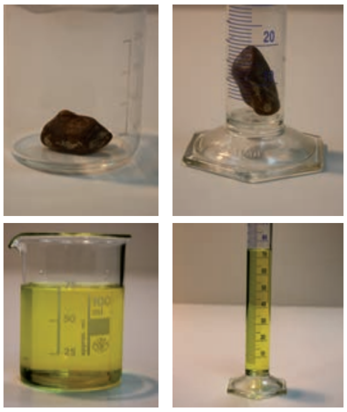
1 States of matter and their properties

As you already know, we understand **matter** to be everything that has mass and **takes up**[1] space. Matter can be visible to our eyes such as a stone, or invisible such as the air.

The ordinary matter that surrounds us can have three states:

- **Solid**, such as the desk you're sitting at.
- **Liquid**, such as the ink of the pen you're using.
- **Gaseous**, such as the air you're breathing.



Substances have different properties depending on what state of matter they're in. If you take a stone from one recipient and put it into another one, its shape and volume stay the same. **Solids don't change shape or volume.**

If we now transfer water from one recipient to another one with a different shape, the **liquid will change shape** to adapt to the shape of the new recipient, although its **volume will remain constant**.

Though it's not easy to appreciate, gases have mass in addition to occupying volume. The four recipients in this photo are full of air. Both the **volume and shape of the air inside them will depend on the recipient**.

Try these simple experiments:

- Try to squeeze a stone with your fingers. Can you **compress**[2] it?
- Now, fill a syringe with water and cover the hole with your finger. Try to squeeze the plunger. Can you compress the water?
- With the empty syringe, pull the **plunger**[3] all the way out to the end, then cover the hole with your finger and try to squeeze it. Can you compress the air?

To summarise, solids don't change their volume or shape. Both liquids and gases change their shape according to the container holding them. Liquid can be compressed, but not much. However, only gases take up the entire volume of the container they're in and they can easily be compressed.

[1]**take up:** fill or use an amount of time or space.

[2]**compress:** reduce something and fit it into a smaller space.

[3]**plunger:** part of a syringe that you push with your finger to get the liquid out.

CLIL activities

1. Find three examples of gaseous, liquid and solid substances. Write them in your notebook. Check if they can change shape or volume.
2. Listen to part of an interview with a famous astronomer. Is there a fourth state of matter? Explain what it is.
3. Copy the table in your notebook and complete it with *true* or *false*.

	Solids	Liquids	Gases
can change volume			
can change shape			
are compressible			

2 What is kinetic particle theory?

[1]**cohesion:** the act or state of keeping together.

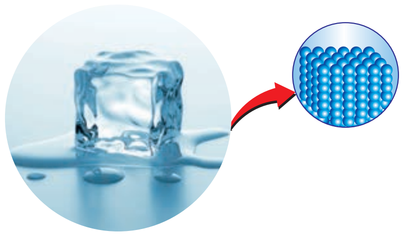
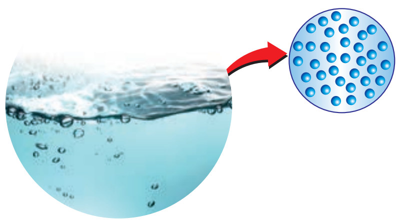
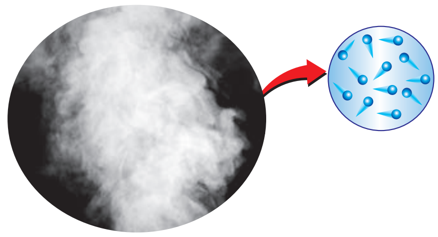
[2]**vibrate:** move or make something move from side to side very quickly and with small movements.

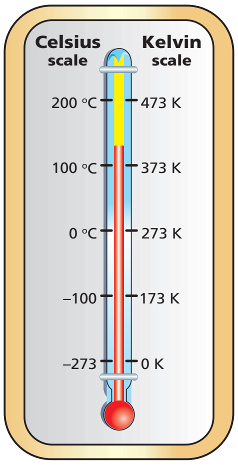
[3]**aggregation:** the act of putting things together into a single group.

Matter behaves differently depending on its temperature. The kinetic particle theory explains this with the following statements.

- Particles make up matter. These particles are invisible to the naked eye, with forces of attraction (or **cohesion**[1]) between them.
- These particles are in continuous movement. As the temperature rises, the speed and the separation between the particles increase, decreasing the cohesion forces between them.

Thanks to this theory, we can explain the fundamental properties of each state of matter.

		
In solids, the particles are **very close** to each other. For this reason, the **forces of attraction** between them are **very intense**, and the particles occupy **fixed positions** where they can only **vibrate**[2], but not move or slide past one another.	In liquids, the particles are relatively **close**. The **attraction forces** are **less intense** than in solids, and this makes their particles **more mobile**: they can move and slide past one another. As a result, liquids can change shape.	In gases, the particles are **further apart**. The **forces of attraction** are **very weak**, which means they can **move freely**. For this reason, gases not only take the shape of the recipient they're in, but also occupy all the volume available. This means they're easily compressible.



The states of matter depend on how close (or **aggregated**[3]) the particles are to each other, so we talk about the **state of aggregation of matter**.

Temperature is the measurement of the internal movement of the particles in a substance.

Absolute temperature

In 1848, William Thomson (known as Lord Kelvin) introduced a temperature scale that's directly related with the movement of particles, known as the **Kelvin** temperature scale (K) or **absolute scale**. In this temperature scale, zero corresponds to the temperature at which particles are at rest, that is, at –273 °C.

The divisions in the kelvin and Celsius scales are identical.

$$T(°C) = T(K) - 273 \qquad T(K) = T(°C) + 273$$

CLIL activities

4 **Express the following temperatures in kelvin. Write them in your notebook.**

a. T = 0 °C

b. T = 150 °C

c. T = −150 °C

d. the temperature at which particles are at rest

5 **Listen to the students' descriptions of the different states of aggregation. Correct the six mistakes and write down the correct answers.**

6 **Discuss with a classmate why, according to the kinetic particle theory, gases and liquids can change shape, but solids can't. Write it down in your notebook.**

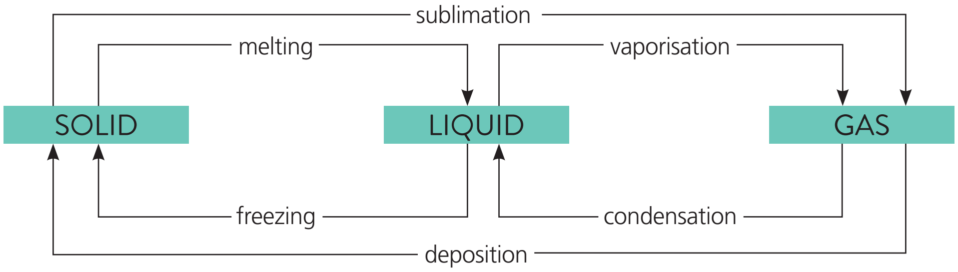
3 Changes of state

You've probably seen an ice cube melting or water boiling in a pot. These are changes of state because the substance (water) passes from one state of aggregation to another.

A **change of state** is a change in the aggregation state of matter, without any variation in its chemical composition (that is, the substance remains the same at all times).

The different states of matter are related to the **disposition**[1] of the particles of a substance. Therefore, a change of state will modify this disposition of particles without changing the type of particle.

The following diagram shows the names of all the changes of state:



- The transition from solid to liquid is called **melting** (or fusion). The transition from liquid to solid is called **freezing** (or solidification).

The temperatures at which these changes of state occur are called, respectively, **melting** and **freezing points**, and they coincide. For example, ice melts at 0 °C at **sea level**[2]. At the same temperature, liquid water freezes (solidifies). Different substances change their state at different temperatures. For instance, in the same conditions, the melting point of gold is 1063 °C.

- The transition from liquid to gas is called **vaporisation.** The transition from gas to liquid is called **condensation**.

Vaporisation can occur in two different ways: **Evaporation** occurs on the surface of the liquid, layer by layer, and **at any temperature**. Thanks to this phenomenon, wet clothes dry both in summer and in winter. **Boiling** happens in the entire mass of the liquid, violently and **at a fixed temperature for each substance**.

The temperature at which a liquid boils and condensates is the same, and they receive the names of **boiling point** and **condensation point**.

[1]**disposition:** the way things are placed or arranged.

[2]**sea level:** the average height of the sea, used for measuring the height of all places on land.

CLIL activities

7 In your notebook, write the type of physical change in the following situations.

a. We leave a piece of ice at room temperature.
b. We put some water in a plastic cup in the freezer.
c. We see how tiny drops of water form on the surface of a can of cold soda on a warm day.
d. You go for a swim at the beach and then dry out without using a towel.

8 Listen to the teacher explaining what fog is. Answer the questions.

a. Which physical change is responsible for fog?
b. Are changes of state reversible?
c. After a change of state, is the substance still the same?

8 While enjoying an ice-cold drink on a hot summer afternoon, you notice that the outside of your glass gets wet. Why does this occur?

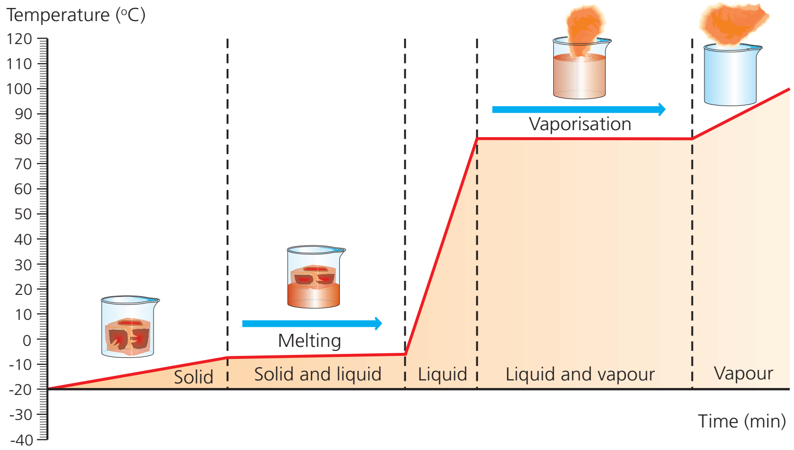
3.1. Heating curve of a substance

[1]**coincide:** take place at the same time

Water boils at 100 °C (at sea level). Gold, on the other hand, would need a temperature of 2856 °C. These temperatures **coincide**[1] with the condensation points of the two substances. The table below shows the melting and boiling points of several substances.

Now, look at the graph below. It shows the temperature variation of a solid as we heat it.

1. When it reaches the melting point, in this case at −7.2 °C, coinciding with the change of the solid into a liquid (fusion).
2. When it reaches the boiling point, in this case at 59 °C, coinciding with the change of the liquid into vapor (vaporisation).



Substance	Melting point (°C)	Boiling point (°C)
Water	0	100
Sodium	97.8	883
Ethanol	–114	78
Bromine	–7.2	59
Acetic acid	17	118
Mercury	–39	356

Although we continue heating the solid, there are two regions where the temperature remains constant.

When a substance starts to change its state, the temperature remains constant until the transformation is completed.

The temperature at which each substance changes state is different, which helps us identify it. In the example in the graph, the substance is bromine.

This representation of temperature and time on a graph is called a **heating curve**. If we cool something down instead of heating something up, we get a similar graph, called a **cooling curve,** but the line will be downward rather than upward.

CLIL activities

10 **Study the information in the table and answer the questions.**

°C	-144	-114	-114	-18	78	78	98
min	0	1	2	3	4	5	6

a. Plot the heating curve in your notebook.
b. What are the melting and boiling points?
c. What is the state of aggregation of this substance at room temperature?

11 **Listen and explain in your own words what sublimation is. Include some examples.**

12 **In your notebook, write which of these changes of state require an increase of energy.**

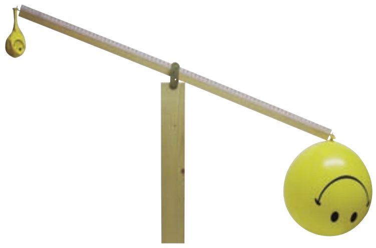
a. condensation
b. evaporation
c. freezing
d. melting

13 **In which state of aggregation will the substances in the table in activity 10 be at these temperatures? Draw a table with your answers.**

a. 70 °C
b. 0 °C
c. 120 °C
d. -5 °C

4 The gases around us: the atmosphere

If we inflate a balloon too much, it can explode due to the pressure that the air **exerts**[1] on it. Our atmosphere, like any gas, also exerts a pressure that we call **atmospheric pressure**.



[1]**exert:** use power to affect something.

What is pressure?

Pressure, ***p***, is the force exerted per unit of area. We obtain it by dividing the force by the value of the surface area.

$$p = \frac{F}{S}$$

The unit of pressure in SI units is newtons per square meter (N / m^2). This unit receives the name of **pascal** (Pa). So, $1\ N / m^2 = 1\ Pa$

- **Atmospheric pressure** is the weight that the atmosphere exerts per unit of area.
- **Atmospheric pressure** is highest at sea level and decreases with altitude.

The images below show what happens to an empty bottle of soda that has been closed at an altitude of 3840 m (left), and when we go down to 1200 m (right).

When we close the bottle, the pressure of the air inside the bottle is the same as the pressure outside (the atmospheric pressure). As the air is trapped in the bottle, its pressure remains the same, but as we go down to 1200 m, the atmospheric pressure increases, compressing the bottle.

CLIL activities

14 **Listen to the science podcast and take notes. Explain to a classmate why the boiling or the melting point of a substance can change.**

15 **Where do you think the atmospheric pressure is higher, on Venus or on Earth? Write your answer in your notebook.**

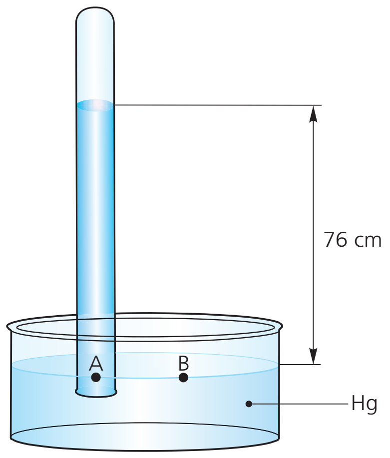
16 **Why do you think these things happen? Write your answers in your notebook, then compare your answers with a classmate.**

- **a.** Our ears block when a plane starts to descend.
- **b.** A bag of crisps expands as we go up to the top of a mountain.
- **c.** The water in Machu Picchu (altitude 2430 m above sea level) boils at 91.1 °C.

[1]**invert:** turn something upside down.

[2]**device:** an object that has been invented for a particular purpose.

4.1. Measuring atmospheric pressure



Evangelista Torricelli, an Italian physicist and mathematician, carried out a historic experiment in 1643. He took a tube and filled it with mercury. He then place the tube **inverted**[1] on a dish full of mercury. This caused the mercury in the tube to drop until the difference in height between the mercury on the surface and in the tube was about 760 mm. At that moment, the pressure on the surface of the dish (point B) is the same as atmospheric pressure. A **device**[2] such as this one that measures air pressure is called a **barometer**. Torricelli concluded that atmospheric pressure is equal to the weight that a column of 76 cm of mercury exerts per unit of area, which is:

$$p_{atmospheric} = 101300\ N/m^2 \text{ or pascals (Pa)}$$

Other units of pressure are:

- **Atmosphere (atm):** the value of atmospheric pressure equal to 101300 Pa, is called 1 atmosphere (1 atm).
- **Millimetres of mercury (mmHg):** since the height of the mercury column that corresponds to 101300 Pa is 76 cm = 760 mm, then: 1 atm = 760 mmHg = 101300 Pa
- **Bar (bar):** exactly equal to 100000 Pa. The atmospheric pressure at sea level is equal to 1.013 bar.

Atmospheric pressure is very large.

Calculate how many people, each with a mass of 50 kg, we will need to place on a surface of 1 m^2 to exert a pressure equal to atmospheric pressure.

The force exerted by each person is their weight:

$$P = m \cdot g = 50 \cdot 9.8 = 490\ N.$$

Dividing the value of the atmospheric pressure, 101300 Pa, by 490, we find that we will need 207 people with a mass of 50 kg placed on a surface of 1 m^2 to exert a pressure equal to the atmospheric pressure.

CLIL activities

17 **Convert the units of pressure. Write them in your notebook.**

a. 920 mmHg in Pa

b. 0.76 atm in mmHg

c. 98300 Pa in atm

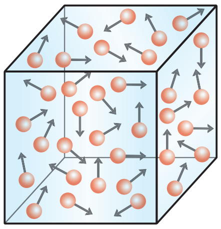
18 **Listen to the weather report. Explain the meaning of *isobars*, *cyclone* and *anticyclone*.**

19 **Discuss these questions with a classmate.**

a. Can you use a mercury thermometer to measure temperature in a volcano where the temperature is 2000 °C? Why?/Why not?

b. What about at the South Pole on a winter's day with a temperature of −50 °C? Why?/Why not?

5 The gas laws



The **pressure of a gas** is due to the continuous collisions of the gas particles against the walls containing it. Since the speed of the particles increases with temperature, the number of collisions and their violence also increases, causing the pressure of the gas to rise.

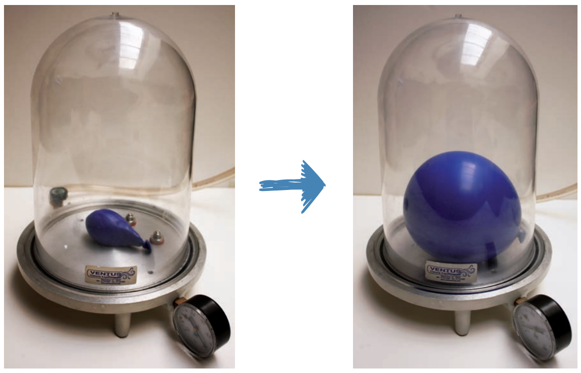
If we move a certain mass of gas into a recipient with half the volume, increasing the **density**[1] of the gas, the number of collisions will also increase and, therefore, the pressure of the gas.

Consequently, the **pressure *p***, the **temperature *T*** and the **volume *V*** of a gas are related to each other. The laws that relate these three variables are known as the **gas laws.**

[1]**density:** mass or number of particles per unit of volume.

[2]**vice-versa:** the same is true in the opposite order.

5.1. Relationship between pressure and volume: Boyle's law



When we press the plunger on the syringe blocking the point, the volume of gas inside decreases. As the volume decreases, the pressure of the gas trapped inside increases and the particles collide with greater frequency because they have less space to move around in.

At a **constant temperature**, the pressure exerted by a gas is inversely proportional to the volume it occupies, so that if the volume decreases, its pressure increases and **vice-versa**[2]. Mathematically, this is expressed as:

$$p \cdot V = \text{constant}$$

If we have a gas with a volume V at a pressure p and we decrease the volume to V', then the pressure will increase to a value p' so that: $p \cdot V = p' \cdot V'$.

CLIL activities

20 **Answer the questions in your notebook.**

a. A gas occupies 11.2 litres at 0.860 atm. What's the pressure if the volume becomes 15.0 L?

b. What would the volume be if the pressure increases to P = 1.72 atm?

21 **Listen to the talk and explain what happens when you breathe. Which gas law applies?**

22 **Read the problem and answer the question.**

We connect three bulbs with a tube and we take the air out of the tube. The volume of the tube is 39.0 mL. Bulb 1 has a volume of 56.0 mL and contains 5.92 atm of argon. Bulb 2 has a volume of 250.0 mL and contains 1.28 atm of neon. And Bulb 3 has a volume of 37.0 mL and contains 8.50 atm of hydrogen.

If we open the valves that isolate all 3 bulbs, what's the final pressure of the whole system in atm?

5.2. Relationship between pressure and temperature: Gay-Lussac's law

At a **constant volume**, the pressure exerted by a gas is directly proportional to its absolute temperature (in kelvin). So, if the temperature increases, the pressure also increases and vice-versa. Mathematically, this is expressed as:

$$\frac{p}{T} = constant$$

Therefore, if we have a gas in a recipient with a temperature T, exerting a pressure equal to p and we increase the temperature to T', the pressure p' that the gas exerts will be:

$$\frac{p}{T} = \frac{p'}{T'}$$

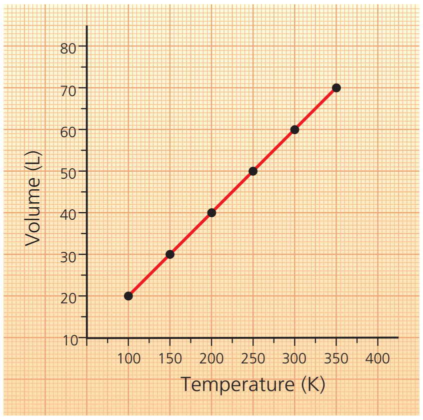
5.3. Relationship between volume and temperature: Charles' law

At a **constant pressure**, the volume that a gas occupies is directly proportional to its absolute temperature, that is:

$$\frac{V}{T} = constant$$

If we have a gas with temperature T, with a volume V and we increase the temperature to T' while keeping the pressure constant, then the gas will expand to a volume V' so:

$$\frac{V}{T} = \frac{V'}{T'}$$



Let's look at an example exercise. The graph below represents the data in this table for a gas at a constant pressure.

Volume (L)	20	30	40	50	60	70
Temperature (K)	100	150	200	250	300	350

a. Check that it obeys Charles' law.

All we need to do is to check if all the V/T quotients have the same value.

$$\frac{V}{T} = \frac{20}{100} = \frac{30}{150} = \frac{40}{200} = ... = 0.2$$

b. What will the volume of the gas be at 50 °C?

We express the temperature in Kelvin: 50 °C = (50 + 273) K = 323 K.

We apply Charles' law and we clear the value of the new volume V'

$$\frac{V'}{T'} = 0.2 \rightarrow V' = 0.2 \cdot 323 = 64.6 \text{ L}$$

CLIL activities

23 We have a gas in a closed recipient. Copy and complete the table in your notebook.

Pressure (atm)	0.25	1.50	3.50	
Temperature (°C)		30		70

24 Which gas exerts more pressure, 2 L of oxygen at T = 27 °C or 2 L of hydrogen at T = 27 °C?

25 Listen and explain why a pressure cooker may be dangerous. Which law explains the scientific reason behind this?

26 TASK STEAM Search for real-life examples or applications of the different gas laws. Make a poster presentation explaining how they work.