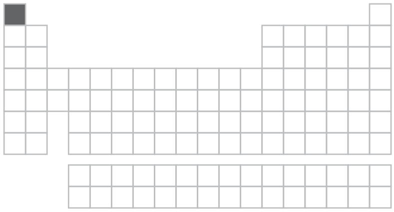


1

H

Hydrogen

1.008

HYDROGEN, H

ROCKET MAN

On *The Table* it sits at the top,

Test tube lit it explodes with a pop!

Most abundant by far,

Power'd rocket, now car?

Less its bonds water'd ne'er be a drop,

And DNA's double helix would flop!

On *The Table* it sits at the top,

THE FIRST ELEMENT OF THE PERIODIC TABLE

An *element* is a substance that cannot be broken down into simpler substances by ordinary chemical processes and is made of atoms of only one type. Elements are the fundamental materials of which all matter is composed.

Hydrogen is the simplest of all the elements in that its atoms consist of just one proton and one electron. It sits proudly atop the periodic table as element number 1. It was also the first element created during the Big Bang at the beginning of time.

Hydrogen gas was known long before it was recognized as an element. As far back as the 1500s, the Swiss alchemist Paracelsus (1493–1541) observed that bubbles of a flammable gas were produced when he added very fine pieces of iron (known as *filings*) to sulfuric acid (H_2SO_4). The Irish scientist Robert Boyle (1627–1691) spotted the same thing in 1671 when he dissolved iron filings in dilute hydrochloric acid (HCl); he called the gas a "factitious air." It wasn't until 1766 that hydrogen was recognized as an element, by the eccentric yet brilliant English chemist Henry Cavendish (1731–1810).

Test tube lit it explodes with a pop!

Hydrogen, as the diatomic molecule H_2, is the lightest of all gases. The time-honored laboratory test for detecting its presence is to light it in a test tube, at which point it burns so rapidly that it explodes with a satisfying, telltale "pop."

Most abundant by far,

Hydrogen is by far the most abundant element in the universe, making up approximately three quarters of the universe's mass. It's also the element that fuels our sun: every second roughly 600 million metric tons of hydrogen are converted to helium, accompanied (crucially for us!) by the conversion of around 5 million metric tons of matter to life-sustaining energy.

Power'd rocket, now car?

When compressed as a liquid and then reacted with liquid oxygen (O_2), hydrogen makes an effective rocket fuel.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{Energy}$$

A space shuttle consumes 1,500,000 L of liquid hydrogen and 500,000 L of liquid oxygen during takeoff.

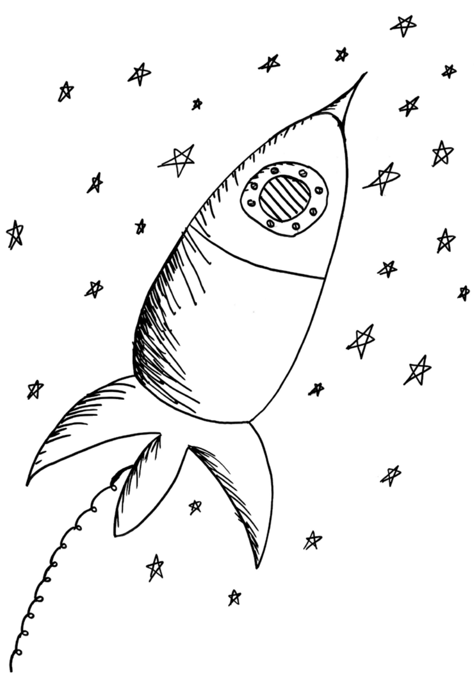
Meanwhile, back on terra firma, researchers are trying to improve the performance of electrochemical fuel cells for general use in pollution-free, hydrogen-powered vehicles (see "Platinum, Pt" on page 226 for more information on this topic). These researchers will need to overcome technological challenges in terms of fuel cell efficiency and cost, as well as the distribution and storage of hydrogen gas. Only then can hydrogen truly be considered a viable alternative to hydrocarbon fossil fuels, such as gasoline and diesel in everyday cars.

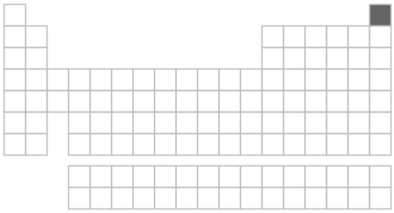
Less its bonds water'd ne'er be a drop,

And DNA's double helix would flop!

A molecule of water (H_2O) consists of two atoms of hydrogen chemically bonded to one atom of oxygen. The hydrogen atoms of one water molecule can also bond to the oxygen atom of another water molecule via a *hydrogen bond*. Hydrogen bonds are relatively weak at room temperature, meaning they're forever being broken and made between different water molecules. Yet they're so numerous they ensure that a collection of water molecules at room temperature will take a liquid rather than a gaseous form, as you'd otherwise expect for such small, light molecules. In a way, hydrogen bonds provide the essential glue that allows water to act as our planet's life-sustaining liquid.

Hydrogen bonds play another life-defining role by maintaining the elegant *double helix* 3D structure of DNA; in this way, they help to orchestrate the genetic code within each of our body's cells.





2

He

Helium

4.0026

HELIUM, He

BALLOON BOY

This super-cool element's a true Big Bang article,

It's high pitch'd and noble, so inertly hierarchical;

Is becoming more rare,

Still balloons fill the air,

Just avoid its dense core, alpha particle!

This super-cool element's a true Big Bang article,

THE FIRST MEMBER OF THE GROUP 18 NOBLE GASES

Helium was one of the three fundamental elements formed during the Big Bang; the other two were hydrogen and lithium. Helium has an ultra-low boiling point of –269°C, making liquid helium an effective super coolant. This super coolant is necessary for superconductors to produce the powerful magnetic fields needed for specialist equipment, such as the MRI scanners hospitals use.

It's high pitch'd and noble, so inertly hierarchical;

In hierarchical terms, helium sits at the very top of the group of noble gases (group 18) on the periodic table. It's a lighter-than-air and chemically unreactive (known as *inert*) gas. These traits made it perfect for inflating airships and an ideal replacement for the flammable hydrogen that was used previously. When inhaled, helium makes your voice high pitched and squeaky because the speed of sound in helium is three times faster than it is in air.

Is becoming more rare,

Still balloons fill the air,

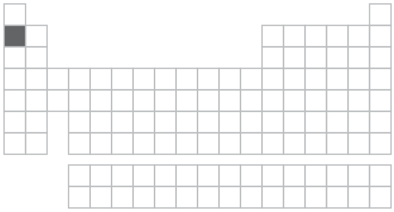
Helium is the second most abundant element in the universe, accounting for approximately one quarter of its mass. But it's only the 71st most abundant element in Earth's crust, where it forms during the radioactive decay of uranium and thorium and is then extracted along with natural gas. Invariably, the demand for helium (including its use in buoyant party balloons!) exceeds supply, and global reserves of the element are currently decreasing.

Just avoid its dense core, alpha particle!

When atoms of some large, unstable elements, such as uranium, thorium, radon, and polonium, undergo radioactive decay, they break up into fragments. One such fragment is a small particle with a dense core that contains just two protons and two neutrons. Known as an *alpha particle*, it's essentially a helium atom without its two electrons; in other words, an alpha particle is simply a helium nucleus (He^{2+}). Alpha particles are highly reactive and will whizz through the air in search of the pair of electrons ($2e^-$) they need to become neutral helium atoms.

$$He^{2+} + 2e^- \rightarrow He$$

Outside the body, these tiny reactive particles pose little threat; yet if they somehow manage to get inside your body, they can cause big trouble! To see just how much trouble, flip forward to "Polonium, Po" on page 244 and read about the case of Alexander Litvinenko.



3
Li
Lithium
6.94

LITHIUM, Li

THE MINI POWER PACK

Li, small and light, the soft metal with mettle!

Keeps much of our mobile-power'd world in good fettle;

In the sea and the soil,

Floats on water and oil,

Has often helped many's the troubled mind settle.

Li, small and light, the soft metal with mettle!

THE FIRST MEMBER OF THE GROUP 1 ALKALI METALS
[*mettle*: noun—*vigor, stamina; strength of spirit or temperament*]

Lithium is the soft, silvery-white metal at the top of the alkali metals in group 1 of the periodic table. It's the smallest of the alkali metals and the lightest of all metals. Lithium is one of only three elements (and the only metal) that can trace its roots back to the Big Bang; the other two are the gaseous elements hydrogen and helium. For much of its existence, lithium has been overlooked in terms of practical applications. But in more recent times the element has assumed a far more prominent role in our everyday lives (see the next line of the poem).

Keeps much of our mobile-power'd world in good fettle;

[*fettle*: noun—*condition; physical state*]

Lithium-ion batteries are so compact and light they've become the power source for most rechargeable, lightweight, mobile electronic devices, such as phones, MP3 players, laptops, notebooks, and tablets. Lithium ion batteries can also store significant amounts of energy from solar and wind power, opening new possibilities for fossil fuel–free energy. For this reason, John B. Goodenough, M. Stanley Whittingham, and Akira Yoshino received the 2019 Nobel Prize in Chemistry for the development of lithium-ion batteries.

In the sea and the soil,

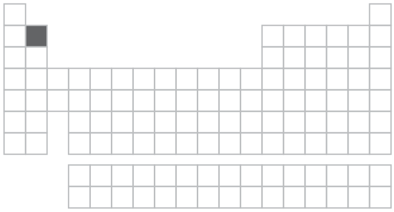
Lithium is the 31st most abundant element in Earth's crust. It's found at approximately 40 parts per million (ppm) in soil and 0.17 ppm in seawater.

Floats on water and oil,

Because lithium metal is so light, it floats on water. In fact, it reacts vigorously with water, whizzing about frantically and shrinking as it produces hydrogen gas (H_2), which sometimes ignites due to the heat liberated during the reaction. It also floats on oil, meaning that it must be coated in Vaseline (petroleum jelly) to be stored safely and protected from contact with water and oxygen!

Has often helped many's the troubled mind settle.

When taken in tablet form as lithium carbonate (Li_2CO_3), the tiny lithium ion (Li^+) is a powerfully effective mood stabilizer for those with bipolar disorder.



4

Be

Beryllium

9.0122

BERYLLIUM, Be

GEMS ’N’ SPRINGS

The neutrons of beryllium were the first that e’er were “seen,”

It sparkles so in crystal gems bedecked in em’rald green,

Its alloys help coil’d springs to make,

And spark-proof tools for safety’s sake.

Yet oh so toxic to the lungs, as dust or fumes I mean!

The neutrons of beryllium were the first that e'er were "seen,"

THE FIRST MEMBER OF THE GROUP 2 ALKALINE EARTH METALS

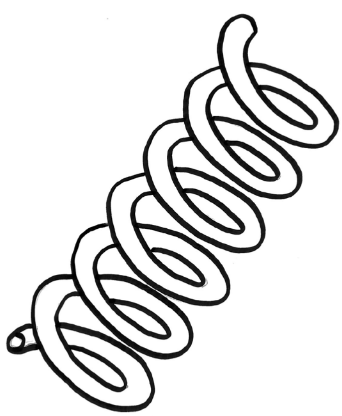
Beryllium is a silvery-white, lustrous metal that heads up the alkaline earth metals in group 2 of the periodic table. This element played a central role in the discovery of the neutron: when English physicist James Chadwick (1891–1974) bombarded a sample of beryllium with alpha particles (nuclei of helium) in 1932, the metal responded by emitting some previously unobserved particles. Chadwick noted that these particles were electrically neutral and possessed about the same mass as the proton. From this, he correctly deduced the existence of a new subatomic particle, the neutron. In a way, beryllium's neutrons were the first ever to be observed, and Chadwick's fundamental discovery in the nuclear science domain earned him the 1935 Nobel Prize in Physics.

It sparkles so in crystal gems bedecked in em'rald green,

Emeralds are crystals of *beryl*, a mineral composed of beryllium aluminum silicate, $Be_3Al_2(SiO_3)_6$. Small amounts of either chromium or vanadium within an emerald's crystal structure give these desirable gemstones their glamorous green color.

Its alloys help coil'd springs to make,

Beryllium displays notable strength for a relatively soft, light metal. When alloyed with copper and nickel, it's also exceptionally elastic, making these alloys ideal for producing springs, in particular those that drive the mechanical movements of wind up watches.

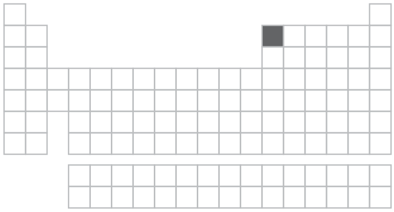


And spark-proof tools for safety's sake.

A property of beryllium-copper alloys is that they don't spark on impact, either during metal to metal impact or when dropped on the ground or on other hard surfaces. This makes them perfect for making spanners, wrenches, and other hand tools used in situations where *impact sparks* could ignite any explosive atmospheres (atmospheres containing flammable gases, vapors, or dusts) that might occur in chemical plants and oil refineries.

Yet oh so toxic to the lungs, as dust or fumes I mean!

Inhaling beryllium compounds as dust or fumes can result in berylliosis, a chronic inflammation of the lungs that produces shortness of breath. Whether the exposure is short lived at higher concentrations or prolonged at lower concentrations, the disease can take up to five years to develop and is fatal in approximately one third of all cases. Those who survive suffer permanent impairment of their lung function.



5
B
Boron
10.81

BORON, B

SUDS ’N’ STUFF

The compounds of this metalloid burn with a soft green flame,

All hail to borosilicate, its heat-stable claim to fame.

Its nitride’s hard and oh so rough,

While borax whips up suds ’n’ stuff,

Its acid’s gentle on the eyes, yet insects fear its name!

The compounds of this metalloid burn with a soft green flame,

GROUP 13 METALLOID

Boron is at the top of group 13 on the periodic table, at the start of a boundary line that descends diagonally toward the right of the periodic table. The vast swathe of elements on the left of this line are metals, while those in the comparatively meager cohort on the right are non-metals. Boron is endowed with metallic and non-metallic properties and is thus classified as a *metalloid*. Interestingly, many of boron's compounds burn with a telltale soft green flame.

All hail to borosilicate, its heat-stable claim to fame.

Pouring boiling water into a normal glass beaker made from silica (silicon dioxide, SiO_2) causes the beaker to shatter because the glass on the inside expands faster than the glass on the outside. But adding 12 to 15 percent boric oxide (B_2O_3) to the silica during the manufacturing process allows the glassware to expand at the same rate throughout when heated rapidly. Therefore, the threat of thermal shock is greatly reduced, making this borosilicate glass—better known as Pyrex® glass—the glassware of choice in laboratories the world over.

Its nitride's hard and oh so rough,

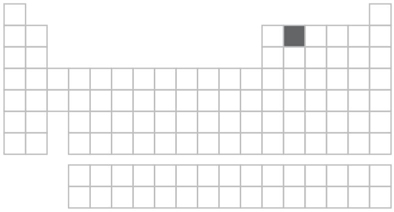
When combined with nitrogen, boron forms a lustrous, crystalline solid almost as hard as diamond. This, coupled with its excellent heat-resistant properties, makes boron nitride (BN) a popular industrial abrasive.

While borax whips up suds 'n' stuff,

Borax—sodium (tetra)borate, $Na_2B_4O_7 \cdot 10H_2O$—can be used as a laundry aid because it helps *soften* the water by tying up calcium ions (Ca^{2+}), thus making it easier to whip up more suds! It also stabilizes (or *buffers*) the water's pH, helping to promote the chemical reactions involved in cleaning.

Its acid's gentle on the eyes, yet insects fear its name!

Boric acid (H_3BO_3) is a weak acid, so much so that it's used as a mild antiseptic and even as an over-the-counter eyewash. Despite being fairly safe for mammals, boric acid is toxic to insects. This makes it quite useful as an insecticide, particularly against cockroaches and ants.



6

C

Carbon

12.011

CARBON, C

THIS "VITAL FORCE" OF LIFE

From CO_2 to CHOs and back to CO_2,

And so this "vital force" of life transfers from me to you.

Its PET scans pinpoint cancers,

While its "dating" undoes chancers.

Bond-friendly with its neighbors so, each day brings compounds new.

To carbon our world's fate is bound through gas and oil and coal,

Organic to our way of life, our true synthetic soul.

From nanotubes and fullerene,

To diamonds, graphite, thin graphene,

This rhyme's too short by far for all its virtues to extol.

see-oh-two see-aytch-ohs see-oh-two

From CO_2 to CHOs and back to CO_2,

And so this "vital force" of life transfers from me to you.

GROUP 14 NON-METAL

Photosynthesis is the process whereby plants harness the sun's energy to drive the reaction between water (H_2O) and atmospheric carbon dioxide gas (CO_2), producing breathable oxygen (O_2) and edible *carbohydrates*—chemical compounds made up of carbon (C), hydrogen (H), and oxygen (O). These CHOs are the primary source of energy for your body's cells, where they react with O_2 from the air you inhale.

$$\text{CHOs} + O_2 \rightarrow CO_2 + H_2O + \text{Energy}$$

You exhale the CO_2 and H_2O vapor, which are waste products, thus returning the CO_2 to the atmosphere. The CO_2 is then taken up again by plants to make more CHOs for someone else to eat, and the *carbon cycle* begins all over again.

In 1828, the German chemist Friedrich Wöhler (1800–1882) successfully synthesized urea (NH_2CONH_2) in his laboratory. This marked the first time that an otherwise naturally occurring, or *organic*, chemical had been artificially created without involving living organisms. Naturally occurring urea is a by-product of protein metabolism in the body and is excreted in urine. Until then, the so-called *vital force theory* had held that such organic chemicals could only be produced by living organisms with the aid of some mysterious vital force within them. Wohler's synthesis of urea sounded the death knell for this vital force theory and heralded the birth of organic chemistry, the chemistry of carbon.

pet, as in "a pet dog"

Its PET scans pinpoint cancers,

Positron emission tomography (PET) is a nuclear magnetic imaging technique that identifies the location of cancer cells in the body. In one application of the technique, a small amount of the vitamin *choline*, doped with radioactive carbon-11 isotope, is injected into a vein. Cancer cells take up this radioactively labeled choline more readily than normal cells and can be detected with a PET scan.

While its "dating" undoes chancers.

[*chancers*: noun, plural (slang)—*a confidence trickster, "con man," or rogue*]

The *carbon dating* process measures quantities of carbon-14 to find out the approximate age of some types of archaeological artifacts. Carbon-14 is a radioactive isotope of carbon that forms in minute amounts when nitrogen in the upper atmosphere is bombarded by cosmic rays. It then makes its way (via atmospheric CO_2) into the structures of all living trees and plants during photosynthesis, accumulating to extremely low yet detectable levels.

Once dead, the tree or plant no longer incorporates any "fresh" carbon-14. The remaining carbon-14 gradually decays radioactively with a half-life of 5,730 years. So, you can estimate the age of an item by measuring how much carbon-14 it still contains. To carbon-date an ancient artifact, such as a wooden-handled knife, you'd first measure the residual amount of carbon-14 within the wooden handle. Then, by comparing this result with the amount of the isotope that would have been present if the wood were still attached to a living tree, you can estimate how long it's been since the piece of wood was cut from the tree to make the handle.

Bond-friendly with its neighbors so, each day brings compounds new.

Carbon's position at the top of group 14 of the periodic table makes it a particularly versatile element. It is capable of forming bonds not only with other carbon atoms but also with atoms of many other elements, such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, and the halogens.

To carbon our world's fate is bound through gas and oil and coal,

Organic to our way of life, our true synthetic soul.

From plastics to medicines (not to mention fuels and energy), today's world relies heavily on the synthetic organic chemistry of carbon. That reliance is destined to be challenged in the years ahead as the planet's finite reserves of carbon-based fossil fuels become ever scarcer.

From nanotubes and fullerene,

To diamonds, graphite, thin graphene,

Depending on how its individual atoms are bonded, carbon can adopt different physical forms (known as *allotropes*). For example, diamond consists of a rigid, semi-infinite, 3D array of carbon atoms; each atom is bonded to four others in a tetrahedral arrangement. In graphene, each carbon atom is bonded to three others in a hexagonal, 2D, semi-infinite, single layer. You can stack multiple sheets of graphene on top of each other to produce graphite, the "lead" you find in pencils (see "Molybdenum, Mo" on page 123 for more about pencil lead). Or you can roll the sheets into cylinders to make nanotubes, which are a type of fullerene. Alternatively, 60 carbon atoms shaped as a hollow spherical shape (so the hexagonal bonding pattern resembles the stitching on a soccer ball) makes buckminsterfullerene, C_{60}, the poster child of the fullerenes!

This rhyme's too short by far for all its virtues to extol.

This line speaks for itself!