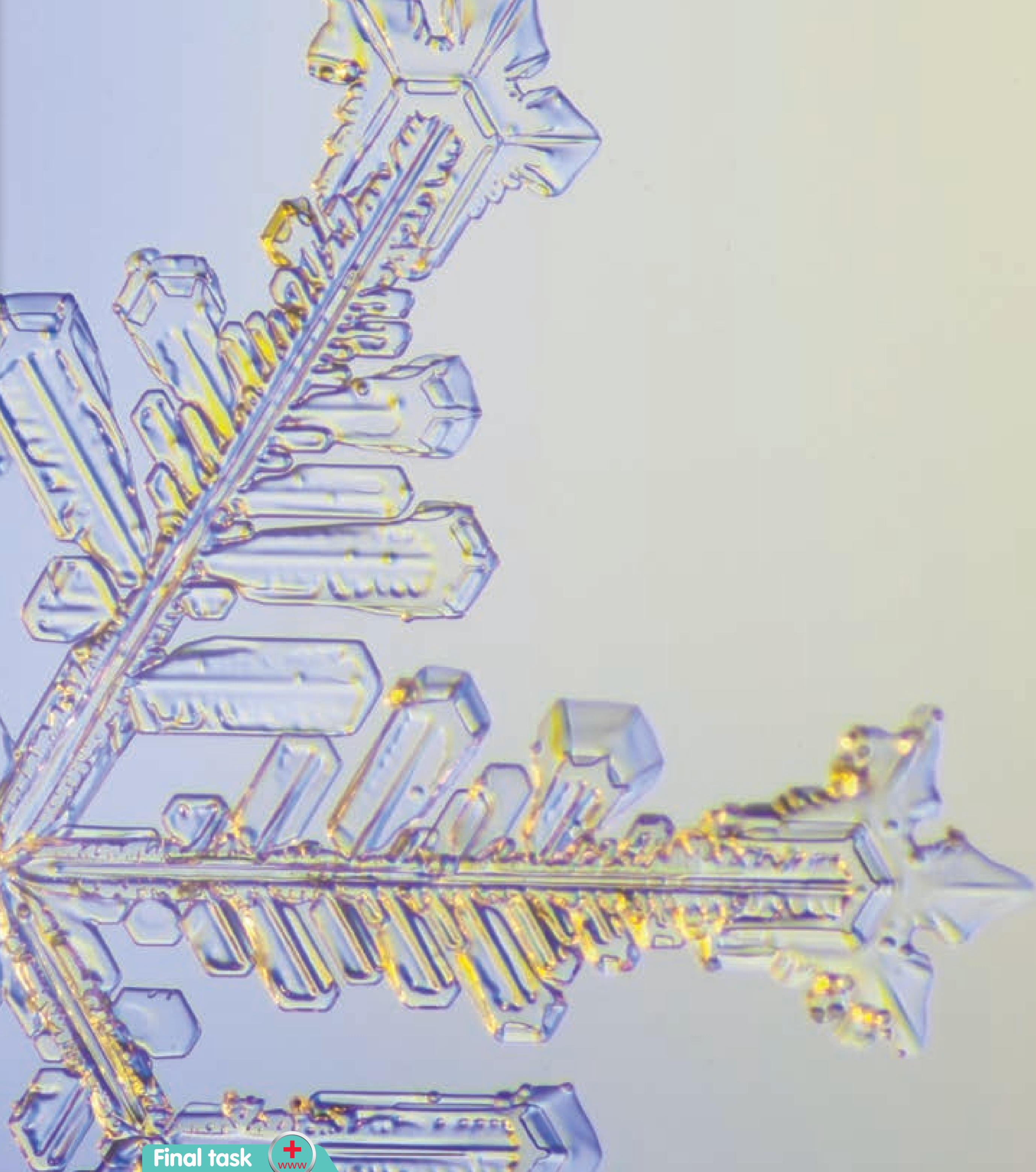
3 THE MATERIAL WORLD: ATOMS

YOU WILL LEARN TO...

- Identify the atom as a constituent of matter.
- Recognise the different constituents of an atom.
- Associate the property of positive and negative charges with the corresponding constituents of atoms.
- Explain the formation of an ion from neutral atoms.
- Represent ions with their usual notation.
- Understand the processes in which substances ionise.
- Recognise how atoms group together in different structures according to the type of substance.
- Interpret the meaning of a chemical formula according to whether it corresponds to molecules or ionised compounds.

- *Are atoms the smallest units of matter? Do you know any smaller particles?*
- *What are molecules? Give an example.*
- *Do you know the chemical formula for water? Do you know any other chemical formulas?*



Final task

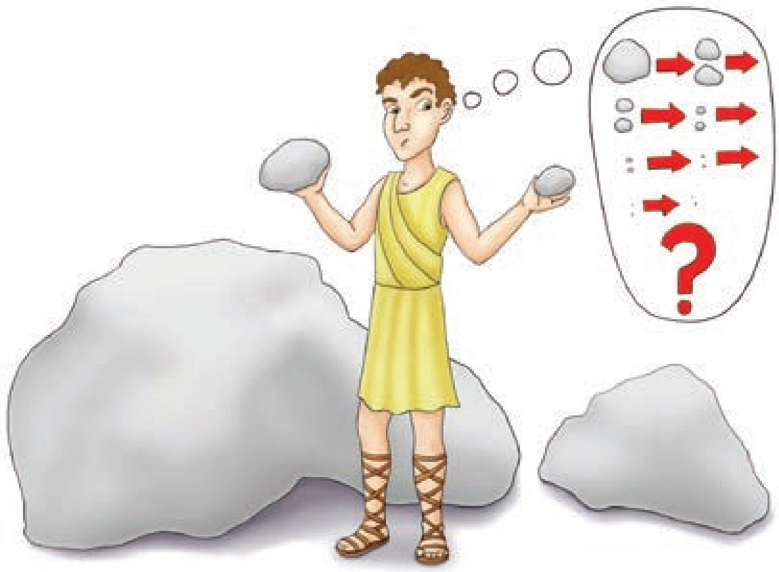
Materials and products in a laboratory: labelling and safety measures

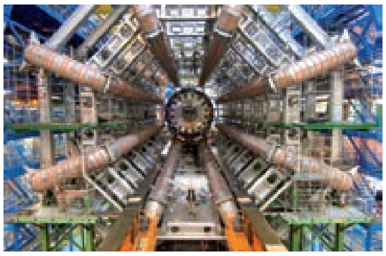
When you walk into a chemistry laboratory, you see lots of glass instruments and apparatus for measuring. You also find chemicals labelled with symbols showing possible dangers, which we have to know in order to take the appropriate safety measures when we handle them. In this task, you will research materials in the laboratory, the labelling and some basic safety rules to follow.

- Look up the words **inflammable, corrosive** and **toxic** in the dictionary. Define them using your own words.

1. A JOURNEY TO THE CENTRE OF MATTER

The Ancient Greeks, 2 500 years ago, wondered what matter around them was made up of. For example, when you hit a rock, it breaks into pieces and if you keep hitting it, it will eventually turn into sand.





Nowadays we have the most powerful machine ever known to break up matter: the Large Hadron Collider (LHC) at CERN in Geneva.

Some of the more **educated**[1] Greeks proposed the existence of **indivisible**[2] particles called atoms, a Greek word meaning just that, 'indivisible'.

[1]**educated:** (adjective) having a lot of knowledge because you have studied

[2]**indivisible:** cannot be divided into separate parts

1.1. Atoms

The Ancient Greeks believed that the atom was the smallest particle of matter that could exist.

Nowadays, nobody doubts the existence of atoms, although, as we will see, they are very different from what the Greeks imagined. For example, at the beginning of the 20th century, even smaller particles were discovered.

All **matter** is made up of **atoms.**

Analyse

1. Find information about the LHC and what its purpose is.

Remember

2. What do you think an atom looks like? Draw it in your notebook. Use your imagination. Do you remember what the dimensions of an atom are?

1.2. How small are atoms?

Scientists have worked out the approximate average size of an atom after carrying out several experiments.

So, for example, the hydrogen atom, which is the most basic atom, is one ten-thousand-millionth of a metre, that is:

size of a hydrogen atom = $0.000\,000\,000\,1$ m = 10^{-10} m

Understand

3. How many atoms would fit lined up in one millimetre on this ruler?

1.3. What are atoms like?

It's difficult to conceive that we can explain what something is like without seeing it. Actually, this knowledge comes from models that scientists have developed to represent their discoveries and observations.

Long ago people thought that atoms were tiny indivisible balls or spheres of matter. However, this rather simple model does not explain many of the properties of matter, such as **electrical phenomena,** that occur in nature.

Any atomic model must explain these in order to be a valid model. Through research and the explanations for these electrical phenomena, scientists have worked out what atoms are really like.

In fact, they have very little to do with the idea of little indivisible 'balls of matter' that you probably imagined in activity 2.

Apply

5. How many atoms are there in a drop of water?

Try an experiment using the following data in order to answer the question:

In a volume of 18 mL of water (corresponding to a mass of 18 g), there are approximately $1\,800\,000\,000\,000\,000\,000\,000\,000 = 1.8 \times 10^{24}$ atoms.

- Put 5 mL of water into a syringe and then inject it into a dropper.
- Now, empty the dropper counting the number of drops in 5 mL.
- Work out how many drops would be in 18 mL of water.
- Once you know how many drops are in 18 mL, work out how many atoms there must be in one drop of water. How many atoms are there in a drop of water?

6. Can you work out from the previous results the volume of an atom, supposing that the drop of water is full of atoms? Give the result in m^3.

Understand

4. There are around 800 000 atoms lined up in the thickness of a page of your book. How thick is the page? Give your answer in suitable units for its dimensions.

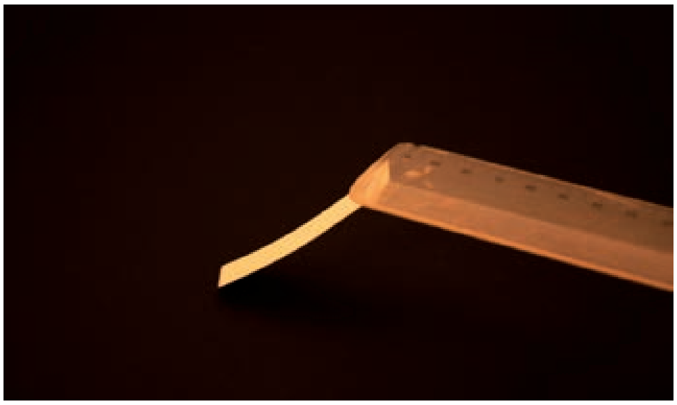
Key concepts

- All matter is made up of atoms.
- The average size of an atom is 10^{-10} m.
- A model of the atom must be able to explain electrical phenomena in matter.

2. ELECTRICAL PHENOMENA IN MATTER

Try the following experiments and note down what happens in each case:

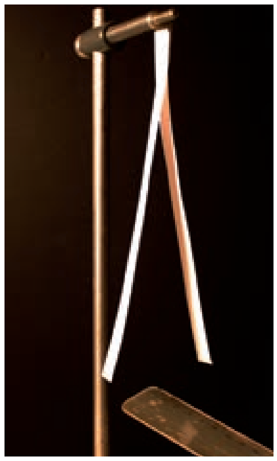
Cut a thin piece of paper. **Rub**[3] your (dry) hair hard with a plastic ruler and hold it near the paper.



Cut a thin piece of clear plastic and rub it against your dry hair. At the same time, do the same with your plastic ruler. Hold it near the piece of paper.

Turn on the tap at home or in the lab so that only a thin **stream**[4] of water comes out. Rub your hair hard with a plastic ruler or comb and hold it near the stream of water.

Hold two thin pieces of paper between your fingers. Rub your ruler against your hair and hold it near the ends of the pieces of paper.



[3]**rub:** put two surfaces together and move them backwards and forwards

[4]**stream:** continuous flow of liquid

From these experiments we can draw the following conclusions:

- When we rub certain materials, it causes a series of events we call **electrical phenomena.**
- Electrical phenomena exhibit either **attraction** or **repulsion.**

Evaluate

7. In which of the experiments above is the interaction attraction? In which one(s) is it repulsion? Can you think of a relationship between the attraction or repulsion in the interaction and the type of material used in each case?

Apply

8. Rub a ruler hard against your hair, then hold it near your hair again. What happens?

2.1. Electric charge

Scientists use different theories to explain the attraction or repulsion of bodies. In this case, they point to a property of matter called electric charge as the cause of electrical phenomena.

Electric charge causes electrical phenomena, attraction and repulsion, which we observe in nature.

As there are two types of electric interaction, attraction and repulsion, we define two types of electric charge: a positive and a negative one.

There are two types of electric charge in nature: a **positive charge** and a **negative charge.**

In nature, bodies are usually electrically neutral so when they exhibit one or another type of charge, we say they are electrified or 'charged'.

It seems logical to think that when we rub together two identical materials, they acquire the same electrical charge. However, when you rub two pieces of plastic against your hair or against some wool and you bring them together, you will observe that they repel each other.

So, we can conclude:

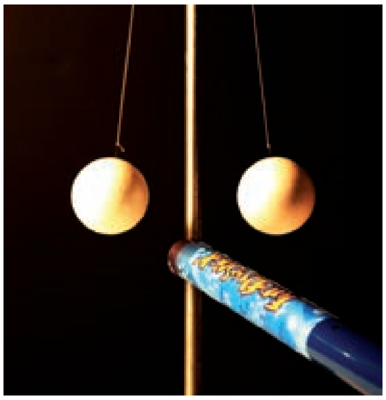
Electrical charges of the **same type** (with the same sign) **repel** each other.

Therefore, two positively-charged materials repel each other as do two negatively-charged materials.

However, when two opposite charges are brought together they attract each other.

Therefore:

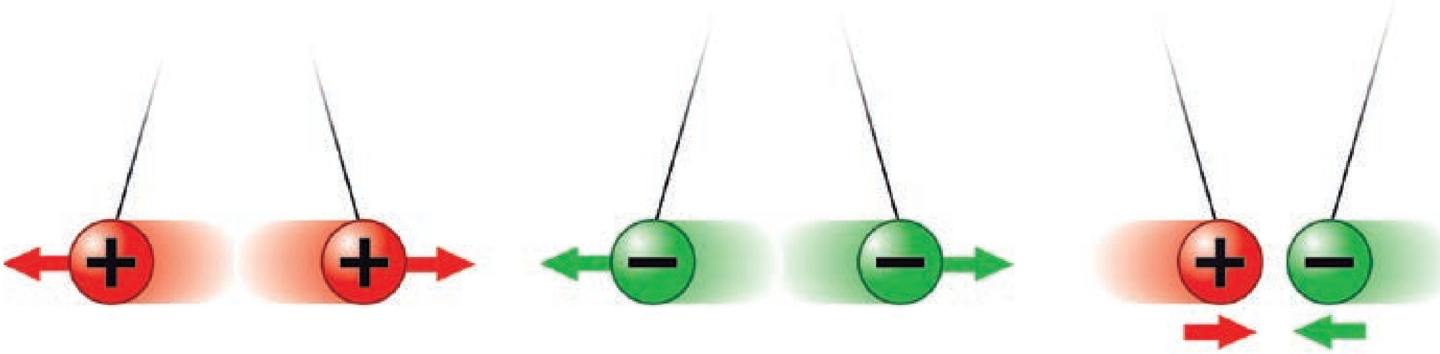
Opposite electrical charges (with different signs) **attract** each other.



When two identical materials are charged in the same way, they repel each other.

Key concepts

- Electrical phenomena can attract or repel and are caused by electric charges.
- Electric charges can be positive or negative.
- Charges with the same sign repel each other.
- Charges with opposite signs attract each other.



Electric charges with the same sign repel each other and charges with opposite signs attract each other.

Understand

9. If you rub two identical objects in the same way, they repel. Listen and say which statement is correct.

3. INSIDE THE ATOM: ITS PARTICLES

The explanation for the property of electric charge in matter lies inside atoms.

Until the end of the 19th century, people thought that the atom was the smallest particle of matter that could exist. However, in 1904, the British physicist **Joseph John Thomson** discovered other particles with very surprising properties.

3.1. Tiny electrons

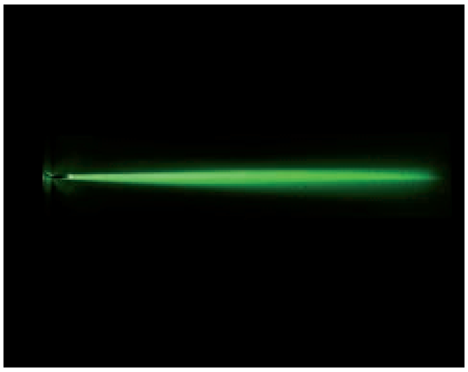
[5]**plate:** thin flat sheet of metal

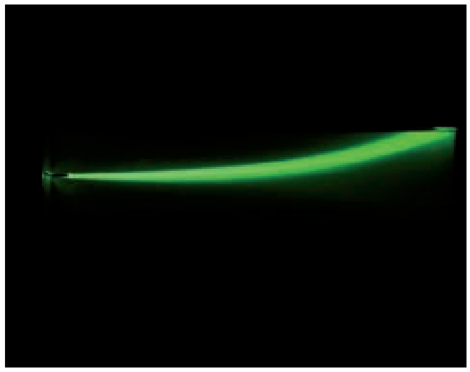
[6]**beam:** line of light

[7]**bend:** make something curve that was straight

Thomson put two metal **plates**[5] into a glass tube in a vacuum. When he sent a strong electric charge between them, a clearly visible **beam**[6] of light moved in a straight line.

This visible beam of light would **bend**[7] when electrically-charged metal plates or even magnets were placed between them. Because the beam of light was attracted by positively-charged plates or repelled by negatively-charged plates, Thomson deduced that the beam was made up of negatively-charged particles, which he and his colleagues called **electrons.**





There was an even bigger surprise when they worked out the mass of the electrons using mathematical calculations. It turned out that the electron was 1 840 times smaller than the most basic element (hydrogen).

So the atom is not the smallest particle of matter. Inside it are other even smaller subatomic particles: electrons.

The mass of an electron

To understand just how small an electron is, write 31 zeros one after the other and then the number 91. If you put a decimal point after the first zero, you get the mass of an electron in kilograms.

The mass of an electron is:
$m_e = 9.1 \times 10^{-31}$ kg

Electrons are very small particles that:

- Are part of atoms.
- Have a mass that is 1 840 times smaller than that of the smallest atom.
- Are negatively charged.

Furthermore, electrons have a very important feature; **it is impossible to take away their negative charge.** So we can say that:

Negative charge is a property of **electrons.**

Create

10. In your notebook, draw what you think an electrically neutral atom with six electrons would look like.

3.2. More surprises… atoms are almost empty!

In 1911, after carrying out a series of experiments, the New Zealand physicist **Ernest Rutherford** came to the surprising conclusion that the inside of an atom was practically **hollow**[8]**,** except for the very centre, which was occupied by a tiny nucleus where all its mass was concentrated. Furthermore, Rutherford established that the nucleus was positively charged.

Atoms are basically empty space and all its mass is concentrated in its **nucleus** which has a **positive charge.**

Until then, all we knew about atoms was that they were so small that we couldn't see them. Imagine how surprised scientists were when they discovered that an atom's mass is concentrated in a nucleus that's between 10 000 and 100 000 times smaller than the actual atom. It's like going to dive into an Olympic-sized swimming pool only to find that all the water is concentrated into one single drop!

Understand

11. The Anoeta stadium is 105 m long. A marble is just 1 cm in diameter. How many times bigger is the Anoeta stadium? Comparatively, this is the relationship between the size of an atom and its nucleus in atoms with relatively large nuclei.

3.3. Protons

The smallest atom that we know of is the hydrogen atom, which is made up of a single electron (negatively-charged) and a nucleus (positively-charged). The nucleus of this atom is also the smallest and it's called a **proton.**

In the first half of the 20th century, scientists discovered techniques that allowed them to **split**[9] the nuclei of most atoms through a process called **nuclear fission.** The smallest fragments turned out to be protons, which were considered to be constituent particles of the nuclei of all atoms.

Protons are particles that:

- Are part of the nuclei of all atoms.
- Have a similar mass to a hydrogen atom.
- Have a positive electrical charge.

Therefore, we can say that:

Positive charge is a property of **protons.**

Empty atoms

Imagine how surprised you would be to discover that when diving into a swimming pool all the water is concentrated in a single, tiny drop.

[8]**hollow:** having empty space inside

[9]**split:** divide into smaller parts

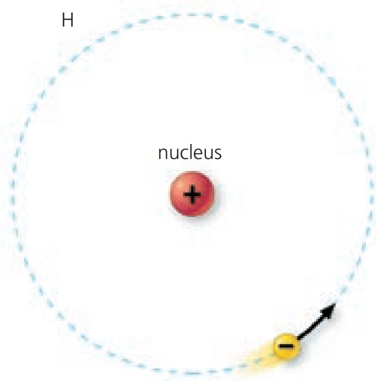
The mass of a proton

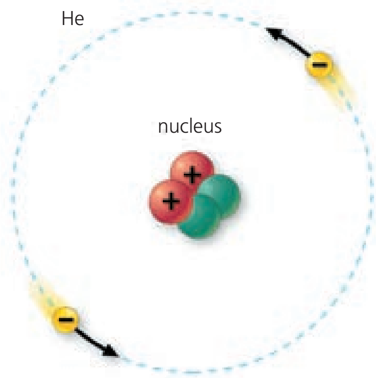
The mass of a proton is:

$$m_p = 1.66 \times 10^{-27}\ \text{kg}$$

Analyse

12. How many times bigger is the mass of a proton than the mass of an electron?





3.4. Neutrons

The two smallest atoms in nature are hydrogen and helium. A hydrogen atom has one proton and one electron and a helium atom has two protons and two electrons. Since the nucleus of the helium atom has two protons and the hydrogen atom only one, you would expect the mass of the helium atom to be double the mass of the hydrogen one. Actually, it's four times the mass.

Rutherford assumed that there were other particles with the same mass as the protons in the nuclei but that these had no electric charge. He called them **neutrons.** He proved to be right when **James Chadwick** discovered neutrons in 1932.

Neutrons are particles that:

- Together with protons, make up the nuclei of all atoms.
- Have a mass that is almost the same as a proton's mass.
- Have no electrical charge. They are **neutral.**

3.5. So, what does an atom look like?

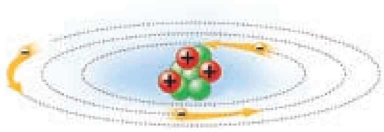
We know that atoms are made up of **electrons** and that the **nucleus** is made up of **protons** and **neutrons.** Since atoms are electrically neutral:

The number of electrons is the same as the number of protons in neutral atoms. This is because the charge of the electron is the same as that of the proton but with the opposite sign.

3.5.1. The planetary model of atoms

Protons and electrons attract each other because they have opposite charges, so the electron is attracted towards the nucleus. To stop this from happening, **electrons move around the nucleus at very high speeds,** just as planets orbit the Sun or satellites orbit the Earth.

The size of the Solar System is measured by the distance that the furthest objects orbit the Sun. Similarly, the size of an atom is determined by the distances from the nucleus to the farthest electrons.



The planetary model of atoms.

Key concepts

- An atom is basically empty and has a nucleus and electrons.
- There are protons and neutrons in the nucleus.
- Electrons move around the nucleus at very high speeds.

Understand

13. Listen and complete the following sentences.

a) A _____ atom is made up of only _____ proton and _____ electron.

b) An _____ atom has _____ protons in its nucleus and its mass is _____ times greater than a hydrogen atom.

c) A _____ atom has _____ electrons and its mass is _____ times greater than a hydrogen atom.

14. Answer the following questions about the statements in activity 13.

a) What must the charges of the proton and the electron be to make the hydrogen atom electrically neutral?

b) How many neutrons and electrons does an iron atom have?

c) How many protons and neutrons are in the nucleus of a uranium atom?

3.6. Representing atoms: atomic parameters

We use atomic **parameters**[10] to summarise the information related to the internal composition of an atom: the **atomic number (*Z*)** and the **mass number (*A*).**

> The **atomic number *Z*** of an atom is the number of protons it contains in its nucleus.

The atomic number is the characteristic that defines a given element; as you can see in the periodic table in the Inorganic Chemistry Appendix, no two elements have the same atomic number. We could say that the atomic number is like the identity card of an atom. The atomic number of oxygen is 8 so an oxygen atom has 8 protons and if it's a neutral atom, it also has 8 electrons.

> The **mass number *A*** is the sum of protons and neutrons in the nucleus of an atom.

Protons and neutrons give the mass of the atom because the mass of electrons is insignificant in comparison. So it's protons and neutrons that define the mass number *A*. If the number of protons is *Z* and we call *N* the number of neutrons, then:

$$A = Z + N$$

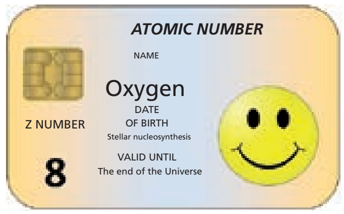
Therefore, we get the number of neutrons in an atom by subtracting $A - Z$.

We **represent** atoms by giving the symbol X of the element and the number *A* and *Z* as **superscript**[11] and **subscript**[12] respectively on the left side of the symbol, like this:

$$^{A}_{Z}\mathbf{X} \quad \text{for example} \quad ^{27}_{13}\mathrm{Al}$$

This shows that aluminium has 13 protons, 13 electrons (if it's electrically neutral) and 14 neutrons.

Atomic number



The atomic number *Z* of an element is like the identity card of an atom. It's the number that differentiates it from all other elements.

[10]**parameter:** something that determines how we do something

[11]**subscript:** written below the normal line of writing

[12]**superscript:** written above the normal line of writing

3.7. Isotopes of an element: atomic mass

Some atoms of the same element (with the same *Z*) can have a different number of neutrons. Consequently, its mass number will be different.

> An **isotope** of an element is an atom that has a different mass number to the standard of that element.

For example, carbon has three isotopes, $^{12}_{6}\mathrm{C}$, $^{13}_{6}\mathrm{C}$, and $^{42}_{6}\mathrm{C}$. However, not all of these are present in nature in the same quantities. Most elements have several isotopes so we represent the mass of an element in the periodic table with its atomic mass. This can be a decimal number because it's the average mass.

> The **atomic mass** of an element is the average mass of the mass numbers of its isotopes according to their relative abundance.

Understand

15. Hydrogen has three isotopes called protium, deuterium and tritium with the following symbols:

$^{1}_{1}\mathrm{H}$, $^{2}_{1}\mathrm{H}$ and $^{3}_{1}\mathrm{H}$

Work out the number of protons, electrons and neutrons in each one.

Apply

16. Uranium has 92 protons and two of its isotopes have 143 and 146 neutrons each. Given that the symbol for uranium is U, represent both isotopes.

4. WHEN ATOMS STOP BEING NEUTRAL: IONS

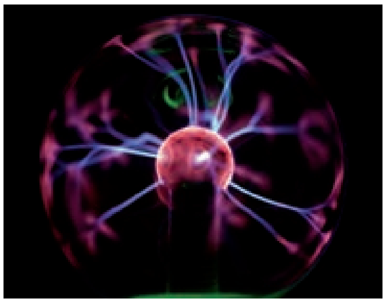
Atoms are not always neutral. Although the number of protons in an atom never changes, the number of electrons can. The number of electrons in an atom can change when there are other atoms near them or in other circumstances, such as electrical discharges or high temperatures.

These changes cause atoms to lose electrons or to gain them from other atoms.

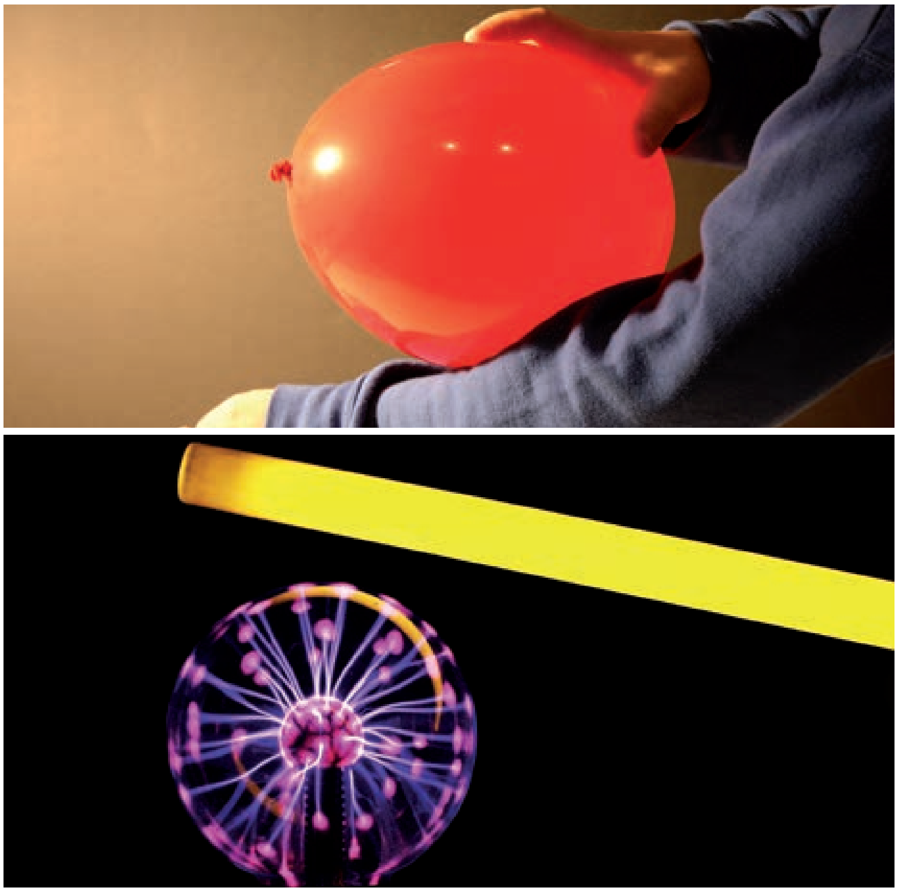
- The process by which atoms gain or lose electrons is called **ionisation.**
- When an atom gains or loses electrons, we say it has been **ionised.**

4.1. How are substances ionised?

If we think about the structure of an atom, it would seem logical to think that when two materials come together, the only part that will come into contact is the outer layer of electrons. This is indeed the case and in fact, the nuclei of atoms never come into contact with each other. Pulling electrons off one substance and transferring them to another is as easy as rubbing a balloon on a woollen sweater. When we do this, we pull electrons from the woollen sweater and transfer them to the balloon, which then becomes negatively charged. Therefore, both materials have been ionised.



The gas inside the sphere is ionised by subjecting it to a high-voltage electrical discharge which, in turn, forms what's known as plasma.



Simple friction of one material against another, or electrical discharges, produce the ionisation of atoms.

Atoms can be ionised in many ways, for example: **friction, electrical discharges, collisions between particles,** or **high temperatures** as in the inside of stars.

4.2. Positive and negative ions

If an oxygen atom gains two electrons, it will end up having ten electrons and eight protons. Therefore, it will no longer be neutral and its **net electric charge** will be:

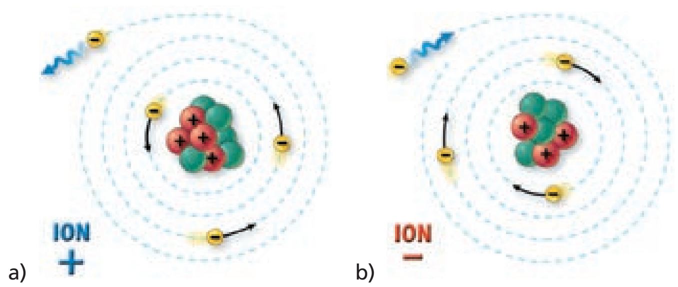
$$-10 + 8 = -2$$

So we say that the oxygen atom is **negatively ionised** because it has gained two electrons. The value –10 represents the negative charge of the 10 electrons and the +8 represents the positive charge of the eight protons.

The opposite process can also happen: a calcium atom, which has twenty electrons and twenty protons, can lose two electrons. In this case, it will end up with 18 electrons and 20 protons so its net electric charge will be:

$$-18 + 20 = +2$$

In this case, the calcium is **positively ionised** because it has lost electrons.



a) b)

Understand

17. When an atom loses electrons, it's positively ionised and if it gains electrons, it's negatively ionised. What is the net electric charge of the atoms in the figures above?

Apply

18. A lead ion has a mass number of 207 and 125 neutrons. If it has 78 electrons, how many protons does it have? What is its net electric charge?

19. An iron ion has a mass number of 56 and in its nucleus there are 30 neutrons. If its oxidation number is +3, how many protons are there in its nucleus? How many electrons are there in the ion?

To summarise:

- **Ionisation** occurs when electrons are gained or lost.
- Atoms that gain electrons have a net negative charge and are called **negative ions** or **anions.**
- Atoms that lose electrons have a net positive charge and are called **positive ions** or **cations.**

4.3. Representing ions. Oxidation number

Atoms are represented by symbols. So, for example, we use F for fluorine and Ca for calcium. If fluorine is ionised by gaining an electron and calcium does it by losing two electrons, we write the process like this:

F + 1 electron = **anion F^-** (we never write the 1)
Ca – 2 electrons = **cation Ca^{2+}**

If the symbol for an element has a + or – sign representing the charge, it tells us it is an ion. If it's negative, it's an anion and if it's positive, it's a cation.

The **net electric charge** of an ionised atom is called the **oxidation number** and it can be positive or negative.

Key concepts

- An atom ionises when it gains or loses electrons.
- When an atom gains electrons, it forms a negative ion or anion.
- When an atom loses electrons, it forms a positive ion or cation.
- The net electric charge of an ion is called the oxidation number.

5. THE ORGANISATION OF ATOMS IN MATTER

Diamonds and the graphite in a pencil are clearly very different from each other but are substances made up of the same chemical element: carbon.

All matter around us is made up of about one hundred **chemical elements.** They are the building blocks of an incredibly varied material world. Each chemical element is defined by the amount of protons in its nucleus.

We can therefore say that:

- A **chemical element** represents all atoms of the same type.
- The number of protons in the nucleus (**atomic number *Z***) defines the type of chemical element and differentiates it from all the others.
- Chemical elements are organised in the **periodic table** according to their atomic number (see the Inorganic Chemistry Appendix).

Therefore, all the oxygen atoms that can be found in nature, **regardless**[13] of how they are organised, make up the 'chemical element oxygen'.

On the other hand, pure substances can be **simple** or **compound substances:**

- A **simple substance** is made up of atoms from the same chemical element.
- A **compound substance** is made up of atoms from different chemical elements.

For example, the oxygen we breathe and the ozone in the stratosphere are simple substances made up of the chemical element oxygen.

On the other hand, water is a compound made up of hydrogen and oxygen.

[13]**regardless:** paying no attention to

[14]**bond:** something that holds things together

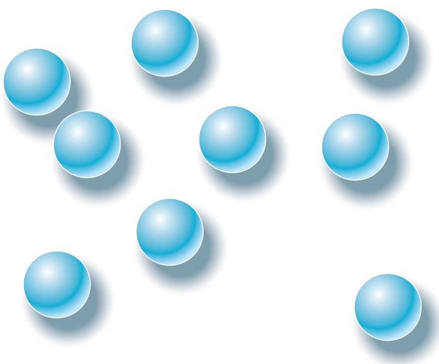
[15]**cluster:** group of the same type of things that are close together

5.1. How are simple substances organised?

Atoms in simple substances are organised in three ways:

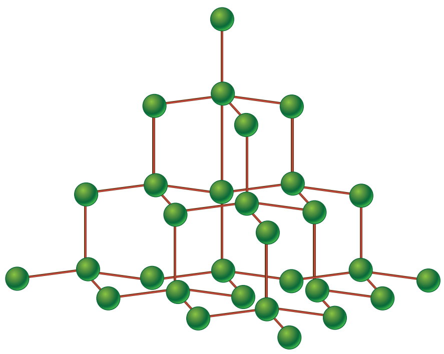
Single atoms

This type of organisation is found in **noble gases** (helium, neon, argon, krypton, xenon and radon) and is made up of single atoms with no **bonds**[14] between them.



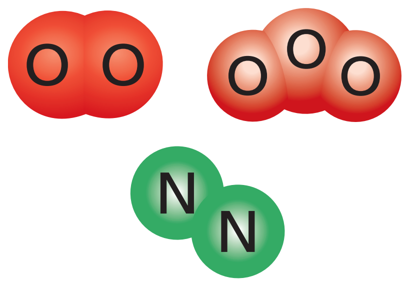
Large clusters[15]

In large clusters, atoms are all bonded to each other. This occurs in metals, diamonds and graphite, which are made up of millions of the same type of atoms all bonded together.



Molecules

In these organisations, two or more atoms of the same type form a **molecule.** The oxygen we breathe, the nitrogen in the air and ozone are made up of molecules. Atoms in molecules come together but the bonds between them are weak or don't exist.



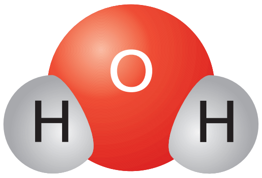
5.2. How are atoms organised in compounds?

Compounds are made up of different types of atoms organised in two different ways:

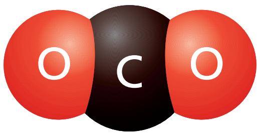
Molecules

In these organisations, molecules are formed by atoms of different types.

For example, water is a compound made up of millions and millions of water molecules which, in turn, are made up of one oxygen atom and two hydrogen atoms.



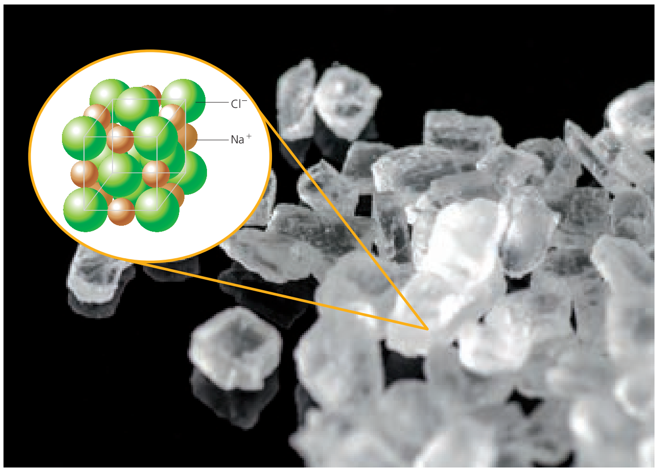
The carbon dioxide that we breathe out in every breath or that is emitted into the atmosphere as a result of combustion is another compound. It's a molecule made up of one carbon atom and two oxygen atoms.



Clusters of ions with different charges

In these organisations, some atoms lose electrons to other atoms which they bond to. In this case, for example, salt or sodium chloride is made up of chlorine and sodium elements. The atom that loses electrons (sodium) is positively ionised, the atom that gains electrons (chlorine) is negatively ionised. Because positive and negative charges attract each other, the ions bond together.

However, an ion with one kind of electric charge attracts all surrounding atoms with the opposite electric charge. So, ions don't bond together to form molecules. Instead, they form clusters called **ionic crystals or compounds.** For example, salt is an ionic compound made up of alternating negative chlorine ions and positive sodium ions in a large structure that forms salt crystals.



Understand

20. Is an atom the same as an element?

21. Match the type of pure substance to the type of structure or group that it can form:

- Simple substance, compound substance
- Molecule, single atoms, large clusters, ion compounds

22. Find out whether the following substances are simple or a compound and which chemical elements they are made up of:

a) Copper **c)** Sulphur
b) Sugar **d)** Alcohol

Key concepts

- Simple substances are made up of only one type of element.
- Compounds are made up of atoms of different elements.
- Simple substances can be single atoms, large clusters or molecules.
- Compounds can be molecules or ion clusters.

6. CHEMICAL FORMULAS

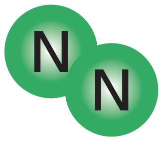
As you can see in the Inorganic Chemistry Appendix, compounds are represented by chemical formulas.

- A **chemical formula** is a symbolic representation of the elements that group up to form substances.
- The numbers on the right of the formula tell us how many atoms form a molecule or the proportion of atoms that form an ionic compound.

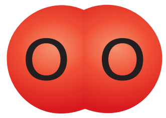
6.1. Formulas for simple substances

The air we breathe is made up of oxygen and nitrogen. However, neither of these gases is found in nature in the form of atoms. Instead, they form molecules of two identical atoms.

Therefore, we say that the molecular formulas of oxygen and nitrogen are:



N_2



O_2

Unit of atomic mass

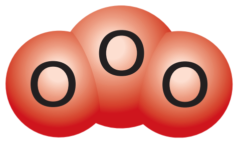
Both atomic mass and molecular mass are expressed in **units of atomic mass (u).** This is equal to the mass of a proton, so:

$$1\ u = 1.66 \times 10^{-27}\ kg$$

Therefore, we can say that the atomic mass of carbon is 12 u.

Similarly, ozone, which is found in the stratosphere and protects us from the ultraviolet radiation from the Sun, is made up of three oxygen atoms.

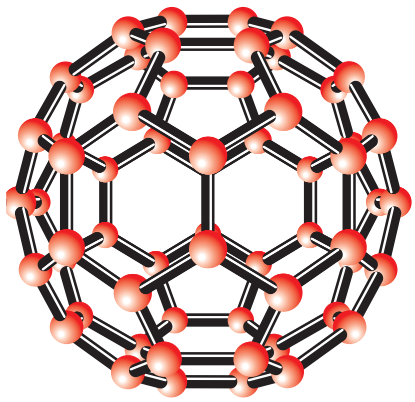
Its formula is:



O_3

In the case of carbon, which is what diamonds and graphite are made of, there are interesting combinations that form spherical or cylindrical structures (nanotubes) called **fullerenes.**

Of these, the most famous one, called a Buckminster fullerene (or bucky-ball), contains sixty carbon atoms:



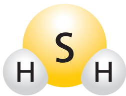
C_{60}

Apart from oxygen and nitrogen, there are other elements that form diatomic molecules: hydrogen, fluorine, chlorine, bromine and iodine. Their chemical formulas are: H_2, F_2, Cl_2, Br_2 and I_2, respectively.

6.2. Formulas in molecular compounds

In the case of compounds made up of molecules, the subscript numbers show how many atoms of each type there are in the molecule. So, the formula for **hydrogen sulphide, H_2S** means:

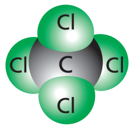
- The compound is formed by the elements hydrogen (H) and sulphur (S).
- The molecule is made up of two hydrogen atoms and one sulphur atom.



H_2S

The formula for **carbon tetrachloride is CCl_4** and means:

- The compound is formed by the elements carbon (C) and chlorine (Cl).
- The molecule is made up of one carbon atom and four chlorine atoms.

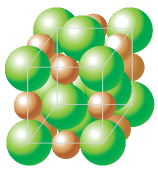


CCl_4

6.3. Formulas in ionic compounds

In the case of **ionic crystals, the chemical formula shows the proportion of ions** which make up the compound. So, the formula for **sodium chloride (NaCl)** means:

- The compound is made up of sodium (Na) and chlorine (Cl).
- In the ionic compound there is one sodium ion for every chlorine ion.



NaCl

6.4. Formulas and molecular masses

The atomic mass of elements is shown in the periodic table, often with decimals, but they are usually close to whole numbers. Thus, we say that the atomic mass of carbon is 12, oxygen 16 and hydrogen 1.

When atoms form molecules or compounds, which we represent with formulas, we refer to the **molecular mass** of a substance.

The **molecular mass** of a substance is the sum of the atomic masses of the atoms that form it in the proportions that are shown in its formula.

EXAMPLE EXERCISE

1. **What is the molecular mass of carbon tetrachloride (CCl_4) if the atomic mass of carbon is 12 and the atomic mass of chloride is 35.5?**

   molecular mass CCl_4 = atomic mass of carbon +
   + 4 × atomic mass of chloride = 12 + (4 × 35.5) = 154

Apply

23. Aluminium oxide is a compound formed by aluminium (Al) and oxygen (O). In this compound, two aluminium atoms combine with three oxygen atoms. Write down the formula with oxygen on the right.

24. Magnesium chloride is an ionic compound made up of chlorine (Cl) and magnesium (Mg) in which the ions of chlorine are double those of magnesium. Write down the formula with chlorine on the right.

25. With the data below, work out the molecular masses for the following substances:

a) H_2O (water)

b) Al_2O_3 (aluminium oxide)

c) C_2H_6O (ethanol)

Data (atomic masses in u):

H = 1; O = 16; Al = 27; C = 12

Key concepts

- Compounds are represented by chemical formulas.
- In molecular compounds, the formula represents the number of atoms of each element combined in the molecule.
- In ionic compounds, the formula represents the proportion of ions in the compound.

Atoms

26. The average thickness of a human hair is 70 microns (μm). How many atoms fit in a line in the thickness of a hair?

27. Look for information about how to calculate the volume of a sphere and supposing that the hydrogen atom is a sphere, calculate its volume given that its diameter is 10^{-10} m.

Electrical phenomena in matter

28. If you rub two pieces of identical plastic against your woollen sweater or your dry hair and then bring the pieces of plastic together, do they attract or repel each other? Explain your answer.

29. Write down and complete in your notebook the following sentence:

"Electrical phenomena can be ___ and ___. They are ___ when charges of the same sign are brought together and ___ when charges of a different sign are brought together."

30. What happens if we put a plastic ruler that you have previously rubbed against your hair near two strips of paper? Why?

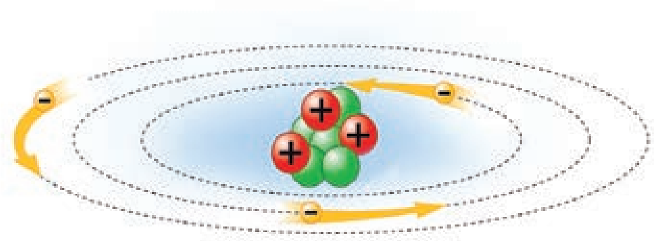
31. What is the name of the process that occurs in the atoms of a plastic ruler when you rub it against your sweater or your hair, which explains its electrification?

Inside the atom: its particles

32. What components of an atom carry an electric charge? Which sign do each of them have?

33. Draw a picture of a helium atom given that it has two protons, two neutrons and two electrons. Draw each component in a different colour and write down the characteristics beside each one.

34. Why do electrons have to be in constant motion around the nucleus?



35. By how many orders of magnitude is the mass of a proton greater than the mass of an electron?

36. Write down and complete the following sentences in your notebook:

a) The centre of an atom is called ___ and has a ___charge.
b) The particles moving around the ___ are called ___and have a ___ charge.
c) Neutral atoms have ___ number of ___ and ___ .
d) ___ have the some mass as ___ but they don't have ___.
e) ___ and ___ form the ___ of all atoms ___.
f) The mass of an atom is determined by the number of ___ and ___ it has.

37. Copy and complete the following table in your notebook:

Atom	Mass number *A*	Number of protons	Number of electrons	Number of neutrons
Hydrogen	1	...	1	...
Sodium	23	11	...	...
Gold	197	...	118	...
Silver	...	...	47	61
Chlorine	35	...	17	...
Iron	56	26	...	...
Oxygen	...	...	8	8
Helium	4	2	...	...

38. An oxygen atom has eight electrons and a mass number of 16. How many protons and neutrons does its nucleus have?

Ions

39. What are ions? Explain how positive and negative ions are formed.

40. Indicate which of the following letters correspond to the same atom:

A^+: 11 protons; 10 electrons; 12 neutrons.
B: 10 protons; 10 electrons; 12 neutrons.
C: 11 protons; 11 electrons; 12 neutrons.
D^+: 2 protons; 11 electrons; 13 neutrons.

41. What will be the net electric charge of an atom with 23 protons that gains three electrons? How many electrons does the resulting ion have?

42. What will be the net electric charge of an atom that had 48 electrons in a neutral state and loses four? How many protons and electrons will the resulting ion have?

43. Work out the electric charge that will remain in each case and specify whether it is positive or negative.

a) A neutral atom gains 3 electrons.

b) A neutral atom loses 2 electrons.

c) An ion of charge +1 gains 1 electron.

d) An ion of charge −3 loses 2 electrons.

e) An ion of charge +1 loses 2 electrons.

f) An ion of charge +1 gains 2 electrons.

44. Copy and complete in your notebook the following table about neutral atoms or ions:

Total charge	Mass number *A*	Number of protons	Number of electrons	Number of neutrons
+3	...	24	...	28
...	80	35	36	...
...	93	...	38	52
−2	79	...	36	...
0	...	...	38	49

Organisation of atoms and formulas

45. Which type of substance; simple or compound, do the following formulas represent? Indicate the number of atoms of each element in the case of compounds:

a) Cl_2 c) H_2SO_4 e) O_3 g) HCl i) F_2

b) S_8 d) H_3PO_4 f) HF h) NaOH j) NH_3

Research the industrial, technological and biomedical applications of these substances.

46. Magnesium chloride is an ionic compound with the formula $MgCl_2$. Choose the right answer:

a) The compound is made up of molecules which have one magnesium atom and two chlorine atoms.

b) The compound is made up of molecules which have two magnesium atoms and one chlorine atom.

c) The compound is made up of one magnesium ion for every chlorine ion.

d) The compound is made up of one magnesium ion for every two chlorine ions.

READ AND UNDERSTAND SCIENCE

Atoms are ageless. Many atoms in your body are almost as old as the Universe itself, passing and recycling through numerous hosts, whether living or inert. For example, when you breathe in, only some of the atoms you inhale are expelled in your next breath. The remaining ones are left in your body and become part of you and then leave your body by various means. You don't 'own' the atoms in your body; they are borrowed. We all share the same reserve of atoms because atoms migrate around, within and among us.

(Translated and adapted)
Paul G. Hewitt.
Conceptual physics.

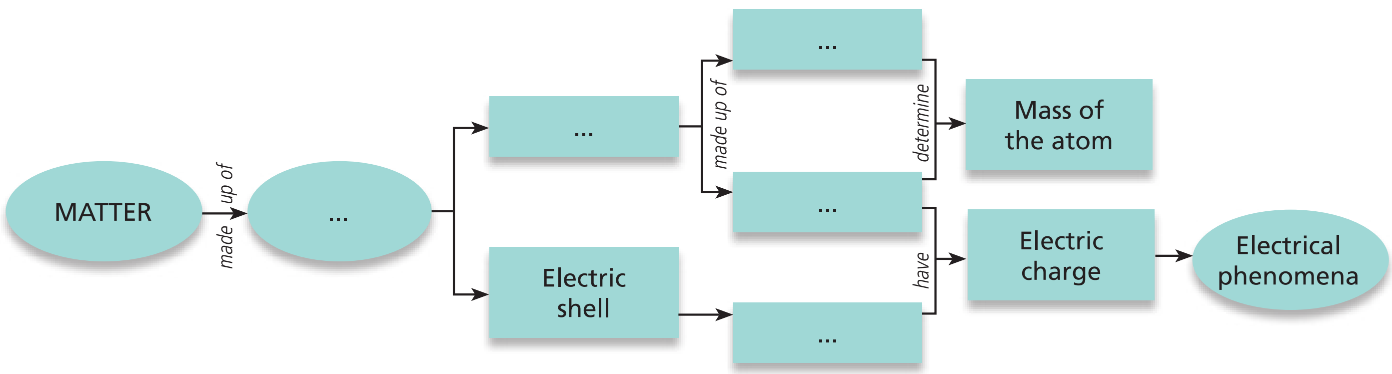
a) In your own words, write a short summary of the main idea presented in this text.

b) It is often said that 'we are stardust'. What do you think it means? Look for information if necessary.

STUDY SKILLS

You can record your summary and listen to it as many times as you like for revision purposes.

- Create your own summary of the unit using the *Key Concepts.* Add any other important information.
- Copy the following diagram and add the missing information to create a concept map of the unit.



- Create your own scientific glossary. Include the following words: *atoms*, *protons*, *electrons*, *neutrons*, *mass number*, *simple substance* and *compound.* You can add other terms you consider important.

Atomic models of pure substances

We are going to represent models of pure substances at an atomic scale by building atoms of different elements with modelling clay to scale. The pure substances we are going to represent are metal iron and solid water (ice). We need to make hydrogen, oxygen and iron atoms. The approximate scale is; hydrogen atom (sphere with diameter of 1 cm); oxygen atom (sphere with diameter of 2 cm); iron atom (sphere with diameter of 3.5 cm).

Materials

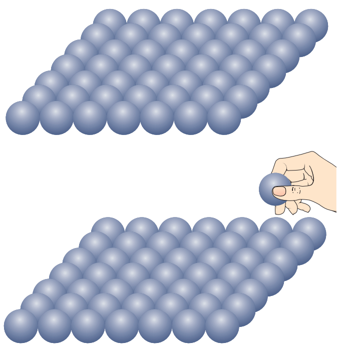
- Yellow modelling clay (hydrogen)
- Blue modelling clay (iron)
- Red modelling clay (oxygen)
- Ruler

Procedure

Form groups of four students and make atoms of the types indicated at the scale suggested (about 30 of each type).

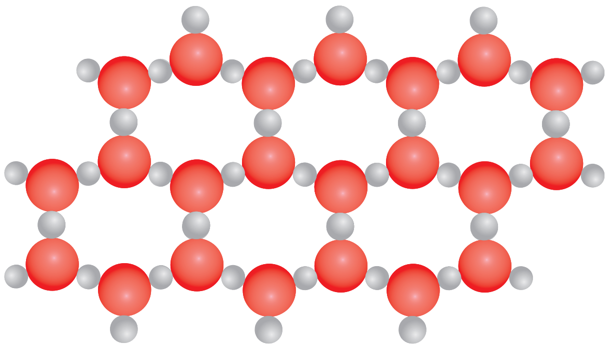
Iron: a simple substance

- Put a few iron atoms together on the table to form a base, as shown in the diagram.
- Put a second layer of atoms above the previous atoms, placing them on the gaps left between the atoms. The second layer should look like the first one.
- Continue in the same way as above to complete a third and fourth layer.



Water: a compound

- The formula for water is H_2O and the shape of the molecule is shown on page 69. Build 30 water molecules.
- Arrange the molecules as shown in the diagram to form the structure of solid water.



Analysis of the results

a) Considering the atomic structures that you have built, which of the two pure substances will be denser? Give an explanation from an atomic point of view.

b) Note that in the case of ice, there are large gaps in the crystal structure. When the ice melts, many of the bonds between the water molecules are broken. Undo some of those joints and allow the molecules to be distributed randomly. Are they closer together now? Is liquid water denser than solid water?

1. Write a scientific report of your work and make a slideshow presentation. Show your results to the rest of your class.

FINAL TASK

Materials and products in a laboratory: labelling and safety measures

Throughout the course you may need to perform some experiments in the chemistry laboratory. Before handling materials or chemicals it's very important to know their names and their uses. It's also essential that you understand the meaning of the labels on chemicals, as they tell us about potential risks and danger. To learn about this you will carry out this research task, in groups, with the collaboration and direction of your teacher.

1. Research

a) What are the most common materials in the chemistry lab and what are they used for?

b) What is the meaning of the hazard labels on chemical products?

2. Experiment

a) Make a list of lab materials used to measure volumes. Indicate whether they are only for measuring a particular volume or if they are graduated. In this case, indicate the grade scale.

b) Under the supervision of the teacher, use a pipette and propipette to collect small volumes of liquid (we start with water and with different volumes) and transfer them to different test tubes.

c) Learn how to use a burette to allow the release of liquid drop by drop and count the number of drops in 1 mL of water.

3. Presentation

a) Make a poster and a presentation on the most common materials and containers in a chemistry lab.

b) Make a poster and a presentation about the hazard labels on chemicals, specifying the meaning in each case.

SELF-ASSESSMENT

After completing the research task, answer the following questions:

1. Did you carry out the tasks in the Research section correctly?
2. Did you carry out the tasks in the Experiment section?
3. Did you collect all information about the meaning of hazard labels?
4. Did you draw or take photographs of the most common materials in a lab?
5. Did you take an active role in writing the report and the presentation?

Procedure

Organise the information

- The research task must be carried out in groups.
- You should be especially careful with the use of glassware and chemicals whose labels must be checked. Your teacher will be in charge of opening them if you need them.

Search for information

- These labels are common on the containers of many chemicals. Investigate the meaning of labels like these, and the measures to be taken should they be damaged during handling.

Draw conclusions and check your results

- Write the report and the presentation, including the conclusions of the study and indicating whether your lab meets the required safety conditions.