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The Free High School Science Texts: Textbooks for High School Students Studying the Sciences
Chemistry
Grades 10 - 12

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Contents

Chapter 11

Physical and Chemical Change - Grade 10

Matter is all around us. The desks we sit at, the air we breathe and the water we drink, are all examples of matter. But matter doesn't always stay the same. It can change in many different ways. In this chapter, we are going to take a closer look at **physical** and **chemical** changes that occur in matter.

11.1 Physical changes in matter

A **physical change** is one where the particles of the substances that are involved in the change are not broken up in any way. When water is heated for example, the temperature and energy of the water molecules increases and the liquid water evaporates to form water vapour. When this happens, some kind of change has taken place, but the molecular structure of the water has not changed. This is an example of a *physical change*.

$$H_2O(l) \rightarrow H_2O(g)$$

Conduction (the transfer of energy through a material) is another example of a physical change. As energy is transferred from one material to another, the *energy* of each material is changed, but not its chemical makeup. Dissolving one substance in another is also a physical change.

Definition: Physical change
A change that can be seen or felt, but that doesn't involve the break up of the particles in the reaction. During a physical change, the *form* of matter may change, but not its *identity*. A change in temperature is an example of a physical change.

There are some important things to remember about physical changes in matter:

- *Arrangement of particles*

  When a physical change occurs, the particles (e.g. atoms, molecules) may re-arrange themselves without actually breaking up in any way. In the example of evaporation that we used earlier, the water molecules move further apart as their temperature (and therefore energy) increases. The same would be true if ice were to melt. In the solid phase, water molecules are packed close together in a very ordered way, but when the ice is heated, the molecules overcome the forces holding them together and they move apart. Once again, the particles have re-arranged themselves, but have not broken up.

$$H_2O(s) \rightarrow H_2O(l)$$

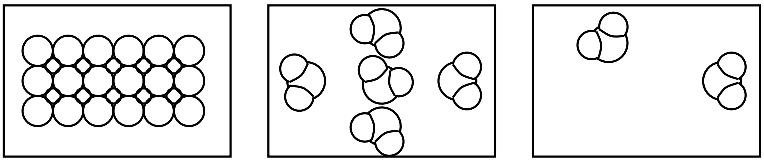


Figure 11.1: The arrangement of water molecules in the three phases of matter

Figure 11.1 shows this more clearly. In each phase of water, the water molecule itself stays the same, but the way the molecules are arranged has changed.

In a physical change, the total mass, the number of atoms and the number of molecules will always stay the same.

- *Energy changes*

  Energy changes may take place when there is a physical change in matter, but these energy changes are normally smaller than the energy changes that take place during a chemical change.

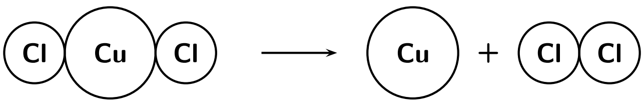
- *Reversibility*

  Physical changes in matter are usually easier to reverse than chemical changes. Water vapour for example, can be changed back to liquid water if the temperature is lowered. Liquid water can be changed into ice by simply increasing the temperature, and so on.

11.2 Chemical Changes in Matter

When a **chemical change** takes place, new substances are formed in a chemical reaction. These new products may have very different properties from the substances that were there at the start of the reaction.

The breakdown of copper(II) chloride to form copper and chlorine is an example of chemical change. A simplified diagram of this reaction is shown in figure 11.2. In this reaction, the initial substance is copper(II) chloride but, once the reaction is complete, the products are copper and chlorine.



$$CuCl_2 \rightarrow Cu + Cl_2$$

Figure 11.2: The decomposition of copper(II) chloride to form copper and chlorine

Definition: Chemical change
The formation of new substances in a chemical reaction. One type of matter is changed into something different.

There are some important things to remember about chemical changes:

- *Arrangement of particles*

During a chemical change, the particles themselves are changed in some way. In the example of copper (II) chloride that was used earlier, the $CuCl_2$ molecules were split up into their component atoms. The number of particles will change because each one $CuCl_2$ molecule breaks down into one copper atom (Cu) and one chlorine molecule (Cl_2). However, what you should have noticed, is that the number of atoms of each element stays the same, as does the total mass of the atoms. This will be discussed in more detail in a later section.

- *Energy changes*

  The energy changes that take place during a chemical reaction are much greater than those that take place during a physical change in matter. During a chemical reaction, energy is used up in order to break bonds, and then energy is released when the new product is formed. This will be discussed in more detail in section **??**.

- *Reversibility*

  Chemical changes are far more difficult to reverse than physical changes.

Two types of chemical reactions are **decomposition reactions** and **synthesis reactions**.

11.2.1 Decomposition reactions

A **decomposition reaction** occurs when a chemical compound is broken down into elements or smaller compounds. The generalised equation for a decomposition reaction is:

$$AB \rightarrow A + B$$

One example of such a reaction is the decomposition of hydrogen peroxide (figure 11.3) to form hydrogen and oxygen according to the following equation:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

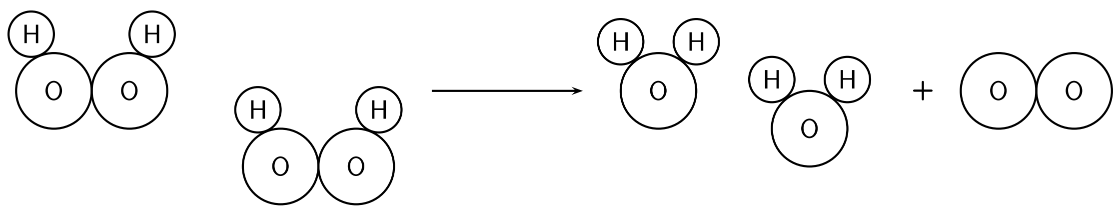


Figure 11.3: The decomposition of H_2O_2 to form H_2O and O_2

The decomposition of mercury (II) oxide is another example.

Activity :: Experiment : The decomposition of mercury (II) oxide

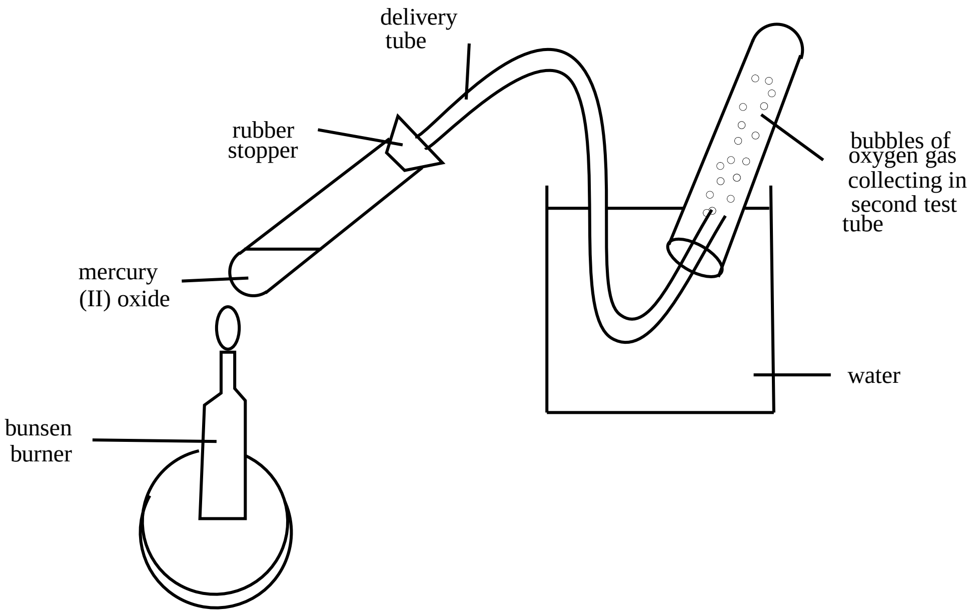
Aim:

To observe the decomposition of mercury (II) oxide when it is heated.

Note: Because this experiment involves mercury, which is a poisonous substance, it should be done in a fume cupboard, and all the products of the reaction must be very carefully disposed of.

Apparatus:

Mercury (II) oxide (an orange-red product); two test tubes; a large beaker; stopper and delivery tube; Bunsen burner; wooden splinter.



Method:

1. Put a small amount of mercury (II) oxide in a test tube and heat it gently over a Bunsen burner. Then allow it to cool. What do you notice about the colour of the mercury (II) oxide?
2. Heat the test tube again, and note what happens. Do you notice anything on the walls of the test tube? Record these observations.
3. Test for the presence of oxygen using a glowing splinter.

Results:

- During the first heating of mercury (II) oxide, the only change that took place was a change in colour from orange-red to black and then back to its original colour.
- When the test tube was heated again, deposits of mercury formed on the inner surface of the test tube. What colour is this mercury?
- The glowing splinter burst into flame when it was placed in the test tube, meaning that oxygen is present.

Conclusions:

When mercury is heated, it decomposes to form mercury and oxygen. The chemical decomposition reaction that takes place can be written as follows:

$$2HgO \rightarrow 2Hg + O_2$$

11.2.2 Synthesis reactions

During a **synthesis reaction**, a new product is formed from smaller elements or compounds. The generalised equation for a synthesis reaction is as follows:

$$A + B \rightarrow AB$$

One example of a synthesis reaction is the burning of magnesium in oxygen to form magnesium oxide. The equation for the reaction is:

$$2Mg + O_2 \rightarrow 2MgO$$

Figure 11.4 shows the chemical changes that take place at a microscopic level during this chemical reaction.

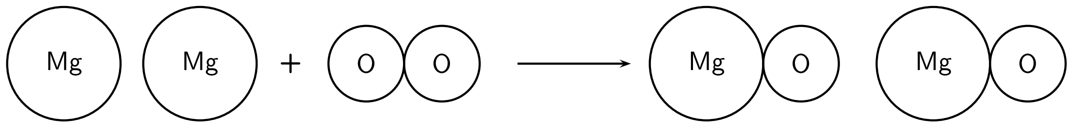


Figure 11.4: The synthesis of magnesium oxide (MgO) from magnesium and oxygen

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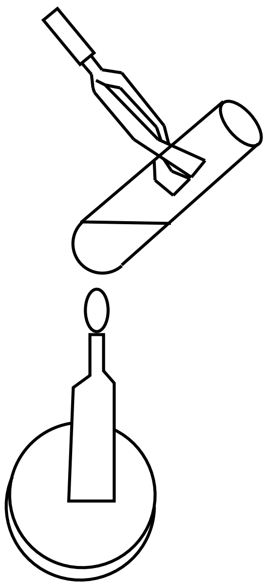
Activity :: Experiment : Chemical reactions involving iron and sulfur

Aim:

To demonstrate the synthesis of iron sulfide from iron and sulfur.

Apparatus:

5.6 g iron filings and 3.2 g powdered sulfur; porcelain dish; test tube; bunsen burner



Method:

1. Before you carry out the experiment, write a balanced equation for the reaction you expect will take place.
2. Measure the quantity of iron and sulfur that you need and mix them in a porcelain dish.
3. Take some of this mixture and place it in the test tube. The test tube should be about 1/3 full.
4. This reaction should ideally take place in a fume cupboard. Heat the test tube containing the mixture over the Bunsen burner. Increase the heat if no reaction takes place. Once the reaction begins, you will need to remove the test tube from the flame. Record your observations.

5. Wait for the product to cool before breaking the test tube with a hammer. Make sure that the test tube is rolled in paper before you do this, otherwise the glass will shatter everywhere and you may be hurt.
6. What does the product look like? Does it look anything like the original reactants? Does it have any of the properties of the reactants (e.g. the magnetism of iron)?

Results:

- After you removed the test tube from the flame, the mixture glowed a bright red colour. The reaction is exothermic and *produces energy*.
- The product, iron sulfide, is a dark colour and does not share any of the properties of the original reactants. It is an entirely new product.

Conclusions:

A synthesis reaction has taken place. The equation for the reaction is:

$$Fe + S \rightarrow FeS$$

Activity :: Investigation : Physical or chemical change?

Apparatus:

Bunsen burner, 4 test tubes, a test tube rack and a test tube holder, small spatula, pipette, magnet, a birthday candle, NaCl (table salt), 0.1M $AgNO_3$, 6M HCl, magnesium ribbon, iron filings, sulfur.

Method:

1. Place a small amount of wax from a birthday candle into a test tube and heat it over the bunsen burner until it melts. Leave it to cool.
2. Add a small spatula of NaCl to 5 ml water in a test tube and shake. Then use the pipette to add 10 drops of $AgNO_3$ to the sodium chloride solution.
3. Take a 5 cm piece of magnesium ribbon and tear it into 1 cm pieces. Place two of these pieces into a test tube and add a few drops of 6M HCl. NOTE: Be very careful when you handle this acid because it can cause major burns.
4. Take about 0.5 g iron filings and 0.5 g sulfur. Test each substance with a magnet. Mix the two samples in a test tube, and run a magnet alongside the outside of the test tube.
5. Now heat the test tube that contains the iron and sulfur. What changes do you see? What happens now, if you run a magnet along the outside of the test tube?
6. In each of the above cases, record your observations.

Questions:

Decide whether each of the following changes are physical or chemical and give a reason for your answer in each case. Record your answers in the table below:

Description	Physical or chemical change	Reason
melting candle wax		
dissolving NaCl		
mixing NaCl with $AgNO_3$		
tearing magnesium ribbon		
adding HCl to magnesium ribbon		
mixing iron and sulfur		
heating iron and sulfur		

11.3 Energy changes in chemical reactions

All reactions involve some change in energy. During a *physical* change in matter, such as the evaporation of liquid water to water vapour, the energy of the water molecules increases. However, the change in energy is much smaller than in chemical reactions.

When a chemical reaction occurs, some bonds will *break*, while new bonds may *form*. Energy changes in chemical reactions result from the breaking and forming of bonds. For bonds to *break*, energy must be *absorbed*. When new bonds *form*, energy will be *released* because the new product has a lower energy than the 'inbetween' stage of the reaction when the bonds in the reactants have just been broken.

In some reactions, the energy that must be *absorbed* to break the bonds in the reactants, is less than the total energy that is *released* when new bonds are formed. This means that in the overall reaction, energy is *released*. This type of reaction is known as an **exothermic** reaction. In other reactions, the energy that must be *absorbed* to break the bonds in the reactants, is more than the total energy that is *released* when new bonds are formed. This means that in the overall reaction, energy must be *absorbed* from the surroundings. This type of reaction is known as an **endothermic** reaction. In the earlier part of this chapter, most decomposition reactions were endothermic, and heating was needed for the reaction to occur. Most of the synthesis reactions were exothermic, meaning that energy was given off in the form of heat or light.

More simply, we can describe the energy changes that take place during a chemical reaction as:

Total energy absorbed to break bonds - Total energy released when new bonds form

So, for example, in the reaction...

$$2Mg + O_2 \rightarrow 2MgO$$

Energy is needed to break the O-O bonds in the oxygen molecule so that new Mg-O bonds can be formed, and energy is released when the product (MgO) forms.

Despite all the energy changes that seem to take place during reactions, it is important to remember that energy cannot be created or destroyed. Energy that enters a system will have come from the surrounding environment, and energy that leaves a system will again become part of that environment. This principle is known as the principle of **conservation of energy.**

Definition: Conservation of energy principle
Energy cannot be created or destroyed. It can only be changed from one form to another.

Chemical reactions may produce some very visible, and often violent, changes. An explosion, for example, is a sudden increase in volume and release of energy when high temperatures are generated and gases are released. For example, NH_4NO_3 can be heated to generate nitrous oxide. Under these conditions, it is highly sensitive and can detonate easily in an explosive exothermic reaction.

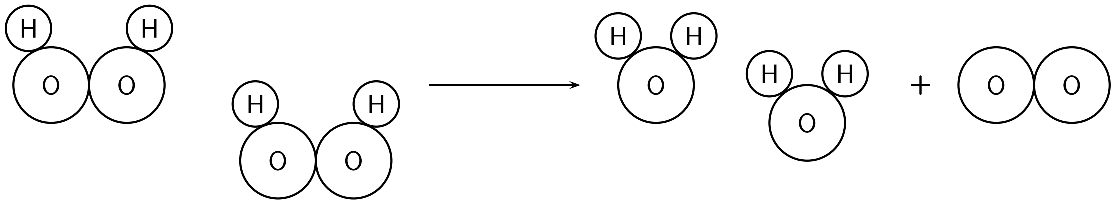
11.4 Conservation of atoms and mass in reactions

The total mass of all the substances taking part in a chemical reaction is conserved during a chemical reaction. This is known as the **law of conservation of mass**. The total number of **atoms** of each element also remains the same during a reaction, although these may be arranged differently in the products.

We will use two of our earlier examples of chemical reactions to demonstrate this:

- The decomposition of hydrogen peroxide into water and oxygen

$$2H_2O_2 \rightarrow 2H_2O + O_2$$



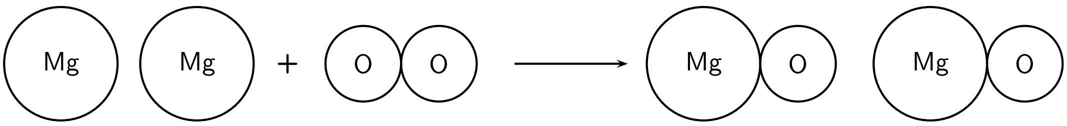
Left hand side of the equation
Total atomic mass = (4 × 1) + (4 × 16) = 68 u
Number of atoms of each element = (4 × H) + (4 × O)

Right hand side of the equation
Total atomic mass = (4 × 1) + (2 × 16) + (2 × 16) = 68 u
Number of atoms of each element = (4 × H) + (4 × O)

Both the atomic mass and the number of atoms of each element are conserved in the reaction.

- The synthesis of magnesium and oxygen to form magnesium oxide

$$2Mg + O_2 \rightarrow 2MgO$$



Left hand side of the equation
Total atomic mass = (2 × 24.3) + (2 × 16) = 80.6 u
Number of atoms of each element = (2 × Mg) + (2 × O)

Right hand side of the equation
Total atomic mass = (2 × 24.3) + (2 × 16) = 80.6 u
Number of atoms of each element = (2 × Mg) + (2 × O)

Both the atomic mass and the number of atoms of each element are conserved in the reaction.

Activity :: Demonstration : The conservation of atoms in chemical reactions

Materials:

- Coloured marbles or small balls to represent atoms. Each colour will represent a different element.

- Prestik

Method:

1. Choose a reaction from any that have been used in this chapter or any other *balanced* chemical reaction that you can think of. To help to explain this activity, we will use the decomposition reaction of calcium carbonate to produce carbon dioxide and calcium oxide.

$$CaCO_3 \rightarrow CO_2 + CaO$$

2. Stick marbles together to represent the reactants and put these on one side of your table. In this example you may for example join one red marble (calcium), one green marble (carbon) and three yellow marbles (oxygen) together to form the molecule calcium carbonate ($CaCO_3$).
3. Leaving your reactants on the table, use marbles to make the product molecules and place these on the other side of the table.
4. Now count the number of atoms on each side of the table. What do you notice?
5. Observe whether there is any difference between the molecules in the reactants and the molecules in the products.

Discussion

You should have noticed that the number of atoms in the reactants is the same as the number of atoms in the product. The number of atoms is conserved during the reaction. However, you will also see that the molecules in the reactants and products is not the same. The *arrangement of atoms* is not conserved during the reaction.

11.5 Law of constant composition

In any given chemical compound, the elements always combine in the same proportion with each other. This is the **law of constant proportions**.

The **law of constant composition** says that, in any particular chemical compound, all samples of that compound will be made up of the same elements in the same proportion or ratio. For example, any water molecule is always made up of two hydrogen atoms and one oxygen atom in a 2:1 ratio. If we look at the relative masses of oxygen and hydrogen in a water molecule, we see that 94% of the mass of a water molecule is accounted for by oxygen, and the remaining 6% is the mass of hydrogen. This mass proportion will be the same for any water molecule.

This does not mean that hydrogen and oxygen always combine in a 2:1 ratio to form H_2O. Multiple proportions are possible. For example, hydrogen and oxygen may combine in different proportions to form H_2O_2 rather than H_2O. In H_2O_2, the H:O ratio is 1:1 and the mass ratio of hydrogen to oxygen is 1:16. This will be the same for any molecule of hydrogen peroxide.

11.6 Volume relationships in gases

In a chemical reaction between gases, the relative volumes of the gases in the reaction are present in a ratio of small whole numbers if all the gases are at the same temperature and pressure. This relationship is also known as **Gay-Lussac's Law**.

For example, in the reaction between hydrogen and oxygen to produce water, two volumes of H_2 react with 1 volume of O_2 to produce 2 volumes of H_2O.

$$2H_2 + O_2 \rightarrow 2H_2O$$

In the reaction to produce ammonia, one volume of nitrogen gas reacts with three volumes of hydrogen gas to produce two volumes of ammonia gas.

$$N_2 + 3H_2 \rightarrow 2NH_3$$

This relationship will also be true for all other chemical reactions.

11.7 Summary

- Matter does not stay the same. It may undergo physical or chemical changes
- A **physical change** means that the form of matter may change, but not its identity. For example, when water evaporates, the energy and the arrangement of water molecules will change, but not the structure of the water molecule itself.
- During a physical change, the **arrangement of particles** may change but the mass, number of atoms and number of molecules will stay the same.
- Physical changes involve small changes in **energy**, and are easily reversible.
- A chemical change occurs when one form of matter changes into something else. A chemical reaction involves the formation of new substances with **different properties**. For example, carbon dioxide reacts with water to form carbonic acid.

$$CO_2 + H_2O \rightarrow H_2CO_3$$

- A chemical change may involve a **decomposition** or **synthesis** reaction. During chemical change, the mass and number of atoms is conserved, but the number of molecules is not always the same.
- Chemical reactions involve larger changes in energy. During a reaction, energy is needed to break bonds in the reactants, and energy is released when new products form. If the energy released is greater than the energy absorbed, then the reaction is exothermic. If the energy released is less than the energy absorbed, then the reaction is endothermic. These chemical reactions are not easily reversible.
- Decomposition reactions are usually **endothermic** and synthesis reactions are usually **exothermic**.
- The **law of conservation of mass** states that the total mass of all the substances taking part in a chemical reaction is conserved and the number of atoms of each element in the reaction does not change when a new product is formed.
- The **conservation of energy principle** states that energy cannot be created or destroyed, it can only change from one form to another.
- The **law of constant composition** states that in any particular compound, all samples of that compound will be made up of the same elements in the same proportion or ratio.
- **Gay-Lussac's Law** states that in a chemical reaction between gases, the relative volumes of the gases in the reaction are present in a ratio of small whole numbers if all the gases are at the same temperature and pressure.

?

Exercise: Summary exercise

1. Complete the following table by saying whether each of the descriptions is an example of a physical or chemical change:

Description	Physical or chemical
hot and cold water mix together	
milk turns sour	
a car starts to rust	
food digests in the stomach	
alcohol disappears when it is placed on your skin	
warming food in a microwave	
separating sand and gravel	
fireworks exploding	

2. For each of the following reactions, say whether it is an example of a synthesis or decomposition reaction:
   (a) $(NH_4)_2CO_3 \rightarrow 2NH_3 + CO_2 + H_2O$
   (b) $4Fe + 3O_2 \rightarrow 2Fe_2O_3$
   (c) $N_2(g) + 3H_2(g) \rightarrow 2NH_3$
   (d) $CaCO_3(s) \rightarrow CaO + CO_2$
3. For the following equation:

$$CaCO_3 \rightarrow CO_2 + CaO$$

   Show that the 'law of conservation of mass' applies.

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