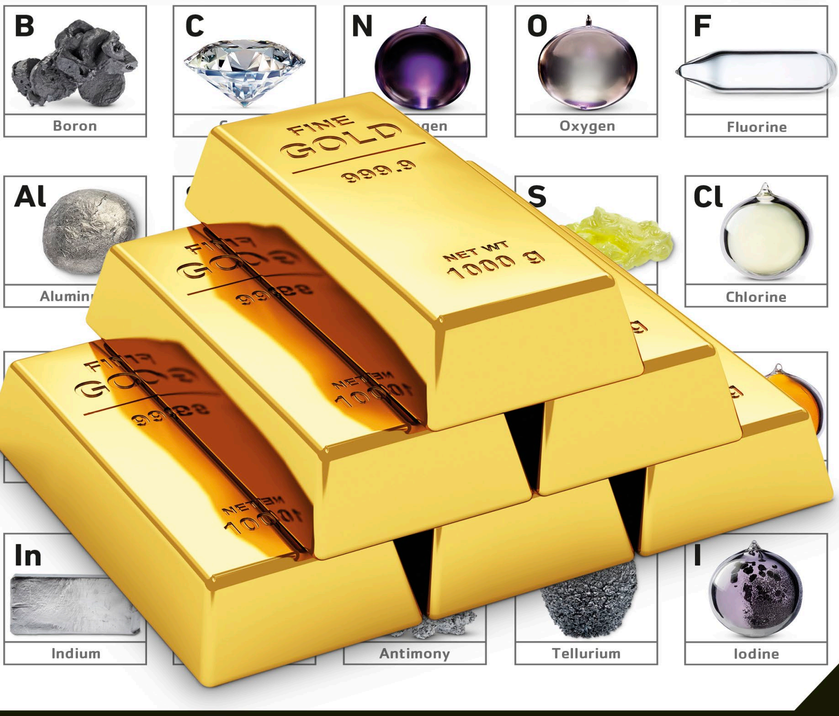
DK Pocket Genius

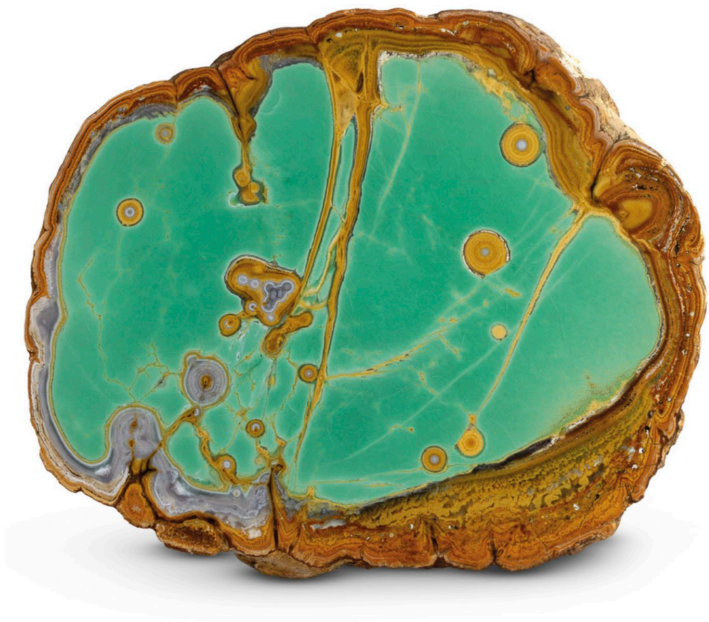
ELEMENTS



FACTS AT YOUR FINGERTIPS

Pocket Genius

ELEMENTS



FACTS AT YOUR FINGERTIPS

DK DELHI
Senior Editors Virien Chopra, Rupa Rao
Senior Art Editor Shreya Anand
Art Editor Noopur Dalal **Assistant Editor** Bipasha Roy
Jacket Designer Priyanka Bansal
DTP Designers Ashok Kumar, Pawan Kumar, Jagtar Singh
Picture Researcher Aditya Katyal
Pre-production Manager Balwant Singh
Production Manager Pankaj Sharma
Picture Research Manager Taiyaba Khatoon
Managing Editor Kingshuk Ghoshal
Managing Art Editor Govind Mittal

DK LONDON
Project Art Editor Renata Latipova **Editor** Jessica Cawthra
US Editor Megan Douglass
US Executive Editor Lori Cates Hand
Jacket Design Development Manager Sophia MTT
Producer, Pre-production Jacqueline Street-Elkayam
Senior Producer Jude Crozier
Managing Editor Christine Stroyan
Managing Art Editor Anna Hall
Publisher Andrew Macintyre
Art Director Karen Self
Publishing Director Jonathan Metcalf

Author Tom Jackson
Consultant John Gillespie

First American Edition, 2020
Published in the United States by DK Publishing
1450 Broadway, Suite 801, New York, NY 10018

20 21 22 23 24 10 9 8 7 6 5 4 3 2 1
001–316703–January/2020

Published in Great Britain by Dorling Kindersley Limited.

A catalog record for this book is available from the Library of Congress.

ISBN: 978-1-4654-9099-5

Printed and bound in China

CONTENTS

ATOMIC MASS: The relative atomic mass of an element. This is the average of the atomic masses of all the forms of an element. In cases where the relative atomic mass is not known, the atomic mass of an element's most stable form is given within brackets.

STATE: The state of an element at 68°F (20°C).

DISCOVERY: The year in which an element was discovered, along with the names of the discoverers. When different people have discovered an element separately, individual dates are given for each discoverer.

What is an element?

An element is a substance that cannot be refined or purified into simpler ingredients. Elements are made of building blocks called atoms and each element has its own unique set of atoms. Everything in the universe is made from elements, either in their pure form, or combined together to make new substances called compounds.

Classical elements

The idea of an element is very old. In ancient cultures, people believed that all things were made from mixtures of just four elements: earth, water, air, and fire. They thought that hot and dry things contained fire and air, while cold and wet things were made of earth and water.

Earth

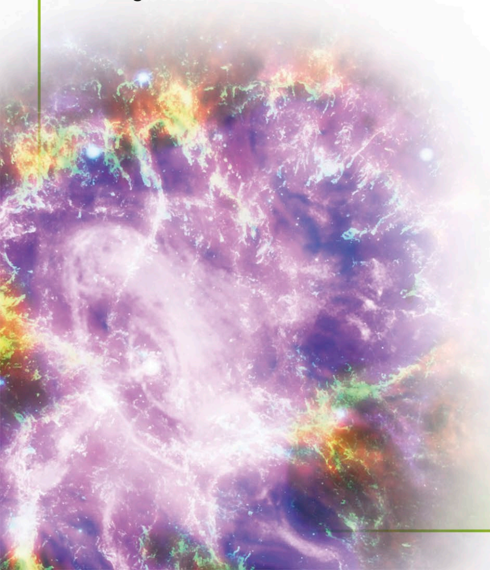
Water

Air

Fire

Modern elements

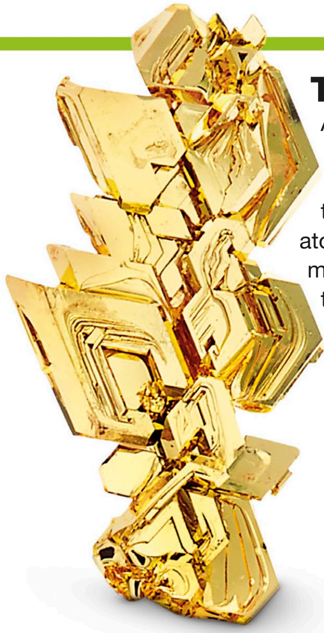
The scientific study of the properties and reactions of elements is called chemistry. This has found that there are at least 118 elements. Most elements are created inside a star or in a supernova—the explosive ending of a big star's life. Scientists have also been able to create the heaviest elements in laboratories.



The Crab Nebula, the remains of a supernova, is rich in hydrogen.

Types of element

Atoms are made of smaller "subatomic" particles called protons, electrons, and neutrons. The properties of an element depend on how these particles are arranged. Elements with the same number of electrons in the outermost shell of their atom have similar physical and chemical properties. Metals mostly have one or two outer electrons, semi-metals have three or four, and nonmetals have up to eight.



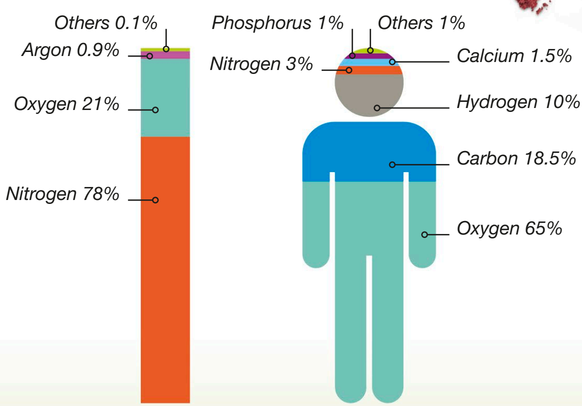
Crystals of gold (metal)

Chunk of boron (semi-metal)

Powdery form of phosphorus (nonmetal)

Building blocks

Everything in the universe is made up of the many types of elements arranged in different combinations. That includes living things such as humans. The human body is made of 60 different elements. Just six of them make up 99 percent of the body's weight, while the other 54 make up the remaining 1 percent. Amazingly, only three elements make up most of Earth's atmosphere.

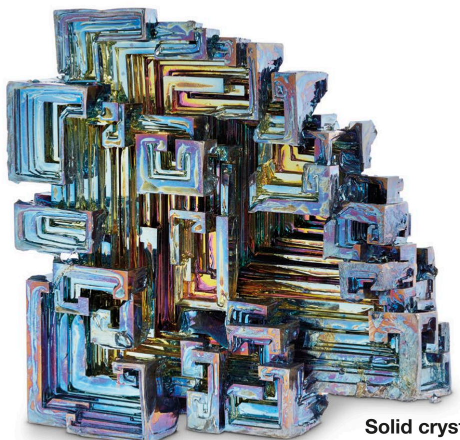


Earth's atmosphere **Human body**

States of matter

Every element has a standard state—solid, liquid, or gas—at room temperature. The atoms of a solid fit together in a tight-knit pattern, while in a liquid the atoms are loosely connected so they flow around. In a gas, the atoms are free of each other and disperse easily. Applying heat can change the state of an element from solid to liquid, and then to gas, or even from solid to gas in some cases.

Chlorine gas in a glass sphere



Solid crystals of bismuth refined in a laboratory

Liquid mercury in a vial

Pure forms

A pure sample of an element contains only atoms of that element. Only a few elements are found pure in nature in significant amounts. These include gold and sulfur (in the ground), and oxygen (in the air). Many elements are found in ores.

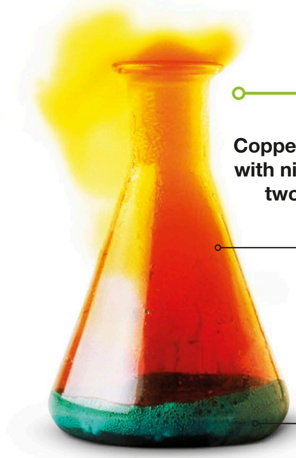
Gold in quartz

This vein of pure gold has occurred naturally inside a chunk of quartz.

Ores

A naturally occurring substance—rock, sand, or crystal—that contains a large amount of an element is called an ore. Ores are mined so that the elements they contain can be removed. Some ores contain more than one element. The mineral malachite (right) is an ore of copper, and chemical reactions are used to extract the metal from the ore.

Malachite



Copper flakes reacting with nitric acid to form two compounds

The red-brown gas is nitrogen dioxide, a compound of nitrogen and oxygen.

Copper nitrate, a green, solid compound, in nitric acid

Compounds

Most elements do not stay pure in nature for long. Instead they react with other elements they come into contact with, which results in the atoms of two or more elements bonding together to make an entirely new substance called a compound. The properties of a compound are always very different to the elements that make it.

Mixtures

Elements combine chemically to form compounds, and it takes a chemical reaction to break the bonds between the atoms in a compound to separate the elements. On the other hand, a mixture is formed when compounds or elements are combined physically. An alloy is a mixture of at least two elements, one or all of which are metals. In a mixture, elements may be so thoroughly mixed that they are impossible to tell apart.

Mixture of food coloring and water

Inside an atom

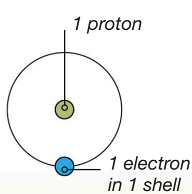
An atom is the smallest unit of an element. Every element has atoms made of a unique combination of even smaller particles, known as subatomic particles. These are the electrons, protons, and neutrons.

Subatomic particles

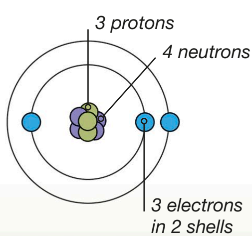
In an atom, protons and neutrons are located in its core, or nucleus. Changes to these particles are called nuclear reactions. The electrons, located outside of the nucleus, participate in chemical reactions, helping elements combine to form compounds.

Atomic number

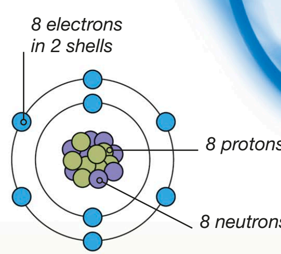
An element's atomic number is defined by the number of protons in one of it's atoms. Every element has a unique atomic number. Hydrogen has the lowest atomic number (1) among the elements as it has only one proton. The number of electrons in an element always matches the atomic number.



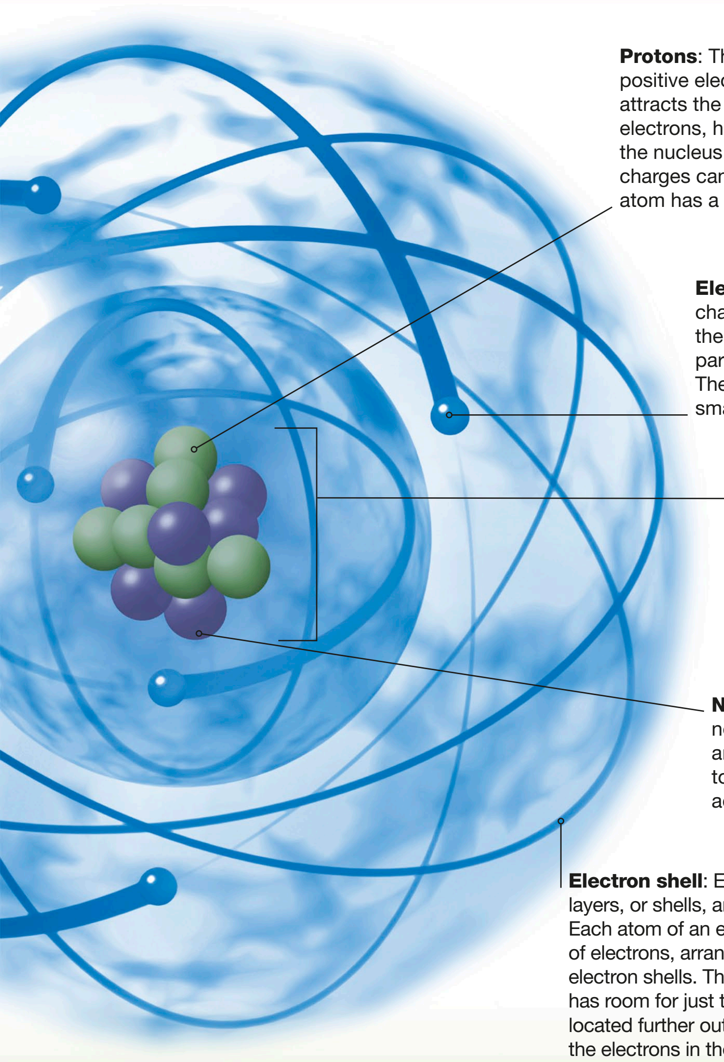
Hydrogen atom (atomic number 1)



Lithium atom (atomic number 3)



Oxygen atom (atomic number 8)



Protons: These particles have a positive electrical charge. This charge attracts the negatively charged electrons, holding them in place around the nucleus. The positive and negative charges cancel out each other, so an atom has a neutral charge.

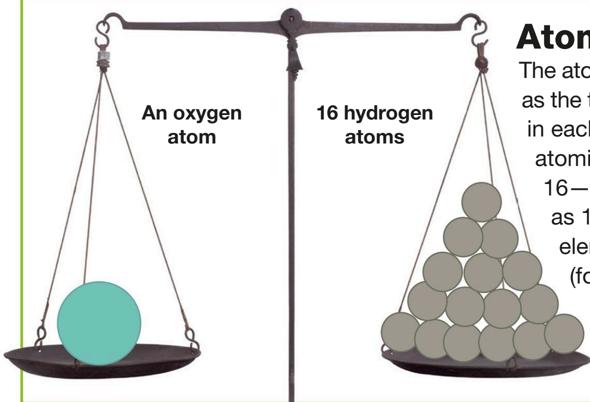
Electrons: Negatively charged electrons were the first type of subatomic particle to be discovered. They are almost 2,000 times smaller than protons.

Nucleus: Almost all of an atom's weight is packed inside the nucleus. Even so, it is 100,000 times smaller than the atom as a whole. Most of an atom is empty space.

Neutrons: A neutron has no overall electrical charge, and helps protons cluster together in the nucleus. It adds weight to the atom.

Electron shell: Electrons are arranged in layers, or shells, around the outside of an atom. Each atom of an element has a unique number of electrons, arranged in a particular way in its electron shells. The shell closest to the nucleus has room for just two electrons, but shells located further out have room for more. Only the electrons in the outermost shell participate in chemical reactions.

Structure of an atom

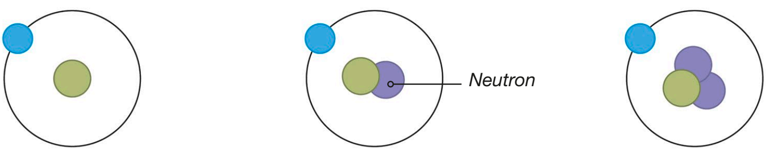


Atomic mass

The atomic mass of an element is measured as the total number of protons and neutrons in each of its atoms. Hydrogen has an atomic mass of 1, while oxygen's is 16—one oxygen atom weighs as much as 16 hydrogen atoms. Since an element can have different isotopes (forms), scientists use its relative atomic mass. This is the average of the atomic masses of all the isotopes of an element.

Isotopes

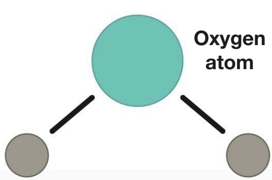
While an atom of an element has a unique number of protons and electrons, the number of neutrons in it may vary. This creates different forms of the same element, known as isotopes. For example, hydrogen has three isotopes.



Hydrogen has no neutrons.

Deuterium (an isotope of hydrogen) has 1 neutron.

Tritium (an isotope of hydrogen) has 2 neutrons.



Forming molecules

During chemical reactions, atoms make bonds with each other to form structures called molecules. Molecules of elements contain atoms of the same element, while molecules of compounds are made of atoms of different elements. For example, a water molecule forms when an oxygen atom bonds to two hydrogen atoms. This molecule is the smallest possible unit of the compound called water.

Piece of charcoal

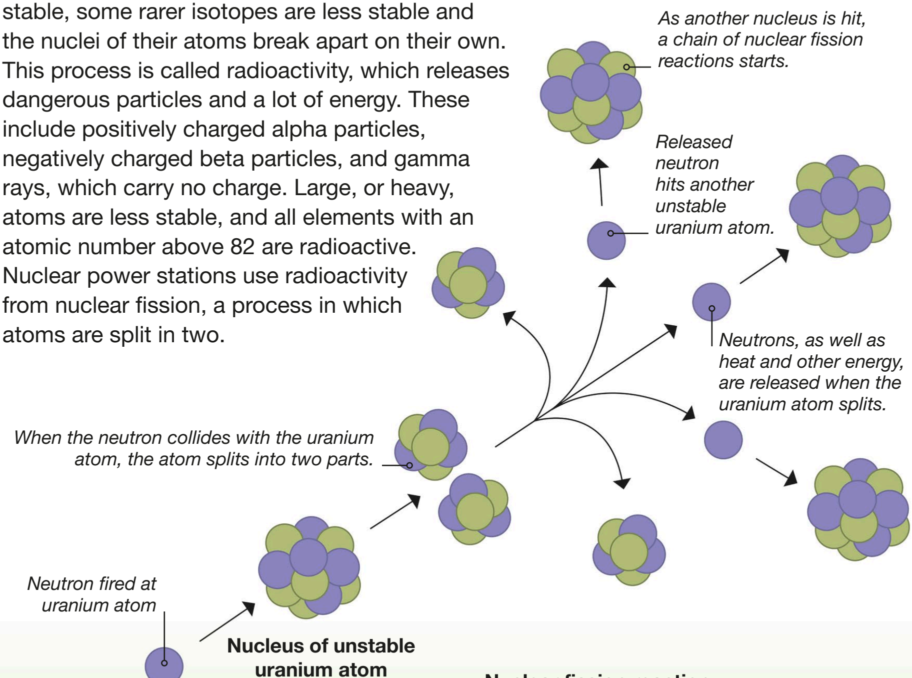
Diamond crystal

Allotropes

Several elements have multiple physical forms, or allotropes. For example, carbon has four allotropes: diamond, graphite, soot (or charcoal), and buckminsterfullerene. They are all made from pure carbon, but look and feel very different.

Radioactivity

While the main isotopes of most elements are stable, some rarer isotopes are less stable and the nuclei of their atoms break apart on their own. This process is called radioactivity, which releases dangerous particles and a lot of energy. These include positively charged alpha particles, negatively charged beta particles, and gamma rays, which carry no charge. Large, or heavy, atoms are less stable, and all elements with an atomic number above 82 are radioactive. Nuclear power stations use radioactivity from nuclear fission, a process in which atoms are split in two.



Nuclear fission reaction

Grouping the elements

Chemistry is the science that seeks to understand how elements behave and how they combine into compounds. In order to achieve this, chemists began trying to organize all known elements according to their physical and chemical properties. Over 200 years later, the result is the modern periodic table, which arranges elements by the similarity of their properties.

Antoine Lavoisier

In 1789, the French scientist Antoine Lavoisier produced an early list of chemical elements, which he called “simple substances.” Lavoisier’s list had 55 entries, divided into metals, nonmetals, and gaseous elements, such as oxygen.

Drops of the liquid metal mercury

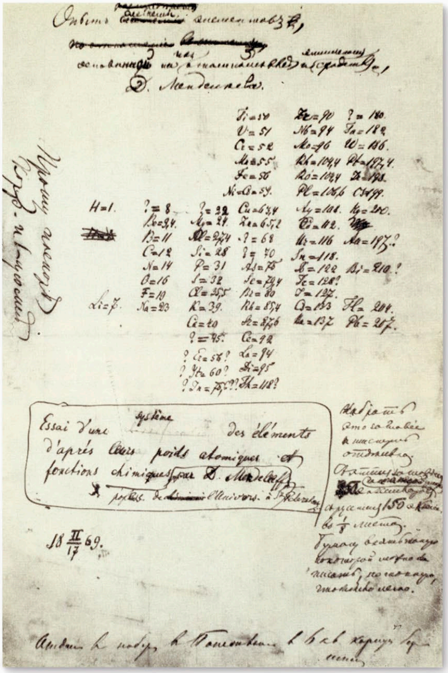
Pure oxygen gas in a glass sphere

Yellow crystals of the nonmetal sulfur in rock

Johann Döbereiner

The German chemist Johann Döbereiner showed in 1817 that most elements could be grouped into threes (or “triads”). Some elements were “missing” at the time as they had not yet been discovered, and this finding encouraged the search for new elements in the 19th century. Elements in each triad—such as lithium, sodium, and potassium—shared chemical properties.

Potassium kept inside an airless glass vial



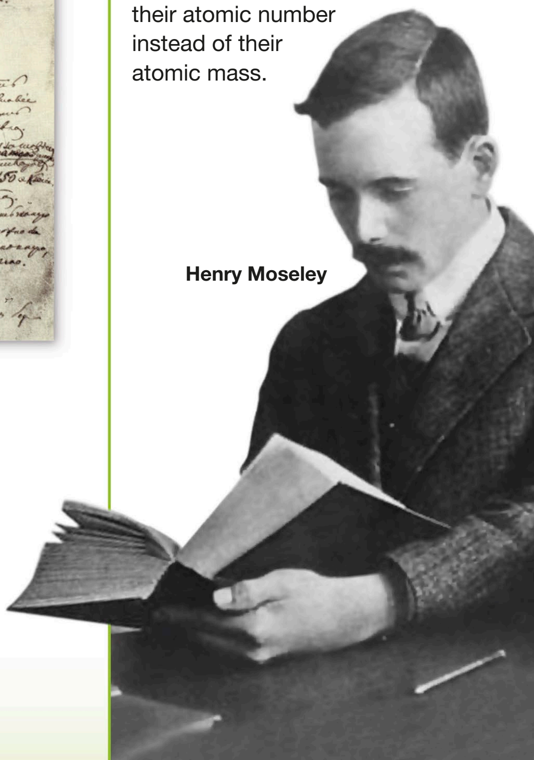
Dmitri Mendeleev's handwritten periodic table from February 1869

Dmitri Mendeleev

In 1869, the Russian chemist Dmitri Mendeleev invented the forerunner of the modern periodic table. He saw that elements had chemical properties that followed a repeating pattern and those with similar patterns could be grouped together. He listed the elements in order of atomic mass, starting a new section with every new pattern.

Henry Moseley

Mendeleev's table worked very well, but no one really knew why. In 1913, the British physicist Henry Moseley discovered the concept of the atomic number—the number of protons in an atom of an element, which is unique to that element. He used X-rays to calculate the atomic numbers of elements, which could now be organized on the basis of their atomic number instead of their atomic mass.



Henry Moseley

Periodic table

The periodic table organizes the 118 known elements by arranging them based on their atomic number, which is the number of protons in each of their atoms. The elements are placed in rows (called "periods") and columns (called "groups"). Elements with similar properties sit in a group. This table is "periodic" because the characteristics of the elements follow a pattern. New elements may be added to it in the future.

Period numbers — Group numbers

Period	1	2	3	4	5	6	7	8	9
1	1 H Hydrogen								
2	3 Li Lithium	4 Be Beryllium							
3	11 Na Sodium	12 Mg Magnesium							
4	19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt
5	37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium
6	55 Cs Cesium	56 Ba Barium	57–71 Lanthanide series	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium
7	87 Fr Francium	88 Ra Radium	89–103 Actinide series	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium

These two rows, known as the Lanthanides and Actinides, are not periods. They sit next to Group 2, but make the table very wide, so are moved to the bottom.

57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium
89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium

KEY

- Hydrogen
- Alkali Metals
- Alkaline Earth Metals
- Transition Metals
- Lanthanides
- Actinides
- Boron Group
- Carbon Group
- Nitrogen Group
- Oxygen Group
- Halogen Group
- Noble Gases

The atomic number is unique to each element.

29 Cu Copper

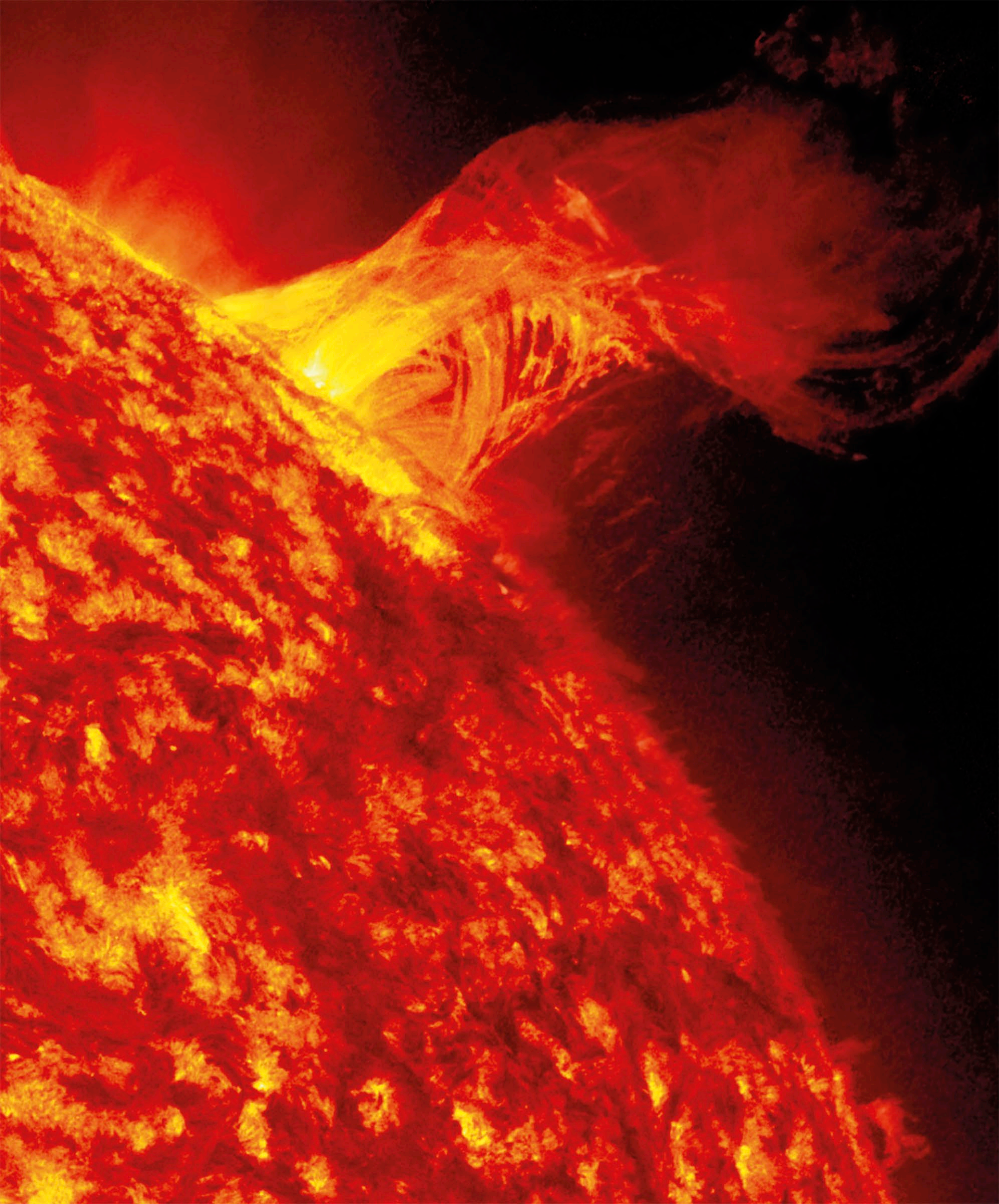
Each element has a unique symbol made of letters.

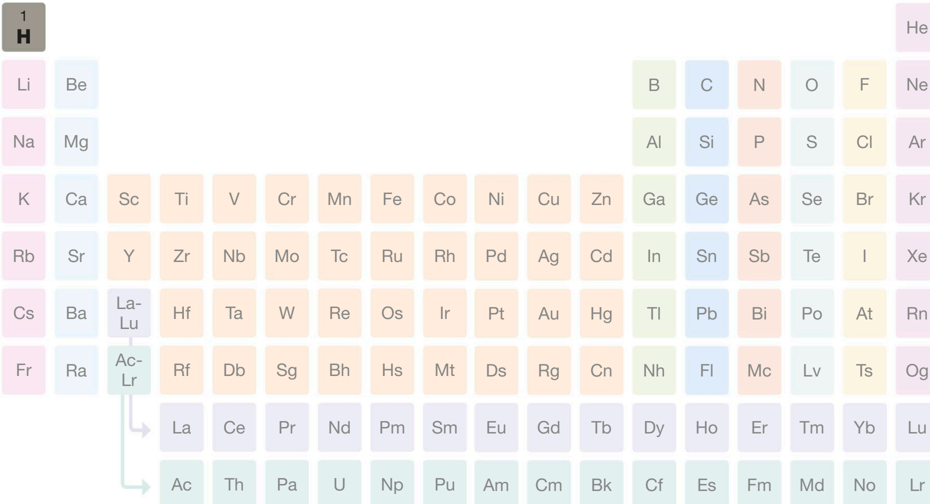
Period: A row of elements with the same total number of electron shells in their atoms.

Group: A column of elements with the same number of electrons in the outermost shell of each of their atoms.

10	11	12	13	14	15	16	17	18
								2 He Helium
			5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
			13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
110 Ds Darmstadtium	111 Rg Roentgenium	112 Cn Copernicium	113 Nh Nihonium	114 Fl Flerovium	115 Mc Moscovium	116 Lv Livermorium	117 Ts Tennessine	118 Og Oganesson

63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium
95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium	103 Lr Lawrencium





Hydrogen

The simplest of all elements, hydrogen has only one proton and one electron. It is the most abundant element in the universe—the sun, like all other stars, is a vast ball of seething hot hydrogen gas.

FOCUS ON…
HYDROGEN

This gas is found in very useful chemicals and even in the human body—one tenth of which is made of hydrogen.

▲ Hydrogen is used in the production of margarine to thicken it.

▲ A new generation of environment-friendly cars use fuel cells powered by hydrogen.

◀ Liquid hydrogen is used as rocket fuel. Combined with oxygen, it produces the thrust to power a rocket.

Hydrogen

Three-quarters of all the atoms in the universe are hydrogen—the lightest of all the elements. The heat and light from stars, including our sun, comes from hydrogen atoms fusing into helium atoms in each star's core. In fact, all heavier elements started out as these small atoms, which have gradually fused together.

Stars form inside a nebula, which is a cloud of hydrogen gas and some dust.

1
H

ATOMIC MASS 1.008

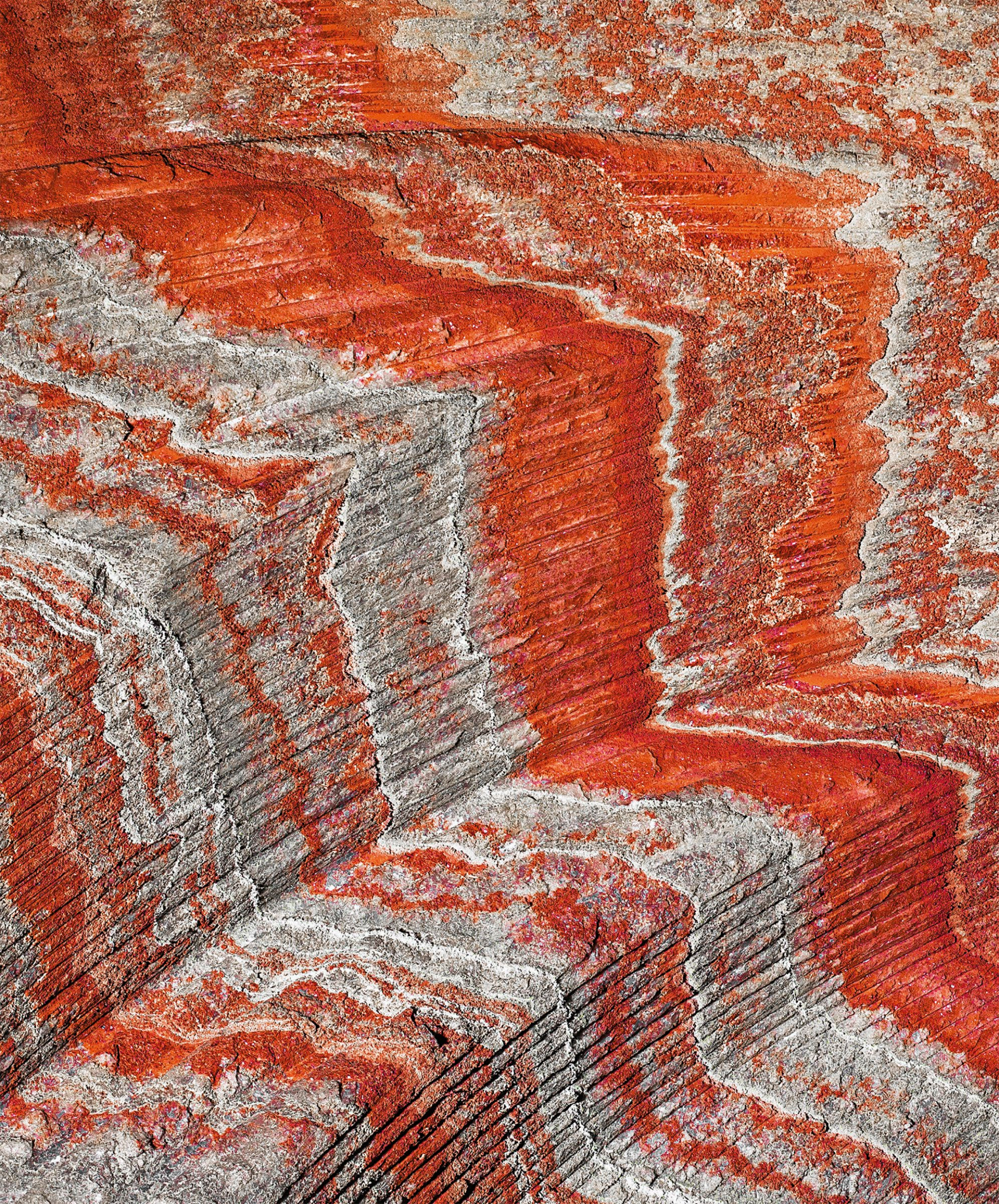
STATE Gas

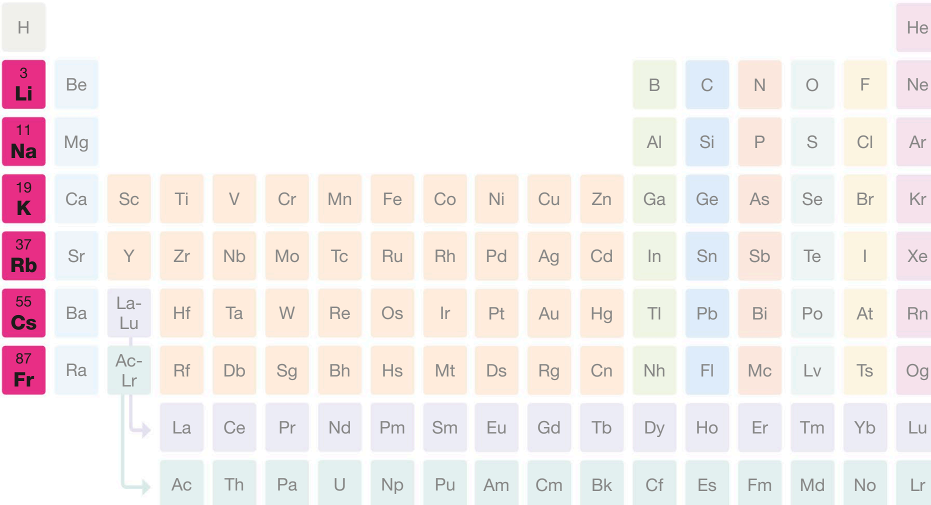
DISCOVERY 1766 (Henry Cavendish)

Hydrogen gives off a purple glow when electrified.

Pure hydrogen gas in a glass sphere

The Carina Nebula is home to clusters of old and new stars.





Alkali Metals

All alkali metals are highly reactive, so they form compounds easily and are found in many minerals. The walls of this potash mine have orange and white stripes due to the many potassium compounds being mined.

Alkali Metals

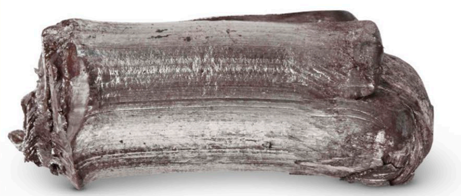
As well as hydrogen, the first column of the periodic table contains the alkali metals, a group of six elements that react vigorously with water to produce chemicals known as alkalis. Members of this group are soft enough to cut with a knife. They are never found pure in nature, but always as a compound, from which the pure metal is extracted.

Colored flames

Each alkali metal burns with a distinctive color. While lithium burns with deep-red flames, potassium's flames are lilac, and sodium's are yellow. Chemists look for these colors to identify the metals involved in reactions.

Easily tarnished

Freshly cut or scraped alkali metals are shiny, but turn dull as their surface reacts with oxygen in the air and forms a thin layer of the metal's oxide. In laboratories, the metals are stored in oil to prevent this.



Oxide layer gives this piece of lithium a dull appearance.

Highly reactive

Alkali metals are usually stored in oil because they are so reactive to the oxygen and water vapor in the air that some of them will burst into flames when they come into contact with it. Lithium tarnishes in the air, but doesn't ignite until it is heated (as pictured on the left). It combines with oxygen to form a whitish compound called lithium oxide.

Salt compounds

Alkali metals react with halogen elements to create salts, such as sodium chloride. These are white crystals that dissolve in water very easily. An example of this is sea salt, which is mostly sodium chloride, but also contains potassium chloride and trace amounts of other salts.

Salt evaporation pools at Salinas de Janubio, Lanzarote, Canary Islands

Lithium

3
Li

The main natural source of lithium is the thick layer of salt left over from when ancient lakes and seas dried out. This alkali metal is used to make long-lasting batteries inside cell phones and electric cars.

ATOMIC MASS 6.94

STATE Solid

DISCOVERY 1817 (Johan August Arfvedson)

Lithium is the lightest of all metals; it will float on water even as it reacts with it.

Purple crystals in this rock contain lepidolite, an ore of lithium

FOCUS ON… SODIUM

The use of sodium dates back thousands of years.

▲ Ancient Egyptians used a sodium compound, natron, to preserve mummies.

▲ Sodium chloride, or common salt, adds flavor to foods.

▲ Sodium compounds give some fireworks their yellow color.

Sodium

11
Na

The most common alkali metal in Earth's crust, sodium is purified by electrifying through sodium chloride. The electric current splits the sodium and chlorine apart in a process known as electrolysis.

ATOMIC MASS 22.99

STATE Solid

DISCOVERY 1807 (Sir Humphry Davy)

Nugget of pure sodium

Potassium

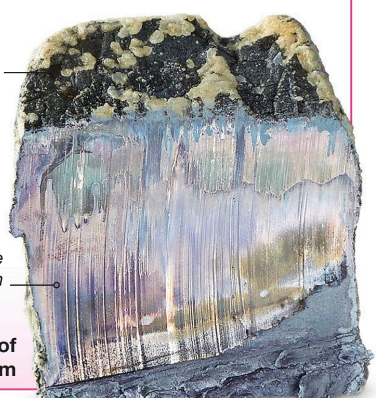
19
K

This metal helps the nerves and muscles in the body work properly. Potassium is found in foods such as bananas and avocados. Its compounds are used in soaps, plant fertilizers, and gunpowder.

ATOMIC MASS 39.098

STATE Solid

DISCOVERY 1807 (Sir Humphry Davy)



A layer of dark oxide covers the outside of the metal.

Pure potassium

Nugget of potassium

LAKE NATRON
Tanzania's Lake Natron is filled with a natural supply of sodium salts, such as sodium carbonate, which wash out of the volcanic rocks in the region. The water is more alkaline than baking soda—perfect for the rapid growth of a kind of bacteria that turns the lake red.

Any creature that falls into Lake Natron quickly gets covered in sodium salts and looks as if it has been

turned to stone

Rubidium

37
Rb

This metal is very rare compared to other alkali metals. Rubidium is named after the Latin word for “red” as it produces a deep-red flame when it burns. It is used only in a few high-tech applications, such as night-vision goggles.

ATOMIC MASS 85.468

STATE Solid

DISCOVERY 1861 (Gustav Kirchhoff and Robert Bunsen)

Leucite, an ore of rubidium

Cesium

55
Cs

The most reactive metal found on Earth, cesium explodes violently on contact with air. It is used in atomic clocks, the most accurate timepieces yet invented.

ATOMIC MASS 132.905

STATE Solid

DISCOVERY 1860 (Gustav Kirchhoff and Robert Bunsen)

Laboratory sample of pure cesium in an airless vial

Francium

87
Fr

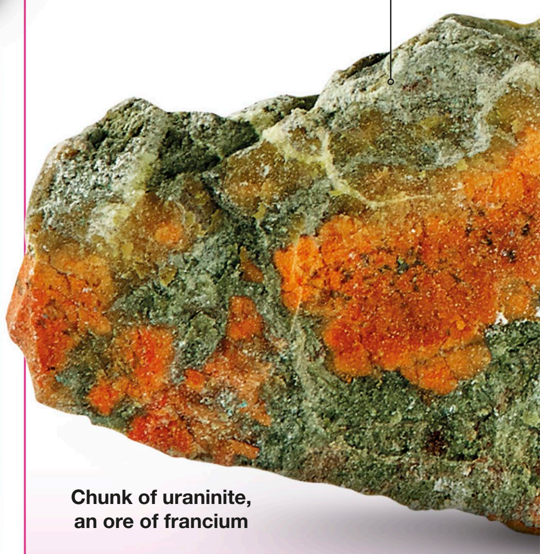
The atoms of this radioactive element exist only for a few minutes before breaking up. As a result, francium is one of the rarest elements. This metal was one of the last elements discovered in nature because of its rarity. It was named after the country in which it was first found, France.

ATOMIC MASS (223)

STATE Solid

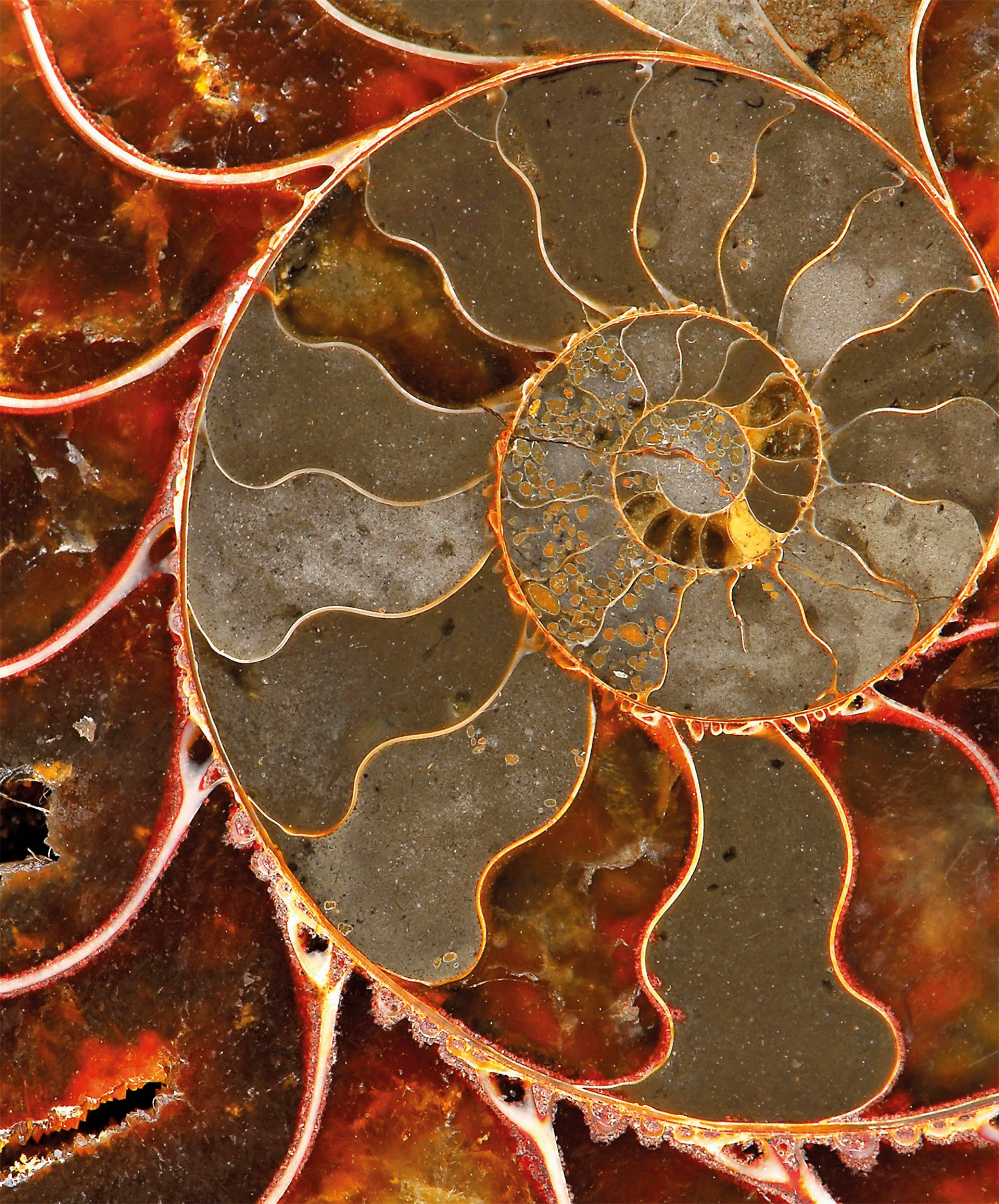
DISCOVERY 1939 (Marguerite Perey)

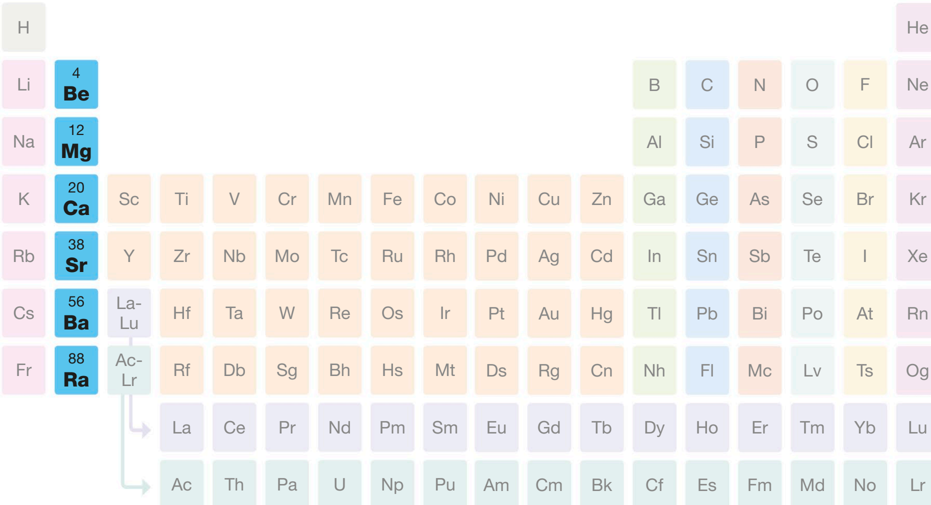
As the uranium in this ore breaks down, it releases actinium atoms, which in turn break down to release francium atoms.



Chunk of uraninite, an ore of francium

The largest sample of francium ever collected was 1 million atoms, in a US laboratory in 2012.





Alkaline Earth Metals

The elements in this group appear in nature as minerals, or “earths,” that mix easily with water to form compounds called alkalis. The minerals of calcium are the most common because they are found in living things—even in the shell of this fossilized ammonite.

Alkaline Earth Metals

Forming the second column—or Group 2—of the periodic table, these metals are not quite as reactive as their neighbors, the alkali metals, which form Group 1. Most alkaline earth metals were first found in Earth's crust as oxide compounds. Solid at room temperature, these elements have low melting and boiling points.

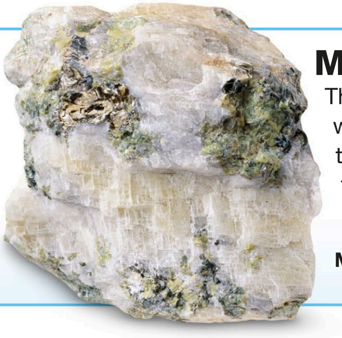
Magnesium can be made into a flexible ribbon

Soft metals

Most members of this group are soft, brittle metals when pure, and are easy to cut with a knife. They also break easily when they are dropped or twisted. One exception is beryllium, which is a hard, tough metal.

Silvery shine

Pure alkaline earth metals, such as calcium (seen above), are shiny. These metals are highly reflective and have a very smooth surface, which creates a mirrorlike shine.



Making alkalis

The crumbly minerals of these elements dissolve in water to form chemicals called alkalis. In the past, these minerals were called "earths," which inspired the name of the group.

Magnesite, a mineral of magnesium

Colorful flames

When alkaline earth metals react with oxygen in the air, they burn and release energy in the form of light and heat. Each member of this group burns with a distinctive, colored flame. Magnesium produces a particularly bright white flame (pictured right).

Magnesium powder produces the bright white sparkles of fireworks.

Fireworks display at Sydney Harbor Bridge, Australia

Beryllium

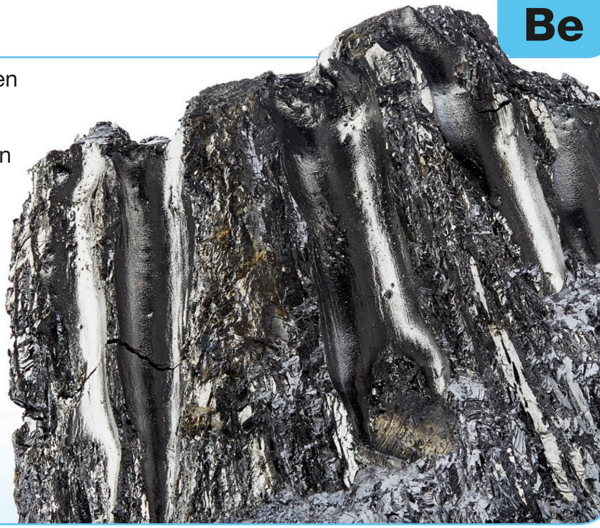
4
Be

While other metals expand when hot and contract when cold, beryllium keeps its shape at all temperatures. This means it can be used in machines such as high-speed aircraft, in which some parts may become extremely hot.

ATOMIC MASS 9.012

STATE Solid

DISCOVERY 1797 (Nicholas Louis Vauquelin)



Laboratory sample of pure beryllium

Magnesium

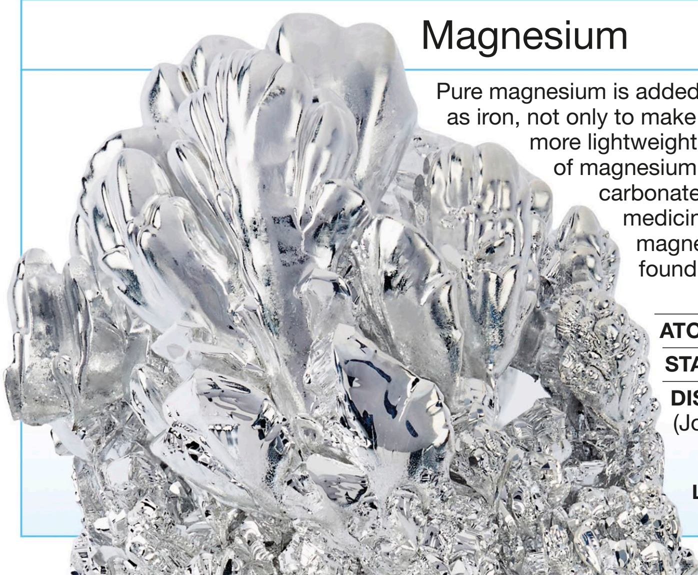
12
Mg

Pure magnesium is added to other metals such as iron, not only to make them stronger but also more lightweight. Useful compounds of magnesium include magnesium carbonate, which is used in medicine for indigestion, and magnesium oxide, which is found in cement.

ATOMIC MASS 24.305

STATE Solid

DISCOVERY 1755 (Joseph Black)



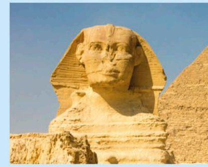
Laboratory sample of pure magnesium

FOCUS ON...
CALCIUM

This element is the most common alkaline earth metal in Earth's rocks, and the most abundant metal in the human body.

▲ Writing chalk is mainly made of a calcium sulfate mineral known as gypsum.

▲ Milk is a source of calcium and helps to strengthen our bones and teeth.



▲ The Sphinx of Giza is made from limestone, a rock formed primarily of calcium carbonate.

Calcium

20
Ca

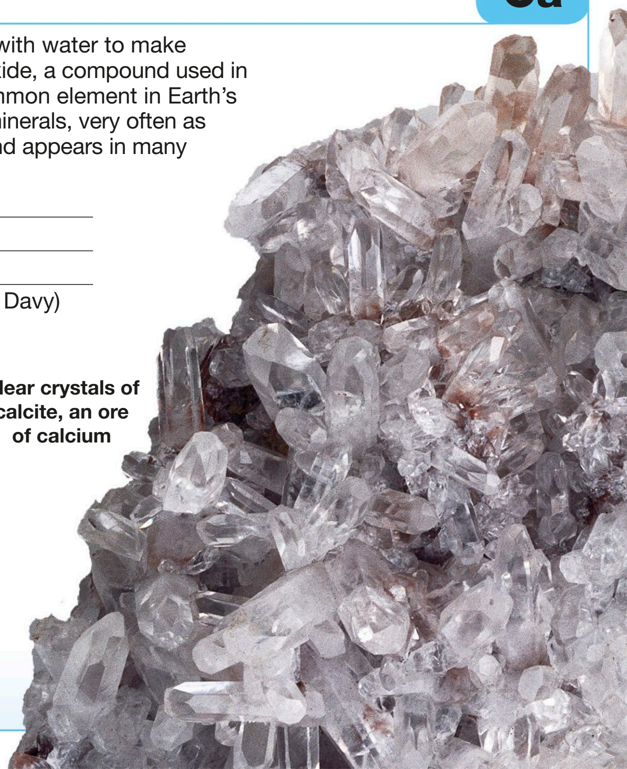
The pure form of calcium reacts with water to make hydrogen gas and calcium hydroxide, a compound used in paper-making. The fifth most common element in Earth's crust, calcium is found in many minerals, very often as calcium carbonate. This compound appears in many forms, including calcite crystals.

ATOMIC MASS 40.078

STATE Solid

DISCOVERY 1808 (Sir Humphry Davy)

Crystals of pure calcium refined in a laboratory



Clear crystals of calcite, an ore of calcium

Strontium

This metal is named after Strontian, a village in Scotland near where the first samples of strontium minerals were discovered. Strontium has a wide range of uses, including in fireworks that burn red and toothpastes for people with sensitive teeth.

ATOMIC MASS 87.62

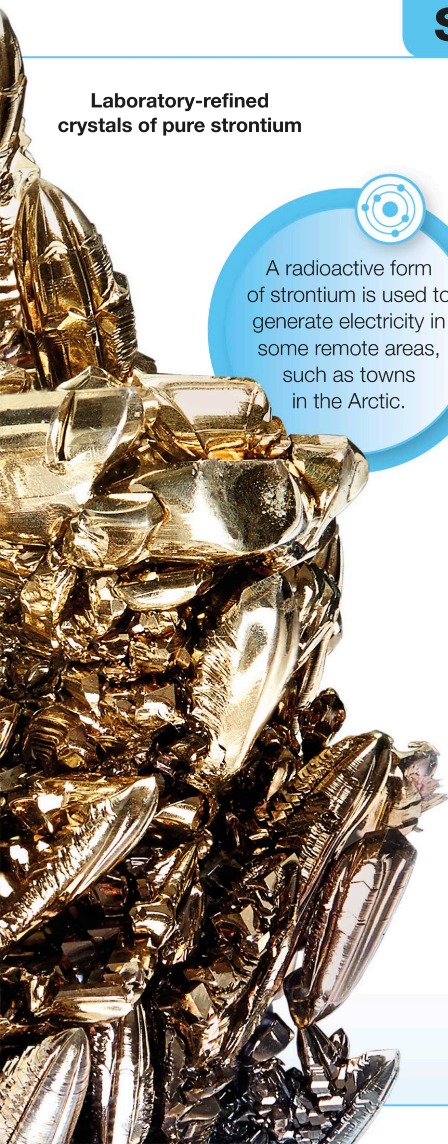
STATE Solid

DISCOVERY 1787 (Adair Crawford), 1791 (Thomas Charles Hope)

Blue crystals of celestine, an ore of strontium

The grayish metal turns yellow in the air.

38
Sr



Laboratory-refined crystals of pure strontium

A radioactive form of strontium is used to generate electricity in some remote areas, such as towns in the Arctic.

Barium

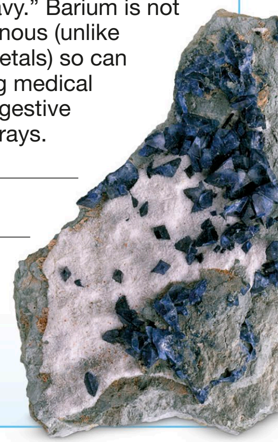
56
Ba

The name of this element comes from the Greek word for "heavy." Barium is not radioactive or poisonous (unlike most other heavy metals) so can be swallowed during medical tests to make the digestive system clearer in X-rays.

ATOMIC MASS
137.327

STATE Solid

DISCOVERY 1808 (Sir Humphry Davy)



Blue crystals of benitoite, an ore of barium, in rock

Radium

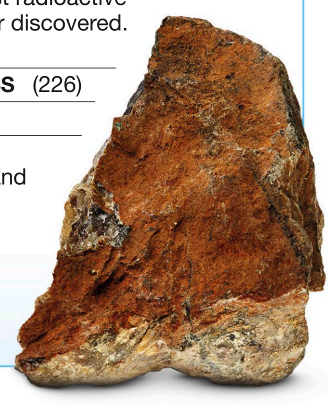
88
Ra

Tiny amounts of radium can be found in ores of more common radioactive elements such as uranium. Radium was one of the first radioactive elements ever discovered.

ATOMIC MASS (226)

STATE Solid

DISCOVERY
1898 (Marie and Pierre Curie)



Chunk of uraninite, an ore of radium

Transition Metals

The hard transition metals are often extracted from their ores in their red-hot, pure, and molten form via a process called smelting. While molten, these metals can be precisely mixed to make alloys, such as steels and brasses, which have useful characteristics.

Transition Metals

The largest collection of elements in the periodic table, there are 38 transition metals. Most of them have high melting and boiling points, conduct heat and electricity well, and are easy to shape. These metals are not as reactive as the alkali metals and alkaline earth metals.

Hard metals

The transition metals tend to be dense and hard compared to metals in other sections of the periodic table. They are frequently mixed together to make alloys, such as steel or brass, which are harder and stronger still.

Strong titanium alloy wheel

Bracelet made of gold

Precious metals

The four "precious" metals—gold, silver, platinum, and palladium—are transition metals. They are called precious because they are rare. They stay shiny without corroding, which makes them ideal for crafting jewelry.

Copper wires inside electrical cable

Good conductors

The elements in this group are good conductors, which means that heat and electric currents move through these substances easily. Silver is the best conductor of all, but it is too expensive to use in large amounts. Electrical and telephone wires and television cables are largely made from copper, which is very common.

Colorful compounds

Each transition metal can form a variety of colorful compounds. Different compounds absorb different amounts of light energy, which produces the variations in color. This is why the Rainbow Mountains in China have multiple hues: iron oxide causes the red color, while iron sulfide results in the yellow.

Rainbow Mountains at the Zhangye Danxia Landform Geological Park in China

Scandium

21
Sc

There are very few ores that contain significant amounts of scandium, so it is not widely used. It is also expensive: 1 lb (0.45 kg) of scandium costs more than $120,000.

ATOMIC MASS 44.956

STATE Solid

DISCOVERY 1879 (Lars Frederik Nilson)

Laboratory sample of pure scandium

Titanium

This metal is as tough as steel but much lighter. Titanium can be easily refined into pure metal from its ore. It is mixed with aluminum to make superstrong alloys for aircraft bodies and engines.

ATOMIC MASS 47.867

STATE Solid

DISCOVERY 1791 (William Gregor)

The body of an Airbus A380 superjumbo contains about 84 tons (77 metric tons) of titanium.

The mineral albite, which does not contain titanium, grows alongside brookite.

22
Ti

The mineral brookite is a natural form of a compound called titanium dioxide.

Laboratory sample of pure titanium

Red-brown crystal of brookite, an ore of titanium

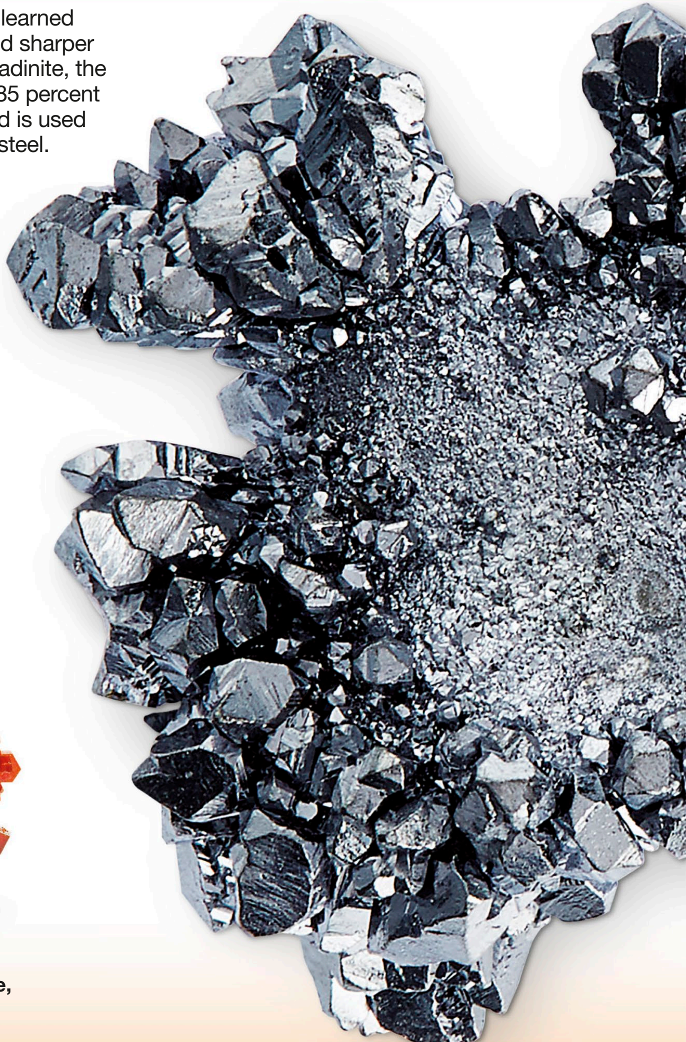
Vanadium

In ancient India, metalworkers learned to make iron swords harder and sharper by adding tiny amounts of vanadinite, the main ore of vanadium. Today, 85 percent of the pure vanadium produced is used to make super-tough types of steel.

ATOMIC MASS 50.942

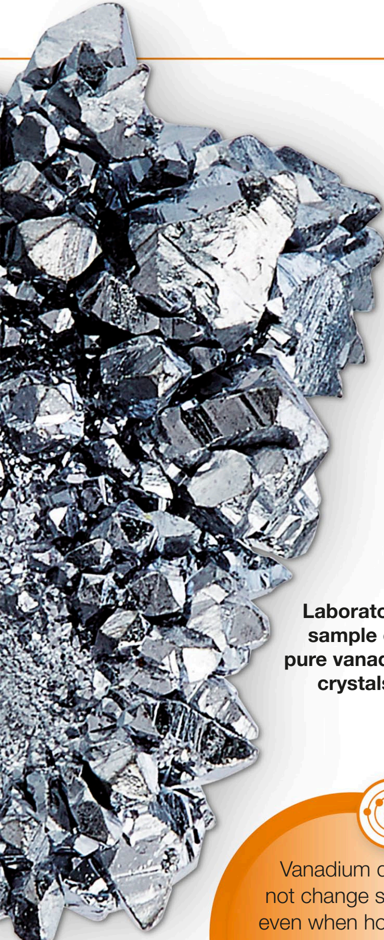
STATE Solid

DISCOVERY 1801 (Andrés Manuel del Rio)



Red crystals of vanadinite, an ore of vanadium

23
V



Laboratory sample of pure vanadium crystals

Vanadium does not change shape, even when hot, so it is used to build the latest nuclear fusion reactors.

Chromium

24
Cr

Pure chromium is mixed with steel to stop it from rusting—producing shiny stainless steel. Compounds of chromium come in bright colors, such as purple, yellow, and red.

Laboratory sample of pure chromium

ATOMIC MASS 51.996

STATE Solid

DISCOVERY 1798 (Nicholas Louis Vauquelin)

Manganese

25
Mn

When pure, manganese is a gray metal that is hard and brittle. It is mixed with silicon into steel to harden it. This tough steel can be used to make tank armor.

Chunk of rhodonite, an ore of manganese

ATOMIC MASS 54.938

STATE Solid

DISCOVERY 1774 (Johan Gottlieb Gahn)

Iron

26
Fe

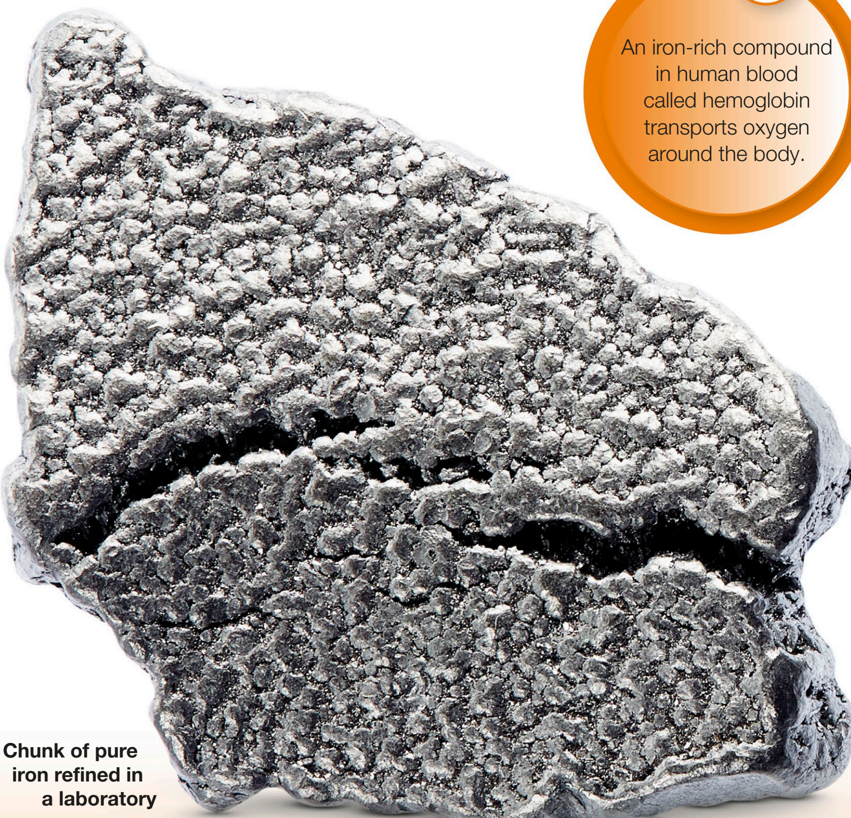
Oxygen, silicon, and aluminum are more common than iron in rocks on Earth's surface, but it is iron that makes up around 35 percent of Earth's mass. Most of it is found in the planet's core, which is a ball made of hot iron and nickel, nearly 3,100 miles (5,000 km) wide.

ATOMIC MASS 55.845

STATE Solid

DISCOVERY Around 3500 BCE

An iron-rich compound in human blood called hemoglobin transports oxygen around the body.

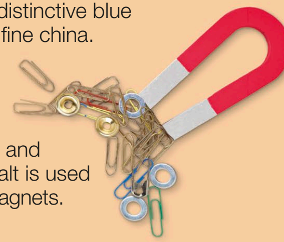


Chunk of pure iron refined in a laboratory

FOCUS ON...
COBALT

Cobalt and its compounds have many uses, such as strengthening steel and making paints.

◀ Cobalt compounds create the distinctive blue coloring in fine china.



▶ Like iron and nickel, cobalt is used in strong magnets.

Cobalt

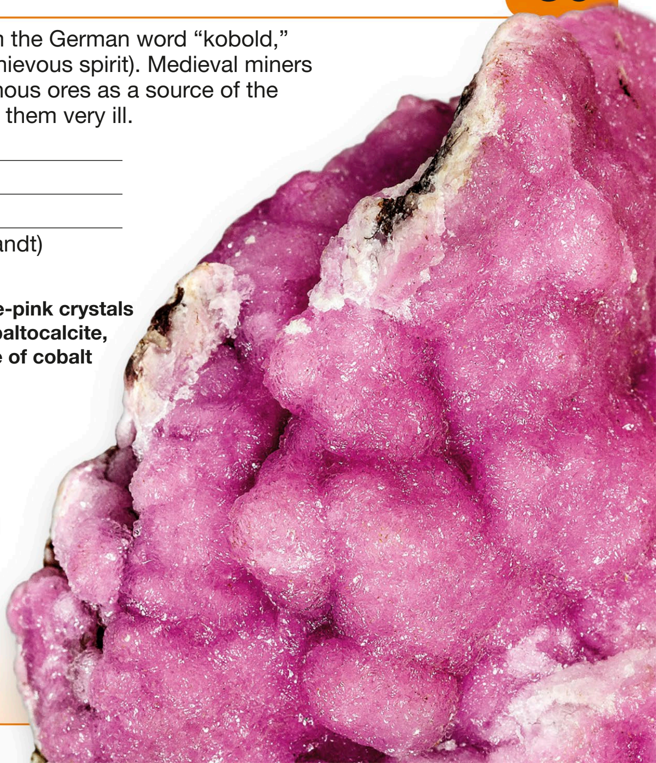
27
Co

This metal's name comes from the German word "kobold," which means "goblin" (a mischievous spirit). Medieval miners would often mistake its poisonous ores as a source of the precious metal silver—making them very ill.

ATOMIC MASS 58.933

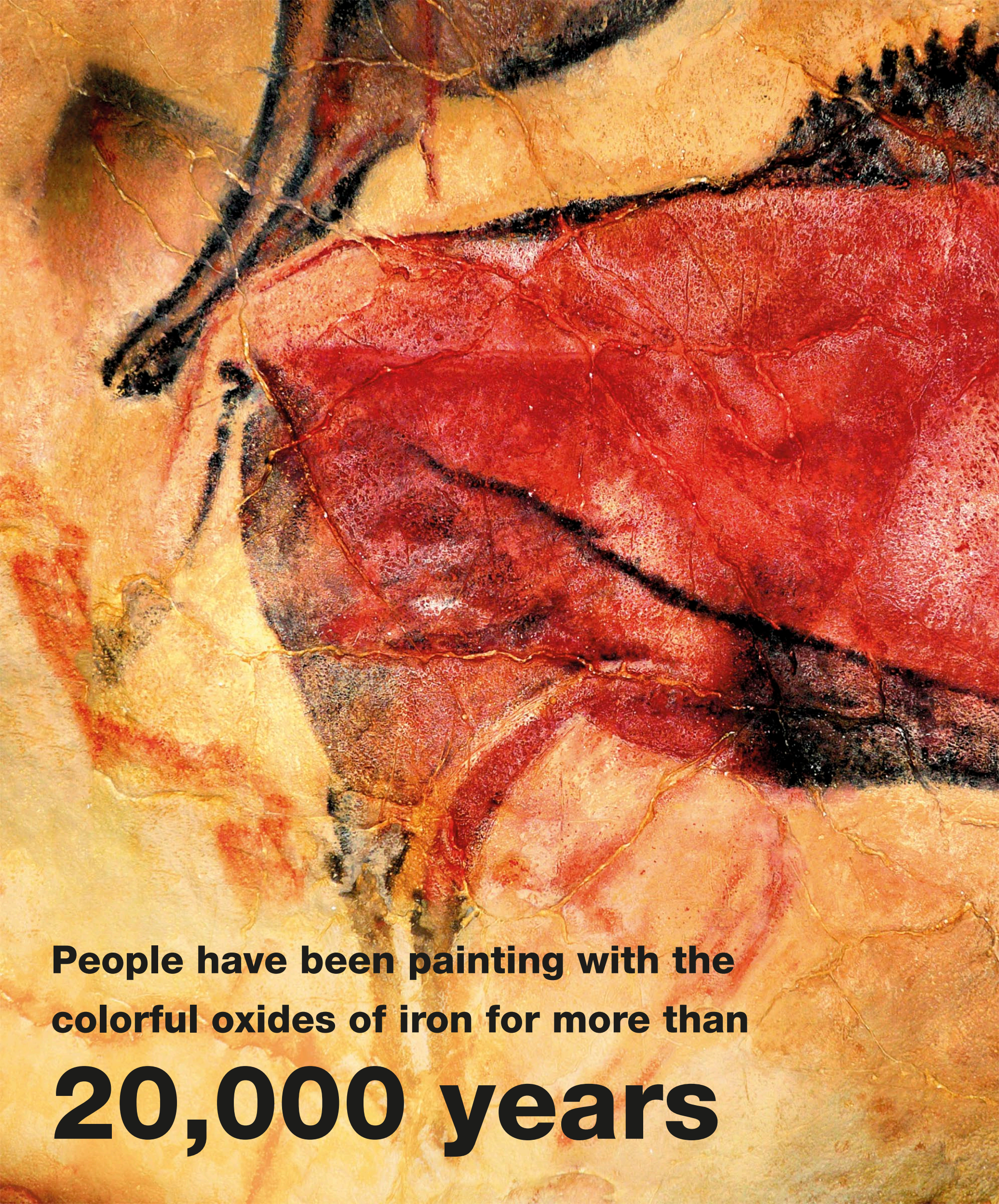
STATE Solid

DISCOVERY 1739 (Georg Brandt)



Purple-pink crystals of cobaltocalcite, an ore of cobalt

Laboratory-refined disk of pure cobalt



People have been painting with the colorful oxides of iron for more than

20,000 years

CAVE PAINTING
This bison was painted on a wall of the Cave of Altamira in Spain around 15,000 BCE. Its red color is from ocher (a mixture of iron oxide, clay, and sand). Many other oxides of transition metals have been used as sources of color since prehistoric times.

Nickel

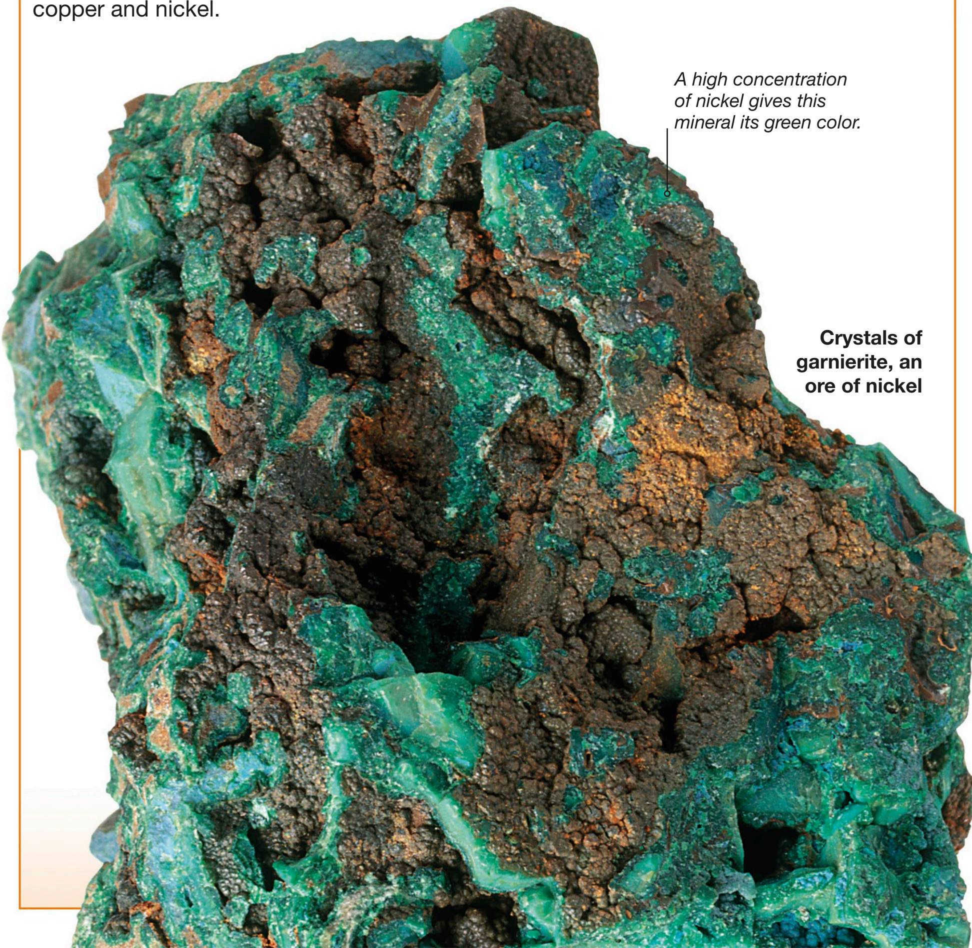
28
Ni

Along with iron and cobalt, nickel is used to make strong magnets, such as those found in electric motors. It is also used in many alloys, protecting them from corrosion. The US 5 cent coin is made of an alloy of copper and nickel.

ATOMIC MASS 58.693

STATE Solid

DISCOVERY 1754 (Axel Fredrik Cronstedt)



Copper

29
Cu

This distinctly red metal is one of the few metallic elements to be found pure in nature. It was one of the first metals to be used by humans. Mixing it with tin forms a tough alloy called bronze, which has been in use for more than 5,000 years.

Pellets of pure copper refined in a laboratory

ATOMIC MASS 63.546

STATE Solid

DISCOVERY Prehistoric

Zinc

30
Zn

Although this element was not recognized until the 18th century, compounds of zinc have been in use for many centuries. Calamine lotion, for example, contains zinc oxide and is an ancient recipe for soothing itches.

ATOMIC MASS 65.38

STATE Solid

DISCOVERY 1746 (Andreas Marggraf)

Laboratory sample of pure zinc

Yttrium

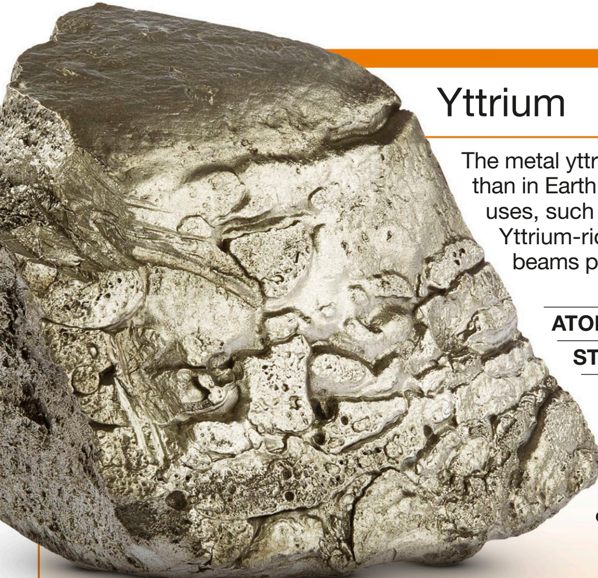
39
Y

The metal yttrium is more common in moon rocks than in Earth's crust. It has a number of high-tech uses, such as in the making of camera lenses. Yttrium-rich crystals can also make laser beams powerful enough to cut through metal.

ATOMIC MASS 88.906

STATE Solid

DISCOVERY 1794 (Johan Gadolin)



Laboratory sample of pure yttrium

Zirconium

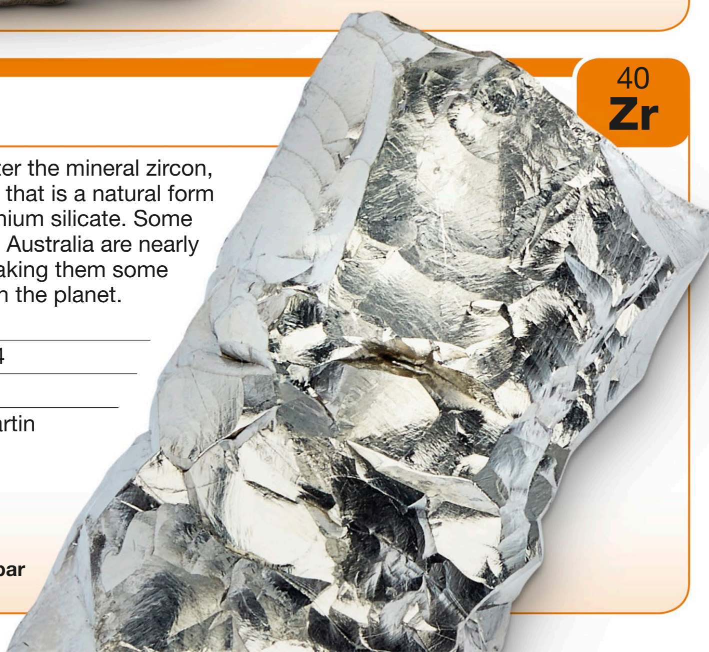
40
Zr

This metal is named after the mineral zircon, a golden-brown crystal that is a natural form of the compound zirconium silicate. Some zircon crystals found in Australia are nearly 4.4 billion years old, making them some of the oldest crystals on the planet.

ATOMIC MASS 91.224

STATE Solid

DISCOVERY 1789 (Martin Heinrich Klaproth)



Laboratory-refined bar of pure zirconium

Niobium

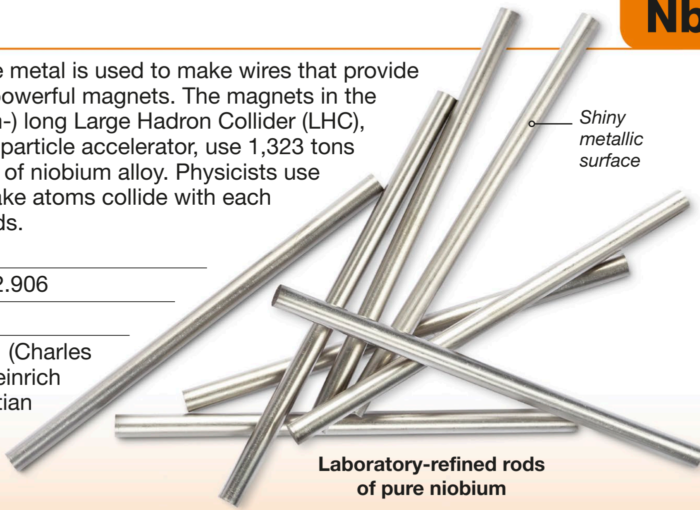
41 **Nb**

An alloy of this rare metal is used to make wires that provide electricity to very powerful magnets. The magnets in the 16.78-mile- (27-km-) long Large Hadron Collider (LHC), the world's largest particle accelerator, use 1,323 tons (1,200 metric tons) of niobium alloy. Physicists use this machine to make atoms collide with each other at high speeds.

ATOMIC MASS 92.906

STATE Solid

DISCOVERY 1801 (Charles Hatchett), 1844 (Heinrich Rose), 1864 (Christian Blomstrand)



Laboratory-refined rods of pure niobium

Molybdenum

42 **Mo**

Molybdenite, the main mineral of molybdenum, is similar in its dark color to galena, an ore of lead. Ancient metalworkers mistook molybdenite for galena and named it "molybdos," which is Greek for "lead." Pure molybdenum is actually much harder than lead and is used to strengthen alloys.

ATOMIC MASS 95.95

STATE Solid

DISCOVERY 1781 (Peter Jacob Hjelm)

Molybdenite, an ore of molybdenum

Technetium

43
Tc

The atoms of this highly radioactive element are very unstable and break down quickly. Technetium was named after “teknetos,” the Greek word for “artificial.” It is the first artificial element to have been created.

ATOMIC MASS (98)

STATE Solid

DISCOVERY 1937 (Carlo Perrier and Emilio Segrè)

Foil of pure technetium

Ruthenium

44
Ru

Ruthenia, the Latin name for Russia, inspired this rare element’s name. Ruthenium is used in turning coal into the liquid fuel petroleum, in X-ray machines, and in making solar cells (devices that turn sunlight into electricity).

Laboratory-refined crystals of pure ruthenium

ATOMIC MASS 101.07

STATE Solid

DISCOVERY 1808 (Jedrzej Sniadecki), 1825 (Gottfried Osann), 1844 (Karl Karlovich Klaus)

Palladium

46
Pd

This precious metal is added in small amounts to gold to make white-gold jewelry. A compound called palladium chloride is an ingredient in sensors that detect levels of poisonous carbon monoxide gas.

ATOMIC MASS 106.42

STATE Solid

DISCOVERY 1803 (William Hyde Wollaston)

Piece of pure palladium

Rhodium

45
Rh

The element rhodium is one of the rarest elements of all. The total annual production of rhodium across the world is a mere 33 tons (30 metric tons). This shiny metal is used in a car's catalytic converter, a device that removes poisonous gases from the exhaust fumes.

ATOMIC MASS 102.906

STATE Solid

DISCOVERY 1803 (William Hyde Wollaston)

The sand on the banks of the Ural River in Central Asia is a major source of rhodium.

The mineral forms as golden needles.

Golden crystals of millerite, an ore of rhodium

FOCUS ON... SILVER

Silver is the most common precious metal and has a wide range of uses.

▲ Thin, edible silver foil is used to decorate sweets.

▲ Silver nitrate mixed with water is used as a gentle antiseptic for cuts and scrapes.

▲ Silver is commonly used in jewelry such as necklaces, bangles, and rings.

Silver

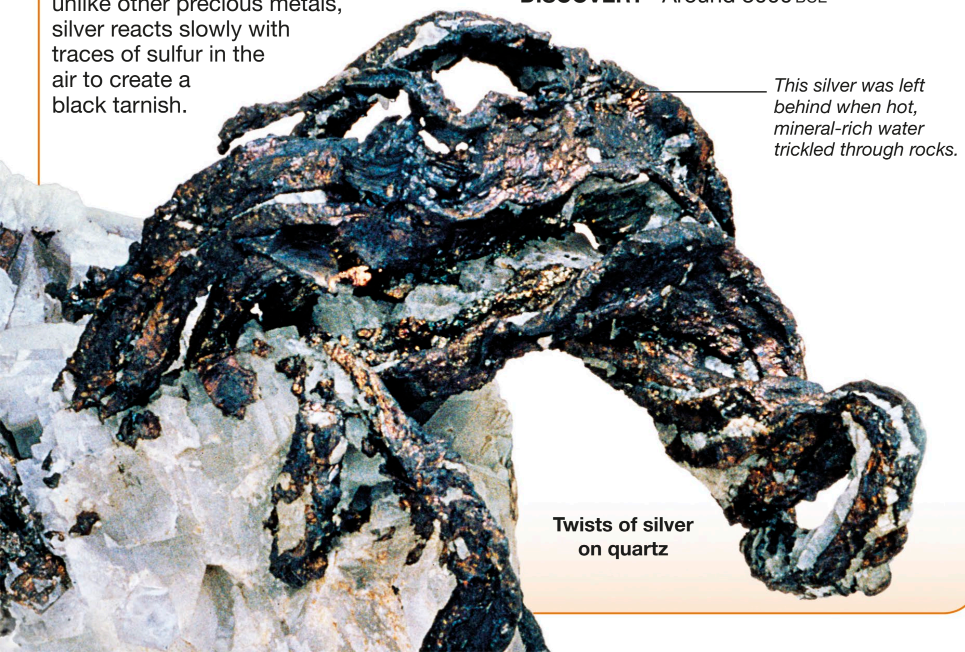
47
Ag

Like the precious metals gold, platinum, and palladium, silver is found pure in nature. It stays shiny for a while, but unlike other precious metals, silver reacts slowly with traces of sulfur in the air to create a black tarnish.

ATOMIC MASS 107.868

STATE Solid

DISCOVERY Around 3000 BCE



Twists of silver on quartz

Cadmium

48
Cd

During the refining and production of zinc from its ore, cadmium is extracted as an impurity. This metal was once used to make vibrant yellow paint, but it is no longer used as it is now known to be highly toxic. Today, cadmium is used mainly in rechargeable batteries.

ATOMIC MASS 112.414

STATE Solid

DISCOVERY 1817 (Friedrich Stromeyer)

This mineral is mainly composed of cadmium sulfide.

Greenockite, an ore of cadmium

Hafnium

72
Hf

Chemists knew there was a gap in the periodic table, underneath zirconium, but couldn't find the missing element for many years. Hafnium was eventually found in crystals of a mineral called zircon. It was discovered to be nearly identical to zirconium, which was also present in the crystals.

ATOMIC MASS 178.49

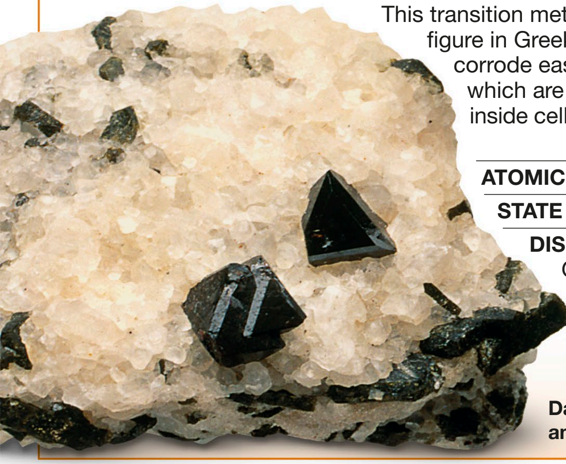
STATE Solid

DISCOVERY 1923 (George Charles de Hevesy and Dirk Coster)

Laboratory sample of pure hafnium

Tantalum

73
Ta



This transition metal gets its name from Tantalus, a figure in Greek mythology. Tantalum does not corrode easily and is used to make capacitors, which are tiny devices for storing electricity inside cell phones and tablets.

ATOMIC MASS 180.948

STATE Solid

DISCOVERY 1802 (Anders Gustav Ekeberg)

Microlite is so named because it forms tiny crystals.

Dark crystals of microlite, an ore of tantalum, in rock

Tungsten

74
W

This element has the highest melting point of any metal: it melts into a liquid at a scorching 6,177.2°F (3,414°C). Due to its heat-resistant properties, tungsten is used to make light bulb filaments, which can get very hot when a bulb is in use. This element is also mixed with carbon to make tungsten carbide, a compound used to harden metal tools.

ATOMIC MASS 183.84

STATE Solid

DISCOVERY 1783 (Juan and Fausto Elhuyar)

Ferberite, an ore of tungsten

Rhenium

75
Re

Liquid rhenium will not boil until it is at 10,094°F (5,590°C), which is about the same temperature as the surface of the sun. This metal has the highest boiling point of any element. Rhenium is used to make heat-resistant superalloys for X-ray machines and the exhaust nozzles for jet fighters and rockets.

ATOMIC MASS 186.207

STATE Solid

DISCOVERY 1925 (Walter Noddack, Ida Tacke, and Otto Berg)

Iridium

77
Ir

One of Earth's rarest elements, iridium is found in a thin layer of clay in the planet's crust, and is especially seen in the Badlands of South Dakota. Scientists think it was distributed by the meteorite that made the dinosaurs extinct.

ATOMIC MASS 192.217

STATE Solid

DISCOVERY 1803 (Smithson Tennant)

Osmium

76
Os

0.06 cubic in (1 cubic cm) of osmium is more than 22 times heavier than the same amount of water. This transition metal is the densest element in the world. It can be used by police investigators to find clues at a crime scene. One of its compounds, osmium oxide, mixes well with oil so it is used in the search for fingerprints.

Pellet of pure osmium refined in a laboratory

ATOMIC MASS 190.23

STATE Solid

DISCOVERY 1803 (Smithson Tennant)

Platinum

78
Pt

The name platinum comes from the Spanish word "platina," which means "little silver." Although the Maya civilization in South America had used this metal for centuries, it was only in the 1750s that Spanish explorers brought it to Europe.

ATOMIC MASS 195.084

STATE Solid

DISCOVERY Around 700 BCE

Platinum is commonly used in catalytic converters, which are devices in cars that reduce toxic exhaust fumes.

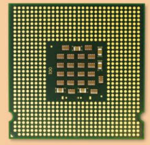
This metal has a high melting point of 3,214.8°F (1,768.2°C).

Laboratory-refined nugget of pure platinum

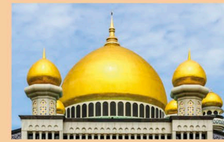
FOCUS ON… **GOLD**

This metal has a wide range of modern practical applications.

▲ Gold coins, such as this Byzantine one from around 600 CE, have been used as currency for a long time.



▲ The most reliable microchips have gold connections that rarely corrode or fail.



▲ The domes of some buildings, such as Brunei's Jame'Asr Hassanil Bolkiah Mosque, are covered in gold.

Gold

79
Au

This precious metal is very soft and easy to shape. 0.06 cubic in (1 cubic cm) of gold can be drawn into a wire 540 ft (165 m) long without breaking, or hammered into 10 sq ft (1 sq m) of foil. Because of this, gold has been used extensively in making jewelry for thousands of years.

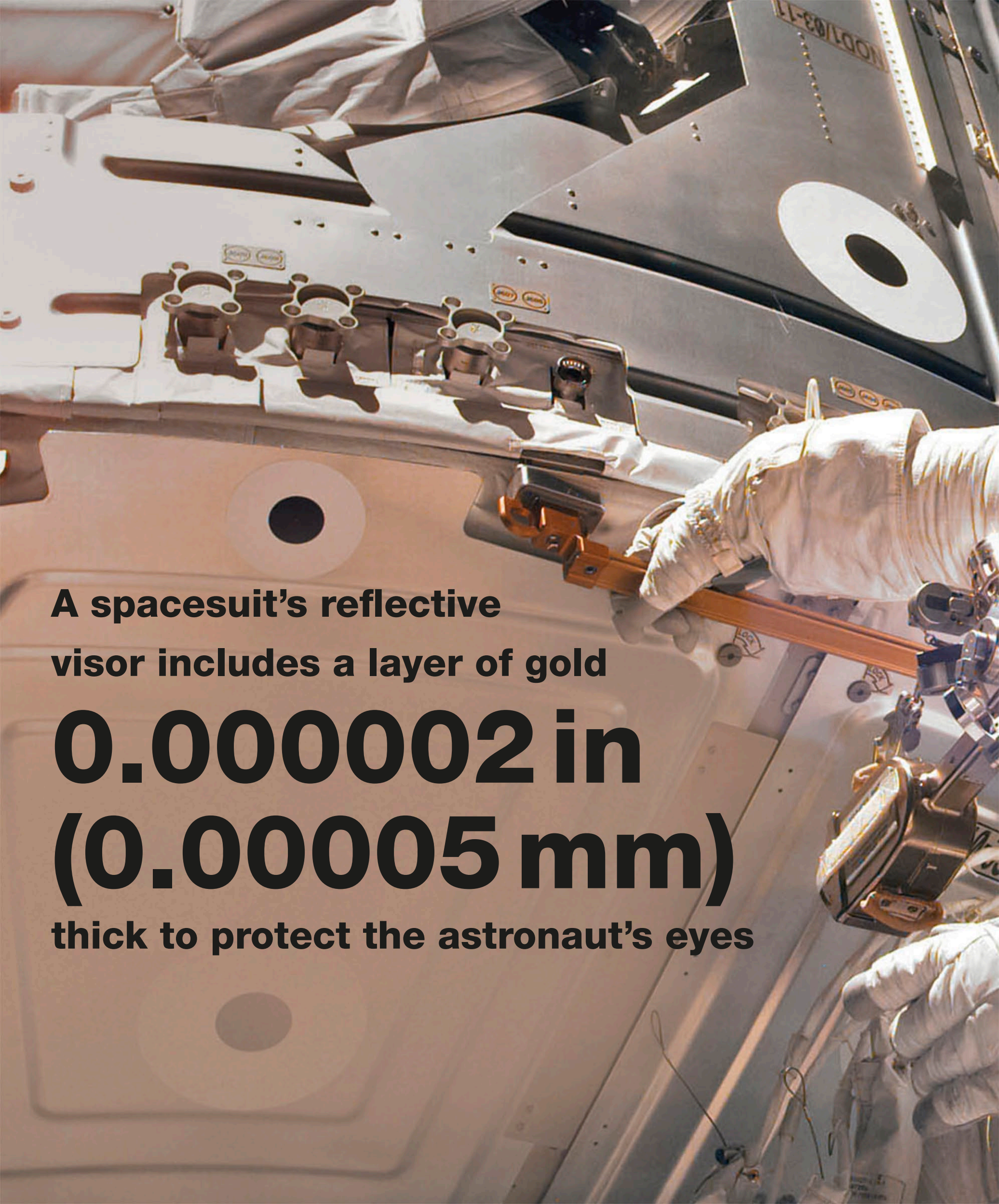
ATOMIC MASS 196.967

STATE Solid

DISCOVERY Around 3000 BCE

Nuggets such as this one are rare as most gold is found as dust mixed into rocks.

Nugget of pure gold



A spacesuit's reflective visor includes a layer of gold

0.000002 in (0.00005 mm)

thick to protect the astronaut's eyes

GOLDEN VIEW
The transition metals are very shiny when clean as their atoms reflect light and other invisible rays. Gold, one of the shiniest transition metals, is used to coat the helmet visors of spacesuits to protect astronauts from the sun's dangerous rays.

Mercury

80
Hg

The only metal that is liquid at room temperature, mercury melts at -37.9°F (-38.8°C) and is solid below this temperature. Pure mercury is easily refined by heating its minerals, such as cinnabar. It is highly poisonous and its use is limited.

ATOMIC MASS 200.592

STATE Liquid

DISCOVERY Around 1500 BCE

Chunk of cinnabar, an ore of mercury

The chemical symbol for mercury, Hg, comes from "hydrargyrum," a Latin term that means "water silver."

Liquid form of pure mercury

Rutherfordium

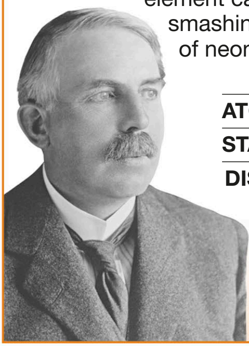
104
Rf

The artificial element Rutherfordium was named after New Zealand chemist Baron Ernest Rutherford, who studied and explained the structure of an atom. This element can be made by smashing together atoms of neon and plutonium.

ATOMIC MASS (267)

STATE Solid

DISCOVERY 1964 (team led by Georgy Flerov), 1969 (team led by Albert Ghiorso)



Ernest Rutherford

Dubnium

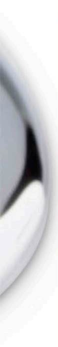
105
Db

Element 105 was discovered by two independent teams in Russia and the US. Dubnium was eventually named after the Russian city of Dubna, which is home to the Joint Institute for Nuclear Research (JINR), the center of atomic research in the country.

ATOMIC MASS (268)

STATE Solid

DISCOVERY 1968 (team led by Georgy Flerov), 1970 (team led by Albert Ghiorso)



Seaborgium

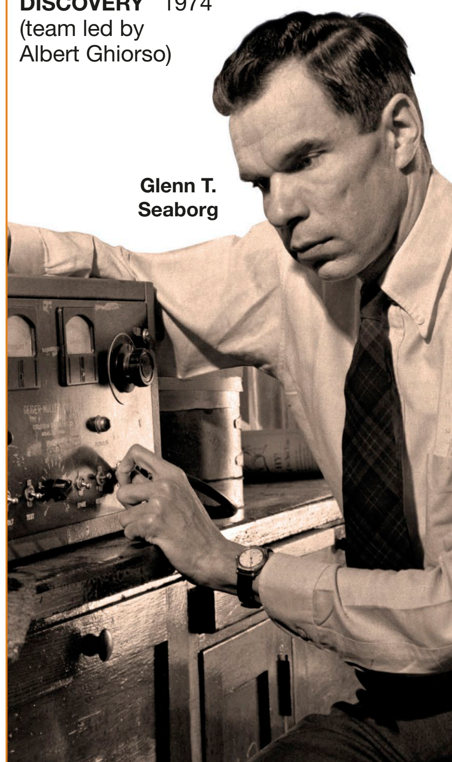
106
Sg

This metal was named after the American chemist Glenn T. Seaborg, who is credited with identifying and studying 10 artificial elements. Seaborgium is radioactive and its atoms break up after only a few minutes.

ATOMIC MASS (269)

STATE Solid

DISCOVERY 1974 (team led by Albert Ghiorso)



Glenn T. Seaborg

Bohrium

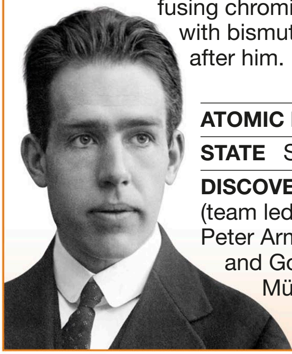
107 Bh

The Danish scientist Niels Bohr was one of the first to figure out how protons, neutrons, and electrons are arranged inside atoms. Element 107, made by fusing chromium atoms with bismuth, is named after him.

ATOMIC MASS (270)

STATE Solid

DISCOVERY 1981 (team led by Peter Armbruster and Gottfried Münzenberg)



Niels Bohr

Hassium

108 Hs

The atoms of hassium are so radioactive that they decay in a matter of seconds, so the only way scientists can study this element is by producing it artificially. Hassium is thought to be a solid metal but so far not enough atoms have been made all at once for this to be confirmed. This element is named after Hesse, the German state where it was first made.

ATOMIC MASS (269)

STATE Solid

DISCOVERY 1984 (team led by Peter Armbruster and Gottfried Münzenberg)

Meitnerium

109 Mt

This element was named for Lise Meitner, an Austrian-Swedish scientist who was one of the leaders of the team that discovered the nuclear fission chain reaction in uranium. This is the process that drives nuclear power and causes nuclear bombs to explode. While her name was left out of the Nobel Prize awarded for this discovery, she eventually got an element named after her.

ATOMIC MASS (278)

STATE Solid

DISCOVERY 1982 (team led by Peter Armbruster and Gottfried Münzenberg)

Bust of Lise Meitner in Berlin, Germany

Darmstadtium

110 **Ds**

The atoms of this element break down quickly, but it is thought to have similar properties to platinum. Many teams tried to make it, but its creation was first confirmed in the Society for Heavy Ion Research in Darmstadt, Germany, before it was named after that city. Darmstadtium is made by smashing nickel atoms into those of lead.

ATOMIC MASS (281)

STATE Solid

DISCOVERY 1994 (Sigurd Hofmann, Peter Armbruster, and Gottfried Münzenberg)

Roentgenium

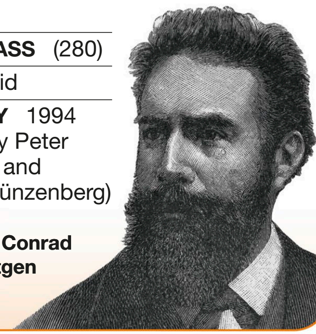
111 **Rg**

This transition metal is made by fusing bismuth with nickel. It is a very radioactive, short-lived metal. Roentgenium is named after the German physicist Wilhelm Conrad Röntgen, the discoverer of X-rays.

ATOMIC MASS (280)

STATE Solid

DISCOVERY 1994 (team led by Peter Armbruster and Gottfried Münzenberg)



Wilhelm Conrad Röntgen

Copernicium

112 **Cn**

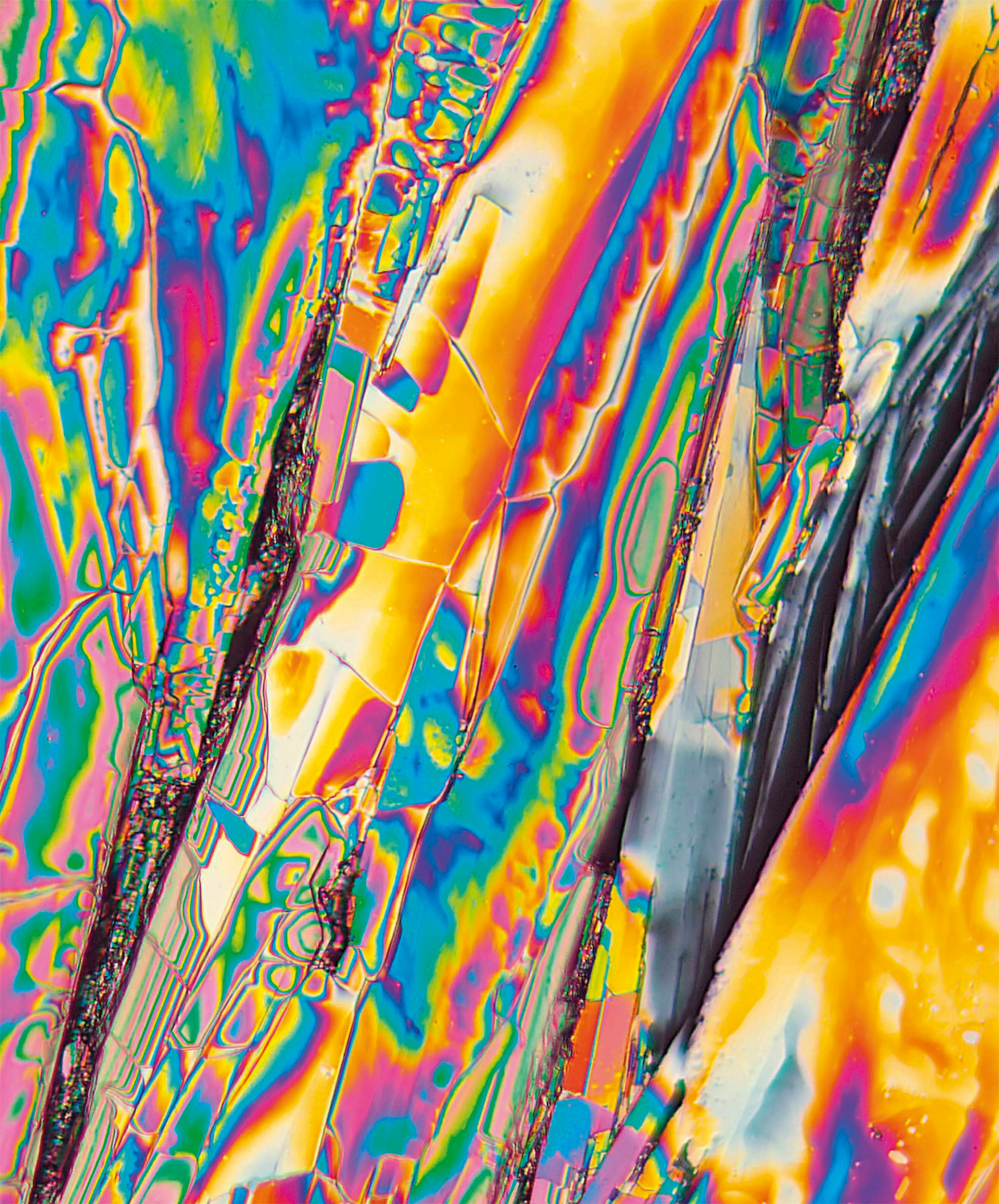
In 1543, the Polish astronomer Nicolaus Copernicus theorized that Earth revolves around the sun. Copernicium was named in his honor. This element is made by firing zinc atoms at lead. Only tiny amounts have been made so far and it has been suggested that a large sample of this metallic element might even be a gas at room temperature.

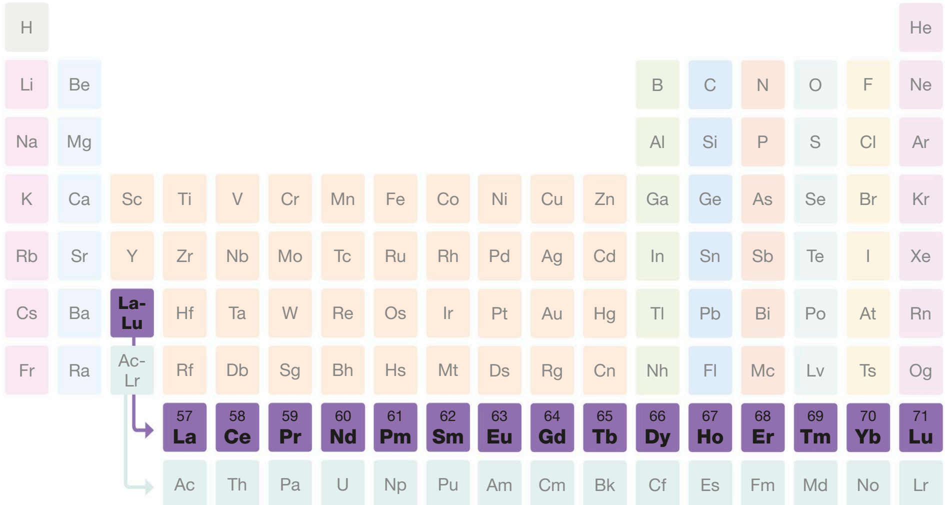
ATOMIC MASS (285)

STATE Solid

DISCOVERY 1996 (team led by Sigurd Hofmann)

Statue of Nicolaus Copernicus in Olsztyn, Poland





Lanthanides

The metals in this series are relatively common on Earth—and very useful in technology—but notoriously difficult to separate from one another. Here, a sliver of lanthanum nitrate, showing off a rainbow of colors under a microscope, has been extracted from a complex mineral filled with many other lanthanides.

Lanthanides

Normally shown as a strip of elements along the bottom of the periodic table (along with the actinides), this series of metals is found in the sixth period (row) between Group 2 and the transition metals. The lanthanides are named after lanthanum, the first element in this series.

Swedish discovery

The lanthanides have very similar chemical and physical properties, and that made it hard for chemists to tell them apart. The discovery of the mineral gadolinite in 1787, in the village of Ytterby, Sweden, was a breakthrough. Gadolinite can be broken down into various lanthanides, and after a century of studying it, nine lanthanides were eventually found. Four of these—erbium, terbium, ytterbium, and yttrium—were named after Ytterby.

Black crystals of gadolinite in rock

Rare earths

Because they were found combined together in various minerals in Earth's crust, the lanthanides were called "rare earth metals" and were thought to be hard to find. Despite the name, lanthanides are quite common. They are found in low concentrations through all kinds of rock, and are seldom seen in large quantities in one place.

This mineral contains traces of almost all lanthanides.

Chunk of monazite, an ore of many lanthanides

Magnetic elements

Several lanthanides are very magnetic, and tiny amounts of them are added to iron and nickel magnets to boost their strength. Lanthanide-rich magnets are used to read and write computer memory and to make pickups—devices in electric guitars that convert the vibrations of the strings into electric signals.

The pickups on this guitar use magnets made of the lanthanide samarium.

Electric guitar

Light emission

Lanthanides are crucial in the production of colored light in light-emitting diodes (LEDs). Blue LEDs get their colors from chemicals containing europium, while green LEDs use chemicals with terbium.

Blue LEDs glow on Dubai's Meydan Bridge

Lanthanum

57
La

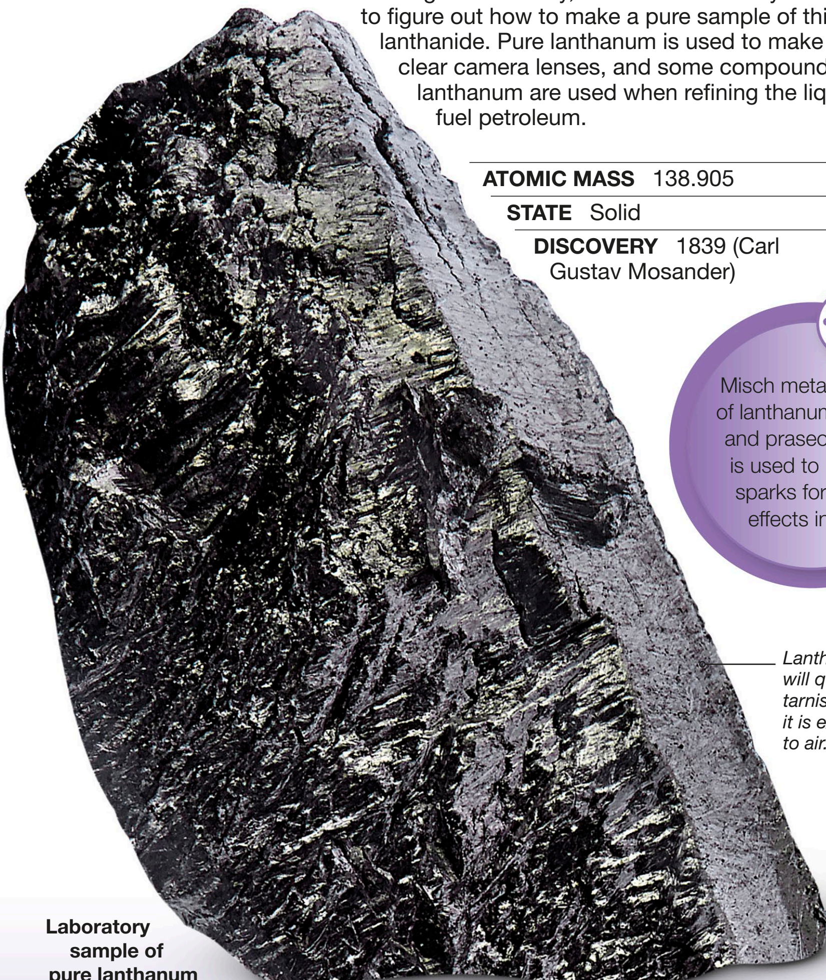
Following its discovery, it took almost 100 years to figure out how to make a pure sample of this lanthanide. Pure lanthanum is used to make clear camera lenses, and some compounds of lanthanum are used when refining the liquid fuel petroleum.

ATOMIC MASS 138.905

STATE Solid

DISCOVERY 1839 (Carl Gustav Mosander)

Misch metal (an alloy of lanthanum, cerium, and praseodymium) is used to produce sparks for special effects in films.



Lanthanum will quickly tarnish when it is exposed to air.

Laboratory sample of pure lanthanum

FOCUS ON…
PRASEODYMIUM

This lanthanide metal has a range of uses, from coloring glass to making alloys for powerful magnets.

▲ Artificial gems, such as this cubic zirconia, are dyed green using praseodymium.

▲ Praseodymium is mixed with magnesium to make superstrong alloys for aircraft engines.

Cerium
58 **Ce**

Of the rare earth elements, cerium is the most common. It is even more common in Earth's rocks than copper or lead. Cerium is used to make touchscreens on devices, some batteries, and glass polish.

Black crystals of allanite, an ore of cerium

ATOMIC MASS 140.116

STATE Solid

DISCOVERY 1803 (Baron Jöns Jacob Berzelius and Wilhelm Hisinger), 1803 (Martin Klaproth)

Praseodymium
59 **Pr**

The name of this metal, which means "green twin" in Greek, refers to how pure samples of praseodymium will transform into a flaky green chemical when left in the air. Glasses tinted with praseodymium have a yellow color and make it easier to see in dark conditions.

ATOMIC MASS 140.908

STATE Solid

DISCOVERY 1885 (Carl Auer von Welsbach)

Chunk of monazite, an ore of praseodymium

Neodymium

60
Nd

When mixed with iron and boron, neodymium makes the most powerful magnets in the world, which can lift objects up to 1,000 times their own weight. They are known as NIB magnets.

ATOMIC MASS 144.242

STATE Solid

DISCOVERY 1885 (Carl Auer von Welsbach)

Laboratory sample of pure neodymium

Promethium

61
Pm

Every form of this lanthanide is highly radioactive. Any natural promethium that was in Earth's rocks broke up billions of years ago. However, new promethium atoms are constantly being formed when the atoms of heavier elements break apart—only for the new promethium atoms to also split up. Scientists can make small amounts of this element artificially.

ATOMIC MASS (145)

STATE Solid

DISCOVERY 1945 (Jacob A. Marinsky, Lawrence E. Glendenin, and Charles D. Coryell)

Europium

Although it is named after the continent of Europe, europium is mainly found in rocks in American and Chinese mines. Europium compounds glow red in ultraviolet light, so they are added to bank notes, including euro notes, to prove they are authentic.

Laboratory sample of pure europium

63
Eu

ATOMIC MASS 151.964

STATE Solid

DISCOVERY 1901 (Eugène-Anatole Demarçay)

The yellowish metal goes black when exposed to air.

Samarium

62
Sm

The small but powerful electric motors that power some electric aircraft use samarium magnets. Samarium is also used in some lasers and in nuclear reactors.

Laboratory sample of pure samarium

ATOMIC MASS 150.36

STATE Solid

DISCOVERY 1879 (Paul-Émile Lecoq de Boisbaudran)

Gadolinium

64
Gd

The Finnish chemist Johann Gadolin inspired the names of this lanthanide and its ore, gadolinite. Gadolinium tarnishes quickly when in contact with air.

ATOMIC MASS 157.25

STATE Solid

DISCOVERY 1880 (Jean Charles Galissard de Marignac)

Laboratory sample of pure gadolinium

Terbium

65
Tb

Pure terbium is soft enough to cut with a knife. Some of its compounds are used to line mercury lamps. When electrified, mercury vapour inside these lamps gives off ultraviolet light, which turns bright yellow due to terbium.

ATOMIC MASS 158.925

STATE Solid

DISCOVERY 1843 (Carl Gustav Mosander)

In the 19th century, scientists got confused between terbium and erbium and accidentally switched their names.

Laboratory sample of pure terbium

Dysprosium

66
Dy

Compared to other lanthanides, this element reacts more easily with oxygen and water. Its name means "hard to get at"; the metal was purified for the first time only in the 1950s.

ATOMIC MASS 162.5

STATE Solid

DISCOVERY 1886 (Paul-Émile Lecoq de Boisbaudran)

Laboratory sample of pure dysprosium

Holmium

67
Ho

The lanthanide holmium is named after the Swedish capital Stockholm, which is called "Holmia" in Latin. It is used in the making of some medical lasers. Holmium lasers are hot enough to burn through skin—surgeons and dentists use them to make delicate cuts that heal quicker than traditional surgical cuts.

ATOMIC MASS 164.93

STATE Solid

DISCOVERY 1878 (Marc Delafontaine and Louis Soret), 1878 (Per Teodor Cleve)

Black crystals of gadolinite, an ore of holmium

Thulium

69
Tm

The rarest of all the lanthanides, thulium glows blue when invisible ultraviolet light shines on it. Small X-ray machines in ambulances use a radioactive form of the metal to produce X-rays.

ATOMIC MASS	168.934
STATE	Solid
DISCOVERY	1879 (Per Teodor Cleve)

Laboratory sample of pure thulium

Erbium

68
Er

Compounds of erbium are used to create pink tints for glass and pottery. Crystals containing this metal can boost laser signals traveling through long-distance Internet cables.

ATOMIC MASS 167.259

STATE Solid

DISCOVERY 1843 (Carl Gustav Mosander)

Laboratory sample of pure erbium

Lutetium

71
Lu

The final member of the lanthanide group is also the densest. It is mainly used to break up complex chemicals in crude oil into smaller and more useful substances.

Laboratory sample of pure lutetium

ATOMIC MASS 174.967

STATE Solid

DISCOVERY 1907 (Georges Urbain), 1907 (Charles James), 1907 (Carl Auer von Welsbach)

Ytterbium

70
Yb

This metal reacts with oxygen in the air, so is stored in sealed containers. Pure ytterbium has several uses, including the strengthening of steel.

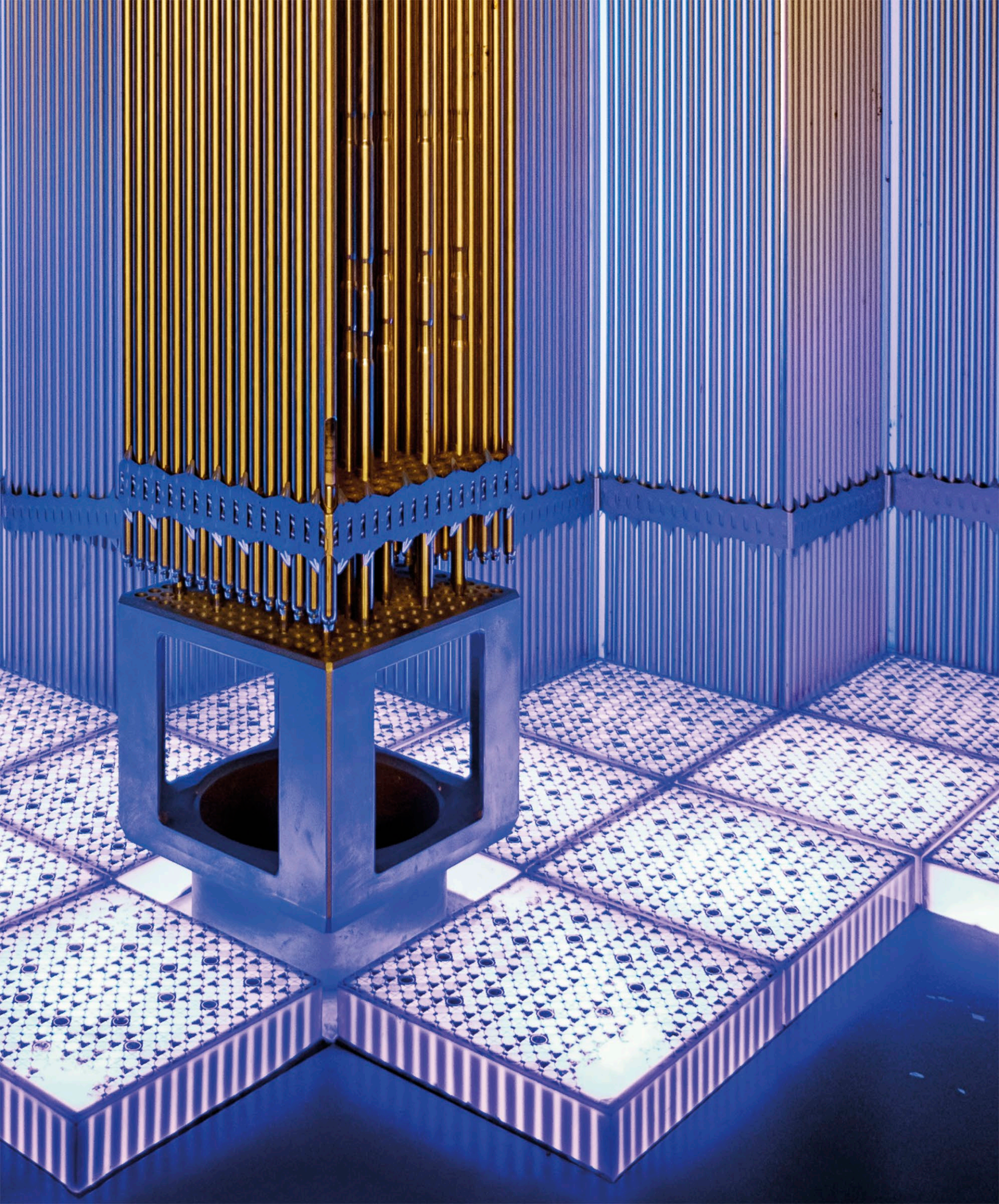
ATOMIC MASS 173.045

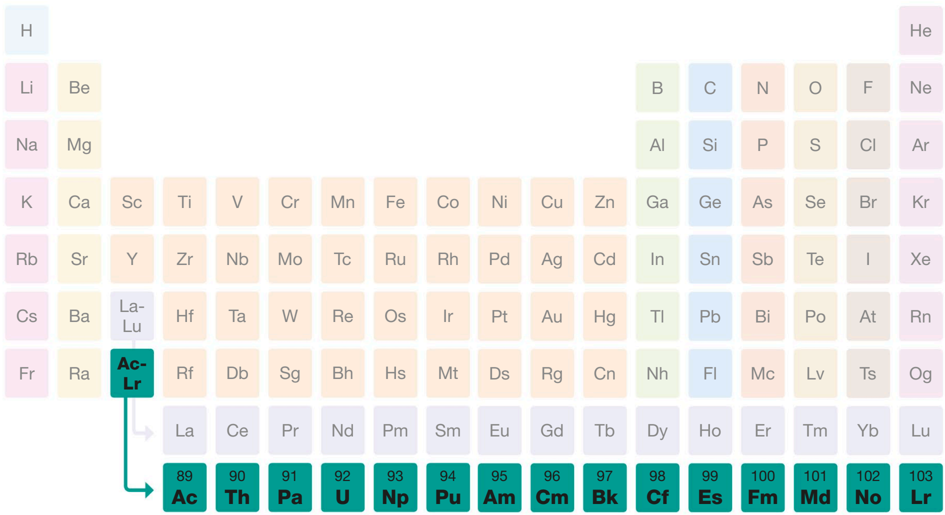
STATE Solid

DISCOVERY 1878 (Jean Charles Galissard de Marignac)

Ytterbium is easy to hammer into thin sheets.

Laboratory sample of pure ytterbium





Actinides

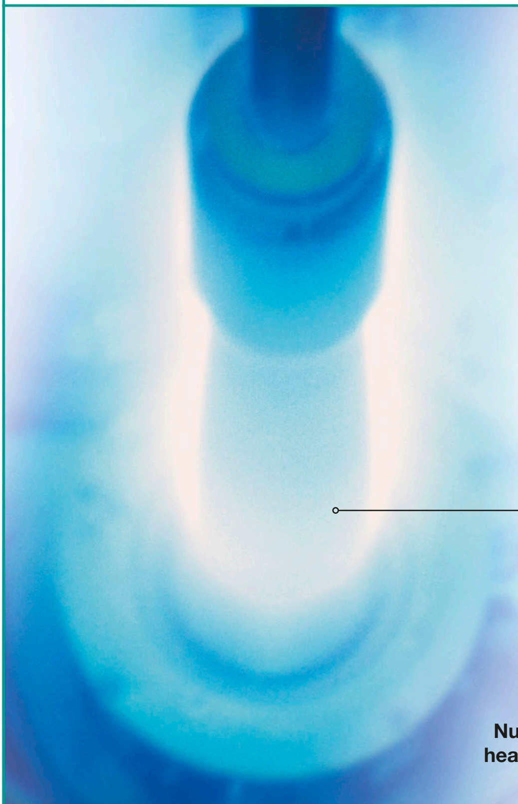
Elements in the actinide series, such as uranium, are unstable and radioactive, and they release heat as they break down. The heat released by uranium atoms can be used for generating power. Here, fuel rods packed with uranium are used in nuclear reactors.

Actinides

This series of metals appears along the bottom of the periodic table, underneath the lanthanides. The group gets its name from actinium, the first member in the series. The heaviest naturally occurring elements of all, such as thorium and uranium, are actinides, along with many elements created artificially.

Radioactivity

Actinides are highly radioactive elements. Given enough time, the atoms of all these elements will break up and decay away. While thorium and uranium are the most stable and will last for billions of years, some other actinides have atoms that break up in a fraction of a second. Actinides are used as nuclear fuels for making electricity. Nuclear reactor complexes include hazardous areas with radiation warning symbols that alert people of the dangers within.



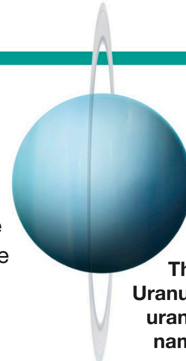
Radioactivity blasting from the uranium rod creates a blue glow. The heat from the fuel makes steam for generating electricity.

Nuclear rod heating water

Radiation symbol

Naming elements

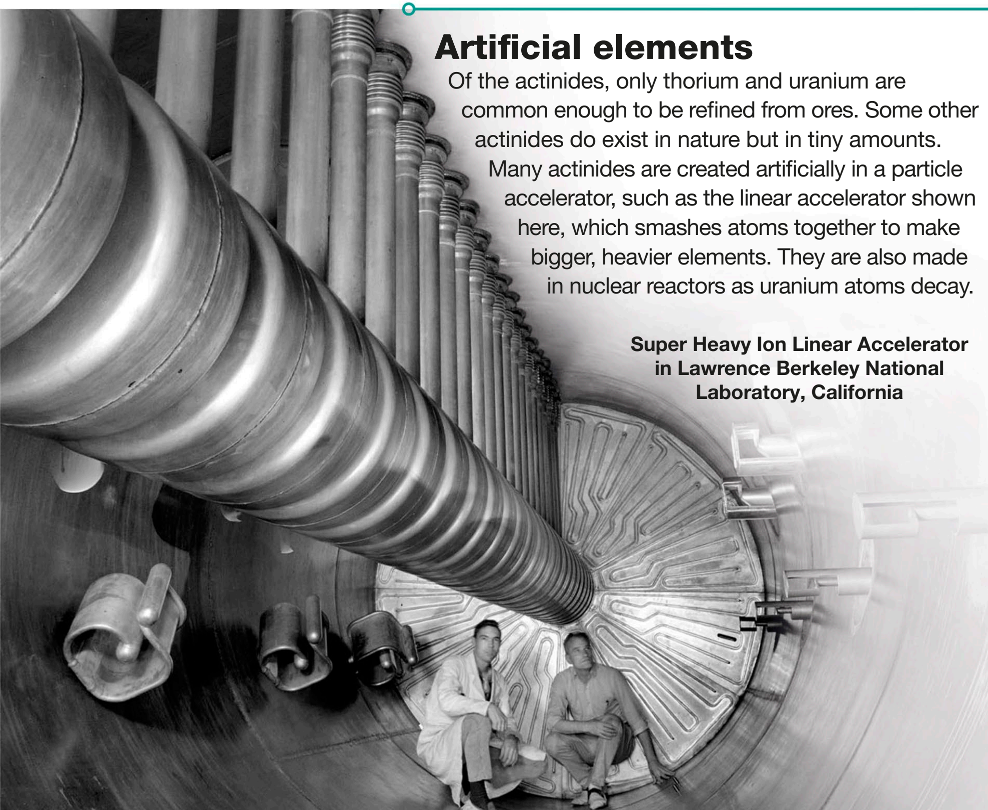
The two most common actinides, thorium and uranium, were discovered much earlier than the others and were named after Thor (the Norse god of thunder) and the planet Uranus, which was a recent discovery when uranium was identified. Most of the actinides were discovered in recent years and many of them were named after famous scientists—curium, after Marie Curie—or places, such as californium, after the state of California.



The planet Uranus, which uranium was named after

Artificial elements

Of the actinides, only thorium and uranium are common enough to be refined from ores. Some other actinides do exist in nature but in tiny amounts. Many actinides are created artificially in a particle accelerator, such as the linear accelerator shown here, which smashes atoms together to make bigger, heavier elements. They are also made in nuclear reactors as uranium atoms decay.



Super Heavy Ion Linear Accelerator in Lawrence Berkeley National Laboratory, California

Actinium

This radioactive metal appears in tiny amounts wherever there is uranium present. The uranium breaks down into actinium, which over time splits itself into radon gas, giving out a form of radiation called alpha particles.

ATOMIC MASS (227)

STATE Solid

DISCOVERY 1899 (Andrew Debierne)

89
Ac

Autunite crystals range in color from bright yellow to green.

Actinium's radioactivity makes it emit an eerie blue glow in the dark.

Chunk of autunite, an ore of actinium

Thorium

90
Th

Named after Thor, the Norse god of thunder, thorium is the most common radioactive metal in Earth's rocks. The heat from thorium's decay deep inside Earth keeps the planet warm, along with the sun's heat.

ATOMIC MASS 232.038

STATE Solid

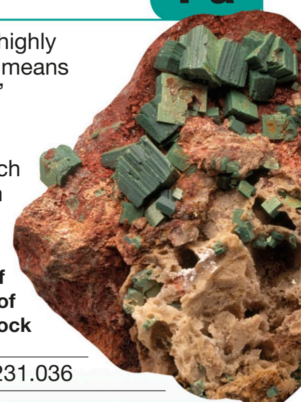
DISCOVERY 1829 (Baron Jöns Jacob Berzelius)

Piece of thorianite, an ore of thorium

Protactinium

91
Pa

The name of this highly radioactive metal means "before actinium," because uranium decays first into protactinium, which then breaks down into actinium.



Green crystals of torbernite, an ore of protactinium, in rock

ATOMIC MASS 231.036

STATE Solid

DISCOVERY 1913 (Kasimir Fajans and Otto Göhring)

Uranium

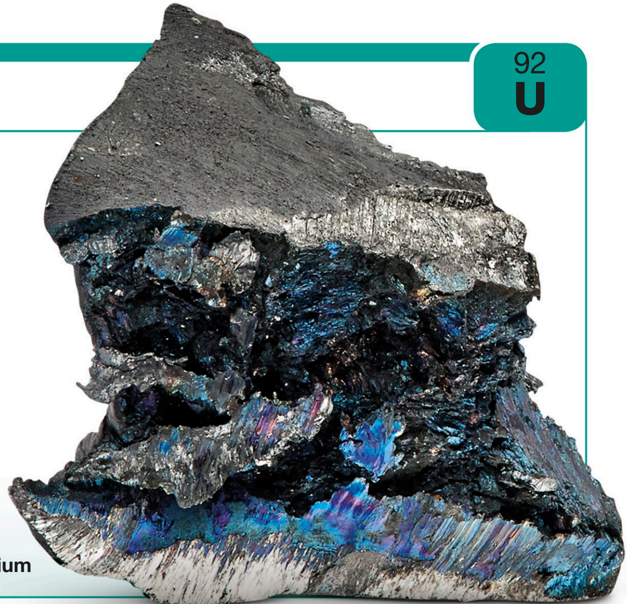
92
U

This heavy metal was the first substance to be identified as radioactive, a discovery made by the French physicist Henri Becquerel in 1896. It is used in the making of nuclear bombs and as fuel for nuclear reactors, which generate electricity.

ATOMIC MASS 238.029

STATE Solid

DISCOVERY 1789 (Martin Heinrich Klaproth), 1841 (Eugène Peligot)



Chunk of pure uranium

Neptunium

93
Np

Sitting next to uranium on the periodic table is another radioactive element called neptunium. This actinide was named after the planet Neptune. Neptunium was first discovered after being made inside a nuclear reactor. It is used mainly in scientific research.

ATOMIC MASS (237)

STATE Solid

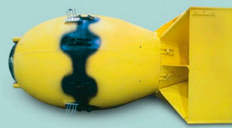
DISCOVERY 1940 (Edwin McMillan and Philip Abelson)

Piece of uraninite, an ore that has tiny traces of neptunium

FOCUS ON... **PLUTONIUM**

Isotopes (forms) of plutonium are radioactive and produce heat. This is converted to electricity for various uses.

▲ Deep space probes, such as Voyager 1, use plutonium batteries as a source of power.



▲ Plutonium was used in early nuclear bombs – one such bomb was used on Japan in World War II.

▲ One form of plutonium is used as nuclear fuel for generating electricity.

Plutonium

94
Pu

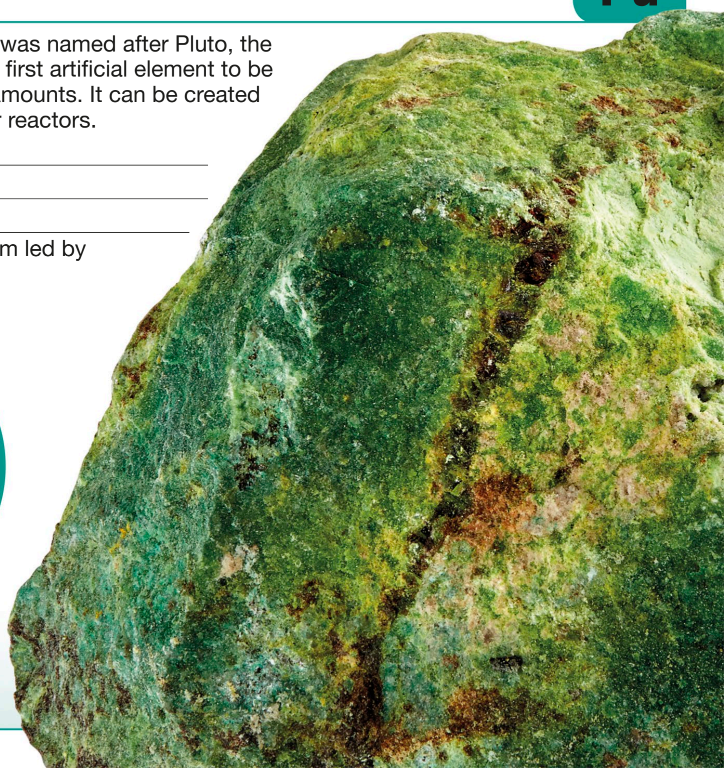
The actinide plutonium was named after Pluto, the dwarf planet. It was the first artificial element to be manufactured in large amounts. It can be created from uranium in nuclear reactors.

ATOMIC MASS (244)

STATE Solid

DISCOVERY 1940 (team led by Glenn T. Seaborg)

"Fat Man," the nuclear bomb dropped over Nagasaki, Japan, in 1945, contained about 14.3 lb (6.5 kg) of plutonium fuel.



Chunk of uraninite, an ore of plutonium

Americium

95

Am

Scientists decided to name americium after North America, where it was first made. Some smoke detectors use tiny amounts of this element, as its radioactivity allows an electric current to pass through the air between two sensors in the device. Any smoke blocking the current causes the detector to sound an alarm.

ATOMIC MASS (243)

STATE Solid

DISCOVERY 1944 (team led by Glenn T. Seaborg)

Berkelium

97

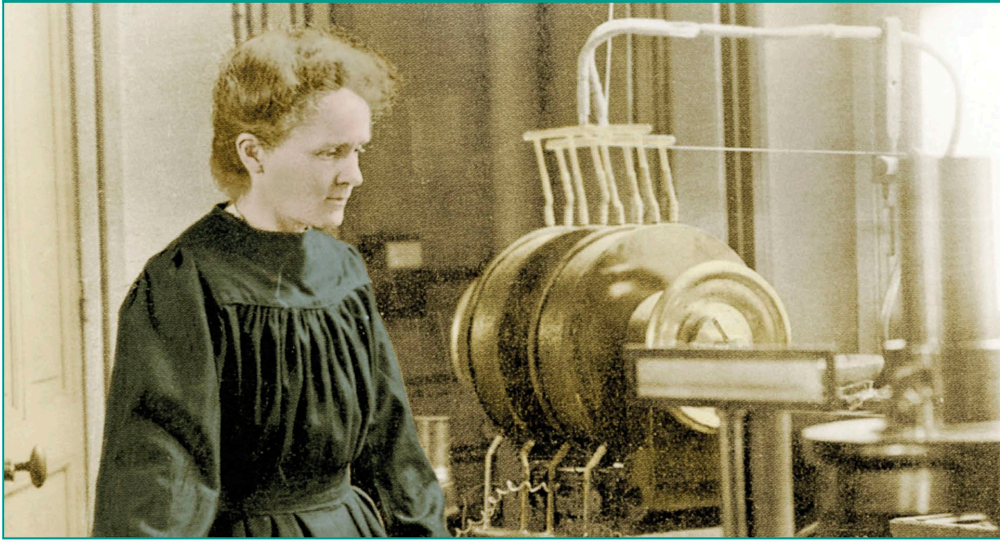
Bk

The first particle accelerators were built in the University of California in Berkeley. It was here that this metal was first created, so it was named after the town. Scientists made berkelium by smashing atoms of helium and americium together. This element is used only to make even heavier elements.

ATOMIC MASS (247)

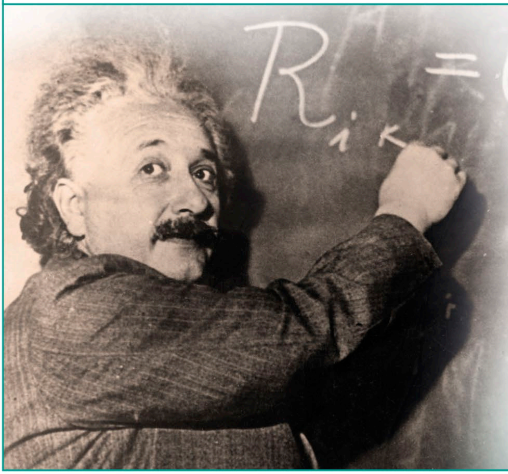
STATE Solid

DISCOVERY 1949 (team led by Glenn T. Seaborg)



Einsteinium

99
Es



In 1952, a new kind of powerful nuclear weapon called the hydrogen bomb (H-bomb) was tested. After the explosion, scientists studying the debris found around 200 atoms of a new actinide. They named this new element after the German-American physicist Albert Einstein.

ATOMIC MASS (252)

STATE Solid

DISCOVERY 1952–5 (team led by Albert Ghiorso)

Albert Einstein

Curium

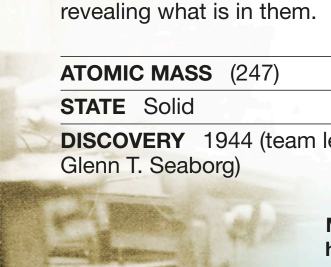
96
Cm

The actinide curium was named after the Polish-French scientist Marie Curie and her husband, the French scientist Pierre Curie—the discoverers of the element radium. Rovers (remote-controlled robot vehicles used for exploration) on Mars use curium to shine X-rays on rock samples, revealing what is in them.

ATOMIC MASS (247)

STATE Solid

DISCOVERY 1944 (team led by Glenn T. Seaborg)



Marie Curie in her laboratory

Californium

98
Cf

This element was named after California, the US state where it was first made. Californium is a raw material used for making very heavy elements, such as oganesson. It is one of the world's most expensive substances: a gram of californium costs $27 million. This is because it is difficult to produce this highly radioactive element, making it rare.

ATOMIC MASS (251)

STATE Solid

DISCOVERY 1950 (Stanley Thompson; Kenneth Street, Jr.; Albert Ghiorso; and Glenn T. Seaborg)

Fermium

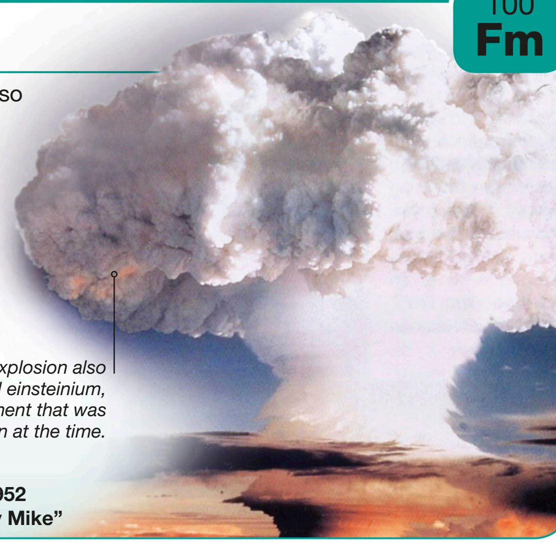
100
Fm

The American physicist Albert Ghiorso and his colleagues found fermium in the debris left behind by the first successful hydrogen bomb explosion in 1952, conducted by the US. This artificial element has no use apart from in research.

ATOMIC MASS (257)

STATE Solid

DISCOVERY 1953 (team led by Albert Ghiorso)



The explosion also produced einsteinium, another element that was unknown at the time.

Mushroom cloud from the 1952 hydrogen bomb test, named "Ivy Mike"

Mendelevium

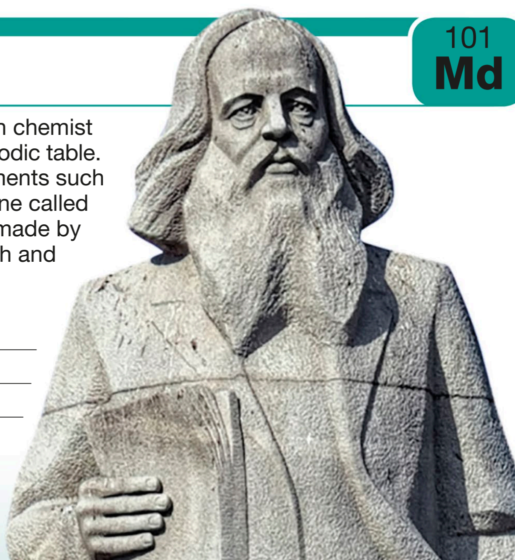
101
Md

This element is named after the Russian chemist Dmitri Mendeleev, who created the periodic table. It has no commercial uses. Artificial elements such as mendelevium are created in a machine called a particle accelerator. This one can be made by smashing together the atoms of bismuth and argon until they fuse into a single large mendelevium atom.

ATOMIC MASS (258)

STATE Solid

DISCOVERY 1955 (team led by Albert Ghiorso)



Statue of Dmitri Mendeleev in Tobolsk, Russia

Nobelium

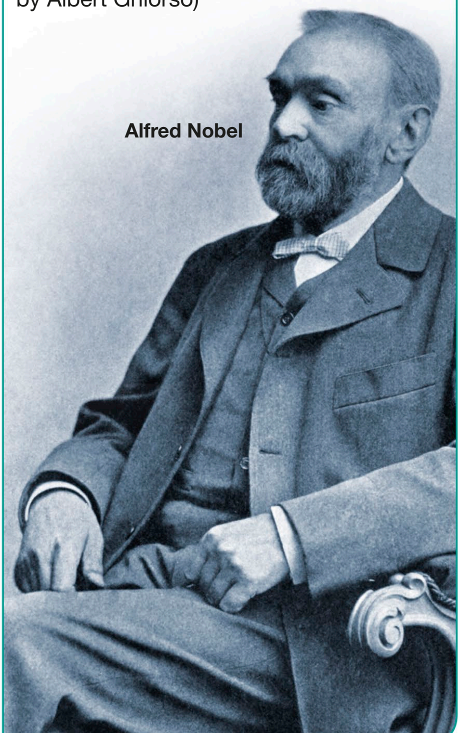
102
No

Scientists in California discovered nobelium by smashing together atoms of curium and carbon in a particle accelerator. It is named after Alfred Nobel, the Swedish chemist who invented dynamite.

ATOMIC MASS (259)

STATE Solid

DISCOVERY 1956 (team led by Georgy Flerov), 1958 (team led by Albert Ghiorso)



Alfred Nobel

Lawrencium

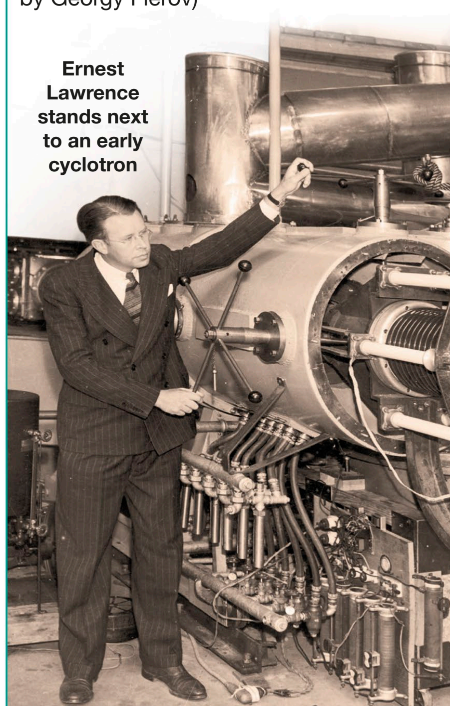
103
Lr

The American physicist Ernest Lawrence, inventor of the cyclotron (a type of particle accelerator), was the inspiration behind the name of this actinide. Only a few atoms of this radioactive element have been made.

ATOMIC MASS (262)

STATE Solid

DISCOVERY 1958 (team led by Albert Ghiorso), 1965 (team led by Georgy Flerov)



Ernest Lawrence stands next to an early cyclotron

Boron Group

The boron group has a wide range of elements—from the ultra-hard semi-metal boron to soft, heavy metals such as thallium—with no obvious features shared by the members. By far the most common of the metals is aluminum, which is used to build strong structures, such as these turbine blades from a jet engine.

Boron Group

Boron is a semi-metal (element with properties of a metal and a nonmetal), while most other members of this group are metals. The properties of the artificial element nihonium, however, are not yet known. Compared to other metals, the boron group metals are not very reactive, and are sometimes referred to as poor metals because they melt at low temperatures.

Making slime

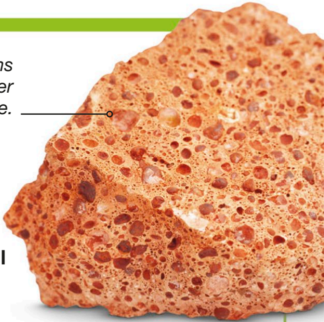
One of the most important compounds of boron is borax, a chemical that also contains sodium and oxygen. This white material, used in cleaners and other common products, is mined in desert areas. When added to glue and water, it makes slime, which is a gooey toy that flows like a liquid but bounces like rubber.

Stretched slime

Soft metals

Most boron group metals, including indium, can be cut with a steel knife, so they are not tough enough for construction. Only aluminum is suitable for building structures. By contrast, boron—the sole nonmetal—is one of the hardest elements of all.

Pure indium mold cast in a laboratory



Aluminum atoms make up a quarter of this ore.

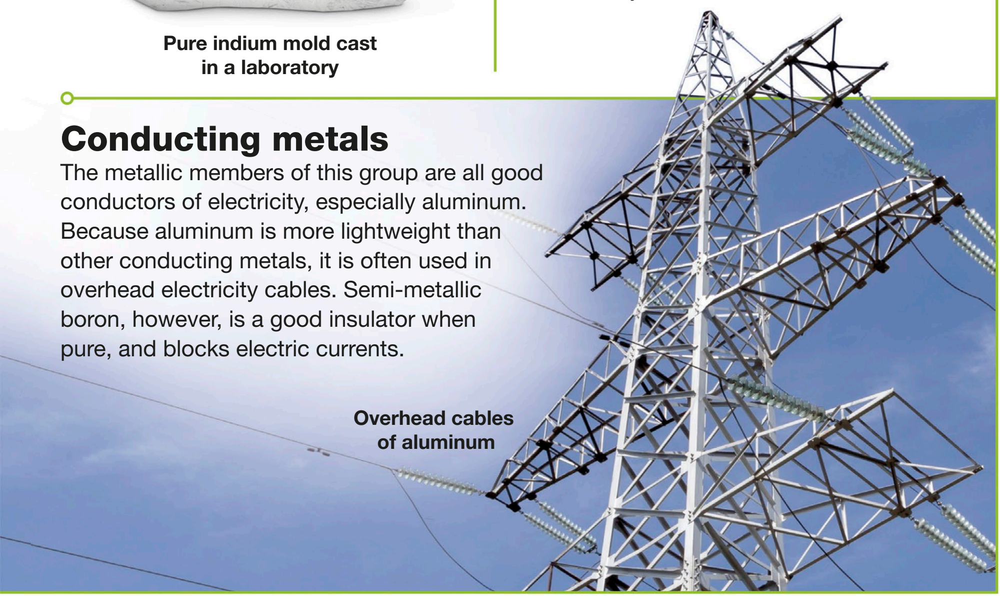
Bauxite, a mineral ore of aluminum

Natural compounds

The elements in the boron group are never found pure in nature, despite not being very reactive. All of them, like members of some other groups, have to be purified from ores. Aluminum is a very common ingredient in minerals, while the other elements are considerably rarer.

Conducting metals

The metallic members of this group are all good conductors of electricity, especially aluminum. Because aluminum is more lightweight than other conducting metals, it is often used in overhead electricity cables. Semi-metallic boron, however, is a good insulator when pure, and blocks electric currents.



Overhead cables of aluminum

Boron

5
B

The first semi-metal in the periodic table, pure boron has a slight shine to it, like a metal, but unlike metals it does not conduct electricity very well. Boron and its compounds have many uses, including in the making of detergents, LCD screens, and even tank armor.

ATOMIC MASS 10.81

STATE Solid

DISCOVERY 1808 (Louis-Josef Gay-Lussac and Louis-Jacques Thénard), 1808 (Sir Humphry Davy)

Boron and carbon form boron carbide, one of the hardest known materials on the planet.

Kernite, an ore of boron

Laboratory sample of pure boron

FOCUS ON...
ALUMINUM

This shiny metal can be found in many everyday objects, from cans to sports equipment.

▲ Cans made of pure aluminum are easy to recycle.

▲ Aluminum is both lightweight and strong and is used to make tennis rackets.

▲ Fire-protection suits have an aluminum coating to reflect heat.

Aluminum

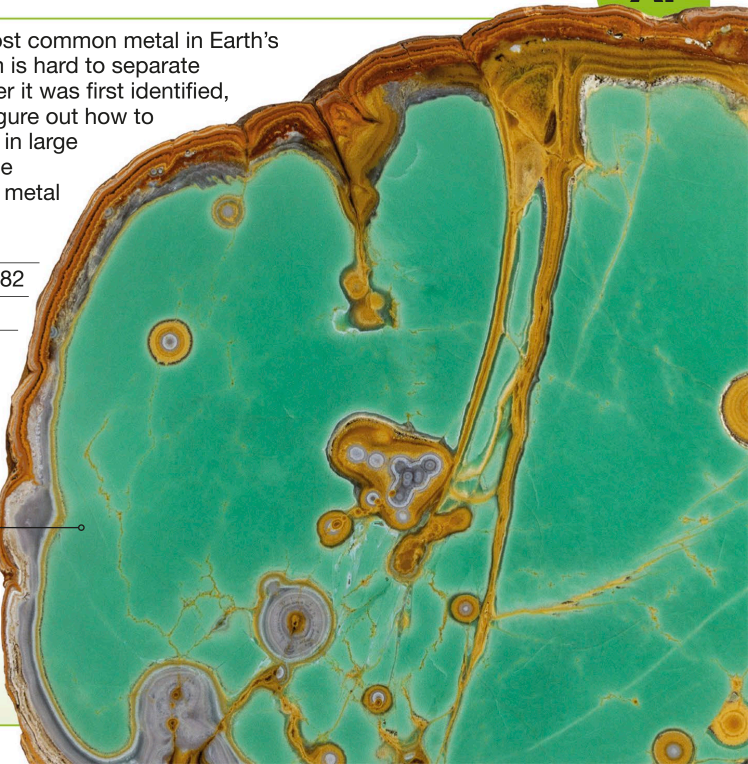
13
Al

Despite being the most common metal in Earth's rocks, pure aluminum is hard to separate from its minerals. After it was first identified, it took a century to figure out how to make pure aluminum in large amounts. Now it is the second-most utilized metal on Earth, after iron.

ATOMIC MASS 26.982

STATE Solid

DISCOVERY 1827 (Friedrich Wöhler)



This blue-green ore contains aluminum, phosphorus, and oxygen.

Chunk of green variscite, an ore of aluminum

Gallium

31
Ga

With a melting point of just 84°F (29°C), the warmth of a person's hand is enough to make this shiny metal melt. A liquid alloy called galinstan, which is used in medical thermometers, is made by mixing tin and indium with gallium.

ATOMIC MASS 69.723

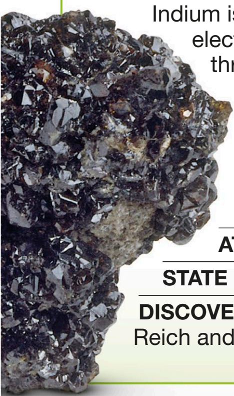
STATE Solid

DISCOVERY 1875 (Paul-Émile Lecoq de Boisbaudran)

Cube of melting gallium

Indium
49
In

When electricity is passed through indium atoms they glow an indigo color, which is where the metal gets its name from. Indium is used to make very thin electrical wires that run through the touchscreens of cell phones.



Black crystals of sphalerite, an ore of indium

ATOMIC MASS 114.818

STATE Solid

DISCOVERY 1863 (Ferdinand Reich and Hieronymous Richter)

Nihonium
113
Nh

This is the only artificial element made in Japan. It was named after the Japanese name for Japan, "Nihon." Nihonium forms when moscovium atoms break apart, but it can also be made by smashing bismuth and zinc atoms together. It is highly radioactive, and is used only in research.

ATOMIC MASS (286)

STATE Solid

DISCOVERY 2004 (team led by Kosuke Morita)

Thallium
81
Tl

This soft metal takes its name from the Greek word "thallos," which means "green shoot or twig," because it burns with a bright green flame. Pure thallium is very toxic: if ingested, it causes stomach pains and makes hair fall out.

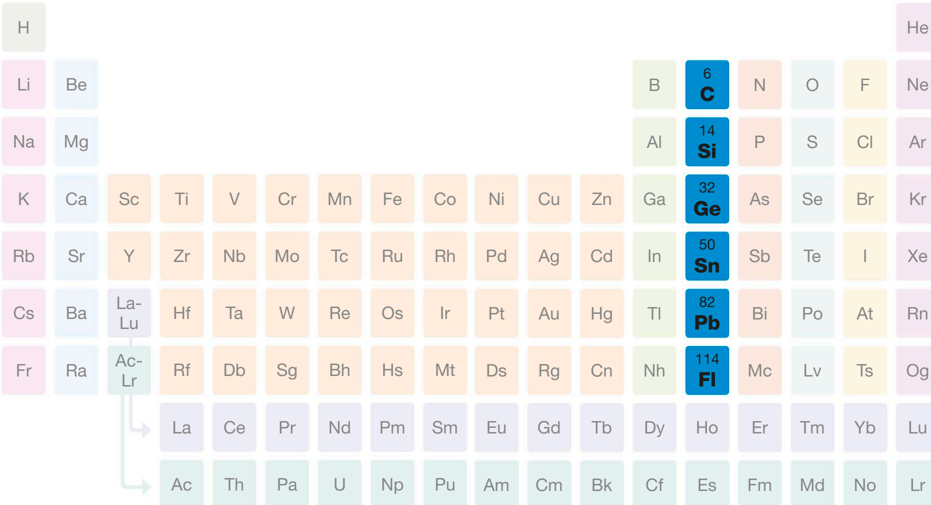
ATOMIC MASS 204.38

STATE Solid

DISCOVERY 1861 (William Crookes)

Laboratory sample of pure thallium in an airless vial

Pure thallium is stored away from air to keep it from tarnishing.

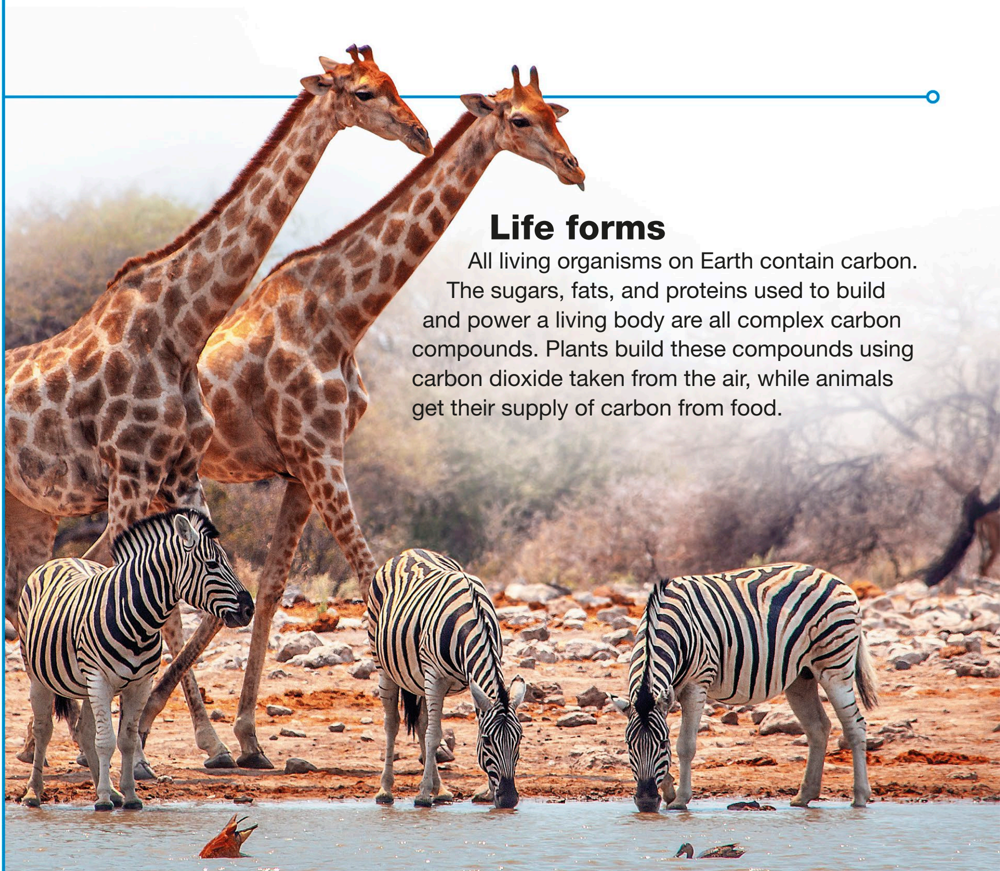


Carbon Group

Atoms of carbon and the other members of this group can bond to four other atoms at once. As a result, these elements form a very wide range of compounds with complex molecules. These compounds include silicon dioxide, which is present with other elements in types of glass. Here, a glass vase is made in a furnace.

Carbon Group

This group of elements is named after the first element in it, carbon. The carbon group is the first in the periodic table to contain metals, semi-metals, and a nonmetal—most of which have played a significant role in human history.



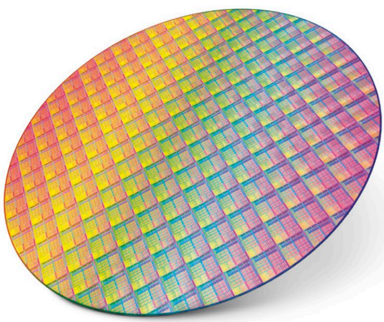
Life forms

All living organisms on Earth contain carbon. The sugars, fats, and proteins used to build and power a living body are all complex carbon compounds. Plants build these compounds using carbon dioxide taken from the air, while animals get their supply of carbon from food.

Bronze

The metal tin was one of the earliest metals to be purified. For thousands of years, people have mixed tin with copper to create an alloy called bronze, which is tougher and more useful than either of the original metals. The first widespread human civilizations used bronze to make tools, statues, and weapons.

6th century BCE bronze statue of two oxen



Semiconducting silicon wafer

Semiconductors

The impure forms of germanium and silicon are used as semiconductors—substances that conduct electricity better than insulators, but not as well as conductors. When pure, these two semi-metals block electricity, but when tiny amounts of other elements are added to them, they can transmit it. These semiconductors are used in electronics.

Carbon chemistry

One carbon atom can bond to anything from one to four other atoms, and as a result, carbon forms a huge range of compounds. Wood, coal, oil, and plastics are all carbon compounds. Common fuels such as gasoline and natural gas are also carbon-based. They release heat when burned, and transform into water and carbon dioxide, as well as carbon monoxide, which is a toxic gas.

Pencil with plastic sharpener

Carbon

6

C

All life forms on this planet are carbon-based. This means that the basic molecules that form the cells, tissues, and organs of all living organisms are a combination of carbon and other elements.

ATOMIC MASS 12.011

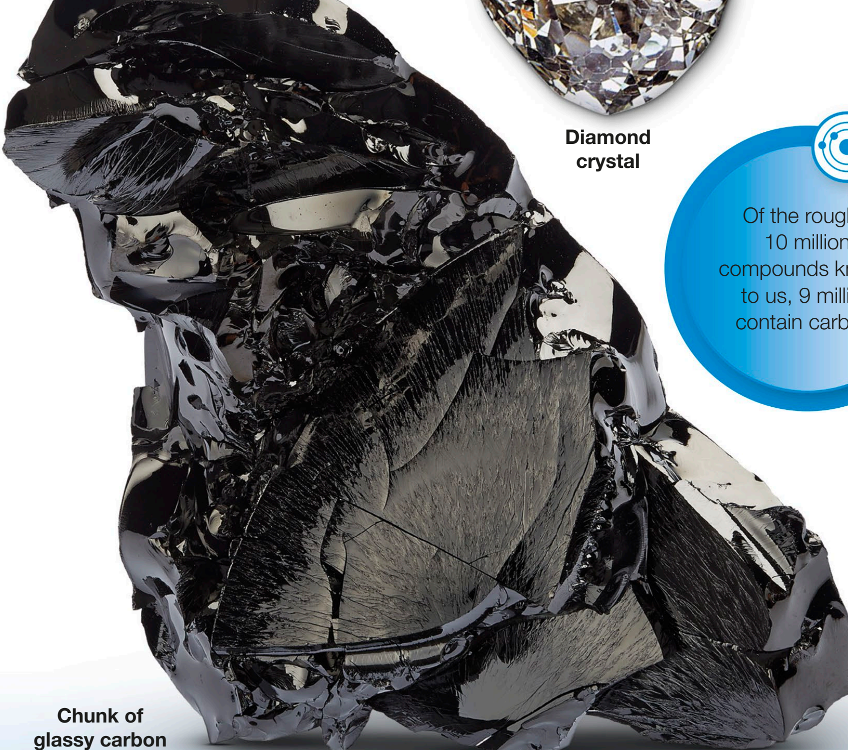
STATE Solid

DISCOVERY Prehistoric

Diamond is made from a rigid network of carbon atoms.

Diamond crystal

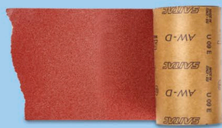
Of the roughly 10 million compounds known to us, 9 million contain carbon.



Chunk of glassy carbon

FOCUS ON… SILICON

This semi-metal can be used to make hard and soft materials.



▲ Sandpaper is made from a compound of silicon and carbon called carborundum.

▲ These cupcake liners containing silicon can be put in an oven as they are heatproof.

▲ Silica gel packets are added to dry food, clothes, and shoes, to absorb moisture.

Silicon

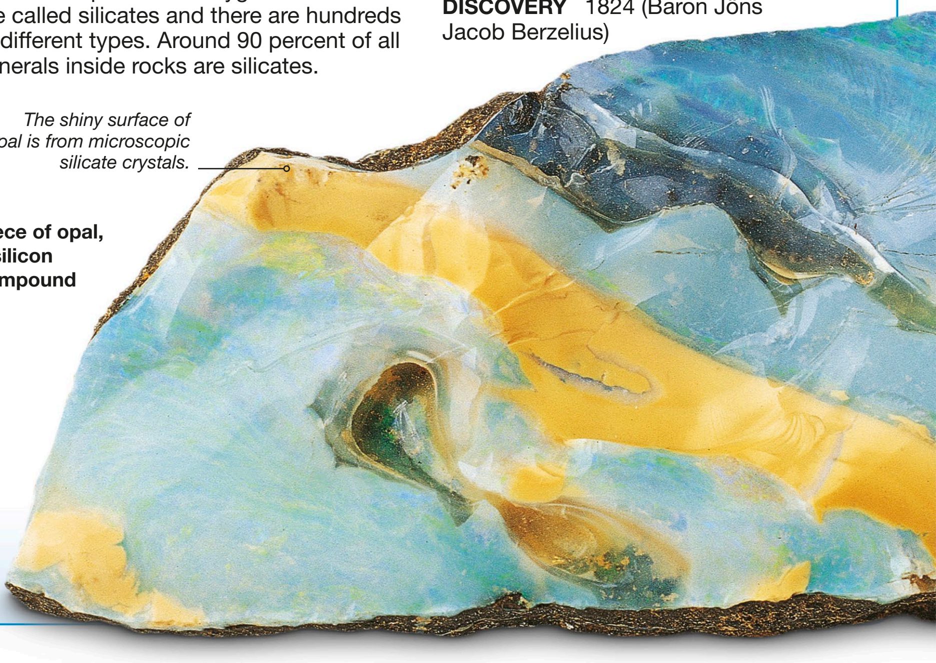
14
Si

After oxygen, this semi-metal is the second most common element in Earth's rocks. Compounds of oxygen and silicon are called silicates and there are hundreds of different types. Around 90 percent of all minerals inside rocks are silicates.

ATOMIC MASS 28.085

STATE Solid

DISCOVERY 1824 (Baron Jöns Jacob Berzelius)



The shiny surface of opal is from microscopic silicate crystals.

Piece of opal, a silicon compound

Methane gas mixed with the water in Siberia’s Lake Baikal gets trapped as

frozen bubbles

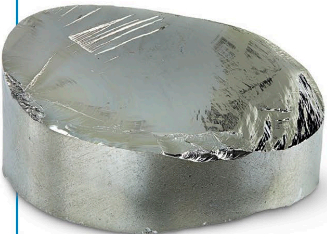
in the winter

BUBBLING UNDER ICE
The gas methane is made of carbon and hydrogen, and is present in underground reservoirs. Lighter than air, it rises into the atmosphere in the summer from Arctic lakes, such as Lake Baikal in Russia's Siberia region. In the winter, the surface of this lake freezes, trapping methane under it as strings of bubbles.

Germanium

32
Ge

After silicon, the semi-metal germanium is the second most important semiconductor used in computer microchips. It is mostly found in ores of silver, lead, and copper.



Laboratory-refined disk of pure germanium

ATOMIC MASS 72.63

STATE Solid

DISCOVERY 1886 (Clemens Winkler)

Flerovium

114
Fl

The name of this element was inspired by the Russian scientist Georgy Flerov. Flerovium was created for the first time by making plutonium and calcium atoms collide in a particle accelerator. Since then, only a few more atoms have been created. It is so radioactive that any atoms that are made last only for a few seconds before breaking apart.

ATOMIC MASS (289)

STATE Solid

DISCOVERY 1998 (team led by Yuri Oganessian and Vladimir Utyonkov)

Tin

50
Sn

This metal is easy to purify from its ores, so humans have used it for more than 5,000 years. When mixed with copper, tin makes the alloys bronze and pewter; with lead, it forms the alloy solder.

ATOMIC MASS 118.71

STATE Solid

DISCOVERY Around 3000 BCE

Laboratory sample of pure tin

FOCUS ON… LEAD

Easy to purify and simple to shape, lead has been in use for 9,000 years.

▲ Lead does not rust, so sheets of this metal are used to waterproof roofs.

▲ The green glaze on this ancient ceramic model of a pigsty comes from lead compounds.

▶ High-quality crystal glasses sparkle in the light because lead oxide is added to the glass.

Lead

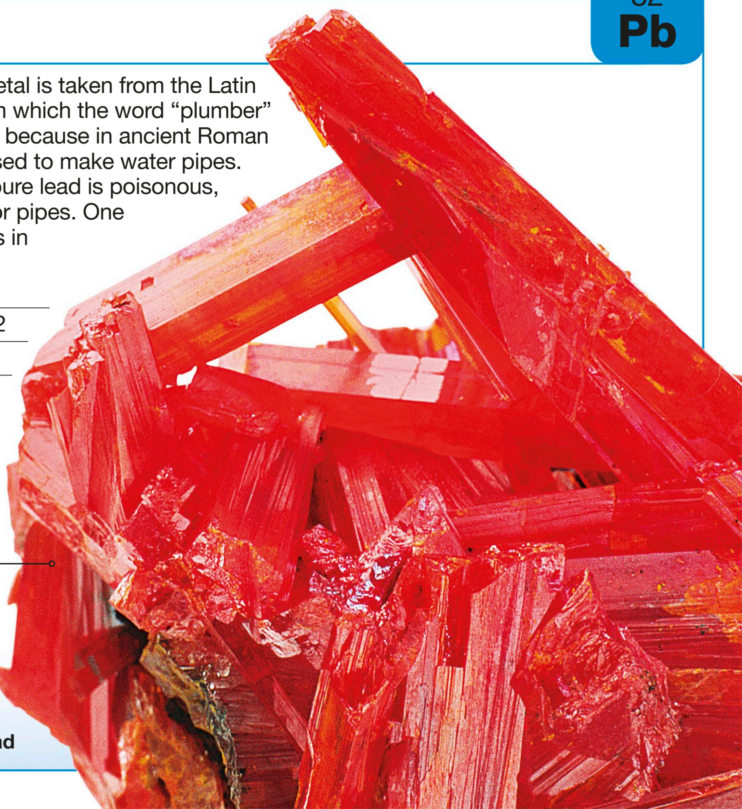
82
Pb

The symbol for this metal is taken from the Latin word "plumbum," from which the word "plumber" also originates. This is because in ancient Roman plumbing, lead was used to make water pipes. Today, we know that pure lead is poisonous, so it is seldom used for pipes. One common use of lead is in car batteries.

ATOMIC MASS 207.2

STATE Solid

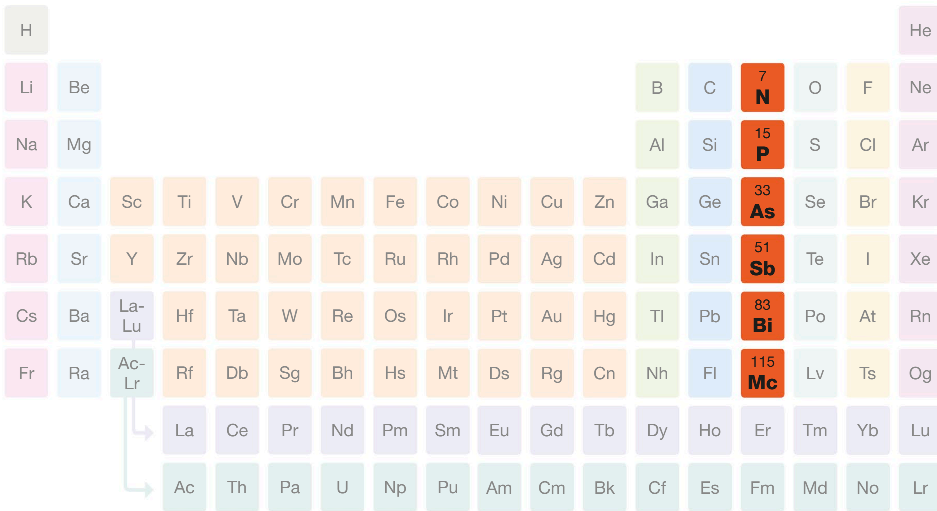
DISCOVERY Prehistoric



This ore is found in the form of long crystals.

Red crystals of crocoite, an ore of lead


GEICO
GEICO
Powersports
LUCAS
OIL PRODUCTS
LUCAS



Nitrogen Group

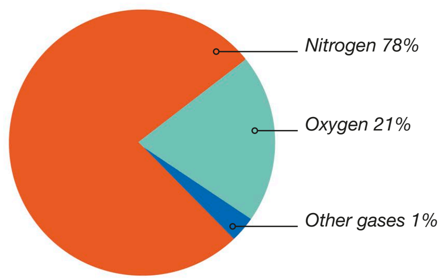
The atoms of nitrogen and other members of this group form strong bonds. They release a burst of energy when the bonds break, making these elements useful in explosives and fuels, such as the nitromethane fuel used to give a power boost to this dragster.

Nitrogen Group

Another name for the members of this group is the "pnictogens," which comes from the Greek word for "to choke." This refers to nitrogen's tendency to cause choking in the absence of oxygen. However, nitrogen, as well as phosphorus, are essential ingredients in bones and muscles. This group includes nonmetals, semi-metals, and metals.

Atmospheric nitrogen

The relatively unreactive nitrogen is the most abundant gas in Earth's atmosphere. Every living thing needs nitrogen compounds to grow, but most cannot use pure nitrogen. Instead, bacteria in soil convert the gas into usable compounds, which are collected by plants via their roots. Animals take in nitrogen through food.



Gases in Earth's atmosphere

Burning phosphorus

The most reactive member of the group is phosphorus. Some forms of it will catch fire on contact with air. A safer version is used in matches, where phosphorus is mixed into the rough strip on the box. When the match is rubbed along here, the phosphorus heats up and reacts with the match head, setting it alight.

Striking a matchstick

Poisonous element

All elements in this group are deadly if used improperly, but arsenic is so toxic that it is often known as the “king of poisons.” Its compounds have been used for many centuries to kill rats and other pests. Erupting volcanoes release large amounts of poisonous arsenic gas and dust, which dilutes in the air.

The Karymsky volcano, in Kamchatka Peninsula, Russia, has been erupting since 1996

FOCUS ON... NITROGEN

Nitrogen is an important ingredient in the chemical industry. It is used in dyes, explosives, and fertilizers.

▲ Nitrogen compounds called azo dyes can be used to make many colors.

▶ Nitrogen-rich compounds are found in explosives such as dynamite. During an explosion, the nitrogen is released as a burst of pure gas.

▲ Farmers add fertilizers containing nitrogen to soil to help crops grow faster and taller.

Nitrogen

Earth's atmosphere is made up of about 78 percent nitrogen, making this gas the most common pure element on Earth. While it is relatively rare in solid minerals, nitrogen is used by plants, fungi, and animals to make proteins.

ATOMIC MASS	14.007
STATE	Gas
DISCOVERY	1772 (Daniel Rutherford)

Pure nitrogen in a glass sphere

This mineral is a mass of tiny crystals that are too small to see.

7
N

Nitratine, a mineral containing a nitrogen compound

Phosphorus

15
P

This element's name means "giver of light" in Greek. There are different types of phosphorus. Its white form is the most reactive and catches fire as soon as it comes into contact with air. White phosphorus is poisonous, and in certain conditions, it glows in the dark.

ATOMIC MASS 30.974

STATE Solid

DISCOVERY 1669 (Hennig Brandt)

Purple crystals of apatite, an ore of phosphorus, in rock

Arsenic

Almost every form of this semi-metal, pure or in compounds, is poisonous to living things. Because of this, arsenic has long been used as a poison for controlling rats. It is also used as a component in microchips.

33
As

ATOMIC MASS 74.922

STATE Solid

DISCOVERY Around 1250 (Albertus Magnus first purified the element)

Realgar is also known as "ruby of arsenic" because of its red color.

Red crystals of realgar, an ore of arsenic, in rock

Antimony

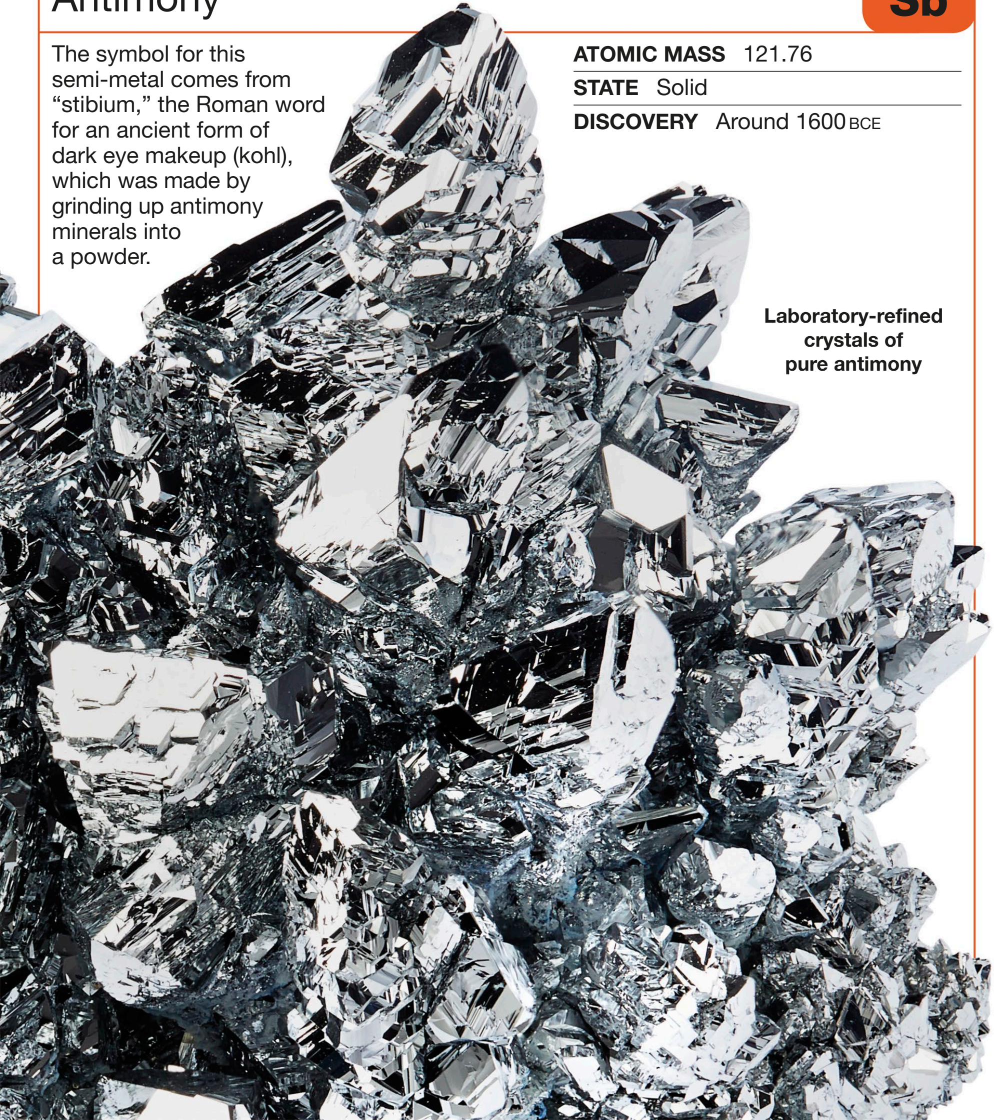
51
Sb

The symbol for this semi-metal comes from "stibium," the Roman word for an ancient form of dark eye makeup (kohl), which was made by grinding up antimony minerals into a powder.

ATOMIC MASS 121.76

STATE Solid

DISCOVERY Around 1600 BCE



Laboratory-refined crystals of pure antimony

FOCUS ON... BISMUTH

Bismuth has a similar weight and melting point to lead but is a much safer, nontoxic alternative.

▲ A soft bismuth alloy inside sprinklers melts during a fire, allowing the water to flow.

▲ Adding bismuth compounds to nail polish gives it a soft pearly shine.

▲ Bismuth-based medicines are used to soothe stomach aches and indigestion.

Bismuth

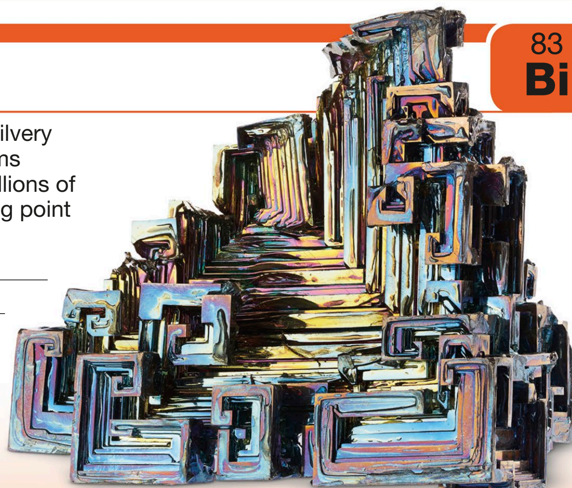
83
Bi

Chemists have found that this silvery metal is radioactive, but its atoms disintegrate very slowly over millions of years. Bismuth has a low melting point and creates colorful crystals.

ATOMIC MASS 208.98

STATE Solid

DISCOVERY Around 1500



Crystals of bismuth grown in a laboratory

Moscovium

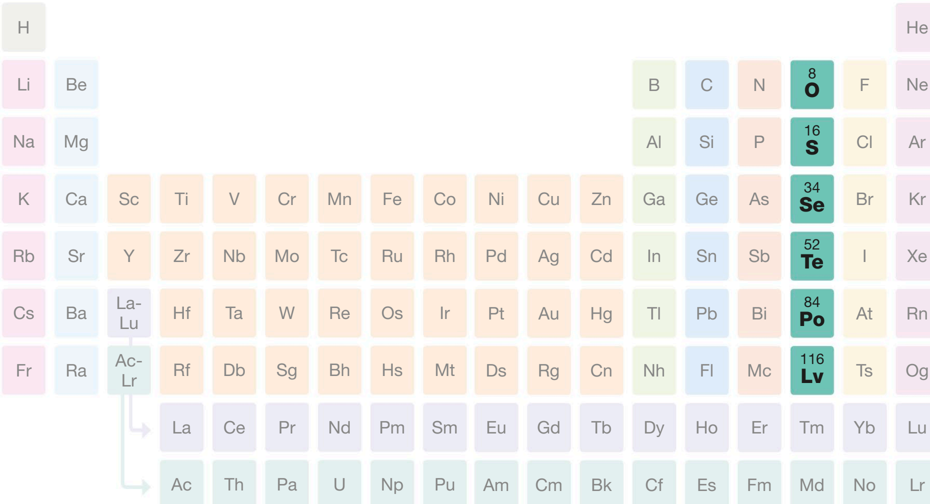
115
Mc

This element is produced by colliding americium with calcium atoms. Only a few atoms of it can be made at a time as they all decay away into nihonium in a fraction of a second. Moscovium was first created in 2010 in the Joint Institute for Nuclear Research (JINR) in Dubna, Russia.

ATOMIC MASS (289)

STATE Solid

DISCOVERY 2010 (team led by Yuri Oganessian and Kenton Moody)



Oxygen Group

Many life forms depend on oxygen for survival, even in coral reefs under the sea—where fish, plants, and tiny animals called corals take in oxygen mixed into the water. Sulfur and selenium are also important for life, but the other group members are not. In fact, radioactive polonium is the deadliest element of all.

Oxygen Group

Some scientists say this might be the first group in the periodic table with no metallic members. There are three nonmetals: oxygen, sulfur, and selenium. Tellurium and polonium are semi-metals, although polonium is sometimes classified as a metal. No one yet knows the nature of livermorium, an artificial element.

Combustion

The chemical reaction that causes burning is called combustion. Of the elements in this group, only oxygen plays a key role in this process. It occurs when pure oxygen bonds to other elements, releasing heat and light in the process. Combustion usually requires heat (to start it) and fuels, which are substances that burn easily, such as wood and oil.

Wood burns in a bonfire

Corrosion

Oxygen is highly reactive and forms compounds known as oxides with other elements. Similar to combustion but much slower, corrosion is a reaction in which oxygen in the air reacts with metals to create oxides. The most common form of corrosion is rust, which forms when iron reacts with oxygen and water.

Pile of rusted screws

Chalcopyrite, a sulfide ore of copper and iron

Ores

Natural substances containing useful materials, such as metals, are known as ores. Many important ores are compounds with members of the oxygen group, most often oxygen and sulfur.

Pure elements

Some members of this group are found pure in nature. While oxygen makes up one-fifth of the air, solid sulfur is found in volcanic areas, where the naturally hot conditions allow pure sulfur to separate from its compounds.

Deposits of pure sulfur in the Danakil Depression, Ethiopia

Oxygen

8
O

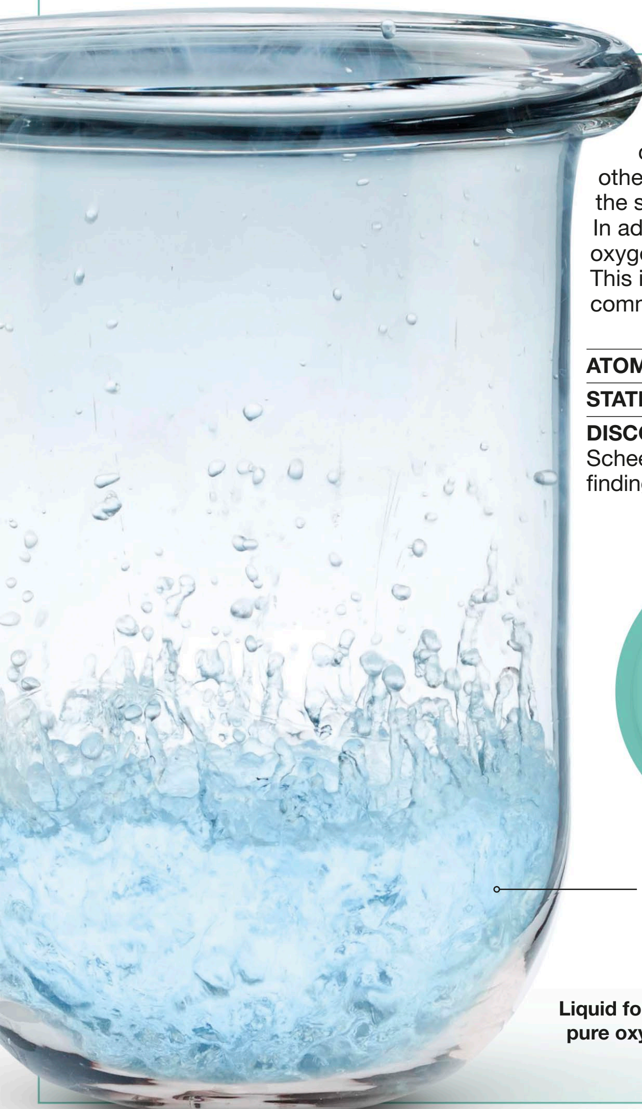
As well as making up a fifth of the air we breathe, this gaseous element also combines with metals and other substances to make many of the solid minerals of Earth's rocks. In addition, along with hydrogen, oxygen forms all the water on Earth. This is why oxygen is the most common element on Earth's surface.

ATOMIC MASS 15.999

STATE Gas

DISCOVERY 1771 (Carl Wilhelm Scheele), 1774 (Joseph Priestley; his finding was published first)

An average person breathes in oxygen up to 23,000 times in a day.



Liquid oxygen is made by cooling the air to -297.4°F (-183°C).

Liquid form of pure oxygen

FOCUS ON... **SULFUR**

Sulfur has been in use for centuries, from keeping food fresh to making rubber stronger.

▲ Sulfur is added to rubber in vehicle tires in order to make them tougher.

▲ Sulfur-rich compounds are added to dried fruits and fresh food to stop them going bad.

▲ Car batteries use sulfuric acid to generate electric currents.

Sulfur

16
S

This yellow nonmetal is found pure in nature as well as in combination with other elements in minerals. When sulfur burns, it melts into a blood-red liquid and produces a blue flame. It is also called brimstone, which means "burning stone." Many ancient cultures thought that sulfur was the fuel that burned in the fires of the underworld.

ATOMIC MASS 32.06

STATE Solid

DISCOVERY Prehistoric

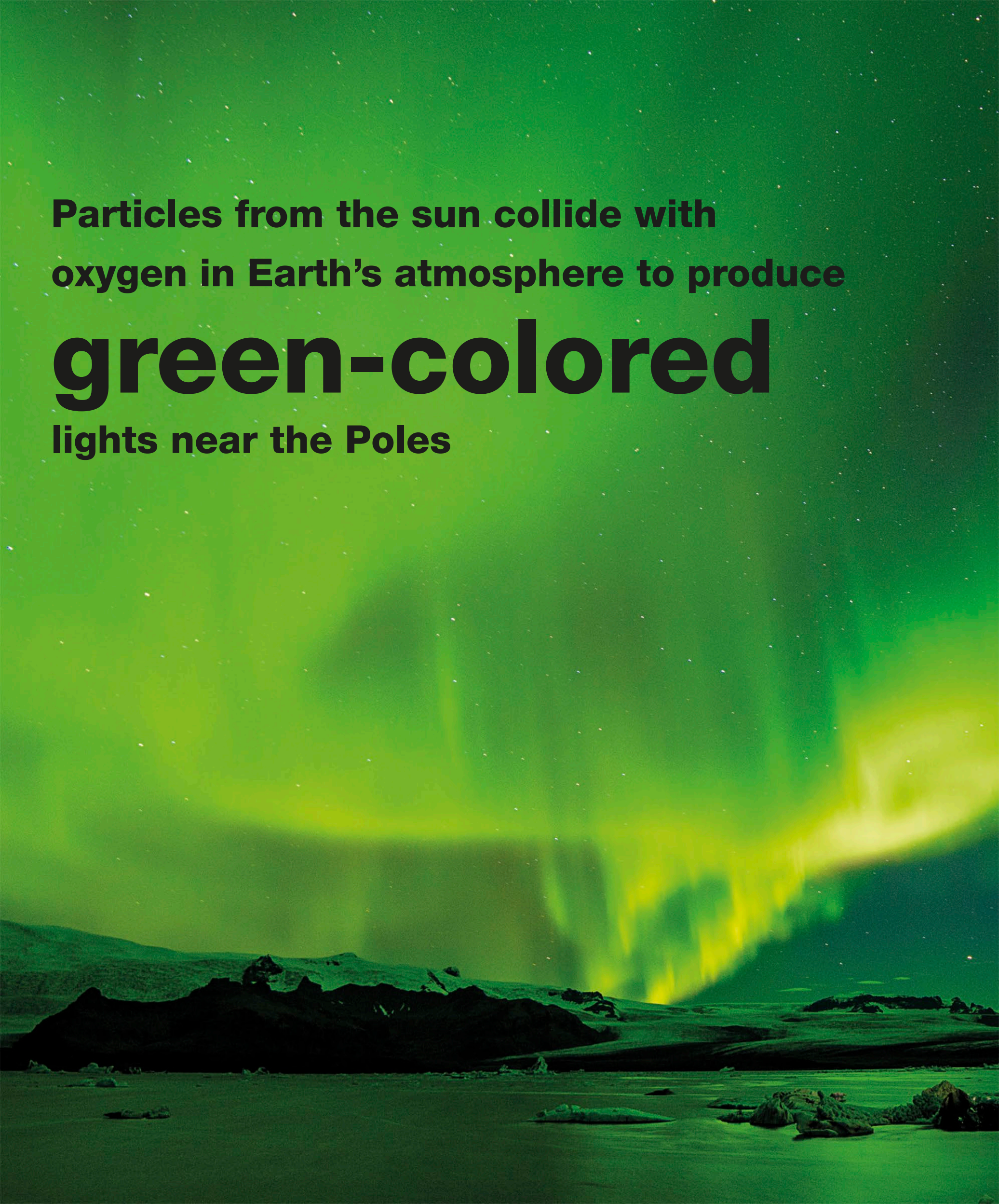
Rectangular crystals are odorless and brittle.

Yellow crystals of pure sulfur

Particles from the sun collide with oxygen in Earth's atmosphere to produce

green-colored

lights near the Poles



POLAR LIGHTS

The sun emits "solar winds" of high-energy particles that are pulled toward Earth's North and South Poles by the planet's magnetic field. These particles collide with the atoms of oxygen and other gases in the atmosphere, producing light displays called auroras.

Selenium

34
Se

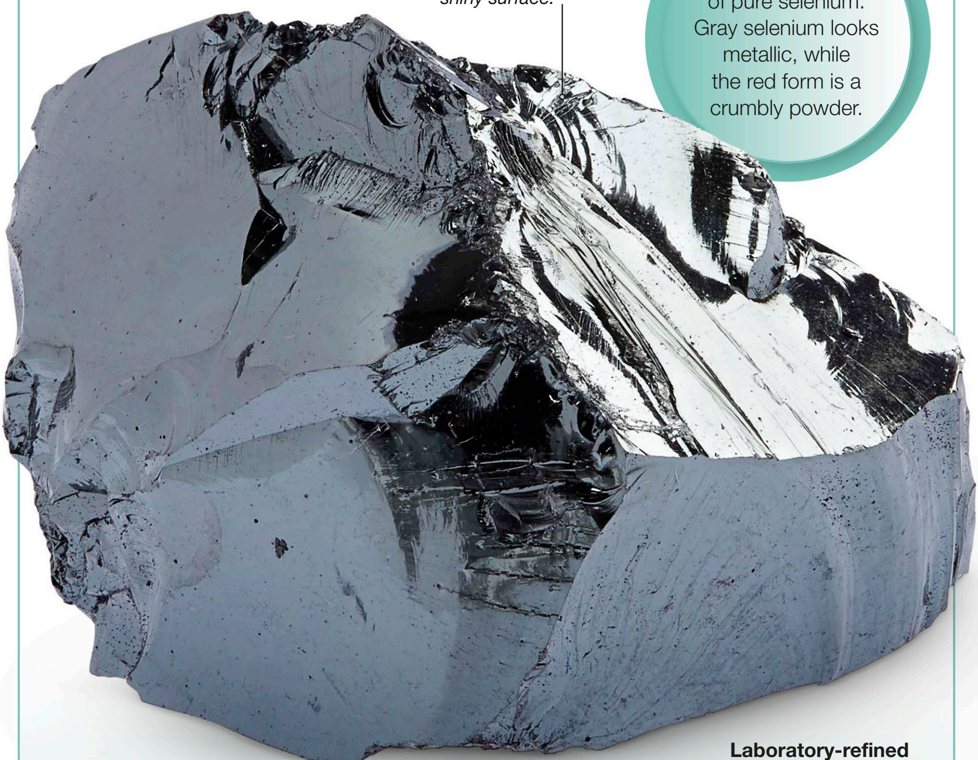
This semi-metal is named after Selene, the Greek goddess of the moon. It is light-sensitive and so is used in solar panels for making electricity and in light-sensors in laser printers and photocopiers. It is also an ingredient in antidandruff shampoos.

ATOMIC MASS 78.971

STATE Solid

DISCOVERY 1817 (Baron Jöns Jacob Berzelius)

There are two forms of pure selenium. Gray selenium looks metallic, while the red form is a crumbly powder.



Laboratory-refined chunk of pure selenium

52 Te
Tellurium

While selenium is named for the moon, the next member of the group, tellurium, is named after “tellus,” the Latin word for Earth. It is used to make high-tech glass such as the kind used in optical fibers—a flexible cable with a glass core, which is used to send long-distance light signals.

ATOMIC MASS 127.6

STATE Solid

DISCOVERY 1783 (Franz-Joseph Müller von Reichenstein)

Laboratory-refined crystals of pure tellurium

84 Po
Polonium

A rare and very dangerous metal, polonium is a powerful source of deadly radioactivity. It has been used in the triggers for atomic bombs.

ATOMIC MASS (209)

STATE Solid

DISCOVERY 1898 (Marie Curie)

Uraninite, an ore of polonium

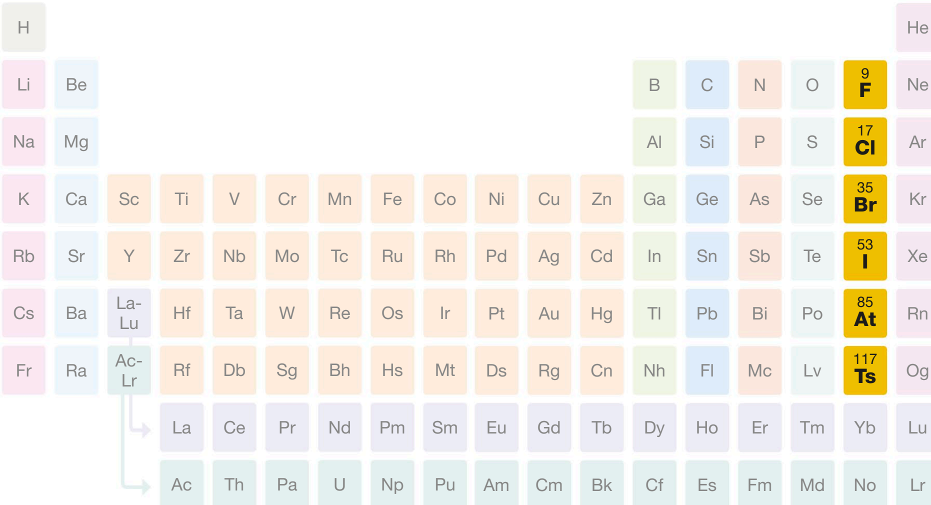
116 Lv
Livermorium

Although first made in the Joint Institute for Nuclear Research (JINR) in the Russian city of Dubna, livermorium was named after Livermore, a town in California, where many other superheavy elements have been created. This element is made by fusing calcium and curium atoms. Its atoms exist for only a few thousandths of a second before breaking apart.

ATOMIC MASS (293)

STATE Solid

DISCOVERY 2000 (team led by Yuri Oganessian, Vladimir Utyonkov, and Kenton Moody)



Halogen Group

The halogens are often found in the form of compounds known as salts. The Dead Sea, a lake in the Middle East, is a very salty water body because of the halogen minerals dissolved in its warm waters. The different salts of bromine, iodine, and chlorine create bands of crystals in its shallows.

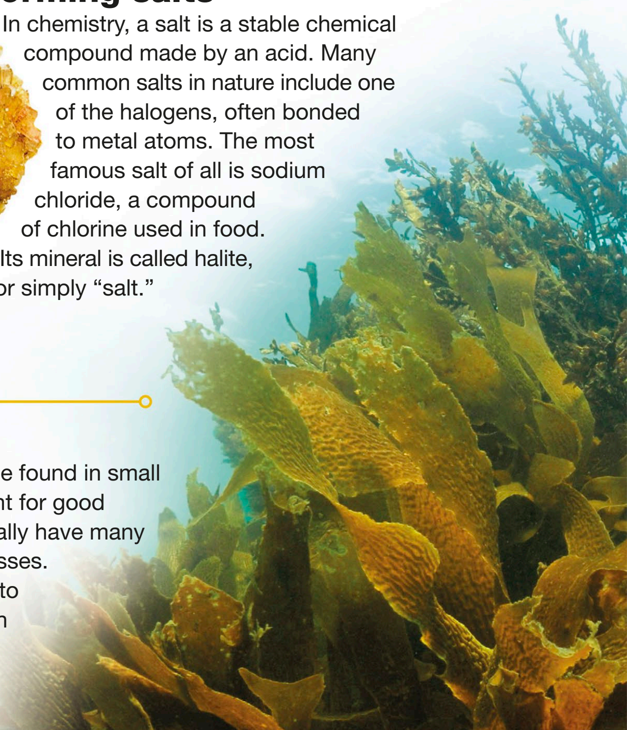
Halogen Group

This group of elements is made up of highly reactive members, which are called halogens. The word "halogen" means "salt former," alluding to how these elements react with metals to form salts. The halogen group is mostly made up of nonmetals, with the rare radioactive member astatine being classified as a semi-metal.

Halite, the mineral form of sodium chloride

Forming salts

In chemistry, a salt is a stable chemical compound made by an acid. Many common salts in nature include one of the halogens, often bonded to metal atoms. The most famous salt of all is sodium chloride, a compound of chlorine used in food. Its mineral is called halite, or simply "salt."



Essential diet

Most of the halogens, which can be found in small amounts in food, are very important for good health. Chlorine and iodine especially have many uses in the body's chemical processes. Compounds of fluorine are added to toothpaste and water to keep teeth strong. Astatine is the only halogen not found in the body.

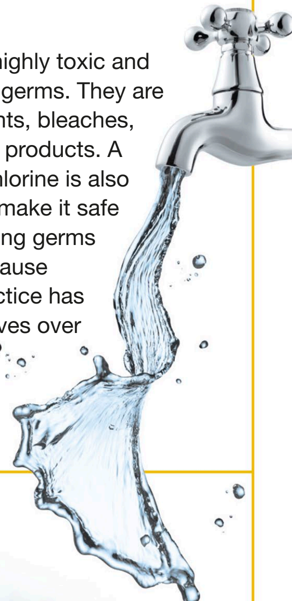
Acids

When bonded to hydrogen, the halogens form mostly strong acids. These compounds can react with many materials, even unreactive elements such as gold. Mixing a halogen acid and a metal produces a salt and pure hydrogen gas.

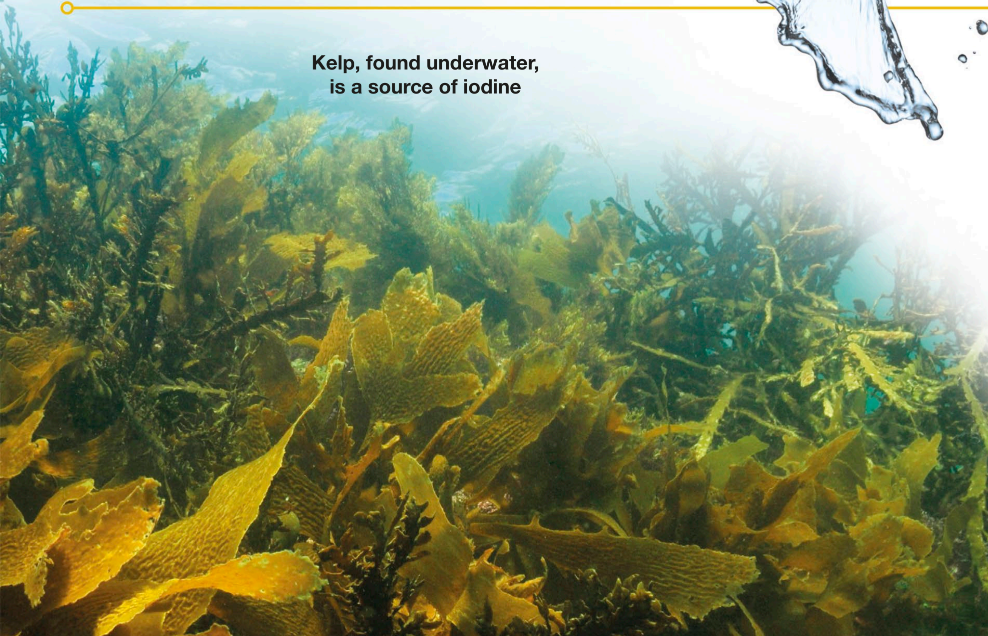
Hydrochloric acid is added to zinc nuggets

Cleaners

The halogens are highly toxic and can be used to kill germs. They are present in detergents, bleaches, and other cleaning products. A small amount of chlorine is also added to water to make it safe for drinking, by killing germs present that may cause diseases. This practice has saved millions of lives over the last century.



Tap water treated with chlorine



Kelp, found underwater, is a source of iodine

Fluorine

9
F

The most reactive nonmetal of all, this pale yellow gas can form compounds with almost every element on the periodic table. Compounds containing fluorine are used in toothpaste, nonstick pans, and waterproof clothing.

ATOMIC MASS 18.998

STATE Gas

DISCOVERY 1886 (Henri Moissan)

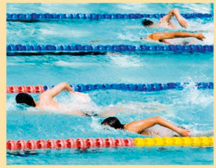
Pure fluorine gas can burn its way through almost anything, including metals and concrete.

Crystals of fluorite, an ore of fluorine

FOCUS ON... CHLORINE

In both its pure form and in compounds, chlorine has plenty of uses.

▲ The bleach used to make paper white contains chlorine.



▲ Chlorine chemicals are used to clean the water in swimming pools.

▶ This suitcase is more durable because it is made of a plastic containing chlorine.

Chlorine

17
Cl

In its pure form, this halogen is a green gas, although it is never found pure in nature. As it is very reactive, many chlorine compounds exist naturally, such as sodium chloride (common salt).

ATOMIC MASS 35.45

STATE Gas

DISCOVERY 1774 (Carl Wilhelm Scheele)

Clear crystals of halite, an ore of chlorine, in rock

Bromine

35
Br

This halogen is the only nonmetal that is liquid at room temperature. The name bromine comes from the Greek word for "stench," because bromine fumes have a strong smell.

Pure bromine in a glass sphere

Liquid bromine is dark and red-brown, while bromine gas is orange.

ATOMIC MASS 79.904

STATE Liquid

DISCOVERY 1826 (Antoine-Jérôme Balard, Carl Löwig)

Iodine

53
I

This halogen was first discovered in seaweed, and is an essential nutrient in food. Iodine is also used in inks and dyes, as an antiseptic for cuts, and for purifying water. When heated, solid iodine does not melt but instead turns directly into a gas.

ATOMIC MASS 126.904

STATE Solid

DISCOVERY 1811 (Bernard Courtois)

Glass sphere containing pieces of pure iodine and iodine vapor

Tennessine

117
Ts

Discovered only in 2010, tennessine is the newest member of the periodic table. It is named after the state of Tennessee, which is home to the Oak Ridge National Laboratory—one of the first atomic research centers. Chemists think tennessine might be a semi-metal, unlike the other halogens.

ATOMIC MASS (294)

STATE Solid

DISCOVERY 2010 (teams from Joint Institute for Nuclear Research, Dubna, Russia; Lawrence Livermore National Laboratory, California; and Oak Ridge National Laboratory, Tennessee)

Astatine

85
At

Only tiny amounts of this radioactive halogen exist in nature—around 1.05 oz (30 g) in all of Earth's rocks put together. Astatine atoms are formed when francium and polonium atoms decay.

ATOMIC MASS (210)

STATE Solid

DISCOVERY 1940 (Dale R. Corson, Kenneth Ross MacKenzie, and Emilio Segrè)

Uraninite, an ore of uranium, contains a very small amount of astatine

新國
蛇羹
城遊戲機
翡翠湖桑拿
國
BLUE GIRL
新都會芬蘭浴
SUN DO WUI SAUNA BATH
108
108 BAR

Noble Gases

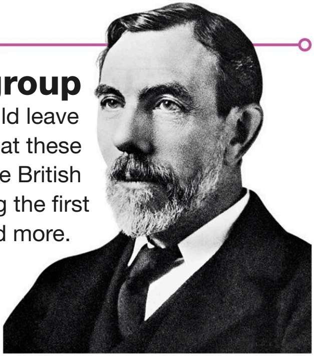
The colorful lights of a busy Hong Kong street are glowing brightly thanks to the noble gases inside them. “Neon” lights are shaped glass tubes filled with neon and other gases. The elements in this group glow brightly when an electric current is passed through them.

Noble Gases

The elements in the final group of the periodic table are the noble gases. They are called "noble" because these gases do not mix with ordinary elements. The noble gases are very unreactive and their atoms only rarely form chemical bonds with the atoms of other elements.

A new group

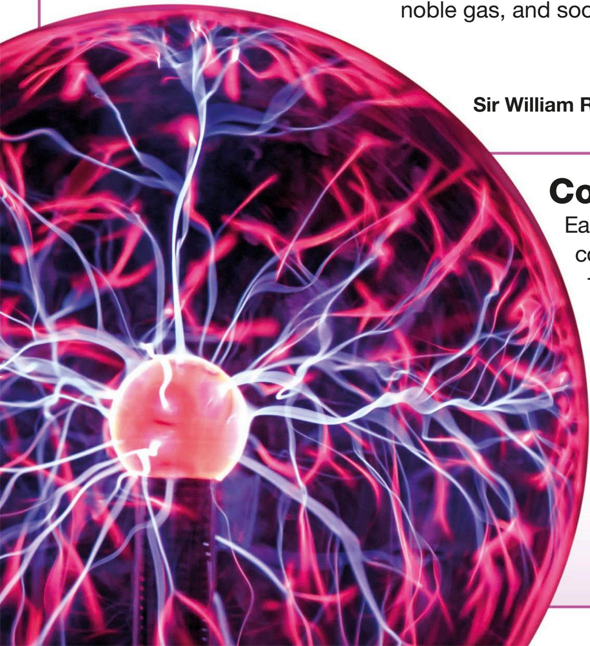
In the 1800s, chemists noticed that some reactions would leave behind tiny amounts of unreactive gases. They realized that these gases must be unknown unreactive elements. In 1894, the British chemist Sir William Ramsay purified argon, discovering the first noble gas, and soon found more.



Sir William Ramsay

Colorful plasma

Each element gives off light of a unique color when heated or electrified. In the 1860s, scientists studying the sun found a pattern of lights that did not correspond to any element known at that time. They named this unknown element helium, and its pattern was one of the first clues to the existence of noble gases. A mixture of noble gases in a plasma ball will emit unique streaks of light when electrified.



Plasma ball

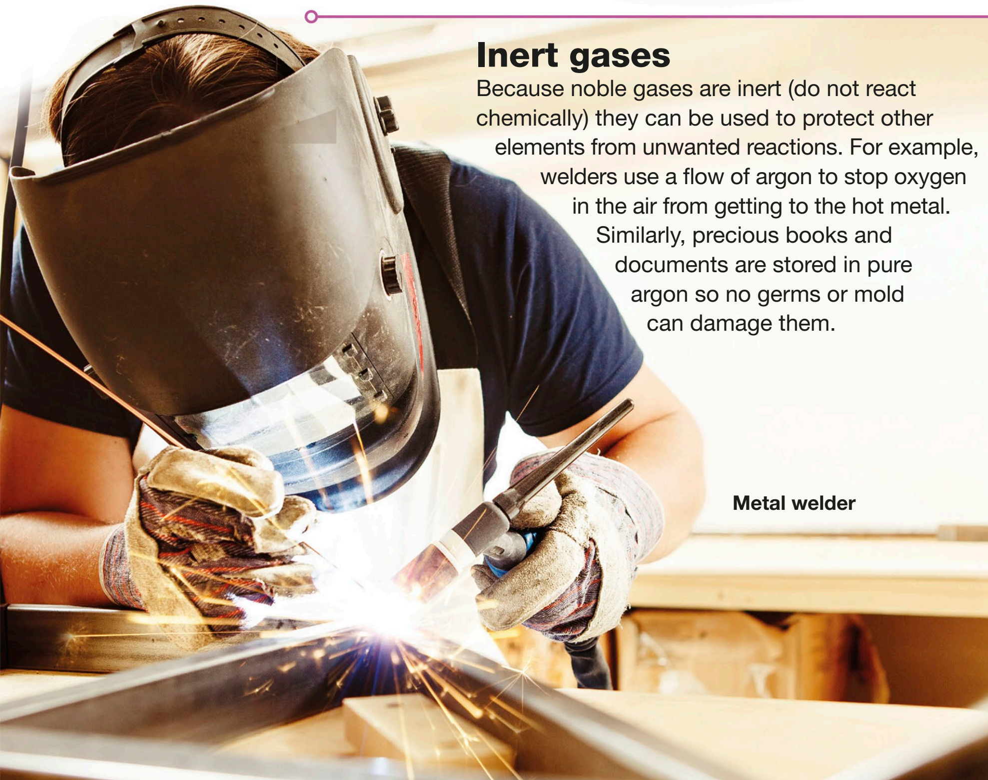
Lighter than air

Airships and balloons filled with helium, a noble gas, are lighter than the surrounding air, so they float upward. Helium is the second-lightest element after hydrogen. However, unlike hydrogen, which is highly flammable, helium is safe to use, although expensive.

Propeller-powered helium blimp

Inert gases

Because noble gases are inert (do not react chemically) they can be used to protect other elements from unwanted reactions. For example, welders use a flow of argon to stop oxygen in the air from getting to the hot metal. Similarly, precious books and documents are stored in pure argon so no germs or mold can damage them.



Metal welder

FOCUS ON… HELIUM

Helium has a very low boiling point so its liquid form is used to keep high-tech devices cold.

▲ Weather balloons filled with helium are sent high into the atmosphere to collect data.

▲ Liquid helium is used to maintain the low temperatures required by the superconducting magnets that make a maglev train (shown here in Shanghai, China) float above the tracks.

Helium

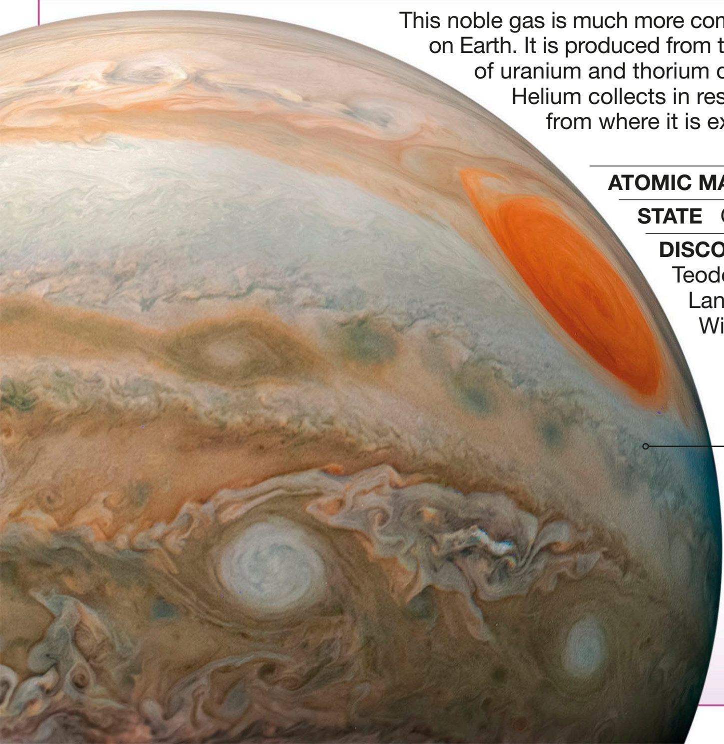
2
He

This noble gas is much more common in space than on Earth. It is produced from the radioactive decay of uranium and thorium deep underground. Helium collects in reservoirs of natural gas, from where it is extracted.

ATOMIC MASS 4.003

STATE Gas

DISCOVERY 1895 (Per Teodor Cleve, Nils Abraham Langlet, and Sir William Ramsay)



Jupiter, the largest planet in the solar system

Neon

10
Ne

The name of this gas means the "new one." Tiny amounts of the element are released in volcanic eruptions and end up in the air. Neon makes up around one thousandth of 1 percent of the atmosphere.

ATOMIC MASS 20.18

STATE Gas

DISCOVERY 1898 (Sir William Ramsay and Morris Travers)

Pure neon in a glass sphere

Argon

18
Ar

About 1 percent of Earth's atmosphere is made up of argon, the most common noble gas on Earth. Argon means the "lazy one" because early chemists were left with it after removing all other gases from air, and they found it did not do anything at all.

ATOMIC MASS 39.95

STATE Gas

DISCOVERY 1894 (Lord Rayleigh and Sir William Ramsay)

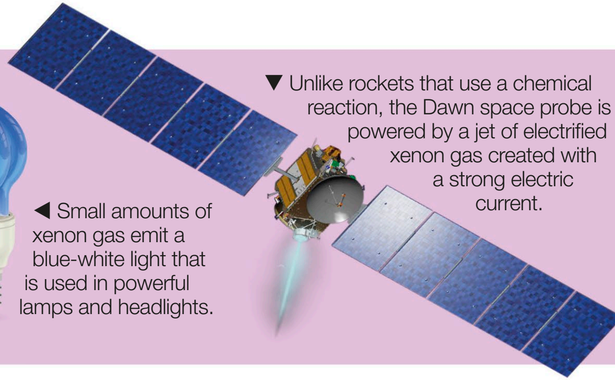
Small amounts of argon gas glow pale purple when electrified.

Pure argon in a glass sphere

FOCUS ON… XENON

Xenon has several specialist uses—as an anesthetic, in bright light bulbs, and even as spacecraft fuel.

◀ Small amounts of xenon gas emit a blue-white light that is used in powerful lamps and headlights.



▼ Unlike rockets that use a chemical reaction, the Dawn space probe is powered by a jet of electrified xenon gas created with a strong electric current.

Krypton

36
Kr

This element's name comes from the Greek word "kryptos," which means the "hidden one." Krypton is naturally present in the air, but it is 20 times less abundant than neon. It is primarily used in lasers and in flash bulbs for high-speed photography.

ATOMIC MASS 83.798

STATE Gas

DISCOVERY 1898 (Sir William Ramsay and Morris Travers)

This light is given off by krypton gas when it is electrified.

Pure krypton in a glass sphere

Xenon

54
Xe

Pure xenon in a glass sphere

A balloon filled with xenon does not float, but drops straight to the ground. This is because this gas is five times heavier than air. Xenon is mixed with air in the atmosphere, but out of every 10 million atoms in the air, only one is xenon.

ATOMIC MASS 131.293

STATE Gas

DISCOVERY 1898 (Sir William Ramsay and Morris Travers)

Radon

86
Rn

Highly radioactive radon is created as the thorium and uranium atoms in rocks naturally break down. Radon can gather in caves and basements in certain areas, and its radiation poses a risk to health.

ATOMIC MASS (222)

STATE Gas

DISCOVERY 1900 (Friedrich Ernst Dorn)

Glass sphere containing radon, air, and thorium

The radon in this sphere is released from a tiny piece of decaying thorium.

Oganesson

118
Og

The final member of the periodic table is oganesson. Its atoms have the highest number of protons, electrons, and neutrons of any element discovered so far. This artificial element is named after the Russian nuclear physicist Yuri Oganessian, who has been involved in the discovery of 12 elements.

ATOMIC MASS (294)

STATE Solid

DISCOVERY 2006 (teams from Joint Institute for Nuclear Research, Dubna, Russia and Lawrence Livermore National Laboratory, California)

Fascinating facts

IN NUMBERS

- The largest stable nucleus belongs to **lead**—it has **208 subatomic particles** (126 neutrons and 82 protons).

- **Bismuth** is very slightly radioactive. It would take **20 million trillion years** for half of its atoms to decay. At less than 14 billion years of age, even the universe is not that old!

- **Buckminsterfullerene** is one of the allotropes (physical forms) of carbon. One molecule of it is made of **60 atoms of carbon** arranged in a ball.

- The **body** of an average adult human contains **94.79 lb** (43 kg) of oxygen and **0.0000071 oz** (0.2 mg) of gold.

- Around **1.2 billion tons** (1.1 billion metric tons) of **iron** are produced annually—enough to make a cube with sides about 2,362 ft (720 m) long, which is more than twice the height of the **Eiffel Tower** in Paris, France.

- Neutron stars are made only of neutrons and not atoms. Astronomers have given this material the nickname **neutronium**. One teaspoon of it would weigh around **100 million tons** (90,718,000 metric tons)!

The aluminum foil used in kitchens is 0.00063 in (16 millionths of a meter) thick.

BREAKING THE BANK

- The **Large Hadron Collider**, the world's largest particle accelerator, has around **$120 million** worth of wire, made from the metals niobium and titanium, in it.

- In the 1850s, **aluminum** was twice as expensive as **gold**—it was even used to make dinner plates for royalty.

- **Palladium** is the most expensive precious metal. It costs almost **100 times** as much as the **same quantity of silver**.

WEIRD BUT TRUE

- **Mercury** is a liquid that is **13.5 times denser** than water. A person could sit on top of a pool of mercury without sinking.

- Recycling **aluminum** uses just **5 percent** of the energy needed to extract pure uranium from its ores.

- **Lightning strikes** occur nearly **50 percent** more often above nuclear power plants because the reactors release charged **krypton** gas.

DISCOVERERS

- The Greek philosopher **Democritus**, in the 5th century BCE, set out the idea that everything is made from tiny units called **atoms**.

- In the early 1800s, the British chemist **John Dalton** offered proof that **atoms** existed by showing that gases always spread out evenly.

- In 1895, the French physicist **Antoine Henri Becquerel** discovered that certain materials gave out invisible rays. This was named as **radioactivity** in the early 1900s by the French physicists Marie and Pierre Curie.

- **Sir J. J. Thomson**, a British physicist, discovered the first subatomic particles in 1897. They are now called **electrons**.

- In 1911, the New Zealand physicist **Baron Ernest Rutherford** led a team that discovered the positively charged core of an atom, which he named the **nucleus**. He later showed that the positive charge was due to a subatomic particle called the **proton**.

- In 1913, the Danish physicist **Niels Bohr** figured out how electrons and protons were **organized in an atom**. This helped scientists understand how atoms could form **bonds**.

IN POPULAR CULTURE

- In the film *Avatar*, **human miners** are destroying the alien moon Pandora to extract a fictional element called **unobtanium** that is crucial to Earth's survival.

- In Marvel comics and films, **vibranium** is a very strong metal found only in the fictional African country of Wakanda. This metal is used to make **Captain America's** almost indestructible **shield**.

- **Adamantium** is a tough fictional alloy used in the **claws of Wolverine**, one of the X-Men in Marvel comics and films.

- In Middle-earth, the fictional world created by the British author J. R. R. Tolkien, **mithril** is a metal that **shines like silver** and is stronger than steel. Once mined by dwarves, this metal is **priceless** because it is no longer produced. The most famous item made of mithril in Tolkien's works is the mail armor worn by Frodo Baggins, a hobbit.

- In *Star Trek*, a crystalline element called **dilithium** is the central component of a Federation spaceship's warp drive that allows it to travel many times **faster than the speed of light**.

The element lead blocks the X-ray vision of Superman, the famous superhero of DC comics and films.

What's in a name?

FROM MYTHOLOGY

- Since it was first discovered not on Earth but in the sun, **helium** was named after the ancient Greek sun god **Helios**.

- The highly radioactive metal **promethium** is named after **Prometheus**, the ancient Greek hero who stole fire from the gods.

- The precious metal **palladium** was named after the asteroid Pallas, which itself was named after the ancient Greek goddess **Pallas Athena**.

- Because it produces many colorful chemicals, the metal **iridium** was named after **Iris**, the ancient Greek goddess of rainbows.

- **Titanium** is a strong, silvery metal, and was named after the **Titans**, a group of powerful deities who battled the Olympian gods in ancient Greek mythology.

- The metal **tantalum** was named after the mythical figure **Tantalus**, who was punished by the ancient Greek gods by being put in a pool of water that he was never able to drink from.

- Because of its similarity to tantalum, **niobium** was named after **Niobe**, the daughter of Tantalus in ancient Greek mythology.

- **Vanadium** is a corrosion-resistant metal named after the Scandinavian goddess Freyja, whose Norse name is **Vanadis.**

REFLECTING COLORS

- **Chlorine** was named after the Greek word **"chloros,"** meaning "**greenish yellow,**" to describe the color of the pure gas.

- **Cesium's** name comes from the Latin word "**caesius,**" meaning "**sky-blue**"—the metal produces blue flames when it burns.

- The element **indium** was named after the color **indigo**. The metal's atoms give off a dark-blue light when they are electrified.

- **Rubidium** gets its name from the Latin word "**rubidus,**" meaning "**deepest red,**" referring to the metal's flames when burned.

- The metal **chromium** was named after the Greek word "**chroma,**" which means "**color.**" Its compounds have many different shades.

- The mineral orpiment, which is the main ore of **arsenic**, is yellow in color. The element gets its name from the Greek word "**arsenikon,**" meaning "**yellow orpiment.**"

TEMPORARY NAMES

- Scientists often need to refer to elements that have not yet been discovered. These elements are given **temporary names** by an organization called **IUPAC** (The International Union of Pure and Applied Chemistry). Even after these elements are discovered, their names and symbols must be approved by IUPAC before they are accepted by scientists throughout the world.

- Three-letter symbols, corresponding to their temporary names, are assigned to elements before they are given official names. Hassium's temporary name was **unniloctium**, with the symbol "**Uno.**"

- Until it was named in 2004, Roentgenium was known as **unununium**, and its symbol was "Uuu." Unununium corresponds to the element's atomic number 111.

- Before they were officially named, flerovium and livermorium were called **ununquadium** and **ununhexium**, Latin words for their respective atomic numbers 114 and 116.

- When element 119 is discovered in the future, it will be first known as **ununennium**, with the symbol "Uue." Element 120 will be **unbinilium**, with the symbol "Ubn."

FROM PLACES

- **Polonium** is named after **Poland**.

- **Gallium** is named after "**Gallia,**" the Latin name for France.

- **Lutetium** is derived from "**Lutetia,**" the Roman name for Paris.

UNUSUAL SYMBOLS

- Sodium's symbol **(Na)** comes from its Latin name "natrium." The word is itself derived from the Arabic word "**natrun,**" meaning "headache"—sodium carbonate was an ancient remedy for a sore head.

- The symbols for iron **(Fe)** and copper **(Cu)** come from the Latin words for these metals, "**ferrum**" and "**cuprum.**" The symbols for silver **(Ag)** and gold **(Au)** are also based on their Latin names, "**argentum**" and "**aurum.**"

- Tungsten's symbol is **W** because it is called "**Wolfram**" in German, which means "wolf soot."

- Tin's symbol **(Sn)** is an abbreviation of its Latin name "**stannum.**"

- Potassium's symbol **(K)** comes from the Latin word "**kalium,**" which means "ash."

Glossary

Acid A reactive chemical that contains hydrogen.

Acidic Having the properties of an acid.

Alkali A chemical that reacts easily with acids and water.

Alkaline Having the properties of an alkali.

Allotrope A physical form of an element where the atoms are arranged differently.

Alloy A substance made by mixing two or more elements together, of which at least one is a metal.

Alpha particle A cluster of two protons and two neutrons emitted by some radioactive elements.

Ammonite A type of shellfish that died out millions of years ago.

Anesthetic A substance given to patients to stop them from feeling pain.

Antiseptic A substance that kills different disease-causing germs.

Artificial element An element produced in a laboratory.

Atmosphere Layers of gases around a body in space.

Atom The smallest unit of an element that contains protons, neutrons, and electrons.

Atomic mass The total number of protons and neutrons in an atom of an element.

Atomic number The number of protons in an atom of an element.

Beta particle An electron given off by an atom during radioactivity.

Boiling point The temperature at which a liquid turns into a gas.

Bond The attraction between atoms that holds them together in an element or a compound.

Brass An alloy of copper and zinc.

Brittle The property of a hard, inflexible solid that makes it break into pieces when hit.

Bronze An alloy of copper and tin.

Cellulose A substance containing carbon that is found in all plants, especially in wood.

Chemistry The scientific study of the properties and reactions of elements.

Combustion A reaction involving oxygen that produces fire and heat.

Compound A substance made of the atoms of two or more elements.

Conductor A substance that lets electricity and heat pass through it.

Corrosion A reaction that attacks a solid object, mostly made of a metal, and weakens it.

Decay The process of radioactive atoms breaking apart.

Electrolysis A process that uses electricity to split a compound into its elements.

Electron A negatively charged particle moving in a shell around the nucleus of an atom.

Electron shell One of the layers surrounding an atom's nucleus that contains electrons.

Element A substance that cannot be broken down any further into simpler ingredients.

Evaporation The process in which a liquid turns to gas at a temperature below its boiling point.

Extraction The process of separating a substance from its source.

Fossils The remains of ancient life forms found in rocks.

Fuel cell A device that generates electricity using a chemical reaction.

Fuel rod A supply of nuclear fuel used to make electricity in a nuclear reactor.

Gamma ray A very high-energy form of radiation released from radioactive atoms.

Halogen Means "salt former." A reactive element that forms salts on reacting with metals.

Isotope A form of an element where the atoms have a different number of neutrons.

Melting point The temperature at which a solid turns into a liquid.

Metal A type of element that is often a hard, shiny solid.

Microchip A piece of silicon with electronic computer circuits.

Microscope A device used to see objects that are too small to be seen by the eye.

Mineral A naturally forming solid substance.

Mixture The result of two or more substances physically mixed together.

Molecule A collection of atoms joined together by sharing their electrons.

Nebula A cloud of gas and dust in space.

Neon light A colored lamp made by passing electricity through neon mixed with other gases in a glass tube.

Neutron A particle with no electric charge, found in the nucleus of an atom.

Noble gas A gas that does not react with any other element.

Nonmetal A solid, liquid, or gaseous element that is not a metal or semi-metal.

Nuclear fission A process in which an atom's nucleus splits in two, releasing a huge amount of energy.

Nuclear reaction A reaction that involves the atomic nucleus of an element.

Nuclear reactor A machine in which controlled nuclear reactions take place.

Nucleus The core of an atom that contains the protons and neutrons.

Ore A mineral that contains a useful element such as a metal.

Organism The scientific term for a life form.

Oxide A compound made of oxygen and another element.

Particle accelerator A machine that makes atoms or subatomic particles travel at high speeds so they can be collided with a target, or be smashed together. A cyclotron is a type of particle accelerator.

Physicist A scientist who studies physics—the field of science concerned with motion, energy, and forces.

Proton A positively charged particle in the nucleus of an atom.

Radioactivity The process in which an atom breaks apart, releasing particles and energy.

Room temperature 68°F (20°C).

Rust A type of corrosion produced when iron reacts with water and oxygen in the air.

Salt A chemical formed when an acid reacts with a metal, an alkali, or a similar substance.

Satellite A body like the moon or a spacecraft that orbits Earth or another body in space.

Semiconductor A substance that can either conduct electricity or block it.

Semi-metal A substance with features of both metals and nonmetals.

Smelting A process used to extract metals from their ores.

Subatomic particle A particle that is smaller than an atom. Protons, electrons, and neutrons are subatomic particles.

Superheavy element An artificial element that has a very high number of protons.

Supernova An explosion that occurs when a giant star dies.

Turbine A machine that converts a flow of gas or liquid into rotational motion.

Ultraviolet An invisible form of light emitted by the sun.

X-ray An invisible form of radiation.

Index

DEF

GHI

JKL

M

NO

PQR

Acknowledgments

Dorling Kindersley would like to thank: Bharti Bedi, Upmanyu Das, Sukriti Kapoor, Sai Prasanna, and Shambhavi Thatte for editorial assistance; Sifat Fatima and Baibhav Parida for design assistance; Nimesh Agrawal, Geetika Bhandari, and Debjyoti Mukherjee for picture research; Harish Aggarwal, Emma Dawson, Priyanka Sharma, and Saloni Talwar for the jacket; Elizabeth Wise for indexing; and Caroline Stamps for proofreading.

The publisher would like to thank the following for their kind permission to reproduce their photographs:

(Key: a-above; b-below/bottom; c-center; f-far; l-left; r-right; t-top, column:row on cover)

123RF.com: alexlmx 144cla, destinacigdem 97ca (Racket), Hapelena 44clb, hxdbzxy 135ca, Tomasz Trybus / irontrybe 4fcrb, Nataliia Kravchu 4crb, Oksana Tkachuk / ksena32 35ca, Viktor Makhnov 56ca (Silver Nitrate), Nik Merkulov 123cl, mipan 125cra, Roman Samokhin 97ca (Can), scanrail 103cl, Vira Dobosh / virynja 109ca; **Alamy Stock Photo:** Archive Pics 66cla, Granger Historical Picture Archive 91br, Heritage Image Partnership Ltd 48–49, Historic Images 13br, Keystone Press 89, Randsc 65br, 83b, Science History Images 88, 90cra, Mieczyslaw Wieliczko 67br, Maksym Yemelyanov 135cra, Zoonar / Christian Wei├ƒ 68, ZUMA / John Rowland / Southcreek Global 110; **Dorling Kindersley:** Bradbury Science Museum, Los Alamos 87ca (Bomb), Durham University Oriental Museum 109ca (Tomb), Oxford University Museum of Natural History 61bc, 123cra, RGB Research Limited 5cl, 5c, 5cr, 6cra, 6cl, 6cr, 12c, 12crb, 19cr, 22cl, 22cr, 22bl, 25bl, 25br, 28bl, 28–29, 32cr, 34cra, 34b, 35clb, 36–37c, 37br, 42bl, 43cr, 44–45c, 45cra, 46, 47clb, 51cra, 51clb, 52cla, 52br, 53ca, 54cra, 54clb, 57b, 59br, 64b, 72, 74cl, 74–75bc, 75cra, 75br, 76, 77cra, 78, 79cla, 79clb, 79br, 85c, 86cra, 86bl, 87br, 95cl, 96c, 98, 99br, 104bc, 108cla, 108br, 114c, 118, 119cr, 124, 128, 129cra, 135crb, 136, 137, 143cra, 143clb, 144cr, 144clb, 145, The Natural History Museum, London 35br, 56b, 60, 99cl, 104cr, The Rolls Royce Heritage Trust 92, The Science Museum, London 10cla, Angela Coppola / University of Pennsylvania Museum of Archaeology and Anthropology 103cra, University of Pennsylvania Museum of Archaeology and Anthropology 61ca (Coin); **Dreamstime.com:** Konstantin Shaklein / 3dsculptor 18clb, Allexxanda 4cr, Thomas Barrat 122, Ilshat Bikmiev 141bl, James Blinn 109cra, Brahman444 73ca, Dave Bredeson 33, Chin797 18cl, Kim Christensen 54crb, Chris Curtis 47ca, Yinan Zhang / Cyoginan 142cra, Daniel127001 45crb, Sharon Day 59cr, Dqran96 41, Elena Elisseeva / Elenathewise 30, Farbled 53crb, Fireflyphoto 61ca, Gaurav Masand / Gauravmasand 56ca, Globo360gradi 134, Elena Gurdina 113, Habrda 119ca (Nail polish), Joyce Vincent / J0yce 25ca, Weerapat Kiatdumrong 114clb (Planting), Jason Kolenda 105cra, Georgios Kollidas 91bl, Viktoriya Kuzmenkova 112, Luis Leamus 35cra, Lifang1025 38, Louella38 40cr, Kevin M. Mccarthy 142ca, Marcel Clemens / Marcelclemens 12cl, Mikhail Markovskiy 90br, Markwaters 66br, Zdeněk Matyáš 61cra, Meinzahn 23, Mikhailsh 140bl, Ruslan Minakryn 47br, Minaret2010 40clb, Inga Myslovska 40cl, Nfransua 125ca, Nicku 67cr, Okea 133cra, Kirsty Pargeter 125ca (Tyre), Tomas Pavelka 116clb, Sean Pavone 138, Pixelrobot 103cb, Pniesen 120, Stepan Popov / Popov48 97cra, Svetlana Popova 95b, Rui Matos / Rolmat 73cra, Abdul Sami Haqqani / Shadow69 141cra, Daniel Poloha / Spiderment 132–133, Studio306 119ca, Bert Folsom / Treb999 119cra, Abel Tumik / Yamahavalerossi 114cla; **Fotolia:** apttone 11ca, efired 71tl, TimurD 114clb, Pavlo Vakhrushev 25cra; **Getty Images:** Hulton Archive / NASA / Gamma Liason 62–63, Moment / WanRu Chen 106–107, Oxford Scientific / Paul & Paveena Mckenzie 26–27, Science & Society Picture Library / SSPL 13cl, Stocktrek Images 87ca; **iStockphoto.com:** BestTravelPhotography 130, E+ / guenterguni 123b, E+ / RichLegg 100, Easyturn 71b, FooTToo 80, Joe_Potato 25cla, PytyCzech 102, RosetteJordaan 2, SergeyMihalenko 20, Reload_Studio 70clb; **Library of Congress, Washington, D.C.:** LC-DIG-ggbain-36570 65cl; **NASA:** 16, JPL 144cra, JPL-Caltech / SwRI / MSSS / Kevin M. Gill 142bl, NASA, ESA, and M. Livio, The Hubble Heritage Team and the Hubble 20th Anniversary Team (STScl) 18–19, NASA, ESA, G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; A. Loll et al.; T. Temim et al.; F. Seward et al.; VLA / NRAO / AUI / NSF; Chandra / CXC; Spitzer / JPL-Caltech; XMM-Newton / ESA; and Hubble / STSc 4bl; **Science Photo Library:** Patrick Landmann 82c; **Unsplash:** v2osk 126–127; **Wellcome Collection http://creativecommons.org/licenses/by/4.0/:** 140cr

Cover images: *Front:* **Dorling Kindersley:** Ruth Jenkinson / RGB Research Limited (1:1), (1:3), (1:4), (1:5), (2:1), (2:4), (2:5), (3:5), (4:1), (4:3), (4:4), (4:5); **Dreamstime.com:** Scanrail c; **Fotolia:** apttone (1:2); *Spine*: **Dreamstime.com:** Scanrail

For further information see:
www.dkimages.com