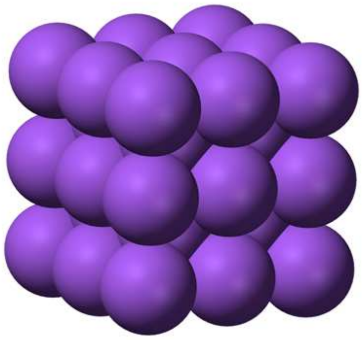
Unit 1. Matter

From the moment you wake up in the morning you don´t stop seeing all sort of objects: chairs, glasses, furniture, bottles full of water, coins… All objects are made of matter. Matter is everything that has **mass** and takes up **space**.

A **substance** is a specific type of matter that is different from any other (water, paper, wood, iron …). Substances forms **materials** which can be used to make objects.

How can you know from what substance an object is made? How can you **differentiate** between substances, and then **identify** them?



In this chapter you will see what are the **characteristic properties of the substances**, and why they are usefull to **identify** them.

You will also learn about the **model** that we use to explain the structure of matter (what would you see if you watch a substance with a powerfull microscope). For example, a solid like copper sulfate...do you think that you would see something similar to a block, like the one on the image?

Learning about this model is going to be very usefull to interpret **the properties of matter,** and you will be able to relate their characteristics in macroscopic scale (experimental) with the ones in microscopic scale (of particles).

1. The properties of substances

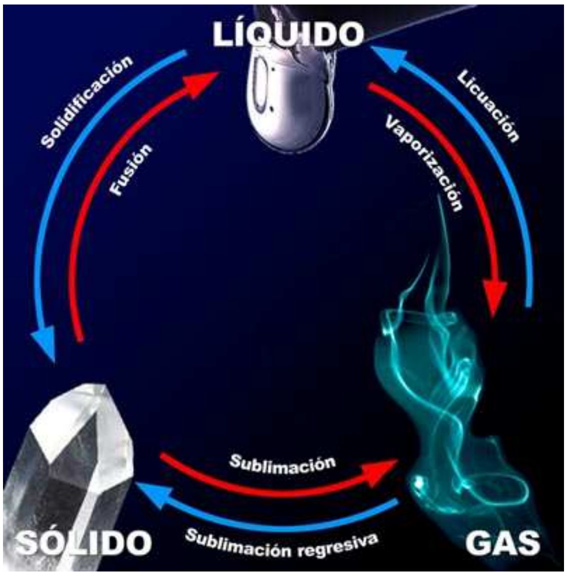
There are a number of **qualitative properties** that are characteristic of any substance and that can be useful to identify them. Some examples of these properties are odor (although there are a lot of odorless substances), color (but there are a lot of them which have the same color!), or flavor (but you´d better not taste some of them, they can be very dangerous!).

The problem that all of these properties have is the fact that they **can´t be measured**: The ability of perception is different for each person. For example, girls are more able to differentiate colors than boys. The sense of taste and smell is different in each person, etc. As a result, these properties only allow us to get an initial idea of the kind of substance we are analysing.

Think of the substance “water”. Its mass and its volume depends on the amount of water you have, and you can have the same mass of water as of any other liquid, or two different liquids can have the same volume. So, the volume is not usefull to distinguish two different liquids.

What about temperature? This property doesn't depend of the amount of matter…but different substances can have the same temperature, so temperature is not usefull to distinguish matter.

As you can see none of these three properties are useful to differentiate substances.



1.1 Characteristic properties

The characteristic properties are those which **can be measured**, have a **concrete value** for each substance, and **don´t depend on the amount** of matter that they have.

You are going to work with two characteristic properties: **change of state points** and **density.**

In the picture you can see the three **states of matter.** Each one has a different name, that you already know, for sure.

Density measures the relationship between the mass of a substance and his volume. Dense substances have a lot of mass in a determined volume, while low dense substances have little mass in the same volume (**d=m/V**).

The boiling and melting points and the density are characteristic of a substance. They have a fixed numerical value and don´t change whatever the amount of substance is.

As you know, water is a colorless, odorless, and tasteless substance, with a melting point of 0 ºC and a boiling point of 100 ºC. Its density is 1 g/cm^3. In the table you have the values of these three magnitudes in a group of common substances, ordered alphabetically. If you use this table it's going to be very easy to identify any substance!

If we have an unknown substance we just have to compare the values of the melting and boiling points and the density. If they are equal to other values of another substance in the table, without doubts the substances will be the same.

The meaning of the density of substances

It indicates the mass that the specific volume of a substance has. It is usually expressed in grams per cubic centimeter (g/cm^3), per milliliter (g/mL, equivalent quantity when talking about a liquid), or per liter (g/L, also for liquids).

IS (International System) unit is kg/m^{3}but it is used less often because its numerical value is 1000 times bigger: it is easier to say that the density of aluminum is 2,7 g/cm^3 than 2700 kg/m^3.

2. The measuring process

We call the properties that can be measured **magnitudes**. You already know some of them: mass, length, volume, temperature, time, and density. We are going to work with them, and we will learn how to measure it in a simple way.

Some of these magnitudes are determined from other ones. We call them **derived units.** For example, the volume is calculated as "length to the third" (the volume of a cube is calculated as its side elevated to the third!), and density is the relationship between mass and volume.

2.1 The International System of Units

To measure that we use **the International System of Units (IS).** It has a unit for each magnitude, that is used as a universal reference. This makes it possible that every unit can be understood in any country.

Magnitud	Símbolo	Unidad SI	Símbolo
Longitud	l	metro	m
Masa	m	kilogramo	kg
Temperatura	T	kelvin	K
Tiempo	t	segundo	s
Volumen	V	metro cúbico	m^3

Observe that temperature is measured in Kelvin in the IS. It is a centigrade scale-like Celsius (ºC) although this one is more common in our daily life. The equivalence between these two magnitudes is 0 ºC is 273 K, in order to change one to the other, you can use the relationship: **T(K) = T(ºC) + 273**.

Writing units

You must always write the units of the magnitudes because a number without units has no practical meaning.

2.2 Scientific notation

It is often used when we work with very big o very small numbers. It is used in calculators and spreadsheets, and you need to know how to work with it. For the moment, you will only use it with **numbers 1000 times bigger or smaller.**

In scientific notation, 1500 is written as $1,5\ 10^{3}$, and 0,0025 is written as $2,5\ 10^{-3}$.

We write just one number before the decimal comma, and then we multiply for the base ten to a power that is the number of digits after the comma in the original number if it is bigger than 1, or before the coma if it is smaller than 1.

Decimal dot or decimal coma?

To indicate decimals, you can use both decimal dot (calculators) or decimal coma (spreadsheets), but written downsides, not upsides. Don´t use the dot to separate thousands. It is right to write 1,25 or 1.25, but it is wrong to write 1´25 or one million as 1.000.000 (1 000 000 is allowed).

2.3 Multiples and submultiples

A lot of times we use units that are multiples or submultiples of the original number to make easier to work with them. You need to know how to work with numbers from 1000 times bigger than the original to numbers 1000 times smaller, as you can see in the table, where you can find other examples that you may already know.

Número	10^n	Prefijo	Abreviatura	Ejemplo
1000000000	10^9	giga	G	gigabyte (GB)
1000000	10^6	mega	M	megavatio (MW)
1000	10^3	kilo	k	kilogramo (kg)
100	10^2	hecto	h	hectopascal (hPa)
10	10^1	deca	da	decámetro (dam)
0,1	10^{-1}	deci	d	decímetro (dm)
0,01	10^{-2}	centi	c	centímetro (cm)
0,001	10^{-3}	mili	m	miligramo (mg)
0,000001	10^{-6}	micro	µ	microgramo (µg)
0,000000001	10^{-9}	nano	n	nanosegundo (ns)

2.4 Conversion factors

To express a measure in a different unit you have to multiply the initial measure by the conversion factor that relates the two units.

How do you transform 11,5 kilometers in meters? You need to know the equivalence between the two units, that it's very easy in this case: 1 km = 1000 m. As the two quantities are the same, their quotient is the unit, and you can write the relationship in two ways:

$$\frac{1\ km}{1000\ m} = 1 \quad \frac{1000\ m}{1\ km} = 1$$

Now you just have to multiply the initial quantity by the conversion factor to eliminate the initial unit and obtain the final one.

$$11{,}5\ km \frac{1000\ m}{1\ km} = 11500\ m$$

You have to notice that the unit km appears in the numerator and the denominator, so it is eliminated and you obtain the unit m, which is the unit you want to get in the end. Realize that **multiplying by a conversion factor is multiplying by the unit!**

Changing units with conversion factors

To express a quantity in a different unit, you have to multiply the initial quantity by the conversion factor that relates the two units, so you can eliminate the initial unit and obtain the unit that you want.

2.5 Significant numbers

When you make a measure, you can express it with more or less significant numbers depending on the instrument used. So, if a scale appreciates until tenths of a gram and indicates 14,6 g, the value has three significant numbers.

If you solve a problem with this value, the result will have a maximum of three significant numbers, and two if you use a value with two significant numbers.

How many significant numbers do we have to write?

a) When you measure something, as many as the instrument provides us.
b) When you do calculations with more than one magnitude, you must give the result with the lower quantity of significant numbers of all the magnitudes you have used.

Besides, you need to consider the sensitivity of the instrument. For example, if you measure masses with 3 significant numbers (10,2 g) in a scale that appreciates tenths of a gram, the result can´t have two decimal numbers because the scale only appreciates one. That is why 3,45 g or 0,27 g won´t be valid results.

3. Identifying solids

To determine the density, you need to determine the mass and the volume of the solid. The result is expressed in g/cm^3 o kg/m^3 (1 g/cm^3 = 1000 kg/m^3).

When you the value of its density you can compare it with the data table and you will be able to identify the substance that forms the solid.

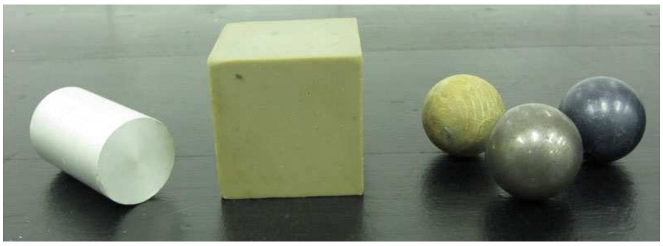
The scale

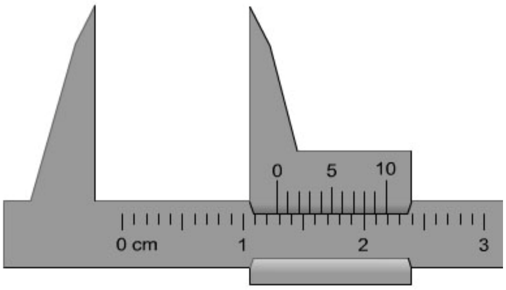
The maximum mass that can be measured by a scale is its capacity. The minimum mass that it can detect is its sensitivity. Scholar laboratories normally have scales with a capacity of 500 g and a sensitivity of 0,1 g.

3.1 Measuring the density of regular solids

Measurement of the mass: press the tare button, put on the solid and read the mass.

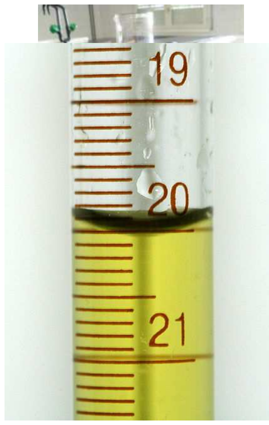
Measurement of volume: measure with a caliper or a pleximeter its side, edge, diameter, etc., depending on the geometric shape of the object. Use the appropriate formula (V = hπr2 in a cylinder, $V=a^3$ in a cube, $V=4/3\ \pi r^3$ in a sphere).





Look at the picture of the caliper. It marks 1,28 cm. To know it, you have to look at the 0 in the mobile scale (the superior one) which is between 1,2 and 1,3, but closer to 1,3. Now, look for the marks in both scales, superior and inferior, that are in the same position. In this case, is the eighth mark in the superior scale, so the value is 1,28 cm.

3.2 And what if the solid is irregular?



The volume is determined by immersion in water: we add water to the measuring cylinder, we read the volume and then we introduce the object. Its volume will be the difference between the two values taken.

Naturally, this method is only useful for small objects that fit inside the measuring cylinders.

To measure the mass, we weight the measuring cylinder with the liquid and then with the solid. The mass of the solid will be the difference between the two measures.

Measuring the volume of liquids with measuring cylinders and burettes

When we add water to a narrow tube, we observe that the surface of the liquid forms a curve called “meniscus”. To read the value properly, you have to put the measuring cylinder or burette at eye-level and write down the value in the lower part of the meniscus.

In the picture, the value is 20,0 mL. Notice that the burette appreciates until 0,1 mL.

3.3 What liquid is it?

You have to put a measuring cylinder in the scale, tare, add the liquid until a given volume, and measure the mass of the liquid. As you already know the mass and the volume, you can calculate the density and identify the liquid using the data table.

3.4 Boling points

As there are liquids with similar densities, sometimes we need to measure also the boiling point to be able to differentiate them. Notice that while the substance is changing its state, the temperature stays constant.

3.5 Temperature and physical states

You must learn to deduce the physical state of a substance by knowing its boiling and melting points, which are in the data table.

Think of the case of water. It melts at 0 ºC and boils at 100 ºC. Which is its physical state at -34 ºC? The temperature is lower than the melting point, so it is in solid-state. If the water is in the liquid state, the temperature will be between 0 ºC and 100 ºC. At a temperature of 145 ºC, which is higher than the boiling point, its state is gaseous.

In what state is it?

- If the temperature is lower than the melting point, the substance is in **solid-state**.
- If the temperature is higher than the melting point but lower than the boiling point, the substance is in the **liquid state**.
- If the temperature is higher than the boiling point, it is in a **gaseous state**.

4. A model for the matter

To explain why the substances have characteristic properties (density, points of change of state, tendency to evaporate, solubility in water) we start studying experimentally the different properties of gases.

Propiedad	Sólidos	Líquidos	Gases
Volumen	Fijo	Fijo	Ocupan totalmente el recipiente
Forma	Fijo	Se adaptan al recipiente	Se adaptan al recipiente
Compresibilidad	Nula	Nula	Grande
Densidad	Grande	Grande, menor en general que los sólidos	Muy pequeña

4.1 The pressure of gases

The gaseous state is the easiest one to study because to explain the situation of a gas inside a closed recipient you only need four magnitudes. You already know three of them: the **quantity** of gas (**n**), the **volume** of the recipient (**V**), and the **temperature** (**T**).

You also need to know the pressure produced by the gas (**P**). What is the meaning of this magnitude?

TABLA DE DENSIDADES Y TEMPERATURAS DE CAMBIO DE ESTADO DE ALGUNAS SUSTANCIAS

Sustancia	Densidad (g/cm^3)	T de fusión (ºC)	T de ebullición(ºC)
Acetona	0,80	-95	56
Ácido clorhídrico	1,26	-115	85
Ácido nítrico	1,50	-42	83
Ácido sulfúrico	1,83	10	317
Agua	1,00	0	100
Aluminio	2,70	659	1997
Amoniaco	0,00077	-78	-33
Benceno	0,89	6	80
Butano	0,0026	-136	-1
Calcio	1,55	838	1440
Carbono (grafito)	2,25	3527	4200
Cloro	0,003	-102	-34
Cloruro de sodio	2,16	801	1413
Cobre	8,94	1083	2582
Dióxido de azufre	0,0029	-75	-10
Dióxido de carbono	0,002	-156	-79
Estaño	7,31	232	2270
Etanol	0,79	-117	79
Glicerina	1,26	20	290
Hidrógeno	0,00009	-259	-253
Hierro	7,89	1539	3000
Mercurio	13,60	-39	356
Níquel	8,96	1083	2595
Nitrógeno	0,0013	-210	-196
Octano	0,70	-57	126
Oro	19,3	1063	2965
Óxido de calcio	3,30	2580	2850
Oxígeno	0,0014	-218	-188
Plata	10,50	961	2210
Platino	21,40	1769	4530
Plomo	11,34	328	1750
Sodio	0,70	98	892

If you want to cut a piece of clay and you have a knife, ¿what should you do? It is sure that you will use the edge of the knife and not the flat part of the blade. If it is sharp, it will be easier to cut, and also if the force you do is bigger.

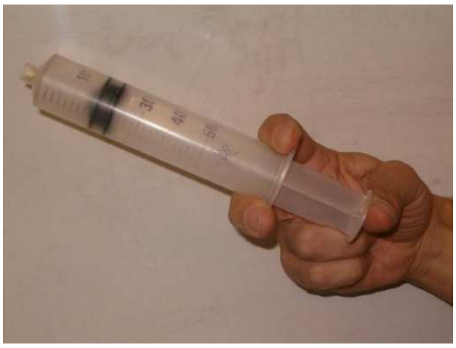
The pressure is the magnitude that measures the deforming effect of a force, and it is calculated as the relationship between the force applied and the surface where it is being applied. Using the IS, it is measured in Pascals (Pa) but in the laboratories, it is very common to use atmospheres (atm) or mercury millimeters (mm or mm Hg).

The bigger the force applied and the smaller the surface, the bigger the pressure will be. Using this simple idea it is easy to explain why we leave traces on wooden floors when we walk with needle heels but not if the heel is wider. Our weigh is the same, so we apply the same force on the floor, but the support surface is different. That's why the effect produced is bigger when there is little surface, in the stiletto (high-heel shoes).

What does pressure measure?

Pressure measures the force by unit of surface. It is calculated by dividing the force applied by the surface where it is applied: **P=F/S**

Compressing the air of a syringe



When you compress a hermetic syringe which contains air and whose tip has been sealed using a drop of glue, you observe that the volume occupied by the gas decreases while you push the plunger of the syringe.

If you want to push the plunger more, you will need to apply more force on the same surface, which means more pressure. When you stop pushing, the gas expands and goes back to the original situation.

In summary, when the pressure increases, the volume decreases.

Heating a beach ball

If you leave a deflated ball in the sun, you will observe that it inflates. When the temperature increases, the volume occupied by the gas increases too.

Heating a bottle

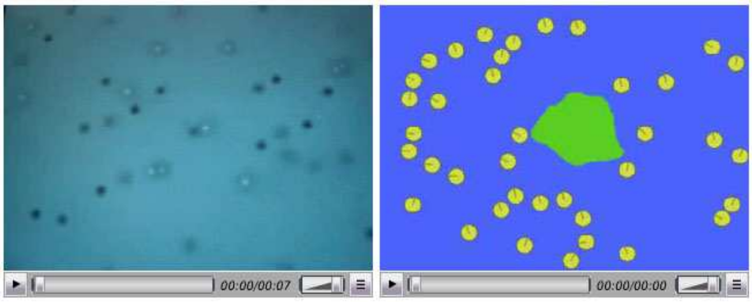
But if the recipient has a fixed volume, when you heat it, the pressure increases and the bottle can explode if it can´t resist the pressure reached. So, when the temperature increases, the pressure increases too.

Injecting air

If you blow air inside a balloon it inflates, but if it is a bottle with fixed volume, the pressure increases.

In summary, the four magnitudes are related: **the pressure produced by a gas is higher when the amount of gas and the temperature are higher, and when the volume of the recipient is lower**.

4. 2 The model of particles



The accepted explanation nowadays is that matter is made of particles so small that they can´t be directly observed by the human eye.

With the picture on the right you will understand the process: The big particle is the one we can see, and the smaller ones are those that we can´t see. The small ones move in a disordered way and, when they hit the big particle, they make it move. In this way, the air particles are the ones that cause the smaller particles (that seem to be suspended in the air) to move. This disordered movement of particles is called **Brownian motion**

Principles of the model of particles

1. The matter is made of very small and invisible particles.

2. All the particles of a substance are equal to each other, but different from those of other substances. For example, they differ in the mass they have.

3. The particles are in constant motion due to the thermal agitation, so when the temperature increases, they move faster.

4. There are forces of attraction between particles, which decrease quickly with distance.

4.3 Properties of substances

As the proposed model says, particles move faster when the temperature of the substance is higher. This effect's more important in gases.

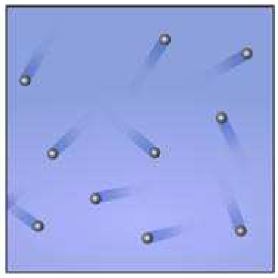
Remember that speed is a property of particles, while the temperature is a property of the substance made of these particles.

In solids, particles are ordered regularly, forming macroscopic structures called crystals. In liquids, particles are more disordered, and in gases the disorder is total.

Partículas y estados físicos		
Sólido	**Líquido**	**Gas**
Ordenadas	Desordenadas	Desordenadas
Cercanas entre sí	Cercanas entre sí	Muy lejanas entre ellas
Velocidad casi nula	Velocidad pequeña	Velocidad muy grande
Se atraen entre ellas	Atracción media	No se atraen

4.4 Pure substances and mixtures

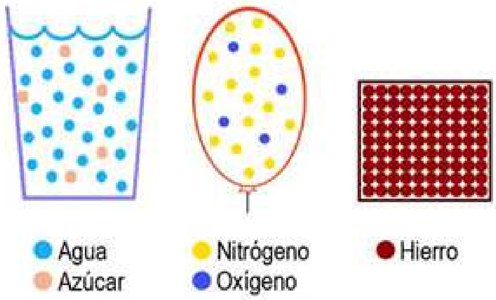
It is easy to represent the substances in a recipient through a particle diagram. A spray bottle filled with gas may be represented as a square box with circles representing the particles of gas.



A substance is **pure** if it is made by only one substance and one kind of particles. If there is more than a substance and so, more than one kind of particle, it is a **mixture**.

If the substances in a mixture are equally distributed through the mixture, it is **homogeneous**, while if the different kinds of particles can be seen just looking at them, it is **heterogeneous**.

The diagram on the left represents a glass of water with sugar. Most of the particles are water. As there are two kinds of particles equally distributed, it is a homogeneous mixture.



In the middle, there is a diagram representing a balloon filled with air, which is made mainly by two gases: oxygen and nitrogen (there are very small quantities of water, CO_2, and other gases). It is also a homogeneous mixture.

On the right, there is a piece of iron, which is of course a pure substance. It is only formed by one kind of particle.

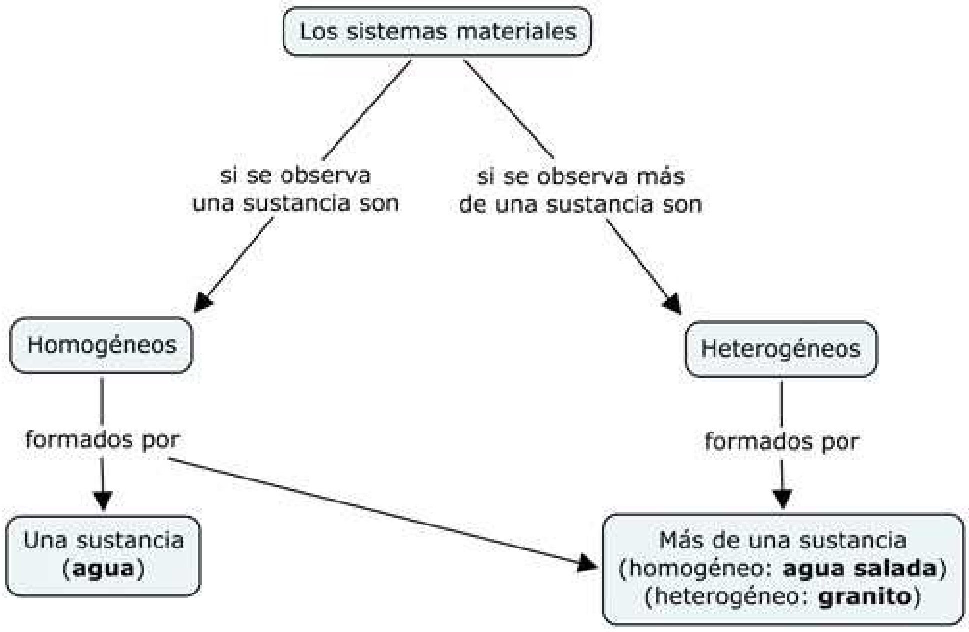
Pure substances and mixtures

The conceptual diagram gives us an experimental vision of homogeneous and heterogeneous systems, depending on if we observe one substance (water, but also salty water), or more than one (granite). Nevertheless, salty water is a mixture of two substances (salt and water), although we can´t differentiate them just by looking at it.

A substance is **pure** if is made by only one substance and one kind of particles. If there is more than a substance and so, more than one kind of particle, it is a **mixture**.

If the substances in a mixture are equally distributed through the mixture, it is **homogeneous**, while if they can be seen different just looking at them, it is **heterogeneous**.

Homogeneous mixtures are often called **dissolutions**, where the component in higher proportion is the **solvent**, and the component in lower proportion is the **solute** (in a dissolution of sugar in water, water is the solvent and sugar is the solute).



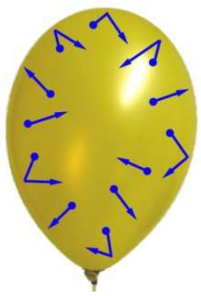
4.5 Diagrams of particles

The diagrams of particles must reflect the physical state of the represented substance.

Solids

Observe different crystalline solids. In all cases, there is a geometric structure on a macroscopic scale of cubic, prismatic or other shapes.

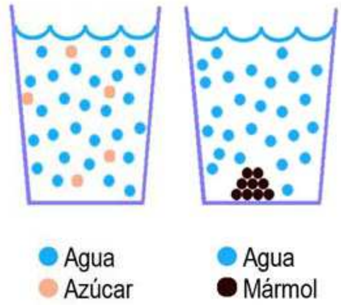
It seems logical to suppose that this happens because the particles that form each substance are ordered at a microscopic scale, and when there is a number of them big enough, we can see the crystal, which reproduces that geometric order.



Gases

In the case of the gas inside the balloon, there is no regular structure because the particles move quickly and in a disordered way, hitting the wall of the balloon to maintain it inflated.

Liquids



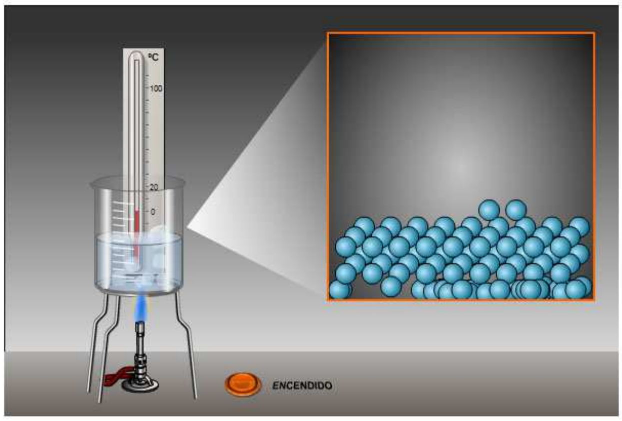
In liquids, the diagrams of particles are different if the substance dissolves, like sugar, or if it doesn´t, like marble. Look at the picture where there is a representation of a homogeneous and a heterogeneous mixture, where the piece of marble not dissolved can be seen easily.

You can represent similar diagrams in other cases that you know: oxygen is dissolved in water (this allows fishes to breathe), whose diagram would be similar to the diagram for sugar dissolved in water, as it is a homogeneous mixture. Another similar diagram could be the one for alcoholic drinks, where alcohol mixes with water.

4.6 Physical states and changes of state

You have applied the model for solids, liquids, and gases. Now it is time to use it also to interpret the changes of state. In the picture, you have ice, liquid water, and water vapor. Ice melts at 0 ºC and water boils at 100 ºC. It is also possible to study the condensation of vapor and solidification of water.

Use the simulation to observe how these changes of state are produced from an experimental point of view, paying special attention to the variations of temperature during the process.



Notice that the energy in the form of heat supplied by the Bunsen burner is used to heat the substance, so the particles start to move faster, and how the distance between them increases.

To explain the melting of ice, the particles separate just a bit, so they can move as you can see in the simulation. In order to do that, they need to overcome the attraction between particles in a solid-state.

Once the melting point is reached, the distance between particles gets bigger as they move faster, so step by step the substance changes from a solid-state to a liquid state.

All the energy is used for this process, and that´s why in a change of state the temperature doesn´t change. Once all the ice is melted, the water starts to heat again and starts to evaporate at low temperatures, although it doesn´t finish until the boiling point is reached.

4.7 Explanation of experimental facts

The two main applications of every model are:

- **Explaining the observed facts.**

-**Predicting facts that are going to happen**.

There is a balloon adjusted to the mouth so that the closure is hermetic. If you heat the flask with the flame of a bunsen burner or on a heating plate, you can see that the balloon swells and that when you leave it to cool to room temperature, it returns to the initial situation.

This situation and a lot more can be explained using the model of matter that you have studied, and you will also be able to predict what will happen when you act on a system (what will happen to the balloon if you put it inside the freezer?).

5. Working at the laboratory

The laboratory is a common working place for scientific subjects. It is necessary that you now the working rules, especially everything related to safety, and the materials you are going to use.

Working at the laboratory

The laboratory is a working place where you are going to use instruments and tools that may be dangerous, so you have to follow some rules to assure your own safety and your companions safety.

1. When you arrive to the laboratory, set yourself in a table with your colleagues (one or two) and leave your belongings in the shelf under the table.

2. Check that you have all the materials you need in the tray on the table.

3. Stay in your working place to facilitate mobility within the laboratory.

4. You should use gloves and glasses when you work with chemical products.

5. You mustn´t touch, smell or taste chemical products. It can be very dangerous if you don´t know their properties.

6. Make sure that you use the right substance or material in each case and that you do it correctly.

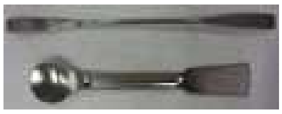
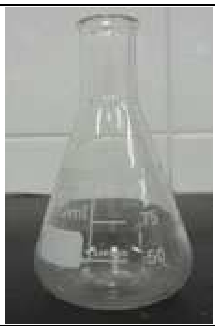
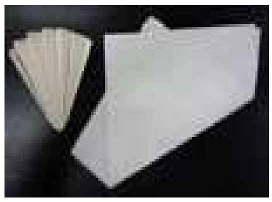
7. Don´t mix products if you are not sure that you have to do it, because you can produce dangerous reactions.

8. Follow the teacher´s instructions to eliminate the residues when you finish your work.

9. Wash your hands before you leave the laboratory.

10. When you finish, leave the material tidy, as you found it.

AND IF YOU HAVE ANY PROBLEM ...
TELL IT IMMEDIATLY TO YOUR TEACHER

			
Balanza digital	Flexómetro	Calibre	Espátulas
			
Probeta	Matraz aforado	Soporte, pinza de bureta y nuez	Bureta en soporte
			
Vaso de precipitados	Erlenmeyer	Embudo	Embudo de decantación
			
Cápsula de porcelana	Cristalizador	Gafas	Vidrio de reloj
			
Gradilla y tubos de ensayo	Frasco lavador	Mechero Bunsen	Papel de filtro