



The Elements

Welcome. 2019 is the International Year of the Periodic Table, and the 150th anniversary of Dmitri Mendeleev's invention of the periodic table. To mark this occasion I have assembled this collection of 33 pure elements, designed to stimulate interest in both the periodic table and chemistry in general. I would particularly like to thank my generous sponsors, listed below, who made this possible.

Stuart Batten
School of Chemistry
Monash University
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5

B

10.81

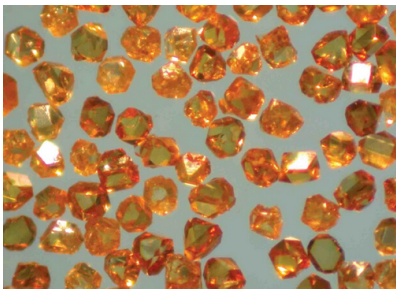


What

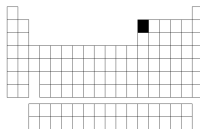
Boron is a metalloid, which means that its properties are a mix of those shown by metals and non-metals. The element has four main polymorphs but none occur naturally on Earth (though some are found in meteoroids). It is also tricky to manufacture without contaminants such as carbon. Crystalline boron is often shiny and black and, like the diamond polymorph of carbon, is extremely hard and a poor conductor of electricity.

Where

Due to the presence of a high concentration of oxygen on earth, boron is always found naturally as borate minerals. Commercially, boron appears in borosilicate glass, fibreglass insulation, detergents (borax), insecticides (boric acid), semiconductors, magnets (e.g. $\text{Nd}_2\text{Fe}_{14}\text{B}$), and materials ranging from soft playthings such as borax slime and silly putty, to superhard materials like boron nitride.



Boron



p-block metalloid

m.p.: 2077 °C

b.p.: 4000 °C

Density: 2.34 g/cm³

[He] 2s² 2p¹

Atomic radius: 87 pm

Main isotopes:

¹⁰B (20%)

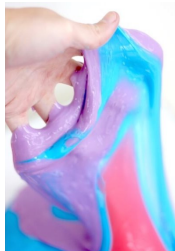
¹¹B (80%)

Universe: 1.0x10⁻⁷ %

Earth's crust: 8.6x10⁻⁴ %

Human: 7.0x10⁻⁵ %

Year of discovery: 1808



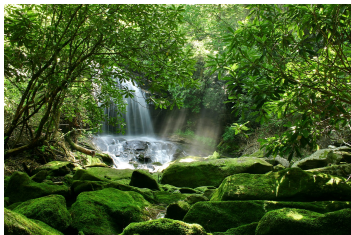


What

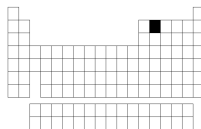
The most common forms of carbon are diamond, the hardest substance known to man and an electrical insulator, and graphite, which conducts electricity and is soft enough to rub off on a piece of paper (it's the 'lead' in a pencil). Carbon can also be made into more exotic elemental forms, including spherical fullerene molecules, carbon nanotubes, amorphous forms, and pyrolytic carbon, which floats above strong magnets. Under atmospheric pressure carbon does not melt but rather transitions straight to a gas (sublimation).

Where

Carbon is everywhere; it's the workhorse element of chemistry. Anything 'organic', by definition, contains carbon, including every living thing. Everything you eat, almost every medicine, the very air you breathe contains carbon. Plastics and polymers all contain carbon, as does coal, petroleum, and carbonate minerals such as limestone and marble.



Carbon



p-block non-metal
 subl.pt.: 3652 °C
 Density: 2.25 g/cm³
 (graphite)
 [He] 2s² 2p²
 Atomic radius: 67 pm
 Main isotopes:
¹²C (98.9%)
¹³C (1.1%)
¹⁴C (trace)
 Universe: 0.50%
 Earth's crust: 0.18%
 Human: 23%
 Year of discovery:
 Ancient times



7

N

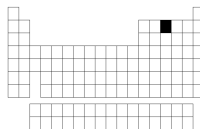
14.01

What

Elemental nitrogen, which makes up 78% of the atmosphere, is composed of discrete and quite unreactive molecules of two tightly bound nitrogen atoms (N_2). It becomes a liquid at $-196\text{ }^\circ\text{C}$, and liquid nitrogen is widely used as a coolant across a wide range of science and industry, due to its very low temperatures, cheapness and ready availability.

Where

Like carbon, nitrogen is everywhere. Another key element of organic chemistry, it's in every living thing, most medicines, and many important plastics, polymers and other man-made materials. A key milestone in human history was the invention of industrial 'nitrogen fixation' chemistry, which converts atmospheric nitrogen into ammonia, which is then used to make the nitrate fertilisers which now underpin the world's food supply. Notable other nitrogen-containing molecules include hydrazine (rocket fuel!), nitric acid, cyanide, explosives (e.g. TNT), nitrous oxide ('laughing gas'), Kevlar, caffeine, morphine, proteins and DNA.

**Nitrogen**

p-block non-metal

m.p.: $-210\text{ }^\circ\text{C}$ b.p.: $-196\text{ }^\circ\text{C}$ Density = 1.251 g/L [He] $2s^2 2p^3$ Atomic radius: 56 pm

Main isotopes:

 ^{14}N (99.6%) ^{15}N (0.4%)

Universe: 0.10%

Earth's crust: 0.0020%

Human: 2.6%

Year of discovery: 1772



12

Mg

24.31

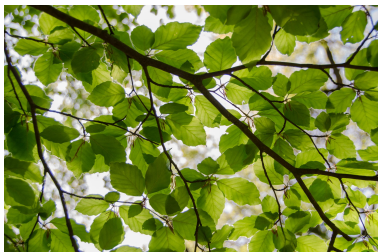


What

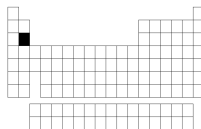
Magnesium is a light yet strong alkaline earth metal that, unlike the heavier alkaline earths, oxidises only slightly in air. It is, however, highly flammable and burns with a very intense flame. It will also react (usually slowly) with water, producing small bubbles of hydrogen.

Where

After sodium, magnesium is the second-most abundant cation in seawater. Its lightness and strength mean both the pure metal and its alloys are used extensively in aircraft and cars. It's essential to life, being found in numerous enzymes in animals, and chlorophyll in plants. Its compounds are used as laxatives, antacids (e.g. milk of magnesia, magnesium hydroxide) and bath salts (Epsom salt is magnesium sulphate). It's also found in fireworks and sparklers, and was once a key component of flash powder and flashbulbs for photography.



Magnesium



s-block metal

m.p.: 650 °C

b.p.: 1090 °C

Density: 1.738 g/cm³

[Ne] 3s²

Atomic radius: 160 pm

Main isotopes:

²⁴Mg (79.0%)

²⁵Mg (10.0%)

²⁶Mg (11.0%)

Universe: 0.060%

Earth's crust: 2.9%

Human: 0.027%

Year of discovery: 1755



13
Al
26.98



What

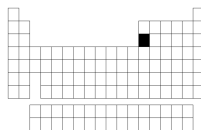
Aluminium most notable properties are its lightness, strength, ductility, high reflectivity and resistance to corrosion due to the formation of a thin protective layer of oxide on its surface. It is a good thermal and electrical conductor, but is non-magnetic.

Where

Aluminium is the third most common element in the Earth's crust, after oxygen and silicon, and is contained in a large range of minerals. The main ore, however, is bauxite, for which Australia is the world's largest producer. Despite its great abundance, it has no known biological role, but is used extensively in cookware, foil, cans, engineering, building and aircraft construction. Sapphires, rubies and emeralds all contain aluminium, while porous aluminosilicate zeolites are used extensively as industrial catalysts.



Aluminium



p-block metal

m.p.: 660 °C

b.p.: 2467 °C

Density: 2.70 g/cm³

[Ne] 3s² 3p¹

Atomic radius: 118 pm

Main isotopes:

²⁶Al (trace)

²⁷Al (100%)

Universe: 0.0050%

Earth's crust: 8.1%

Human: 9.0x10⁻⁵ %

Year of discovery: 1825



14
Si
28.09

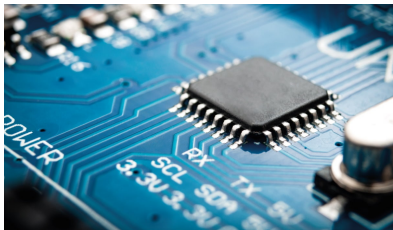


What

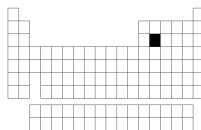
Silicon, a metalloid, gives crystals with a blue-grey metallic sheen. The atoms, however, are covalently bonded and arranged in the same way as the carbon atoms in diamond. But while diamond is an insulator, elemental silicon is, famously, a semiconductor. The semiconducting properties can be improved by introducing impurities such as P or N into the crystalline silicon lattice, often through irradiation with neutrons from a nuclear reactor like the one run by ANSTO in Sydney.

Where

While pure silicon is rare in nature, about 95% of the rocks in the earth's crust contain silicon atoms; only oxygen is more abundant. Minerals that contain silicon include beach sand and quartz (both SiO_2), silicates such as zircon, garnets and micas, and aluminosilicates such as feldspars and zeolites. As well as its wide-spread use in electronics, silicon can also be found in cements, ceramics, glass, lubricants, silicon carbide, and silicone polymers.



Silicon



p-block metalloid

m.p.: 1410 °C

b.p.: 2355 °C

Density: 2.33 g/cm³

[Ne] 3s² 3p²

Atomic radius: 111 pm

Main isotopes:

²⁸Si (92.2%)

²⁹Si (4.7%)

³⁰Si (3.1%)

³²Si (trace)

Universe: 0.070%

Earth's crust: 27%

Human: 0.026%

Year of discovery: 1824



What

Sulphur, also known as brimstone in ancient times, is distinctive for its bright yellow colour. It has more than 30 allotropes, but the usual form is composed of cyclic S_8 molecules and is odourless. The infamous smell comes from impurities, and sulphur-based compounds are also responsible for other distinctive smells, including 'rotten egg gas' (hydrogen sulphide, H_2S), onions and garlic.

Where

Sulphur can commonly be found in its elemental form near volcanic vents. It is also a component of numerous minerals, including sulphates (e.g. gypsum, calcium sulphate) and sulphides (e.g. pyrite or 'fool's gold', iron sulphide). It is essential to life, being found in the amino acids cysteine, cystine and methionine, the vitamins biotin and thiamine, and numerous proteins. The mechanical strength of skin, hair and feathers is due to the formation of S-S bonds in keratin (S-S bonds are also used to stiffen rubber in a process called vulcanisation). Many medicines (including penicillin) contain sulphur, while sulphuric acid is one of the most produced industrial inorganic chemicals worldwide.

**Sulphur**

p-block non-metal

m.p.: 115 °C

b.p.: 445 °C

Density: 2.07 g/cm³[Ne] 3s² 3p⁴

Atomic radius: 88 pm

Main isotopes:

³²S (94.99%)³³S (0.75%)³⁴S (4.25%)³⁵S (trace)³⁶S (0.01%)

Universe: 0.050%

Earth's crust: 0.042%

Human: 0.20%

Year of discovery:

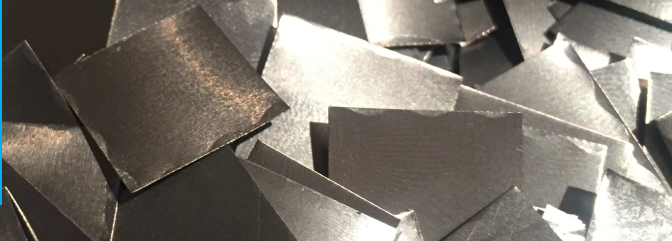
500BC



22

Ti

47.88



What

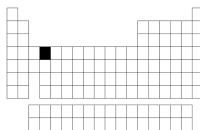
Titanium is a transition metal with the highest strength-to-density ratio of any metallic element. Although 60% denser than Al, it is more than twice as strong. It is also highly corrosion resistant, relatively ductile and has a high melting point. Its thermal and electrical conductivities are low for a metal. It oxidises rapidly in air, but the oxide forms a passive layer on the surface (only a few nanometres thick) that prevents further oxidation and protects it from corrosion.

Where

Titanium is found in minerals such as anatase, brookite, ilmenite, perovskite, rutile and titanite. Titanium oxide (TiO_2) is a very widely used white pigment, due to its brilliance, resistance to fading in sunlight, and chemical inertness. It is found in paints, paper, toothpaste and plastics, as well as in sunscreens. The metal and its alloys are widely used in aircraft, including the famous SR-71 "Blackbird" spy plane, boats and submarines, racing cars, pipes and equipment in chemical industry, biomedical implants, sports equipment, and laptop computers.



Titanium



d-block metal

m.p.: 1660 °C

b.p.: 3287 °C

Density: 4.506 g/cm³

[Ar] 3d² 4s²

Atomic radius: 176 pm

Main isotopes:

⁴⁶Ti (8.25%)

⁴⁷Ti (7.44%)

⁴⁸Ti (73.72%)

⁴⁹Ti (5.41%)

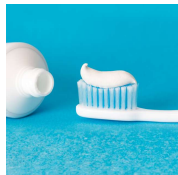
⁵⁰Ti (5.18%)

Universe: 3.0x10⁻⁴ %

Earth's crust: 0.66%

Human: none

Year of discovery: 1791



23

V

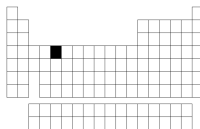
50.94

What

Vanadium is a hard, ductile, malleable, silver-grey transition metal. It is electrically conductive but thermally insulating. Its chemistry is notable its multiple oxidation states, which form different coloured solutions in water: lilac (II), green (III), blue (IV) and yellow (V).

Where

Vanadium is found in numerous minerals and is the 20th most abundant element in the Earth's crust. It is also abundant in seawater. Its hardness means that its major use is in increasing the strength of steel and in alloys with other metals such as iron (ferrovanadium) or titanium and aluminium. Compounds of vanadium, vanadium pentoxide (V_2O_5) in particular, are widely used as industrial catalysts. Vanadium is also found in some biomolecules, particularly in marine organisms. It can also be found in significant quantities in some fungi, though the reason is currently unknown.

**Vanadium**

d-block metal

m.p.: 1910 °C

b.p.: 3407 °C

Density: 5.96 g/cm³[Ar] 3d³ 4s²

Atomic radius: 171 pm

Main isotopes:

⁵⁰V (0.25%)⁵¹V (99.75%)Universe: 1.0x10⁻⁴ %

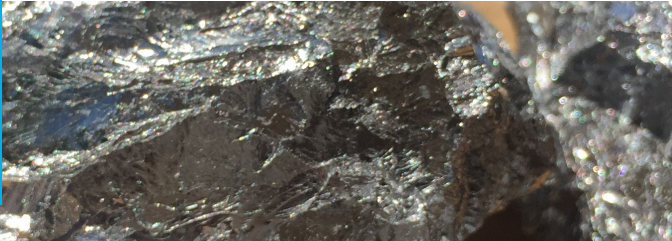
Earth's crust: 0.019%

Human: 3.0x10⁻⁶ %

Year of discovery: 1801



24
Cr
52.00



What

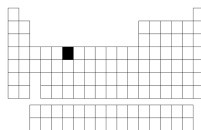
Chromium is the third hardest element (behind the diamond allotrope of carbon, and boron) but is also brittle. It is known for being highly reflective and tarnish resistant. Many of its compounds are brightly coloured, giving rise to the element's name (from the Greek *chrōma*, meaning colour). Compounds in the VI oxidation state are toxic and carcinogenic, while those in the III oxidation state and the metal are not.

Where

Chromium is often used to coat other metals due to its hardness, resistance to corrosion, and attractive lustre. It is also used to harden steel (to give 'stainless steel') and other alloys. Its compounds are commonly used as pigments (the mineral crocoite, PbCrO_4 , once provided the distinctive yellow of American school buses), while rubies are red and emeralds green due to Cr impurities. Chromium salts are also used to preserve wood and tan leather, while CrO_2 is used in magnetic tape.



Chromium



d-block metal

m.p.: 1907 °C

b.p.: 2671 °C

Density: 7.15 g/cm³

[Ar] 3d⁵ 4s¹

Atomic radius: 166 pm

Main isotopes:

⁵⁰Cr (4.345%)

⁵²Cr (83.789%)

⁵³Cr (9.501%)

⁵⁴Cr (2.365%)

Universe: 0.0015%

Earth's crust: 0.014%

Human: 3.0x10⁻⁶ %

Year of discovery: 1797



25

Mn

54.94



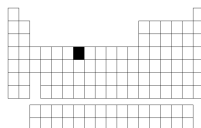
What

Manganese in its pure state is silver-grey, but, like iron, it “rusts” (i.e. oxidises) very easily. It is hard and brittle, and displays oxidation states from -III to +VII (though II, III, IV, VI and VII are the most common).

Where

Manganese plays a key role in iron and steel production due to its readiness to react with sulphur and oxygen. Manganese compounds have been used as pigments since the Stone Age. The purple potassium permanganate (KMnO_4) contains Mn(VII) and is a strong and commonly used oxidiser, often used to sterilise and disinfect water supplies. Manganese dioxide (MnO_2) is a vital component of alkaline batteries. Manganese is essential to the functioning of many important enzymes in animals and bacteria, as well as photosynthesis in plants. The human body contains approximately 12 mg of manganese.

Manganese



d-block metal

m.p.: 1246 °C

b.p.: 2061 °C

Density: 7.20 g/cm³

[Ar] 3d⁵ 4s²

Atomic radius: 161 pm

Main isotopes:

⁵³Mn (trace)

⁵⁵Mn (100%)

Universe: 8.0x10⁻⁴ %

Earth's crust: 0.11%

Human: 2.0x10⁻⁵ %

Year of discovery: 1774



26

Fe

55.85



What

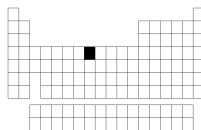
Pure iron is a silver-grey metal that is ferromagnetic up to 770 °C. It reacts readily with water and oxygen to give hydrated iron oxides ("rust"), and unlike many other metals, where oxidation produces thin layers of oxide that protect the bulk metal, rust takes up a much larger volume, producing flakes that fall away and expose more of the bulk metal. The most common oxidation states are II and III.

Where

Iron is, by mass, the most abundant element on Earth, with the inner core of the planet thought to be an iron-nickel alloy. It is widely used across numerous fields (construction particularly) in various types of iron alloys (including wrought and cast iron) and steels (Fe+C). Its magnetic properties make it useful in ancient compasses and modern fridge magnets, and it is found in pigments such as Prussian Blue and Berlin Green. It is essential to life, being, among other things, the gas-binding centre of haemoglobin, which allows red blood cells to move oxygen and carbon dioxide between the lungs and the rest of the body.



Iron



d-block metal

m.p.: 1538 °C

b.p.: 2862 °C

Density: 7.874 g/cm³

[Ar] 3d⁶ 4s²

Atomic radius: 156 pm

Main isotopes:

⁵⁴Fe (5.85%)

⁵⁶Fe (91.75%)

⁵⁷Fe (2.12%)

⁵⁸Fe (0.28%)

⁶⁰Fe (trace)

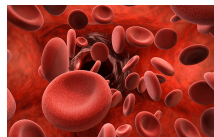
Universe: 0.11%

Earth's crust: 6.3%

Human: 0.0060%

Year of discovery:

3500BC



27
Co
58.93



What

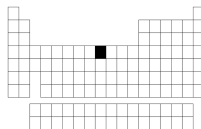
Cobalt is a hard, lustrous, silver-grey metal which is ferromagnetic below 1115 °C. Its common oxidation states are II and III.

Where

The majority of the world's cobalt is currently produced by the Democratic Republic of the Congo. LiCoO_2 is used in lithium-ion batteries, while SmCo_5 alloys make very strong magnets. The colour of the "cobalt blue" pigment is distinctive of Co(II) ions in a tetrahedral geometry. Cobalt is also the key component of cobalamin coenzymes, including vitamin B_{12} . The ^{60}Co radioisotope emits high intensity gamma-rays upon decay, and has a half-life of 5.2 years. As a result, it is widely used in applications such as sterilisation of medical equipment and food, industrial radiography, and in medical radiotherapy.



Cobalt



d-block metal

m.p.: 1495 °C

b.p.: 2927 °C

Density: 8.86 g/cm³

[Ar] 3d⁷ 4s²

Atomic radius: 152 pm

Main isotopes:

⁵⁹Co (100%)

⁶⁰Co (synthetic)

Universe: 3.0x10⁻⁴ %

Earth's crust: 0.0030%

Human: 2.0x10⁻⁶ %

Year of discovery: 1735



28

Ni

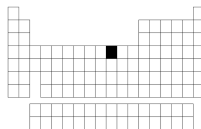
58.71

What

Nickel is a lustrous silver-white metal (with a slight golden tinge when highly polished) which is hard and ductile. It is one of only three elements that are ferromagnetic at room temperature, with the others being Fe and Co (Gd is also magnetic below 20 °C).

Where

A number of countries have used pure nickel in coins at various stages, however this practise has now been mostly discontinued in favour of cheaper alloys. However, pure nickel is corrosion resistant and thus nickel-plating of other materials is common. It also forms a number of alloys, with more than half the world's production used in stainless steel. Nickel can also be found in batteries and magnets, while "Raney nickel" is used as a catalyst to convert unsaturated oils into margarine.

**Nickel**

d-block metal

m.p.: 1455 °C

b.p.: 2913 °C

Density: 8.908 g/cm³[Ar] 3d⁸ 4s²

Atomic radius: 149 pm

Main isotopes:

⁵⁸Ni (68.077%)⁵⁹Ni (trace)⁶⁰Ni (26.223%)⁶¹Ni (1.140%)⁶²Ni (3.635%)⁶⁴Ni (0.926%)

Universe: 0.0060%

Earth's crust: 0.0089%

Human: 1.0x10⁻⁵ %

Year of discovery: 1751

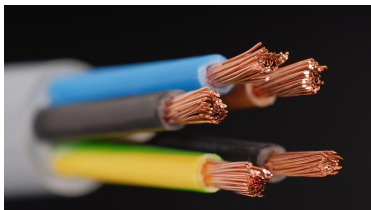
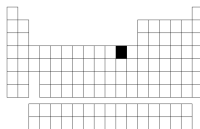


What

Pure copper is a lustrous red-orange metal, however surface oxidation can result in a brown-black appearance, and green copper carbonate can also form over time on e.g. copper roofing. It is soft, malleable and has very high thermal and electrical conductivity.

Where

Like silver and gold, copper can be found naturally as nuggets. Uses of the metal include electrical wiring and motors, architecture, plumbing, decorative metalwear, coins, antimicrobial applications, and in numerous alloys, including brass (Cu/Zn), bronze (Cu/Sn) and sterling silver (Ag/Cu). The Statue of Liberty contains more than 80 tonnes of copper. Copper proteins are used across a wide range of roles in the body. Notably, the blood of some animals, such as molluscs and the horseshoe crab, is blue due to the use of a copper protein as the oxygen carrier rather than the red iron-based haemoglobin molecule in other animals.

**Copper**

d-block metal

m.p.: 1085 °C

b.p.: 2567 °C

Density: 8.92 g/cm³

[Ar] 3d¹⁰ 4s¹

Atomic radius: 145 pm

Main isotopes:

⁶³Cu (69.15%)

⁶⁴Cu (synthetic)

⁶⁵Cu (30.85%)

⁶⁷Cu (synthetic)

Universe: 6.0x10⁻⁶ %

Earth's crust: 0.0068%

Human: 0.0001%

Year of discovery:

8000BC



30

Zn

65.37

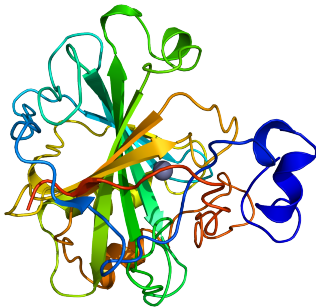


What

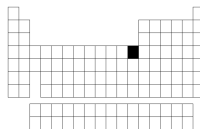
Zinc is (when oxidation is removed) a silvery-blue metal that is diamagnetic and slightly brittle. Strictly, like Cd and Hg, it is a main group metal, however they are often grouped with the transition metals due to their similar chemistry. The only oxidation state of any significance is II.

Where

Zinc form alloys with a number of metals, including copper to give brass. It is also used to protect other metals through use as coatings (galvanisation) or as sacrificial anodes. Zinc oxide is a very popular white pigment, and also protects polymers, plastics and people from UV radiation. Numerous enzymes in plants and animals contain zinc. One example is carbonic anhydrase, which is used to remove carbon dioxide from the blood and helps regulate pH in the body.



Zinc



d-block metal

m.p.: 420 °C

b.p.: 907 °C

Density: 7.14 g/cm³

[Ar] 3d¹⁰ 4s²

Atomic radius: 142 pm

Main isotopes:

⁶⁴Zn (49.2%)

⁶⁶Zn (27.7%)

⁶⁷Zn (4.0%)

⁶⁸Zn (18.5%)

⁷⁰Zn (0.6%)

Universe: 3.0x10⁻⁵ %

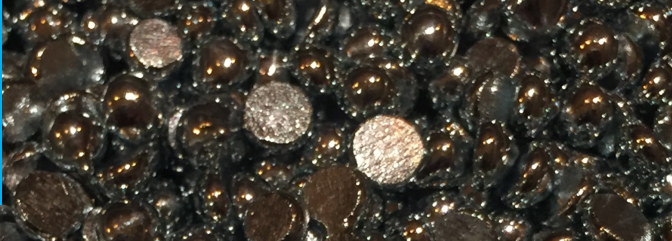
Earth's crust: 0.0078%

Human: 0.0033%

Year of discovery: 20BC



31
Ga
69.72

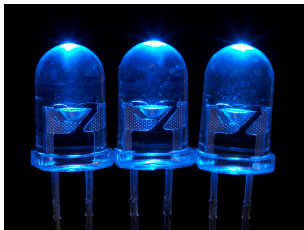


What

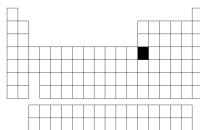
Gallium is a soft, silvery-blue metal that melts at just 29.76°C – low enough that it can melt in your hands. Once melted it can often form supercooled liquids, which means that it stays liquid when returned to below its freezing point (though ‘seeding’ can induce crystallisation). It will wet (stick to or stain) glass, skin and plastic, has no natural biological role but is non-toxic. Its existence and properties were correctly predicted by the inventor of the periodic table, Dmitri Mendeleev, four years before it was discovered.

Where

Gallium arsenide, gallium nitride and indium gallium nitride are used extensively in semiconductors, including in blue LEDs and violet Blu-ray lasers. The Galinstan alloy is a mixture of gallium, indium and tin, and is a shiny metallic liquid at room temperature that is used in place of mercury in thermometers. ^{67}Ga and ^{68}Ga are used as radioisotopes in nuclear medicine.



Gallium



p-block metal

m.p.: 30 °C

b.p.: 2403 °C

Density: 5.904 g/cm³

[Ar] 3d¹⁰ 4s² 4p¹

Atomic radius: 136 pm

Main isotopes:

^{67}Ga (synthetic)

^{68}Ga (synthetic)

^{69}Ga (60.11%)

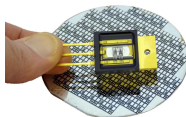
^{71}Ga (39.89%)

Universe: 1.0×10^{-6} %

Earth's crust: 0.0019%

Human: none

Year of discovery: 1875



34

Se

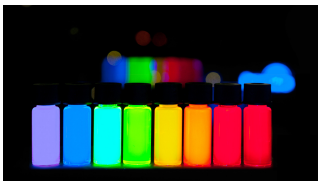
78.96

What

Selenium forms several allotropes, including red, black and grey varieties. Many contain discrete Se_6 , Se_7 or (like sulphur) Se_8 rings. Large amounts of selenium salts are toxic, but trace quantities are essential to animal life. Like silicon, pure selenium is a semiconductor.

Where

Selenium is usually found naturally as an impurity in sulphide ores. About half of the Se produced is used in glass, where it produces a red colour (often cancelling out green or yellow colours produced by iron impurities). Quantum dots, which can convert UV light into bright, vibrant visible light, are commonly composed of cadmium selenide nanoparticles. The amino acids selenocysteine and selenomethionine both contain selenium but are much rarer than their sulphur analogues, while selenium disulphide can be found in anti-dandruff shampoos. The element's photoelectric properties have made it a useful material in electronics, including light meters, photocopiers and laser printers.

**Selenium**

p-block non-metal

m.p.: 221 °C

b.p.: 685 °C

Density: 4.81 g/cm³[Ar] 3d¹⁰ 4s² 4p⁴

Atomic radius: 103 pm

Main isotopes:

⁷⁴Se (0.86%)⁷⁶Se (9.23%)⁷⁷Se (7.60%)⁷⁸Se (23.69%)⁷⁹Se (trace)⁸⁰Se (49.80%)⁸²Se (8.82%)Universe: 3.0x10⁻⁶ %Earth's crust: 5.0x10⁻⁶ %Human: 5.0x10⁻⁶ %

Year of discovery: 1817



40
Zr
91.22



What

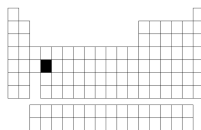
Zirconium is a soft, greyish-white malleable metal when pure, though impurities can make it hard and brittle. Its chemistry is very similar to hafnium, which can make them difficult to fully separate industrially.

Where

The chief ore for zirconium is zircon ($ZrSiO_4$), from which it takes its name. Two-thirds of the world's mining of zircon occurs in Australia and South Africa. The most familiar use of zirconium is in cubic zirconia (ZrO_2) jewels, which are low cost yet have similar durability and visual appeal to diamond. They can also be made in a range of colours by doping the crystals with small amounts of other elements. Zirconium is also used as cladding for nuclear reactor fuels, industrial catalysis, and in medical implants such as dental implants, knee and hip replacements, and prosthetic devices. The most commonly used piezoelectric material is lead zirconate titanate ($Pb[Zr_xTi_{1-x}]O_3$, PZT).



Zirconium



d-block metal

m.p.: 1852 °C

b.p.: 4377 °C

Density: 6.511 g/cm³

[Kr] 4d² 5s²

Atomic radius: 206 pm

Main isotopes:

⁸⁹Zr (synthetic)

⁹⁰Zr (51.45%)

⁹¹Zr (11.22%)

⁹²Zr (17.15%)

⁹³Zr (trace)

⁹⁴Zr (17.38%)

⁹⁶Zr (2.80%)

Universe: 5.0x10⁻⁶ %

Earth's crust: 0.013%

Human: 5.0x10⁻⁶ %

Year of discovery: 1789



41

Nb

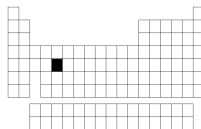
92.91

What

Niobium, once known as columbium, is a strong and ductile transition metal. It normally oxidises slowly, however the depth of the natural oxide layer can be increased using an electric current (a process known as anodizing). This changes the colour from its natural silver-grey to a range of vibrant colours which are related to the depth of the oxide layer. This process also works for a number of other metal elements, notably Al, Ti and Ta.

Where

Niobium is hypoallergenic; this plus the iridescent colours produced through anodization mean that it's commonly used in jewellery. Niobium based superconducting magnets are used in MRI and NMR instruments, as well as at the Large Hadron Collider and in maglev trains. Lithium niobate is used widely in optics and electronics (e.g. mobile phones), while niobium capacitors offer an alternative to tantalum analogues.

**Niobium**

d-block metal

m.p.: 2477 °C

b.p.: 4741 °C

Density: 8.57 g/cm³[Kr] 4d⁴ 5s¹

Atomic radius: 198 pm

Main isotopes:

⁹²Nb (trace)⁹³Nb (100%)Universe: 2.0x10⁻⁷ %

Earth's crust: 0.0017%

Human: none

Year of discovery: 1801



42

Mo

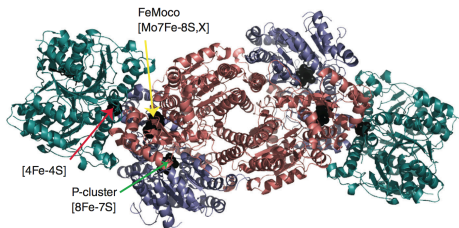
95.94

What

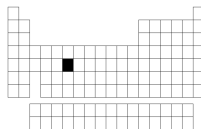
Molybdenum is a silver-grey second row transition metal which has a high melting point and a low coefficient of thermal expansion. Like Cr and W, its chemistry is notable for its large range of oxidation states, namely -II to +VI. Mo (and W) also regularly forms high nuclearity clusters and oxoanions (e.g. $\text{Mo}_6\text{Cl}_{14}^{2-}$, $\text{Mo}_8\text{O}_{26}^{4-}$).

Where

The vast majority of molybdenum produced is used in metallurgy, mostly in various steel alloys. Molybdenum is also an essential element in all plants and animals, and more than 50 molybdenum enzymes known. The most notable are the nitrogenases, which are used by bacteria to reduce nitrogen to ammonia, a key step in nitrogen fixation, which is essential to all forms of life. The radioactive ^{99}Mo is produced in nuclear reactors such as the OPAL reactor in Sydney, and decays to the short-lived $^{99\text{m}}\text{Tc}$, which is the most widely-used medical radioisotope in the world.



Molybdenum



d-block metal

m.p.: 2622 °C

b.p.: 4639 °C

Density: 10.2 g/cm³[Kr] 4d⁵ 5s¹

Atomic radius: 190 pm

Main isotopes:

 ^{92}Mo (14.65%) ^{94}Mo (9.19%) ^{95}Mo (15.87%) ^{96}Mo (16.67%) ^{97}Mo (9.58%) ^{98}Mo (24.29%) ^{99}Mo (synthetic) ^{100}Mo (9.74%)Universe: 5.0×10^{-7} %Earth's crust: 1.1×10^{-4} %Human: 1.0×10^{-5} %

Year of discovery: 1781





What

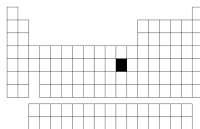
Silver is a soft, lustrous transition metal which has the highest electrical and thermal conductivity and reflectivity of any metal. Its chemistry is typified by insoluble, light-sensitive Ag(I) compounds.

Where

Like copper and gold, it can be found naturally as nuggets, but it is usually produced as a byproduct of mining for other metals. Apart from its important roles in currency and investment, silver can also be found in jewelry, tableware and cutlery ('silverware'), mirrors and electronics. The light sensitivity of silver compounds, particularly silver nitrate and silver halides, once led to its widespread use in film-based photography, while their antibiotic properties give rise to their use in wound dressings.



Silver



d-block metal

m.p.: 962 °C

b.p.: 2162 °C

Density: 10.5 g/cm³

[Kr] 4d¹⁰ 5s¹

Atomic radius: 165 pm

Main isotopes:

¹⁰⁷Ag (51.84%)

¹⁰⁹Ag (48.16%)

Universe: 6.0x10⁻⁸ %

Earth's crust: 7.9x10⁻⁶ %

Human: none

Year of discovery:

3000BC



48

Cd

112.40



What

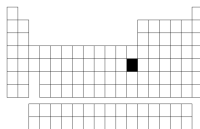
Cadmium is a soft, malleable silver-white metal. Its chemistry is similar to zinc, with the +2 oxidation state being the dominant one, though cadmium compounds are typically much more toxic.

Where

Cadmium is produced mainly as a byproduct of zinc, lead or copper mining. Toxicity issues are today limiting its use, with most cadmium currently being used for nickel-cadmium batteries. Another significant use is for the electroplating of steel to reduce corrosion. Cadmium compounds are also used as vibrant pigments, including 'cadmium yellow' (CdS), 'cadmium red' (CdSe), and 'cadmium orange' (a mixture of both).



Cadmium



d-block metal

m.p.: 321 °C

b.p.: 767 °C

Density: 8.642 g/cm³

[Kr] 4d¹⁰ 5s²

Atomic radius: 161 pm

Main isotopes:

¹⁰⁶Cd (1.25%)

¹⁰⁸Cd (0.89%)

¹¹⁰Cd (12.47%)

¹¹¹Cd (12.80%)

¹¹²Cd (24.11%)

¹¹³Cd (12.23%)

¹¹⁴Cd (28.75%)

¹¹⁶Cd (7.51%)

Universe: 2.0x10⁻⁷ %

Earth's crust: 1.5x10⁻⁵ %

Human: 7.0x10⁻⁵ %

Year of discovery: 1817



49

In

114.82



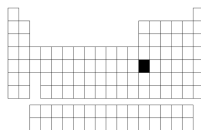
What

Indium is a ductile silvery-white main group metal that is soft enough to be cut with a knife. It has a relatively low melting point, and like its neighbour gallium, it is able to wet (i.e. stick to) glass. Its name comes from the indigo blue line observed in its emission spectrum, which was observed before the element was first isolated.

Where

The main consumption of indium production is in LCD displays, including televisions and computer monitors, which contain thin films of indium tin oxide. It also forms a number of low-melting alloys used as solders, as well as a number of other useful compounds (e.g. InSb, InP, InGaN, InGaP and $\text{CuIn}_{1-x}\text{Ga}_x\text{Se}_2$ ('CIGS')) used as semiconductors. Its ability to capture neutrons makes it a useful component of control rods in nuclear reactors.

Indium



p-block metal

m.p.: 157 °C

b.p.: 2080 °C

Density: 7.31 g/cm³

[Kr] 4d¹⁰ 5s² 5p¹

Atomic radius: 156 pm

Main isotopes:

¹¹¹In (synthetic)

¹¹³In (4.28%)

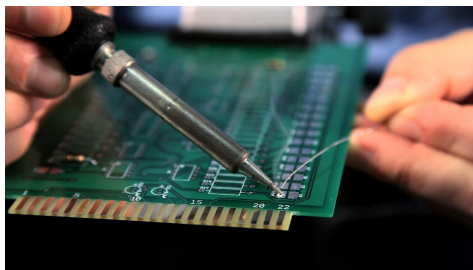
¹¹⁵In (95.72%)

Universe: 3.0x10⁻⁸ %

Earth's crust: 1.6x10⁻⁵ %

Human: none

Year of discovery: 1863



50

Sn

118.69



What

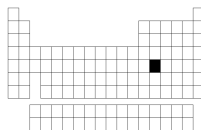
Tin has two important allotropes. The usual form is β -tin ('white tin'), which is metallic, soft and malleable, however below 13°C α -tin ('grey tin') becomes stable; this allotrope is non-metallic and brittle. This leads to 'tin pest' or 'tin disease', where β -tin transforms into brittle α -tin in cold weather. This is thought by some to have played an important role in ill-fated historical events such as Napoleon's 1812 Russian campaign or Robert Scott's Antarctic expedition of 1910.

Where

About half of the tin produced each year is used as solder. Tin cans are not pure tin, but rather are composed of steel plated with tin to prevent corrosion. Tin also forms a number of important alloys, including bronze, pewter and a range of tin-lead alloys used in pipe organs. Organotin compounds are used to prevent degradation of PVC plastics, and as wood preservatives, pesticides, fungicides, algacides, and antifouling agents.



Tin



p-block metal

m.p.: 232°C

b.p.: 2260°C

Density: 7.287 g/cm^3

[Kr] $4d^{10} 5s^2 5p^2$

Atomic radius: 145 pm

Main isotopes:

^{112}Sn (0.97%)

^{114}Sn (0.66%)

^{115}Sn (0.34%)

^{116}Sn (14.54%)

^{117}Sn (7.68%)

^{118}Sn (24.22%)

^{119}Sn (8.59%)

^{120}Sn (32.58%)

^{122}Sn (4.63%)

^{124}Sn (5.79%)

^{126}Sn (trace)

Universe: $4.0 \times 10^{-7}\%$

Earth's crust: $2.2 \times 10^{-4}\%$

Human: $2.0 \times 10^{-5}\%$

Year of discovery:

2100BC

51

Sb

121.75



What

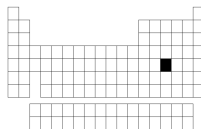
The most common form of the metalloid element antimony is a shiny grey metallic form which is both soft and brittle. Less common polymorphs include black and yellow forms, as well as an explosive form which is, fortunately, very rare.

Where

The mineral stibnite (Sb_2S_3) is the main source of antimony. The major use of antimony is in flame retardants, however it is also used extensively in alloys with other metals, particularly with lead and tin. These alloys include pewter, an alloy used since the Bronze Age, and others used today in lead-acid car batteries, solders, bullets and bearings. A Pb/Sn/Sb alloy was used by Johann Gutenberg for his invention of movable type in the 15th century; his printing presses made books widely available for the first time. Other uses include electronics and specialised antimony-based drugs.



Antimony



p-block metalloid

m.p.: 631 °C

b.p.: 1587 °C

Density: 6.697 g/cm³

[Kr] 4d¹⁰ 5s² 5p³

Atomic radius: 133 pm

Main isotopes:

¹²¹Sb (57.21%)

¹²³Sb (42.79%)

Universe: 4.0x10⁻⁸ %

Earth's crust: 2.0x10⁻⁵ %

Human: none

Year of discovery:

1600BC





What

The crystalline allotrope of tellurium is shiny silvery-white, while the amorphous allotrope is brown or black. It is mildly toxic, with poisoning victims often having garlic-smelling breath due to the formation of dimethyl telluride gas ((CH₃)₂Te). The elements in this group of the periodic table (O, S, Se, Te, Po) are known as the chalcogens. The final element in this group, livermorium (Lv), is also predicted to display chalcogen-like chemistry, but its very short half-life makes it difficult to test.

Where

Tellurium is very scarce on Earth, though it can occur in Nature as the pure element. More commonly, however, it is found mixed with metals such as gold and silver. Its most significant industrial use is in compounds with metals such as zinc, cadmium and mercury, which are used in solar cells and semiconductors.



Tellurium



p-block metalloid

m.p.: 450 °C

b.p.: 988 °C

Density: 6.232 g/cm³

[Kr] 4d¹⁰ 5s² 5p⁴

Atomic radius: 123 pm

Main isotopes:

¹²⁰Te (0.09%)

¹²²Te (2.55%)

¹²³Te (0.89%)

¹²⁴Te (4.74%)

¹²⁵Te (7.07%)

¹²⁶Te (18.84%)

¹²⁸Te (31.74%)

¹³⁰Te (34.08%)

Universe: 9.0x10⁻⁷ %

Earth's crust: 9.9x10⁻⁸ %

Human: none

Year of discovery: 1783



70
Yb
173.04



What

Ytterbium is a lanthanoid metal, which refers to elements La-Lu, and is also known as a rare earth element (which also includes Sc and Y). The rare earth elements are all chemically very similar and can be difficult to separate from one another, particularly from their mixed metal ores. Ytterbium is soft and malleable, and like most lanthanoids it will react with oxygen (though much more slowly than the early lanthanoids).

Where

Ytterbium is named after the Ytterby mine in Sweden, which produced the gadolinite ore from which it was discovered (as were six other elements, including yttrium, erbium and terbium, all named after the same mine). The most notable current use of ytterbium is as a dopant in Yb:YAG solid-state infrared lasers.



Ytterbium



f-block metal

m.p.: 824 °C

b.p.: 1196 °C

Density: 6.965 g/cm³

[Xe] 4f¹⁴ 6s²

Atomic radius: 222 pm

Main isotopes:

¹⁶⁸Yb (0.126%)

¹⁷⁰Yb (3.023%)

¹⁷¹Yb (14.216%)

¹⁷²Yb (21.754%)

¹⁷³Yb (16.098%)

¹⁷⁴Yb (31.896%)

¹⁷⁶Yb (12.887%)

Universe: 2.0x10⁻⁷ %

Earth's crust: 2.8x10⁻⁴ %

Human: none

Year of discovery: 1878

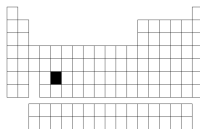


What

Tantalum is a hard, chemically inert transition metal that shows high conductivity of heat and electricity, and high resistance towards corrosion. It is chemically similar to niobium, which means that the two elements are commonly found together in most ores. It displays two crystalline phases: the more common alpha phase is relatively soft and ductile, while the beta phase is hard and brittle. The rare ^{180m}Ta isotope is 'metastable', but its decay is yet to be observed; by comparison, the ^{180}Ta isotope has a half-life of only 8 hours.

Where

Currently the main source of tantalum worldwide is two mines in Western Australia. The main use of tantalum is in electrical components, such as capacitors and resistors, and it is considered a technology-critical element. Other uses include in a range of metal alloys for specialised uses, and in surgical implants and instruments, due to its chemical inertness.

**Tantalum**

d-block metal

m.p.: 3017 °C

b.p.: 5455 °C

Density: 16.4 g/cm³

[Xe] 4f¹⁴ 5d³ 6s²

Atomic radius: 200 pm

Main isotopes:

^{180m}Ta (0.012%)

^{181}Ta (99.988%)

Universe: 8.0x10⁻⁹ %

Earth's crust: 1.7x10⁻⁴ %

Human: none

Year of discovery: 1802





What

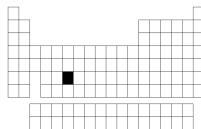
Tungsten, sometimes earlier known as wolfram, is a hard third-row transition metal that has the highest melting and boiling points of all the elements, as well as one of the highest densities. It also shows the lowest coefficient of thermal expansion of any pure metal. Its chemistry is notable for the formation of oxoanions such as WO_4^{2-} , $\text{W}_7\text{O}_{24}^{6-}$ and $\text{H}_2\text{W}_{12}\text{O}_{40}^{6-}$ (the 'Keggin anion').

Where

The main ores for tungsten are wolframite and scheelite. The production of hard materials accounts for about half the world's production of tungsten, including in tungsten carbide (WC), which is widely used as an abrasive and in cutting tools. Its high melting point makes it useful in arc welding and as filaments in incandescent light bulbs. Tungsten compounds are also used as industrial catalysts.



Tungsten



d-block metal

m.p.: 3414 °C

b.p.: 5555 °C

Density: 19.35 g/cm³

[Xe] 4f¹⁴ 5d⁴ 6s²

Atomic radius: 193 pm

Main isotopes:

¹⁸⁰W (0.12%)

¹⁸²W (26.50%)

¹⁸³W (14.31%)

¹⁸⁴W (30.64%)

¹⁸⁶W (28.43%)

Universe: 5.0x10⁻⁸ %

Earth's crust: 1.1x10⁻⁴ %

Human: none

Year of discovery: 1783





What

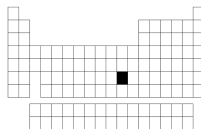
Gold is a soft and malleable metal, which means it's often alloyed with other metals (typically silver, copper, palladium or nickel) when used in things like jewellery to make it more structurally sound. It is generally quite unreactive (making it a 'noble metal'), and is a good conductor of heat and electricity. It is one of the densest elements, and unusually for a metal, it is not grey or silver-white in colour, but reddish-yellow.

Where

The chemical inertness of gold means that it can be found naturally as small flakes or large nuggets, often alloyed with silver. There are also significant quantities of gold dissolved in the world's oceans. Jewelry production and investment consume about 90% of the new gold produced each year, but it still finds use in areas such as electronics (a typical cell phone contains about 50mg of gold), dentistry and medicine.



Gold



d-block metal

m.p.: 1064 °C

b.p.: 2836 °C

Density: 19.3 g/cm³

[Xe] 4f¹⁴ 5d¹⁰ 6s¹

Atomic radius: 174 pm

Main isotope:

¹⁹⁷Au (100%)

Universe: 6.0x10⁻⁸ %

Earth's crust: 3.1x10⁻⁷ %

Human: 1.0x10⁻⁵ %

Year of discovery:

3000BC



82

Pb

207.19



What

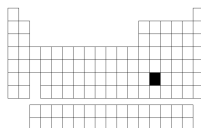
Lead is the heaviest non-radioactive element, and is dense, soft and highly malleable. Both its tensile strength and melting point are low relative to other metals. Freshly cut lead is silver in colour, but it then tarnishes to a dull grey (though it is resistant to corrosion). Its atomic symbol comes from the Latin word *Plumbum*, which also gives us 'plumbing'.

Where

Concerns over lead toxicity have meant that its use in many applications which stretch back thousands of years is now often discouraged, including in plumbing, construction, decorative glazes, glass, fishing sinkers and bullets. Tetraethyllead, widely used to improve petrol combustion, was phased out in the early 2000s. Lead, however, is still one of the most effective materials for shielding radiation, and lead-acid batteries continue to be widely used, including in most cars.



Lead



p-block metal

m.p.: 327 °C

b.p.: 1749 °C

Density: 11.34 g/cm³

[Xe] 4f¹⁴ 5d¹⁰ 6s² 6p²

Atomic radius: 154 pm

Main isotopes:

²⁰⁴Pb (1.4%)

²⁰⁵Pb (trace)

²⁰⁶Pb (24.1%)

²⁰⁷Pb (22.1%)

²⁰⁸Pb (52.4%)

²⁰⁹Pb (trace)

²¹⁰Pb (trace)

²¹¹Pb (trace)

²¹²Pb (trace)

²¹⁴Pb (trace)

Universe: 1.0x10⁻⁶ %

Earth's crust: 9.9x10⁻⁴ %

Human: 1.7x10⁻⁴ %

Year of discovery:

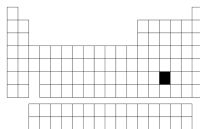
4000BC

What

Bismuth is a heavy p-block metal that is actually weakly radioactive. The decay of its most common isotope, Bi-209, was only discovered in 2003, and it has a half-life that's a billion times the age of the universe. The element crystallises as highly reflective silver-grey crystals, or as beautiful multi-hued crystals when very thin layers of oxide are allowed to form on the surface (the colour is determined by the layer thickness).

Where

Bismuth forms alloys with a number of other metals which are used for various applications, including as solders, steels, and specialised aluminium alloys. A bismuth compound, bismuth subsalicylate, is the active ingredient in Pepto-Bismol, and is also used (along with bismuth subcitrate) to treat peptic ulcers. The low melting "Wood's metal", an alloy of bismuth and cadmium, is used in automatic fire sprinklers.

Bismuth

p-block metal

m.p.: 271 °C

b.p.: 1564 °C

Density: 9.780 g/cm³[Xe] 4f¹⁴ 5d¹⁰ 6s² 6p³

Atomic radius: 143 pm

Main isotope:

²⁰⁹Bi (100%)Universe: 7.0x10⁻⁸ %Earth's crust: 2.5x10⁻⁶ %

Human: none

Year of discovery: 1500



Group 1

(1A)

Periodic Table

Group 18

(8A)

1	2																	3																																			
Group 1 H 1.01 (1A)	Group 2 He 4.00 (8A)	Group 13 (3A)	Group 14 (4A)	Group 15 (5A)	Group 16 (6A)	Group 17 (7A)	Group 18 (8A)																	Group 3 (3B)	Group 4 (4B)	Group 5 (5B)	Group 6 (6B)	Group 7 (7B)	Group 8 (8B)	Group 9 (8B)	Group 10 (8B)	Group 11 (1B)	Group 12 (2B)																				
Period 1	Period 2	5	6	7	8	9	10																	11	12																	13	14	15	16	17	18						
Li 6.94 9.01	Be 9.01	B 10.81	C 12.01	N 14.01	O 16.00	F 19.00	Ne 20.18																	Na 22.99	Mg 24.31																	Al 26.98	Si 28.09	P 30.97	S 32.06	Cl 35.45	Ar 39.95						
Period 3	Period 4	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36																	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54
K 39.10	Ca 40.08	Sc 44.96	Ti 47.88	V 50.94	Cr 52.00	Mn 54.94	Fe 55.85	Co 58.93	Ni 58.71	Cu 63.54	Zn 65.37	Ga 69.72	Ge 72.59	As 74.92	Se 78.96	Br 79.91	Kr 83.80																	Rb 85.47	Sr 87.62	Y 88.91	Zr 91.22	Nb 92.91	Mo 95.94	Tc 98.91	Ru 101.07	Rh 102.91	Pd 106.42	Ag 107.87	Cd 112.40	In 114.82	Sn 118.69	Sb 121.75	Te 127.60	I 126.90	Xe 131.30		
Period 5	Period 6	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71																	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86				
Cs 132.91	Ba 137.34	* La 138.91	Ce 140.12	Pr 140.91	Nd 144.24	Pm 146.92	Sm 150.35	Eu 151.96	Gd 157.25	Tb 158.92	Dy 162.50	Ho 164.93	Er 167.26	Tm 168.93	Yb 173.04	Lu 174.97																	Hf 178.49	Ta 180.95	W 183.85	Re 186.21	Os 190.23	Ir 192.22	Pt 195.09	Au 196.97	Hg 200.59	Tl 204.37	Pb 207.19	Bi 208.98	Po (209)	At (210)	Rn (222)						
Period 7		87	88	** Ac (227)	Th 232.04	Pa 231.04	U 238.03	Np (237)	Pu (244)	Am (243)	Cm (247)	Bk (247)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (261)																	Rf (261)	Db (268)	Sg (269)	Bh (270)	Hs (277)	Mt (278)	Ds (281)	Rg (282)	Cn (285)	Nh (286)	Fl (289)	Mc (290)	Lv (293)	Ts (294)	Og (294)				

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**

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La 138.91	Ce 140.12	Pr 140.91	Nd 144.24	Pm 146.92	Sm 150.35	Eu 151.96	Gd 157.25	Tb 158.92	Dy 162.50	Ho 164.93	Er 167.26	Tm 168.93	Yb 173.04	Lu 174.97
89	90	91	92	93	94	95	96	97	98	99	100	101	102	103
Ac (227)	Th 232.04	Pa 231.04	U 238.03	Np (237)	Pu (244)	Am (243)	Cm (247)	Bk (247)	Cf (251)	Es (252)	Fm (257)	Md (258)	No (259)	Lr (261)