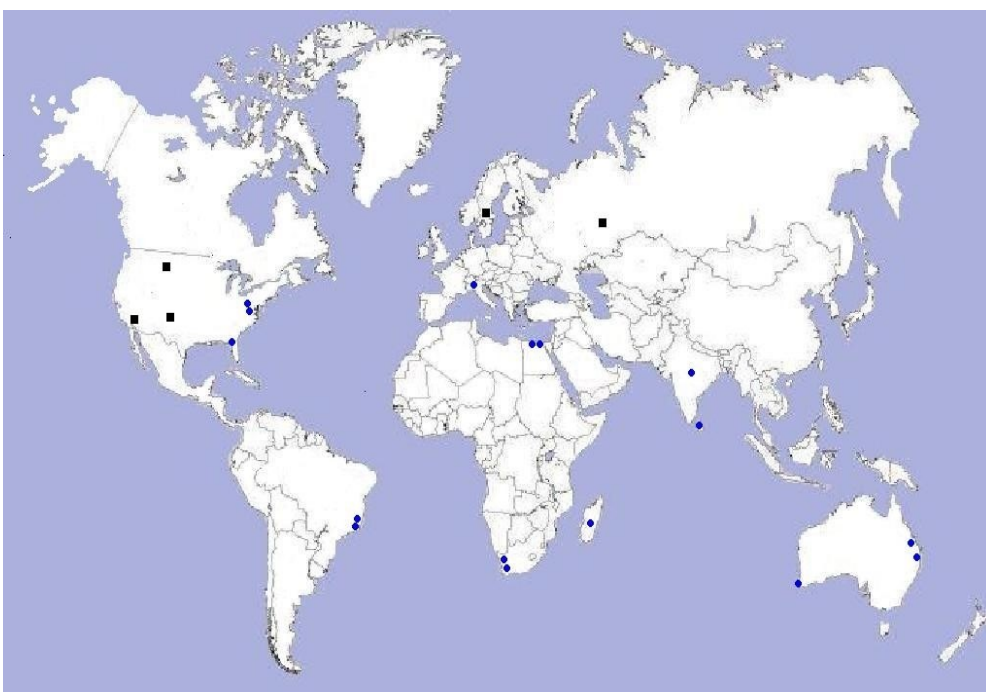
Ce Cerium , 58

Cerium is a major component of mischmetal or misch alloy (a natural alloy of about 50% cerium and about 25% lanthanum with small amounts of neodymium and praseodymium).

A combination of misch alloy with iron and magnesium oxides produces the very hard ferrocerium alloy which gives intense sparks on friction with rough surfaces (pyrophoricity) and is extensively utilized in lighter flints.

Cerium is used in carbon-arc lighting. Cerium monosulfide is a very hard material with a high melting temperature (2450°C) and is utilized for making refractory vessels.

Mineral ore locations



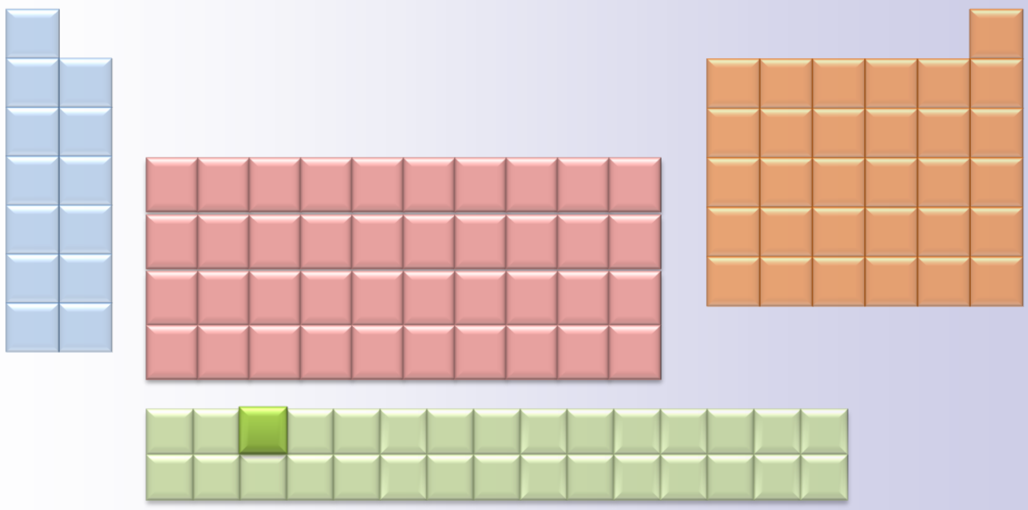
● Monazite ■ Bastnasite

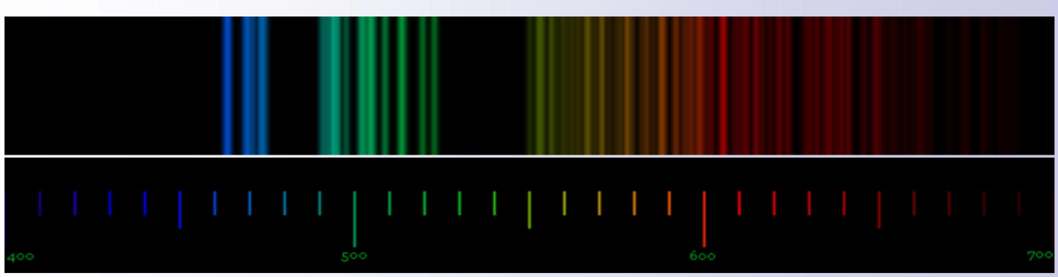
Ce Cerium , 58

Physical and chemical properties

Symbol	Ce	Relative atomic mass	140.116
Atomic number	58	Melting point (ºC)	798
Group	3	Boiling point (ºC)	3425
Period	6	Specific heat (J/g.K)	0.192
Family	Rare earth metals	Oxidation numbers	+3, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.12
Atomic radius(pm)	182.5	Thermal conductivity (W/m.K)	11.4
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	8.87
Electronic configuration	$[Xe]4f^2 6S^2$	Heat of vaporization (kJ/mol)	313.8
Molar volume (cm3/mole,273K)	17.00	Ist. ionization potential (kJ/mole)	527.4
Density (g/cm3)	8.240	2nd.Ionization potential (kJ/mole)	1047
Number of isotopes	30	3rd. ionization potential (kJ/mol)	1949

Praseodymium Pr





Praseodymium is a silvery, malleable and ductile lanthanide element that occurs naturally (in low concentrations) and constitutes about 5% of the rare earth metals present in monazite and bastnasite ores.

Praseodymium is chemically active and is readily oxidized in air to form a green oxide layer that instantly shatters to expose the metal surface to further erosion (the metal is usually stored immersed in dry mineral oil or in an atmosphere of an inert gas).

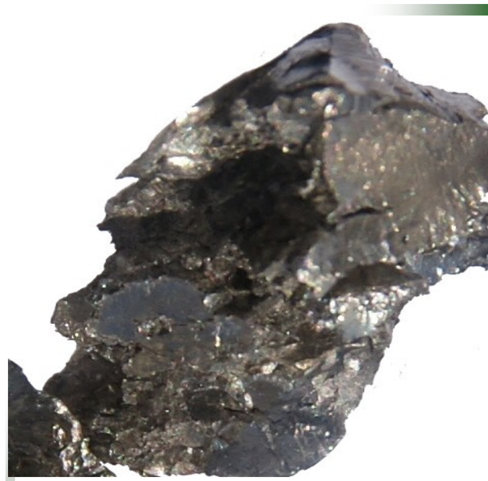
Praseodymium metal is a component of misch alloy (a natural alloy of about 50% cerium and about 25% lanthanum with small amounts of neodymium and praseodymium).

Iron and magnesium oxides are added to misch alloy to obtain the hard ferrocerium alloy which has the ability to give intense sparks on friction with rough surfaces (pyrophoricity) and is extensively utilized in lighter flints.

Praseodymium is added to a number of other important alloys such as nickel alloys which are characterized by unique thermal and magnetic properties. It is added to steel alloys to enhance the durability and toughness. It is also added to zirconia (zirconium oxide) and to components of glass and enamel to give a bright yellow color.

The metal oxide, like other rare earths, is one of the best refractory materials known.

Praseodymium is believed to have adverse effects on the environment and human health. The major pollution sources are the oil industry and the city waste containing household electronic and electrical equipment.



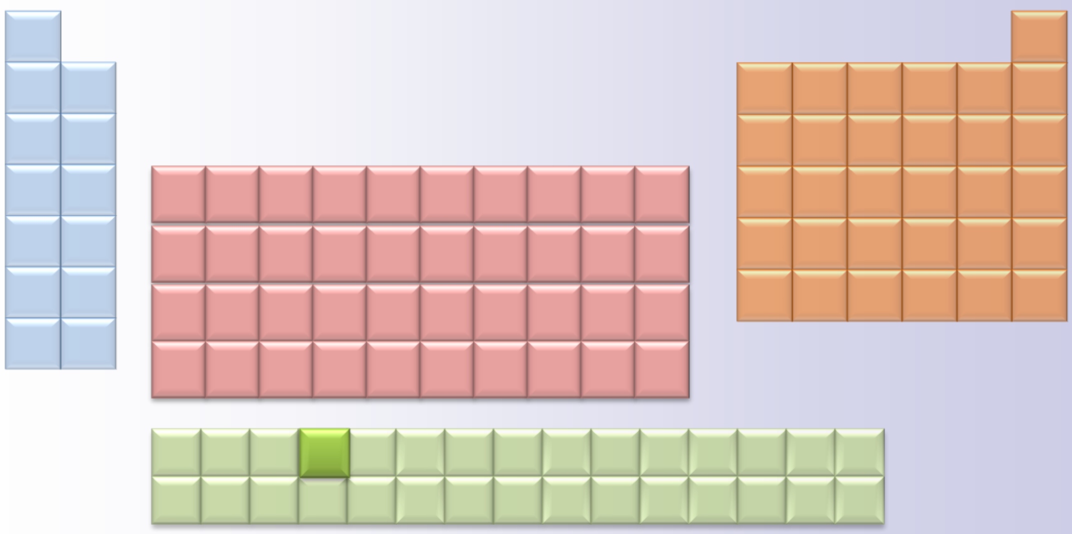
Praseodymium metal

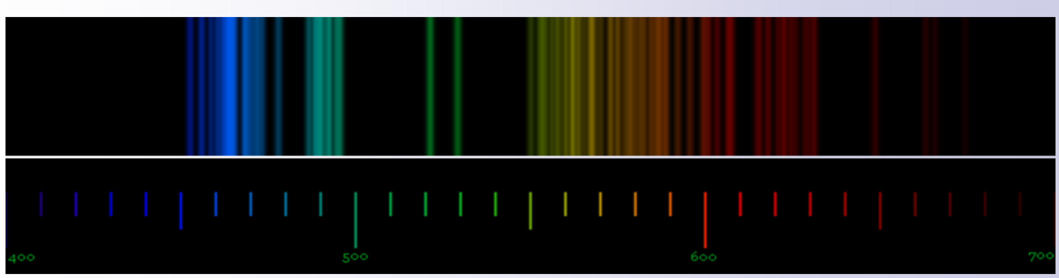
Pr Praseodymium , 59

Physical and chemical properties

Symbol	Pr	Relative atomic mass	140.908
Atomic number	59	Melting point (ºC)	930
Group	3	Boiling point (ºC)	3511
Period	6	Specific heat (J/g.K)	0.193
Family	Rare earth metals	Oxidation numbers	+3, +4
Physical state (20°C)	solid	Electronegativity (pouling)	1.13
Atomic radius (pm)	182.8	Thermal conductivity (W/m.K)	12.5
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	11.3
Electronic configuration	$[Xe]4f^36S^2$	Heat of (kJ/mol)	332.6
Molar volume(cm3/ mole,273K)	20.80	Ist. ionization potential (kJ/mole)	523.1
Density (g/cm3)	6.773	2nd.Ionization potential (kJ/mole)	1018
Number of isotopes	26	3rd. ionization potential (kJ/mol)	2086

Neodymium Nd





Neodymium is a bright, silvery-white rare earth element and one of the most abundant in the earth's crust among the lanthanides (it is the most plentiful after cerium and lanthanum).

Neodymium exists in a chemically combined form, in the company of other rare earth elements, in monazite and bastnasite ores. The pure metal was isolated for the first time in 1925.

Neodymium is chemically active and quickly corrodes in air forming the oxide which instantly shatters to expose the metal surface to further attack (the metal is usually stored immersed in dry mineral oil or in an atmosphere of an inert gas).

Neodymium is alloyed with iron and boron to make permanent magnets characterized by durability and light weight and hence, appropriate for the manufacture of electronic equipments such as loudspeakers, headphones and CDs.

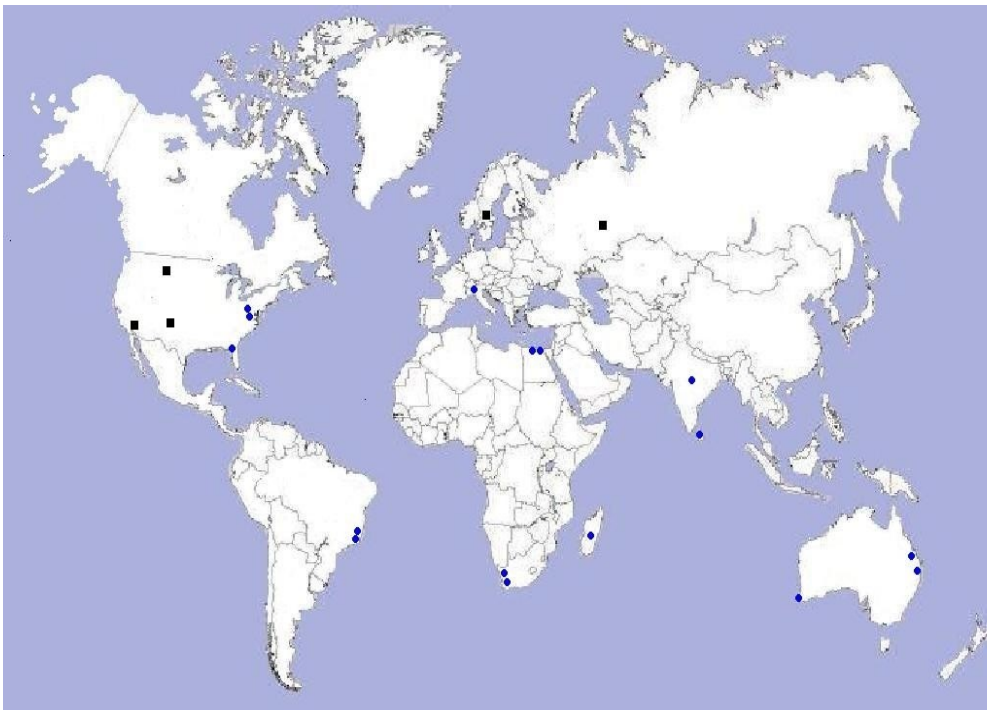
A number of neodymium compounds are used in the manufacture of laser and electronic equipments such as multi-layer capacitors. They are also utilized in carving and coloring glass and paints with a distinctive purple color.

Neodymium is a component of mischmetal which is a natural alloy of about 50% cerium and about 25% lanthanum and small amounts of neodymium and praseodymium. Iron and magnesium oxides are added to mischmetal to obtain the very hard ferrocerium alloy which has the ability to give intense sparks on friction with rough surfaces (pyrophoricity) and is extensively utilized in lighter flints.

Neodymium metal

Nd Neodymium , 60

Mineral ore locations



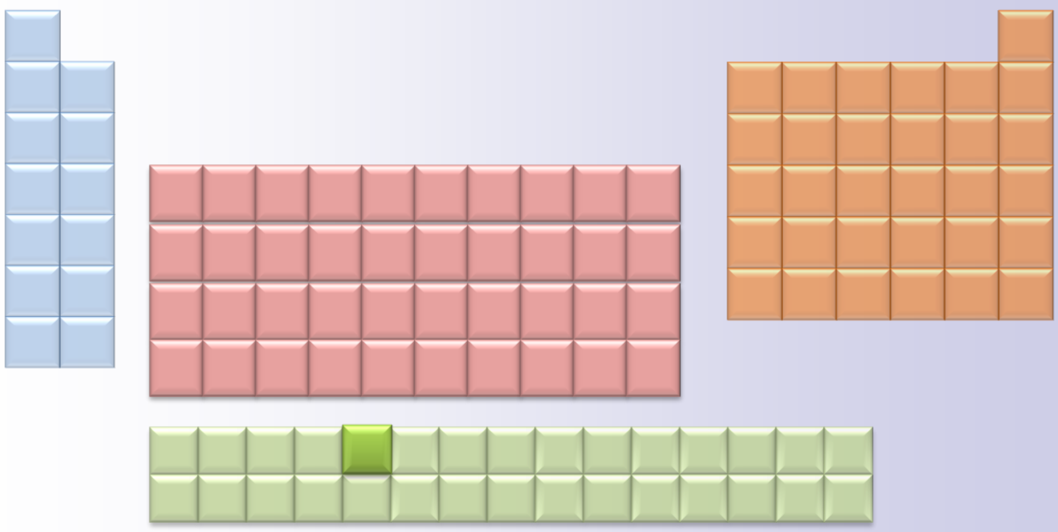
■ Bastnasite ● Monazite

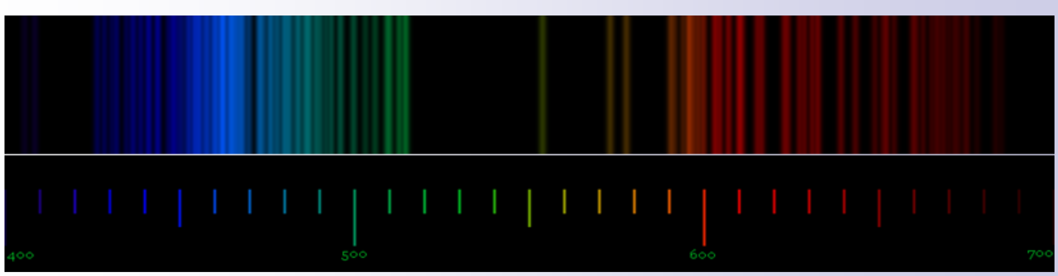
Nd Neodymium , 60

Physical and chemical properties

Symbol	Nd	Relative atomic mass	144.24
Atomic number	60	Melting point (°C)	1020.85
Group	3	Boiling point (°C)	3067.85
Period	6	Specific heat (J/g.K)	0.190
Family	Rare earth metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.14
Atomic radius (pm)	181.4	Thermal conductivity (W/m.K)	16.5
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	7.113
Electronic configuration	[XE]$4f^{4}6s^{2}$	Heat of vaporization (kJ/mol)	283.7
Molar volume (cm3/mole,273K)	20.59	Ist. ionization potential (kJ/mole)	529.6
Density (g/cm3)	7.007	2nd.Ionization potential (kJ/mole)	1035
Number of isotopes	24	3rd. ionization potential (kJ/mol)	2130

Promethium Pm





Promethium is a radioactive rare earth element discovered in 1947 during the separation and analysis of spent uranium nuclear fuel.

In 1963 a few grams of the element were extracted from spent nuclear fuel by using ion exchange techniques . The element was then successfully synthesized by bombarding neodymium-146 isotope with neutrons in nuclear laboratories to produce the radioactive isotope promethium -147(half-life 2.6 years).

It is worth mentioning that the two elements, promethium and technetium (Atomic number 43) are the only light elements distinguished by the property of radioactivity. Promethium has no stable isotope and the traces of the element occurring naturally are the result of the spontaneous disintegration of uranium.

Promethium-145 with a half-life of 17.7 years is the most stable isotope of the element and is an active beta emitter. The main applications of the element are in the field of scientific research. Other few applications include its utilization as a beta particles emitter in nuclear powered batteries. These batteries contain a phosphor which is activated by beta particles (electrons) to produce light which is converted to electrical current (nuclear batteries are distinguished with a life of up to 5 years).

Promethium salts glow in the dark producing blue or green light as a result of the intense radiation and a re used in light signals.

Applications of promethium in pacemakers, watches and clocks and self-luminous paint are being suppressed by safety regulations and promethium , as well as other radioisotopes, are being replaced by phosphorescent substances. For pacemakers promethium has been largely replaced by lithium-based primary cells.

Promethium

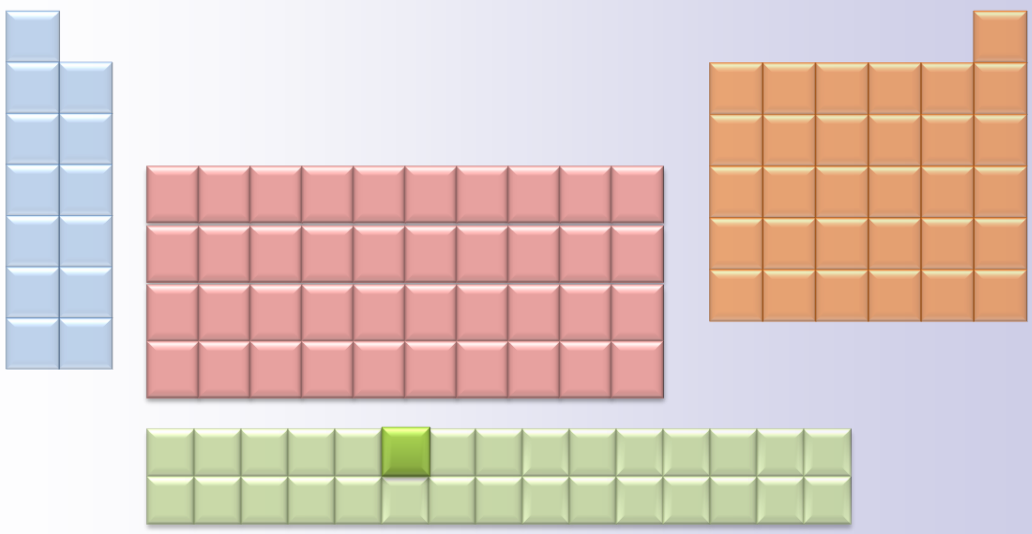
and technetium are the only light elements showing radioactivity

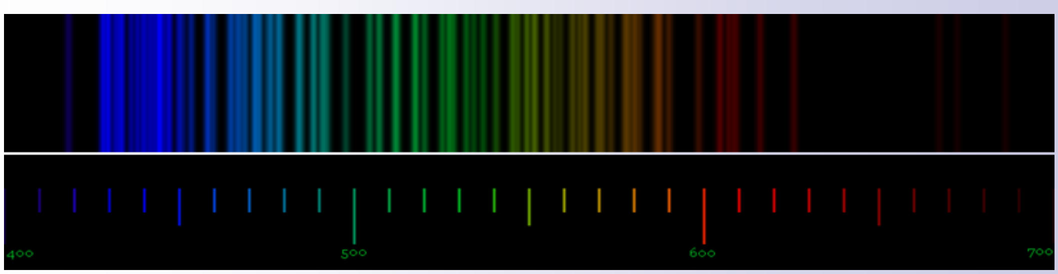
Pm Promethium , 61

Physical and chemical properties

Symbol	Pm	Relative atomic mass	144.913
Atomic number	61	Melting point (°C)	1167.85
Group	3	Boiling point (°C)	2726.85
Period	6	Specific heat (J/g.K)	###
Family	Rare earth metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.07
Atomic radius (pm)	183.4	Thermal conductivity (W/m.K)	17.9
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	12.6
Electronic configuration	[XE]$4f^5 6s^2$	Heat of vaporization (kJ/mol)	###
Molar volume(cm3/ mole,273K)	20.1	Ist. ionization potential (kJ/mole)	535.9
Density (g/cm3)	7.220	2nd.Ionization potential (kJ/mole)	1052
Number of isotopes	36	3rd. ionization potential (kJ/mol)	2150

Samarium Sm





Samarium is a hard, silver-bright lanthanide element occurring (only chemically combined) in monazite and bastnasite ores and in a number of other minerals in the company of rare earth elements. It also occurs in the natural misch alloy in which it constitutes about 1% by weight.

Extraction procedures of samarium involve dissolution in sulfuric and hydrochloric acids and the separation is conducted using ion exchange and solvent extraction techniques.

The metal is further purified by the electrolysis of the molten chloride (in the presence of molten sodium chloride or calcium chloride) in graphite cells where chlorine is obtained as a by-product.

Samarium has medium resistance to corrosion in the atmosphere. It gradually develops a layer of the oxide when exposed to air and spontaneously catches fire at 150 °C.

Samarium and cobalt form a permanent magnet characterized by exceptional resistance to loss of magnetism.

Samarium is characterized by a high ability to absorb neutrons and is utilized in nuclear control rods to maintain a smooth chain reaction in nuclear power plants.

Other commercial applications of the element include its utilization in alloys, carbon arc lamps , head phones and a number of electronic and laser devices.

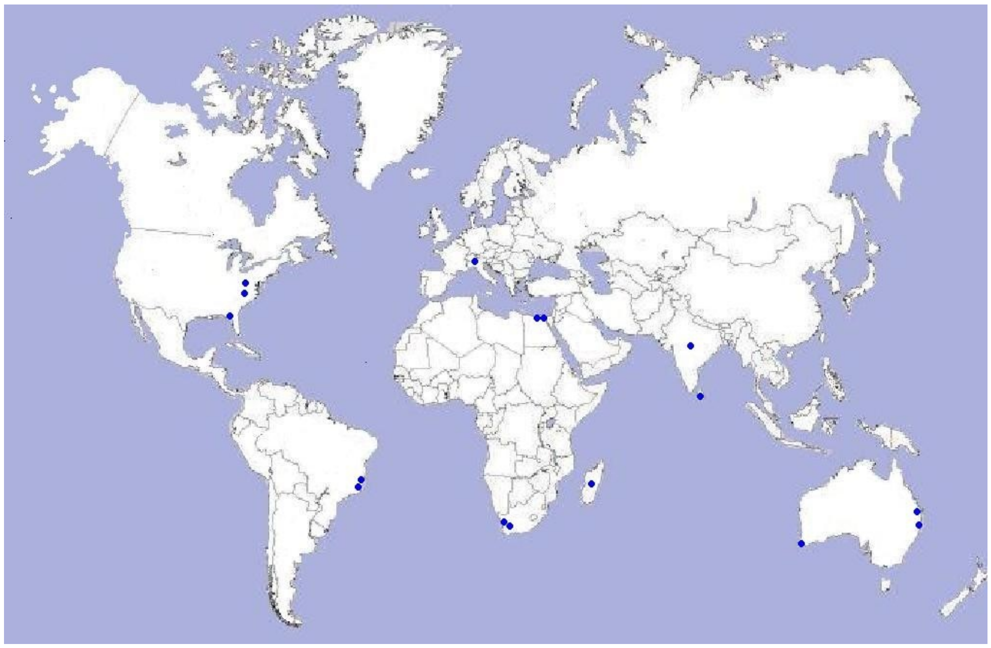
Samarium oxide acts as a chemical intermediate (catalyst) in the dehydration and dehydrogenation processes of ethanol. It is added to glass in the manufacture of lenses used for protection from infrared light.

The radioactive isotope samarium - 153 is used in the field of radiotherapy.

Samarium metal

Sm Samarium , 62

Mineral ore locations



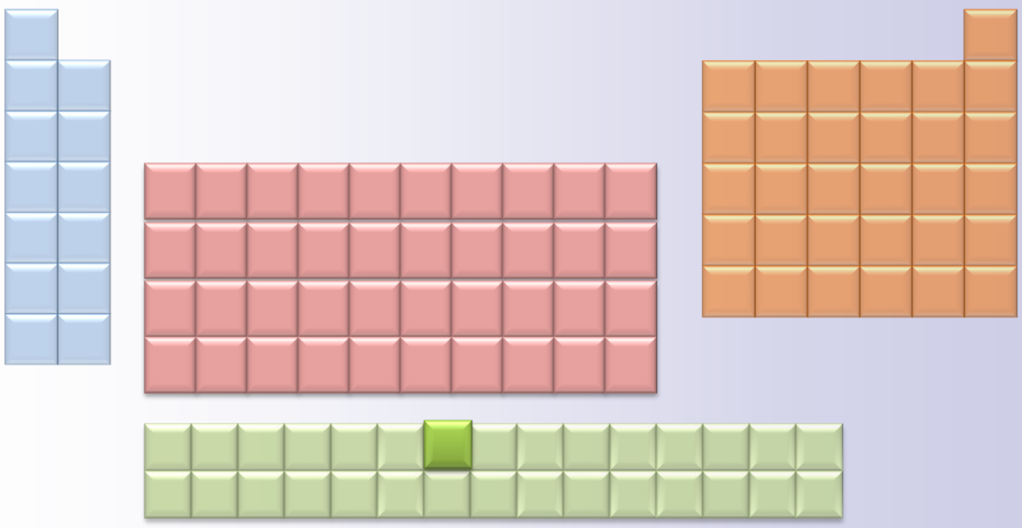
• Monazite

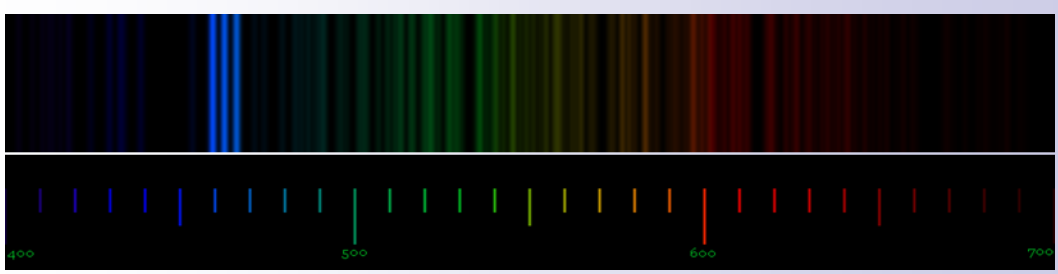
Sm Samarium , 62

Physical and chemical properties

Symbol	Sm	Relative atomic mass	150.36
Atomic number	62	Melting point (ºC)	1076.85
Group	3	Boiling point (ºC)	1790.85
Period	6	Specific heat (J/g.K)	0.197
Family	Rare earth metals	Oxidation numbers	+2, +3
Physical state(20°C)	solid	Electronegativity (pouling)	1.17
Atomic radius (pm)	180.4	Thermal conductivity (W/m.K)	17.9
Crystal structure	Rhombohedral	Heat of fusion (kJ/mol)	12.6
Electronic configuration	$[XE]4f^6 5d^0 6s^2$	Heat of vaporization (kJ/mol)	####
Molar volume (cm3/mole,273K)	20.00	Ist. ionization potential (kJ/mole)	535.9
Density (g/cm3)	7.520	2nd.Ionization potential (kJ/mole)	1052
Number of isotopes	21	3rd. ionization potential (kJ/mol)	2150

Europium Eu





Europium is a silvery, soft and malleable lanthanide element discovered in 1901 and obtained in a pure form for the first time in 1951.

Europium occurs naturally - along with other rare earth elements - in a number of minerals but principally in monazite and bastnasite ores. It is commercially obtained from monazite using ion-exchange procedures and is also obtained, as a by-product, of nuclear fission waste (spent fuel) of uranium and plutonium.

The pure metal is prepared through the reduction of the oxide using lanthanum in tantalum crucibles at high temperature and pressure.

Europium is the most reactive of the lanthanide group. It is rapidly oxidized in air and it reacts vigorously with cold water (the metal loses its luster and becomes covered by a distinctive green oxide even when submerged in dry mineral oil).

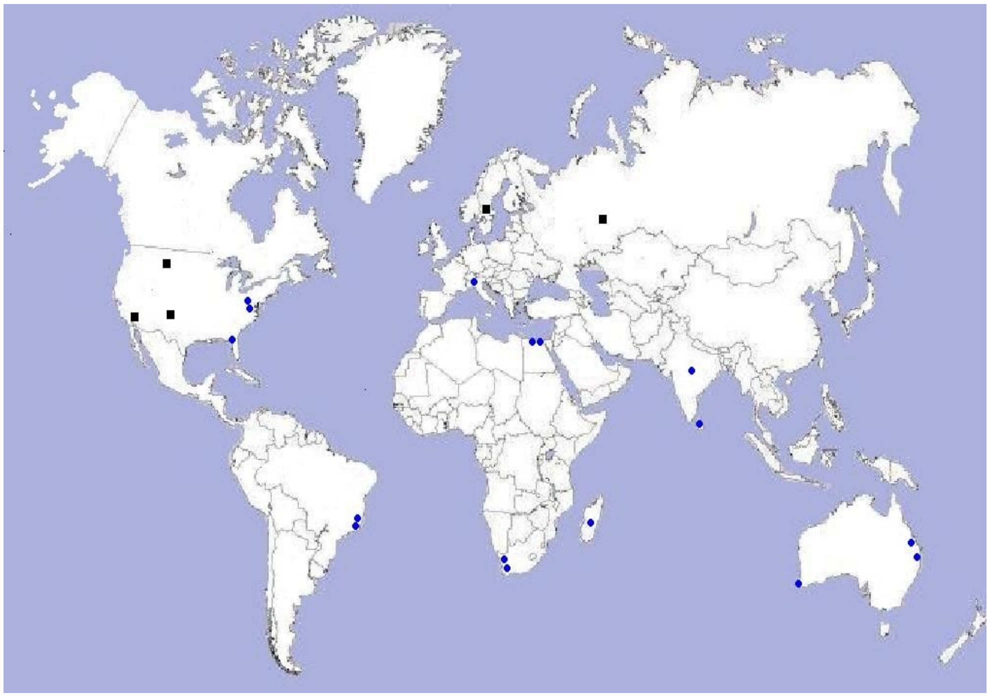
Europium element is characterized by an exceptional ability to absorb neutrons and is thus qualified for use in nuclear rods that control the chain reaction in nuclear furnaces.

Europium is one of the rarest and costliest natural elements, a fact which limits its commercial uses. It is utilized - with some other elements - in the production of laser and in color television tubes (to give the red and blue colors). However, the principal applications of europium are limited to the field of scientific and medical research.

Europium metal

Eu Europium , 63

Mineral ore locations



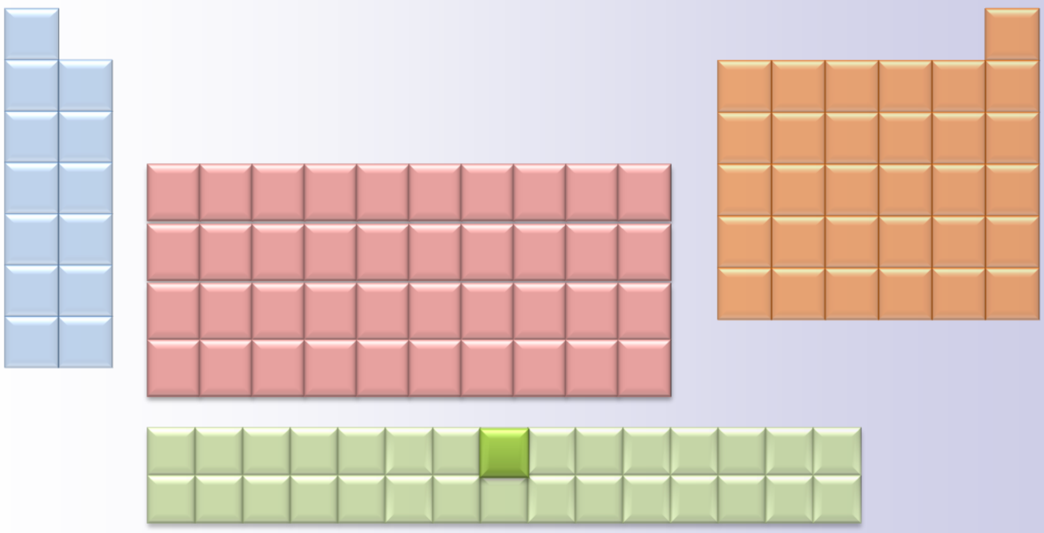
■ Bastnasite ● Monazite

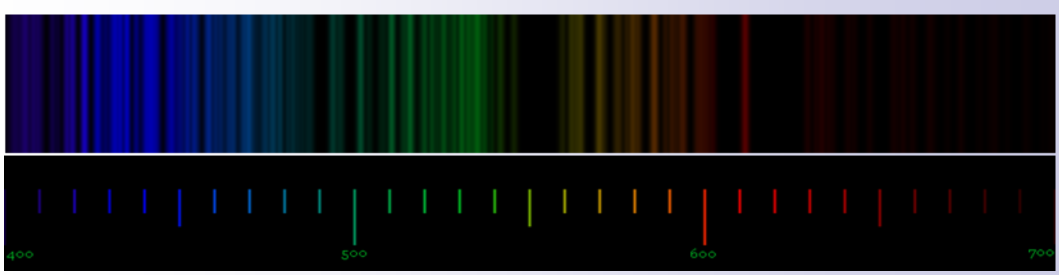
Eu Europium , 63

Physical and chemical properties

Symbol	Eu	Relative atomic mass	151.965
Atomic number	63	Melting point (ºC)	821
Group	3	Boiling point (ºC)	1596
Period	6	Specific heat (J/g.K)	0.182
Family	Rare earth metals	Oxidation numbers	+2, +3
Physical state(20°C)	solid	Electronegativity (pouling)	1.01
Atomic radius (pm)	204.2	Thermal conductivity (W/m.K)	13.9
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	10.5
Electronic configuration	$[Xe]4f^7 6S^2$	Heat of vaporization (kJ/mol)	175.7
Molar volume (cm3/mole,273K)	28.98	Ist. ionization potential (kJ/mole)	546.7
Density (g/cm3)	5.243	2nd.Ionization potential (kJ/mole)	1085
Number of isotopes	26	3rd. ionization potential (kJ/mol)	2404

Gadolinium Gd





Gadolinium is a silvery-white, ductile and malleable lanthanide element that occurs naturally along with other members of the group in a number of ores but principally in monazite and gadolinite .

The pure metal can be prepared by reducing the anhydrous fluoride with calcium metal.

Gadolinium has moderate resistance to chemical attack and is relatively stable in dry air but oxidizes rapidly in moist air forming the oxide which spalls off exposing the metal surface to further attack. It reacts slowly with water and dissolves in dilute acids with evolution of hydrogen gas.

Gadolinium is added to enhance the durability and corrosion resistance of chromium steel for use in memory components of computers.

Gadolinite

Gadolinium metal

It is also used for making gadolinium yttrium garnets for some microwave applications and some gadolinium salts are used as phosphors for color TV tubes.

Gadolinium is highly ferromagnetic and some of its metal alloys, particularly with silicon and germanium, are characterized by thermo magnetic effect (temporary rise in temperature on subjecting to a magnetic field).

The exceptional ability of the isotope gadolinium - 157 for neutron absorption is only exceeded by xenon – 135. It is thus one of the most suitable materials for use as components of nuclear rods that control the chain reaction in nuclear reactors.

Gd Gadolinium , 64

Mineral ore locations

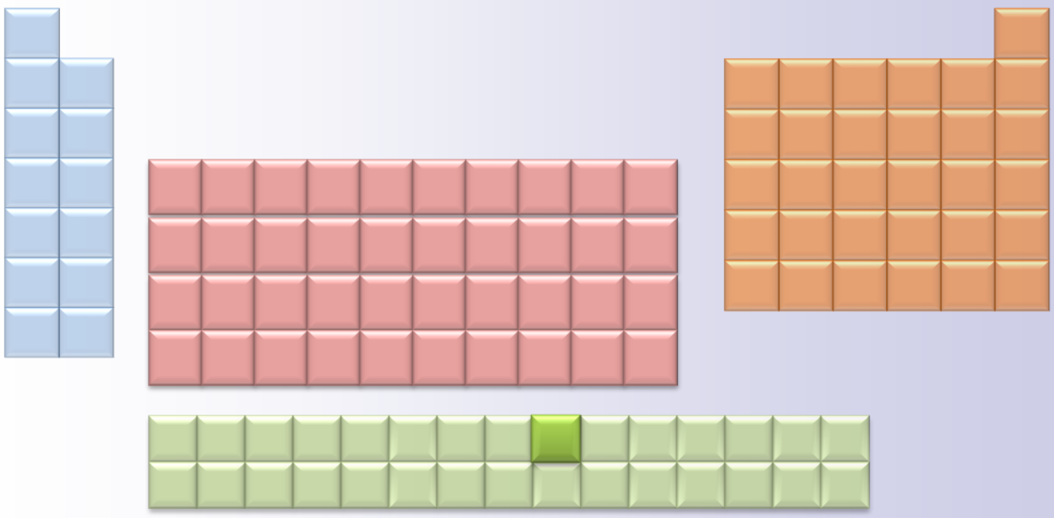
■ Bastnasite ▫ Monazite ● Gadolinite

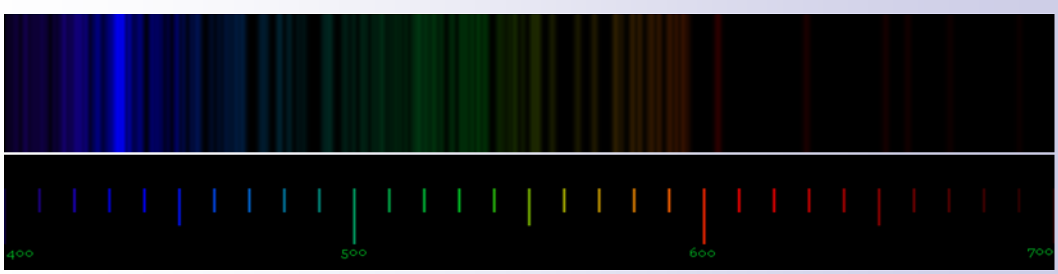
Gd Gadolinium , 64

Physical and chemical properties

Symbol	Gd	Relative atomic mass	157.25
Atomic number	64	Melting point (°C)	1312
Group	3	Boiling point (°C)	3265
Period	6	Specific heat (J/g.K)	0.236
Family	Rare earth metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.20
Atomic radius (pm)	180.2	Thermal conductivity (W/m.K)	10.6
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	15.5
Electronic configuration	$[Xe]4f^7 5d^1 6S^2$	Heat of vaporization (kJ/mol)	311.7
Molar volume(cm3/ mole,273K)	19.90	Ist. ionization potential (kJ/mole)	592.5
Density (g/cm3)	7.900	2nd.Ionization potential (kJ/mole)	1167
Number of isotopes	29	3rd. ionization potential (kJ/mol)	1990

Terbium Tb





Terbium is a silvery-white, soft, ductile and malleable lanthanide element and, compared with group members, is rather abundant in the earth's crust (more abundant than many common metals such as silver and mercury).

Terbium occurs - in a chemically combined form only - in a number of minerals including cerite, gadolinite and monazite ores and is usually recovered from these ores through ion exchange and solvent extraction procedures.

The pure metal can be obtained through the reduction of the anhydrous chloride or fluoride with calcium metal at high temperatures.

Terbium is chemically active . It gradually loses its luster as it is slowly oxidized in humid air. It reacts with the halogens, dissolves readily in mineral acids and slowly in cold water.

At elevated temperatures the metal readily combines with nitrogen, carbon, sulfur, phosphorus, boron, selenium, silicon and arsenic.

Terbium is fluorescent (it gives off light when it receives radiation from another source).

The metal oxide (terbia) is used in fluorescent tubes, X-ray machines and in green phosphors in color TV tubes.

Terbium is used in metal alloys for the manufacture of electronic equipment and some of its salts such as sodium terbium borate are utilized in the production of laser, semiconductors and other solid state devices.

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Terbium metal

Tb Terbium , 65

Mineral ore locations

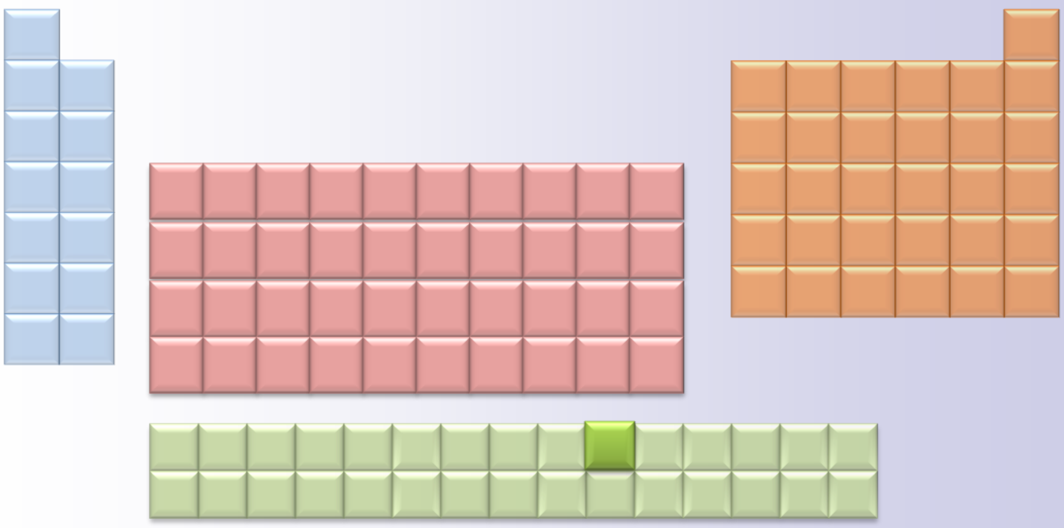
■ Gadolinite ● Monazite

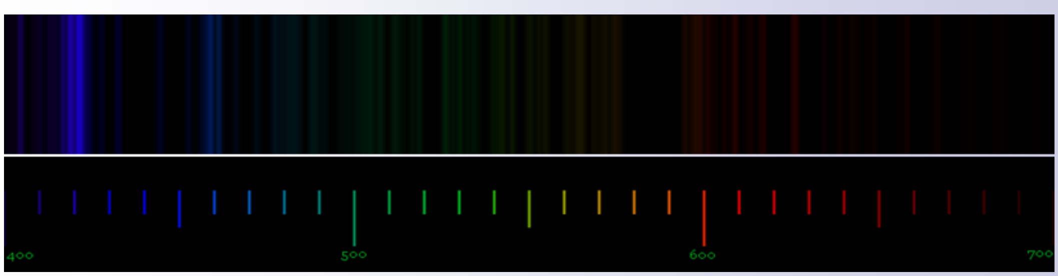
Tb Terbium , 65

Physical and chemical properties

Symbol	Tb	Relative atomic mass	158.925
Atomic number	65	Melting point (ºC)	1355
Group	3	Boiling point (ºC)	3122
Period	6	Specific heat (J/g.K)	0.182
Family	Rare earth metals	Oxidation numbers	+3,+4
Physical state (20°C)	solid	Electronegativity (pouling)	1.10
Atomic radius (pm)	178.2	Thermal conductivity (W/m.K)	11.1
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	16.3
Electronic configuration	$[Xe]4f^96S^2$	Heat of vaporization (kJ/mol)	391
Molar volume(cm3/ mole,273K)	19.31	Ist. ionization potential (kJ/mole)	564.6
Density (g/cm3)	8.229	2nd.Ionization potential (kJ/mole)	1112
Number of isotopes	31	3rd. ionization potential (kJ/mol)	2114

Dysprosium Dy





Dysprosium is a silvery bright, soft and malleable lanthanide element that occurs naturally (chemically combined) in dysprosia (dysprosium oxide) in the company of rare earth minerals like xenotime, bastnasite and monazite. The latter is the major commercial source, and the element is usually extracted through the reduction of the trifluoride with calcium and is further purified by ion exchange techniques. Dysprosium is also obtained as a by-product of yttrium extraction processes.

The metal has relative resistance to attack in normal conditions. It tarnishes slowly in air but dysprosium powder or thin foils represent an explosion hazard when mixed with air or when an ignition source (spark or static electricity) is present. The metal reacts slowly with cold water and quickly with hot water to form the hydroxide. It dissolves in dilute and concentrated mineral acids with evolution of hydrogen gas, and reacts vigorously with halogens at temperatures above 200 °C. It combines with nonmetals like hydrogen, boron, carbon, nitrogen, phosphorous, sulfur and boron at high temperatures to form stable compounds.

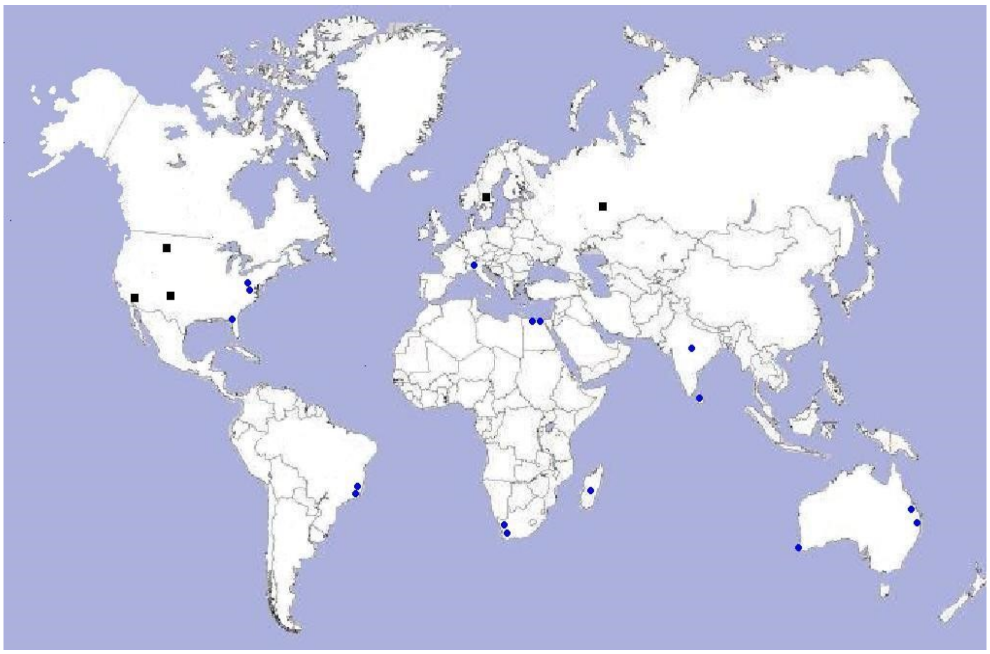
Dysprosium is characterized by a high melting point and a high thermal neutron absorption cross-section and is thus a suitable component of nuclear control rods in nuclear reactors.

The metal is ferromagnetic and its alloys with iron and boron are permanent magnets. Its alloys with terbium and iron are characterized by the highest value of room temperature magnetostriction (a property of ferromagnetic materials that undergo a change in shape when subjected to a magnetic field).

Dysprosium metal chips

Dy Dysprosium , 66

Mineral ore locations



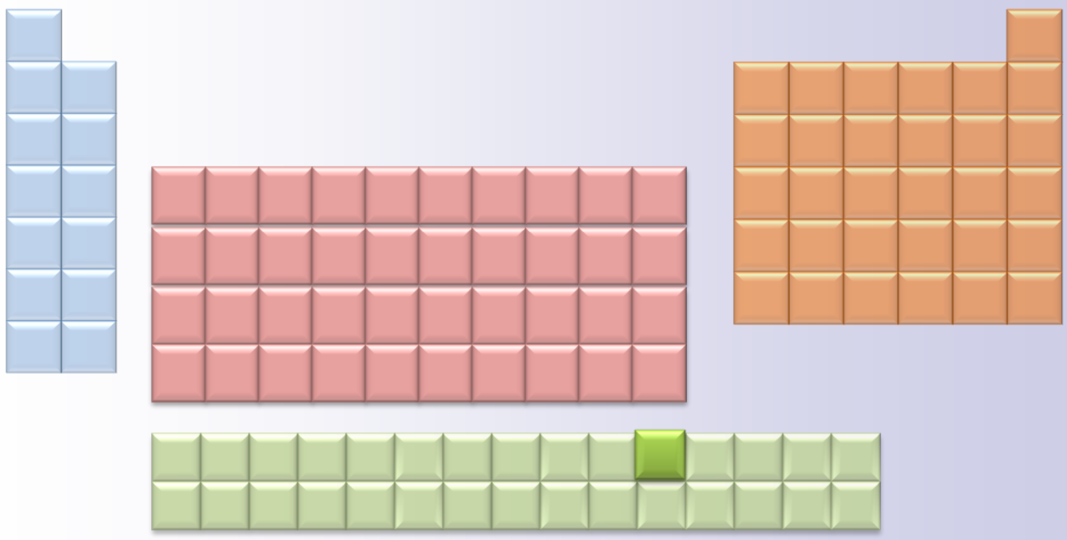
■ Bastnasite ● Monazite

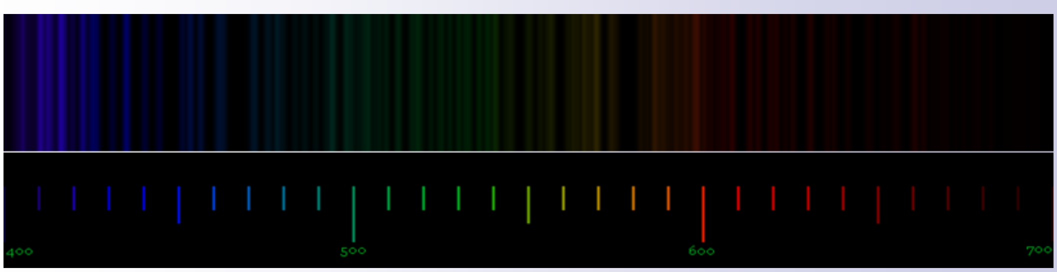
Dy Dysprosium , 66

Physical and chemical properties

Symbol	Dy	Relative atomic mass	162.50
Atomic number	66	Melting point (°C)	1411
Group	3	Boiling point (°C)	2561
Period	6	Specific heat (J/g.K)	0.173
Family	Rare earth metals	Oxidation numbers	+2,+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.22
Atomic radius (pm)	177.3	Thermal conductivity(W/m.K)	10.7
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	17.2
Electronic configuration	$[Xe]4f^{10}6S^2$	Heat of vaporization (kJ/mol)	293
Molar volume(cm3/ mole,273K)	19.00	Ist. ionization potential (kJ/mole)	571.9
Density (g/cm3)	8.550	2nd.Ionization potential (kJ/mole)	1162
Number of isotopes	36	3rd. ionization potential (kJ/mol)	2200

Holmium Ho





Holmium

Holmium is a silvery-white, soft, ductile and malleable metal, and one of the most paramagnetic substances known. It is among the rarest lanthanide elements. It occurs in monazite, gadolinite, xenotime and other rare earth minerals and is commercially obtained from monazite in which it occurs to the extent of about 0.05% through ion-exchange techniques. It is also recovered from products of nuclear fission. The pure metal is obtained by the reduction of the anhydrous chloride or fluoride with calcium metal.

Holmium is rather stable in normal conditions, but is rapidly attacked in moist air or at elevated temperatures to form the oxide and is readily soluble in dilute mineral acids.

The metal is characterized by some unusual magnetic and electrical properties and by the highest magnetic moment of any naturally occurring element (10.6 μB). It is combined with yttrium to create the strongest artificially-generated magnetic field and is utilized in yttrium-iron-garnet (YIG) lasers for microwave equipment and a variety of medical and dental applications.

Holmium is also characterized by a great ability to absorb neutrons and is utilized in nuclear control rods of nuclear reactors. Holmium oxide (holmia) is added to the components of some special glasses (to provide a yellow color) and is also used to color zirconium in the manufacture of yellow gemstones.

Holmium Metal

Ho Holmium , 67

Mineral ore locations

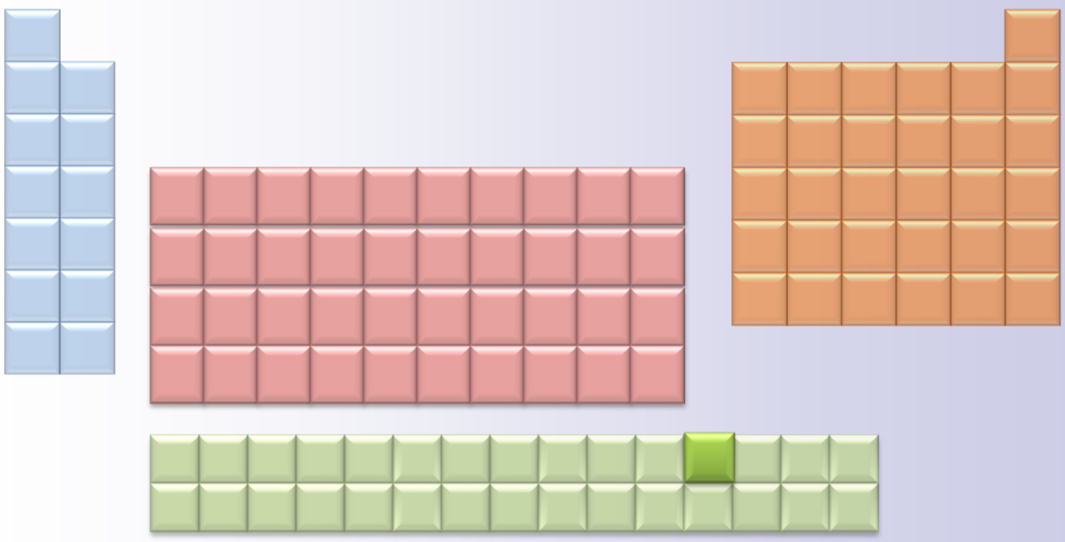
• Monazite ■ Gadolinite

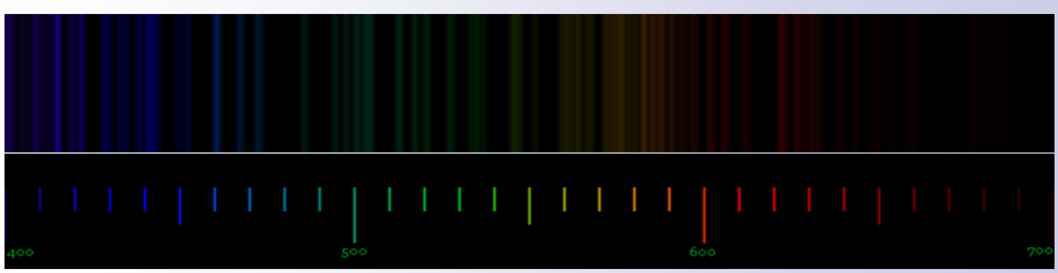
Ho Holmium , 67

Physical and chemical properties

Symbol	Ho	Relative atomic mass	164.930
Atomic number	67	Melting point (ºC)	1473
Group	3	Boiling point (ºC)	2694
Period	6	Specific heat (J/g.K)	0.165
Family	Rare earth metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.23
Atomic radius (pm)	176.6	Thermal conductivity (W/m.K)	16.2
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	17.2
Electronic configuration	[Xe]$4f^{11}6S^{2}$	Heat of vaporization (kJ/mol)	251.0
Molar volume(cm3/ mole,273K)	18.75	Ist. ionization potential (kJ/mole)	580.7
Density (g/cm3)	8.795	2nd.Ionization potential (kJ/mole)	1139
Number of isotopes	39	3rd. ionization potential (kJ/mol)	2204

Erbium Er





Erbium is a soft, silvery-bright, and malleable metal and one of the rarest lanthanide elements.

It is found – in a chemically combined form only- along with other members of the group in monazite, Gadolinite and xenotime minerals. The element is usually isolated and purified through ion exchange techniques.

Erbium occurs as a mixture of six natural isotopes which are all stable. It was isolated as a pure oxide in 1905 and the pure metal was prepared for the first time in 1934.

Erbium is the most stable and the most corrosion –resistant lanthanide element. It tarnishes very slowly in air and water but reacts with acids to form rose colored salts and the finely divided metal spontaneously catches fire in dry air.

Commercial uses of the element include addition to metal alloys (especially vanadium alloys) to reduce the rigidity and to facilitate restructuring processes. It is used in the manufacture of electronic equipment (chiefly as an amplifier in fiber optics). It is used in laser materials for photography and imaging and in dental and cosmetic surgery.

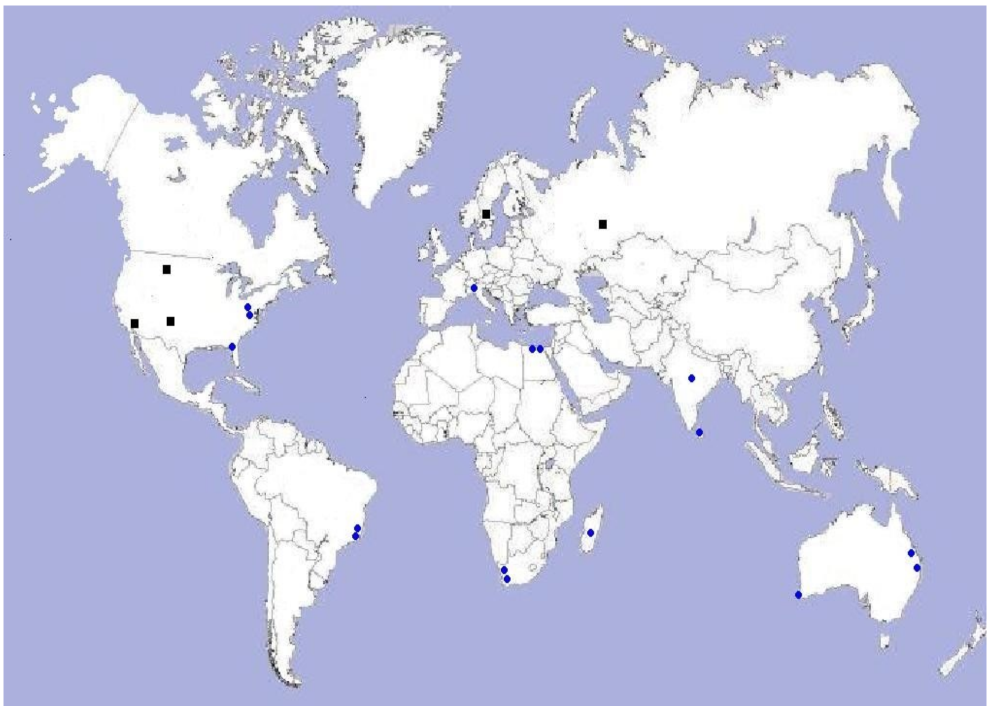
Erbium is also used as a component of control rods to absorb neutrons in nuclear reactors.

Erbia (erbium oxide) is used as a colorant (to offer a pink tint) for glass, ceramics and synthetic jewelry.

Erbium metal

Er Erbium , 68

Mineral ore locations



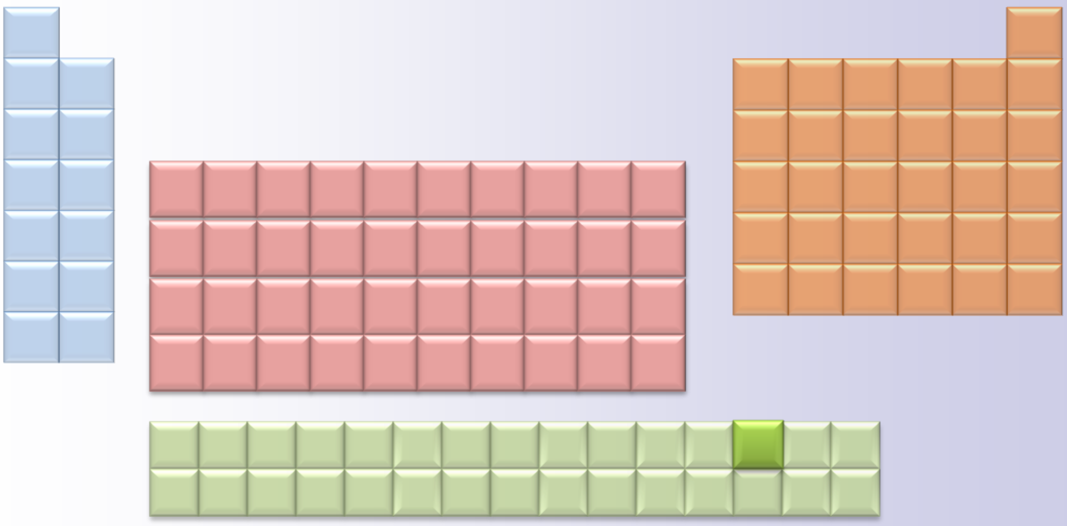
■ Bastnasite ● Monazite

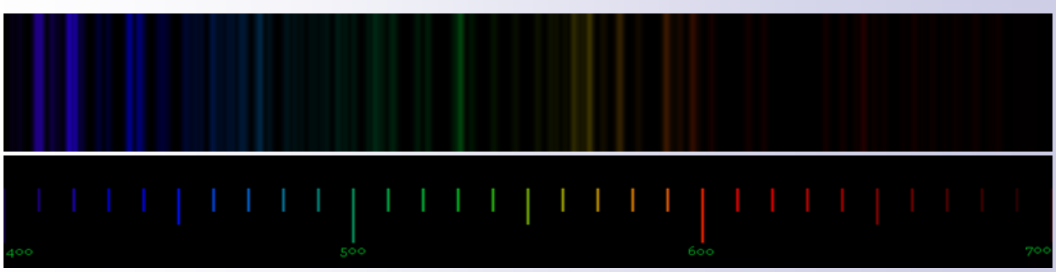
Er Erbium , 68

Physical and chemical properties

Symbol	Er	Relative atomic mass	167.26
Atomic number	68	Melting point (°C)	1528
Group	3	Boiling point (°C)	2862
Period	6	Specific heat (J/g.K)	0.168
Family	Rare earth metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.24
Atomic radius (pm)	175.7	Thermal conductivity (W/m.K)	14.3
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	17.2
Electronic configuration	$[Xe]4f^{12}6S^{2}$	Heat of vaporization (kJ/mol)	292.9
Molar volume(cm3/ mole,273K)	18.44	Ist. ionization potential (kJ/mole)	588.7
Density (g/cm3)	9.066	2nd.Ionization potential (kJ/mole)	1151
Number of isotopes	25	3rd. ionization potential (kJ/mol)	2194

Thulium Tm





Thulium is a soft, silvery-gray, ductile and malleable lanthanide, and one of the rarest members of the group.

It occurs, in very low concentrations, in rare earth minerals such as gadolinite, euxenite, and xenotime but is commercially extracted from monazite where its concentration reaches 7 grams in one metric ton of the crude ore.

Extraction of the element involves ion exchange and solvent extraction techniques and the pure metal can be obtained through the reduction of the oxide (tholia) by lanthanum or calcium metal.

Thulium is rather resistant to attack in normal conditions, but it gradually loses its luster in moist air, and the finely divided metal spontaneously catches fire in the air. It reacts slowly with water and more rapidly with acids.

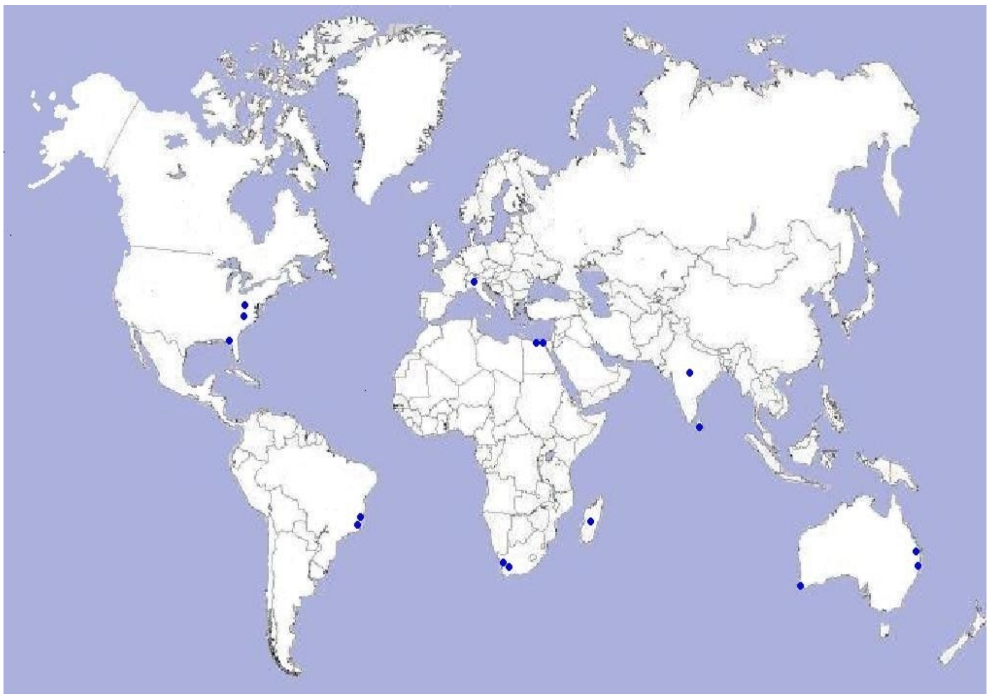
The natural element consists of one stable isotope which is thulium -169. More than 30 radioactive isotopes are artificially prepared with half- lives usually shorter than a few hours or a few minutes.

As a result of the scarcity and the high cost, applications of thulium are largely in the field of scientific research and a few applications in the field of laser materials and electronic equipment.

The radiactive isotopes thulium-170 (half-life 128.6 day) and thulium -171 (half-life 1.92 years) are produced by irradiating thulium-169 in nuclear reactors. The former is used in portable X-ray machines and in solid-state lasers, while thulium -171 is considered as an important potential source of energy.

Thulium metal

Mineral ore locations



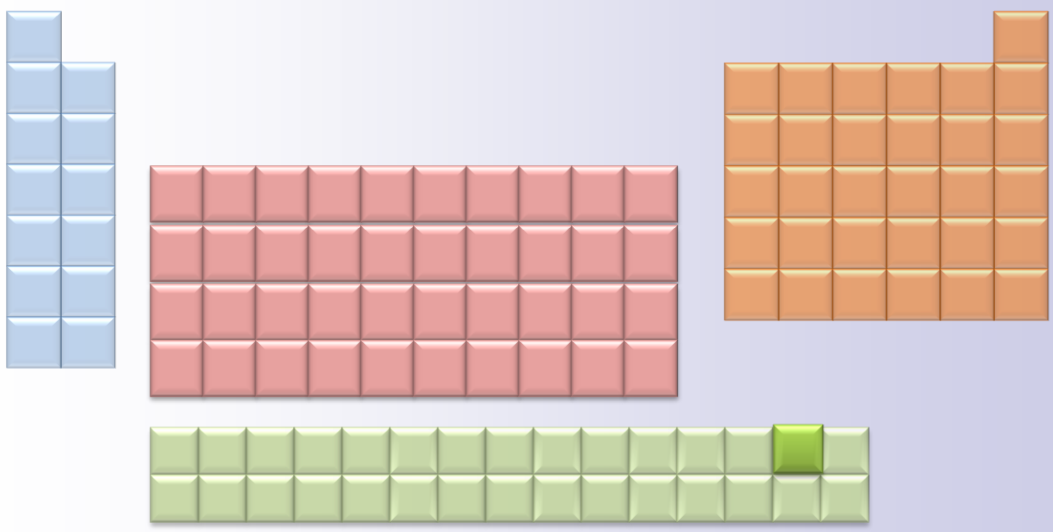
- Monazite

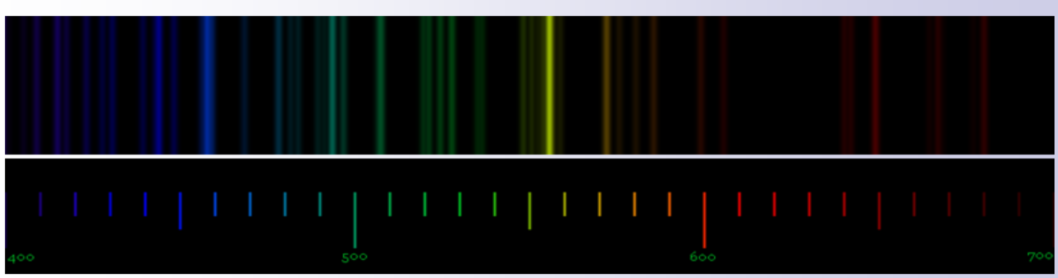
Tm Thulium , 69

Physical and chemical properties

Symbol	Tm	Relative atomic mass	168.934
Atomic number	69	Melting point (°C)	1544
Group	3	Boiling point (°C)	1946
Period	6	Specific heat (J/g.K)	0.160
Family	Rare earth metals	Oxidation numbers	+2,+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.25
Atomic radius (pm)	174.6	Thermal conductivity (W/m.K)	16.8
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	18.6
Electronic configuration	$[Xe]4f^{13}6S^2$	Heat of vaporization (kJ/mol)	247
Molar volume (cm3/mole,273K)	18.12	Ist. ionization potential (kJ/mole)	596.7
Density (g/cm3)	9.321	2nd.Ionization potential (kJ/mole)	1163
Number of isotopes	32	3rd. ionization potential (kJ/mol)	2285

Ytterbium Yb





Ytterbium is a soft, silvery- bright, malleable and rather ductile metal .

It is the last rare earth element to be discovered. It occurs naturally in the company of other lanthanide elements in a number of rare earth minerals, but is commercially recovered from monazite ores which contain about 0.03% of the element.

Ion-exchange and solvent extraction are the usual techniques for ytterbium recovery and purification from other rare earth metals.

Ytterbium is chemically active. It readily dissolves in mineral acids and reacts slowly with cold water to liberate hydrogen. It reacts in air to form a thin protective surface layer of the oxide that prevents further corrosion.

The metal is utilized in the amplification techniques in optical fibers and in components of silicon photovoltaic cells that convert light directly to electric current.

Ytterbium oxide enhances the durability of magnesium and aluminum alloys. It is added to steel alloys to improve some of its mechanical properties. It is doped with iron and aluminum to make magnets with unique properties and is mixed with aluminum to make artificial diamond.

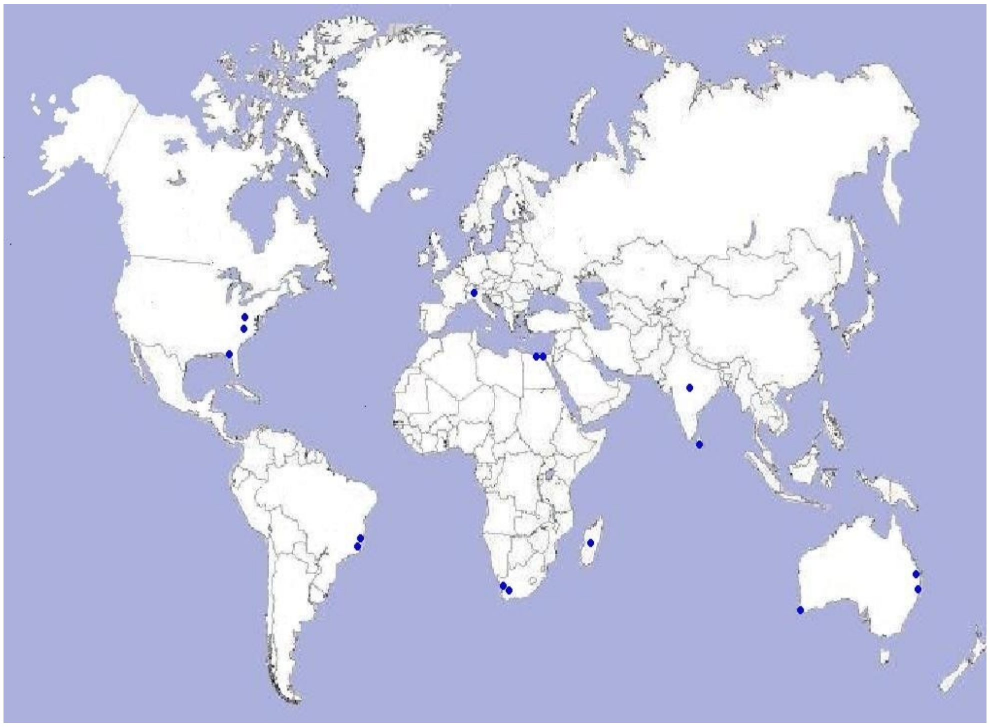
Ytterbium oxide is a component of the phosphor material in color TV tube and is a catalyst in ethylene polymerization processes for the production of polyethylene plastics.

A unique characteristic of ytterbium is an observed increase in the electrical resistance when subjected to strain, and the element is used in censoring equipments used to control ground deformations resulting from earthquakes or explosions.

Ytterbium metal

Yb Ytterbium , 70

Mineral ore locations



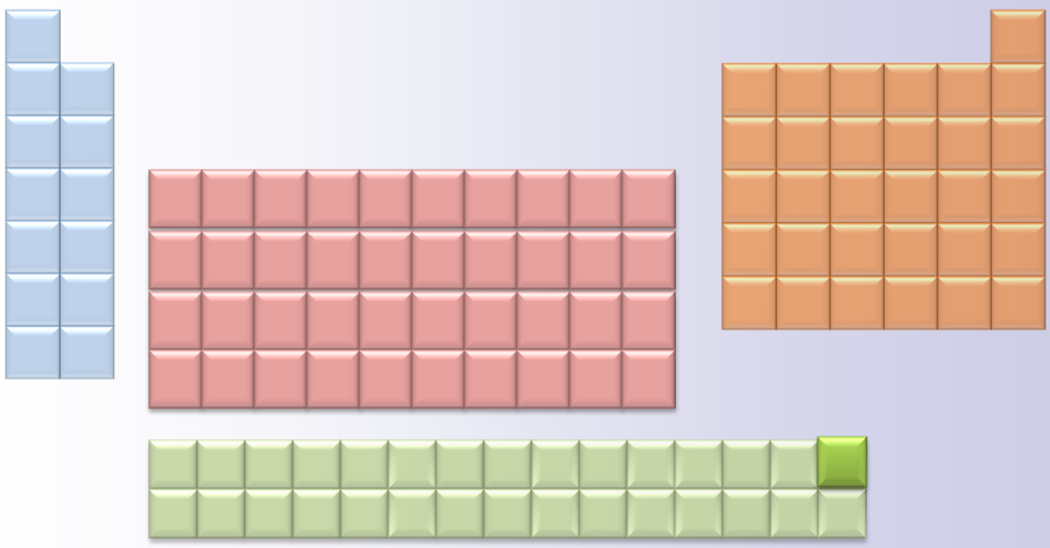
- Monazite

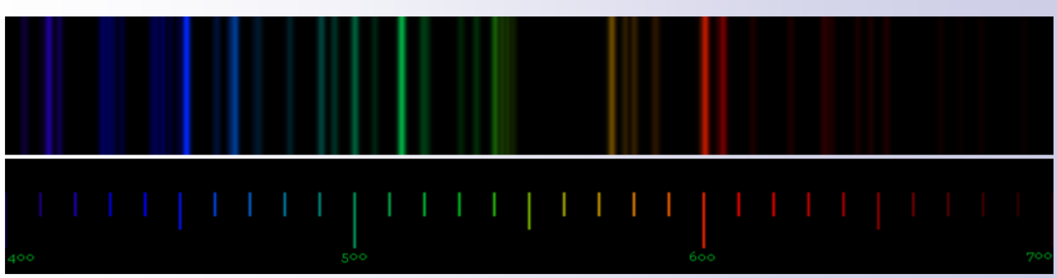
Yb Ytterbium , 70

Physical and chemical properties

Symbol	Yb	Relative atomic mass	173.04
Atomic number	70	Melting point (ºC)	823
Group	3	Boiling point (ºC)	1192
Period	6	Specific heat (J/g.K)	0.155
Family	Rare earth metals	Oxidation numbers	+2,+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.06
Atomic radius (pm)	194	Thermal conductivity (W/m.K)	34.9
Crystal structure	BodyCentered Cubic	Heat of fusion (kJ/mol)	9.20
Electronic configuration	$[Xe]4f^{14}6S^{2}$	Heat of vaporization (kJ/mol)	159
Molar volume(cm3/ mole,273K)	24.84	Ist. ionization potential (kJ/mole)	603.4
Density (g/cm3)	6.965	2nd.Ionization potential (kJ/mole)	1176
Number of isotopes	31	3rd. ionization potential (kJ/mol)	2415

Lutetium Lu





Lutetium is a rare, silvery-white metal and the last member of the lanthanide series. It was discovered and identified as very low concentrations in rare earth ores in 1957 and is commercially extracted from monazite sand in which it is present to the extent of about 0.003%.

The pure metal can be prepared by the reduction of the anhydrous chloride or fluoride with an alkali or alkaline earth metal.

Lutetium is the heaviest and the hardest rare earth metal and is characterized by the highest melting point in the group. It is resistant to chemical attack and is relatively stable in the normal atmosphere.

Due to the difficulty and complexity of the separation and purification techniques, lutetium became the costliest metal (it is more than 5 times costly than gold). Its applications are thus limited to the manufacture of some special metal alloys and the catalysis of some industrial processes such as hydrogenation, polymerization and thermal cracking of oil.

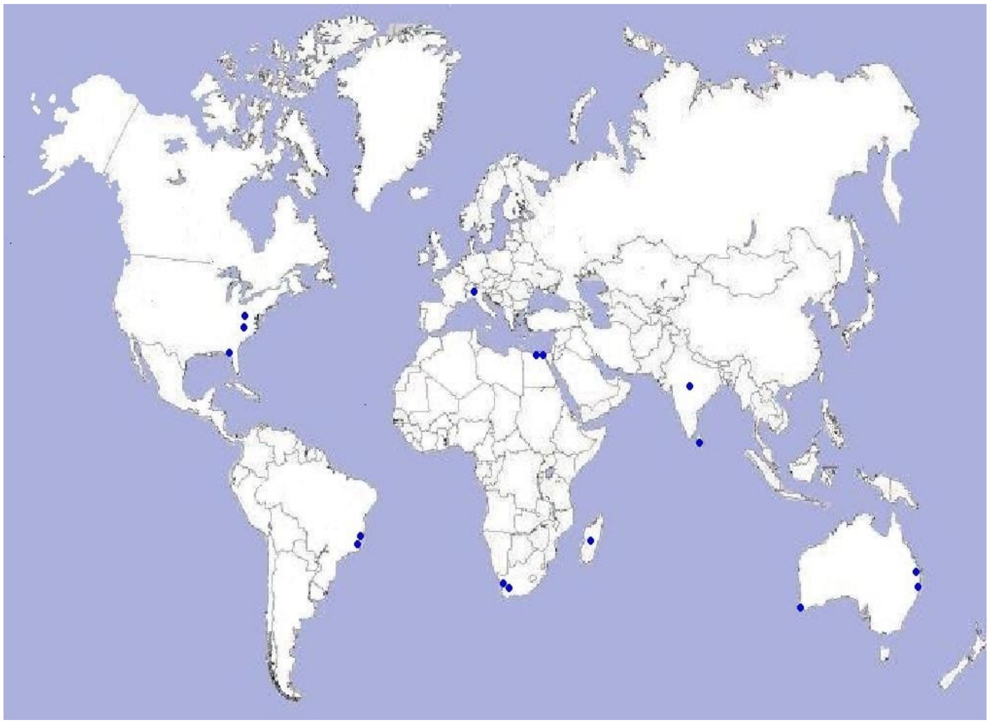
Natural lutetium consists of a stable isotope , lutetium-175 (natural abundance 97.4%) and a radioactive isotope, lutetium-176 with a half-life of 3×10^{10} years and a 2.6 percent natural abundance. The radioactive isotope is used in radioactive dating to estimate the age of fossils and meteorites.

Lutetium-177 is an artificial isotope that decays by emitting beta radiation (electrons) to form hafnium-177. Its half-life is very short (about 6.7 days) and is considered as a promising material for radio-diagnosis and radiotherapy in the medical field.

Lutetium metal

Lu Lutetium , 71

Mineral ore locations



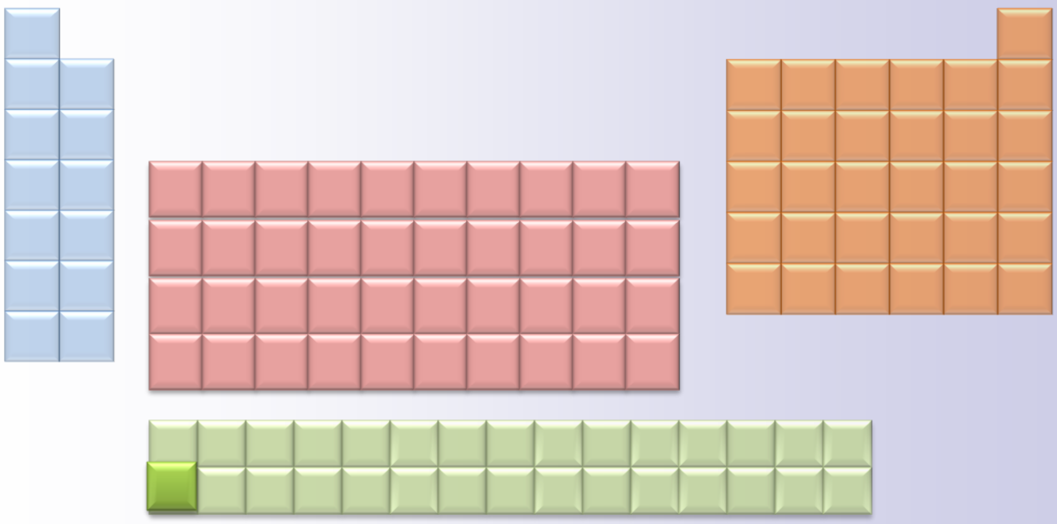
- Monazite

Lu Lutetium , 71

Physical and chemical properties

Symbol	Lu	Relative atomic mass	174.967
Atomic number	71	Melting point (°C)	1662
Group	3	Boiling point (°C)	3394
Period	6	Specific heat (J/g.K)	0.154
Family	Rare earth metals	Oxidation numbers	+3
Physical state (20°C)	solid	Electronegativity (pouling)	1.27
Atomic radius (pm)	173.4	Thermal conductivity (W/m.K)	16.4
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	19.2
Electronic configuration	$[Xe]4f^{14}5d^{1}6S^{2}$	Heat of vaporization (kJ/mol)	428
Molar volume(cm3/ mole,273K)	17.78	Ist. ionization potential (kJ/mole)	523.5
Density (g/cm3)	9.840	2nd.Ionization potential (kJ/mole)	1340
Number of isotopes	41	3rd. ionization potential (kJ/mol)	2022

Actinium Ac



Actinium is a radioactive element from which the actinoid (actinide) series adopted its name. It is a silvery-white and a chemically active element that glows in the dark with a faint blue light due to the intense radiation.

Actinium has thirty-six known isotopes, all of which are radioactive. Actinium-227 with a half-life of about 21.8 years is the most stable isotope of the element. It occurs naturally in trace amounts in thorium and uranium ores as a result of the spontaneous decay of the isotopes of these elements.

Actinium is commercially recovered from uranium ores in which it is found in concentrations of about 100 milligrams of actinium-227 in each metric ton of pitchblende. The pure metal is obtained by reducing actinium fluoride with lithium vapor at high temperatures (about 1200 °C).

Actinium-227 is artificially synthesized through neutron irradiation of radium-126 .

The element is used as a portable source of neutrons, and the isotope actinium-225 is applied as a tracer in some medical and scientific research fields.

Actinium is a powerful alpha emitter

Actinium is extremely dangerous and hazardous. Its radioactivity is 150 times that of radium (which is 1,000,000 times more radioactive than plutonium) . The extreme toxicity and the intense radiation of the destructive alpha particles (helium ions) is considered a serious environmental hazard, a fact which limits the number of available actinium derivatives.

The actinium decay series or simply the actinium series is one of the three natural decay series that include thorium and uranium series. The actinium series begins with the naturally-occurring isotope uranium-235 and terminates with the stable isotope lead-107.

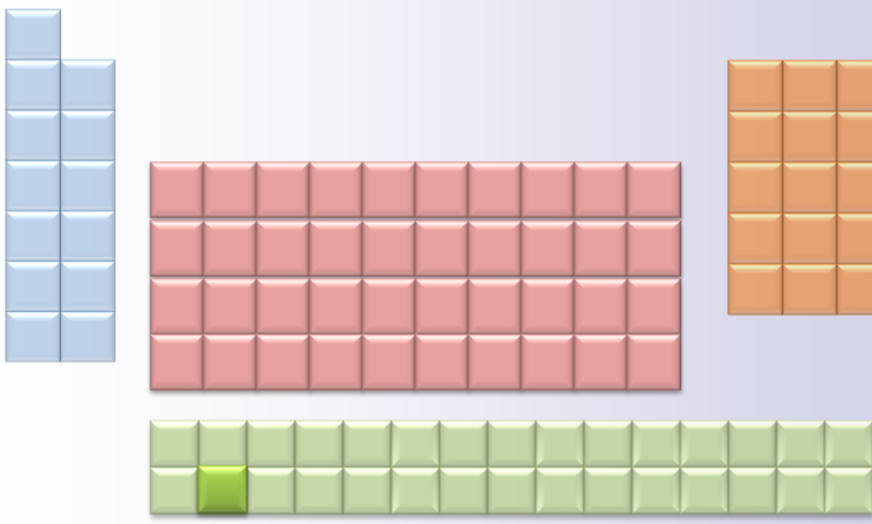
Actinium metal

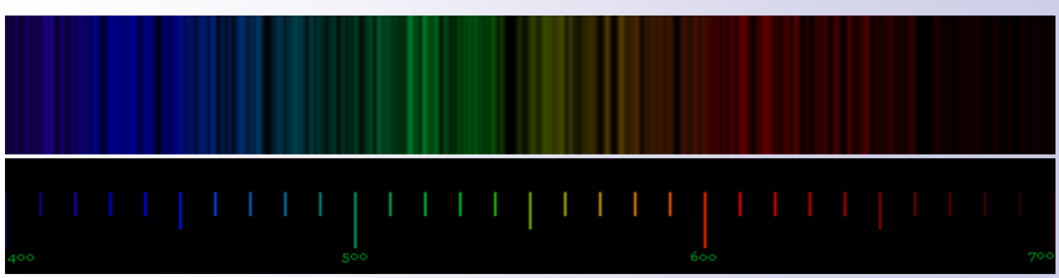
Ac Actinium , 89

Physical and chemical properties

Symbol	Ac	Relative atomic mass	227.028
Atomic number	89	Melting point (ºC)	1046.85
Group	38	Boiling point (ºC)	3196.85
Period	7	Specific heat (J/g.K)	0.120
Family	Actinoids	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.1
Atomic radius (pm)	187.8	Thermal conductivity(W/m.K)	12
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	14.2
Electronic configuration	$[Rn]6d^17s^2$	Heat of vaporization (kJ/mol)	293
Molar volume(cm3/ mole,273K)	22.6	Ist. ionization potential (kJ/mole)	499
Density (g/cm3)	0.3	2nd.Ionization potential (kJ/mole)	1170
Number of isotopes	36	3rd. ionization potential (kJ/mol)	1900

Thorium Th





Thorium is a radioactive actinoid element. It is soft, silvery-white, ductile and malleable metal. Its natural occurrence is due to the long half-life of the isotope thorium-232 (about 14 billion years) and also to the spontaneous decay of uranium to yield thorium-234 isotope.

The element is usually isolated from thorite (thorium silicate), thorianite (thorium and uranium oxides) ores , and from monazite which contains 6-7% thorium phosphate.

Thorium is chemically active. It readily dissolves in cold water and dilute acids and gradually oxidizes and loses its luster in air (contamination with the oxide enhances oxidation of the metal) On heating in air, thorium metal turnings ignite and burn with a brilliant white flame.

Thorium dioxide (thoria) is a refractory material characterized by the highest melting point temperature among all known metal oxides (3300 °C).

Thorium metal is used in the manufacture of laboratory crucibles for high temperature use and for the production of a number of important alloys, especially with magnesium metal.

Although thorium is a low level radioactive material, yet radiation hazards, particularly the internal hazards from inhalation or ingestion of the radioactive isotopes must be considered. Emissions are mainly alpha particles (helium nuclei) but gamma and beta radiations are also emitted.

Including thorium in tungsten arc welding electrodes (thoriated tungsten) which was a common practice is now restricted for the sake of users safety and concerns for the environment.

Thorium is a potential source of nuclear energy

Other criticized practices include the use of thorium oxide in heat-resistant ceramics and addition of the metal to glass to enhance its properties for use in high quality lenses and scientific instruments.

Thorite

(thorium silicate)

- Ontario, Canada-

Th Thorium , 90

Due to the relatively high natural abundance of thorium (estimated at three times the uranium reserves), the element is considered as an important source of nuclear energy.

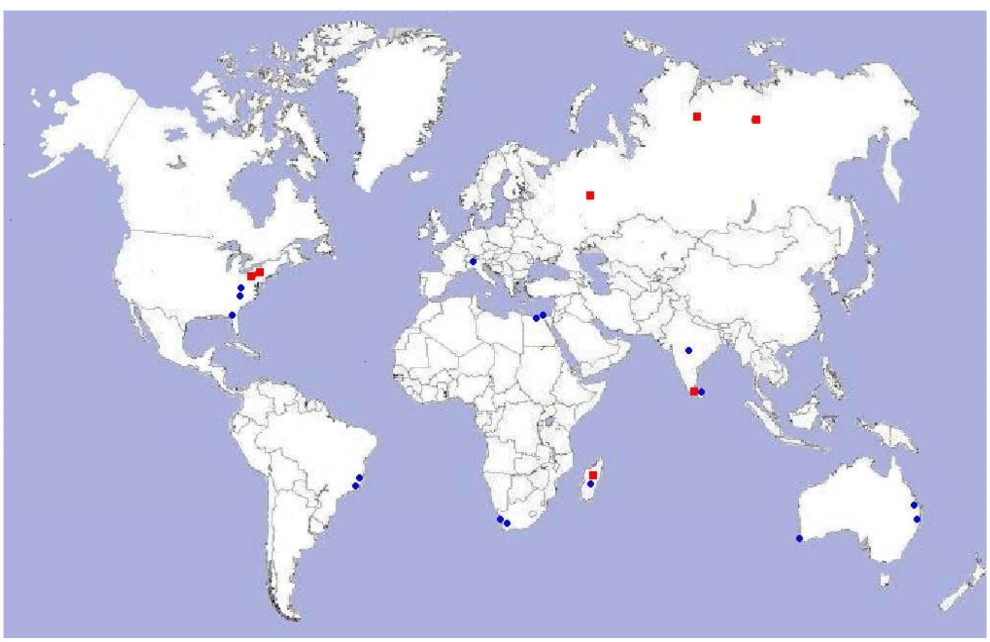
In a thorium reactor the fertile isotope thorium -232 will breed the fissile isotope uranium-233 as a result of bombardment with slow neutrons from a fissile material such as uranium-235 or plutonium-239.

The nuclear reaction will continue to run entirely with thorium and uranium-233 which is continuously bred and fed in the reactor core.

Drawbacks of thorium fuel cycle are the high radioactivity of uranium-233 and the appearance of other hazardous isotopes such as thallium-208 in the course of the nuclear cycle in addition to the technical problems associated with running and control of the nuclear cycle.

However, the thorium nuclear fuel is attractive and the thorium fuel cycle is considered a significant potential source of nuclear energy.

Mineral ore locations



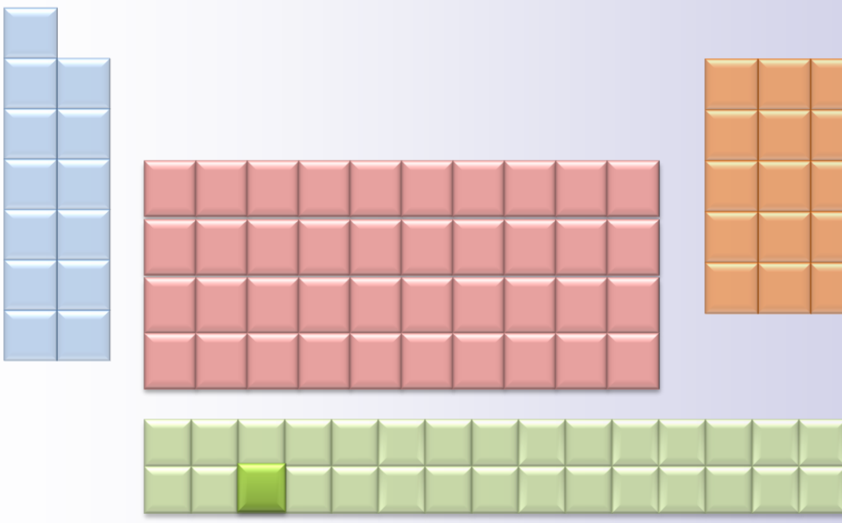
• Monazite ▪ Thorianite

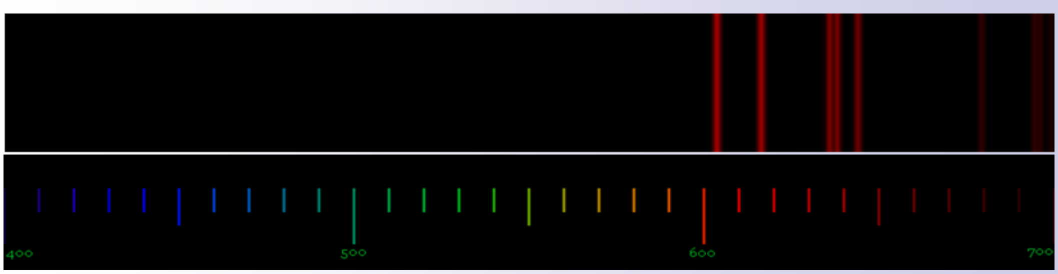
Th Thorium , 90

Physical and chemical properties

Symbol	Th	Relative atomic mass	232.038
Atomic number	90	Melting point (ºC)	1749
Group	3	Boiling point (ºC)	4786
Period	7	Specific heat (J/g.K)	0.133
Family	Actinoids	Oxidation numbers	+3,+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	179.8	Thermal conductivity (W/m.K)	54.0
Crystal structure	Body Centered Cubic	Heat of fusion (kJ/mol)	19.2
Electronic configuration	$[Rn]6d^2 7s^2$	Heat of vaporization (kJ/mol)	543.9
Molar volume(cm3/ mole,273K)	19.80	Ist. ionization potential (kJ/mole)	587
Density (g/cm3)	11.720	2nd.Ionization potential (kJ/mole)	1110
Number of isotopes	28	3rd. ionization potential (kJ/mol)	1978

Protactinium Pa





Protactinium is a radioactive actinoid element discovered in 1913. It occurs naturally due to the continuous decay of uranium and thorium isotopes and uranium ores are the principal commercial source of the element (1 metric ton of depleted uranium contains about 2 grams of protactinium).

Protactinium is also obtainable in nuclear reactors by neutron irradiation of thorium.

Protactinium is a very strong emitter of alpha particles (helium nuclei) and is thus considered as a serious source of radiation pollution.

The isotope protactinium-231 (half-life 32,760 years) is the most stable isotope of the element. More than 20 other isotopes have been artificially prepared but the half-lives of most of them do not exceed a few minutes or a few seconds.

Protactinium is one of the rarest and the most precious natural elements and its applications are largely in the field of pure scientific research.

Protactinium

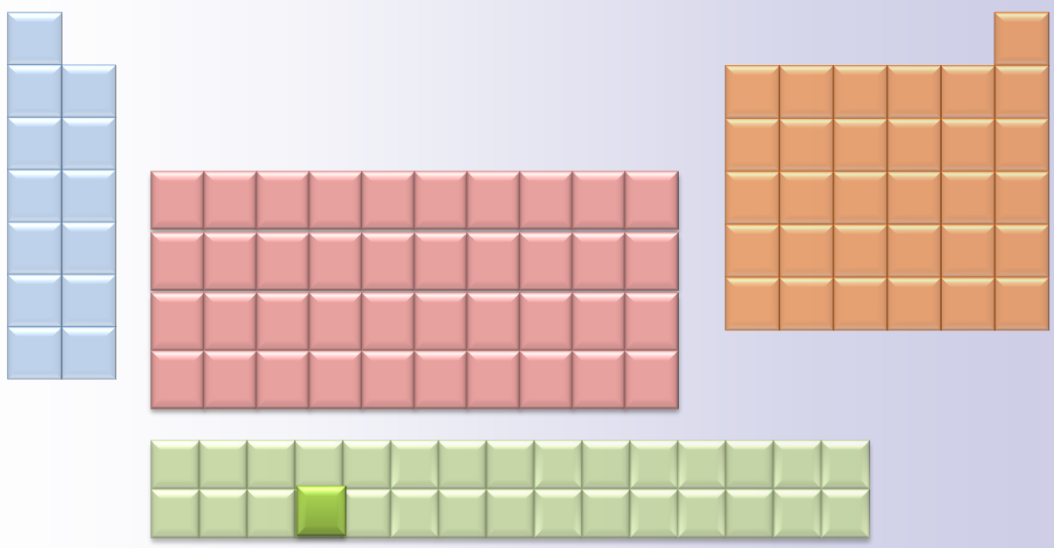
A radioactive element and one of the costliest and rarest elements

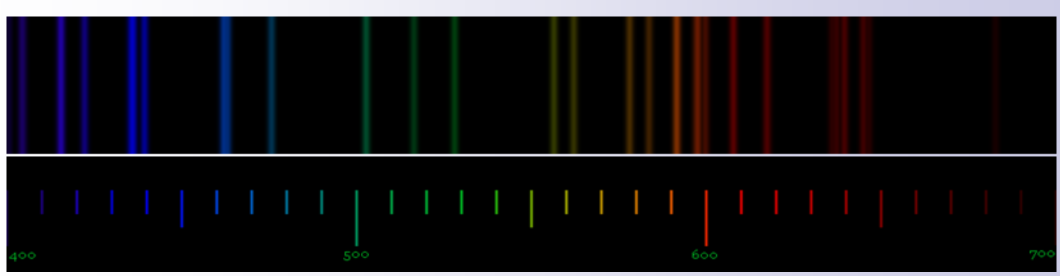
Pa Protactinium , 91

Physical and chemical properties

Symbol	Pa	Relative atomic mass	231.036
Atomic number	91	Melting point (°C)	1839
Group	3	Boiling point (°C)	4026
Period	7	Specific heat (J/g.K)	
Family	Actinoids	Oxidation numbers	+3,+4,+5
Physical state(20°C)	solid	Electronegativity (pouling)	1.5
Atomic radius (pm)	160.6	Thermal conductivity (W/m.K)	47
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	16.7
Electronic configuration	$[Rn]5f^2 6d^1 7s^2$	Heat of vaporization (kJ/mol)	481
Molar volume(cm3/ mole,273K)	15.0	Ist. ionization potential (kJ/mole)	568.30
Density (g/cm3)	15.370	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	26	3rd. ionization potential (kJ/mol)	####

Uranium U





Uranium is a dense, silvery-white radioactive element of the actinoid group.

Its natural occurrence is due to the long half-life of the isotope uranium-238 (4.5 billion years). It is characterized by the highest atomic number (92) and the largest atomic mass (238) of a natural element.

Uraninite or pitchblende (uranium oxide), carnotite (potassium uranium vanadate) and autunite (calcium uranyl phosphate) are the major commercial mineral sources of uranium.

Canada is the world largest supplier of uranium. The metal is usually extracted through the electrolysis of the fluoride or by the reduction of the oxide with calcium or carbon (coke) at high temperatures.

Uranium is chemically very active. It reacts with almost all nonmetals and dissolves in mineral acids, but is insoluble in alkalis. It is readily oxidized in air at room temperature and the finely divided metal spontaneously catches fire at 100 °C.

The naturally occurring element is over 99% by mass uranium-238 while the fissile isotope U-235 comprises about 0.7% and a third natural isotope (uranium-234) occurs as minor traces in the mined ore (< 0.006%).

Uranium is the major nuclear fuel for domestic purposes (generation of electric power) as well as for military purposes (nuclear weapons).

Production of nuclear power will commence and will be sustained as long as a critical mass of a fissile isotope is available. For this purpose the nuclear fuel must be enriched to a U-235 concentration of 2.5 --5% by weight for typical domestic use (in graphite and light water reactors). Weapon-grade uranium may contain over 80% U-235.

Pitchblende (uraninite)

(uranium oxide)

- Cape Province, South Africa -

U Uranium , 92

The most common uranium enrichment techniques are the gaseous diffusion and the gaseous centrifuge methods.

Both methods are dependent upon the slight difference between the molar mass of the two isotopes (U-238 and U-235).

In the gaseous diffusion method the volatile uranium hexafluoride is forced through permeable membranes where the lighter isotope (U-235) flows faster than the heavier isotope (U-238) and its ultimate concentration increases.

In the (more advanced) gaseous centrifuge enrichment method a strong centrifugal force is applied by rotating large cylinders containing uranium hexafluoride of the two isotopes which show different response to the centrifugal force. The heavier isotope is more pulled outward and the concentration of the lighter isotope builds up around the centre of the rotating drums.

One kilogram of the enriched uranium-235 has the capacity to produce energy of about 20 trillion joules and that is equivalent to the energy produced by 1500 tons of coal.

Production of plutonium is a normal part of the fissioning process in all types of reactors and is responsible for providing a significant amount of energy of power plants.

Nuclear fission produces high energy neutrons (fast neutrons) which are unsuitable for a normal fission reaction. Moderators such as water or helium are used to cool and slow down fast neutrons
and provide neutrons with optimum energy (thermal neutrons).

Fast reactors, on the other hand, use moderate coolants such as liquid sodium and high energy neutrons are captured by uranium-238 which is converted into fissionable plutonium-239 that readily produces the fissile isotope, uranium-239. These reactors represent a source of weapon-grade plutonium which can be recovered from burned uranium after a few months of irradiation.

Uranium-239 runs the nuclear reaction with more efficiency than uranium-235 and fast reactors (or breeder reactors) produce more nuclear fuel than they consume.

However, accumulation of hazardous radioactive waste that includes dangerous sources of radiation such as plutonium-240 is the main factor that limits the number of commercial breeder reactors world wide.

Depleted uranium (DU) is a by-product of enriching uranium for nuclear purposes and is also a by-product of the nuclear reaction as it constitutes the bulk of the spent nuclear fuel.

U Uranium , 92

Depleted uranium is very dense and is about half as radioactive as naturally occurring uranium (It contains only about 0.2% uranium-235). It is widely used for civil as well as for military purposes. It is used in radiation shields, containers for storage and transport of radioactive materials and in air craft industry. However, the use of depleted uranium in parts of bullets and other destructive ammunition is responsible for serious environmental contamination, particularly the pollution risk caused by the highly toxic uranium oxides.

Mineral ore locations

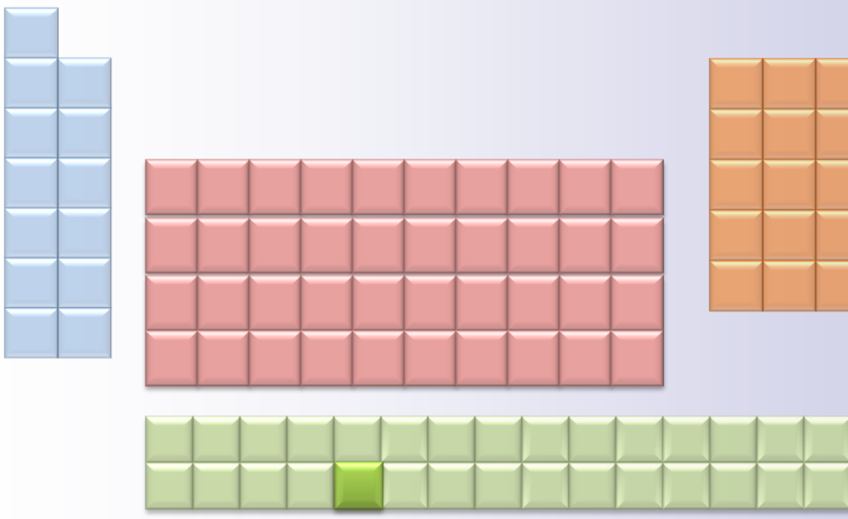
▪ Autunite ∘ Carnotite • Pitchblende

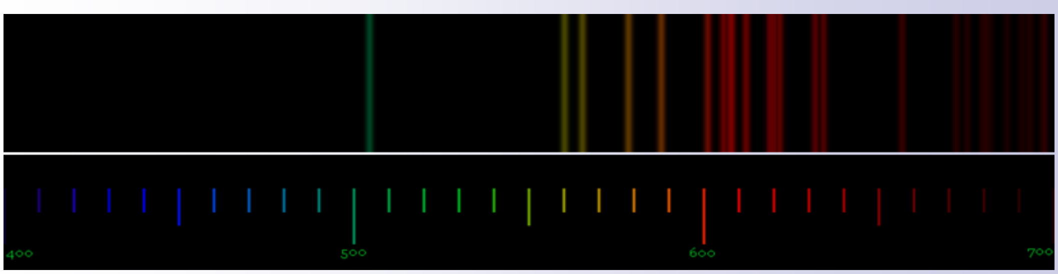
U Uranium , 92

Physical and chemical properties

Symbol	U	Relative atomic mass	238.029
Atomic number	92	Melting point (°C)	1132
Group	3	Boiling point (°C)	3744
Period	7	Specific heat (J/g.K)	0.116
Family	Actinoids	Oxidation numbers	+3, +4, +5, +6
Physical state(20°C)	solid	Electronegativity (pouling)	1.38
Atomic radius (pm)	138.5	Thermal conductivity (W/m.K)	27.6
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	15.5
Electronic configuration	$[Rn]5f^3 6d^1 7s^2$	Heat of vaporization (kJ/mol)	422.6
Molar volume (cm3/mole,273K)	12.56	Ist. ionization potential (kJ/mole)	597.64
Density (g/cm3)	18.950	2nd.Ionization potential (kJ/mole)	1420
Number of isotopes	21	3rd. ionization potential (kJ/mol)	####

Neptunium Np





Neptunium is a silvery metallic radioactive element and the first transuranium element to be artificially prepared (1940) by neutron bombarding of uranium –238 to yield neptunium-239 isotope (half-life 2.4 days).

Traces of neptunium occur naturally in uranium ores as a result of neutron capture by uranium isotopes.

The isotope neptunium-237, with a half-life 2.14 million years , is the most stable isotope and is usually recovered as a by-product of spent nuclear fuel in plutonium production reactors.

Pure neptunium metal can be obtained by reduction of the fluoride using barium or lithium at temperatures of 1200 °C.

Neptunium-237 isotope decays by emitting alpha radiation (helium nuclei) and the element is used in the manufacture of components of neutron detection instruments and smoke detectors.

Neptonium is also used for the production of the rare isotope, plutonium-238 which is utilized in special military purposes and in a number of aviation industry requirements.

Other uses of neptunium are mainly encountered in the field of scientific research, especially in projects related to nuclear energy and super conductive materials.

The element represents a health hazard in case of ingestion or inhalation of neptunium –contaminated dust.

When they enter the body, neptunium isotopes are deposited on bone surfaces and liver tissues where their ionizing radiation leads to deformation of bone marrow and liver cells.

Neptunium is a radioactive element that occurs as traces in uranium ores

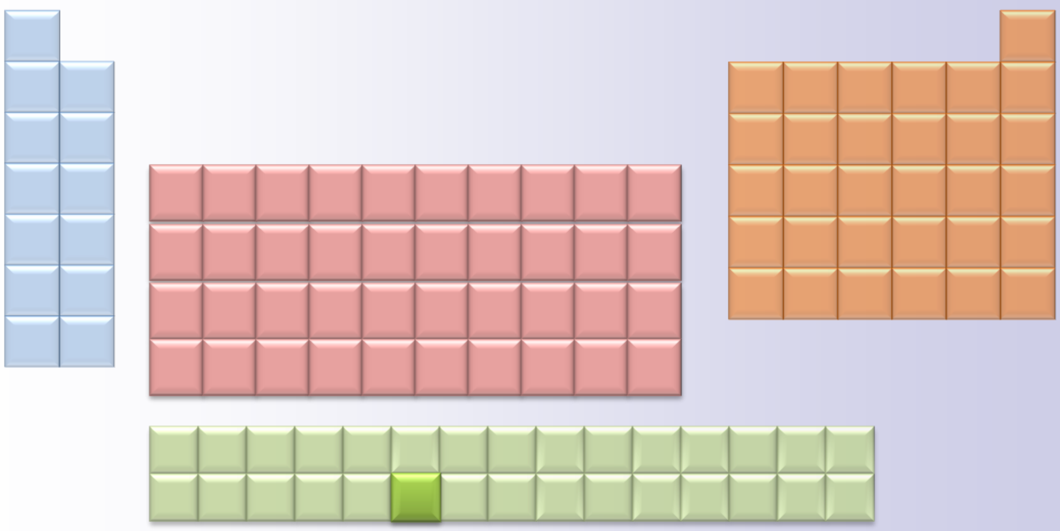
Neptunium metal

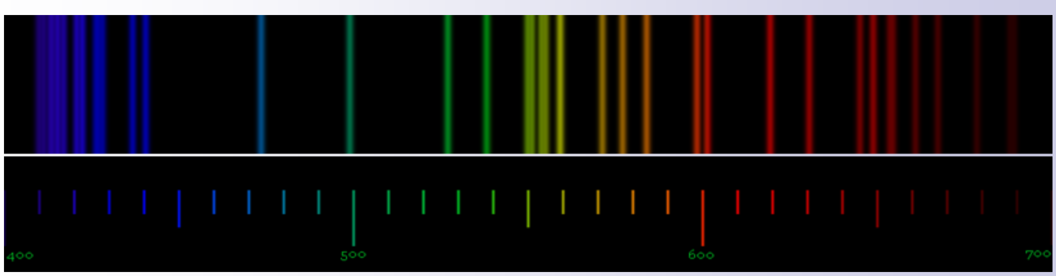
Np Neptunium , 93

Physical and chemical properties

Symbol	Np	Relative atomic mass	237.0482
Atomic number	93	Melting point (ºC)	644
Group	3	Boiling point (ºC)	3900
Period	7	Specific heat (J/g.K)	0.12
Family	Actinoids	Oxidation numbers	+3, +4, +5, +6
Physical state(20°C)	solid	Electronegativity (pouling)	1.36
Atomic radius (pm)	131	Thermal conductivity (W/m.K)	6.3
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	9.46
Electronic configuration	$[Rn]5f^4 6d^1 7s^2$	Heat of vaporization (kJ/mol)	336.6
Molar volume(cm3/ mole,273K)	11.62	Ist. ionization potential (kJ/mole)	597
Density (g/cm3)	20.45	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	22	3rd. ionization potential (kJ/mol)	####

Plutonium Pu





Plutonium is a silvery-white actinoid metal prepared in a pure form for the first time in 1941.

All the known (twenty) isotopes of plutonium are radioactive and the natural occurrence of the element is due to the high stability of the isotope plutonium-244 (half-life 80 million years) which occurs - as traces - in uranium ores.

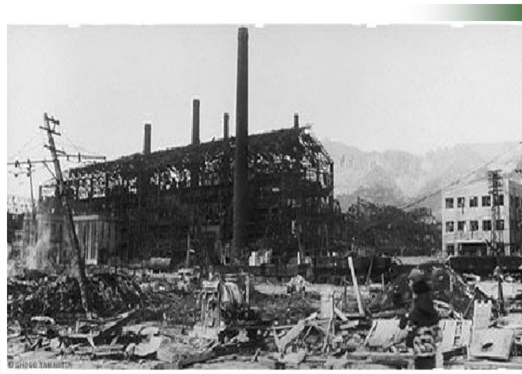
Plutonium is chemically active. It gains a yellow color on exposure to humid atmosphere and eventually turns to an explosive powder of the hydride and the oxide. It readily combines with carbon, nitrogen, silicon and the halogens.

Plutonium is commercially produced as a by-product of the irradiation of natural uranium in nuclear reactors. Plutonium-239(half-life 24110 years) which is the most common isotope of the element is bred from uranium-238 through neutron capture followed by beta decay (this occurs in breeder reactors as well as in normal light water reactors).

This (reactor grade) plutonium is responsible for running nuclear power plants after most other fissile isotopes are consumed and is responsible for more than one third of the energy output of nuclear power plants for production of electric power.

Plutonium is one of the most dangerous substance known.

Plutonium-239 captures neutrons to generate energy and gamma radiation with simultaneous production of additional neutrons to sustain the nuclear chain reaction. It is a strong alpha emitter and is used in nuclear military bombs as well as in domestic nuclear plants for production of electricity



Nagasaki city in Japan was bombed with a plutonium-239 bomb (Fat man) in 1945

Pu Plutonium , 94

The total energy produced by one kilogram of plutonium is equivalent to the energy resulting from 20,000 metric tons of conventional chemical explosives.

Plutonium can be recovered through reprocessing of the irradiated reactor fuel rods for reuse as a nuclear fuel (and sometimes for military purposes). This process is costly and unsafe due to the release of hazardous gases and highly radioactive material.

Weapon-grade plutonium, which also consists of plutonium-239, is obtained from fast reactors (breeder reactors) where liquid sodium is used as the reactor coolant (moderator). Fast neutrons are absorbed by uranium-238 to give plutonium-239. They cause less fission than thermal neutrons and are thus ideal for weapon grade plutonium production.

Weapon-grade plutonium is recovered after a short periods of irradiation (usually 2-3 months) to stop the conversion of plutonium-239 into uranium-239 and plutonium-240. These isotopes represent an intense neutron emission source and are considered as serious hazards for workers as well as for the environment and most breeder reactors round the world have either been stopped or suspended.

Plutonium-238 (half-life 88 years) is a product of uranium-238 irradiation with deuterons. This isotope is a strong alpha emitter and is a relatively safe energy source (alpha particles are used as a source of power in radioisotope thermoelectric generators that need no control such as in remote areas and space probes).

Inhalation of plutonium oxide is the most serious hazard caused by the element. The inhaled material ultimately reaches the internal organs of the human body particularly liver and bone tissues to act as a local source of destructive alpha radiation that may eventually initiate malignancy in these tissues.

Weapon grade plutonium

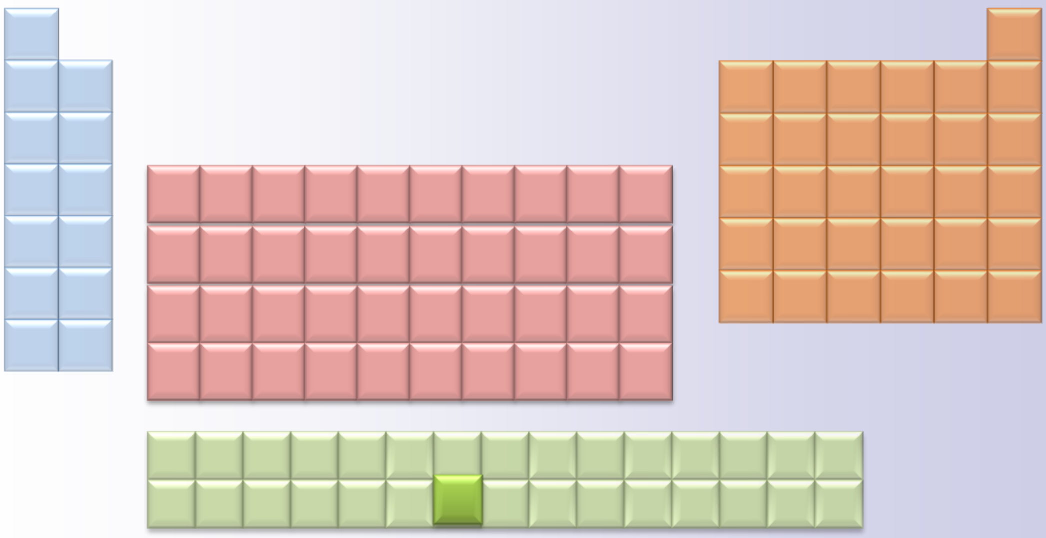
(purity 99.9% +)

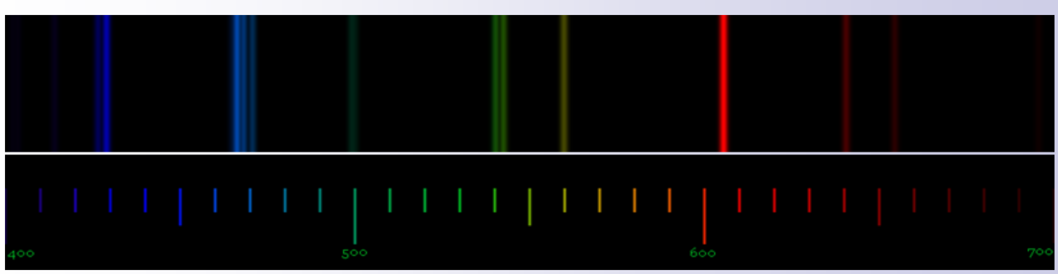
Pu Plutonium , 94

Physical and chemical properties

Symbol	Pu	Relative atomic mass	244.064
Atomic number	94	Melting point (ºC)	640
Group	3	Boiling point (ºC)	3231
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3,+4,+5,+6
Physical state(20°C)	solid	Electronegativity (pouling)	1.28
Atomic radius (pm)	151	Thermal conductivity (W/m.K)	6.74
Crystal structure	Monoclinic	Heat of fusion (kJ/mol)	2.8
Electronic configuration	$[Rn]5f^6 7s^2$	Heat of vaporization (kJ/mol)	343.5
Molar volume (cm3/mole,273K)	12.3	Ist. ionization potential (kJ/mole)	585
Density (g/cm3)	19.840	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	20	3rd. ionization potential (kJ/mol)	####

Americium Am





Americium is a synthetic actinoid element. It is soft, silvery-white, ductile and malleable.

The element was discovered in 1944 and the isotope americium-241 was artificially prepared by bombarding plutonium-239 with neutrons.

Americium is recovered from the spent nuclear fuel of nuclear power plants where it exists as a result of the radioactive decay of plutonium-241 isotope (half-life 14 years).

The most stable isotopes of the element are americium-243 with a half-life of 7370 years, and americium-241 with a half-life of 433 years. The latter is a source of heavy alpha radiation (helium nuclei) and is three times more active than radium. All other isotopes of the element are short lived and their half-lives are usually less than 50 hours.

The isotope americium-241 is utilized as a portable source of gamma and alpha radiation. It is used in radio- diagnosis and in X-ray imaging devices to detect cracks in sensitive equipment and machinery such as aircraft parts and turbines.

Americium is also used as a source of ionizing radiation in smoke-sensitive fire alarms.

With increasing concern over nuclear weapon proliferation risk, plutonium denaturing is becoming a major political issue in nuclear -armed states (USA, UK, Russia and France). Americium-241 is among a number of actinoid metals now used in denaturing plutonium fuel rods to disable its conversion to nuclear weapons (in other states).

Americium-241 can be used for denaturing plutonium fuel rods to disable its conversion to nuclear weapons

Americium

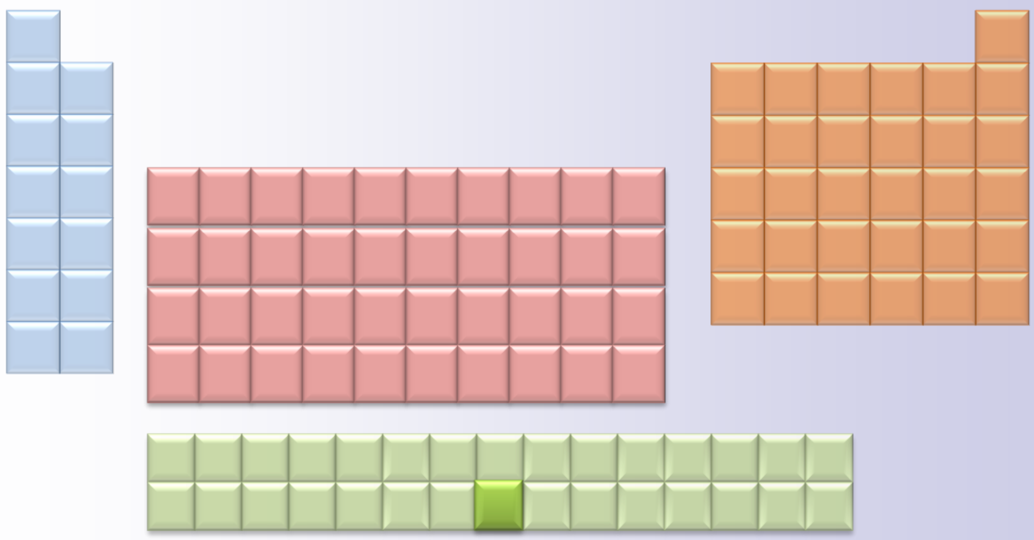
(under the microscope)

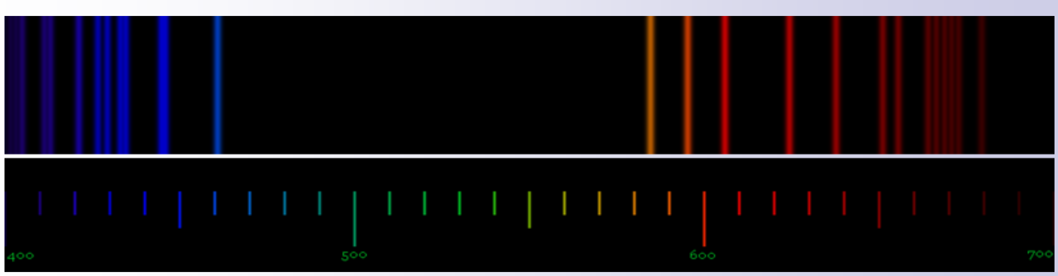
Am Americium , 95

Physical and chemical properties

Symbol	Am	Relative atomic mass	243.061
Atomic number	95	Melting point (°C)	948
Group	3	Boiling point (°C)	2606
Period	7	Specific heat (J/g.K)	0.033
Family	Actinoids	Oxidation numbers	6+,5+,4+,3+
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	151.3	Thermal conductivity (W/m.K)	10
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	14.4
Electronic configuration	$[Rn]5f^7 7s^2$	Heat of vaporization (kJ/mol)	238.5
Molar volume(cm3/ mole,273K)	17.78	Ist. ionization potential (kJ/mole)	578.2
Density (g/cm3)	13.670	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	18	rd. ionization 3 potentia (kJ/mol)	####

Curium Cm





Curium is a synthetic actinoid element . It is silvery-white, ductile and malleable.

The element was discovered after the irradiation of plutonium-239 with accelerated alpha particles in an orbital accelerator (cyclotron) in 1944.

The pure metal was prepared for the first time in 1951 through the reduction of curium fluoride with barium metal.

Curium-247 is the most stable isotope (half-life 16 million years).

Curium is chemically active. It is rapidly oxidized in air at normal temperatures and readily reacts with cold water and mineral acids to free hydrogen gas.

Curium is a dangerous radioactive source and, like other actinoids, in the case of absorption in the body it settles on bone tissue where its radiations act to destroy the bone marrow cells that produce red blood cells.

curium-244 (half-life 18 years) and curium-242 (half-life 163 days) are strong alpha emitters that generate thermal power during the process of decay. These isotopes are very suitable for utilization in radioisotope thermoelectric generators which are utilized as mobile sources of thermal energy in space stations and remote areas.

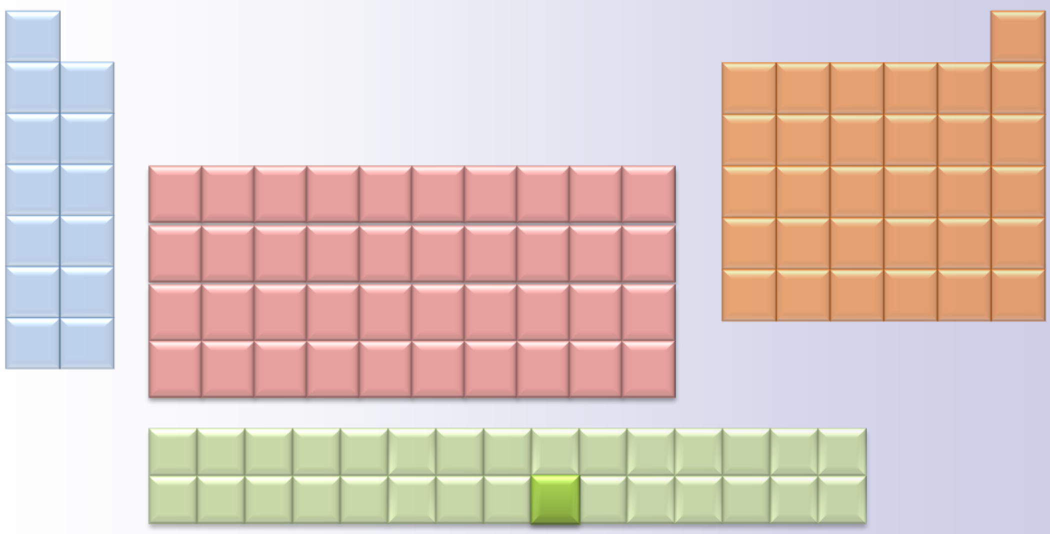
Curium is highly radioactive and its effect is cumulative in the living body. It finds its way to   bone tissue where its radiations act to destroy the bone marrow cells that produce red blood cells

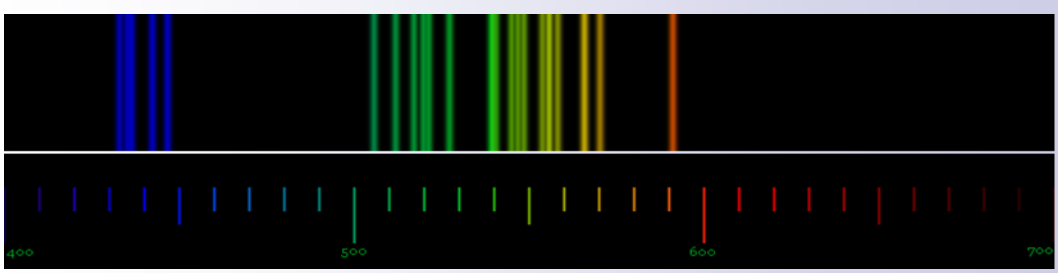
Cm Curium , 96

Physical and chemical properties

Symbol	Cm	Relative atomic mass	247
Atomic number	96	Melting point (ºC)	####
Group	3	Boiling point (ºC)	####
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	174	Thermal conductivity (W/m.K)	10
Crystal structure	####	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]5f^7 6d^1 7s^2$	Heat of vaporization (kJ/mol)	####
Molar volume(cm3/ mole,273K)	18.6	Ist. ionization potential (kJ/mole)	581
Density (g/cm3)	13.300	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	19	3rd. ionization potential (kJ/mol)	####

Berkelium Bk





Berkelium is a synthetic actinoid element discovered in 1949 and a sample of less than one microgram of the isotope berkelium-243 (half-life 4.6 hours) was artificially prepared by the irradiation of americium-241 with alpha particles in an orbital accelerator (cyclotron).

This was followed by successful preparation of a number of isotopes of the element with atomic masses ranging from 242 to 251, including berkelium-247 which is the most stable isotope (half-life 1380 years).

No pure sample of berkelium is available but it was possible to prepare a pure sample containing a few molecules of berkelium chloride in 1962.

Thus, berkelium is one of the rarest elements and not much is known about its properties or the nature of its compounds, and its uses are limited to pure scientific research.

Berkelium is speculated to be a silvery-white metallic element, chemically active, soluble in mineral acids and readily oxidized in air at normal temperatures.

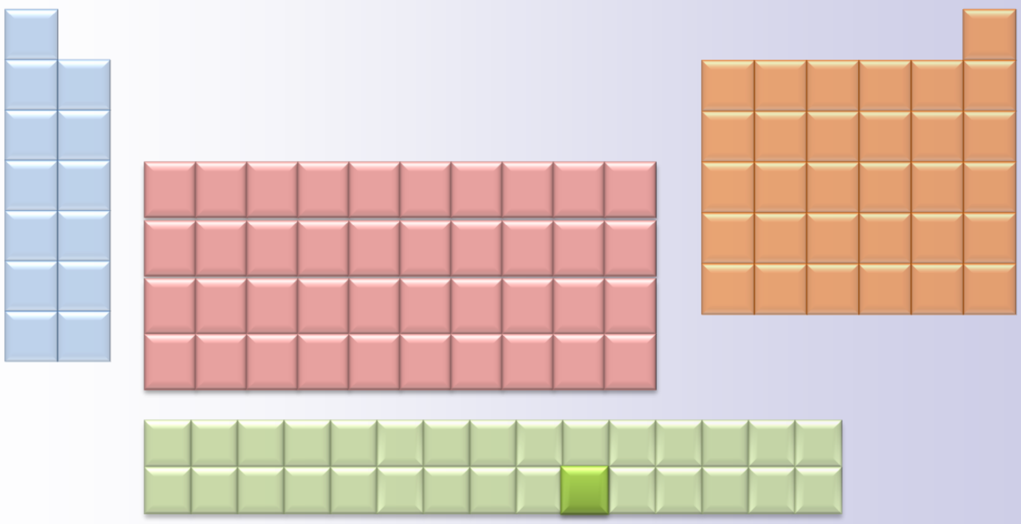
Although berkelium is one of the rarest elements, it represents a serious hazard .It is highly radioactive and it accumulates in bone tissue to destroy the bone marrow cells that produce red blood cells

Bk Berkelium , 97

Physical and chemical properties

Symbol	Bk	Relative atomic mass	247.070
Atomic number	97	Melting point (ºC)	####
Group	3	Boiling point (ºC)	####
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3,+4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	170	Thermal conductivity (W/m.K)	10
Crystal structure	####	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]5f^9 7s^2$	Heat of vaporization (kJ/mol)	####
Molar volume(cm3/ mole,273K)	16.70	Ist. ionization potential (kJ/mole)	601
Density (g/cm3)	14.790	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	19	3rd. ionization potential (kJ/mol)	####

Californium Cf



Californium is a synthetic actinoid element and the 6th transuranium element to be discovered.

The isotope californium-245 (half-life 44 minutes) was artificially prepared in 1950 by bombarding curium-242 with alpha particles (helium nuclei) in an orbital accelerator (cyclotron).

The element is now synthesized through different neutron capture and radioactive decay routes and is also obtained as a by-product of plutonium production.

Californium is characterized by a high radiation activity and its principally used as a source of neutrons. One microgram of californium-252 isotope (half-life 2.6 years) radiates 170 million neutrons per minute. This isotope is used as a starter in nuclear reactors and as a portable neutron source in research studies. It is used in radiotherapy and in equipments of routine test for glitches and holes in aircraft parts and turbines. It is also used in technical equipment for remote exploration of precious metals, oil and ground water.

Californium-251 which is prepared by neutron irradiation of uranium is the most stable isotope of the element (half-life 900 years). It is highly toxic and hazardous and is characterized by a small critical mass (5 kg) which is considered favorable for nuclear warfare.

In case of ingestion (with food or drinks) californium will be deposited on bones and liver tissues where a number of isotopes such as californium-249 and californium-251 act as local sources of ionizing radiation (alpha particles) that usually causes cancer.

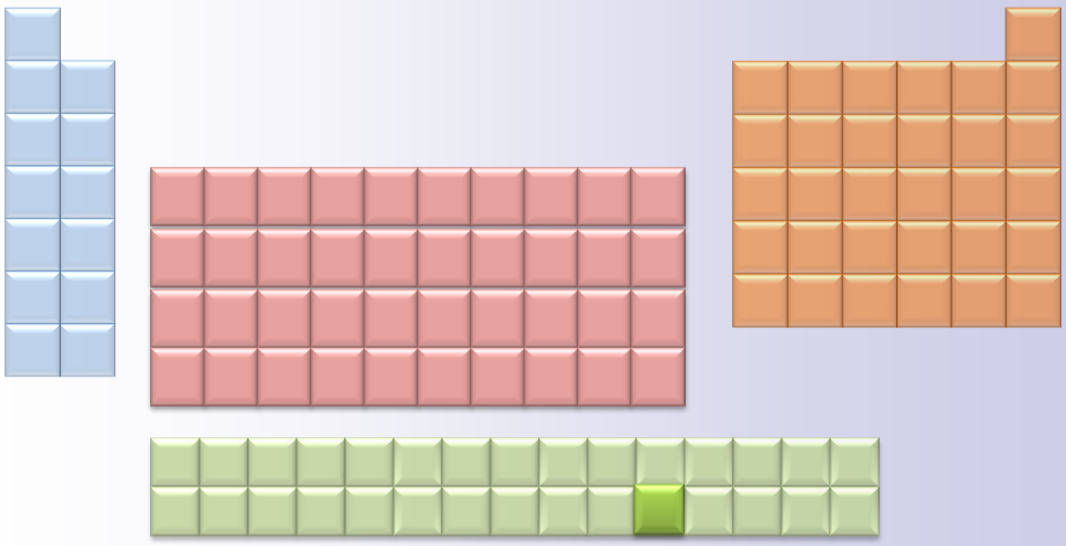
Californium is a serious health hazard and is a strong emitter of the destructive alpha radiation

Cf Californium , 98

Physical and chemical properties

Symbol	Cf	Relative atomic mass	251.08
Atomic number	98	Melting point (°C)	####
Group	3	Boiling point (°C)	####
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	186	Thermal conductivity (W/m.K)	10
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]5f^{10}7s^2$	Heat of vaporization (kJ/mol)	####
Molar volume(cm3/ mole,273K)	####	Ist. ionization potential (kJ/mole)	607.86
Density (g/cm3)	####	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	20	3rd. ionization potential (kJ/mol)	####

Einsteinium Es



Einsteinium is a synthetic actinoid element discovered in the remnants of the first thermonuclear bomb (hydrogen bomb) in 1952 when the isotope einsteinium-253 (half-life about 20 days) was isolated and studied.

Afterwards a number of isotopes with atomic masses ranging from 240.07 to 258.1 atomic mass units were prepared through irradiation of plutonium with neutrons.

The isotope einsteinium-252 (half-life 472 days) is the most stable isotope. No other isotope is found with a half-life over 30 minutes.

A number of einsteinium compounds including the chloride, bromide, iodide and the oxide have been successfully prepared.

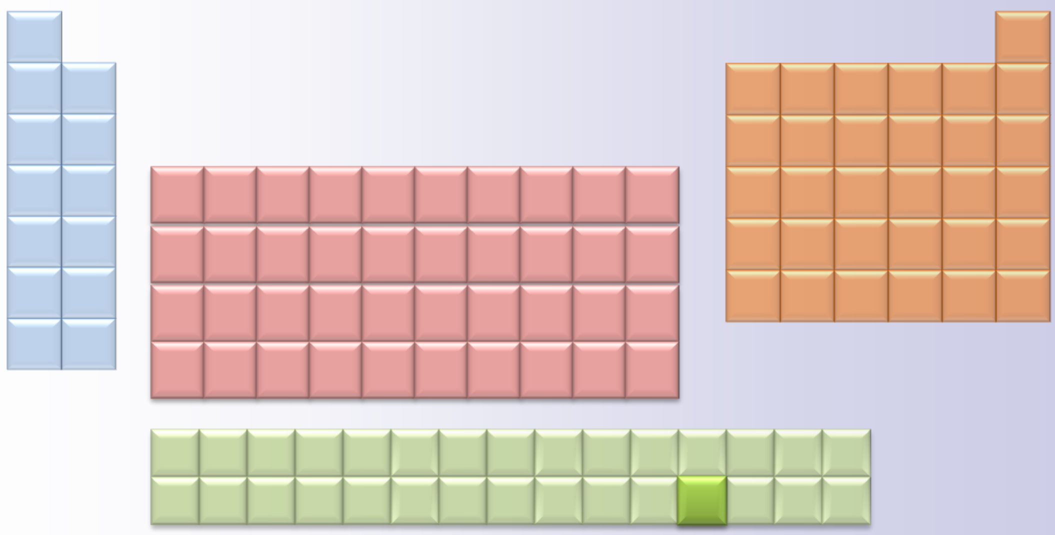
Einsteinium was discovered in the remnants of the first hydrogen bomb in 1952.

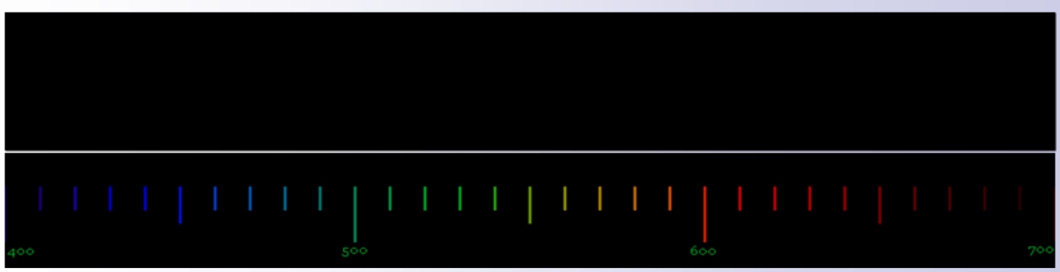
Es Einsteinium , 99

Physical and chemical properties

Symbol	Es	Relative atomic mass	252.083
Atomic number	99	Melting point (°C)	####
Group	3	Boiling point (°C)	####
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	186	Thermal conductivity (W/m.K)	10
Crystal structure	####	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]5f^{11}7s^{2}$	Heat of vaporization (kJ/mol)	####
Molar volume (cm3/mole,273K)	####	Ist. ionization potential (kJ/mole)	619.44
Density (g/cm3)	####	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	17	3rd. ionization potential (kJ/mol)	####

Fermium Fm





Fermium is a synthetic actinoid element discovered and isolated in 1952 from the remnants of the first thermonuclear explosion (hydrogen bomb).

It was concluded that the isotope fermium-255 was formed from the union of 17 neutrons with uranium-238 in a nuclear transformation facilitated by the drastic conditions (pressure and heat) of the thermonuclear reaction.

Afterwards it was possible to prepare a number of isotopes of the element by bombarding lighter elements (principally uranium and plutonium) with neutrons in nuclear reactors.

Fermium-257 (half-life about 100 days) is the most stable isotope of element.

As a result of the scarcity of quantities available and the short lives of all isotopes, there are no special applications of fermium except in the fields of pure scientific research.

Fermium-257 with a half-life of about 100 days is the longest lived isotope of Fermium

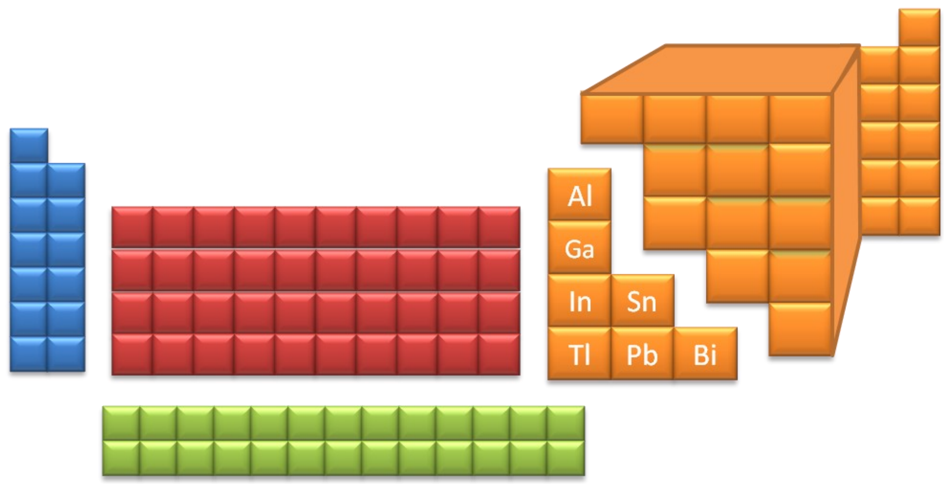
Fm Fermium , 100

Physical and chemical properties

Symbol	Fm	Relative atomic mass	257.095
Atomic number	100	Melting point (ºC)	####
Group	3	Boiling point (ºC)	####
Period	7	Specific heat (J/g.K)	####
Family	Actinoids	Oxidation numbers	+3, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.3
Atomic radius (pm)	####	Thermal conductivity (W/m.K)	10
Crystal structure	####	Heat of fusion (kJ/mol)	####
Electronic configuration	$[Rn]5f^{12}7s^{2}$	Heat of vaporization (kJ/mol)	####
Molar volume(cm3/ mole,273K)	####	Ist. ionization potential (kJ/mole)	627.16
Density (g/cm3)	####	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	19	3rd. ionization potential (kJ/mol)	####

Chapter 6

POOR METALS

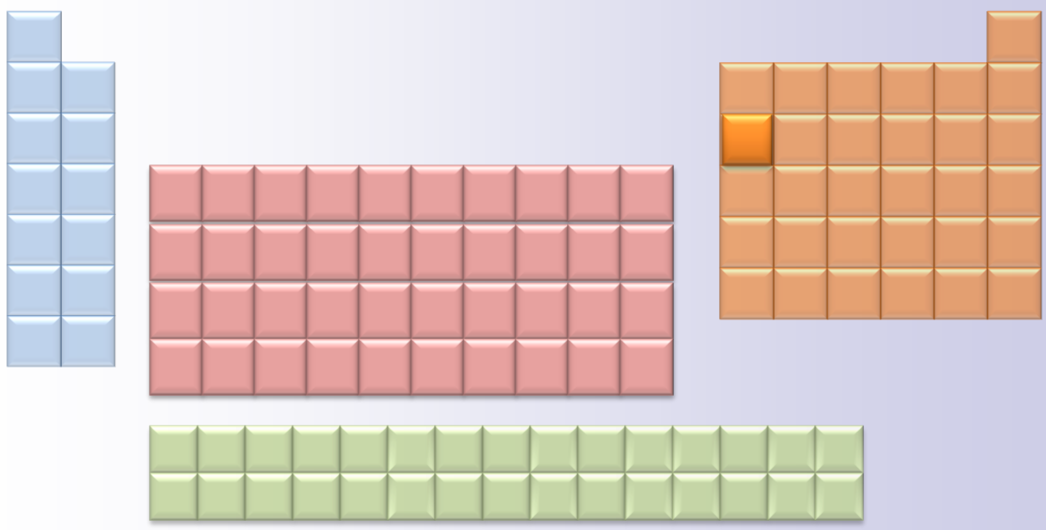


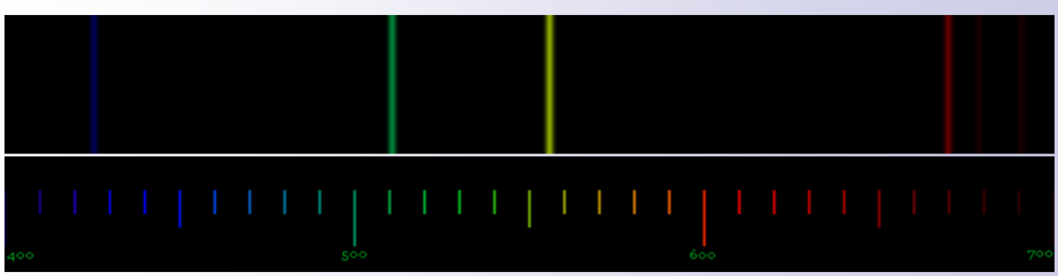
Poor metals, also called 'post-transition metals' or 'other metals' are the seven elements to the left of the transition metals in the periodic table.

Poor metals differ from transition elements in their electronic distribution of atoms and in being softer and less electropositive. Otherwise, this group acquires all the metallic properties of the transition metals.

The poor metals group includes aluminum, gallium, indium, tin, thallium, lead and bismuth elements.

Aluminum Al





Aluminum is a silvery metal characterized by lightweight and high tensile strength. It is found (only in combination with other elements) in sandstone and clay representing about 8% of the mass of the earth's crust (this is the highest proportion of a metal).

Aluminum is commercially produced through the electrolysis of bauxite ore in Hall cell where its purity reaches 99%.

Aluminum is very reactive and readily dissolves in solutions of alkalis and mineral acids (except concentrated nitric acid). It reacts violently with a number of metal oxides which are reduced to the corresponding elements, and the molten metal reacts vigorously with water. However, aluminum is characterized by high resistance to weathering and erosion due to the formation of a tough oxide coating that forms on its surface.

Bauxite
(A mixture of aluminum oxide and hydroxide)

Ruby crystal
A form of corundum
(the red color is due to chromium impurities)

Aluminum ranks second (after iron) in the world commercial production of metals. Main commercial uses include production of strong, light weight and corrosion- resistant alloys with copper and a number of metals, and the manufacture of electric cables and aluminum mirrors.

Unlike most metals aluminum has no aroma and is extensively used in cooking utensils and food packaging.

The exothermic reaction of aluminum filings with iron oxide (The thermite reaction) yields liquid iron and temperatures reaching 3000 °C. This process is utilized in metal cutting and welding operations and is also used to provide the energy for the thrust that enables space shuttles to take off.

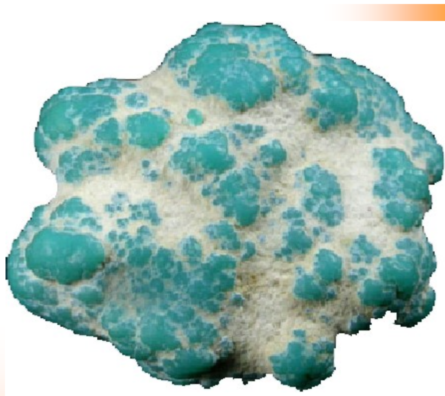
Al Aluminum , 13

Important compounds of aluminum include the natural rigid oxide or corundum mineral which forms a number of precious stones including ruby which is used in ornamental and laser industries.

Other important natural compounds are topaz gemstones (silicate minerals of aluminum and fluorine) and turquoise gemstone which is a form of aluminum phosphate that acquires brilliant colors due to the presence of copper and traces of iron.

The rare tanzanite gemstone is another natural aluminum compound. It is characterized by a bright purple-blue color and is found only in the foothills of the Kilimanjaro Mountain in Tanzania.

Topaz
(silicates of aluminum and fluorine)
- Brazil -



Turquoise
(Aluminum phosphate)
- Arizona -

Aluminum is a toxic element and is a serious pollutant of air, water and soil. It can easily be absorbed in the body where it accumulates in different organs. Its effects are particularly serious when exposure is heavy or prolonged and adverse effects are recognized when the element is deposited in organs like kidneys or brain where it acts as a neurotoxin.

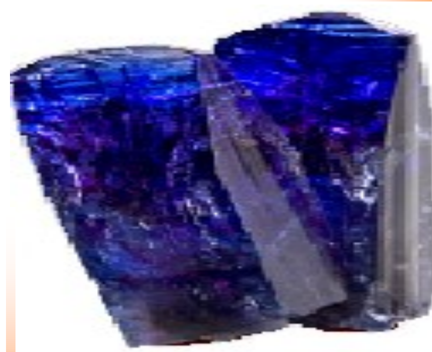
Aluminum is found in air, soil and water(acid rain leeches aluminum out of soil and into drinking water) cooking ware and foil are major sources of aluminum contamination.

Other sources of the element are processed food, drugs and medical preparations, products of personal hygiene and deodorants (which commonly contain up to 20% of aluminum chlorohydrate).

Al Aluminum , 13

Aluminum sulfate (alum) is poisonous and has been widely used in the purification of urban water and treatment of wastewater. Its us in food industry and drinking water has already been condemned all over the world.

On the other hand trace amounts of aluminum are needed in the body and have to be supplied from natural organic sources to activate a number of vital enzyme systems.



Tanzanite

(Calcium aluminum silicates)

Mineral ore locations

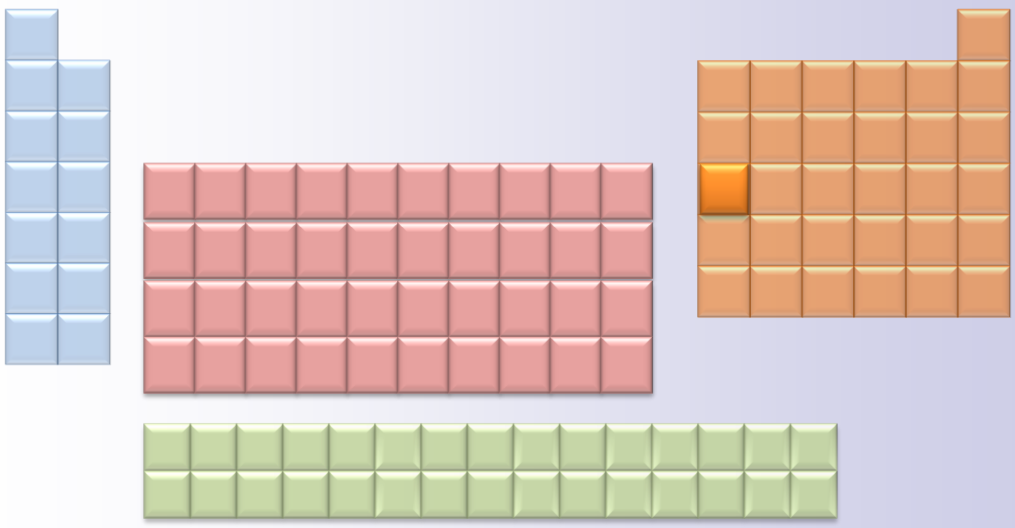
● Bauxite

Al Aluminum , 13

Physical and chemical properties

Symbol	Al	Relative atomic mass	26.982
Atomic number	13	Melting point (°C)	660.35
Group	13	Boiling point (°C)	2466.85
Period	3	Specific heat (J/g.K)	0.897
Family	Poor metals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.61
Atomic radius (pm)	143.1	Thermal conductivity (W/m.K)	237
Crystal structure	Face centered Cubic	Heat of fusion (kJ/mol)	10.67
Electronic configuration	$[Ne]3S^23P^1$	Heat of vaporization (kJ/mol)	293.72
Molar volume(cm3/ mole,273K)	10.00	Ist. ionization potential (kJ/mole)	577.4
Density (g/cm3)	2.698	2nd.Ionization potential (kJ/mole)	1816.6
Number of isotopes	15	3rd. ionization potential (kJ/mol)	2744.6

Gallium Ga



Gallium is a soft silvery metallic element and one of five metals that can be found in the liquid state near room temperature (together with mercury, cesium, rubidium and francium).

Gallium is a poor conductor of electricity and has an unusual property of expansion on freezing. It is distinguished by the largest liquid temperature range of any metal and by a low vapor pressure even at high temperatures. It is widely used in high- temperature thermometers.

The element occurs naturally as traces in coal, diaspore, bauxite, germanite, and sphalerite ores. It is commercially obained as a by-product of aluminum and zinc smelting processes and flue dusts from burning coal.

Gallium metal is not affected by oxygen at normal temperatures. However, it is rapidly attacked by the halogens and by dilute hydrochloric acid. It dissolves slowly in alkalis with evolution of hydrogen gas.

By virtue of being commercially available in a high pure form (99.9999 +), gallium became one of the most important elements in the field of electronic industry.

Thus, semiconductors are produced from alloys with aluminum and gold and from gallium nitride and gallium arsenide. The latter is capable of converting electricity directly into coherent light. It is used in semiconductors for different applications including laser diodes and solar panels.

Some gallium compounds such as gallium nitrate and gallium citrate are used pharmaceutical preparations for treatment of a number of diseases.

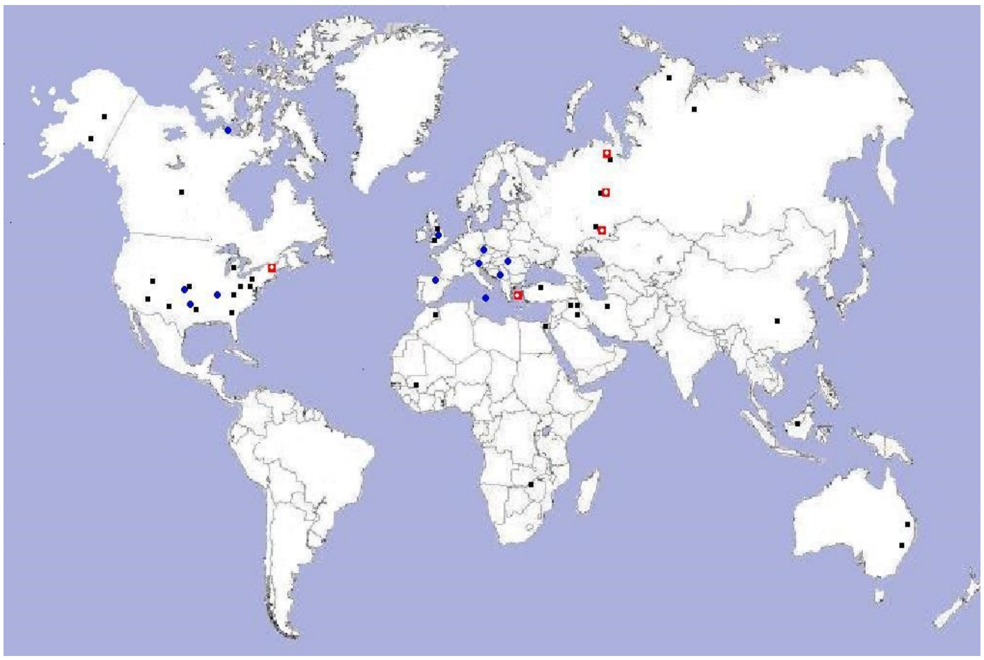
Some radioisotopes such as gallium-67 which is an emitter of gamma radiation with a half-life within 78 hours is applied in the field of nuclear medicine.

Gallium is used as a component in low-melting alloys (an alloy of 24% indium - 76% gallium is liquid at room temperature). Such alloys are suitable for use in medical thermometers as non-toxic substitutes for mercury

Gallium metal

Ga Gallium , 31

Mineral ore locations



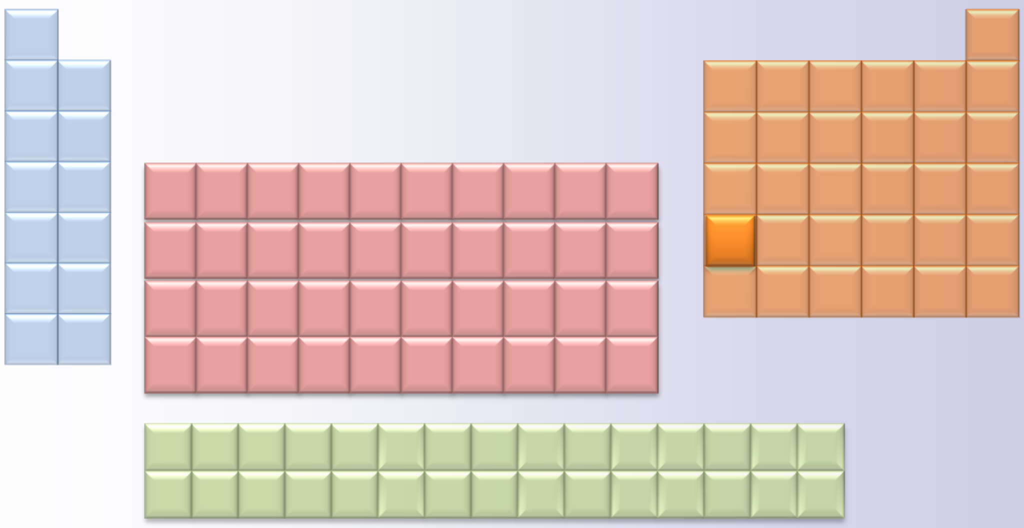
Diaspore   Sphalerite   Coal

Ga Gallium , 31

Physical and chemical properties

Symbol	Ga	Relative atomic mass	69.723
Atomic number	31	Melting point (°C)	29.78
Group	13	Boiling point (°C)	2402
Period	4	Specific heat (J/g.K)	0.371
Family	Poor metals	Oxidation numbers	+2,+3
Physical state(20°C)	solid	Electronegativity (pouling)	1.81
Atomic radius (pm)	133.2	Thermal conductivity (W/m.K)	40.6
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	5.59
Electronic configuration	$[Ar]3d^{10}4S^{2}4P^{1}$	Heat of vaporization (kJ/mol)	256.1
Molar volume(cm3/ mole,273K)	11.81	Ist. ionization potential (kJ/mole)	578.8
Density (g/cm3)	5.907	2nd.Ionization potential (kJ/mole)	1979
Number of isotopes	24	3rd. ionization potential (kJ/mol)	2963

Indium In



Indium is a soft, silvery-white and shiny metal and one of the rarest elements in nature.

It is found naturally – as traces- associated with copper, zinc and lead ores and is usually obtained, as a by-product, from zinc mining operations (British Columbia in Canada being the major commercial source of the element).

Indium is not attacked in normal conditions and is oxidized in air only at high temperatures.

The metal is used to make alloys with low melting point temperature (an alloy of 24% indium - 76% gallium is liquid at room temperature).

Indium metal

Indium wire

(Indium is ductile and malleable)

Indium tin oxide (ITO) is an important ingredient used in the production of transparent electrodes for liquid crystal screens (LCD) of televisions and computers.

Indium is used with gallium phosphide and gallium nitride in laser manufacture and in light emitting diodes. It is also used in metal plating and glass coating to make weather-proof mirrors and as a component in some lead-free solders.

Indium compounds with antimony (antimonides), phosphorus (phosphides) and with nitrogen (nitrides) are all important semiconductor materials utilized in the field of electronic industry.

Indium radioactive isotopes with relatively short half -lives are commonly used for diagnostic purposes in nuclear medicine.

The isotope indium-113^m (half-life 99.8 minutes) is obtained by nuclear excitation of indium by X-rays for clinical imaging applications.

In Indium , 49

Indium-111 (half-life 2.8 days) is incorporated in white blood cells to be used as an imaging agent for tracing and localizing tumors and other bodies (Indium - 111 leukocyte scanning).

Silver-indium-cadmium alloys containing 15% indium are commonly used in control rod material for pressurized water reactors.

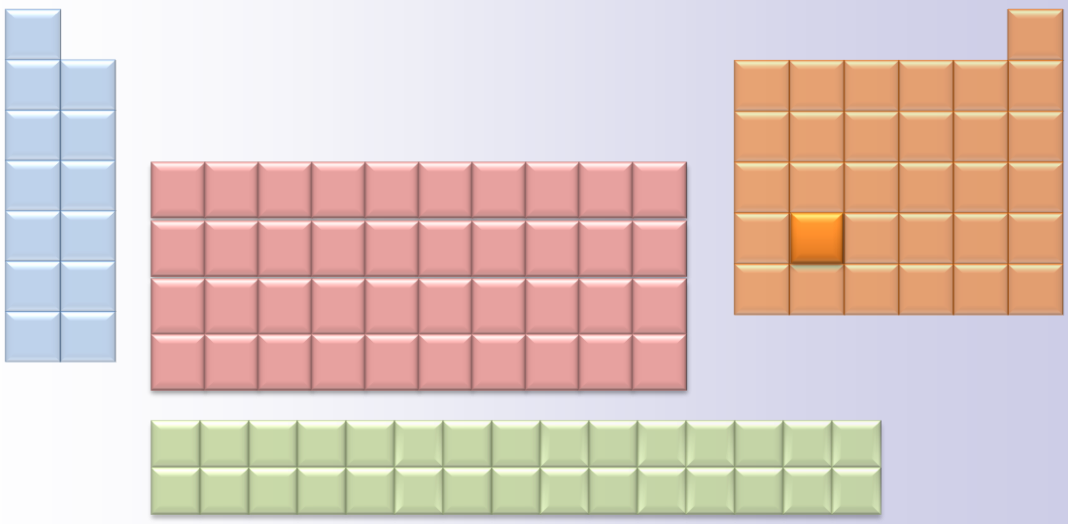
Claims about indium's benefits on health and alleged characteristics as a factor that elevate immune activity and reduce the severity of a number of conditions are not supported by medical authorities who usually regard all indium compounds as highly toxic materials that may cause serious damage in the heart, kidney and liver tissues.

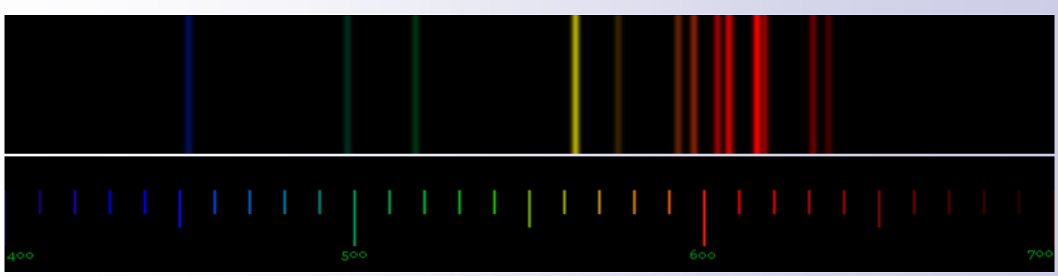
In Indium , 49

Physical and chemical properties

Symbol	In	Relative atomic mass	114.818
Atomic number	49	Melting point (ºC)	156.17
Group	13	Boiling point (ºC)	2079
Period	5	Specific heat (J/g.K)	0.233
Family	Poor metals	Oxidation numbers	+1, +2, +3
Physical state(20°C)	solid	Electronegativity (pouling)	1.78
Atomic radius (pm)	162.6	Thermal conductivity (W/m.K)	81.6
Crystal structure	Tetragonal	Heat of fusion (kJ/mol)	3.27
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{1}$	Heat of vaporization (kJ/mol)	226.4
Molar volume(cm3/ mole,273K)	15.71	Ist. ionization potential (kJ/mole)	558.3
Density (g/cm3)	7.310	2nd.Ionization potential (kJ/mole)	1820.6
Number of isotopes	59	rd. ionization 3 potential (kJ/mol)	2704

Tin Sn





Tin is a bright, silvery-white metal, known and used since ancient history. It is ductile and moderately malleable.

The element is primarily obtained from cassiterite ore (tin oxide) and is usually extracted by roasting the mineral with carbon (cock).

Tin is resistant to corrosion in water, but is attacked by concentrated acids, acid salts and bases.

The element exists in two allotropic forms: White tin (or β form) is the normal form of the metallic element and is stable at normal temperatures. Below13.2°C tin will gradually lose its metallic properties and change to gray tin or the α-form. This α-β transformation could be inhibited by addition of trace amounts of antimony and bismuth.

Tin is utilized as a protective coating on other metals, particularly on iron and steel (Traditional tin cans are the most familiar example).

The metal is used in the manufacture of a number of alloys, the most important being the historical bronze alloy (an alloy of tin with copper).

Other alloys of tin includes soft solder (with lead) and pewter (with lead and some other metals like copper, antimony and bismuth)

Tin salts are sprayed on glass to obtain electrically conductive coatings. Tin chloride is applied as an oxidizing agent and as a color mordant, and tin oxide is used in metal and glass finishing.

Tin metal is characterized by a highly crystalline structure and a characteristic cracking sound (*tin cry*) is heard on bending a bar of the metal.

Cassiterite

- Sichuan, China -

Sn Tin , 50

Mineral ore locations

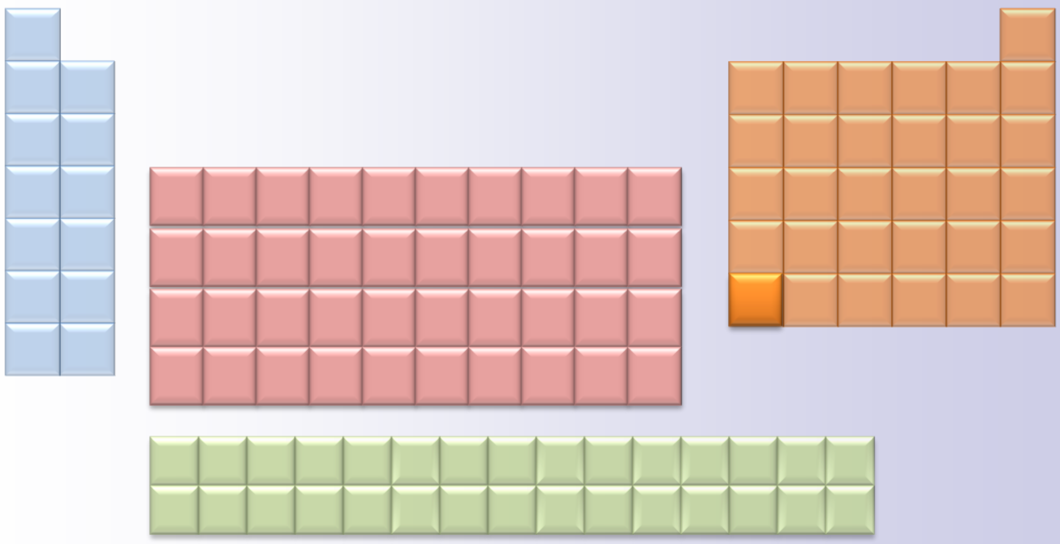
- Cassiterite

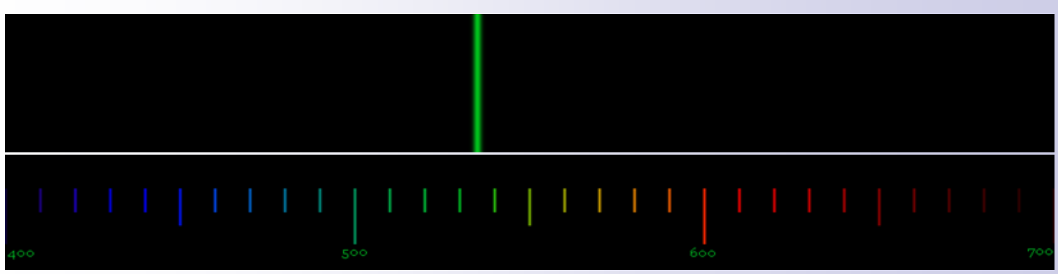
Sn Tin , 50

Physical and chemical properties

Symbol	Sn	Relative atomic mass	118.710
Atomic number	50	Melting point (°C)	232
Group	14	Boiling point (°C)	2269
Period	5	Specific heat (J/g.K)	0.228
Family	Poor metals	Oxidation numbers	+2, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.96
Atomic radius (pm)	140.5	Thermal conductivity(W/m.K)	66.6
Crystal structure	Tetragonal	Heat of fusion (kJ/mol)	7.20
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{2}$	Heat of vaporization (kJ/mol)	293.4
Molar volume(cm3/ mole,273K)	16.24	Ist. ionization potential (kJ/mole)	708.6
Density (g/cm3)	7.310	2nd.Ionization potential (kJ/mole)	1411.8
Number of isotopes	37	3rd. ionization potential (kJ/mol)	2943.0

Thallium Tl





Thallium is a bluish - gray, soft, ductile and malleable metal occurring naturally-in a chemically combined form- along with copper and silver ores.

The metal is usually recovered from the stacks of lead and tin smelters and from pyrite wastes in sulfuric acid processing factories.

Thallium is isolated from other metals by chemical precipitation procedures and is further purified by electrolysis to isolate contaminants which usually include arsenic, cadmium, germanium, lead, zinc and selenium elements.

Thallium is chemically active and quickly loses its metallic luster in the air to develop a heavy layer of the oxide. It dissolves in water and mineral acids and readily combines with sulfur, selenium, phosphorus, arsenic, antimony and the halogens.

Most of the commercial product of thallium is used in the manufacture of electronic components, optical lenses, semiconductor materials, low temperature thermometers, and green fireworks.

The element and its compounds are usually very toxic and despite the World Health Organization recommendation against its use in 1973 , thallium is still being used in many countries.

Thallium sulfate is a serious pollution factor. It is tasteless and odorless and is a suspected carcinogen. Its applications as a pesticide,
insecticide and as a rat poison have lead to contamination of food and herbal medications.

Thallium is similar in size to potassium and readily accumulates in tissues with high potassium concentrations such as muscle, heart, and central and peripheral nerve tissue.

On the other hand ,thallium-201 is a radioactive isotope with a short half-life (73 hours) and is commonly used in radio- diagnosis.

Thallium metal

Tl Thallium , 81

Mineral ore locations

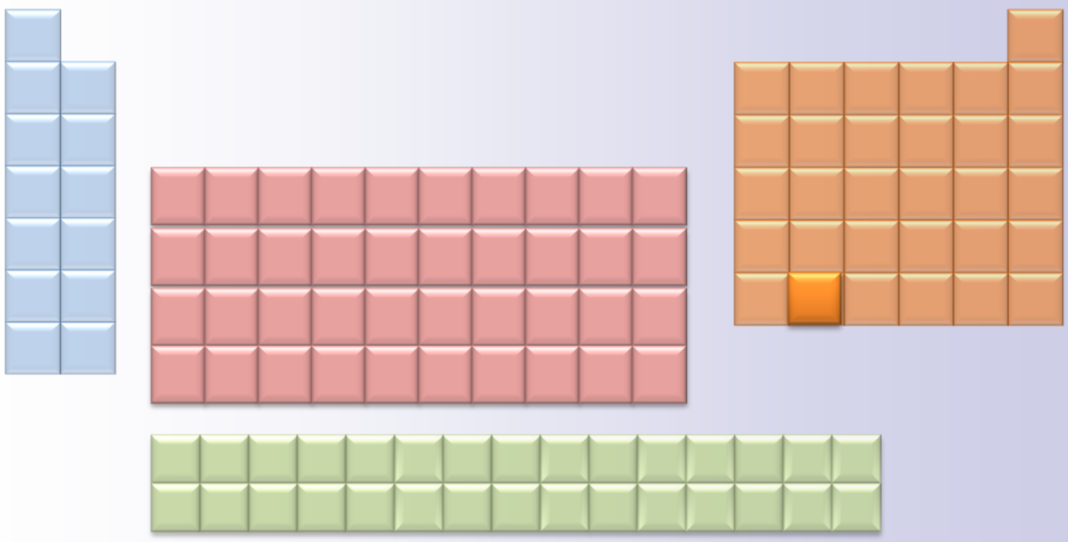
• Pyrite

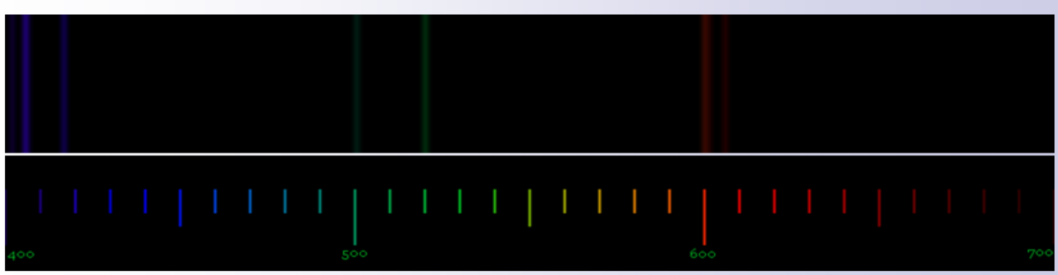
Tl Thallium , 81

Physical and chemical properties

Symbol	Tl	Relative atomic mass	204.383
Atomic number	81	Melting point (°C)	303.45
Group	13	Boiling point (°C)	1456
Period	6	Specific heat (J/g.K)	0.129
Family	Poor metals	Oxidation numbers	+1, +3
Physical state(20°C)	solid	Electronegativity (pouling)	1.62
Atomic radius (pm)	170.4	Thermal conductivity (W/m.K)	46.1
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	4.31
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{2}6P^{1}$	Heat of vaporization (kJ/mol)	162.1
Molar volume(cm3/ mole,273K)	17.24	Ist. ionization potential (kJ/mole)	589.36
Density (g/cm3)	11.850	2nd.Ionization potential (kJ/mole)	1971.02
Number of isotopes	41	3rd. ionization potential (kJ/mol)	2878.18

Lead Pb





Lead is a soft, silvery- gray, ductile and malleable metal known and used since ancient history.

The metal occurs naturally in the free elemental form in limited areas and in weak concentrations. It is identified as a mixture of four stable isotopes representing the final output of nuclear transformation series of the natural radioactive elements (uranium, actinium and thorium series).

Mineral sources of lead are cerussite (lead carbonate), anglesite (lead sulfate) and galena (lead sulfide). The latter represents the principal commercial source of the element.

Galena crystals
-Missouri, USA

Lead metallurgical operations usually involve oxidation of ores (roasting) followed by reduction of the oxide (smelting) with carbon (coke) and finally electrolysis for further purification.

Lead ores usually contain impurities of valuable metals such as gold, silver and bismuth. These elements are commercially recovered after roasting and smelting operations are complete.

Lead is highly resistant to corrosion and is only slightly affected by most mineral acids. However, it dissolves in nitric acid and it loses resistance with increasing temperature or in the presence of oxygen to interact even with water.

Lead is used in solder and other metal alloys. It is used in ammunition, accumulators and in coating electric cables (lead is a bad conductor of electricity).

Lead is also used as a buffer for voice and the element is the best shield for X-rays and nuclear radiation.

Lead and its compounds are toxic, and the element acquires a cumulative effect in the human body. It is considered as one of the major threats in the environment as it acts to destroy the nerve cells especially in children.

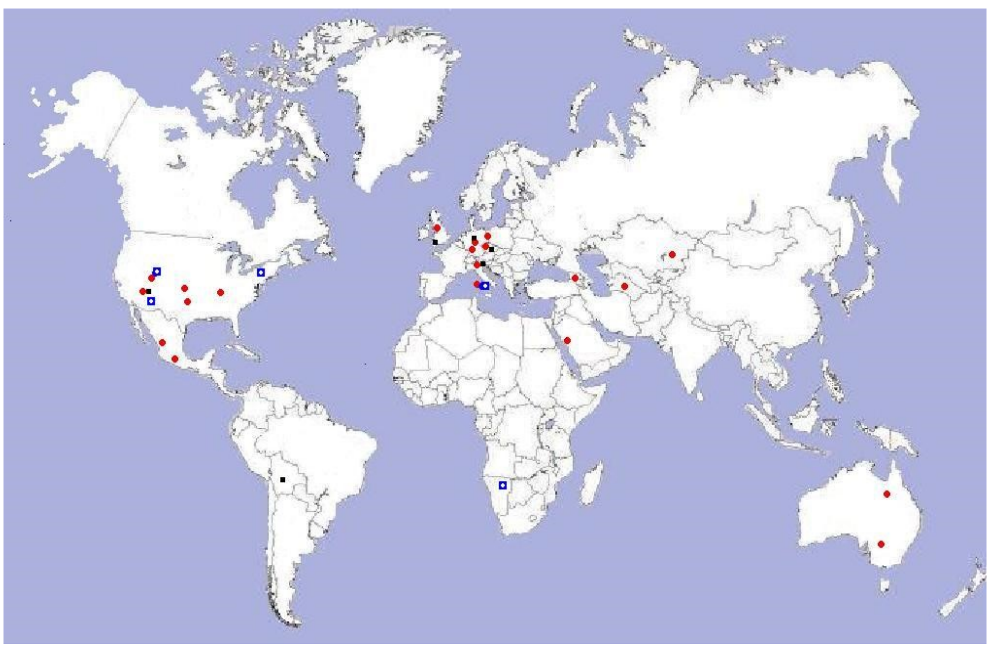
Pb Lead , 82

Stringent laws are now initiated in most countries to limit or completely prohibit industrial products containing lead. Lead and lead compounds are being replaced by materials such as plastics, aluminum, iron, tin, bismuth and silver.

Practices which are now fully or partially prohibited include using lead in drinking-water systems, pottery, children toys and plastic products for food packaging.

Other important measures that helped to reduce lead emission in the atmosphere include the replacement of ethyl lead additive used as an antiknock in gasoline by methyl tertiary butyl ether (MTBE) and the replacement of chrome yellow (lead chromate) in paints with cadmium yellow (cadmium sulfide).

Mineral ore locations



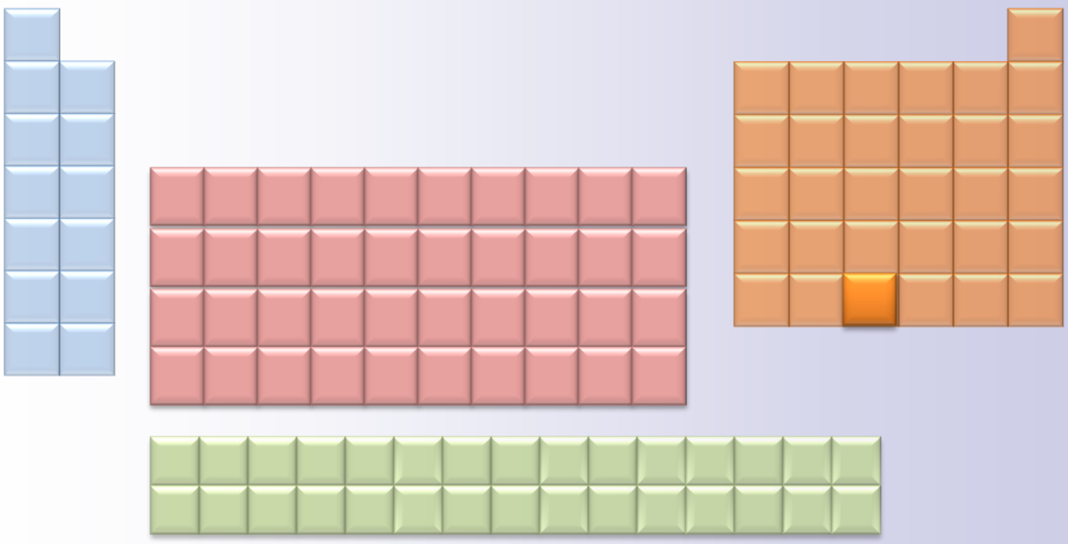
▫ Anglesite ▪ Ournonite • Galena

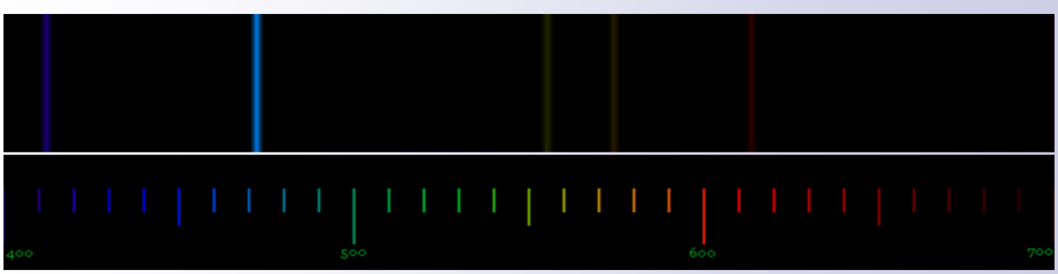
Pb Lead , 82

Physical and chemical properties

Symbol	Pb	Relative atomic mass	207.19
Atomic number	82	Melting point (ºC)	327.5
Group	4A	Boiling point (ºC)	1739.85
Period	6	Specific heat (J/g.K)	0.129
Family	Poor metals	Oxidation numbers	+2 +4
Physical state(20° C)	solid	Electronegativity (pouling)	2.33
Atomic radius (pm)	175.0	Thermal conductivity (W/m.K)	35.3
Crystal structure	FaceCentered Cubic	Heat of fusion (kJ/mol)	5.121
Electronic configuration	$[Xe]4f^{14}5d^{10}6s^2 6p^2$	Heat of vaporization (kJ/mol)	179.4
Molar volume (cm3/mole,273K)	18.26	Ist. ionization potential(kJ/mole)	715.5
Density (g/cm3)	11.350	2nd.Ionization potential(kJ/mole)	1450.4
Number of isotopes	41	rd. ionization 3 potential (kJ/mol)	3081.5

Bismuth Bi





Bismuth is a reddish-white, crystalline element that occurs, as traces of the free element, in the company of arsenic and tellurium in a number of ares. It also occurs- chemically combined- principally in bismuthinite (bismuth sulfide) and bismite (bismuth oxide) minerals along with copper, tin, lead, silver and gold ores.

These metal ores are the major commercial sources of the element which is usually obtained as a-by product of mining and refining processes.

Bismuth is the heaviest non-radioactive natural element and is characterized by the highest atomic number and the largest atomic mass of a stable element.

Bismuth is stable in air and is not affected by oxygen or water but dissolves in concentrated mineral acids. It has unique magnetic properties and is distinguished by the lowest thermal conductivity of an element. It possesses an unusual characteristic of expanding in cooling which is a favorable property for alloy making.

Bismuth is alloyed with manganese to make permanent magnets with high magnetic coercivity and is mixed with cadmium, lead and zinc to make alloys with low melting point temperatures (usually less than 50°C) for special purposes such as fire alarms and other safety device techniques.

Bismite

(Bismuth oxide)

Bismuth

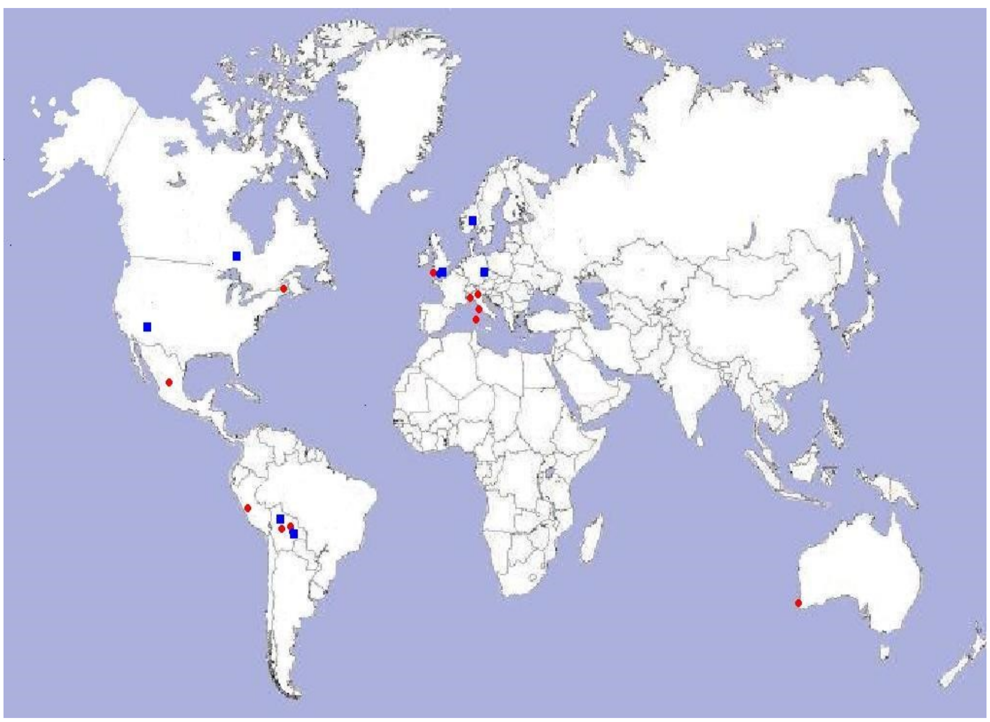
Bi Bismuth , 83

Elemental bismuth is non-toxic and is increasingly being used as a substitute for lead in metal alloys, especially for lead-free solders to be used in food processing equipment and water pipes.

On the other hand, bismuth compounds are usually toxic, but by virtue of their insolubility in aqueous media they find a number of commercial uses in the field of pharmaceutical products and cosmetics.

Although bismuth-209 is considered (and is mentioned above) as the most heavy stable isotope, reports of some recent research studies show that it is an alpha emitter with a half-life of about 20 trillion years.

Mineral ore locations



■ Native Bismuth ● Bismuthinite

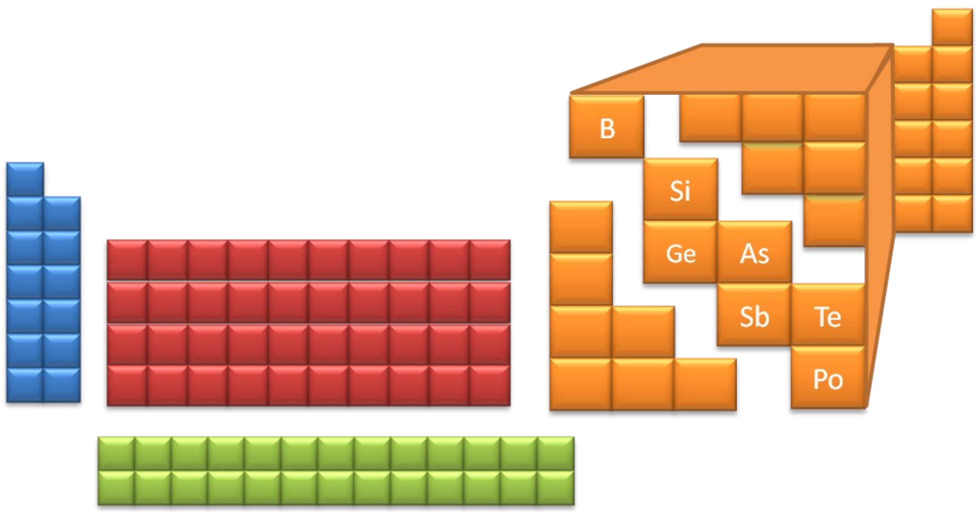
Bi Bismuth , 83

Physical and chemical properties

Symbol	Bi	Relative atomic mass	208.980
Atomic number	83	Melting point (°C)	327.5
Group	15	Boiling point (°C)	1739
Period	6	Specific heat (J/g.K)	0.129
Family	Poor metals	Oxidation numbers	+4 +2
Physical state(20°C)	solid	Electronegativity (pouling)	2.33
Atomic radius (pm)	155	Thermal conductivity (W/m.K)	35.3
Crystal structure	Rhombohedral	Heat of fusion (kJ/mol)	5.121
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{2}6P^{3}$	Heat of vaporization (kJ/mol)	179.4
Molar volume(cm3/mole,273K)	21.44	Ist. ionization potential (kJ/mole)	715.60
Density (g/cm3)	9.747	2nd.Ionization potential (kJ/mole)	1450.40
Number of isotopes	35	3rd. ionization potential (kJ/mol)	3081.50

Chapter 7

SEMIMETALS



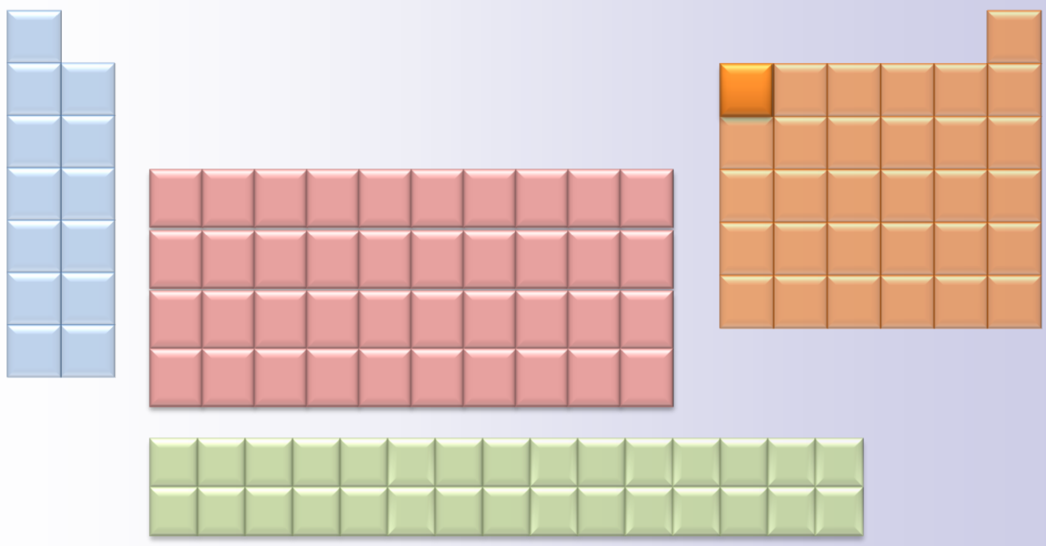
Semimetals or metalloids are the seven elements occupying the zigzag line between metals and nonmetals in the periodic table. These elements start with boron and end with polonium and acquire both metallic and nonmetallic characters.

Semimetals are distinguished by usually being semiconductors (the most important in this respect are silicon and germanium).

A unique chemical behavior of semimetals is the ability of their oxides to behave both as acids and bases.

Semimetals are boron, silicon, germanium, arsenic, antimony, tellurium, and polonium.

Boron B



Boron is a hard and brittle semimetal occurring naturally (chemically combined) in borax (sodium tetraborate) and boric acid that represent its major commercial source. It is also extracted from kernite (sodium borate) and colemanite (calcium borate) ores. The pure element is industrially obtained through the electrolysis of the oxide or by reducing boron halides with hydrogen at high temperatures.

Boron is found in a number of allotropic forms but mostly as the amorphous brown form or the black and hard crystalline form.

Boron crystals

Kernite
(Sodium borate hydroxide)

As would be expected from its position in the periodic table (at the top of the group) boron tends to show nonmetallic rather than metallic behavior. It is relatively inert and is only slightly affected by strong acids and is slowly oxidized in air.

Boron forms significantly hard compounds with carbon and nitrogen (carbides and nitrides). On the other hand, boron hydrides (boranes) are unstable materials that spontaneously explode in humid air.

Sodium perborate is used in bleaches, detergents and disinfectants, and zinc borate is a fire retardant commonly added to the components in the manufacture of plastics, rubber and cotton products.

B Boron , 5

Boric acid is a natural crystalline white solid distinguished by a strong anti-bacterial property and widely used as an antiseptic, insecticide and as a preservative. It is also applied as a fire retardant.

Because of the high ability to absorb neutrons, boron is used in the manufacture of neutron shields as well as in control rods which are used to maintain a steady nuclear chain reaction inside nuclear reactors.

Boron is a vital element for life and traces of the element are essential for normal growth of both plants and animals

Traces of boron are added to high-purity silicon and a number of semiconductors to control the electrical characteristics (doping) . It is also added to reactor-grade graphite which is used as a moderator in some nuclear reactors.

Borax
(Sodium tetraborate)
- California -

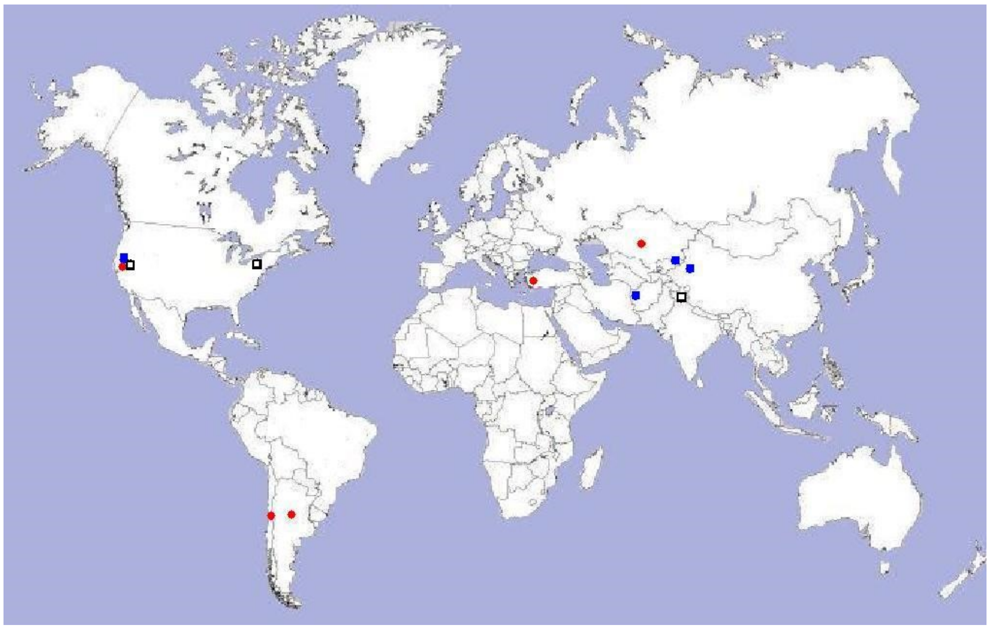
Boron silicate is widely used in glass industry to produce glass with high capacity to withstand big temperature changes (Pyrex and Duran products)

Boron silicate glass
(Pyrex and Duran products)

Boron is characterized by the lowest thermal expansion value among all types of glass and used in laboratory glass ware and kitchen ware

B Boron , 5

Mineral ore locations



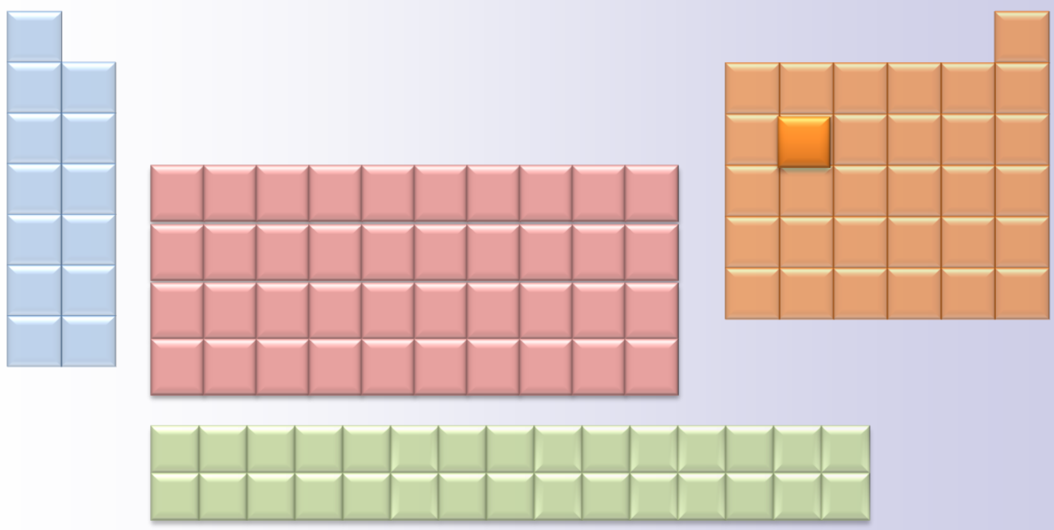
• Borax ▪ Kernite • Colemanite

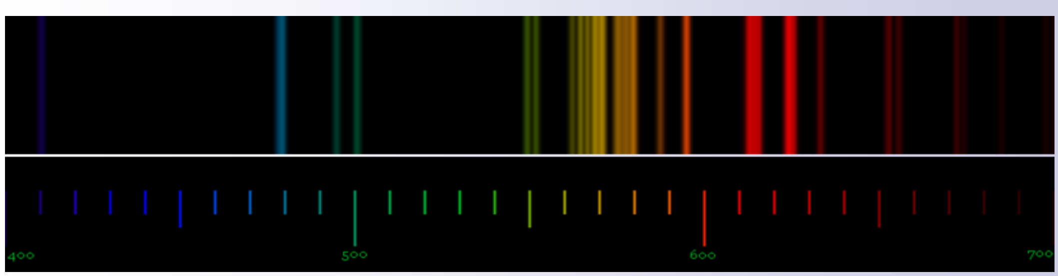
B Boron , 5

Physical and chemical properties

Symbol	B	Relative atomic mass	10.811
Atomic number	5	Melting point (°C)	2299.85
Group	13	Boiling point (°C)	3657.85
Period	2	Specific heat (J/g.K)	1.026
Family	Semimetals	Oxidation numbers	+3
Physical state(20°C)	solid	Electronegativity (pouling)	2.04
Atomic radius (pm)	83	Thermal conductivity (W/m.K)	27.0
Crystal structure	Simple trigonal	Heat of fusion (kJ/mol)	22.2
Electronic configuration	$[He]2S^22P^1$	Heat of vaporization (kJ/mol)	538.9
Molar volume (cm3/mole,273K)	4.62	Ist. ionization potential (kJ/mole)	800.6
Density (g/cm3)	2.340	2nd.Ionization potential(kJ/mole)	2427
Number of isotopes	6	3rd. ionization potential (kJ/mol)	3660

Silicon Si





Silicon is a hard semimetallic element that ranks second (after oxygen) with respect to abundance in the earth's crust (up to 26% by weight). It occurs naturally in the form of compounds of which the most important are the silicates (granite, asbestos, clay and mica). It occurs as silicon dioxide which is the most abundant material in the earth's crust found in all types of rocks as- sand and quartz.

The pure element is obtained through the reduction of molten silica (sand) with carbon (coke) or magnesium in electric furnaces.

Silicon is relatively inert and is not affected by acids (except hydrofluoric acid), but is attacked by halogens and dilute alkalis.

Silicon is characterized by a high ability to link and make long chains with other elements (mostly with oxygen).

Silicones are important industrial compounds prepared by the hydrolysis of silicon organic compounds such as silanes and used in the manufacture of synthetic rubber, hydraulic fluids and lubricants.

Silica is the principal component in glass , and silicon carbide which is prepared by melting silicon with carbon at about 2000 °C, is the hardest substance known with the ability to withstand temperatures up to 2000 °C.

High-purity silicon (impurities less than 0.1 ppm) is the major semiconductor used for manufacturing photovoltaic cells, transistors and resistors.

Ultra-pure silicon

(Silicon is the major semiconductor used for manufacturing photovoltaic cells, transistors and resistors).

Mica

(Hydrous aluminosilicates)

Occurs as easily cleaved thin sheets. It is specified by high resistance to heat and high insulation power and is commonly used in

Si Silicon , 14

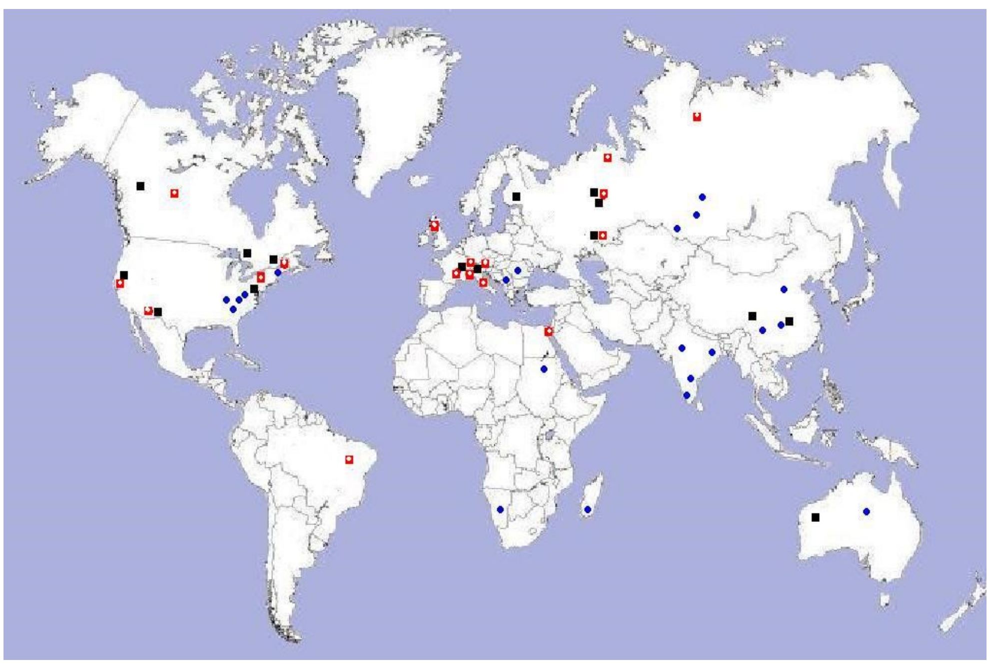
Silicon is an essential element in the manufacture of stainless steel. It is also used - in the form of sand or clay- in the manufacture of refractory materials, building materials and pottery.

The element is vital for the human body and is necessary for the growth of bone tissue.

Agate gemstone

(Crystalline quartz usually found in volcanic rocks)

Mineral ore locations



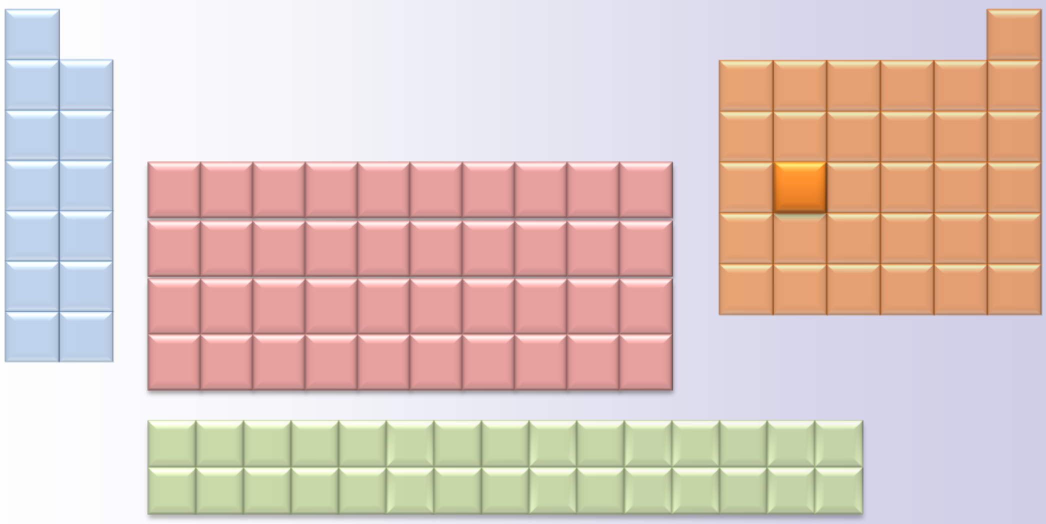
▫ Quartz • Mica ▪ Asbestos

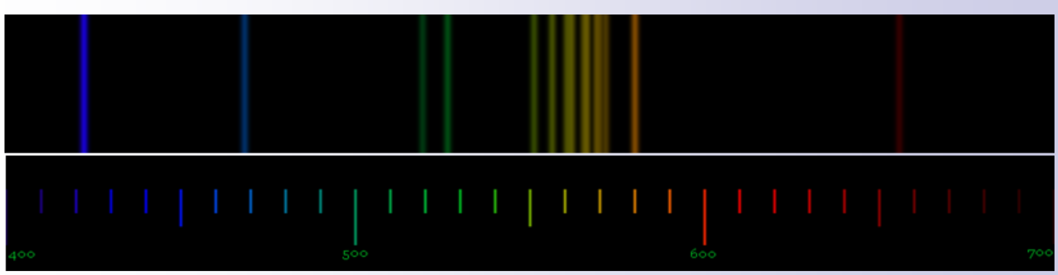
Si Silicon , 14

Physical and chemical properties

Symbol	Si	Relative atomic mass	28.086
Atomic number	14	Melting point (°C)	1409
Group	14	Boiling point (°C)	2354
Period	3	Specific heat (J/g.K)	0.705
Family	Semimetals	Oxidation numbers	-4, +2, +4
Physical state(20°C)	solid	Electronegativity (pouling)	1.90
Atomic radius (pm)	117.6	Thermal conductivity (W/m.K)	148
Crystal structure	Tetrahedral packing	Heat of fusion (kJ/mol)	39.6
Electronic configuration	$[Ne]3S^2 3P^2$	Heat of vaporization (kJ/mol)	383.3
Molar volume (cm3/mole,273K)	12.06	Ist. ionization potential (kJ/mole)	786.5
Density (g/cm3)	2.329	2nd.Ionization potential (kJ/mole)	1577.1
Number of isotopes	11	3rd. ionization potential (kJ/mol)	3231.4

Germanium Ge





Germanium is a hard white -gray metalloid which is rare in nature. It is crystalline and brittle in the pure form and is chemically inert and retains its luster in air at normal temperatures.

Germanium is found in germanite mineral but is commercially obtained, as a by-product, of a number of metallurgical operations. Its principal commercial sources are the remnants of coal burning and the dusts of zinc smelter chimneys. The element is usually subjected to further purification through the fractional distillation of its volatile tetrachloride.

High-purity germanium (impurity of less than 1 ppb) is produced by zone-refining techniques to be used for doping with elements such as silicon, arsenic and gallium in the manufacture of semiconductors for transistors and integrated circuits.

Unlike most semiconductors, germanium is transparent to infrared light and is utilized in infrared spectrometers and infrared detectors.

Germanium is used as a phosphor in light bulbs and photovoltaic cells.

It is also used as an alloying agent and as a catalyst in the pharmaceutical industry.

The average daily consumption of germanium is estimated by one milligram for an adult. Claimed benefits of organic or inorganic germanium compounds as dietary supplements or as drugs for different medical treatments are debatable and suspicious.

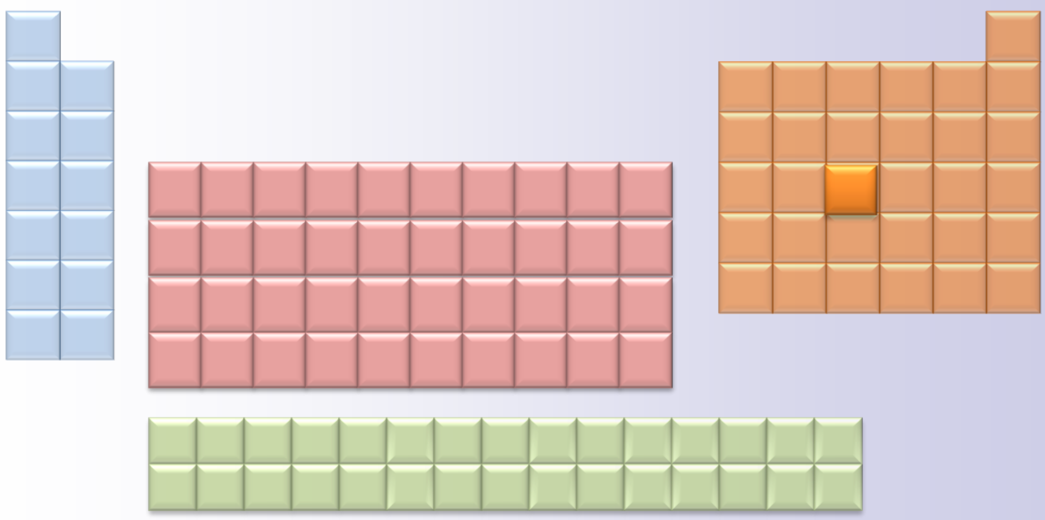
Germanium (crystalline)

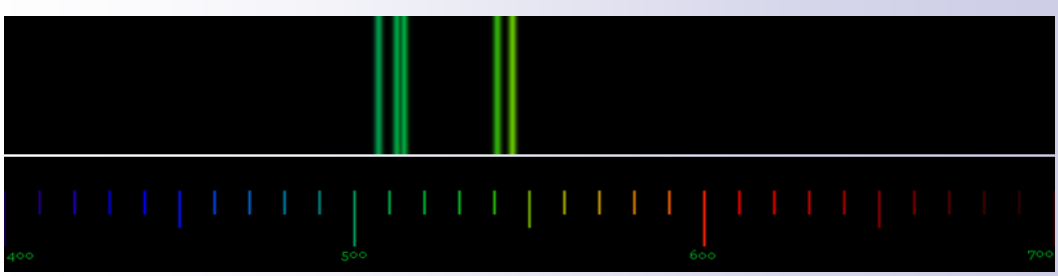
Ge Germanium , 32

Physical and chemical properties

Symbol	Ge	Relative atomic mass	72.61
Atomic number	32	Melting point (ºC)	937.45
Group	14	Boiling point (ºC)	2829
Period	4	Specific heat (J/g.K)	0.320
Family	Semimetals	Oxidation numbers	-4,+2,+4
Physical state(20°C)	solid	Electronegativity (pouling)	2.01
Atomic radius (pm)	122.5	Thermal conductivity (W/m.K)	59.9
Crystal structure	FaceCentered Cu-bic	Heat of fusion (kJ/mol)	34.7
Electronic configu-ration	$[Ar]3d^{10}4S^{2}4P^{2}$	Heat of vaporization (kJ/mol)	334.3
Molar volume (cm3/mole,273K)	13.64	Ist. ionization potential (kJ/mole)	762.1
Density (g/cm3)	5.323	Ttttpotential (kJ/mole)	1537
Number of isotopes	24	3rd. ionization potential (kJ/mol)	3302

Arsenic As





Arsenic is a hard, gray, crystalline and brittle semimetal that occurs free in nature (but in week concentrations) in a number of allotropic forms. It is also found, chemically combined, as the sulfide or the oxide and as copper and lead arsenates and most commercial arsenic is extracted as a by-product of mining and purification processes of these elements.

Arsenic resembles phosphorus in a number of chemical properties. It is oxidized by nitric acid to form arsenic acid (with the strength of phosphoric acid) and, also like phosphorus, it forms an unstable volatile hydride.

Native arsenic

-British Columbia, Canada -

Arsenopyrite

(Iron and arsenic sulfides)

with calcite

- Portugal -

Important arsenic compounds include the oxide (or white arsenic) which is the main source of most commercial arsenic compounds, and the red crystalline sulfide which is aleather tanning agent and a component of red colors. Other important compounds are calcium and lead arsenates which are used as pesticides. Arsenic is added to the components of glass in order to remove undesired colors and impurities caused by traces of iron.

As Arsenic , 33

Elemental arsenic and many of its compounds are usually classified as carcinogenic agents and are considered as toxic and serious contaminants in the environment. The element occurs in land and in ground water and represents a serious hazard in various arias where its concentration in drinking water exceeds the allowed levels (10 ppm).

Pesticides and fertilizers used in tobacco cultivation are believed to be the main source of arsenic found in tobacco smoke which is one of the causal factors of lung cancer.

Mineral ore locations

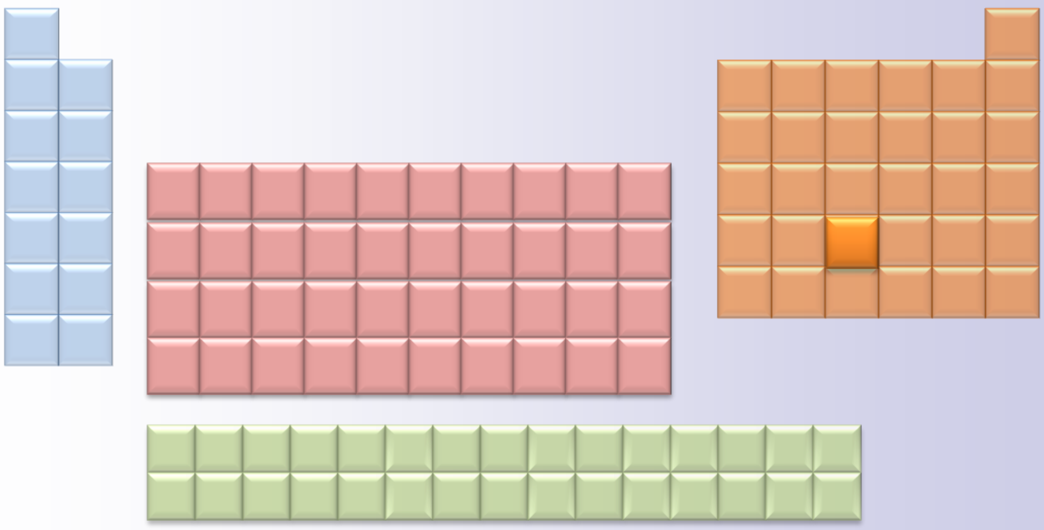
■ Arsenopyrite ● Native arsenic

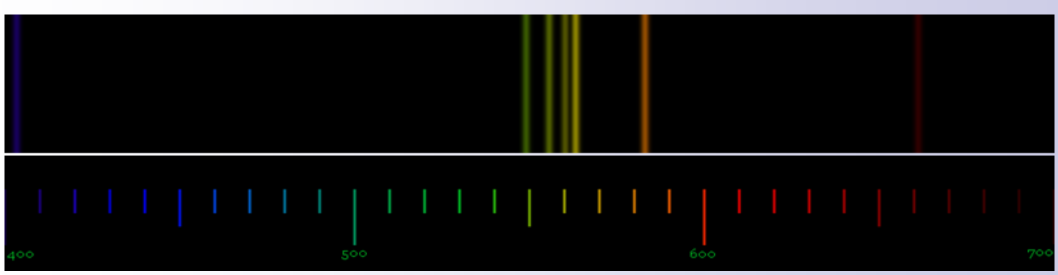
As Arsenic , 33

Physical and chemical properties

Symbol	As	Relative atomic mass	74.922
Atomic number	33	Melting point (°C)	816
Group	15	Boiling point (°C)	615
Period	4	Specific heat (J/g.K)	0.329
Family	Semimetals	Oxidation numbers	-3,+3,+5
Physical state(20°C)	solid	Electronegativity (pouling)	2.18
Atomic radius (pm)	125	Thermal conductivity (W/m.K)	50.0
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	27.7
Electronic configuration	$[Ar]3d^{10}4S^{2}4P^{3}$	Heat of vaporization (kJ/mol)	31.9
Molar volume(cm3/ mole,273K)	12.95	Ist. ionization potential (kJ/mole)	947.0
Density (g/cm3)	5.780	2nd.Ionization potential (kJ/mole)	1798
Number of isotopes	21	3rd. ionization potential (kJ/mol)	2735

Antimony Sb





Antimony is a silvery-white and brittle semimetal known and used in drugs and cosmetics since ancient history. It is found naturally in the form of the sulfide (stibnite or kohl stone), while week concentrations of the free elemental antimony occur in a number of locations.
The industrial production of the element involves roasting (oxidation) of the sulfide ores, followed by smelting (reduction) of the oxide by iron or sodium carbonate and carbon (coke).
Antimony is also obtained ,as a by-product, of mining processes of copper and lead.

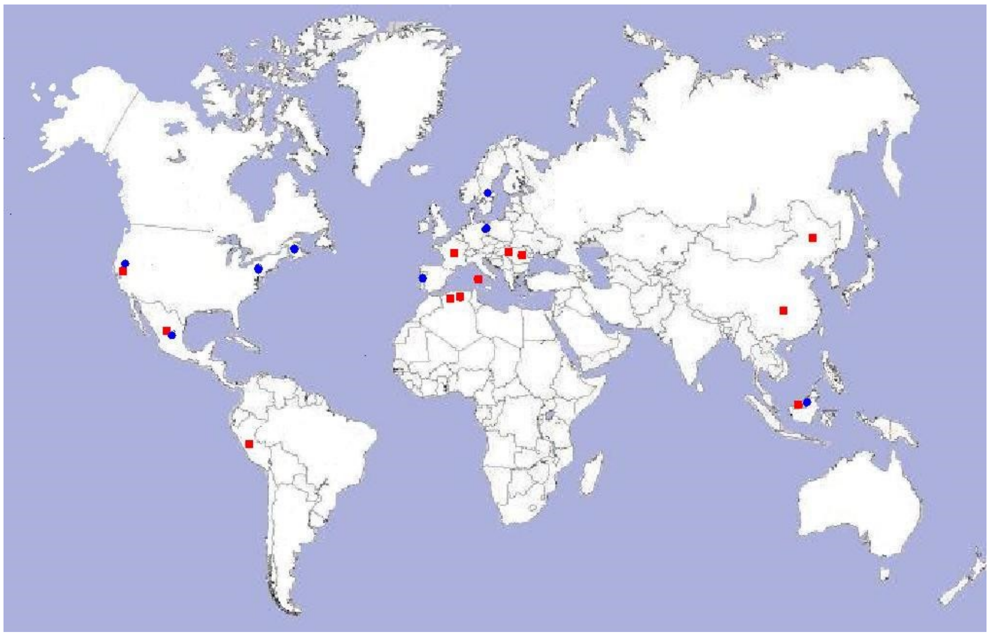
Antimony crystals
- lower Saxsony,germany -

Stibnite
(Antimony sulfide)
It is known and used in cosmetics and medicine since ancient history
- Romania -

The element is stable in air and is unaffected by water or weak acids. However, it dissolves in concentrated nitric acid to form antimonic acid. It burns in air at high temperatures to give the oxide and reacts violently with halogens to form the respective halides.
The principal application of antimony is in the field of semiconductors (diodes, infrared detectors, etc.). It is also used in alloys for accumulators and in welding materials as an alternative to lead. Some antimony compounds are used in the manufacture of coloring materials and in fire retardants.

Sb Antimony , 51

Mineral ore locations



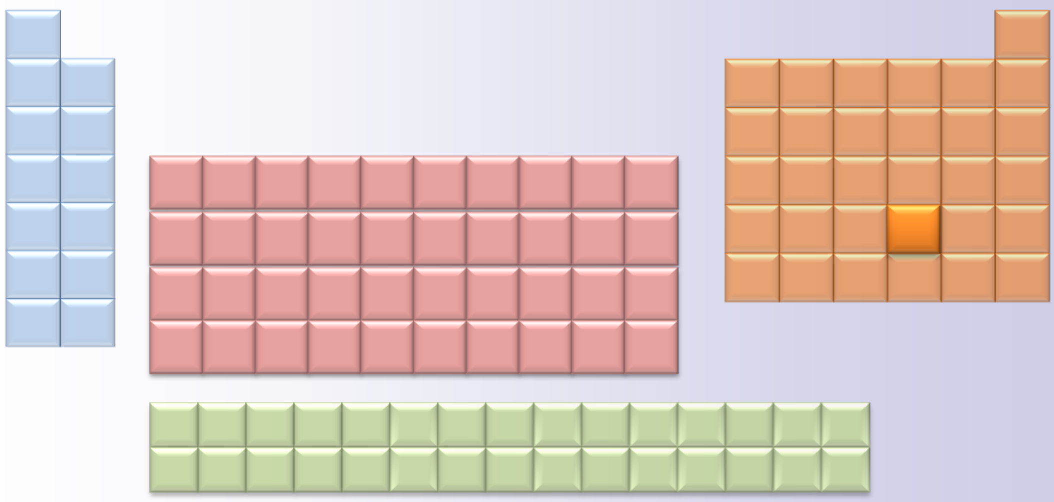
■ Stibnite ● Native antimony

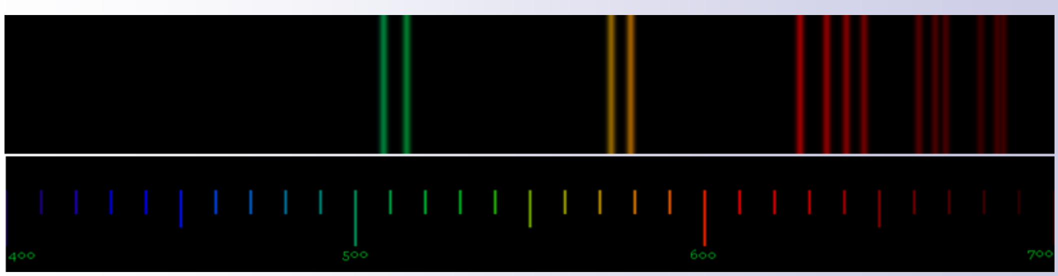
Sb Antimony , 51

Physical and chemical properties

Symbol	Sb	Relative atomic mass	121.757
Atomic number	51	Melting point (°C)	630.75
Group	15	Boiling point (°C)	1634
Period	5	Specific heat (J/g.K)	0.207
Family	Semimetals	Oxidation numbers	-3, +3, +5
Physical state(20°C)	solid	Electronegativity (pouling)	2.05
Atomic radius (pm)	182	Thermal conductivity (W/m.K)	24.3
Crystal structure	Rhombohedral	Heat of fusion (kJ/mol)	20.9
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{3}$	Heat of vaporization (kJ/mol)	77.14
Molar volume (cm3/mole,273K)	18.20	Ist. ionization potential (kJ/mole)	833.7
Density (g/cm3)	6.691	2nd.Ionization potential(kJ/mole)	1794
Number of isotopes	40	3rd. ionization potential (kJ/mol)	2443

Tellurium Te





Tellurium is a silvery-white, shiny and brittle semimetal, and one of the rarest elements in the earth's crust.

It occurs, as traces of the free elemental form along with gold and some other elements and is commercially obtained, as a by-product, of copper refining and lead smelting processes.

Tellurium combines directly with the halogens, readily dissolves in nitric and sulfuric acids and burns in air with a blue flame to form the oxide.

Tellurium is a semiconductor and a slight increase in light intensity causes slight increase in its conductivity (photoelectric effect).

Doping with metals like gold, silver or copper gives tellurium the specific properties that made its principal applications in the field of the electronic industry.

Tellurium is a component of ceramics and blasting capsules. It is also used with iron, lead and copper to make alloys with high resistance to corrosion and friction.

Elemental tellurium and its compounds are considered as toxic substances.

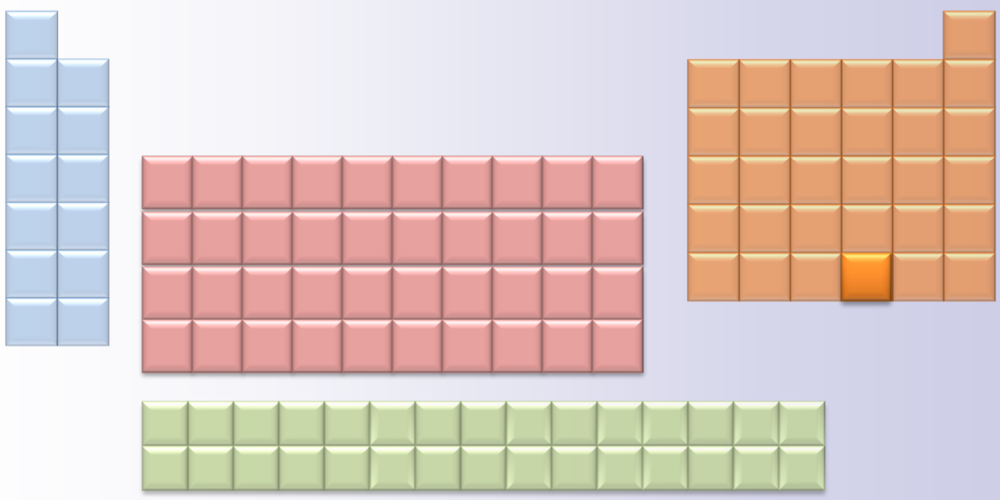
Native tellurium

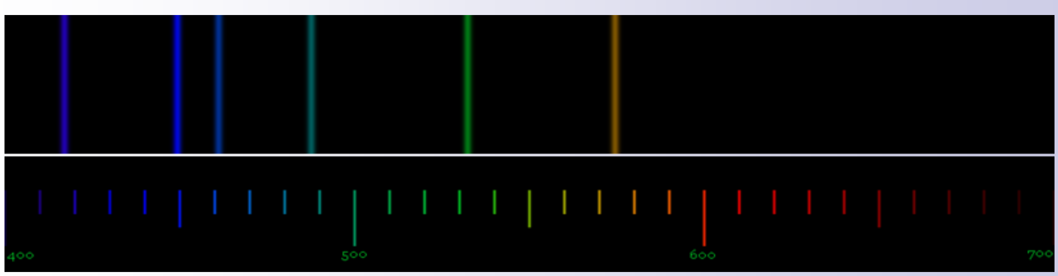
Te Tellurium , 52

Physical and chemical properties

Symbol	Te	Relative atomic mass	127.60
Atomic number	52	Melting point (°C)	449.55
Group	16	Boiling point (°C)	986
Period	5	Specific heat (J/g.K)	0.202
Family	Semimetals	Oxidation numbers	-2, +4, +6
Physical state(20°C)	solid	Electronegativity (pouling)	2.1
Atomic radius (pm)	143.2	Thermal conductivity (W/m.K)	2.35
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	13.5
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{4}$	Heat of vaporization (kJ/mol)	50.63
Molar volume (cm3/mole,273K)	20.45	Ist. ionization potential (kJ/mole)	869.2
Density (g/cm3)	6.240	2nd.Ionization potential(kJ/mole)	1795
Number of isotopes	39	3rd. ionization potential (kJ/mol)	2698

Polonium Po





Polonium is a radioactive semimetal and one of the rarest elements in the earth's crust. All its isotopes are radioactive and its natural occurrence is a result of the continuous disintegration of heavy radioactive elements such as radium and uranium (it is found in uranium ores to 100 micrograms per metric ton).

Polonium is chemically similar to tellurium and bismuth. It is a lethal substance (it is one thousand times more toxic than hydrogen cyanide) and is a powerful gamma and alpha emitter with more activity than radium. It is thus considered as one of the most dangerous elements known.

Although it is a hard metal with a high melting point temperature (within 254 °C), polonium is a volatile substance that vaporizes at room temperature with a distinctive blue glow resulting from the ionization of the surrounding air.

The isotope polonium–210 is used as a mobile source of heat for the operation of electrothermal cells in space and in remote areas.

Phosphate fertilizers used in tobacco plantation contain a considerable proportion of this isotope which makes its way to the leaves through the roots of plants and eventually to tobacco smokers where it settles in the lungs to constitute a local source of the destructive alpha radiation.

Polonium is one of the most dangerous substances known. It is highly toxic and its activity as a gamma and alpha emitter is many folds that of radium

Polonium -210 isotope reaches the lungs of smokers (and companions) with tobacco smoke to constitute a local source of alpha radiation.

Po Polonium , 84

Physical and chemical properties

Symbol	Po	Relative atomic mass	208.982
Atomic number	84	Melting point (ºC)	253.85
Group	16	Boiling point (ºC)	961.85
Period	6	Specific heat (J/g.K)	--------
Family	Semimetals	Oxidation numbers	+2, +4, +6
Physical state(20°C)	solid	Electronegativity (pouling)	2.0
Atomic radius (pm)	167	Thermal conductivity (W/m.K)	20
Crystal structure	Simple cubic	Heat of fusion (kJ/mol)	10
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{2}6P^{4}$	Heat of vaporization (kJ/mol)	100.8
Molar volume(cm3/ mole,273K)	22.4	Ist. ionization potential (kJ/mole)	812
Density (g/cm3)	9.320	2nd.Ionization potential(kJ/mole) (kJ/mole)	1800
Number of isotopes	33	3rd. ionization potential (kJ/mol)	2700

NONMETALS

Nonmetals are the chemical elements occupying the left side of the periodic table with the exception of hydrogen which belongs to this group but is located on the top of the alkali metal group (Group 1) only because of its atomic number.

Nonmetals are distinguished from metals by the following characteristics:

They are:

1– Usually gases or brittle and non crystalline solids with low density and low melting and boiling points
2– Usually dull and non-lustrous.
3- Characterized by poor thermal conductivity (except carbon as diamond) and poor electrical conductivity (except carbon as graphite)
4- Characterized by high electronegativity values.
5- They form acidic oxides

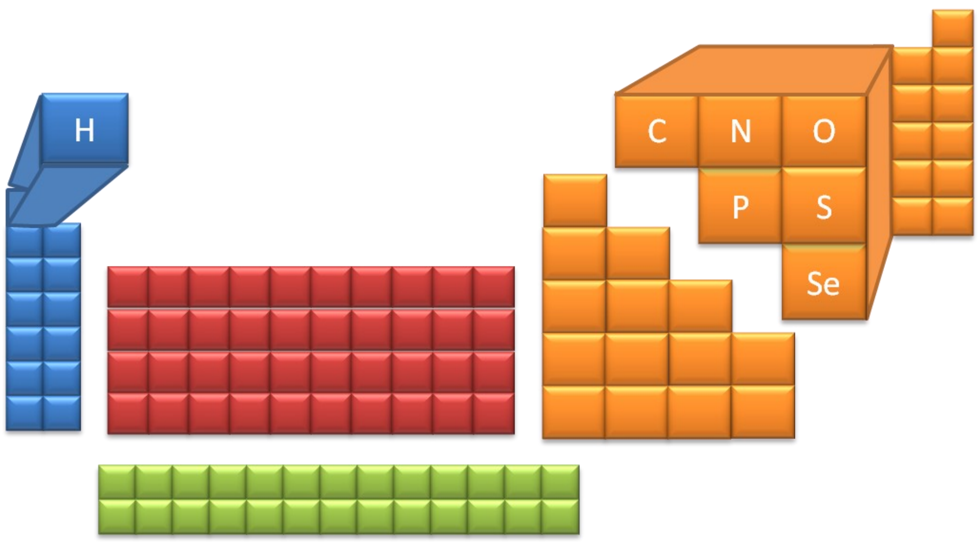
Nonmetals represent less than 15% of the total natural chemical elements. However, they form most of the living organisms and most of the mass of the earth's crust, atmosphere, rivers and seas. Hydrogen and helium form about 99% of the material of the known universe.

Nonmetal subgroups include:

1 – Hydrogen
2 - Other nonmetals: Carbon, Nitrogen, Oxygen, Sulfur, Phosphorus and Selenium.
3 - Halogens: Fluorine, Chlorine, Bromine, Iodine and Astatine.
4 - Noble gases: Helium, Neon, Krypton, Xenon and Radon.

Chapter 8

HYDROGEN AND OTHER NONMETALS



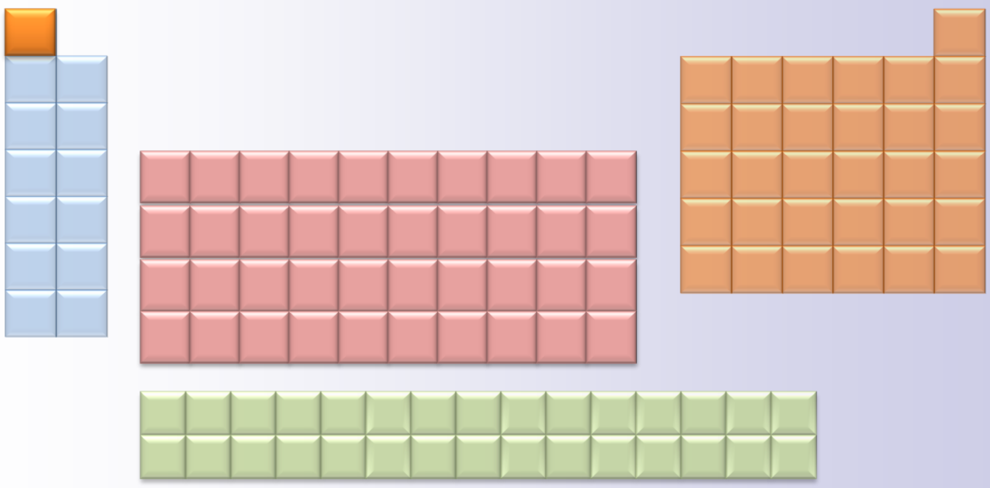
Hydrogen is the only nonmetal situated within metal groups, and that is only because of its atomic number.

The so called other nonmetals are the six elements in the upper left corner of the periodic table.

These elements are : Carbon, Nitrogen, Oxygen, Sulfur, Phosphorus and Selenium.

Carbon, nitrogen and oxygen together with hydrogen are the 4 elements that form the living body and most of the earth's crust.

Hydrogen H



Hydrogen is a colorless, odorless and tasteless flammable gas found free in the earth's atmosphere in concentrations of less than one part per million (1ppm).

However, hydrogen is abundant naturally in combination with oxygen as water, and in all organic materials including plants, oil and coal. It is the most abundant element in the solar universe and is the main ingredient of stars where the thermonuclear fusion of hydrogen atoms creates helium and heavier elements and provides the thermal energy that radiates into outer space.

There are two stable isotopes of hydrogen: Hydrogen-1 (normal hydrogen) and hydrogen-2 (deuterium). The latter combines with oxygen to form heavy water and combines with lithium to form lithium deuteride. A third isotope of the element is the radioactive hydrogen-3 (or tritium) with a half-life of 12.5 years.

Hydrogen is industrially prepared by a number of methods including the electrolysis of water and the interaction of steam with red-hot cock to produce a mixture of carbon monoxide and hydrogen (water or synthesis gas).

Hydrogen is also produced, as a by-product of a number of industrial operations including petroleum cracking, the destructive distillation of oil and the processes of re-formation of methane by water vapor under high pressure and temperature.

Hydrogen is combined with nitrogen in the industrial process of ammonia preparation (Haber process). It is utilized in the hydrogenation processes of vegetable oils and in the production of methyl alcohol and hydrochloric acid. It is also used in metal welding,, reduction of minerals and as a fuel for rockets and spacecrafts.

The Hydrogen Bomb

The first Thermonuclear Detonation

USA, 1953

H Hydrogen , 1

Hydrogenation is an important industrial process in which molecular hydrogen is added to an element or compound usually in the presence of a catalyst . It is used to saturate organic compounds in the petroleum and pharmaceutical industry and is employed in food industry to convert unsaturated fats (liquid oils) to solid saturated fats (Non-saturated molecules are related to a number of known cardiovascular disease).
Hydrogenation of coal at high temperature and pressure is utilized to convert coal to liquid hydrocarbons (Bergius Process).

Tritium is very rare in nature but is artificially prepared through bombardment of lithium nuclei with high energy photons.

Tritium and deuterium are produced from lithium deuteride during the first stages of the thermonuclear explosion and their fusion into helium ions is responsible for the enormous energy of the thermonuclear reaction (hydrogen bomb).

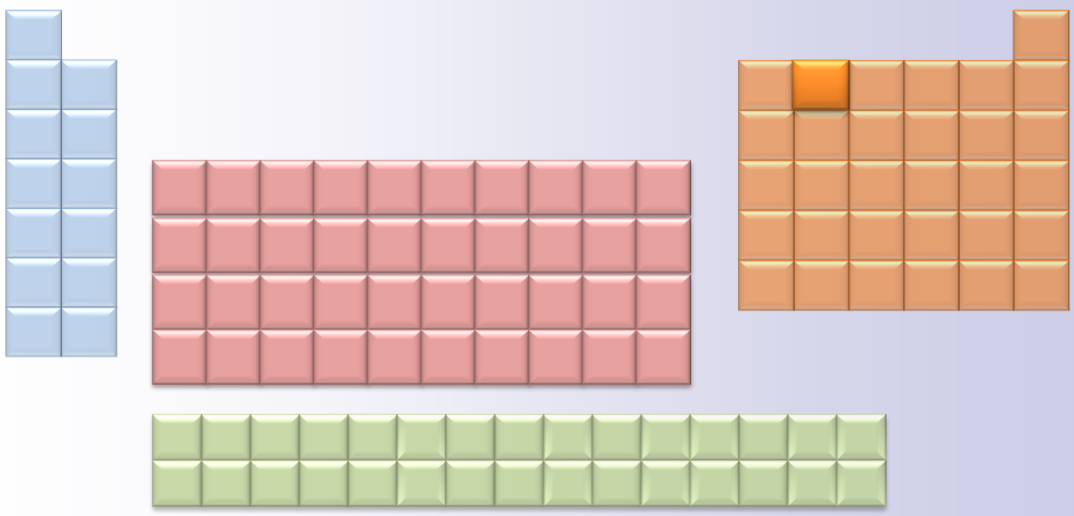
Heavy water is used as a moderator in special nuclear reactors that are operated with natural uranium (uranium-238). The significance of these processes is not only in bypassing uranium enrichment but also in the production of plutonium and tritium as by-products of the breeding reaction.
Electrolytic analysis of sea water and thermonuclear reactions are two promising future energy sources.

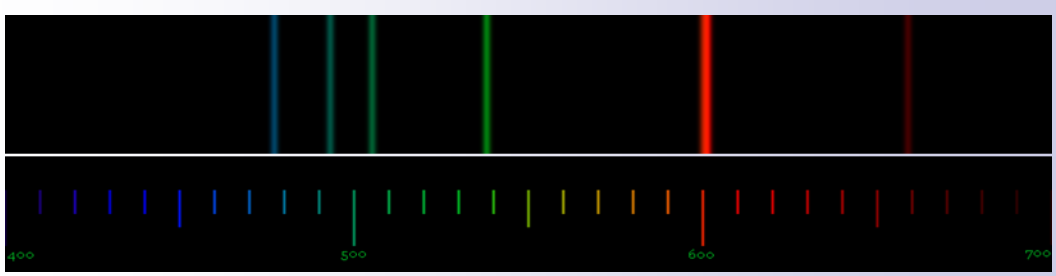
H Hydrogen , 1

Physical and chemical properties

Symbol	H	Relative atomic mass	1.008
Atomic number	1	Melting point (ºC)	-259.14
Group	1	Boiling point (ºC)	-252.87
Period	1	Specific heat (J/g.K)	14.304
Family	Non-metals	Oxidation numbers	-1, +1
Physical state(20°C)	Nonmetal	Electronegativity (pouling)	2.2
Atomic radius (pm)	78	Thermal conductivity (W/m.K)	0.01815
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	0.12
Electronic configuration	$1s^1$	Heat of vaporization (kJ/mol)	0.46
Molar volume (cm3/mole,273K)	13.26	Ist. ionization potential (kJ/mole)	1312.06
Density (g/cm3)	0.076	2nd.Ionization potential(kJ/mole) (kJ/mole)	####
Number of isotopes	3	3rd. ionization potential (kJ/mol)	####

Carbon C





Carbon is a non-metallic element widely distributed in nature in the form of compounds as well as in the pure elemental form.

It is found in a vast number of variable compounds due to its unique ability to form long chains and create multiple bonds. It occurs naturally as a component of limestone rocks (calcium carbonate), coal, petroleum and natural gas and in hundreds of thousands of organic compounds which are essential for life.

Free carbon exists in several allotropic forms of which the most recognized are graphite, diamond and amorphous carbon (which includes coal and soot). All forms are characterized by high stability and high melting points but, each allotrope of carbon has its own distinct inherent features. Thus, diamond is the hardest and most rigid substance while graphite is one of the softest materials known.

Diamond is characterized by the highest thermal conductivity among the elements and is one of the most precious gems. It is used in electronics and ornaments, and in making edges of cutting equipments.

Graphite is a dark material in which carbon atoms form hexagonal flat sheets that slide freely over each other. It is a good conductor of electricity but a poor conductor of heat. It is used in the manufacture of electrodes, pencils, paints and lubricants for high temperature.

Diamond
The hardest substance
- Brazil-

Pure graphite
(One of the softest substances known)

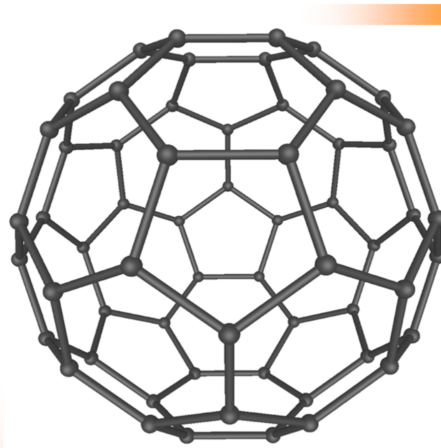
Graphite is also used as a moderator in several types of nuclear reactors.

Fullerenes represent another form of carbon discovered in 1985 while some experiments on carbon were conducted in space.

The molecule of the first discovered Fullerene homologue (C_{60}) is composed of 60 carbon atoms coordinated in 12 pentagons interlinked with 20 hexagons to form a hollow ball. Other forms of fullerene with different numbers of carbons (C_{70}, C_{84} etc) and with varying geometric patterns (flat, folded and tubular) are now isolated. The discovery of the fullerene family is considered as a breakthrough in different fields of science.

The isotope, carbon -14 is used for dating old specimens such as rocks and archaeological specimens by comparing the ratio (C-14/C-12) in the item and in the atmosphere.

In 1961 the International Union of Pure and Applied Chemistry (IUPAC) adopted the isotope carbon -12 as a standard for atomic masses of all the chemical elements and was assigned a value of 12.0000 atomic mass units (amu).



Fullerene -60

A form of carbon discovered in 1985

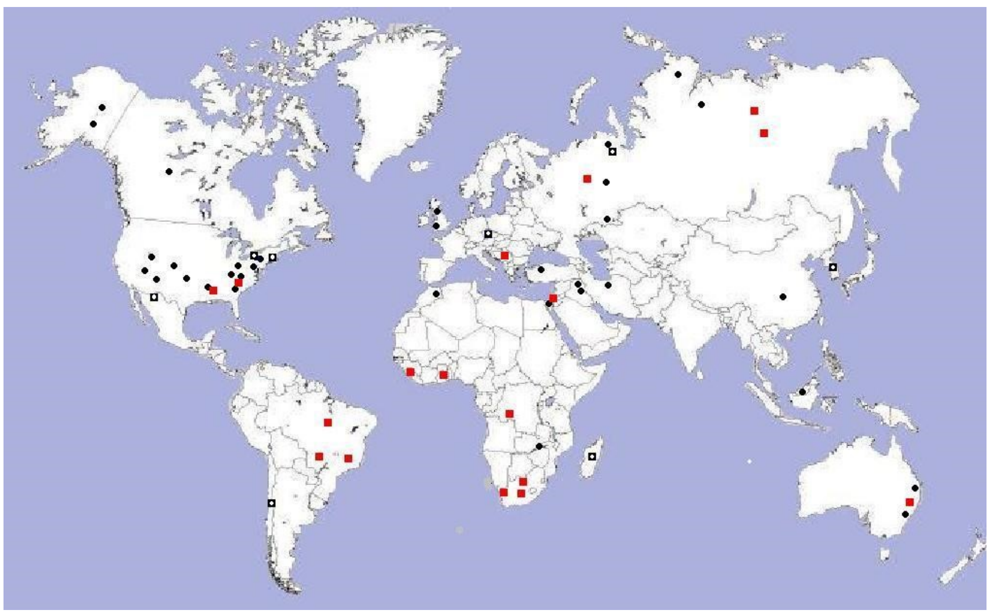
Coal

An allotropic form of carbon element

C Carbon , 12

Carbon dioxide constitutes about 0.03% of the volume of the atmosphere . It is absorbed by green cells of plants (plastids) and combines with water to form glucose in the process of photosynthesis in which oxygen gas is produced as a by-product to maintain the optimum level of air components in the atmosphere.

Mineral ore locations



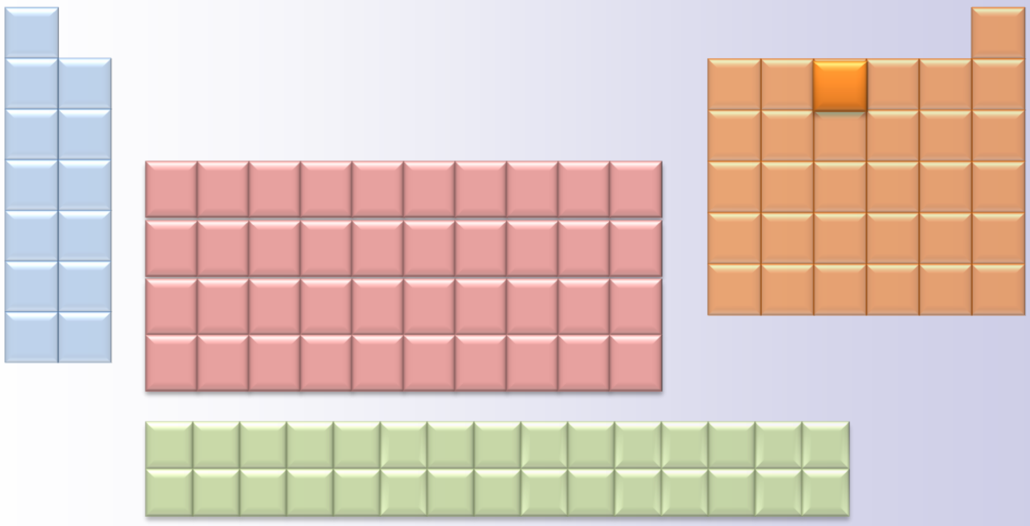
Diamond   Graphite   Coal

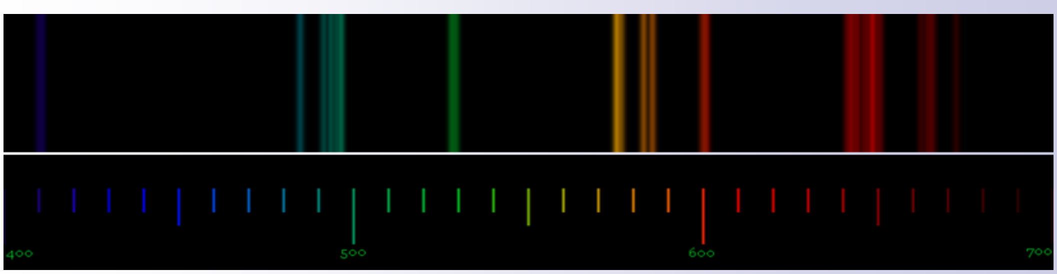
C Carbon , 12

Physical and chemical properties

Symbol	C	Relative atomic mass	12.011
Atomic number	6	Melting point (ºC)	3546.85
Group	14	Boiling point (ºC)	4826.85
Period	2	Specific heat (J/g.K)	0.709
Family	Nonmetals	Oxidation numbers	-4, +2, +4
Physical state(20°C)	solid	Electronegativity (pouling)	2.55
Atomic radius (pm)	77.2	Thermal conductivity (W/m.K)	900-2320
Crystal structure	Simple hexagonal	Heat of fusion (kJ/mol)	105.0
Electronic configuration	[He]2S²2P	Heat of vaporization (kJ/mol)	710.9
Molar volume (cm3/mole,273K)	3.42	Ist. ionization potential (kJ/mole)	461086.
Density (g/cm3)	3.513	2nd.Ionization potentia (kJ/mole)	2352.65
Number of isotopes	8	3rd. ionization potential (kJ/mol)	4620.50

Nitrogen N





Nitrogen is a colorless, odorless and tasteless gaseous element that forms about 78% of the volume of atmospheric air.

It is industrially prepared by fractional distillation of liquid air, where it evaporates at- 196 °C, leaving oxygen which boils at -183 °C.

Nitrogen is chemically inert and generally resistant to chemical attack. However, it combines directly with lithium metal at room temperature and with magnesium and calcium metals at higher temperatures.

Atmospheric nitrogen is essential for life as it acts to dilute air oxygen to provide the optimum oxygen level for breathing of living things.

Liquid nitrogen

Boils at -196 °C

Liquid nitrogen is commonly used in laboratories and industrial cooling and is utilized as an inert shield in smelting and cutting operations of sensitive metals

Nitrogen nodules

Built by Azobacter bacteria and represent one of the natural nitrogen fixation processes

Nitrogen is a principal component in the composition of amino acids which are the building blocks of plant and animal protein. However, nitrogen concentration is so low in the earth's crust that it does not commensurate with the needs of green plants. Nitrogen fixation is a term used for a number of methods that provide the element in the soil in the form of soluble nitrogen compounds.

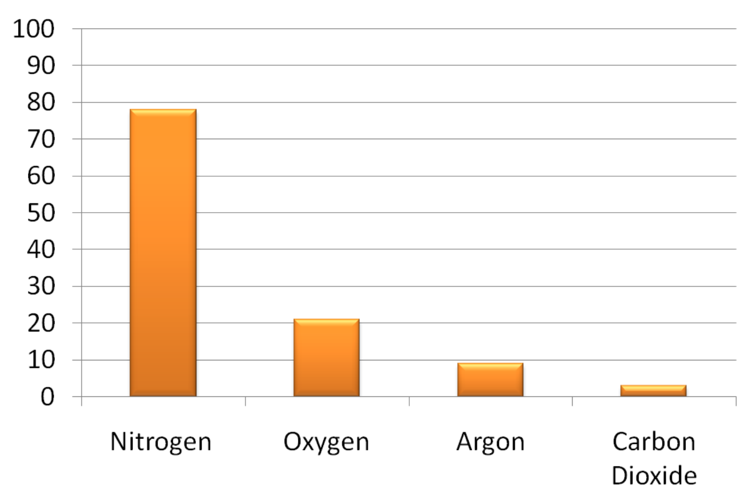
N Nitrogen , 7

Nitrogen fixation occurs in a number of ways and is an important part of the natural nitrogen cycle.

An important natural nitrogen fixation process occurs in the course of rainfall by the action of an electric spark of lightning on air nitrogen which combines with oxygen to form nitrogen oxide which, in turn, reacts with oxygen and water to form nitric acid which acts as a source of nitrate salts in the soil.

Another natural nitrogen fixation process is the action of specific bacteria which build nodules in the roots of legumes and produce special enzymes to transmute air nitrogen into nitrogen compounds that remain in the soil after the plant cycle is complete.

The industrial manufacture of ammonia by Haber process is the most important way of artificial nitrogen fixation in the soil. In this process a mixture of equal volumes of nitrogen and hydrogen combine under high pressure (› 300 atm) and high temperature (around 500 °C) in the presence of an iron catalyst to produce ammonia which is the starting material of most nitrogen fertilizers.



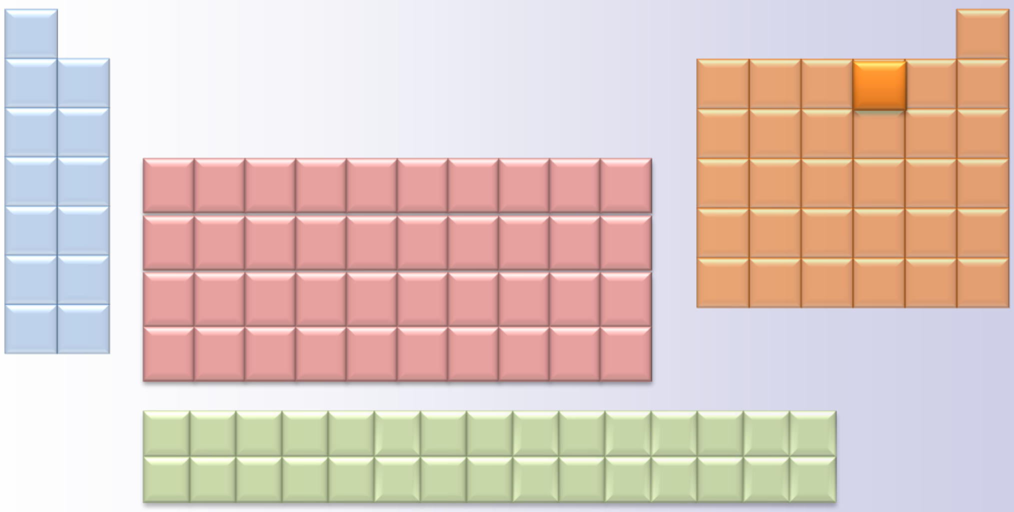
Nitrogen constitutes 78% by volume of atmospheric air

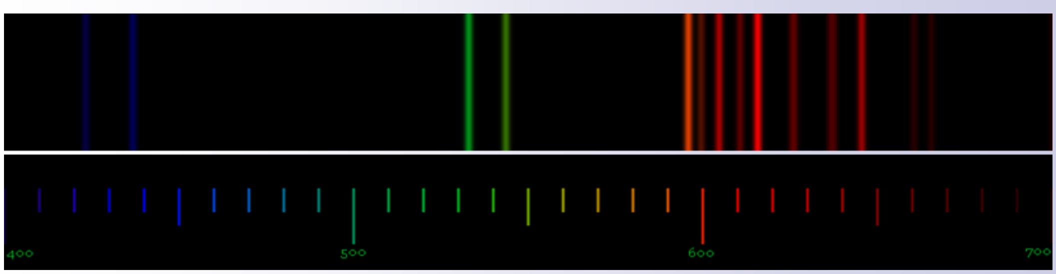
N Nitrogen , 7

Physical and chemical properties

Symbol	N	Relative atomic mass	14.007
Atomic number	7	Melting point (°C)	-209.86
Group	15	Boiling point (°C)	-195.79
Period	2	Specific heat (J/g.K)	1.040
Family	Nonmetals	Oxidation numbers	-3,-2,-1,+1,+2
Physical state(20°C)	Gas	Electronegativity (pouling)	3.04
Atomic radius (pm)	71	Thermal conductivity (W/m.K)	0.02598
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	0.720
Electronic configuration	$[He]2S^22P^3$	Heat of vaporization (kJ/mol)	5.577
Molar volume(cm3/ mole,273K)	13.65	Ist. ionization potential (kJ/mole)	1402.3
Density (g/cm3)	1.026	2nd.Ionization potential(kJ/mole)	2856.1
Number of isotopes	8	3rd. ionization potential (kJ/mol)	4578

Oxygen O





Oxygen is a colorless and odorless gaseous element that constitutes about 21% of the volume of atmospheric air.

It is the most common element in the earth's crust with an abundance estimated within 45% of the mass of the earth's crust. It occurs in various chemical forms including the oxides, the sulfates and the carbonates of different elements. It is combined with hydrogen in water and is a constituent of hundreds of thousands of organic compounds.

Oxygen is industrially prepared by fractional distillation of liquid air, where nitrogen evaporates (-196 °C), leaving oxygen (-183 °C).

Oxygen is chemically very active and readily combines with most elements. It is vital to the process of respiration of living organisms and it is the agent of all combustion and oxidation processes.

Oxygen is the only gaseous element that exists in allotropic forms. These are the di-oxygen (normal oxygen) and the tri-oxygen or ozone.

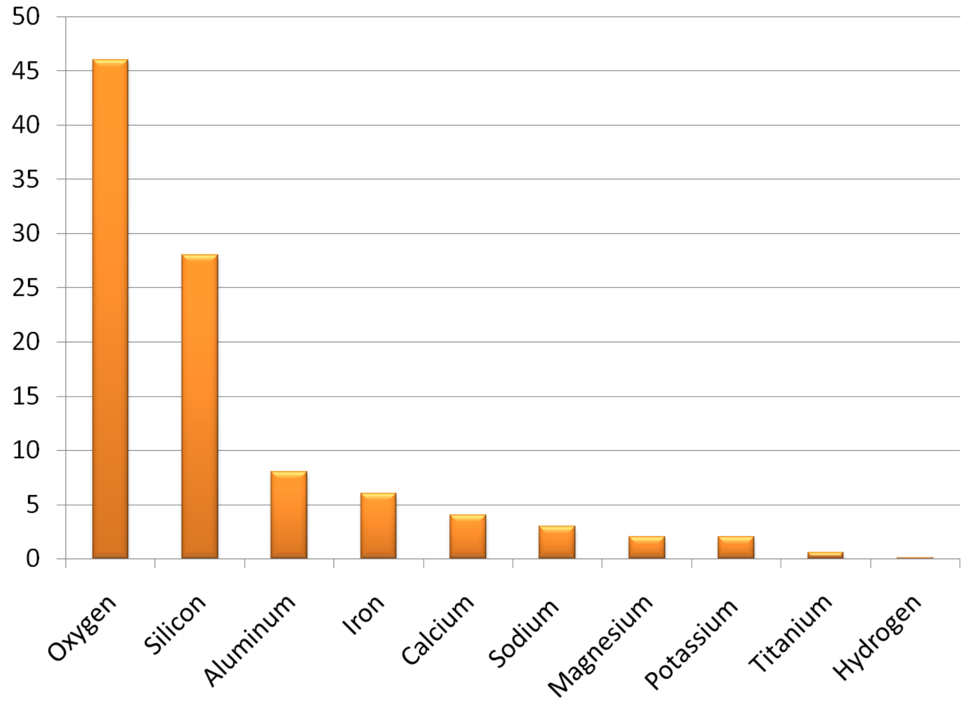
The latter is an active and toxic form of the element which is readily prepared by the action of ultraviolet radiation or an electric spark on oxygen gas. It is a powerful oxidizing agent and is widely used in the sterilization of air and drinking water, where its molecules decompose into oxygen without leaving harmful residues.

Ozone therapy is practiced by many medical authorities, and therapeutic doses are administered by medical ozone generators in treatment of different disorders. However healing properties and claims of merits of ozone therapy are debatable and ozone benefits are denied by many medical authorities who even claim that ozone therapy could be unsafe.

Ozone is found in the upper layers of the atmosphere (ozone layer). Its ability to absorb ultraviolet radiation and disintegrate into oxygen is necessary to prevent harmful UV radiations (of the sun) from reaching the surface of the earth.

Oxygen therapy is practiced as a medical treatment for various purposes. It is utilized for tissue oxygenation in which oxygen is administered in doses reaching 35% of breathing gas.

O Oxygen , 8



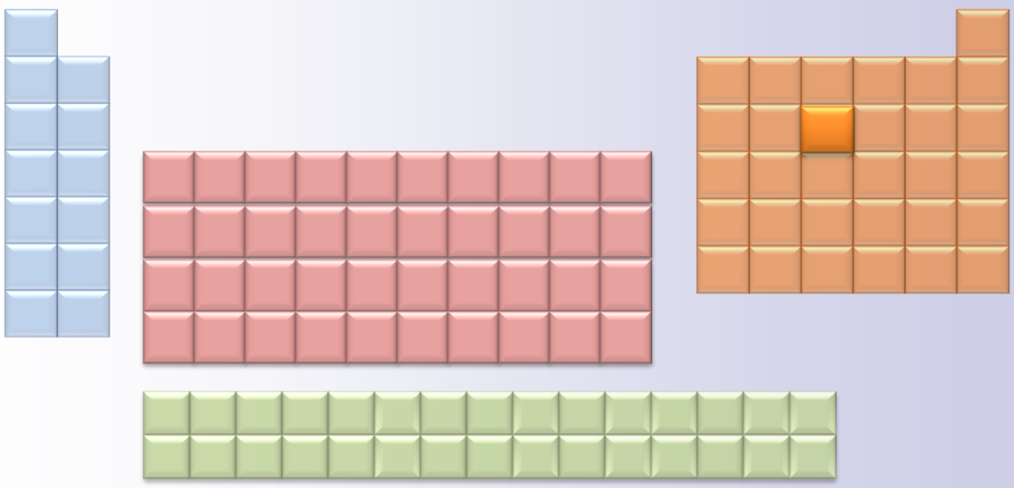
Oxygen constitutes about 45% the mass of the earth's crust

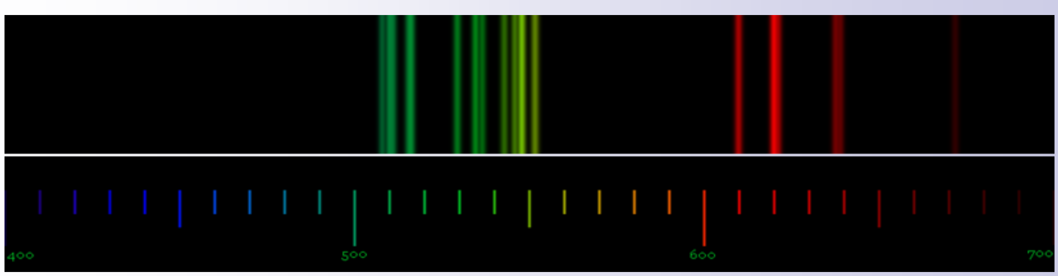
O Oxygen , 8

Physical and chemical properties

Symbol	O	Relative atomic mass	15.999
Atomic number	8	Melting point (°C)	-218.35
Group	16	Boiling point (°C)	-182.96
Period	2	Specific heat (J/g.K)	0.918
Family		Oxidation numbers	-2
Physical state(20°C)	Nonmetals	Electronegativity (pouling)	3.44
Atomic radius (pm)	Gas	Thermal conductivity (W/m.K)	0.2674
Crystal structure	60.4	Heat of fusion (kJ/mol)	0.444
Electronic configuration	Base centered monoclinic	Heat of vaporization (kJ/mol)	6.82
Molar volume (cm3/mole,273K)	[He]$2S^22P^4$	Ist. ionization potential (kJ/mole)	1313.9
Density (g/cm3)	8.00	2nd.Ionization potential (kJ/mole)	3388.2
Number of isotopes	2.000	3rd. ionization potential (kJ/mol)	5300.3

Phosphorus P





Phosphorous is a non-metallic element occurring naturally in apatite ores (calcium phosphate). The pure element is obtained through roasting and smelting processes using sand (silicon dioxide) and carbon (coke) in electric furnaces.

Phosphorous occurs in a number of allotropic forms that have different properties. The most common forms are the black phosphorous, white phosphorus and red phosphorus.

White phosphorus (also called yellow phosphorus) is a hard waxy substance soluble in carbon disulfide, olive oil and petrol, but insoluble in water and alcohol. It is a highly toxic and chemically active substance that reacts with most metals and non-metals and spontaneously catches fire in air at 34 °C to form phosphorus pentoxide. It is usually stored under water or mineral oil.

Red phosphorus is produced as an amorphous material when white phosphorous is exposed to sun light for several days or heated to about 250°C. A crystalline product of red phosphorous is formed on further heating. Red phosphorus is the safest allotrope . It is less active and less toxic than white phosphorous. It does not dissolve in carbon disulphide and will not ignite in air at temperatures below 240 °C.

Black phosphorus resembles graphite in both appearance and properties. It is made up of shiny crystals and is the most stable form of the element with the least solubility in solvents. It is obtainable by heating white phosphorous under high pressure (about 12,000atmosphere).

Phosphorous is used in explosives, flares and smoke bombs.

Apatite
(Calcium phosphate)
- Maine, USA -

P Phosphorous , 15

White phosphorous is an incendiary material that persists and causes second or third degree burns and penetrates the body through the burned areas to destroy the internal organs. Fatal injuries of phosphorous also occur in case of ingestion or inhalation of phosphorus fumes.

White phosphorus was used in the form of bombs, artillery ammunition and rocket-propelled grenades to destroy infantry personnel and civilians in the First World War, in Vietnam, Iraq, Afghanistan and recently in Gaza.

Phosphorus is an important component in bronze and steel alloys and is an ingredient of matches (red phosphorous only).

White phosphorous incendiary bombs (Elfaloga city, Iraq, 2004)

Red Phosphorous

Organic phosphorus compounds are used in the preparation of herbicides and chemical weapons (nerve gas).

phosphoric acid is utilized in fertilizers and sodium phosphate is used in detergents, food products and pharmaceutical industries.

Phosphorous is vital for the biological processes within the living cell . It is a basic element in the composition of the cell protoplasm, nerve and bone tissues.

Meat and dairy products are the major food sources of phosphorus.

P Phosphorous , 15

Mineral ore locations

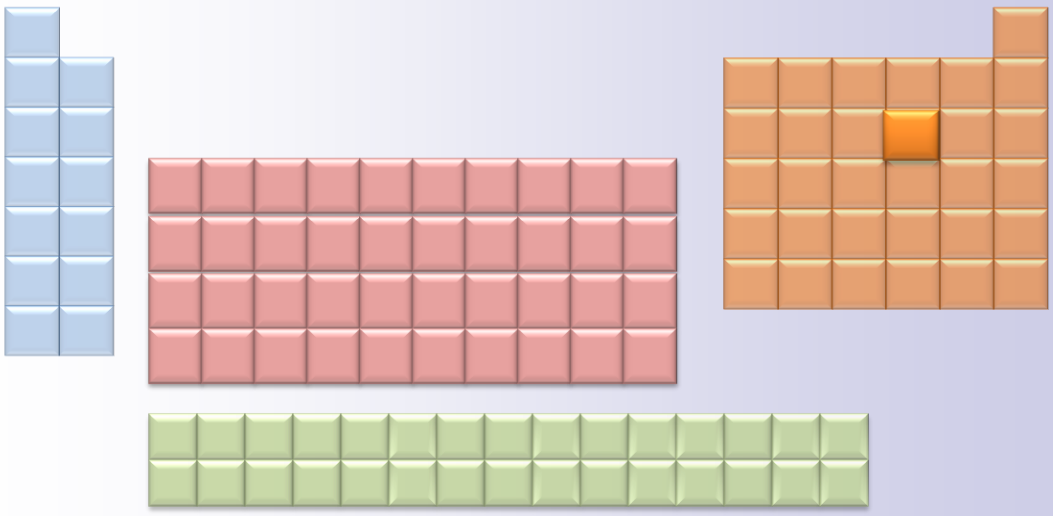
- Apatite

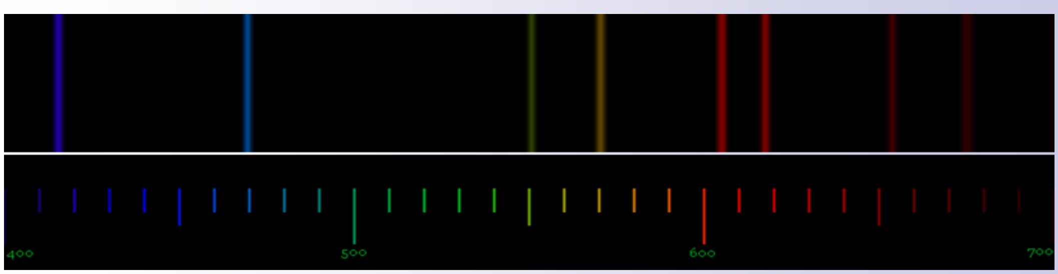
P Phosphorous , 15

Physical and chemical properties

Symbol	P	Relative atomic mass	30.974
Atomic number	15	Melting point (°C)	44.15
Group	15	Boiling point (°C)	279.9
Period	3	Specific heat (J/g.K)	0.769
Family	Nonmetals	Oxidation numbers	-3,+3,+4,+5
Physical state(20°C)	solid	Electronegativity (pouling)	2.19
Atomic radius (pm)	115	Thermal conductivity (W/m.K)	0.235
Crystal structure	Monoclinic	Heat of fusion (kJ/mol)	2.51
Electronic configuration	$[Ne]3S^2 3P^3$	Heat of vaporization (kJ/mol)	51.9
Molar volume(cm3/ mole,273K)	17.02	Ist. ionization potential (kJ/mole)	1011.7
Density (g/cm3)	1.820	2nd.Ionization potential(kJ/mole) (kJ/mole)	1903.2
Number of isotopes	10	3rd. ionization potential (kJ/mol)	2912

Sulfur S





Sulfur is a pale yellow, hard and brittle non-metallic element. It has an extremely low density and is tasteless and odorless (the bad smell of sulfur is due to the associated impurities of hydrogen sulfide gas). It occurs naturally in its pure elemental form in many areas. It also occurs chemically combined in a number of mineral ores, principally gypsum (calcium sulfate) and pyrite (iron sulfide).

Native sulfur occurs in a large number of allotropic forms containing sulfur rings of 6, 7, 9 and up to 20 atoms, but the most common natural form is the yellow form or α-sulfur with puckered rings of eight sulfur atoms (S_8).

Frasch process is the common industrial method for sulfur extraction. Superheated water and hot air are injected into sulfur deposits through a system of three concentric pipes and the melted sulfur is forced out through the middle pipe. Sulfur obtained by this method is 99.5 percent pure.

Sulfur ores are the major sources of sulfur dioxide gas which is mainly used in the industrial production of sulfuric acid (by Contac process). Sulfur is also present - to varying degrees - in all types of crude oil.

Native sulfur crystals

- Sicily -

Sulfur is soluble in carbon disulphide and carbon tetrachloride but is insoluble in water. It burns in air with a blue flame to form sulfur dioxide gas and reacts with most elements to form stable compounds.

Pyrite
(iron sulfide)
Known as *Fool's* gold for its similarity of gold

S Sulfur , 16

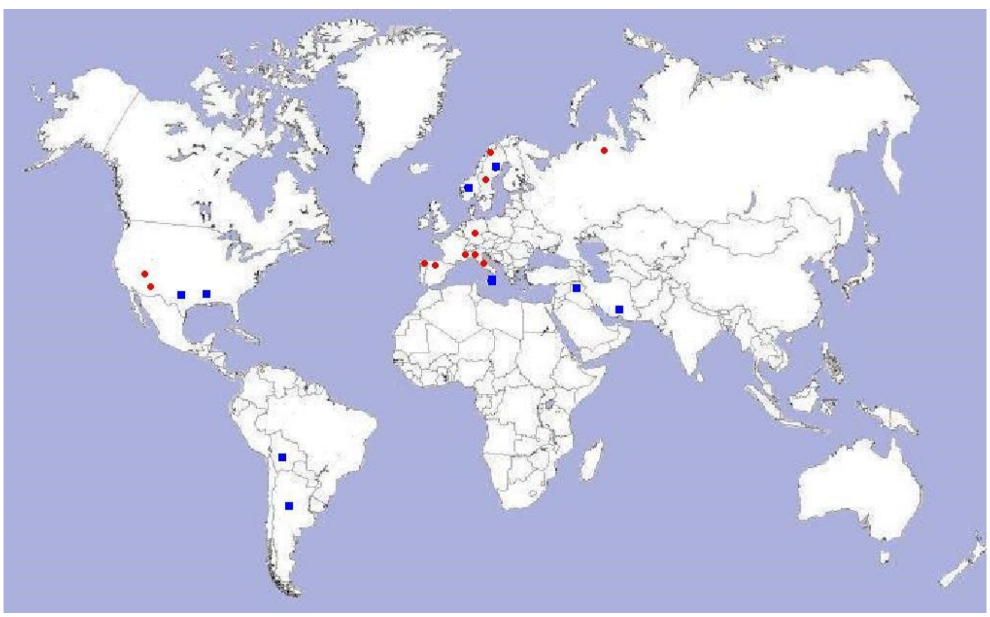
Elemental sulfur is used in hardening natural rubber (galvanization) and is usually a major component in ammunition, pesticides and fungicides formulations. It is also used in detergents, fertilizers, safety matches and for paper bleaching and preservation of dried fruits .

Sulfuric acid is ranked first in the global industrial production of chemicals. Its principal uses include petroleum refining, lead-acid automobile batteries, fertilizers ,and production of various chemicals.

Sulfur element is essential for many biological processes within the living cell. It is important for bone growth and is a principal component in the structure of animal and plant proteins.

The main dietary sources of sulfur include eggs, apricots, figs, onions, cabbage and beans.

Mineral ore locations



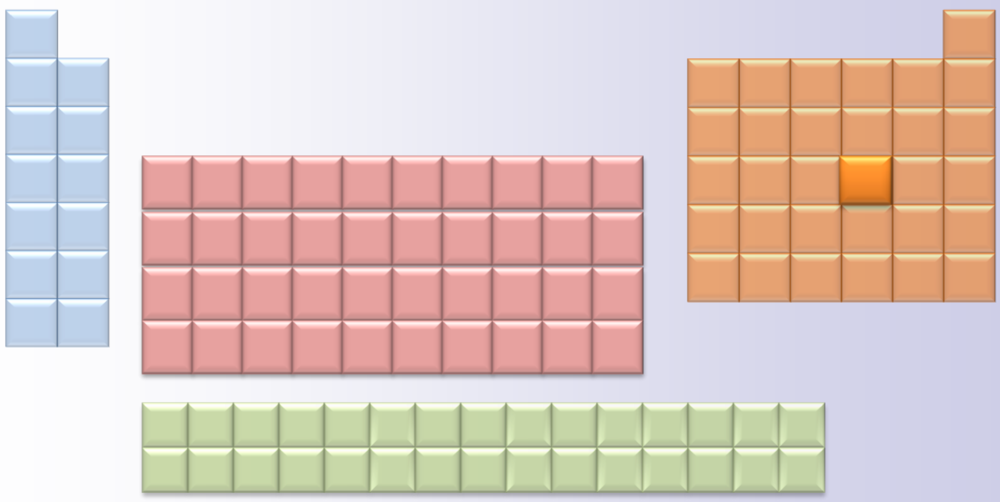
■ Native sulfur ● Iron pyrite

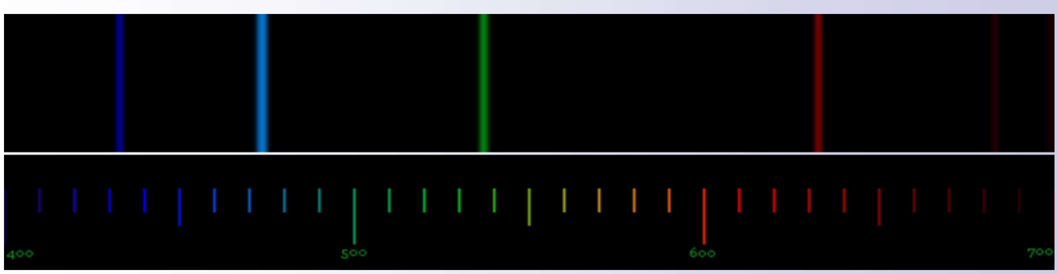
S Sulfur , 16

Physical and chemical properties

Symbol	S	Relative atomic mass	32.066
Atomic number	16	Melting point (ºC)	112
Group	16	Boiling point (ºC)	444.67
Period	3	Specific heat (J/g.K)	0.710
Family	Nonmetals	Oxidation numbers	-2, +2, +4, +6
Physical state(20°C)	solid	Electronegativity (pouling)	2.58
Atomic radius (pm)	104	Thermal conductivity (W/m.K)	0.269
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	1.23
Electronic configuration	$[Ne]3S^{2}3P^{4}$	Heat of vaporization (kJ/mol)	9.62
Molar volume(cm3/ mole,273K)	15.49	Ist. ionization potential (kJ/mole)	999.6
Density (g/cm3)	2.070	2nd.Ionization potential (kJ/mole)	2251
Number of isotopes	11	3rd. ionization potential (kJ/mol)	3361

Selenium Se





Selenium is a non-metallic element widely distributed in nature. It is similar to sulfur with respect to appearance, chemical properties and existence in a number of allotropic forms.

Selenium occurs naturally in sulfide ores, usually associated with silver, copper, lead and nickel minerals and is usually commercially obtained, as a by-product, of metallurgical , refining and industrial processes involving these elements. Electrolytic copper refining and Sulfuric acid manufacture are the most important in this respect.

Selenium is characterized by unique photoelectric properties (direct conversion of light into electrical energy) and photoconductivity (decrease in electrical resistance with increase of light intensity). Its conductivity could be increased 1000-fold if the element is moved from shadow to bright light.

The element also allows conversion of alternating electric current (AC) to direct current (DC). Thus, most of the commercial product of selenium is used in the electronics industry, especially in the manufacture of photovoltaic cells and resistors.

Selenium is added to components of glass, ceramics, paints, pesticides and rubber.

Grey and red allotropes of selenium

The element is essential to animal life and is a trace mineral incorporated in proteins to make selenoproteins which are antioxidant enzymes that play an important role in cell protection against many serious diseases in both humans and animals.

Major food sources of selenium include vegetables, brazil nuts, marine products, meat, beans, garlic and whole grains.

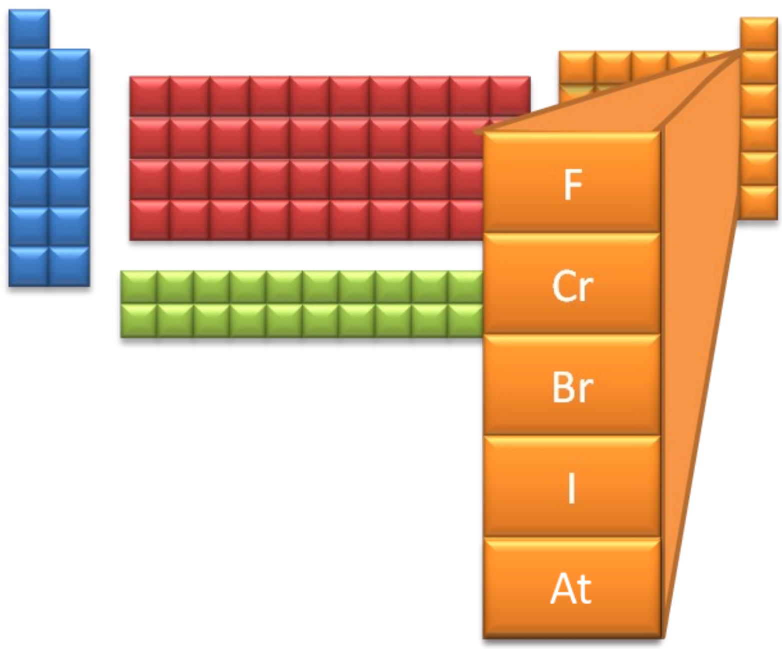
Grapes and garlic are natural sources of selenium

Se Selenium , 34

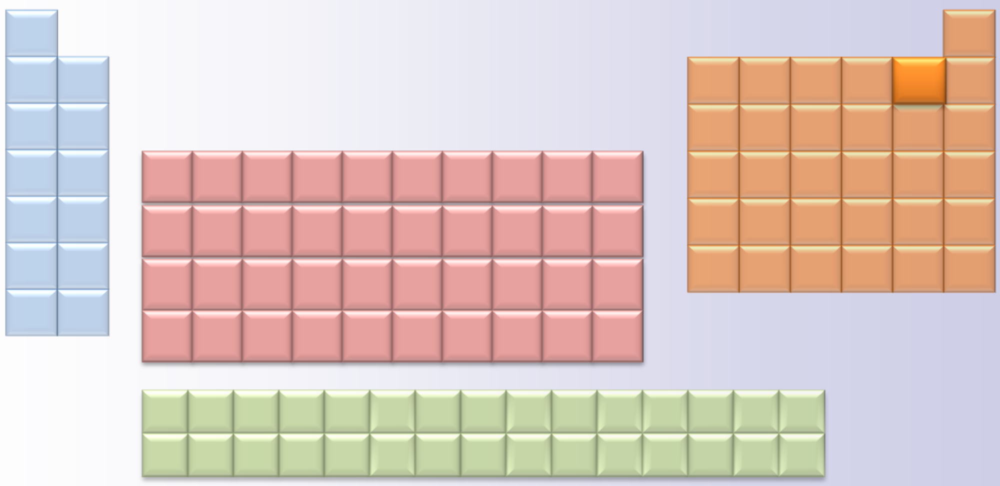
Physical and chemical properties

Symbol	Se	Relative atomic mass	78.96
Atomic number	34	Melting point (°C)	216
Group	16	Boiling point (°C)	684
Period	4	Specific heat (J/g.K)	0.321
Family	Nonmetals	Oxidation numbers	-2,+4,+6
Physical state(20°C)	solid	Electronegativity (pouling)	2.55
Atomic radius (pm)	215.2	Thermal conductivity (W/m.K)	2.04
Crystal structure	Simple monoclinic	Heat of fusion (kJ/mol)	5.1
Electronic configuration	$[Ar]3d^{10}4S^{2}4P^{4}$	Heat of vaporization (kJ/mol)	37.7
Molar volume(cm3/mole,273K)	16.48	Ist. ionization potential (kJ/mole)	940.9
Density (g/cm3)	4.790	2nd.Ionization potential(kJ/mole) (kJ/mole)	2044
Number of isotopes	26	3rd. ionization potential (kJ/mol)	2974

HALOGENS



Fluorine F



Fluorine is a pale yellow corrosive gaseous halogen. It is the 13th most abundant element in the earth's crust and it occurs naturally –only chemically combined- in a number of ore minerals but mostly in the fluorescent mineral fluorspar (fluorite).

The pure elemental gas is industrially obtained through the electrolysis of a molten mixture of hydrogen fluoride and potassium fluoride where fluorine is evolved at the anode and hydrogen at the cathode.

Fluorine is the most electronegative and the most chemically active element. It is a powerful oxidizing agent and it reacts vigorously with all organic and inorganic compounds including metals, glass, ceramics, carbon and even water. It combines directly with all elements except helium, neon and argon.

Important commercial applications of fluorine include the industrial preparation of high temperature plastics and the production of hydrofluoric acid which has the ability to dissolve sand and glass.

Other applications include the production of Fluorochlorohydrocarbons (freons) which are characterized by chemical inertness and heat resistance.

Freons are widely used in air conditioning and refrigeration and are considered among the major factors of environmental pollution.

Sodium fluoride is used in wood preservatives and in pesticides formulations, and is the starting material for many other commercial fluorochemicals.

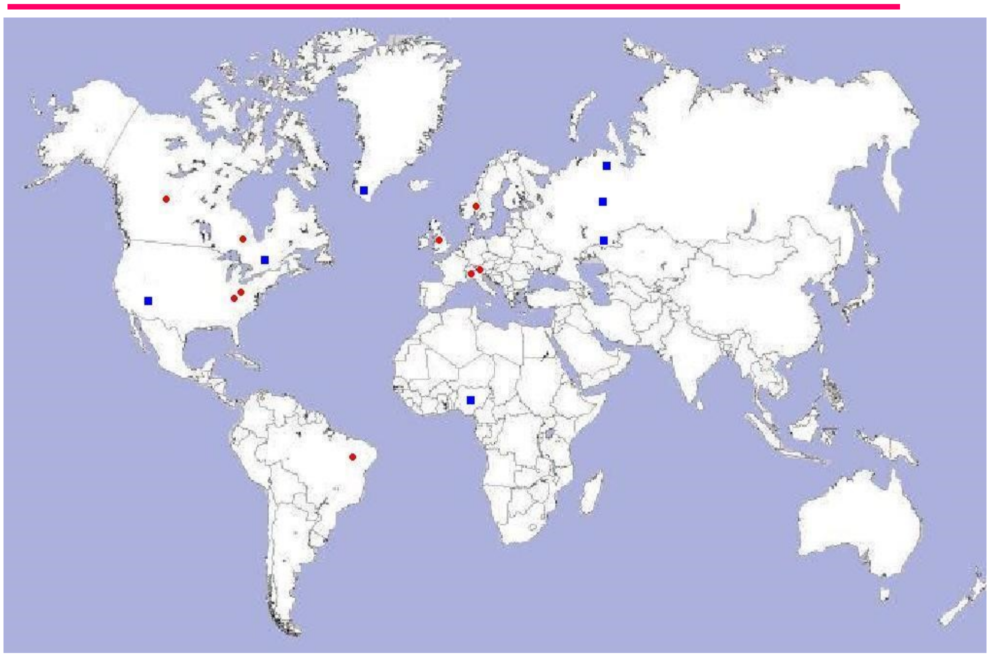
Fluorite
-France-

F Fluorine , 9

Elemental fluorine is highly toxic and its characteristic pungent and suffocating odor can be felt in concentrations less than 20 parts per billion parts of air (allowed levels are 1 - 5 ppm). On the other hand fluorine (in the form of fluoride), is an essential component in the composition of teeth and bone tissue. The use of fluoride in community drinking water (about 1 ppm) and in dietary supplements and tooth paste is recommended by scientific and public health organizations for prevention of dental caries (tooth decay).

Fish and sea products, raw salt, fluorinated city water and tea leaves are the major food sources of fluorine.

Mineral ore locations



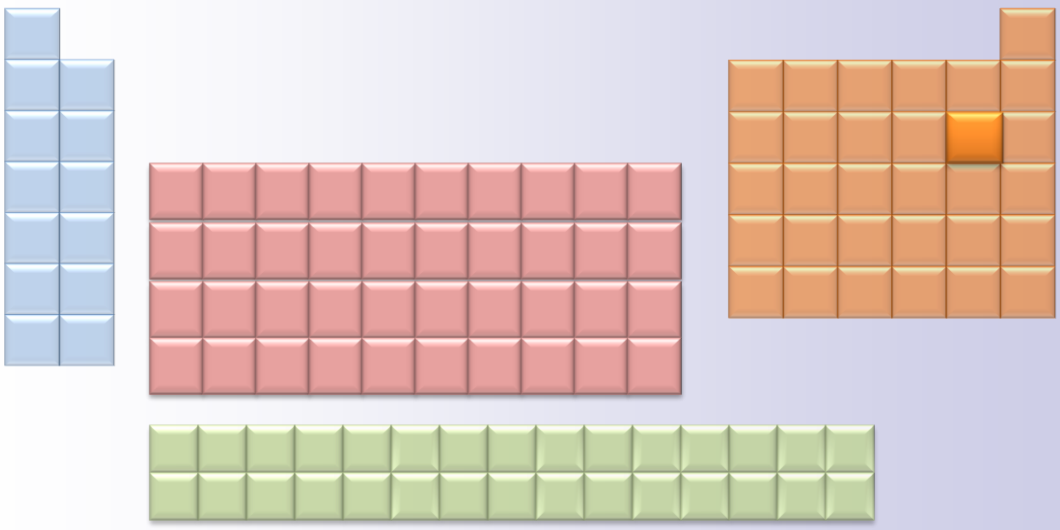
● Fluorspar ■ Cryolite

F Fluorine , 9

Physical and chemical properties

Symbol	F	Relative atomic mass	18.998
Atomic number	9	Melting point (°C)	-219.62
Group	17	Boiling point (°C)	-188.14
Period	2	Specific heat (J/g.K)	0.824
Family	Halogens	Oxidation numbers	-1, +7
Physical state(20°C)	Gas	Electronegativity (pouling)	3.98
Atomic radius (pm)	70.9	Thermal conductivity (W/m.K)	0.0279
Crystal structure	Base centered monoclinic	Heat of fusion (kJ/mol)	5.10
Electronic configuration	$^{5}1S2^{2}S^{2}2P$	Heat of vaporization (kJ/mol)	6.548
Molar volume(cm3/ mole,273K)	18.05	Ist. ionization potential (kJ/mole)	1681
Density (g/cm3)	1.516	2nd.Ionization potential (kJ/mole)	3374
Number of isotopes	7	3rd. ionization potential (kJ/mol)	6050

Chlorine Cl



Chlorine is a greenish - yellow gaseous halogen which can easily be liquefied by increasing the pressure at room temperature. It is an irritating and highly poisonous gas detectable as an odor at levels of 3.5 ppm.

Chlorine occurs naturally – in a chemically combined form only- in a number of compounds, but chiefly as sodium chloride (in sea water and in halite mineral) and as potassium chloride. It is chemically very active and combines directly with all elements except carbon, nitrogen, oxygen and the noble gases.

The gas is industrially prepared by the electrolysis of sodium chloride solution (sea water or brine). Caustic soda (sodium hydroxide) and hydrogen are obtained as by-products of the process. Chlorine is also obtained, as a by-product, of sodium metal production by the electrolysis of molten sodium chloride in Downs cell.

Chlorine is extensively used in the production of petroleum products, paper products, textiles, pharmaceutical products, plastic polymers, chemicals, food products and many other consumer products. It is widely used in sanitation of urban water and waste water treatment.

Calcium hypochlorite is an effective bleach and a sterilizer and . It is widely used in water purification. Sodium hypochlorite is a strong oxidizing agent and is used in cleaning and sterilization.

House-hold bleaches contain 3—5 % sodium hypochlorite. These solutions are heat sensitive and will lose sterilizing properties at temperatures above 40°C or on dilution with water or acids.

Chlorine was used as a war gas in the First World War (1914-1918). The highly toxic gas is not safe in concentrations exceeding one part per million parts of air (1 ppm).

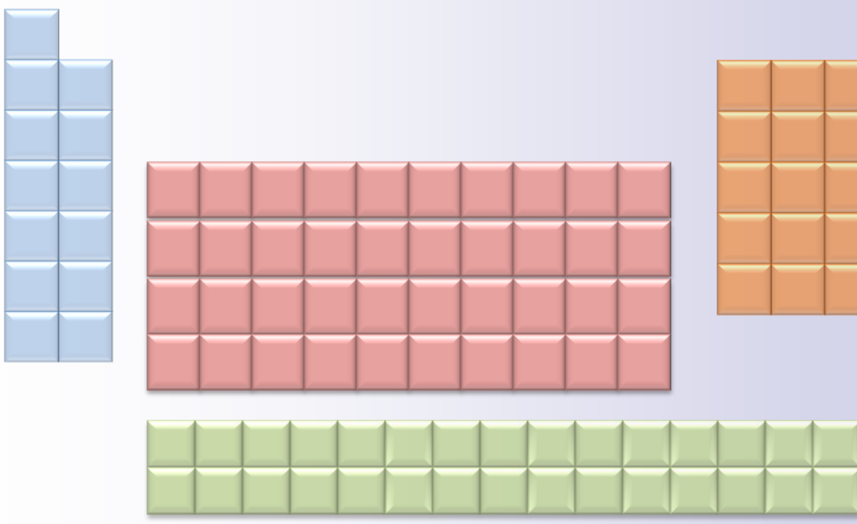
Liquid chlorine

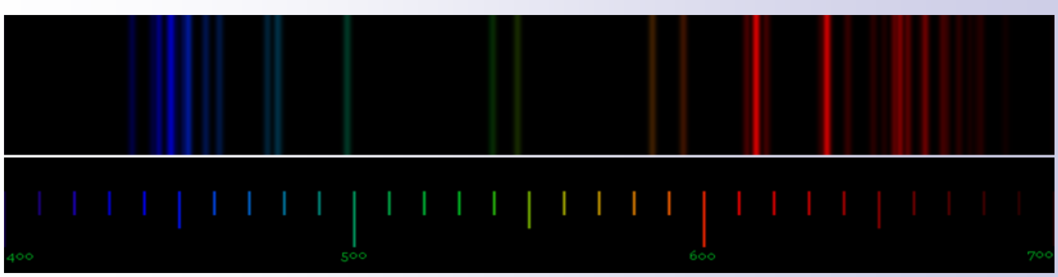
Cl Chlorine , 17

Physical and chemical properties

Symbol	Cl	Relative atomic mass	35.453
Atomic number	17	Melting point (ºC)	-100.95
Group	17	Boiling point (ºC)	-34.55
Period	3	Specific heat (J/g.K)	0.479
Family	Halogens	Oxidation numbers	-1,+1,+3,+5,+7
Physical state(20°C)	Gas	Electronegativity (pouling)	3.16
Atomic radius (pm)	99.4	Thermal conductivity (W/m.K)	0.0089
Crystal structure	Base centered Or-thorhombic	Heat of fusion (kJ/mol)	6.41
Electronic configuration	$[Ne]3S^{2}3P^{5}$	Heat of vaporization (kJ/mol)	20.4033
Molar volume(cm3/ mole,273K)	17.46	Ist. ionization potential (kJ/mole)	1251.1
Density (g/cm3)	2.030	2nd.Ionization potential (kJ/mole)	2297
Number of isotopes	13	3rd. ionization potential (kJ/mol)	3826

Bromine Br





Bromine is a dark red, heavy halogen characterized by red poisonous and suffocating vapors. It is the only nonmetallic element that exists in the liquid state in normal conditions.

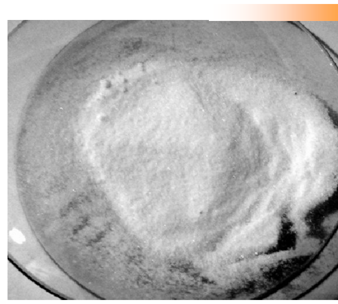
Iodine is rare in the earth's crust but is available in sea water and salt lakes from which it is commercially extracted (together with iodine which is present in the same source) through oxidation with chlorine gas.

Bromine is chemically very active (less active than fluorine and chlorine but more active than iodine). It dissolves in alcohol, ether and carbon disulfide and behaves in aqueous solutions as a strong oxidizing agent (bromine water). It reacts with many elements- including other halogens- to form bromides and reacts rapidly with unsaturated organic compounds.

Bromine

Bromine compounds are used in pesticides, in fire retardants and in the field of photography and pharmaceutical industry.

Potassium bromate is a white solid salt. It is a toxic and a powerful oxidizing agent but is readily disintegrated by heat. It has been widely used to improve the quality of bread and pastry before being assigned as a cancer-causing substance. Its use as a food additive was prohibited in Europe in 1990 and later in most other countries.



Potassium bromate

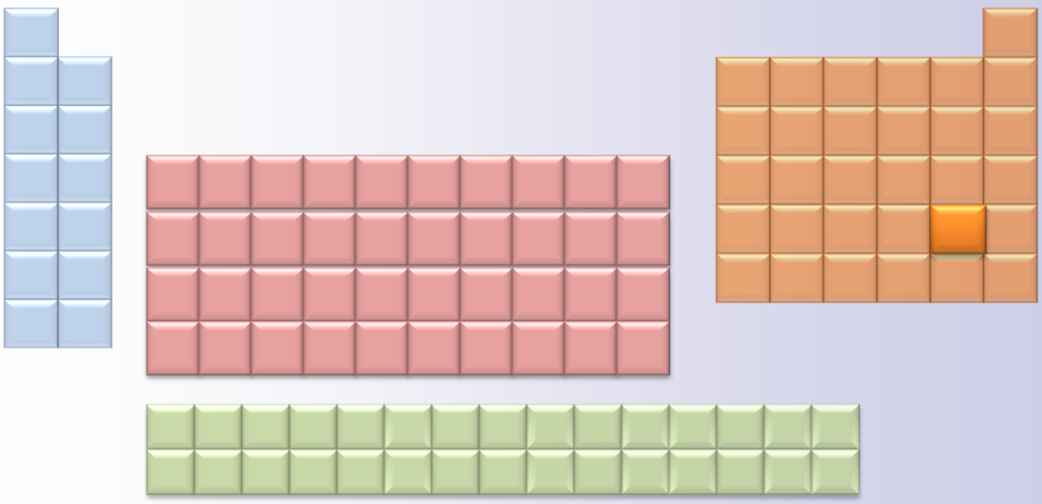
A white salt which is toxic, carcinogenic and a powerful oxidizing agent

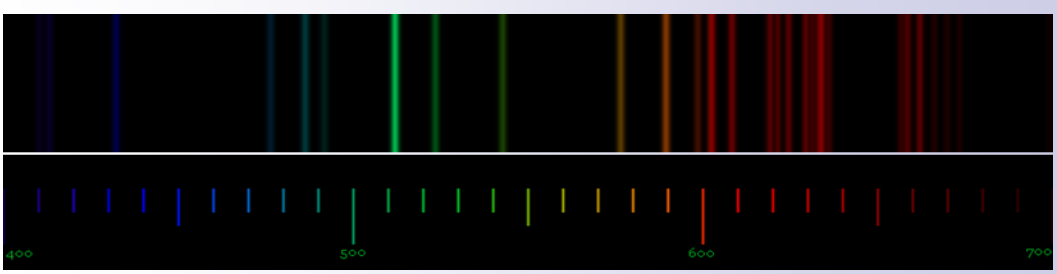
Br Bromine , 35

Physical and chemical properties

Symbol	Br	Relative atomic mass	79.904
Atomic number	35	Melting point (°C)	-7.25
Group	17	Boiling point (°C)	58.75
Period	4	Specific heat (J/g.K)	0.226
Family	Halogens	Oxidation numbers	-1,+1,+5,+7
Physical state(20°C)	Liquid	Electronegativity (pouling)	2.96
Atomic radius (pm)	114.5	Thermal conductivity (W/m.K)	0.122
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	10.8
Electronic configuration	$[Ar]3d^{10}4S^{2}4P^{5}$	Heat of vaporization (kJ/mol)	30.0
Molar volume(cm3/ mole,273K)	19.73	Ist. ionization potential (kJ/mole)	1139.9
Density (g/cm3)	4.050	2nd.Ionization potential (kJ/mole)	2104
Number of isotopes	28	3rd. ionization potential (kJ/mol)	3500

Iodine I





Iodine is a dark-blue and shiny solid halogen that volatilizes at room temperature with characteristic blue-violet irritating fumes.

It is rare in the earth's crust and is commercially recovered from sea water and salt lakes (together with bromine) through oxidation with chlorine gas.

Important compounds of iodine include sodium and potassium iodides and potassium iodate. The latter is used as a source of iodine in iodide salt and is administered in case of nuclear emergency to release safe iodine and block the absorption of radioactive iodine isotopes.

Sodium and potassium iodides are used in a number of drugs and are dissolved with iodine in alcohol to obtain an external disinfectant solution (iodine tincture).

The isotope iodine-127 is the only stable natural isotope of the element. Many other isotopes are artificially prepared with half-lives ranging from a few minutes to a few days. These radioisotopes are used on a large scale in applied scientific research and in the medical field particularly in the diagnosis and treatment of heart disease, pancreatic and thyroid disorders.

Iodine crystals

Iodine is essential to life and is a component of thyroxin hormone which is secreted by the thyroid gland. Deficiency of iodine causes inflation of the thyroid gland with serious disturbances in the body functions. The element is added to table salt and is commercially marketed as iodide salt to compensate for the lack of the element, especially in children.

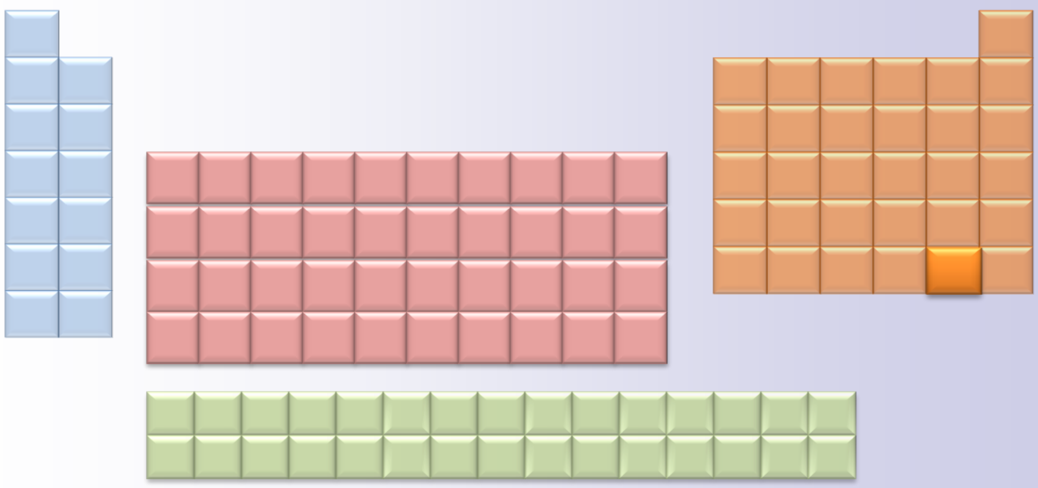
Seafood, eggs, vegetables and dairy products are the principal natural food sources for the element.

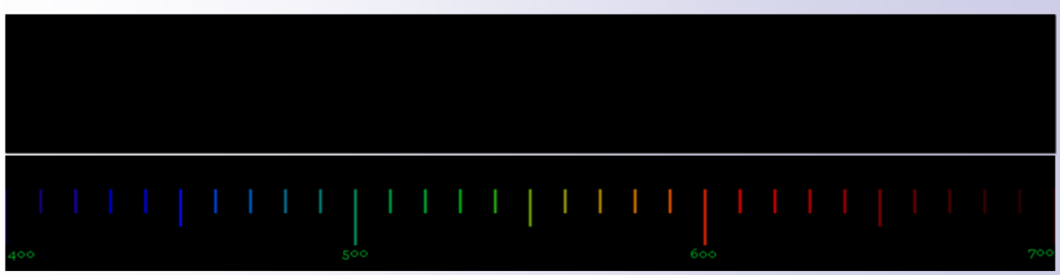
I Iodine , 53

Physical and chemical properties

Symbol	I	Relative atomic mass	126.904
Atomic number	53	Melting point (ºC)	113.55
Group	17	Boiling point (ºC)	184.35
Period	5	Specific heat (J/g.K)	0.145
Family	Halogens	Oxidation numbers	-1, +1, +5,+7
Physical state(20°C)	solid	Electronegativity (pouling)	2.66
Atomic radius (pm)	133.1	Thermal conductivity(W/m.K)	0.449
Crystal structure	Orthorhombic	Heat of fusion (kJ/mol)	15.27
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{5}$	Heat of vaporization (kJ/mol)	41.67
Molar volume (cm3/mole,273K)	25.74	Ist. ionization potential (kJ/mole)	1008.4
Density (g/cm3)	4.930	2nd.Ionization potential (kJ/mole)	1845.9
Number of isotopes	37	3rd. ionization potential (kJ/mol)	3200

Astatine At





Astatine is a radioactive solid halogen predicted and described by Mendeleev in 1868. Its natural occurrence as short-lived isotopes is attributed to the spontaneous radioactive decay of uranium and thorium isotopes.

The element was artificially prepared in 1940 by bombarding bithmus-209 with alpha particles (helium nuclei) to yield a number of short-lived isotopes of astatine.

Thirty three known isotopes of astatine are known. All are radioactive with atomic masses ranging from 191 to 223 atomic mass units.

Astatine-210 and astatine-211 are the most important isotopes of the element with half-lives of 8 and 7 hours respectively.

There are no special uses of astatine except in pure scientific research. This is due its rarity and inertness and to the short lives of all its isotopes (the most stable isotope of element is astatine -210).

Astatine is inert and rare in nature.

Astatine -210 with a half-life of 8 hours is the most stable isotope of the element

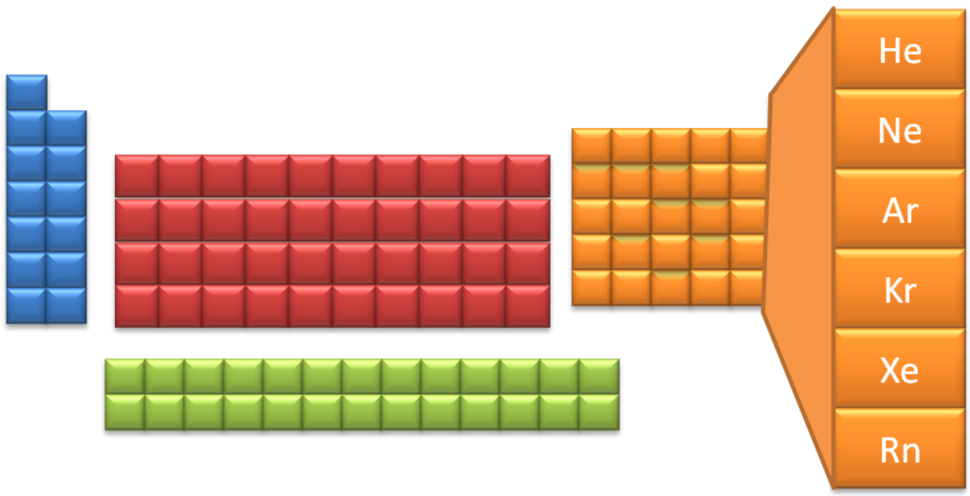
At Astatine , 83

Physical and chemical properties

Symbol	At	Relative atomic mass	209.987
Atomic number	85	Melting point (°C)	301.85
Group	17	Boiling point (°C)	336.85
Period	6	Specific heat (J/g.K)	####
Family	Halogens	Oxidation numbers	-1, +1, +5, +7
Physical state(20°C)	solid	Electronegativity (pouling)	2.2
Atomic radius (pm)	145	Thermal conductivity (W/m.K)	1.7
Crystal structure	####	Heat of fusion (kJ/mol)	23.8
Electronic configuration	[Xe] $4f^{14}5d^{10}6S^{2}6P^{5}$	Heat of vaporization (kJ/mol)	####
Molar volume (cm3/mole,273K)	####	Ist. ionization potential (kJ/mole)	930
Density (g/cm3)	####	2nd.Ionization potential l(kJ/mole)	1600
Number of isotopes	33	3rd. ionization potential (kJ/mol)	2900

Chapter 9

NOBLE GASES



Noble gases are the seven elements in group 18 of the periodic table. These elements were believed to be completely inert until the mid-twentieth century, when several compounds were successfully prepared particularly with fluorine and oxygen.

Noble gases are found in minute quantities in the atmosphere (except argon which is relatively abundant). They are colorless, odorless and tasteless and are all non-flammable and monatomic.

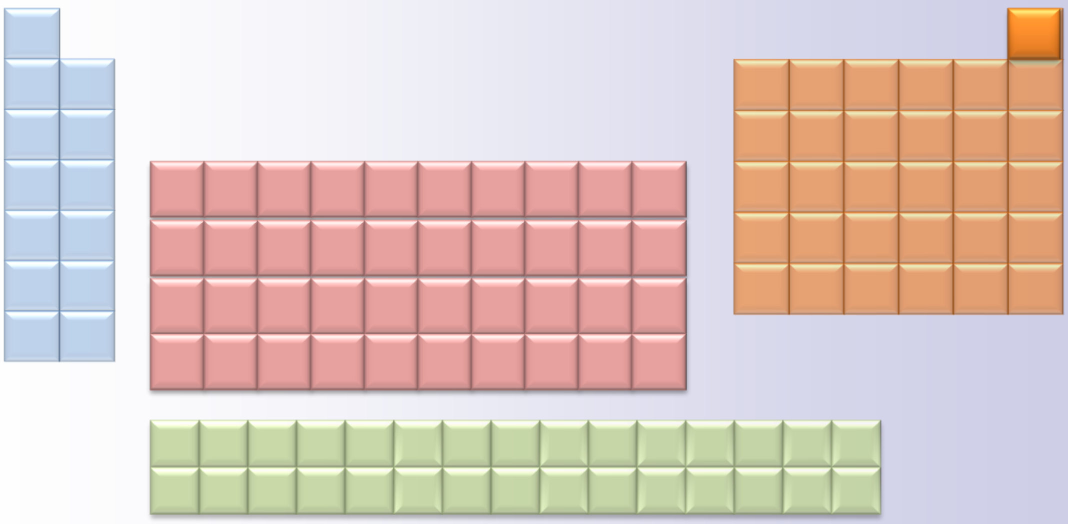
Noble gases include helium, neon, argon, krypton, xenon and radon.

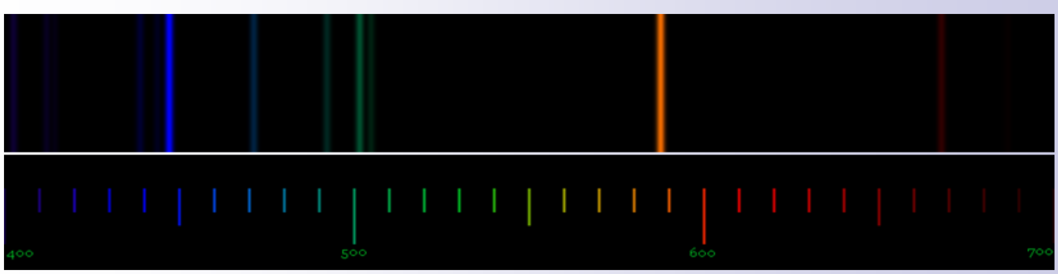
The main commercial uses are in the field of laser industry, and because they are chemically inert are also widely used to fill light bulbs and make protective shields during welding operations of air-sensitive metals.

Argon is the most abundant noble gas in the Earth's atmosphere and constitutes about 1% of the total mass of atmospheric air.

With the exception of helium, the principal commercial source of the noble gases is the fractional distillation processe of liquid air.

Helium He





Helium is a colorless, odorless and tasteless noble gas which is chemically inert and non-flammable. It was detected in the sun's spectrum in 1868 and then discovered on earth in 1895.

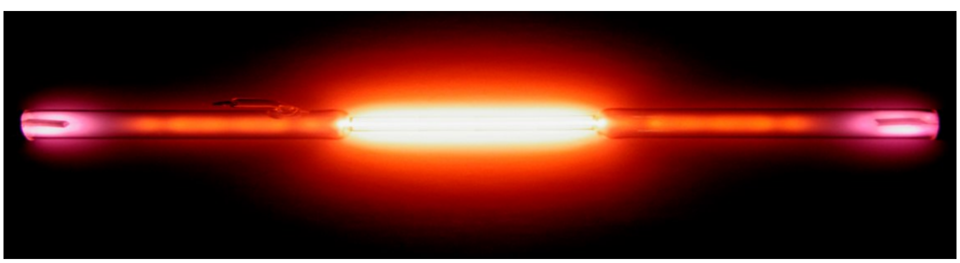
It is the most abundant element (after hydrogen) across the known universe, but the rarest element in the earth's atmosphere where it rates within one part per 200 thousand parts of atmospheric air.

Natural gas deposits are the principal commercial source of helium where it accumulates as a result of the continuous natural decay of uranium, thorium and other radioactive elements that release helium nuclei. The gas is isolated through fractional distillation after liquefaction of all the components of the gaseous mixture (helium is characterized by the lowest boiling point temperature of a substance).

Liquid helium is thus the coolest material known. It is used as a cryogenic refrigerant, and since it is not affected by radiation, it is utilized for cooling nuclear reactors.

Helium gas is used as a protective shield to prevent oxidation during welding of light metals such as magnesium and Aluminum. It is also used to dilute oxygen in deep- sea breathing kits (helium is nontoxic).

Although the density of helium is twice that of hydrogen, helium has a great lift force and its loading capacity is about 98% that of hydrogen. For this reason and also because it is safe and non-flammable , helium is the best substitute for hydrogen for use in the mobilization of balloons and air ships.



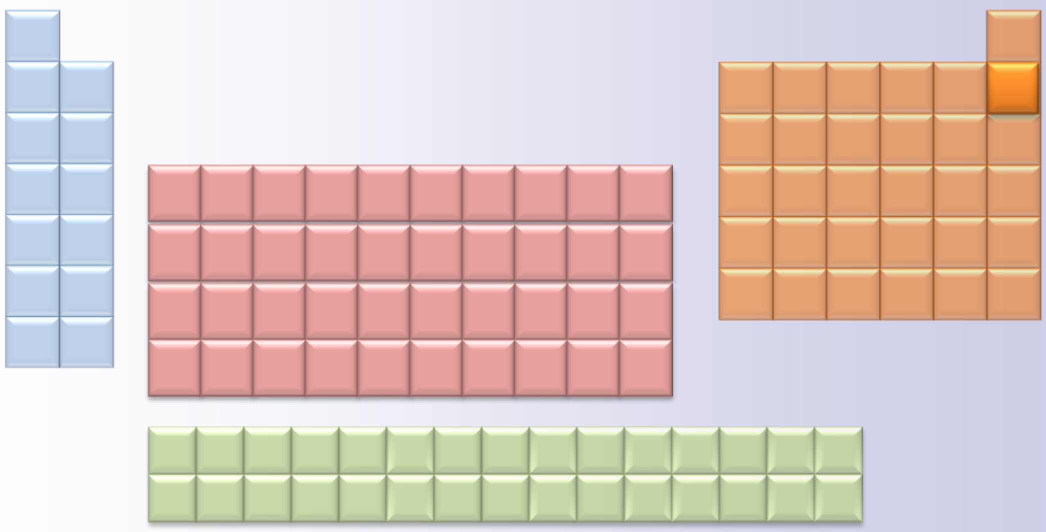
Helium discharge tube

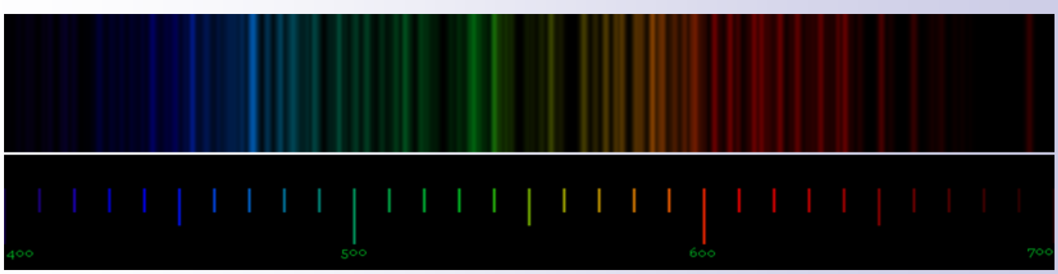
He Helium , 2

Physical and chemical properties

Symbol	He	Relative atomic mass	4.003
Atomic number	2	Melting point (ºC)	-272.2
Group	18	Boiling point (ºC)	-268.934
Period	1	Specific heat (J/g.K)	5.193
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	0
Atomic radius (pm)	128	Thermal conductivity (W/m.K)	0.152
Crystal structure	Hexagonal	Heat of fusion (kJ/mol)	0.021
Electronic configuration	$1S^2$	Heat of vaporization (kJ/mol)	0.082
Molar volume(cm3/ mole,273K)	32.07	Ist. ionization potential(kJ/mole)	2372.2
Density (g/cm3)	0.125	2nd.Ionization potential (kJ/mole)	5250.4
Number of isotopes	5	3rd. ionization potential (kJ/mol)	####

Neon Ne



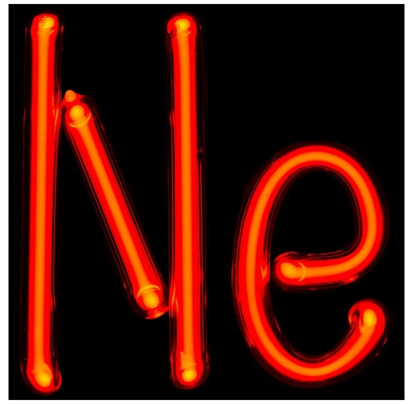


Neon is a colorless and odorless noble gas and is one of the rarest elements in the earth's atmosphere (accounting for about 0.0015% of atmospheric air).

Neon is an ideal noble gas and its scarcity in the earth's atmosphere is attributed to its chemical inertness and its low density. However, neon is one of the most abundant elements across the known universe.

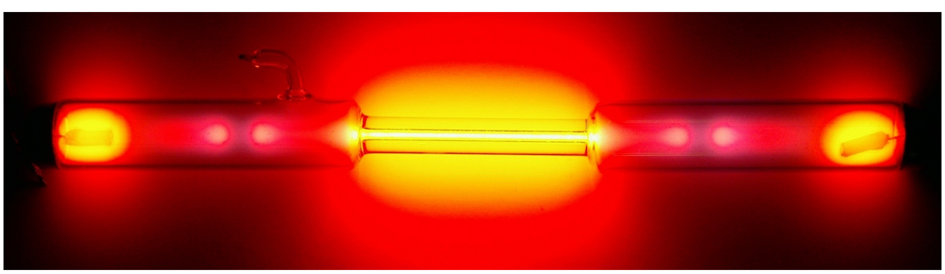
The gas is usually obtained (together with argon, krypton and xenon) as a by-product of the industrial processes of air liquefaction for production of oxygen and nitrogen. Gases are further purified by selective adsorption on activated charcoal.

Neon is used for cooling purposes and is used (with helium) to generate laser beams.



Neon is the least active noble gas and hence is the most inert among all the chemical elements.

Application of an electric discharge through neon gas under low pressure results in a distinctive red- orange glow used extensively in glowing neon signs and in tubes of visual display screens.



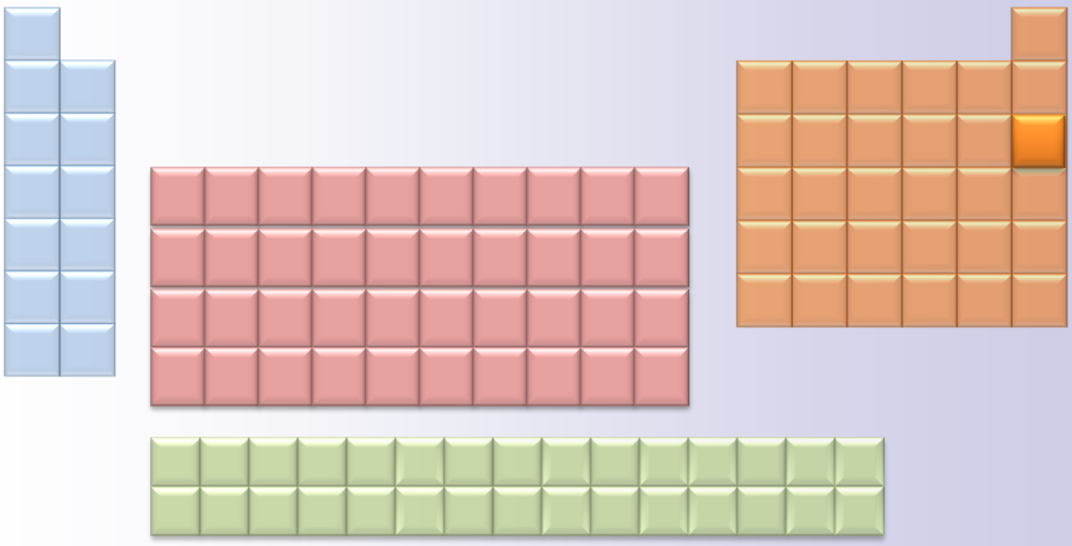
Neon discharge tube

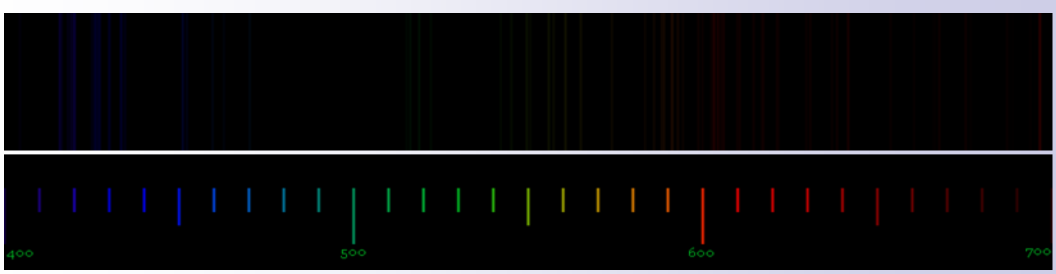
Ne Neon , 10

Physical and chemical properties

Symbol	Ne	Relative atomic mass	20.179
Atomic number	10	Melting point (°C)	-248.67
Group	18	Boiling point (°C)	-246.05
Period	2	Specific heat (J/g.K)	1.030
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	0
Atomic radius (pm)	154	Thermal conductivity (W/m.K)	0.0493
Crystal structure	Face centered Cubic	Heat of fusion (kJ/mol)	0.324
Electronic configuration	$[He]2S^2 2P^6$	Heat of vaporization (kJ/mol)	1.736
Molar volume (cm3/mole,273K)	13.97	Ist. ionization potential (kJ/mole)	2080.6
Density (g/cm3)	1.444	2nd.Ionization potential (kJ/mole)	3952.2
Number of isotopes	9	3rd. ionization potential (kJ/mol)	6122

Argon Ar



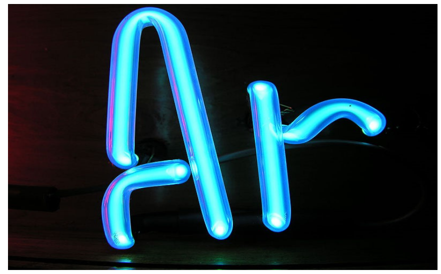


Argon is a colorless, odorless and tasteless noble gas and the first element to be discovered in the group (1893).

It is rather abundant in the earth's atmosphere and constitutes about 1% of the total mass of atmospheric air. It is thus, ranked first in the noble gas group and third among atmospheric gases (after nitrogen and oxygen).

The natural existence of argon is attributed to the natural degradation of potassium-40 isotope (this phenomenon is used to estimate the age of rocks).

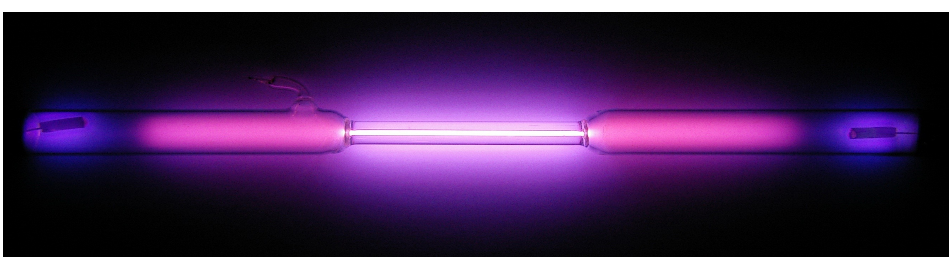
Argon is chemically inert and has no known stable compounds under normal conditions. The gas is commercially produced (along with other noble gases) as a by-product of the fractional distillation of liquid air and is further purified through adsorption and silica gel separation techniques.



Argon is used in vacuum tubes with mercury vapor to give a blue glow

Argon is the cheapest and most widely used noble gas. It is extensively used in light bulbs and in providing a protective shield during high – temperature metallurgical operations involving air-sensitive metals such as aluminum and steel.

Argon is used in laser production (the issuance of the light blue laser). The gas is particularly useful in fire-fighting operations involving articles which are sensitive to movement.



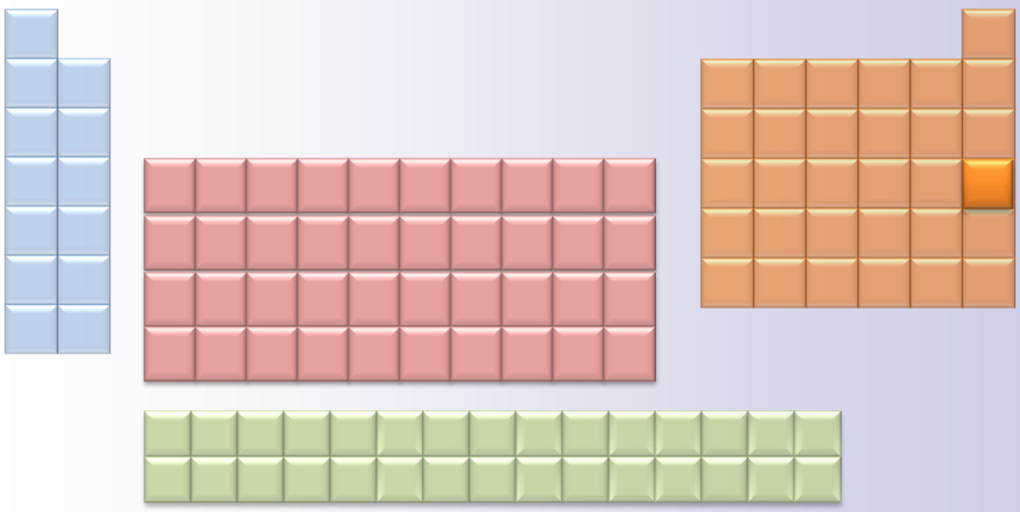
Argon discharge tube

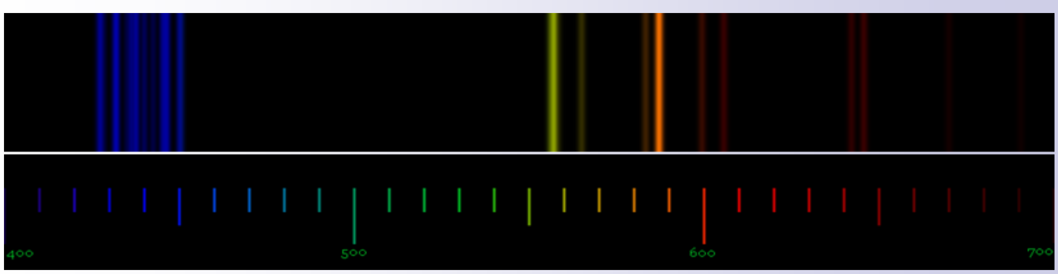
Ar Argon , 18

Physical and chemical properties

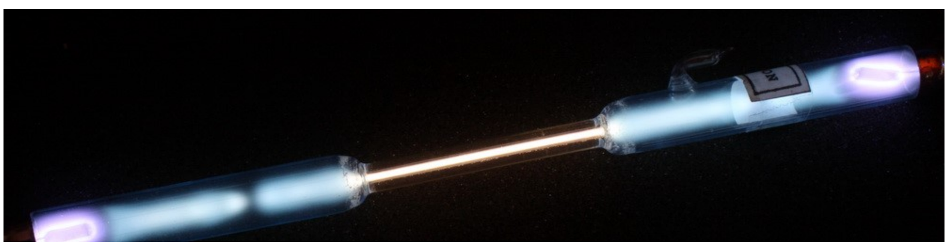
Symbol	Ar	Relative atomic mass	39.948
Atomic number	18	Melting point (ºC)	-189.35
Group	18	Boiling point (ºC)	-185.85
Period	3	Specific heat (J/g.K)	0.520
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	0
Atomic radius (pm)	174	Thermal conductivity (W/m.K)	0.0177
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	1.21
Electronic configuration	$[Ne]3S^2 3P^6$	Heat of vaporization (kJ/mol)	6.53
Molar volume (cm3/mole,273K)	24.12	Ist. ionization potential (kJ/mole)	1520.4
Density (g/cm3)	1.656	2nd.Ionization potential (kJ/mole)	2665.2
Number of isotopes	15	3rd. ionization potential (kJ/mol)	3928

Krypton Kr





Krypton is a colorless and odorless noble gas that constitutes one part per million parts of atmospheric air.
 The gas is commercially produced (along with other noble gases) as a by-product of fractional distillation of liquid air where nitrogen evaporates (-195 °C) with traces of oxygen and argon , leaving krypton (and xenon) with oxygen to be separated in further steps through fractional distillation, adsorption or silica gel separation techniques. Also a number of krypton radioisotopes are extracted from the remnants of furnace nuclear fuel.
 Krypton is not an ideal noble gas, and it was possible to perform a number of reactions and to successfully prepare some volatile compounds such as the polychlorinated fluoride which was prepared by several methods for use in the production of laser beams.
 Krypton gas is used (with argon) in the mobilization of fluorescent and incandescent lamps.
 Krypton-85, a radioactive isotope with a half-life of 10.76 years, was adopted in 1960 by the international union of units as a measure to identify the unit of length so that the length of one meter is equal to 1650,763.73 wavelengths (in vacuum) for the red-orange line of this isotope.
 The bright white light of ionized gas in the discharge tube is used in the field of photography and a mixture of krypton and xenon is used in incandescent lamps to extend the life of tungsten filament as it allows temperature rise and hence increases the power of light.



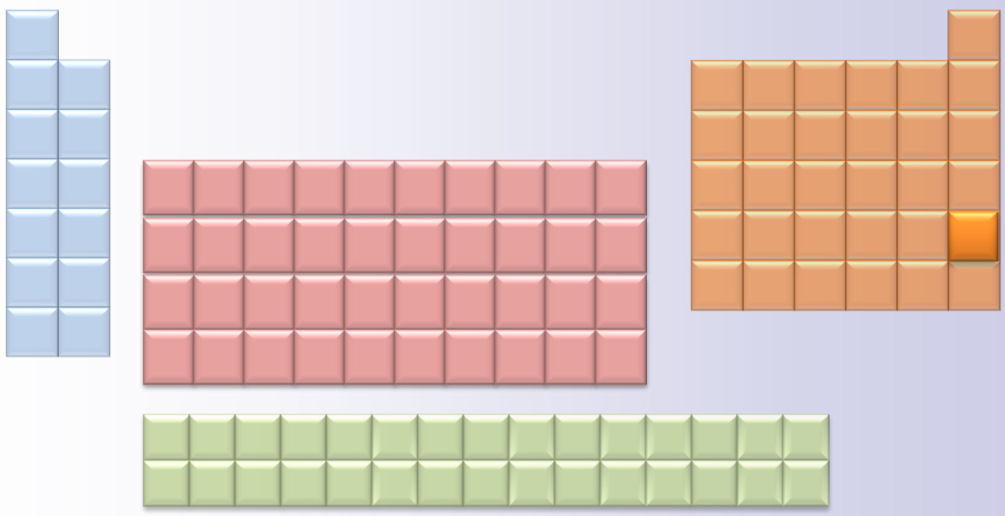
Krypton discharge tube

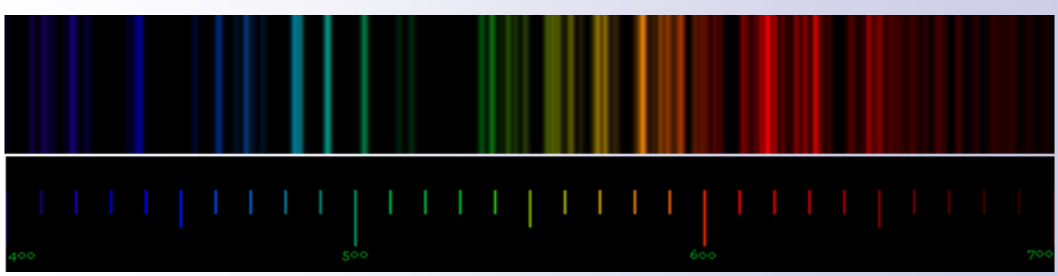
Kr Krypton , 36

Physical and chemical properties

Symbol	Kr	Relative atomic mass	83.80
Atomic number	36	Melting point (°C)	-156
Group	18	Boiling point (°C)	-152
Period	4	Specific heat (J/g.K)	0.248
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	0
Atomic radius (pm)	202	Thermal conductivity (W/m.K)	0.0095
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	1.64
Electronic configuration	$[Ar]3d^{10}4S^{2}4P^{6}$	Heat of vaporization (kJ/mol)	9.05
Molar volume(cm3/ mole,273K)	29.68	Ist. ionization potential (kJ/mole)	1450.7
Density (g/cm3)	2.823	2nd.Ionization potential (kJ/mole)	2350
Number of isotopes	27	3rd. ionization potential (kJ/mol)	3565

Xenon Xe

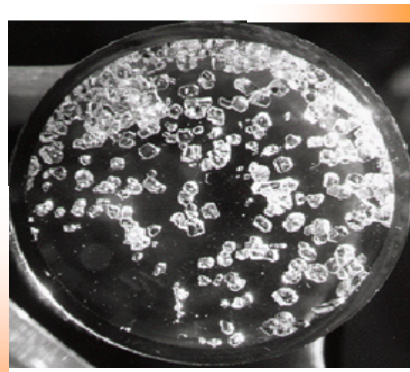




Xenon is a rare, colorless, odorless and heavy noble gas. It is estimated to contribute one part per 11 million parts of the earth's atmosphere. Minor impurities of the gas are present in emissions of mineral springs due to the spontaneous decay of uranium isotopes.

The gas is commercially produced (along with other noble gases) as a by-product of fractional distillation of liquid air where nitrogen evaporates (-195 °C) leaving xenon (with krypton) and oxygen to be separated in further steps through fractional distillation, adsorption or silica gel separation techniques.

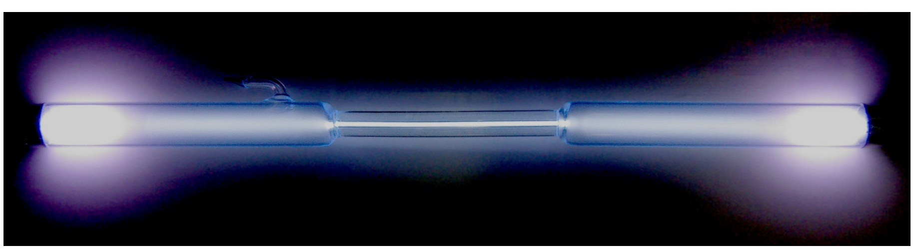
Xenon is not an ideal noble gas. It is inert towards most chemicals but it readily combines with oxygen to form xenon trioxide and xenon tetroxide which are both highly explosive.



Xenon tetrafluoride

Xenon also reacts with alkali metals and with fluorine to form fluorides that are readily hydrolyzed (decomposed in water) to produce an acidic solution containing xenon trioxide which is also an explosive compound.

Xenon is applied in medicine as a safe sedative and a general anesthetic .



Xenon discharge tube

A number of radioisotopes of xenon are used in radio-diagnosis. Xenon-133 is a beta and gamma emitter with a short half-life (5.3 days) is utilized in medical imaging.

Xenon gas is widely used in high intensity discharge xenon lamps which are used in photographic flashes and arc lamps for motion picture production. It is also used in high pressure arc lamps to produce ultraviolet light.

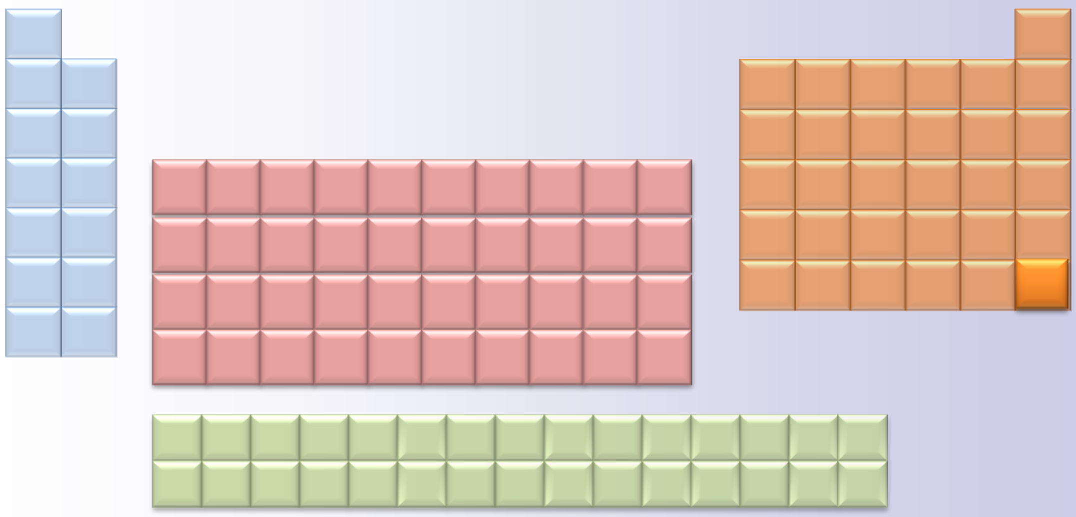
High intensity discharge xenon lamp emits light at the end of the violet end of the spectrum where the human eye is most sensitive at night

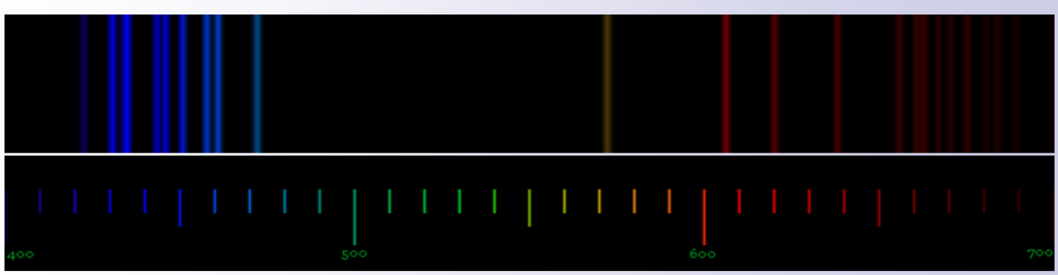
Xe Xenon , 54

Physical and chemical properties

Symbol	Xe	Relative atomic mass	131.29
Atomic number	54	Melting point (ºC)	-111.97
Group	18	Boiling point (ºC)	-107.05
Period	5	Specific heat (J/g.K)	0.158
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	0
Atomic radius (pm)	218	Thermal conductivity (W/m.K)	0.00569
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	3.1
Electronic configuration	$[Kr]4d^{10}5S^{2}5P^{6}$	Heat of vaporization (kJ/mol)	12.65
Molar volume(cm3/ mole,273K)	37.09	Ist. ionization potential (kJ/mole)	1170.4
Density (g/cm3)	3.540	2nd.Ionization potential (kJ/mole)	2046
Number of isotopes	35	3rd. ionization potential (kJ/mol)	3097

Radon Rn





Radon is a heavy radioactive noble gas discovered in 1900 . It is the least abundant noble gas and its natural occurrence is due to the spontaneous decomposition of radium and thorium radioisotopes. It is found, as traces, in the air and in water springs , and is usually extracted, as a by-product, from mining processes of uranium ores.

Radon is chemically inert. It is poisonous and is continuously emitted from the earth's crust, and - despite the low concentration in the air – it is one of the most persistent threats to the environment world –wide. The isotope radon-222 (half-life less than 4 days) is inhaled with air during the process of breathing and begins to decompose in a few minutes to form the solid isotope polonium-218 which is deposited within the tissues to act as a local source of destructive alpha radiation (helium nuclei).

Radon is hazardous because it is colorless, odorless, and tasteless gas, and also because it is heavy and chemically inert and unaffected by weather.

It escapes from natural sources to the atmosphere and is concentrated in low-lying areas and inside residential buildings (radon is the heaviest gaseous element and is more than 7 times heavier than air).

The presence of radon in the air is ranked second (after smoking) as a cause of lung cancer.

On the other hand, and due to the very short life of the isotope radon-222 (which is the longest-lived isotope of the element) radon is applied in some radiotherapy applications.

Radon is highly toxic and represents one of the major pollution threats in the environment world-wide.

Rn Radon , 86

Physical and chemical properties

Symbol	Rn	Relative atomic mass	222.018
Atomic number	86	Melting point (ºC)	-71.15
Group	18	Boiling point (ºC)	-61.75
Period	6	Specific heat (J/g.K)	0.094
Family	Noble gases	Oxidation numbers	0
Physical state(20°C)	Gas	Electronegativity (pouling)	####
Atomic radius (pm)	240	Thermal conductivity (W/m.K)	0.00364
Crystal structure	Face Centered Cubic	Heat of fusion (kJ/mol)	2.7
Electronic configuration	$[Xe]4f^{14}5d^{10}6S^{2}6P^{6}$	Heat of vaporization (kJ/mol)	18.1
Molar volume(cm3/ mole,273K)	50.5	Ist. ionization potential (kJ/mole)	1037.08
Density (g/cm3)	4.400	2nd.Ionization potential (kJ/mole)	####
Number of isotopes	34	3rd. ionization potential (kJ/mol)	####

APPENDICES

Appendix A: Tables

A 1: Chemical elements sorted by Density (g cm^{-3})

1	Hydrogen	1	0.076×10^{-3}
2	Helium	2	0.125×10^{-3}
3	Nitrogen	7	1.026×10^{-3}
4	Neon	10	1.444×10^{-3}
5	Fluorine	9	1.516×10^{-3}
6	Argon	18	1.656×10^{-3}
7	Oxygen	8	2×10^{-3}
8	Chlorine	17	2.03×10^{-3}
9	Krypton	36	2.823×10^{-3}
10	Xenon	54	3.54×10^{-3}
11	Radon	86	4.4×10^{-3}
12	Lithium	3	0.534
13	Potassium	19	0.862
14	Sodium	11	0.971
15	Rubidium	37	1.532
16	Calcium	20	1.55
17	Magnesium	12	1.738
18	Phosphorus	15	1.82
19	Beryllium	4	1.8548
20	Cesium	55	1.873
21	Sulfur	16	2.07
22	Silicon	14	2.329
23	Boron	5	2.34
24	Strontium	38	2.54
25	Aluminum	13	2.698
26	Scandium	21	2.989
27	Carbon	6	3.513
28	Barium	56	3.594
29	Bromine	35	4.05
30	Yttrium	39	4.469
31	Titanium	22	4.54
32	Selenium	34	4.79
33	Iodine	53	4.93
34	Radium	88	5
35	Europium	63	5.243

A1: Chemical elements sorted by Density (g cm^{-3})

36	Germanium	32	5.323
37	Arsenic	33	5.78
38	Gallium	31	5.907
39	Vanadium	23	6.11
40	Lanthanum	57	6.145
41	Tellurium	52	6.24
42	Zirconium	40	6.506
43	Antimony	51	6.691
44	Praseodymium	59	6.773
45	Ytterbium	70	6.965
46	Neodymium	60	7.007
47	Zinc	30	7.133
48	Chromium	24	7.19
49	Promethium	61	7.22
50	Indium	49	7.31
51	Tin	50	7.13
52	Manganese	25	7.144
53	Samarium	62	7. 52
54	Iron	26	7.874
55	Gadolinium	64	7.9
56	Terbium	65	8.229
57	Cerium	58	8.24
58	Dysprosium	66	8.55
59	Niobium	41	8.57
60	Cadmium	48	8.65
61	Holmium	67	8.795
62	Cobalt	27	8.9
63	Nickel	28	8.902
64	Copper	29	8.96
65	Erbium	68	9.066
66	Polonium	84	9.32
67	Thulium	69	9.321
68	Bismuth	83	9.747
69	Lutetium	71	9.84
70	Actinium	89	10.06

A1: Chemical elements sorted by Density (g cm^{-3})

71	Molybdenum	42	10.22
72	Silver	47	10.5
73	Lead	82	11.35
74	Technetium	43	11.5
75	Thorium	90	11.72
76	Thallium	81	11.85
77	Palladium	46	12.02
78	Ruthenium	44	12.37
79	Rhodium	45	12.41
80	Curium	96	13.3
81	Hafnium	72	13.31
82	Mercury	80	13.546
83	Americium	95	13.67
84	Berkelium	97	14.79
85	Protactinium	91	15.37
86	Tantalum	73	16.654
87	Uranium	92	18.95
88	Tungsten	74	19.3
89	Gold	79	19.32
90	Plutonium	94	19.84
91	Neptunium	93	20.25
92	Rhenium	75	21.02
93	Platinum	78	21.45
94	Iridium	77	22.42
95	Osmium	76	22.59

A2: Chemical elements sorted by Boiling point (°C)

1	Helium	2	-272.2
2	Hydrogen	1	-259.14
3	Neon	10	-248.67
4	Fluorine	9	-219.62
5	Oxygen	8	-218.35
6	Nitrogen	7	-209.89
7	Argon	18	-189.35
8	Krypton	36	-156.55
9	Xenon	54	-111.85
10	Chlorine	17	-100.59
11	Radon	86	-71.15
12	Mercury	80	-38.78
13	Bromine	35	-7.25
14	Francium	87	26.85
15	Cesium	55	28.45
16	Gallium	31	29.78
17	Rubidium	37	39.05
18	Phosphorus	15	44.15
19	Potassium	19	63.65
20	Sodium	11	97.81
21	Sulfur	16	112.85
22	Iodine	53	113.55
23	Indium	49	156.17
24	Lithium	3	180.54
25	Selenium	34	216.16
26	Tin	50	231.968
27	Polonium	84	253.35
28	Bismuth	83	271.25
29	Astatine	85	301.85
30	Thallium	81	303.45
31	Cadmium	48	320.95
32	Lead	82	327.5
33	Zinc	30	419.58
34	Tellurium	52	449.55
35	Antimony	51	630.75

A2: Chemical elements sorted by Boiling point (°C)

36	Neptunium	93	639.85
37	Plutonium	94	640.85
38	Magnesium	12	648.85
39	Aluminum	13	660.35
40	Radium	88	699.85
41	Barium	56	728.85
42	Strontium	38	768.85
43	Cerium	58	798.85
44	Arsenic	33	816.85
45	Rubidium	37	821.85
46	Ytterbium	70	823.85
47	Calcium	20	838.85
48	Lanthanum	57	920.85
49	Praseodymium	59	930.85
50	Germanium	32	973.45
51	Americium	95	948.85
52	Silver	47	961.95
53	Neodymium	60	1020.85
54	Actinium	89	1046.85
55	Gold	79	1064.43
56	Samarium	62	1076.85
57	Copper	29	1083.45
58	Uranium	92	1132.35
59	Promethium	61	1167.85
60	Manganese	25	1243.85
61	Beryllium	4	1277.85
62	Gadolinium	64	1312.85
63	Terbium	65	1355.85
64	Silicon	14	1409.85
65	Dysprosium	66	1411.85
66	Nickel	28	1452.85
67	Holmium	67	1473.85
68	Cobalt	27	1494.85
69	Yttrium	39	1521.85
70	Erbium	68	1528.85

A2: Chemical elements sorted by Boiling point (°C)

71	Iron	26	1534.85
72	Scandium	21	1540.85
73	Thulium	69	1544.85
74	Palladium	46	1551.85
75	Titanium	22	1659.85
76	Lutetium	71	1662.85
77	Thorium	90	1749.85
78	Platinum	78	1771.85
79	Protactinium	91	1839.85
80	Zirconium	40	1851.85
81	Chromium	24	1856.85
82	Vanadium	23	1886.85
83	Rhodium	45	1965.85
84	Technetium	43	2171.85
85	Hafnium	72	2229.85
86	Boron	5	2299.85
87	Ruthenium	44	2309.85
88	Iridium	77	2409.85
89	Niobium	41	2467.85
90	Molybdenum	42	2616.85
91	Tantalum	73	2995.85
92	Osmium	76	3053.85
93	Rhenium	75	3179.85
94	Tungsten	74	3406.85
95	Carbon	6	3546.85

A3: Chemical elements sorted by Electrical Resistance (Ω m)

1	Silver	47	1.59×10^{-8}
2	Copper	29	1.68×10^{-8}
3	Gold	79	2.35×10^{-8}
4	Aluminum	13	2.67×10^{-8}
5	Calcium	20	3.43×10^{-8}
6	Beryllium	4	4.0×10^{-8}
7	Sodium	11	4.2×10^{-8}
8	Magnesium	12	4.38×10^{-8}
9	Rhodium	45	4.51×10^{-8}
10	Molybdenum	42	5.2×10^{-8}
11	Iridium	77	5.3×10^{-8}
12	Tungsten	74	5.65×10^{-8}
13	Zinc	30	5.92×10^{-8}
14	Potassium	19	6.15×10^{-8}
15	Cobalt	27	6.24×10^{-8}
16	Cadmium	48	6.83×10^{-8}
17	Nickel	28	6.84×10^{-8}
18	Ruthenium	44	7.6×10^{-8}
19	Osmium	76	8.12×10^{-8}
20	Indium	49	8.37×10^{-8}
21	Lithium	3	8.55×10^{-8}
22	Iron	26	9.17×10^{-8}
23	Platinum	78	10.6×10^{-8}
24	Palladium	46	10.8×10^{-8}
25	Tin	50	11.0×10^{-8}
26	Tantalum	73	12.45×10^{-8}
27	Rubidium	37	12.5×10^{-8}
28	Niobium	41	12.5×10^{-8}
29	Chromium	24	12.7×10^{-8}
30	Thorium	90	13.0×10^{-8}

A3: Chemical elements sorted by Electrical Resistance (Ω m)

31	Protactinium	91	17.7 $\times 10^{-8}$
32	Thallium	81	18.0 $\times 10^{-8}$
33	Rhenium	75	19.3 $\times 10^{-8}$
34	Cesium	55	20.0 $\times 10^{-8}$
35	Lead	82	20.65 $\times 10^{-8}$
36	Technetium	43	22.6 $\times 10^{-8}$
37	Strontium	38	23.0 $\times 10^{-8}$
38	Vanadium	23	24.8 $\times 10^{-8}$
39	Arsenic	33	26 $\times 10^{-8}$
40	Gallium	31	27 $\times 10^{-8}$
41	Ytterbium	70	29.0 $\times 10^{-8}$
42	Uranium	92	30.8 $\times 10^{-8}$
43	Hafnium	72	35.1 $\times 10^{-8}$
44	Antimony	51	39.0 $\times 10^{-8}$
45	Titanium	22	42.0 $\times 10^{-8}$
46	Zirconium	40	42.1 $\times 10^{-8}$
47	Barium	56	50 $\times 10^{-8}$
48	Promethium	61	50 $\times 10^{-8}$
49	Yttrium	39	57.0 $\times 10^{-8}$
50	Dysprosium	66	57 $\times 10^{-8}$
51	Lanthanum	57	57.10 $\times 10^{-8}$
52	Scandium	21	61.0 $\times 10^{-8}$
53	Neodymium	60	64.0 $\times 10^{-8}$
54	Praseodymium	59	68 $\times 10^{-8}$
55	Americium	95	68 $\times 10^{-8}$
56	Cerium	58	73 $\times 10^{-8}$
57	Thulium	69	79.0 $\times 10^{-8}$
58	Lutetium	71	79.0 $\times 10^{-8}$
59	Holmium	67	87.0 $\times 10^{-8}$
60	Erbium	68	87 $\times 10^{-8}$

A3: Chemical elements sorted by Electrical Resistance (Ω m)

61	Europium	63	90.0×10^{-8}
62	Samarium	62	94.0×10^{-8}
63	Mercury	80	94.1×10^{-8}
64	Radium	88	100×10^{-8}
65	Bismuth	83	106.8×10^{-8}
66	Terbium	65	114×10^{-8}
67	Neptunium	93	122×10^{-8}
68	Gadolinium	64	134.0×10^{-8}
69	Polonium	84	140×10^{-8}
70	Plutonium	94	146×10^{-8}
71	Manganese	25	185.0×10^{-8}
72	Carbon	6	1.375×10^{-5}
73	Silicon	14	0.001
74	Tellurium	52	4.36×10^{-3}
75	Selenium	34	0.01
76	Germanium	32	0.46
77	Boron	5	18000
78	Iodine	53	1.37×10^{7}
79	Phosphorus	15	1×10^{9}
80	Sulfur	16	2×10^{15}

A4: Chemical elements sorted by Thermal Conductivity (W m^{-1} k^{-1})

1	Radon	86	0.00364
2	Xenon	54	0.00569
3	Chlorine	17	0.0089
4	Krypton	36	0.00949
5	Argon	18	0.0177
6	Nitrogen	7	0.02598
7	Fluorine	9	0.0279
8	Neon	10	0.0493
9	Bromine	35	0.122
10	Helium	2	0.152
11	Hydrogen	1	0.1815
12	Phosphorus	15	0.235
13	Oxygen	8	0.2647
14	Sulfur	16	0.269
15	Iodine	53	0.449
16	Astatine	85	1.7
17	Selenium	34	2.04
18	Tellurium	52	2.35
19	Neptunium	93	6.3
20	Plutonium	94	6.74
21	Manganese	25	7.82
22	Bismuth	83	7.87
23	Mercury	80	8.34
24	Americium	95	10
25	Curium	96	10
26	Berkelium	97	10
27	Californium	98	10
28	Einsteinium	99	10
29	Fermium	100	10
30	Mendelevium	101	10
31	Nobelium	102	10
32	Lawrencium	103	10
33	Gadolinium	64	10.6
34	Dysprosium	66	10.7
35	Terbium	65	11.1

A4: Chemical elements sorted by Thermal Conductivity (W m^{-1} k^{-1})

36	Cerium	58	11.4
37	Actinium	89	12
38	Praseodymium	59	12.5
39	Samarium	62	13.3
40	Lanthanum	57	13.5
41	Europium	63	13.9
42	Erbium	68	14.3
43	Francium	87	15
44	Scandium	21	15.8
45	Holmium	67	16.2
46	Lutetium	71	16.4
47	Neodymium	60	16.5
48	Thulium	69	16.8
49	Yttrium	39	17.2
50	Promethium	59	17.9
51	Barium	56	18.4
52	Radium	88	18.6
53	Polonium	84	20
54	Titanium	22	21.9
55	Zirconium	40	22.7
56	Hafnium	72	23
57	Antimony	51	24.3
58	Boron	5	27
59	Uranium	92	27.6
60	Vanadium	23	30.7
61	Ytterbium	70	34.9
62	Strontium	38	35.3
63	Lead	82	35.3
64	Cesium	55	35.9
65	Gallium	31	40.6
66	Thallium	81	46.1
67	Protactinium	91	47
68	Rhenium	75	47.9
69	Arsenic	33	50
70	Technetium	43	50.6

A4: Chemical elements sorted by Thermal Conductivity (W m^{-1} k^{-1})

71	Niobium	41	53.7
72	Thorium	90	54
73	Tantalum	73	57.5
74	Rubidium	37	58.2
75	Germanium	32	59.9
76	Tin	50	66.6
77	Platinum	78	71.6
78	Palladium	46	71.8
79	Iron	26	80.2
80	Indium	49	81.6
81	Lithium	3	84.7
82	Osmium	76	87.6
83	Nickel	28	90.7
84	Chromium	24	93.7
85	Cadmium	48	96.8
86	Cobalt	27	100
87	Potassium	19	102.4
88	Zinc	30	116
89	Ruthenium	44	117
90	Molybdenum	42	138
91	Sodium	11	141
92	Iridium	77	147
93	Silicon	14	148
94	Rhodium	45	150
95	Magnesium	12	156
96	Tungsten	74	174
97	Beryllium	4	200
98	Calcium	20	200
99	Aluminum	13	237
100	Gold	79	317
101	Copper	29	401
102	Silver	47	429
103	Carbon (Diamond)	6	990-2320

Appendix B: Glossary

Alfa Particle (α): A helium nucleus emitted in radioactive decay

Allotropes: Different structural modifications of the same element.

Annihilation: A process in which a subatomic particle collides with its corresponding antiparticle, vanish and reappear in some other form that has equivalent energy.

Antimatter: Material made from antiparticles.

Antiparticle: **A** particle with the same mass of a matter particle but opposite values of charges. An anti-electron for example is the positron which has a positive charge

Atomic Mass : The mass (in atomic mass units) of protons and neutrons in a nucleus of an element.

Atomic Mass Unit (*amu*): 1/12 of the mass of the isotope carbon-12 which is assigned a value of 12.0000 amu.

Atomic Number: The number of protons in the nuclei of the isotopes of a particular element

Atomic Radius: An estimation of the size of an atom which is assumed to be spherical. It is equal to half the distance between atoms for simple diatomic molecules.

Atomic Spectra: light emission with characteristic frequencies (or wavelengths) emitted when an atom returns to the ground state after being excited by a flame or electric spark.

Atomic Weight (Relative Atomic Mass): The average value of the masses of all naturally occurring isotopes of an element.

Beta Particle (β): A negatively charged particle produced during radioactive emission as a high speed electron

Beta (β) Emission : A radioactive decay in which a beta particle is emitted

Baryon: A composite matter particle made from three quarks.

Big Bang Theory: The theory that assumes an origin of the universe before 10 to 20 billion years within an instant of a violent explosion (big bang) of an extremely dense matter at extremely high temperature and pressure

Boson: A particle such as a photon or gluon that obeys rules permiting any number of particles to occupy the same quantum state (opposite to fermions, boson have integer spin values) .

Cathodic Protection: . A technique used to protect metal structures from corrosion by connection to a sacrificial anode (a more electropositive metal). The steel structure acts as the cathode in the electrochemical cell while the (sacrificial) anode is gradually eroded leaving the metallic structure free of damage.

Coercivity : A measure of the strength of a magnetic field. It is equal to the intensity of the applied magnetic field required to reduce the magnetization of a fully magnetized ferromagnetic material to zero.

Control Rods: Long tubes containing neutron-absorbing materials such as hafnium, samarium or boron inserted or withdrawn from the core of a nuclear reactor to control the rate of the nuclear chain reaction and sustain a smooth chain reaction.

Corrosion : Oxidation of metals in an electrochemical process that takes place in the presence of both water and oxygen (over one ampere for one year is enough for the erosion of 9 kg of iron).

Cracking: High temperature petroleum refining process that lead to the formation of small hydrocarbon molecules from large ones in the presence of certain catalysts.

Cosmology : The study of the history of the universe.

Cryogenics. Studies involving the production of very low temperatures (*below -150 degrees Celsius*) and the behavior of materials at these conditions.

Dark Matter: unverified matter believed to form most of the universe. It emits no radiation and is thus invisible. It is assumed that about 90% of the matter in a typical galaxy is dark.

Decay: see radioactive decay

Electronegativity: A measure of the tendency of an atom to attract a pair of electrons in a molecule and the main factor in the formation of chemical bonds between atoms.

Electrolytic Cell : A cell that uses an externally generated electric current to decompose chemical compounds through a nonspontaneous reaction.

Electronic Configuration: The arrangement of electrons in in the orbitals of an atom or molecule . An orbital represents the probability of finding an electron at a particular point in space. It is described by four numbers that indicate the energy level, the shape of the orbital, symmetry in space and spin.

Emission (*line*) Spectra: *See atomic spectra*

Fermion : A matter particle such as an electron or nucleon which is subject to Pauli exclusion principle(a fermion spin is an integer of ½ and thus no two fermions can occupy the same quantum level).

Ferromagnetism A property of some substances that possess a net magnetic moment as a result of the alignment of the magnetic moments of atoms. This alignment is disturbed on heating and ferromagnetism is lost above a specific temperature called the Cure point.

Fuel Rods : Long tubes (about 4 meters long) made of nuclear grade zirconium and contain nuclear fuel (usually uranium oxide) in nuclear reactors. Zirconium is hard, corrosion resistant and has low probability of neutron absorption.

Fuel Cell : A voltaic cell that can generate a continuous flow of electricity from the reaction of oxygen and hydrogen to produce water

Galvanic Cell : An electric cell that generates electrical energy from an irreversible chemical reaction.

Gamma Radiation : A high energy form of electromagnetic radiation emitted from a radioactive nucleus.

Gluon: The carrier particle of the strong interactions.

Half -life $t_{1/2}$ (*of a radioactive isotope*): Time required for a radioactive isotope to decrease by half.

Higgs Boson : the Higgs Boson (a hypothetical fundamental particle suggested by particle physics as a factor responsible for the mass of mater).

Hydrogenation: An industrial process in which molecular hydrogen is added to an element or compound usually in the presence of a catalyst.

Infra Red Light (IR) : Light with wave lengths longer than those of red light but shorter than microwaves, radio and TV waves.

Ionic Radius : An estimate of the size of an ion . It is equal to half the distance between a negative ion and an adjacent positive ion in a crystal lattice and is measured in either picometres (pm) or Angstrom (Å)

Ionization Energy : *See ionization potential.*

Ionization Potential Energy required to remove completely an electron from an atom which is turned into a positively charged ion. It reflects the degree of the binding energy of the electron in the outer orbit and hence the extent to which the atom will interact with other atoms.

Isotopes: Mixtures of atoms of the same element that exist naturally with slightly different masses. Isotopes have identical chemical properties but may have different physical properties particularly those associated with mass like boiling point .

IUPAC: The International Union of Pure and Applied Chemistry

Laser: Acronym for Light Amplification by Stimulated Emission of Radiation. A coherent light of a single color produced by a device using certain elements including noble gases and a number rare earth elements.

Lepton: A fundamental fermion that does not participate in strong interactions. Electrically-charged leptons include the electron (e^-) , the muon (μ) and their antiparticles. Electrically-neutral leptons are the neutrinos (ν).

LHC: The Large Hadron Collider at the CERN laboratory in Geneva, Switzerland. As the most powerful particle accelerator, LHC can facilitate collision of protons at a center-of-mass energy of about 14 TeV.

Mass Number : The number of nucleons (neutrons and protons) in a nucleus

Metallurgy : Different industrial operations that lead to he conversion of metal ores into metals

Meson: A hadron made from an even number of quark-antiquark constituents. The basic structure is usually one quark and one antiquark.

Moderator. Material used to cool the reactor core and slow down the fast neutrons produced in the fission reaction . The common moderator is water but graphite and heavy water are also applied.

Nitrogen Fixing Bacteria: A natural method of converting air nitrogen into plant available forms. Rhizobium types of soil bacteria living inside the nodules of leguminous plants, feed on plant sugars and convert air nitrogen into ammonia available form in a symbiotic relationship.

Nuclear Fussion: The combination of two small nuclei to form a larger nucleus resulting in the production of energy

Nuclear Binding Energy: The energy necessary to dissociate a nucleus into separate nucleons (protons and neutrons) or the energy that would be released when all the nucleons come together to form a nucleus.

Nuclear Fuel: Pellets of enriched uranium oxide arranged in long zirconium tubes (fuel rods) located in the reactor core to act as the fuel that runs the fission reaction in a nuclear reactor.

Nucleon: A subatomic particle that makes up a nucleus (a proton or a neutron)

Nuclear Fission: The splitting of a large unstable nucleus into two smaller nuclei resulting in the production of energy

Oxidation Number: An indication of the change in the number of electrons in the event of a chemical reaction.

Particle Accelerator: A device such as a cyclotron increase the kinetic energy of charged particles by accelerating particles to high speeds and direct them to cause high-energy collisions with other particles or nuclei.

Pauli Exclusion Principle: The principle that no two particles in the same quantum state may exist in the same place at the same time. Particles that obey this principle are called fermions; particles that do not are called bosons.

Quark (q): A fundamental matter particle (a fermion) with an electric charge of either +2/3 (up) or -1/3 (down q) in atomic mass units (amu).

Radioactive Decay: A process in which a radioactive isotope disappears while different (daughter) nuclides are being born.

Radioactive Decay Series: A series of elements formed from the successive emission of alpha and beta particles starting from a long- lived radioactive isotope (principally of uranium) and ending with a stable isotope of lead

Thermal Conductivity: Susceptibility to heat transfer through a body without a change in the crystal structure of the material.
Thermal conductivity is measured in watts per kelvin per metre ($W \cdot K^{-1} \cdot m^{-1}$).

Transmutaion: The changing of one element into another through a nuclear reaction

Ultra Violet light (UV): Electromagnetic waves with wavelengths(400 nm - 10 nm) shorter than those of violet light but longer than x-rays.

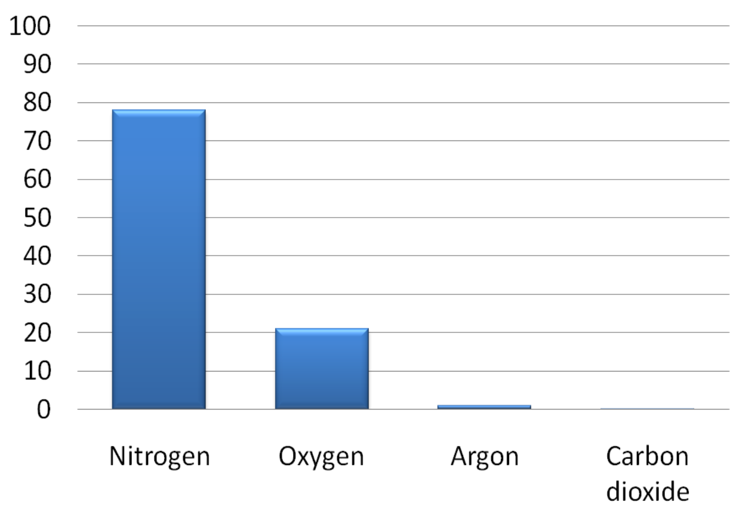
White Gold: An alloy of gold and one of the white metals such as nickel, palladium or silver. A common formulation of white gold consists of 90% gold and 10 % by weight of nickel.

White Metals: Metals that make up white metal alloys. Common white metals are nickel, palladium and silver together with manganese, antimony, tin, lead, cadmium, bismuth, and zinc.

Appendix C: Charts

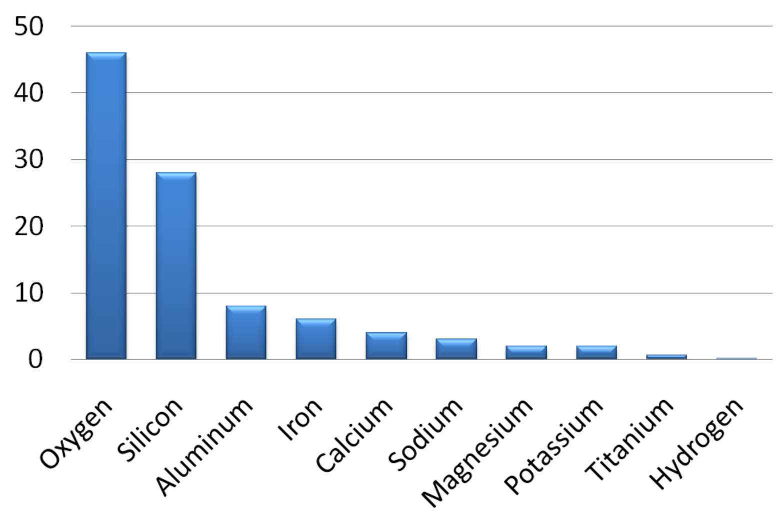
C1: COMPOSITION OF ATMOSPHERIC AIR AT SEA LEVEL

Element	by mass %
Nitrogen	78.08
Oxygen	20.94
Argon	0.94
Carbon dioxide	0.033
Neon	0.0018
Helium	0.0005
Krypton	0.0001
Xenon	0.000009
Radon	x10-186



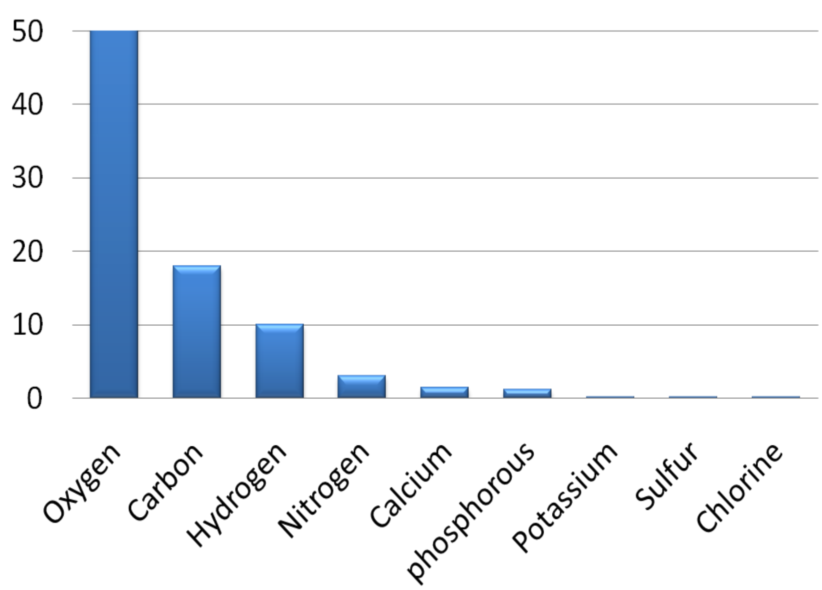
C2: THE MOST ABUNDANT ELEMENTS IN THE EARTH'S CRUST

Element	% By mass
Oxygen	46
Silicon	28
Aluminum	8
Iron	6
Calcium	4
Sodium	3
Magnesium	2
Potassium	2
Titanium	0.6
Hydrogen	0.1

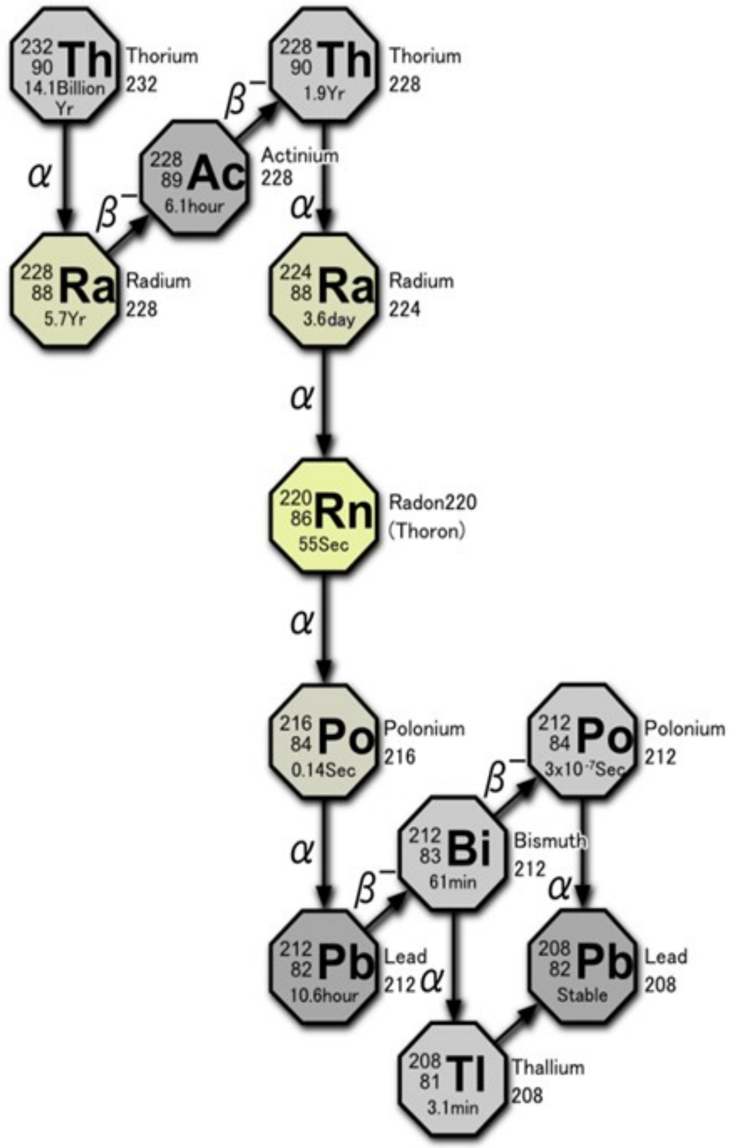


C3: MAJOR ELEMENTS IN THE HUMAN BODY

Element	% by mass
Oxygen	65
Carbon	18
Hydrogen	10
Nitrogen	3
Calcium	1.5
phosphorous	1.2
Potassium	0.2
Sulfur	0.2
Chlorine	0.2
Sodium	0.1
Magnesium	0.05
Iron	0.05 >
Cobalt	0.05 >
Copper	0.05 >
Zinc	0.05 >
Iodine	0.05 >
Selenium	0.01 >
Fluorine	0.01 >

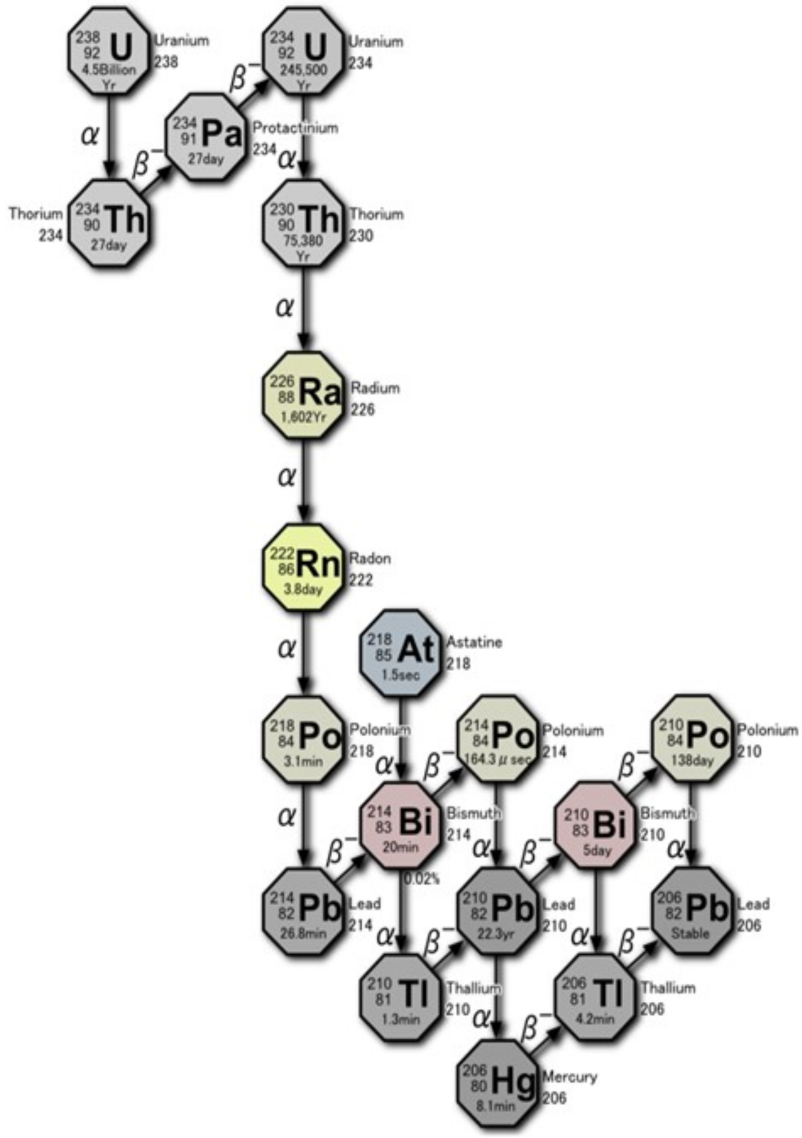


Appendix D: Natural decay series



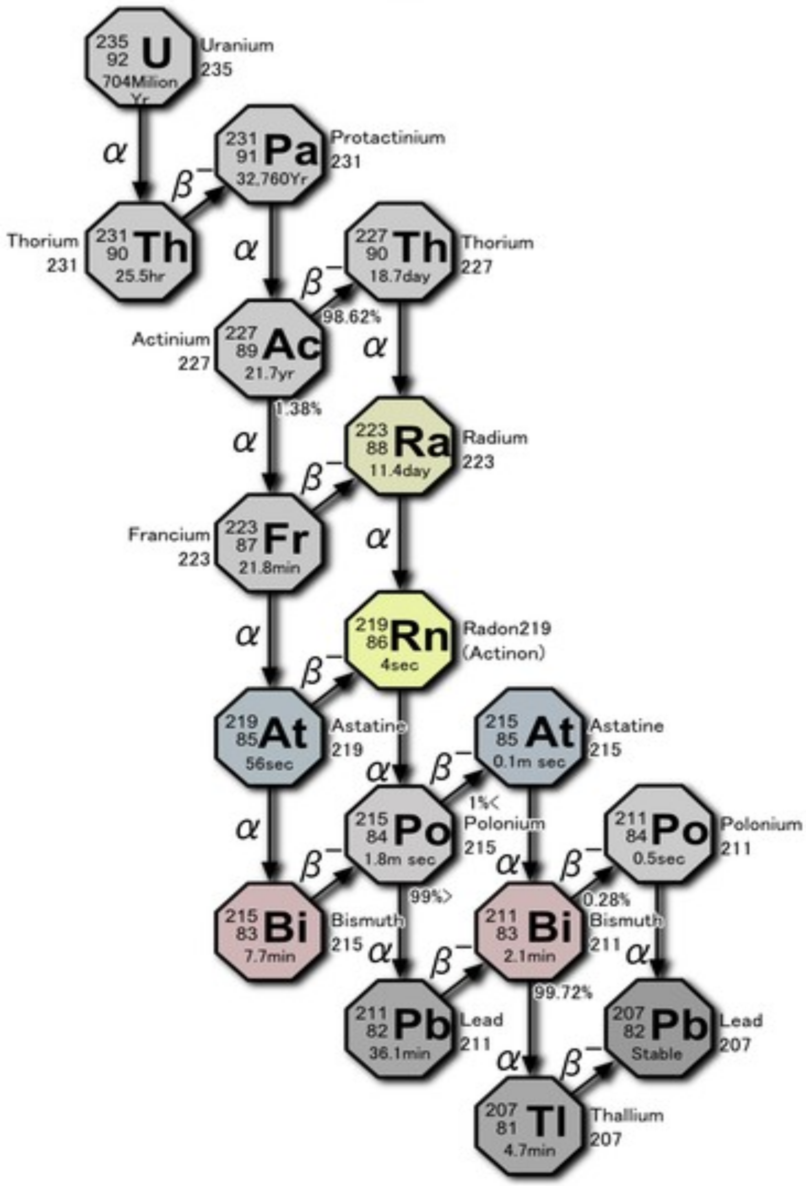
D1: Natural decay series

Thorium Series



D2:Natural decay series

Radium (uranium) Series



D3:Natural decay series

Actinium Series

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Table of Atomic Masses and Atomic Numbers

Actinium	Ac	89	227	Helium	He	2	4.0026	Rhenium	Re	75	186.207
Aluminum	Al	13	26.9815	Holmium	Ho	67	164.9303	Rhodium	Rh	45	102.9055
Americium	Am	95	243	Hydrogen	H	1	1.0079	Rubidium	Rb	37	85.4678
Antimony	Sb	51	121.76	Indium	In	49	114.818	Ruthenium	Ru	44	101.07
Argon	Ar	18	39.948	Iodine	I	53	126.9045	Rutherfordium	Rf	104	261
Arsenic	As	33	74.9216	Iridium	Ir	77	192.217	Samarium	Sm	62	150.36
Astatine	At	85	210	Iron	Fe	26	55.845	Scandium	Sc	21	44.9559
Barium	Ba	56	137.327	Krypton	Kr	36	83.8	Seaborgium	Sg	106	266
Berkelium	Bk	97	247	Lanthanum	La	57	138.9055	Selenium	Se	34	78.96
Beryllium	Be	4	9.0122	Lawrencium	Lr	103	262	Silicon	Si	14	28.0855
Bismuth	Bi	83	208.9804	Lead	Pb	82	207.2	Silver	Ag	47	107.8682
Bohrium	Bh	107	264	Lithium	Li	3	6.941	Sodium	Na	11	22.9897
Boron	B	5	10.811	Lutetium	Lu	71	174.967	Strontium	Sr	38	87.62
Bromine	Br	35	79.904	Magnesium	Mg	12	24.305	Sulfur	S	16	32.065
Cadmium	Cd	48	112.411	Manganese	Mn	25	54.938	Tantalum	Ta	73	180.9479
Calcium	Ca	20	40.078	Meitnerium	Mt	109	268	Technetium	Tc	43	98
Californium	Cf	98	251	Mendelevium	Md	101	258	Tellurium	Te	52	127.6
Carbon	C	6	12.0107	Mercury	Hg	80	200.59	Terbium	Tb	65	158.9253
Cerium	Ce	58	140.116	Molybdenum	Mo	42	95.94	Thallium	Tl	81	204.3833
Cesium	Cs	55	132.9055	Neodymium	Nd	60	144.24	Thorium	Th	90	232.0381
Chlorine	Cl	17	35.453	Neon	Ne	10	20.1797	Thulium	Tm	69	168.9342
Chromium	Cr	24	51.9961	Neptunium	Np	93	237	Tin	Sn	50	118.71
Cobalt	Co	27	58.9332	Nickel	Ni	28	58.6934	Titanium	Ti	22	47.867
Copper	Cu	29	63.546	Niobium	Nb	41	92.9064	Tungsten	W	74	183.84
Curium	Cm	96	247	Nitrogen	N	7	14.0067	Uranium	U	92	238.0289
Dubnium	Db	105	262	Nobelium	No	102	259	Vanadium	V	23	50.9415
Dysprosium	Dy	66	162.5	Osmium	Os	76	190.23	Xenon	Xe	54	131.293
Einsteinium	Es	99	252	Oxygen	O	8	15.9994	Ytterbium	Yb	70	173.04
Erbium	Er	68	167.259	Palladium	Pd	46	106.42	Yttrium	Y	39	88.9059
Europium	Eu	63	151.964	Phosphorus	P	15	30.9738	Zinc	Zn	30	65.39
Fermium	Fm	100	257	Platinum	Pt	78	195.078	Zirconium	Zr	40	91.224
Fluorine	F	9	18.9984	Plutonium	Pu	94	244				
Francium	Fr	87	223	Polonium	Po	84	209				
Gadolinium	Gd	64	157.25	Potassium	K	19	39.0983				
Gallium	Ga	31	69.723	Praseodymium	Pr	59	140.9077				
Germanium	Ge	32	72.64	Promethium	Pm	61	145				
Gold	Au	79	196.9665	Protactinium	Pa	91	231.0359				
Hafnium	Hf	72	178.49	Radium	Ra	88	226				
Hassium	Hs	108	277	Radon	Rn	86	222				

PERIODIC TABLE OF THE ELEMENTS

Group / Period	1	2		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca		21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr		39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	*	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	**	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Uub	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr