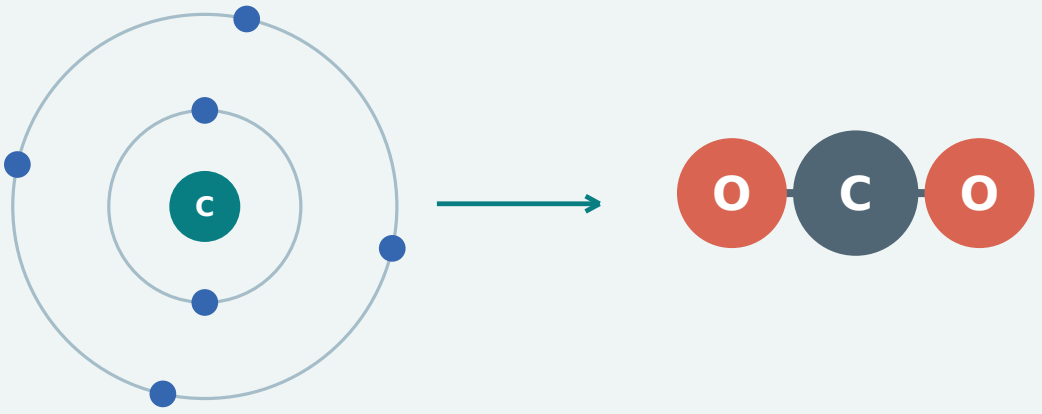
Basic Chemistry

Small particles.
Big explanations for the world around you.



UNDERSTAND ATOMS

EXPLAIN CHANGE

Why does ice melt? What is inside an atom? Why does every element have its own place in the periodic table? This book connects the drawings from your chemistry class to ideas you can explain in your own words.

Read one topic at a time. Follow the labels in each sketch, then try the quick check. The drawings are models: their colors, sizes and spacing help explain ideas, but they are not photographs of particles.

YOUR ROUTE THROUGH THE BOOK

02-08 Matter, atoms and bonds

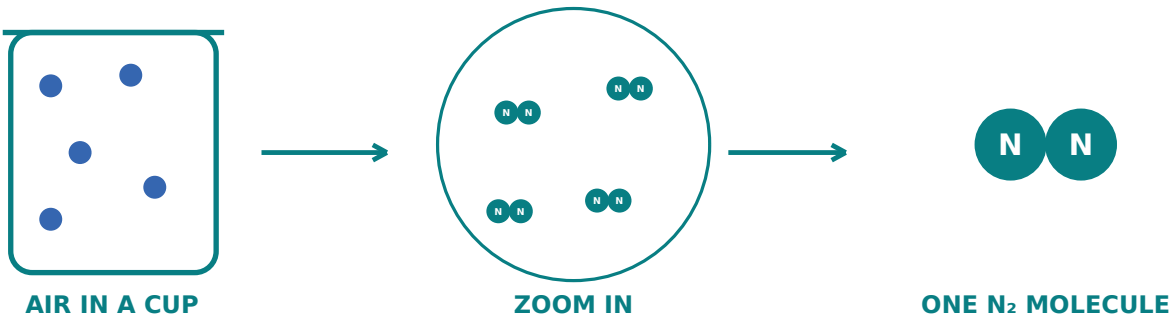
09-12 States, energy and change

13-14 The periodic table

15-16 Practice and answers

What is everything made of?

The big idea: ordinary matter is made of particles that are far too small to see.



Matter is anything that has mass and takes up space. Your desk, your skin, water and the air around you are all matter. Air is easy to miss because you usually cannot see it. Blow air into a balloon, though, and it pushes the balloon outward. The air takes up space.

Mass and volume answer different questions

Mass tells us how much matter something contains. We often measure it in grams or kilograms. **Volume** tells us how much space it takes up. We can measure volume in milliliters, liters or cubic centimeters. A large empty box can have more volume but less mass than a small stone.

Imagine zooming in again and again

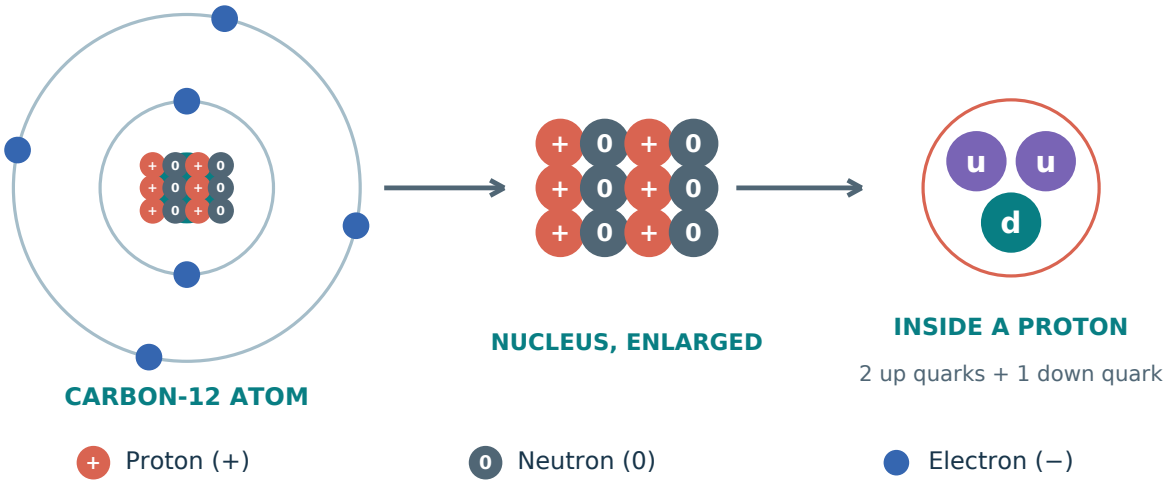
A grain of salt looks tiny, but it contains an enormous number of particles. Ordinary materials are built from **atoms**. Atoms can join into groups called **molecules**, or arrange themselves in much larger repeating structures. In this book, “particle” is a useful general word for the tiny units we are discussing.

Chemistry studies what matter is made of, what it is like and how it changes. Melting chocolate, rusting metal and cooking food all raise chemistry questions. Light and sound are different: they carry energy, but they are not ordinary matter made of atoms.

QUICK CHECK An inflated balloon takes up more space than a flat one. What has been added? **Air: matter made of tiny particles.**

Inside an atom

Three small particles explain an enormous amount of chemistry.



An **atom** is the smallest unit that identifies a chemical element. At its center is a tiny, dense **nucleus**. The nucleus contains positively charged **protons** and, in most atoms, uncharged **neutrons**. Negatively charged **electrons** occupy the space around it. The most common hydrogen atom is an exception: its nucleus has one proton and no neutron.

What does “charge” mean?

Electric charge affects how particles push or pull on one another. Opposite charges attract; matching charges repel. A proton and an electron have equal amounts of charge with opposite signs. If an atom has six protons and six electrons, their charges balance. The atom is **neutral**, meaning its total charge is zero.

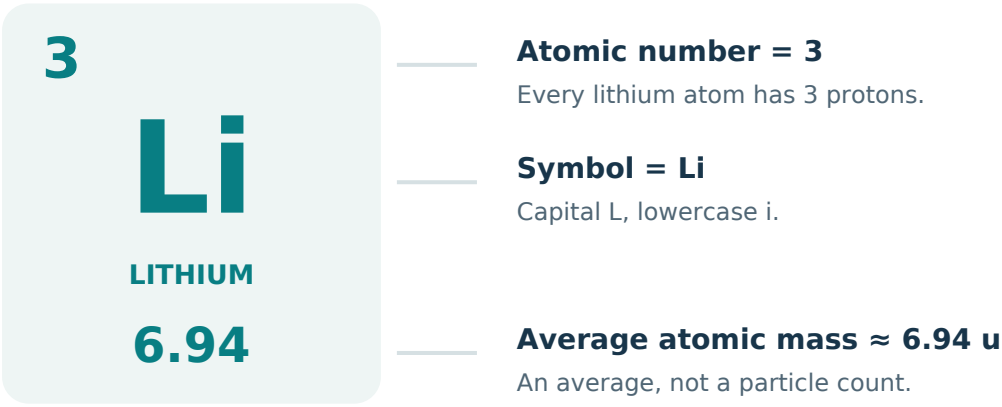
Protons and neutrons have similar masses. An electron has much less mass, so nearly all an atom’s mass is packed into its nucleus. Yet the nucleus occupies only a tiny fraction of the atom’s size. We enlarge it in drawings so you can see what is inside.

One step deeper: protons and neutrons contain smaller particles called quarks. A proton contains two “up” quarks and one “down” quark; a neutron contains one up and two down. Electrons are not made of quarks. For basic chemistry, focus on protons, neutrons and electrons.

DRAW IT Use six + circles and six 0 circles for a carbon-12 nucleus. Add six electron dots around it. The rings are a model, not real tracks.

An element has an identity

Change the number of protons and you change the element.



An **element** is a pure substance made of one kind of atom. The kind is decided by the number of protons in each atom’s nucleus. Every hydrogen atom has one proton. Every carbon atom has six. Every oxygen atom has eight. This proton count is called the **atomic number**.

Imagine that each element has an identity card. Its atomic number is the number that never changes while it remains that element. A carbon atom can gain an electron or have an extra neutron and still be carbon. If its proton count changes from six to seven, it becomes nitrogen. Ordinary chemical reactions do not change proton counts.

Read the symbols carefully

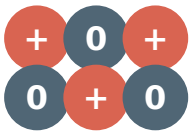
A chemical symbol is a short name used around the world. Some symbols have one letter, such as C for carbon. Others have two, such as Li for lithium. The first letter is uppercase and the second is lowercase. **Co** means cobalt, but **CO** is a formula containing carbon and oxygen. Letter size changes the meaning.

For a **neutral** atom, the electron count equals the proton count. Neutral lithium therefore has three protons and three electrons. The number 6.94 on its tile is different: it describes average atomic mass in atomic mass units, written **u**. It does not mean that a lithium atom has 6.94 particles. The next page explains the decimal.

QUICK CHECK An atom has eight protons and ten neutrons. What element is it? **Oxygen. The eight protons decide its identity.**

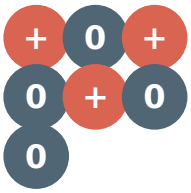
Same element, different mass

Protons decide the name. Neutrons can change the mass.



LITHIUM-6

3 protons + 3 neutrons



LITHIUM-7

3 protons + 4 neutrons

Atoms of the same element can have different numbers of neutrons. These versions are called **isotopes**. Lithium-6 and lithium-7 both contain three protons, so both are lithium. Lithium-6 has three neutrons; lithium-7 has four. Neutral atoms of either isotope have three electrons.

Mass number is a whole-number count

The **mass number** counts the protons and neutrons in one atom’s nucleus. For lithium-7, that is 3 + 4 = 7. Electrons are not included in this count. If you know the mass number and atomic number, you can find the neutron count by subtraction: **neutrons = mass number − atomic number**.

Why does the periodic table use decimals?

A sample of an element can contain a mixture of isotopes. Its average atomic mass depends on both the mass of each isotope and how common each one is. This is a **weighted average**: a more common isotope has more influence on the answer.

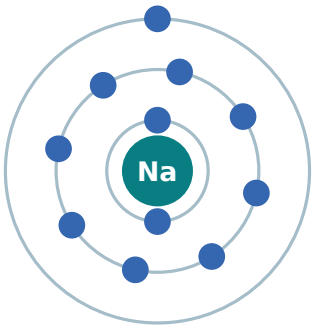
A SIMPLE NUMBER EXAMPLE Imagine ten atoms: nine have a mass of about 7 u and one has a mass of about 6 u. The average is **(9 × 7 + 1 × 6) ÷ 10 = 6.9 u**. No atom in this example has a mass of 6.9 u. This invented mixture explains averaging; it is not an exact natural lithium sample.

Actual isotope masses are measured, and they are not exactly equal to the whole-number mass numbers. This helps explain why real tables show values such as 6.94. Some isotopes are stable; others have nuclei that change over time, called radioactive decay. Being an isotope does not automatically mean being radioactive.

QUICK CHECK Carbon-14 has six protons. How many neutrons does it have? **14 − 6 = 8 neutrons.**

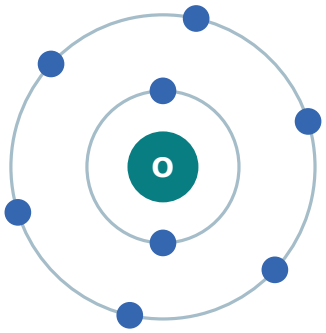
Where do electrons fit?

Simple shell drawings help us count electrons and predict behavior.



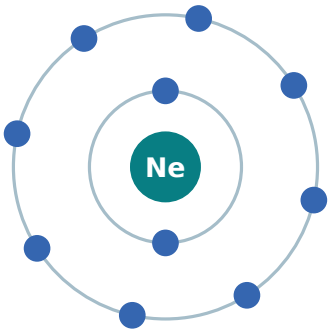
SODIUM

2, 8, 1



OXYGEN

2, 6



NEON

2, 8

Electrons do not travel around the nucleus like planets on tidy circular roads. Scientists describe regions where electrons are likely to be found. These regions belong to different **energy levels**. For a first explanation, we draw the levels as rings called **shells**. The rings help us organize information; they are not solid layers or exact paths.

Start near the center and count outward

The first shell can hold up to two electrons. The second can hold up to eight. Neutral sodium has eleven electrons, arranged 2, 8, 1 in this model. Oxygen has eight electrons, arranged 2, 6. Neon has ten, arranged 2, 8. Say each list from the innermost shell to the outermost.

For these examples, the electrons in the outermost occupied shell are called **valence electrons**. They play a major part in bonding. Sodium has one valence electron, oxygen has six and neon has eight. Neon’s full outer shell helps explain why it rarely reacts with other substances under ordinary conditions.

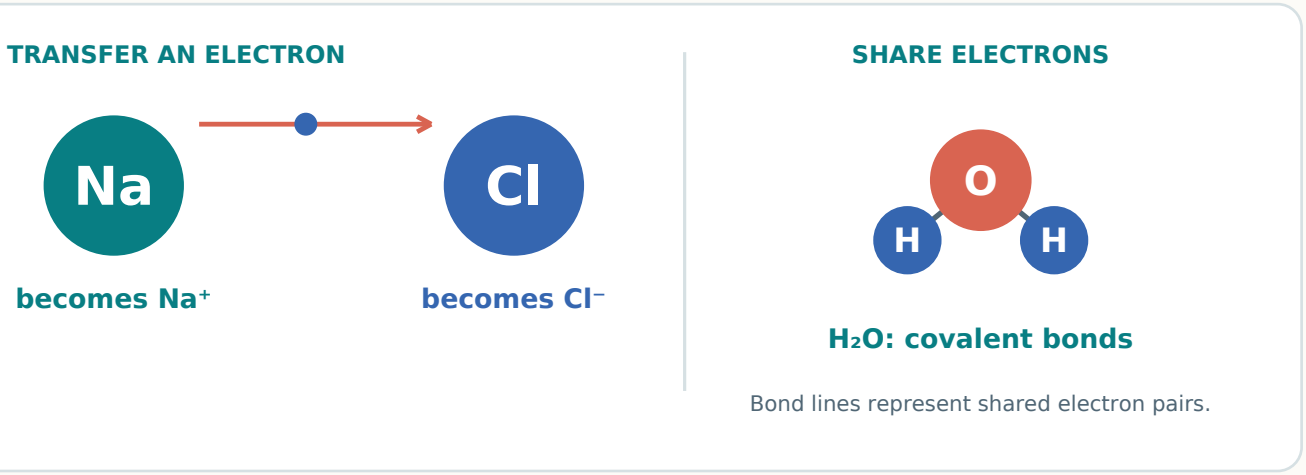
A useful rule, with limits

Many simple reactions form arrangements with filled outer shells. Atoms may lose, gain or share electrons in reaching a more stable arrangement. They do not think or “want” anything; this is a result of how electric forces and energy work. Shell filling becomes more complicated for larger atoms. The third shell can hold up to eighteen electrons, even though sodium has only one electron there.

QUICK CHECK Which sketch has six valence electrons? **Oxygen.** Count only its outer ring, not all eight electron dots.

How atoms connect

Electrons help explain both charged particles and chemical bonds.



An **ion** is an atom, or a bonded group of atoms, with an overall electric charge. Start with a neutral sodium atom: eleven positive protons balance eleven negative electrons. If it loses one electron, it still has eleven protons but only ten electrons. Its total charge is now +1. We write this sodium ion as **Na^+**.

A chlorine atom can gain one electron. It then has one more electron than proton, giving it a −1 charge. This is a chloride ion, written **Cl^-**. Losing a negative electron makes an atom more positive; gaining one makes it more negative. The nuclei do not change in these steps.

Two ways that bonds form

Ionic bonding: positive and negative ions attract one another. In sodium chloride, ordinary table salt, many Na^+ and Cl^- ions form a repeating crystal. They are not arranged as separate little NaCl molecules. The formula tells us that the crystal has one sodium ion for every chloride ion.

Covalent bonding: atoms share pairs of electrons. A water molecule contains an oxygen atom joined to two hydrogen atoms by covalent bonds. Sharing changes how electrons are arranged around the atoms. A bond is an electrical interaction, not a stick, even though we often draw bonds as lines.

QUICK CHECK A neutral atom gains two electrons. Is its ion positive or negative?
Negative, with a charge of −2. Its proton count stays the same.

Elements, compounds, mixtures

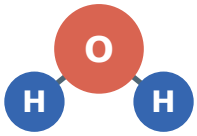
These words answer different questions. They are not interchangeable.

ELEMENT



O_2: one kind of atom

COMPOUND



H_2O: two kinds, bonded

MIXTURE



O_2 + N_2: mixed together

A **molecule** is a distinct group of two or more atoms joined by covalent bonds. The atoms can be the same element or different elements. Oxygen gas contains O_2 molecules: two oxygen atoms joined together. It is still an **element** because it contains only one kind of atom.

A **compound** is a pure substance in which two or more elements are chemically combined in a fixed ratio. Water is a compound. Each H_2O molecule has two hydrogen atoms and one oxygen atom. Sodium chloride is also a compound, but it has a repeating ionic structure instead of separate molecules. So not every compound is molecular.

Read a formula like a tiny set of instructions

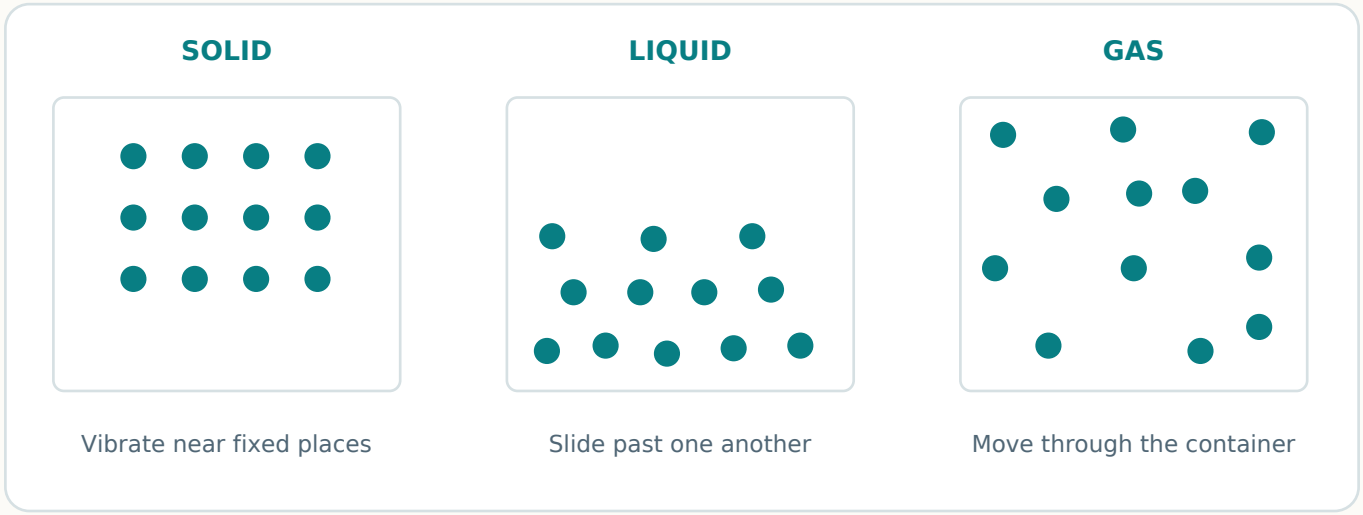
A small lowered number, called a **subscript**, tells you how many atoms of the preceding element occur in a molecule. CO_2 has one carbon atom and two oxygen atoms. If no subscript follows a symbol, the number is one. Changing a subscript can change the substance: H_2O is water; H_2O_2 is hydrogen peroxide.

A **mixture** contains substances together without a fixed chemical recipe between them. Air is a mixture, mainly nitrogen and oxygen gases. Salt water is another mixture. You can add more salt or more water and change its proportions. Mixtures can often be separated by physical methods; for example, water can evaporate from salt water and leave the salt behind.

QUICK CHECK Is O_2 a compound because it contains two atoms? **No.** Both atoms are oxygen. A compound must contain at least two different elements.

Particles are always moving

A material’s state depends on particle motion, attractions, temperature and pressure.



A stone may look completely still, but its particles are moving. In a **solid**, particles stay close together and vibrate around fairly fixed positions. Attractions between them help keep the material together. That is why a solid normally keeps its own shape and volume.

In a **liquid**, particles are also close together, but they can move past one another. Pour water from a cup into a bowl and its shape changes. Its volume stays almost the same. A liquid takes the shape of the part of its container that it occupies; it does not expand to fill every empty space.

In a **gas**, particles are usually much farther apart. They travel in different directions and collide with one another and the container walls. Those collisions produce **gas pressure**. A gas spreads out to fill its container, so it has no fixed shape or fixed volume. It is easier to squeeze a gas because there is lots of space between its particles.

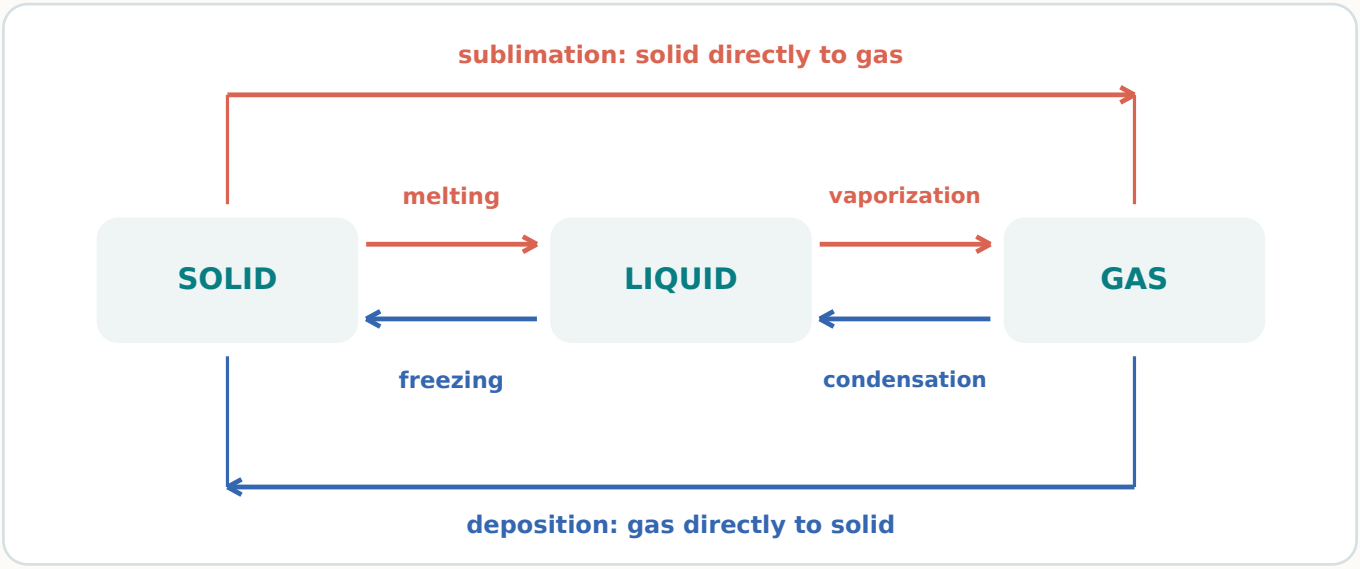
What changes when you heat something?

Heating usually increases the particles’ average energy of motion, called **kinetic energy**. Temperature is related to that average motion. Faster motion can help particles move against the attractions between them. The particles themselves do not simply grow larger. During a change of state, added energy can change their arrangement without raising the temperature.

MODEL NOTE Each box has twelve dots. They represent particles of the same substance. The real differences in spacing are much greater than these sketches can show.

Changing state, staying the same

Ice, liquid water and water vapor are all H_2O.



When ice absorbs enough energy, its molecules can move out of their fixed arrangement. The ice **melts**. When liquid water loses energy, molecules can settle into an ordered arrangement and it **freezes**. The water molecules stay water molecules. A change of state is a **physical change**, because it does not create a different substance.

Evaporation and boiling both make gas

Evaporation happens at a liquid's surface. Some molecules escape even when the liquid is not boiling, which is why a puddle can dry on a cool day. **Boiling** happens throughout a liquid when vapor bubbles can form inside it. Both are types of **vaporization**. Pure water boils at about 100°C at sea-level air pressure; its boiling point changes with pressure.

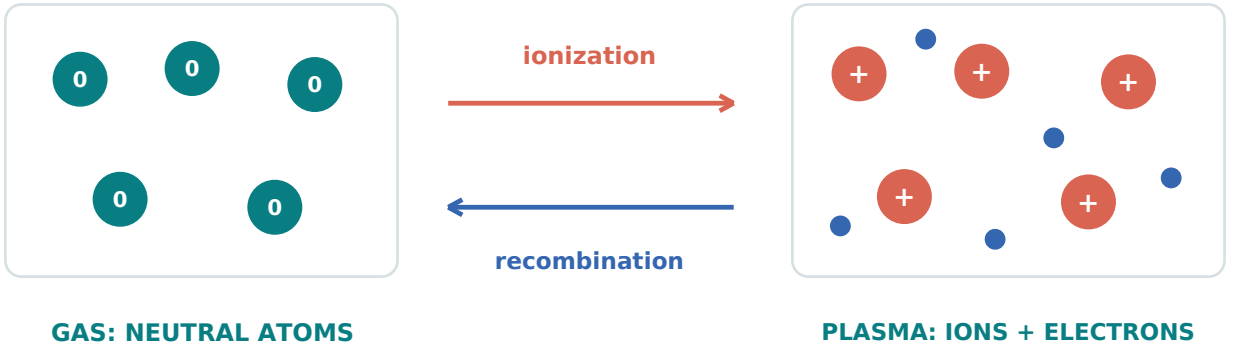
Condensation turns gas into liquid. Drops on the outside of a cold glass come from water vapor in the air. They did not pass through the glass! Invisible water vapor becomes tiny liquid droplets when it cools. The white cloud near a kettle is also mostly tiny droplets, not invisible gaseous water.

Sublimation skips the liquid stage: solid changes directly into gas. **Deposition** goes the other way; frost can form when water vapor becomes ice directly. Melting, vaporization and sublimation absorb energy. The reverse changes release energy to the surroundings.

A WATER SURPRISE Ice has a more open particle arrangement than liquid water. This makes it less dense, so it floats. Do not assume every solid packs more tightly than its liquid.

Meet the fourth state: plasma

Some electrons are free to move separately from atoms.



A gas can gain enough energy for some electrons to break away from atoms. An atom that loses electrons becomes a positive ion. The mixture of freely moving electrons and ions can form **plasma**. Some plasmas also contain many neutral atoms. In the sketch, each of five neutral atoms loses one electron; both electric charge and particle ingredients are accounted for.

Removing an electron from an atom is called **ionization**. When a free electron joins a positive ion again, the process is called **recombination**. These processes change the electron arrangement. They do not, by themselves, change the number of protons in the nucleus or turn one element into another.

Where can you find it?

The Sun and other stars contain plasma. Lightning produces a short-lived channel of plasma in the air. Electric signs can contain glowing plasma too. Because plasma contains charged particles that can move, it conducts electricity and responds strongly to electric and magnetic fields. A plasma can still have nearly equal positive and negative charge overall.

Very high temperatures can create plasma, but heating is not the only way. Electricity can supply energy to electrons in a gas. Not every glowing material is plasma, and an ordinary candle flame is mostly hot gas, with relatively few charged particles. For this class, remember the key difference: plasma contains freely moving electrons and ions.

CONNECT THE IDEAS Melting changes how particles are arranged. Ionization can remove electrons from atoms. Neither process needs to change the nuclei into a new element.

Atoms rearrange; matter remains

New substances can form without creating new atoms.



REACTANTS PRODUCT

1 carbon atom + 2 oxygen atoms on BOTH sides

In a **chemical reaction**, atoms are rearranged into new substances. The starting substances are called **reactants**; the substances made are **products**. Bonds may break and new bonds may form. This differs from melting ice, where H_2O molecules remain H_2O.

The sketch shows a particle-level summary of carbon reacting with oxygen to make carbon dioxide: **$C + O_2 \rightarrow CO_2$**. Count the atoms. There is one carbon and two oxygens before, and one carbon and two oxygens after. The drawing is a counting model, not an instruction to burn anything. In solid carbon, the carbon atoms belong to a larger structure.

Keep track of everything, including gases

In an ordinary chemical reaction, atoms are not created or destroyed. This leads to the **law of conservation of mass**: if no matter enters or leaves a system, its total mass stays the same. For example, if 12 g of carbon reacts completely with 32 g of oxygen to make only carbon dioxide, the product has a mass of 44 g.

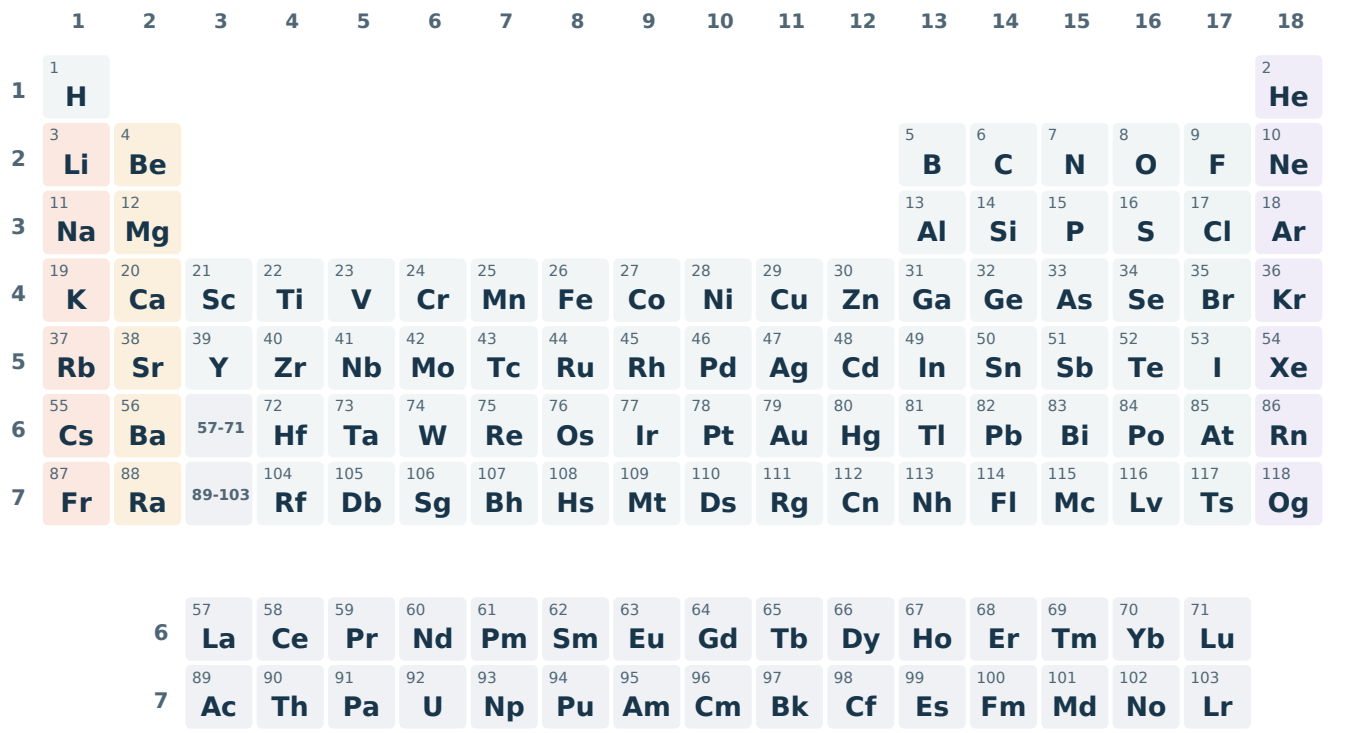
In an open container, gas can escape or enter. The mass you measure may then change because you have stopped measuring all the matter. If a reaction releases a gas, the material left in the cup can weigh less even though matter has not vanished.

Color change, a new solid, gas production or a temperature change can be clues to a reaction. A clue alone is not proof: boiling water makes bubbles without making a new substance. Ask what the evidence shows about the substances before and after.

QUICK CHECK Does a melted ice cube become a new substance? **No.** Its arrangement and state change, while its molecules remain water.

A map of all the elements

Read across the rows in order of atomic number.



Top labels: groups 1-18. Left labels: periods 1-7. Each tile shows atomic number + symbol.

The **periodic table** organizes elements by increasing atomic number. Find carbon, number 6, then nitrogen, number 7. Moving to the next element adds one proton to the identity of the atom. The chart is more than a list: its shape helps reveal repeating patterns in how elements behave.

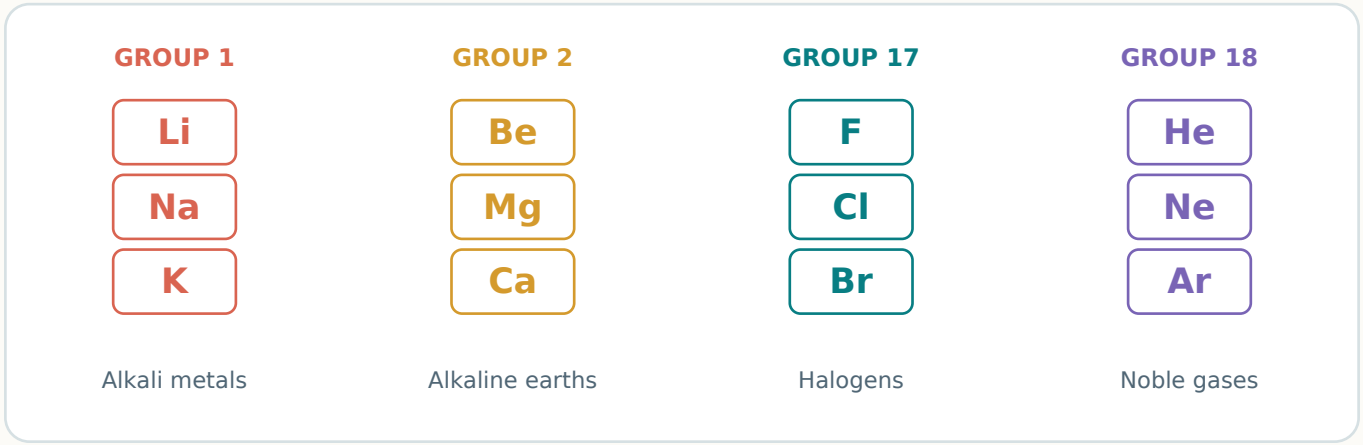
A horizontal row is called a **period**. A vertical column is called a **group**. The groups are numbered 1 to 18. Elements in a group often have similar chemical behavior. For many main-group elements, this connects to a similar arrangement of valence electrons.

The two rows drawn underneath belong inside periods 6 and 7. They are moved down to keep the table from becoming too wide. The number ranges show where they fit. These rows are often called the **lanthanides** and **actinides**. They are part of the same table, not extra elements outside it.

FIND IT Sodium, Na, is number 11: period 3, group 1. Oxygen, O, is number 8: period 2, group 16. Use the numbers at the edges to check both addresses.

Patterns make the table useful

An element’s position gives clues, but real chemistry also has exceptions.



Group 1: lithium, sodium and potassium are alkali metals. Each has one valence electron in the simple model and often forms a +1 ion by losing it. Hydrogen sits above them but is a nonmetal with its own behavior. It is not an alkali metal.

Group 2: magnesium and calcium are alkaline earth metals. They have two valence electrons and often form +2 ions. **Group 17:** fluorine and chlorine are halogens. They have seven valence electrons and often form −1 ions by gaining one electron.

Group 18: the noble gases, such as helium, neon and argon, have filled outer shells and usually react very little. Helium’s first and only shell is full with two electrons. Neon and argon each have eight electrons in their outer shell. “Full” does not always mean “eight.”

Metals, nonmetals and a boundary region

Most elements are metals, found mainly on the left and in the middle of the table. Metals usually conduct heat and electricity well, and many can be bent or shaped. Nonmetals lie mainly toward the upper right, with hydrogen on the left. Their properties vary: oxygen is a gas, while sulfur is a solid at room temperature.

Near the boundary are elements often called **metalloids**, including silicon. They have some metal-like and some nonmetal-like properties. Silicon is useful in electronic devices. The middle block contains many familiar transition metals, such as iron and copper. Their bonding patterns are more varied than the simple outer-shell rules above.

QUICK CHECK Why might sodium and potassium behave similarly? **They are in the same group and each has one valence electron.** This gives a clue, not a promise of identical behavior.

Think, sketch, investigate

Use the earlier pages when you need a clue. Explain your thinking as well as your answer.

Two simple observations

A / FOLLOW AN ICE CUBE Put an ice cube in a clear plastic cup and cover it loosely. Sketch it now and again after it melts at room temperature. What changed? What stayed the same? Describe the water particles before and after. If you have a balance, compare the mass of the whole covered setup before and after; small changes can come from water on the outside or measurement limits.

B / WHERE DID THE SALT GO? Stir half a teaspoon of table salt into half a cup of room-temperature water. The crystals may disappear from sight, but the salt has not vanished. Draw a particle model showing salt spread through the water. With adult permission, leave a small amount in an open dish for several days and observe what remains as water evaporates.

Use only the listed materials. Do not taste experiment materials. Wipe up spills, wash your hands and use a tray. These observations need no flame, hot plate or boiling water.

Eight questions to test your understanding

1. A neutral atom has 8 protons and 9 neutrons. Name the element and give its electron count and mass number.

2. What is the difference between an isotope and an ion?

3. A sodium atom loses one electron. What happens to its charge? Does it become a different element?

4. Classify each sample as an element, compound or mixture: pure O_2, pure H_2O and air.

5. Draw particle sketches for solid and gaseous water. What should stay the same in each water molecule?

6. Water droplets appear outside a cold glass. Name the change of state and explain where the water came from.

7. In a closed system, 10 g of reactants becomes 4 g of a solid and some gas. What mass of gas was made?

8. Find chlorine (Cl) on the table. Give its atomic number, period and group. Predict the charge of its common ion.

Stretch question: An element has two isotopes. Why can its table entry show a decimal average even though each nucleus contains a whole number of protons and neutrons?

Check your understanding

A strong answer connects what you observe to what the particles are doing.

Answers to page 15

1. Oxygen; 8 electrons; mass number 17. Eight protons fix its identity, and 8 + 9 = 17.

2. Isotopes of an element differ in neutron count. Ions have an overall electric charge because electrons and protons do not balance.

3. It becomes Na^{+}, with charge +1. It stays sodium because its 11 protons are unchanged.

4. O_2: element. H_2O: compound. Air: mixture. Two atoms do not automatically mean two elements.

5. Show H_2O groups close in the solid and far apart in the gas. Each group still has two H atoms and one O atom.

6. Condensation. Water vapor in the air cools and becomes liquid on the glass.

7. 6 g. The solid and gas together must have the original 10 g of mass.

8. Atomic number 17; period 3; group 17. Chlorine commonly gains one electron to form Cl^{-}.

Stretch. The table gives a weighted average of isotope masses. An average can be a decimal without describing a fraction of a particle.

What the observations show

Ice: the state and particle arrangement change; the substance stays water. **Salt:** sodium and chloride ions spread through the water. As water evaporates, ions can join into crystals again.

Keep these words handy

Matter: Has mass and takes up space.

Atom: The smallest unit identifying an element.

Nucleus: An atom’s center, containing protons and usually neutrons.

Element: A substance with one kind of atom.

Atomic number: The number of protons.

Isotope: A version of an element with a particular neutron count.

Ion: An atom or group with a net charge.

Molecule: A distinct group of covalently bonded atoms.

Compound: Different elements chemically combined in a fixed ratio.

Mixture: Substances together in variable amounts.

Valence electrons: Outer-shell electrons in the simple model used here.

Plasma: Matter containing free electrons and ions.

Conservation of mass: Total mass stays the same when no matter enters or leaves during an ordinary reaction.

About this book. Original explanations and redrawn teaching diagrams based on the five supplied photographs of class pages 8-15. Models are simplified and not to scale. The title and author of the photographed book were not visible.

Further learning and fact checks: American Chemical Society, Middle School Chemistry (matter, atoms and bonding); IUPAC, Periodic Table of Elements (symbols and layout); U.S. Department of Energy, DOE Explains...Plasma. Links checked 31 October 2026.