COSMOS LESSONS

Chemistry

Chemical Reactions: Exploding myths

You may have seen your teacher drop a sliver of sodium into water – it's a classic chemistry demonstration with explosive results. A team of scientists in the Czech Republic was so intrigued by this reaction they spent their Saturday afternoons investigating what really happens.

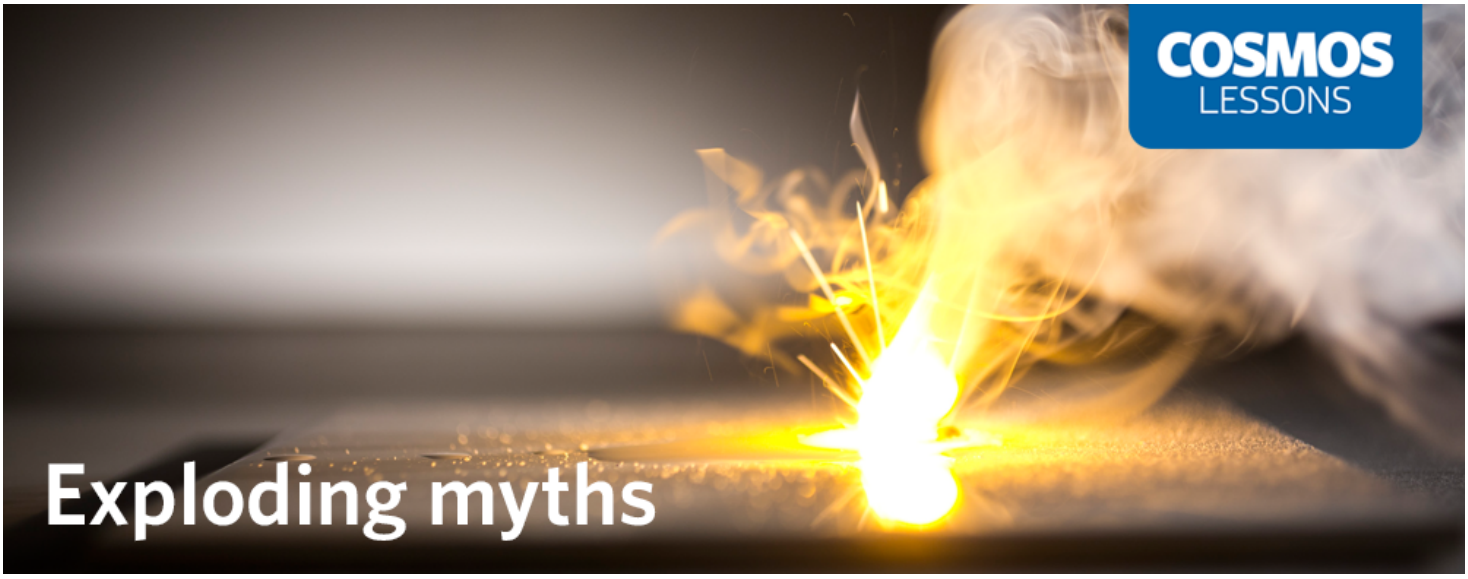
In this lesson you will investigate the following:

- What is a chemical reaction?
- How do we represent chemical reactions?
- Why do chemical equations need to be balanced?
- What happens during an explosion?

Get ready for a mind-blowing look at chemical reactions!

This is a print version of an interactive online lesson.
To sign up for the real thing or for curriculum details about the lesson go to **http://www.cosmosforschools.com**

Introduction: Chemical Reactions



Explosions in the chemistry lab are guaranteed to brighten up every lesson. An old favourite is when the teacher drops a lump of sodium into water to demonstrate one of the more violent chemical reactions. Sodium is a highly reactive metal that rips apart the water molecules to release hydrogen gas and heat. The cloud of hot gas rapidly expands and often ignites, creating a spectacular explosion.

You would think that after generations of school students learning this basic lesson it would hold few secrets. But it turns out that the old textbook explanation had some holes in it.

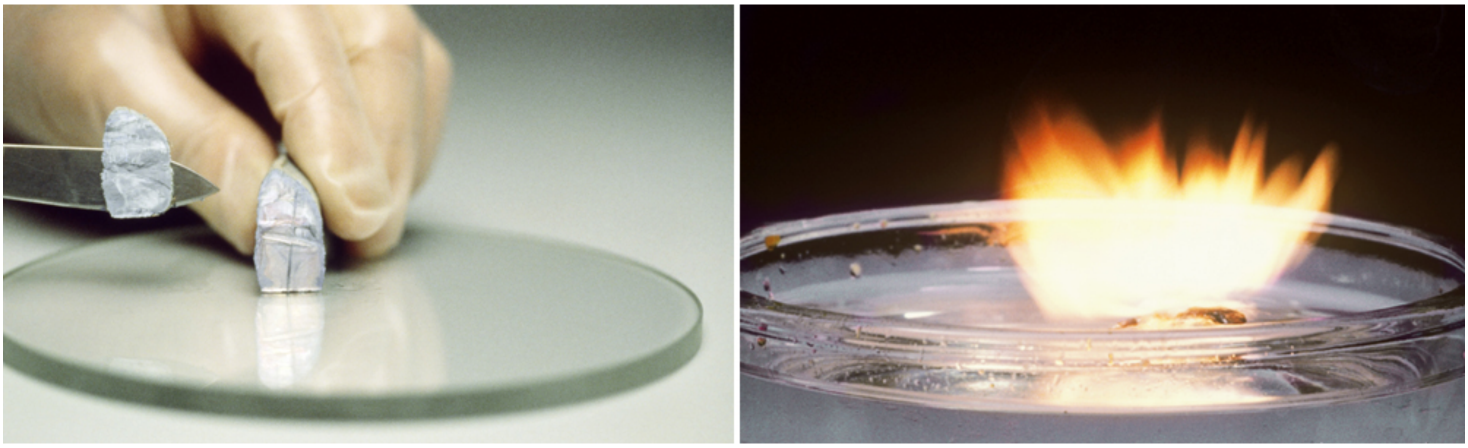
A team of chemists working in the Czech Republic noticed something was wrong. A good gas explosion requires that the ingredients keep mixing together so that the reaction can continue. But in the standard explanation of the sodium–water reaction this shouldn't happen. As soon as the lump of metal hits the water, it will be instantly enveloped in a cloud of hydrogen gas. This should cut the sodium off from the water and stop the reaction. Plainly, this doesn't happen.

The scientists came up with an alternative explanation. As the lump of sodium reacts with the water the particles around its edges become positively charged because of the chemical reaction. But positive charges repel each other. They hypothesized that the repulsive forces between these tightly packed particles might force sodium out through the film of gas to react with more water.

The only way the scientists could test this hypothesis was to film the reaction, using a super-high-speed camera to catch the sodium in the act. Sure enough, within 100 microseconds of hitting the water, spikes of sodium shot out like hairs standing on end. Then BOOM! The explosion.

It just goes to show, we can never stop questioning things – even when we think we know them for sure.

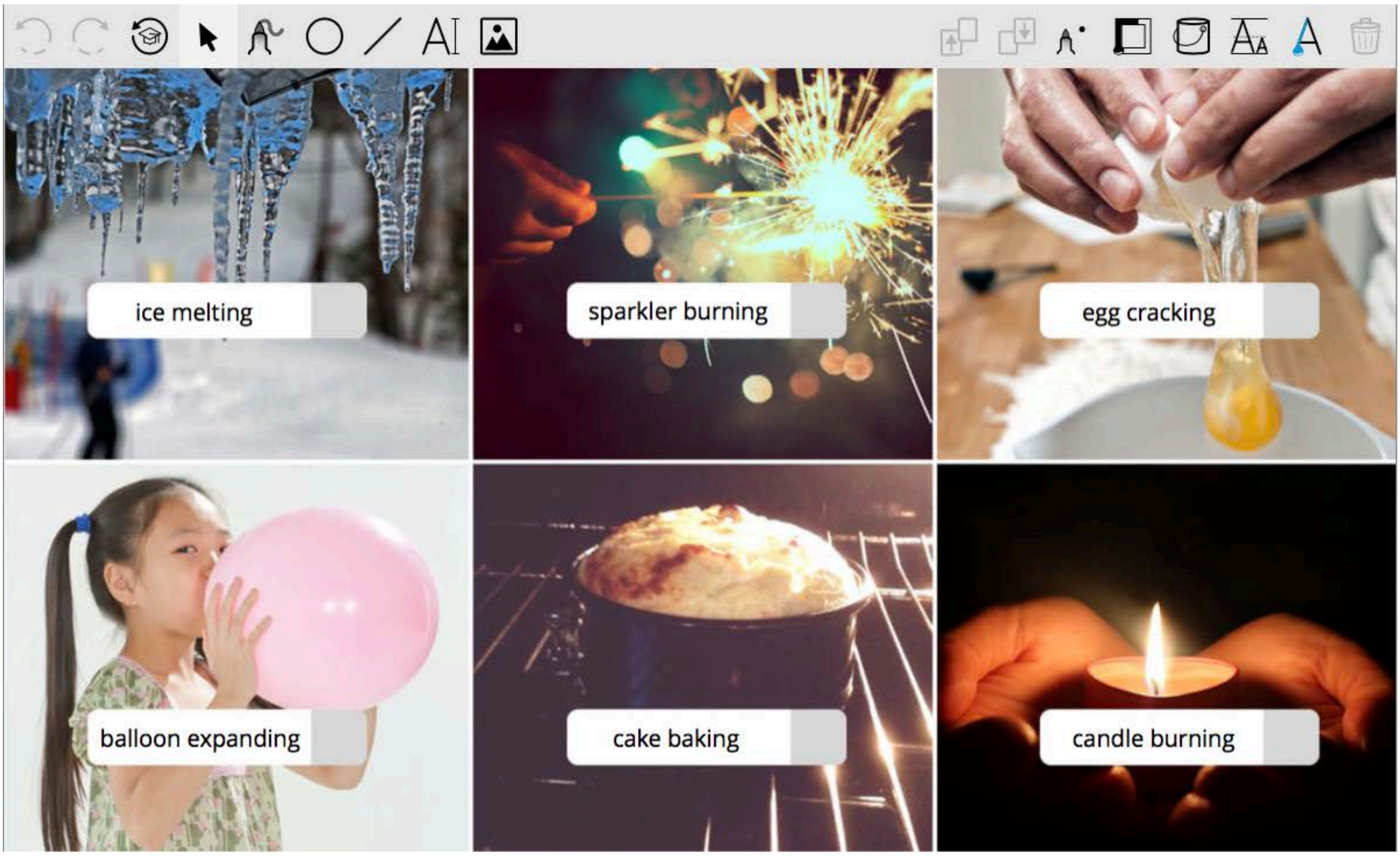
Read or listen to the full *Cosmos Magazine* article here.



Left: The chemical element sodium is a silvery metal that is soft enough to cut with a knife. Right: When sodium is added to water a vigorous chemical reaction produces explosions of gas that often burst into flames.

Question 1

Identify: Can you spot a chemical reaction when you see one? Based on your prior knowledge, identify whether each of the images below shows a chemical reaction (C) or a merely physical change (P).



Gather: Chemical Reactions

COSMOS LESSONS

Chemical reactions

All chemical reactions involve the conversion of one or more chemicals, known as **reactants**, into one or more *new* chemicals, known as **products**. For example, when you pass electricity through water it breaks down to form two gases: hydrogen and oxygen. Water is the reactant and hydrogen and oxygen are the products.

Question 1

Identify: Chemical compounds consist of atoms of two or more elements joined together in certain fixed combinations. Which of the following are compounds?

- [ ] Lead oxide
- [ ] Oxygen
- [ ] Water
- [ ] Hydrogen

Question 2

Recall: Electricity can be used to break down water into its component elements. This chemical reaction produces:

- [ ] equal amounts of hydrogen and oxygen.
- [ ] only oxygen.
- [ ] only hydrogen.
- [ ] twice as much hydrogen as oxygen.
- [ ] twice as much oxygen as hydrogen.

Chemical equations

Any reaction can be represented by a **chemical equation** with the following form:

$$\textit{reactants} \longrightarrow \textit{products}$$

For example: water $\longrightarrow$ hydrogen gas + oxygen gas

This is an example of a **word equation**, which uses the *names* of the chemicals involved. Although this is useful, it doesn't tell us what's going on at the atomic level. In every reaction:

- chemical bonds between atoms in the reactants are broken,
- the atoms are rearranged and form new bonds to create the products.

These changes can be represented by replacing the names of the chemicals with their **chemical formulas**. The letters in a chemical formula are the symbols for the elements that make up the substance. The subscripted numbers tell you the relative number of atoms of each element. In many cases the chemical formula tells you how many atoms of each element make up one molecule. In others it relates to the ratio of elements in a continuous structure such as a salt crystal.

For example, the chemical formula of water – H_2O – tells you that each molecule of water is made up of two hydrogen atoms bound to one oxygen atom. Oxygen gas, O_2, consists of molecules in which two oxygen atoms are bound together. Rewritten with chemical formulas, the above equation becomes:

$$H_2O \longrightarrow H_2 + O_2$$

This equation is still incomplete – we'll look at why below.

Question 3

Classify: Rusting is a chemical reaction in which iron reacts with oxygen in the air to form iron oxide. The reactants are:

- ☐ oxygen and iron oxide
- ☐ iron
- ☐ iron and oxygen
- ☐ iron, oxygen and iron oxide

Question 4

Analyze: How many hydrogen atoms are there in each molecule of ammonia, NH_3?

- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4

Did you know?

There are rules for naming chemicals based on their chemical formulas. For example, table salt has the formula NaCl so it has the chemical name "sodium chloride". Using these rules, H_2O can be given the chemical name "dihydrogen monoxide" because "di-" means two and "mon-" means one: two hydrogens and one oxygen.

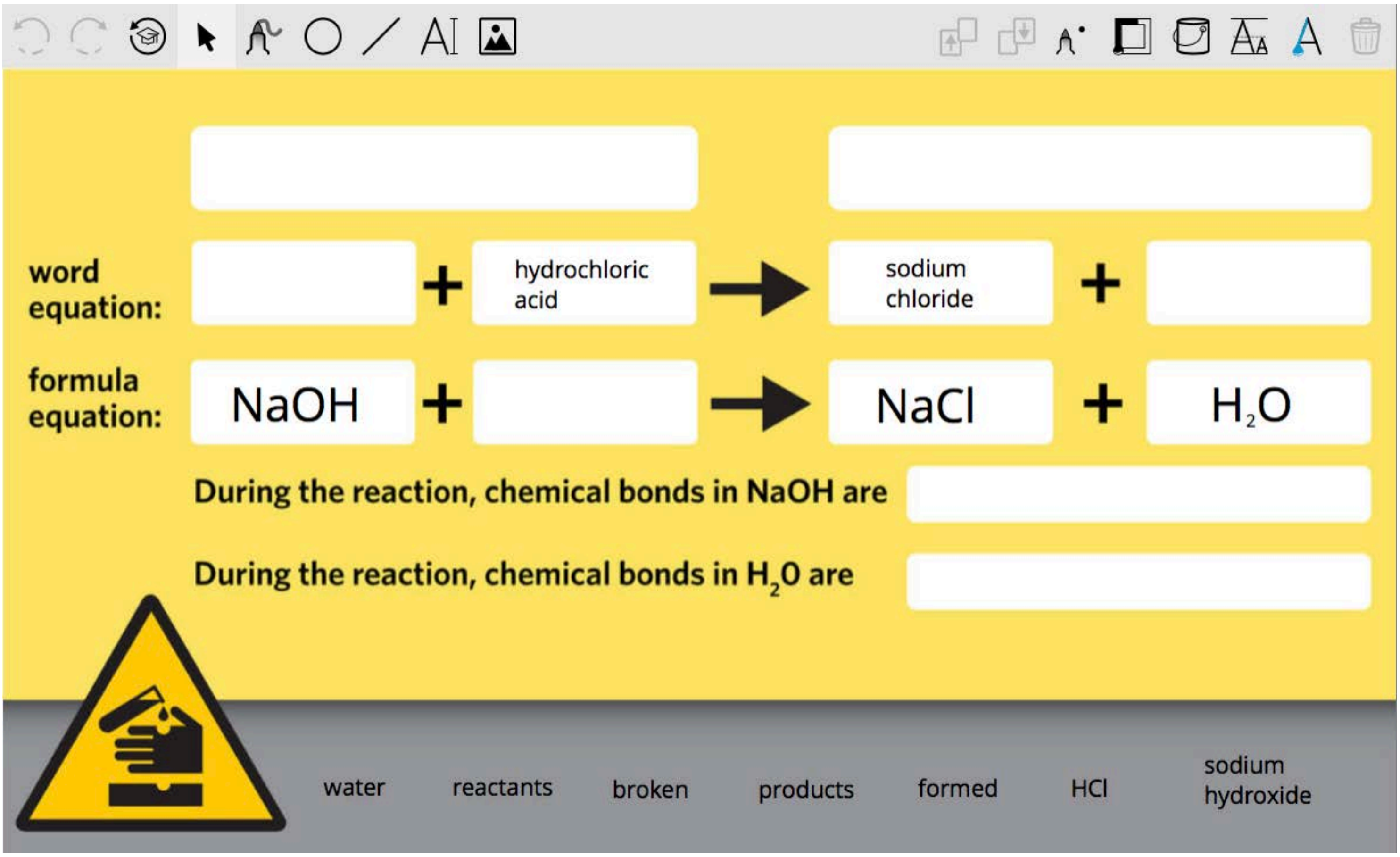
This unfamiliar name for the very familiar substance of water gave rise to a hoax. One website claimed to represent a "Coalition to Ban Dihydrogen Monoxide" or "DHMO". Among other things, it warned the public that this dangerous chemical kills thousands of people each year through accidental inhalation and that it forms the major component of acid rain!

This just goes to show how easy it is to use scientific language in a misleading way.

A mock warning sign used to deter swimming in a public fountain in Kentucky, United States.

Question 5

Label: Two equations – one in words and one in formulas – for the chemical reaction between sodium hydroxide (NaOH) and hydrochloric acid (HCl) are shown. Drag and drop the words from the bottom of the sketchpad to fill in the blanks.



Left: Sodium hydroxide is also known as caustic soda and is used to clean drains. Centre: Hydrochloric acid is one of the chemicals used to keep the water in swimming pools clean. Right: Sodium chloride is just regular table salt.

Balancing chemical equations

Let's go back to our equation for the decomposition of water into hydrogen and oxygen gases:

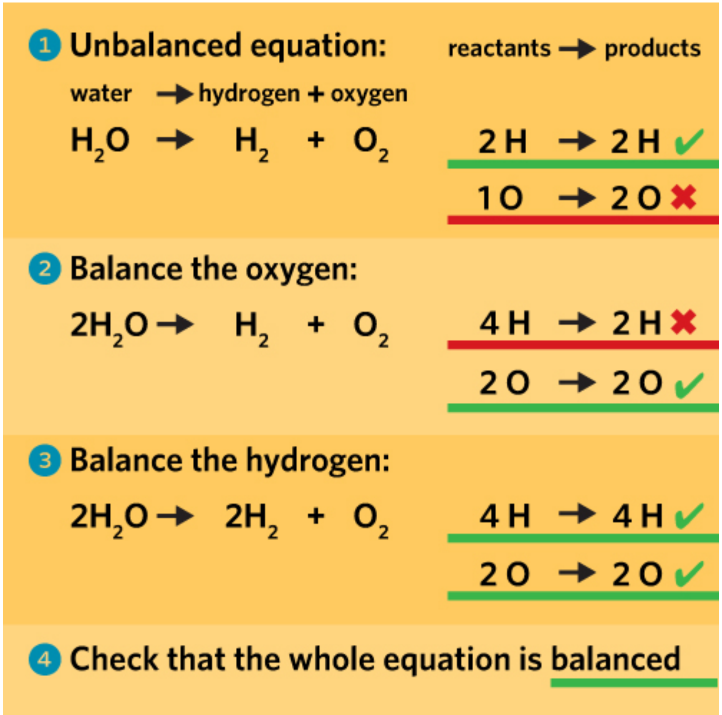
$$H_2O \longrightarrow H_2 + O_2$$

We know that during the reaction the bonds that hold the water molecule together are broken to give 2 atoms of hydrogen and 1 atom of oxygen. The hydrogen atoms then form a new bond to make a molecule of hydrogen gas. But how can we make a molecule of oxygen gas out of only a single oxygen atom?

This is impossible – matter can't just appear out of nothing! The **law of conservation of matter** says that during all chemical reactions the total number of atoms of each element remains the same. To satisfy this law we need to make sure that chemical equations are balanced.

We do this by placing whole numbers *in front of* chemical formulas as needed. These are known as **coefficients** and they tell you the relative amounts of the chemicals involved in the reaction. If we added subscripts *within* formulas then this would change them into completely different chemicals.

Check out the worked example on the right to see how this process can go through a number of steps before an equation is completely balanced.



Balancing a chemical equation by adding coefficients can take several steps.

Question 6

Calculate: How many hydrogen atoms are there in the products of the following balanced equation?

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

- [ ] 2
- [ ] 3
- [ ] 5
- [ ] 6

Question 7

Analyze: The number of atoms of potassium (K), oxygen (O) and hydrogen (H), respectively, in the products of the following balanced equation is:

$$2K + 2H_2O \longrightarrow 2KOH + H_2$$

- [ ] 2, 1, 3
- [ ] 2, 2, 2
- [ ] 2, 2, 1
- [ ] 2, 2, 4

Question 8

Paraphrase: Explain in your own words why it's essential that we only adjust *coefficients* when balancing chemical equations and not *subscripts*.

Question 9

Balance: Add coefficients to balance the following two equations, leaving some spaces blank if necessary.

	H_2	+		F_2	→		HF			
	hydrogen gas	+		fluorine gas	→		hydrogen fluoride			
	CS_2	+		O_2	→		SO_2	+		CO_2
	carbon disulfide	+		oxygen gas	→		sulfur dioxide	+		carbon dioxide

Structural equations

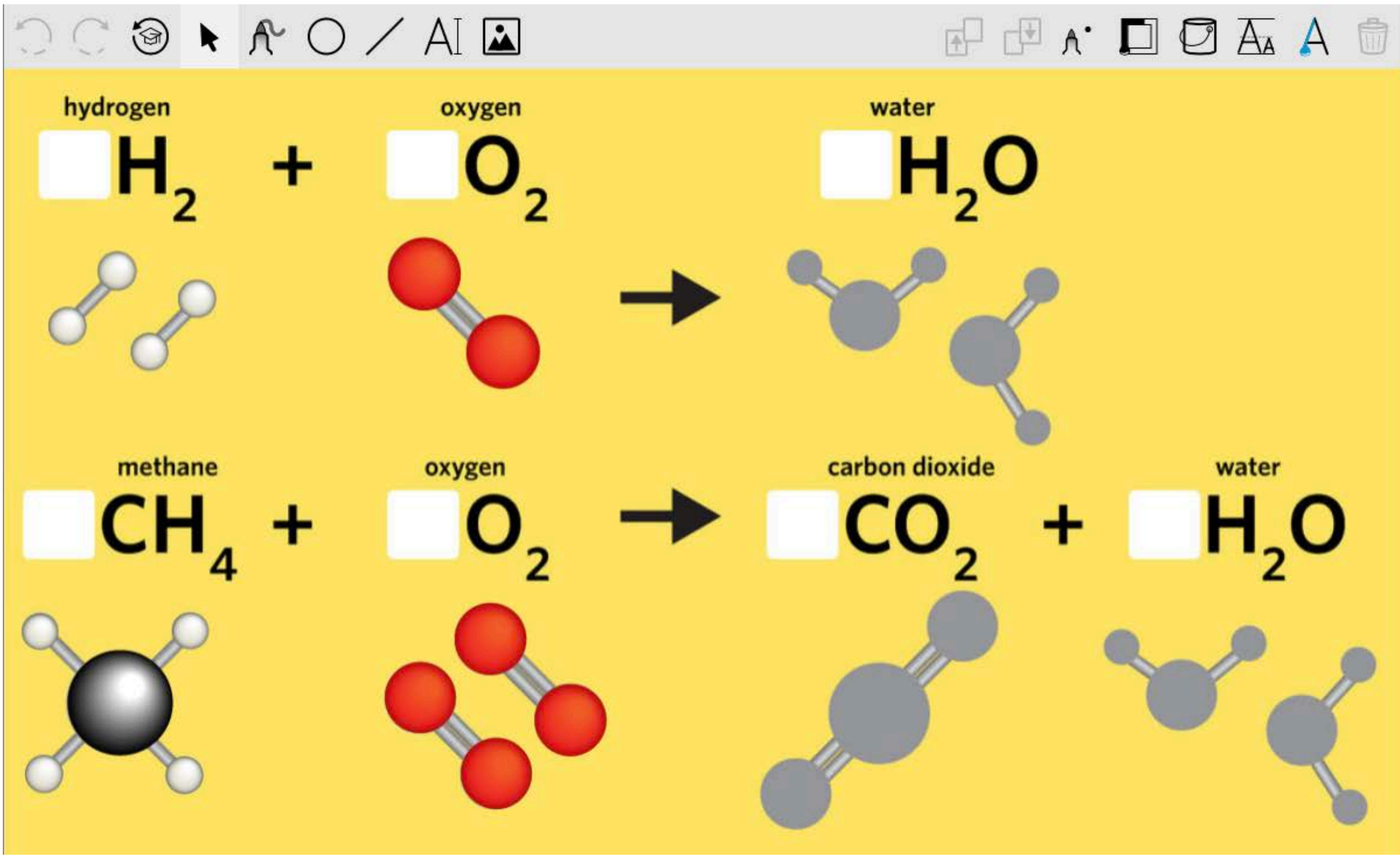
Although writing equations with chemical formulas allows you to keep track of the number and types of atoms in each reactant and product, they don't tell you much about how the atoms are bonded together to form molecules. To visualize this we can use **ball and stick models** in which atoms are pictured as balls and the bonds between them as sticks.

Then we can write down **structural equations** that show the spatial structure of the molecules in either two or three dimensions.

Question 10

Rearrange: In the following sketchpad:

1. Balance the two formula equations by adding coefficients. If only one molecule is needed then leave the box blank.
2. Drag and drop the atoms from the reactant side to the product side to show how they are rearranged during the reaction. The outlines of the product molecules are provided for you.

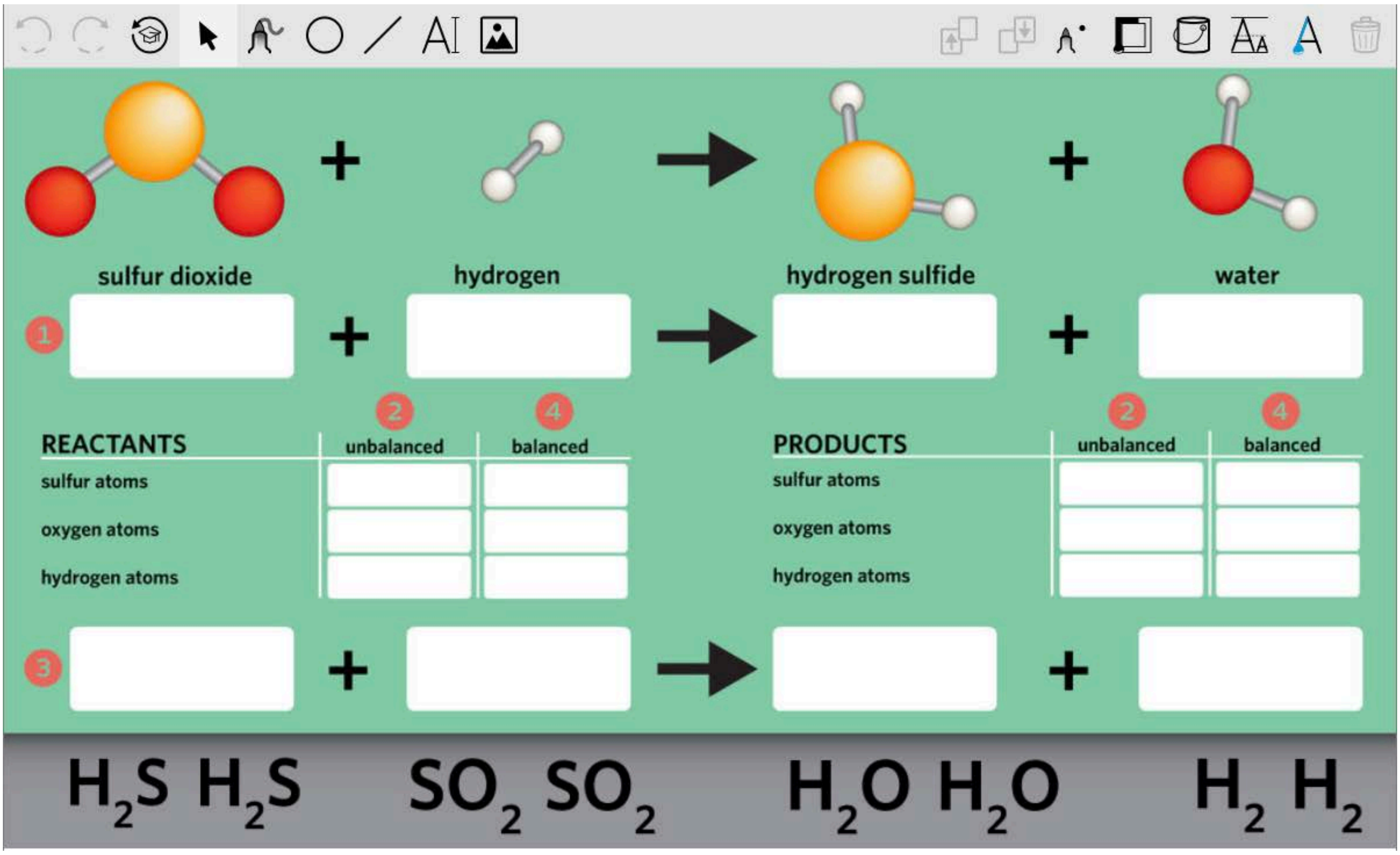


Left: A geothermal hot spring in Yellowstone National Park, USA, where microorganisms use hydrogen sulfide as an energy source. Right: Sulfur crystals deposited around a vent issuing hydrogen sulfide and other gases in Hawaii.

Question 1

An *unbalanced* structural equation is provided below showing the reaction of sulfur dioxide (SO_2) and hydrogen gases to produce hydrogen sulfide (H_2S) and water.

1. Drag and drop chemical formulas from the bottom of the sketchpad to write an *unbalanced* formula equation in the spaces provided.
2. Count the number of atoms of each element in both the reactants and the products, as shown in the ball-and-stick models. Enter these numbers into the first column, labelled "unbalanced", in each table.
3. Drag and drop chemical formulas to create another equation. This time, balance the equation by adding coefficients where needed. *Hint: First check if the sulfur atoms are balanced, then balance the oxygen and leave the hydrogen for last.*
4. Complete the table by entering the numbers of atoms in the reactants and products in the *balanced* equation.



The sodium–water reaction

As mentioned in the *Introduction*, when you drop a lump of sodium metal in water the chemical reaction between them has explosive results. In the aftermath of World War 2 the United States government dumped a large amount of sodium metal into a lake to get rid of it. Watch what happened next!

Question 2

Balance: The reaction between sodium metal (Na) and water produces sodium hydroxide (NaOH) and hydrogen gas (H_2).

1. Write the chemical equation using formulas.
2. Balance the equation by adding coefficients.

Question 3

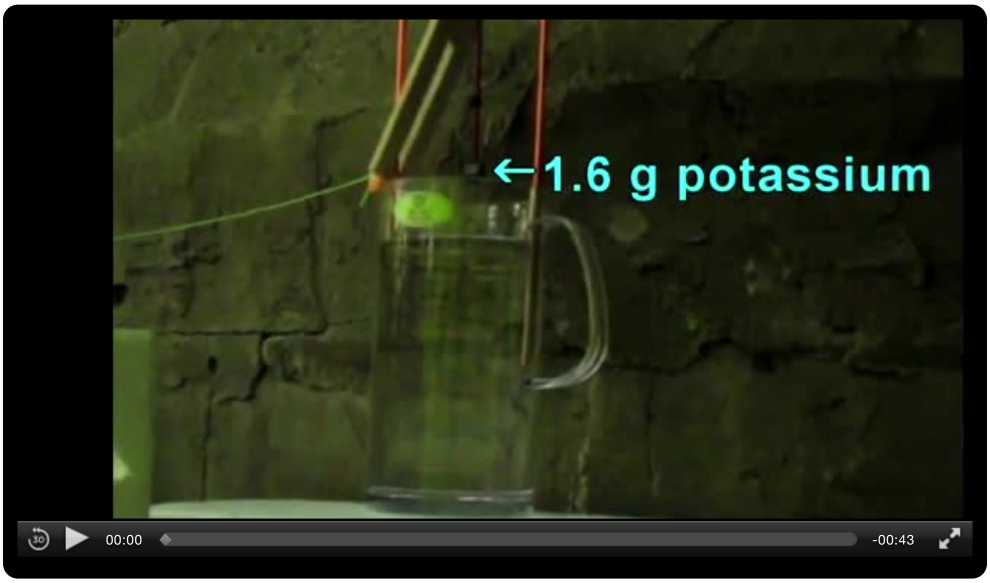
Propose: Although the reactants are a *solid* metal and *liquid* water, one of the products is a *gas*: hydrogen. Because the reaction takes place very quickly a large amount of hot gas is produced in a very short time. Propose an explanation for how this causes at least some of the explosions seen in the video.

Did you notice the flames in the video footage? If not, take another look at the section from 0:58 to 1:03. Flames are often seen when sodium reacts with water but they are actually produced by a second chemical reaction. The hot hydrogen gas produced by the main reaction ignites in air to produce a fiery explosion. So maybe this second reaction is what makes the sodium–water reaction so explosive.

The *Cosmos Magazine* article describes how this explanation has been ruled out by a team of scientists working in the Czech Republic.

Sodium belongs to a group of elements known as the **alkali metals** which includes potassium (K) and lithium (Li). They all explode when dropped in water, with the same type of chemical reaction. In the following video one of the scientists, Philip Mason, explains why the combustion of hydrogen isn't necessary for these reactions to be explosive.

He uses potassium for his experiment.

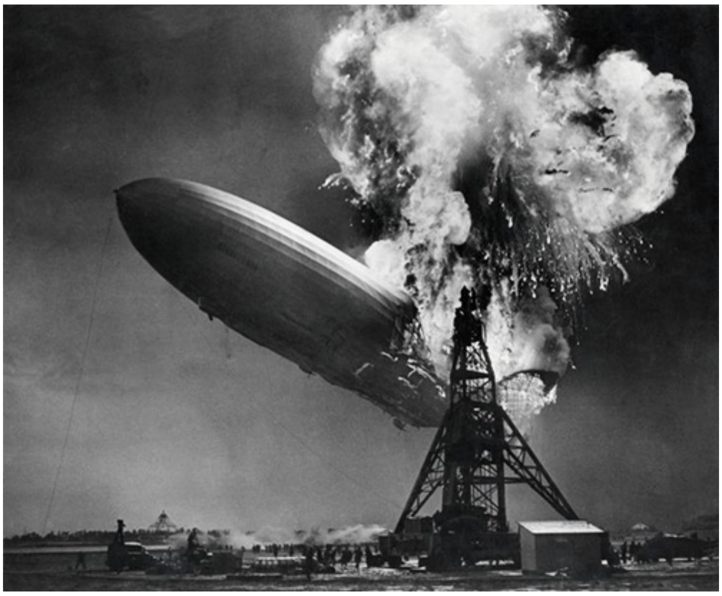


Question 4

Explain: You've already seen the equation for the combustion of hydrogen in oxygen:

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

Explain why this reaction can't take place when the potassium is quickly submerged in water – even though hydrogen gas and heat are produced by the main reaction.



Did you know?

One of the most famous examples of a hydrogen explosion is the 1937 Hindenburg disaster. The Hindenburg was an airship, or zeppelin, that was used to transport passengers between Europe and the United States in great luxury.

This type of air travel was brought to an end when a single spark ignited the hydrogen gas contained within the Hindenburg's massive balloon. Of the 97 passengers and crew on board, 35 died while 62 miraculously survived the fireball!

Question 5

Propose: The video above clearly showed that the combustion of hydrogen occurred some time *after* the initial explosion between the potassium and water. This suggests that rapid expansion of hydrogen gas is the driving force of the first explosion. But there's still a problem with this explanation: the gas is created where the metal and water are in contact, so it should immediately form a layer between them. With contact between the reactants gone the reaction should shut down, or at least proceed much more slowly.

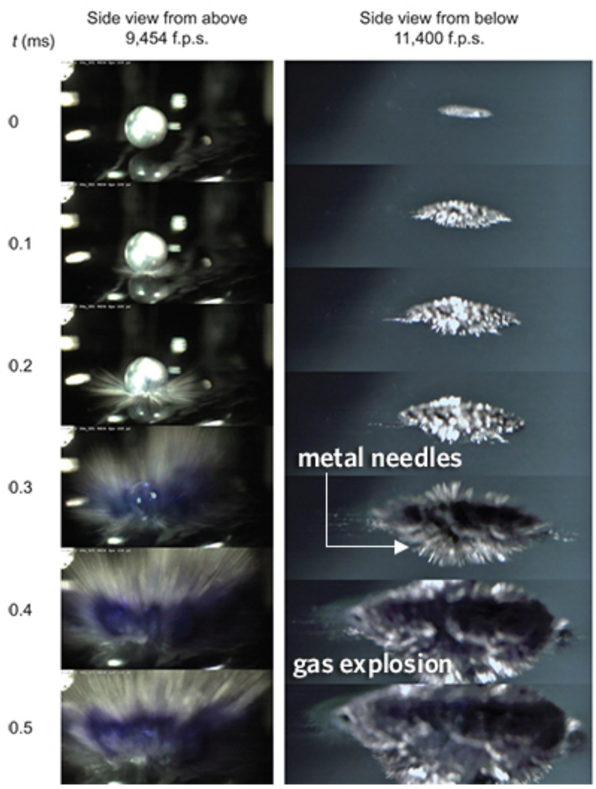
Suggest why continued *contact* between the reactants is important in order to keep the reaction going.

Hint: Think about what happens during a chemical reaction at the atomic level.

Philip Mason and his colleagues came up with a hypothesis to explain how the potassium and water keep in contact.

During the reaction the potassium atoms each lose an electron and become positively charged. The charged particles in the metal must be trying to get away from one another. Mason and his team reasoned that this could force the metal to divide into thin needles that would push out through the hydrogen layer and into the water, creating more contact between the two reactants. And so the reaction could continue, explosively creating more and more hydrogen.

To test the hypothesis the scientists observed the reaction closely using a high-speed camera. The photos on the right show metal needles expanding out into the water only 0.1 milliseconds before the hydrogen gas explosion.



Photos of the potassium–water reaction from two angles taken with a high-speed camera. F.p.s. stands for frames per second and the timespan from top to bottom is 0.5 milliseconds (ms).

Left: Many smartphones and laptops are powered by rechargeable lithium-ion batteries, dramatically increasing our need for the element lithium. Right: About half of the world's lithium deposits are buried under this salt plain, the Salar de Uyuni in Bolivia. Miners have formed these mounds of salt using pickaxes.

Question 6

Infer: Another element in the group of alkali metals is lithium (Li). It reacts with water to form lithium hydroxide (LiOH) and hydrogen gas. Choose the correct balanced chemical equation for this reaction from the following three options and explain what's wrong with the other two.

1. $Li + H_2O \rightarrow LiOH_2$
2. $Li + H_2O \rightarrow LiOH + H_2$
3. $2Li + 2H_2O \rightarrow 2LiOH + H_2$

Question 7

Explain: Suggest a reason for why lithium is typically stored in oil.



Question 8

Discuss: Explosive chemical reactions have been harnessed to create gunpowder and bombs for warfare and terrorism, at great cost to human life and property. On the other hand, planned explosions are also used for mining, road building and fireworks displays.

Choose *one* of the following three chemicals:

- potassium nitrate, KNO_3, a major component of gunpowder
- ammonium nitrate, NH_4NO_3, a component of explosives used for blasting rocks
- lithium carbonate, Li_2CO_3, used to create an intense red colour in fireworks

For your chosen chemical:

1. List the names and symbols of the elements that make it up.
2. Carry out a quick internet search to find the chemical equation for *one* reaction in which the chemical is either a reactant or a product. Write the chemical equation using both words and formulas.
3. Search the internet to create a list of the *uses* of your chosen chemical. With this chemical as an example, discuss the importance to society of understanding chemistry and chemical reactions.

Note: You can use the project space to present any other interesting information or images relating to your chosen chemical.

Apply: Chemical Reactions

COSMOS LESSONS

Experiment: Combustion of charcoal and steel wool

Left: The familiar sight of charcoal burning on a fire. Right: One of the spectacular visual displays that can be made by spinning steel wool as it burns – don't try this at home!

Aims

To observe and explain what happens during the combustion of two household products: charcoal (Part I) and steel wool (Part II).

Background

Charcoal consists of about 80% carbon and steel wool is composed of about 99% iron. Combustion is a chemical reaction in which a fuel reacts with oxygen and releases heat.

The chemical equations in words and chemical formulas for the two combustion reactions are:

Part I: carbon + oxygen gas → carbon dioxide gas

$$C + O_2 \rightarrow CO_2$$

Part II: iron + oxygen gas → iron(III) oxide

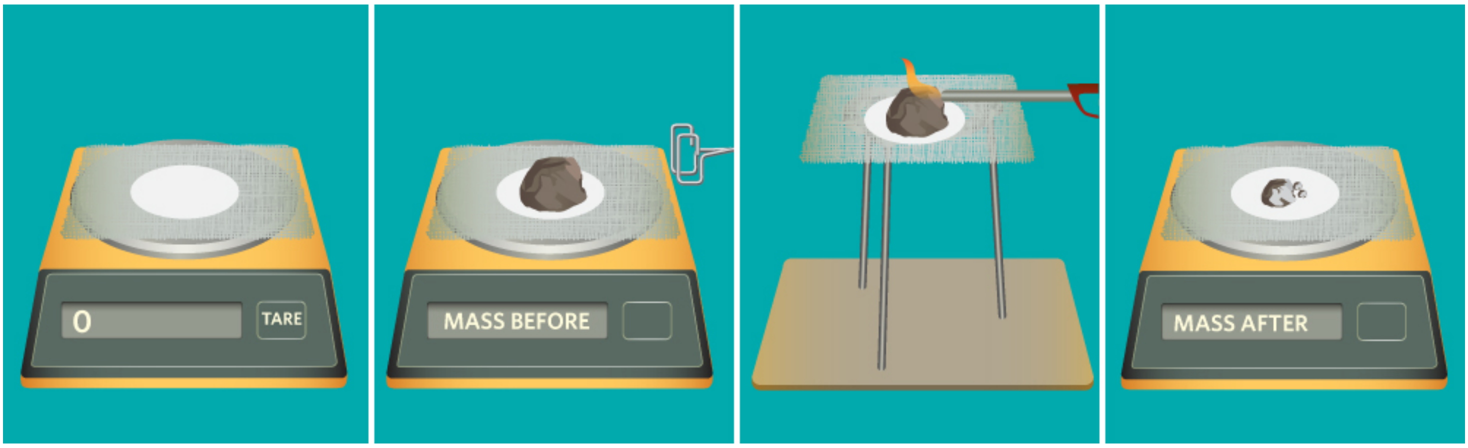
$$4Fe + 3O_2 \rightarrow 2Fe_2O_3$$

Materials

- fireproof Bunsen burner gauze mat
- paintbrush for cleaning gauze mat
- mass balance (precision of ± 0.01 g if available)
- metal tongs
- approx. 1 g chunk of charcoal
- tripod
- fireproof bench mat
- hand-held butane kitchen lighter (*Note: A Bunsen burner may be used.*)
- approx. 3 g ball of fine–medium steel wool (free of oil and soap)
- 9 V battery

Safety

This experiment presents safety risks so check with your teacher about the necessary precautions before going ahead.

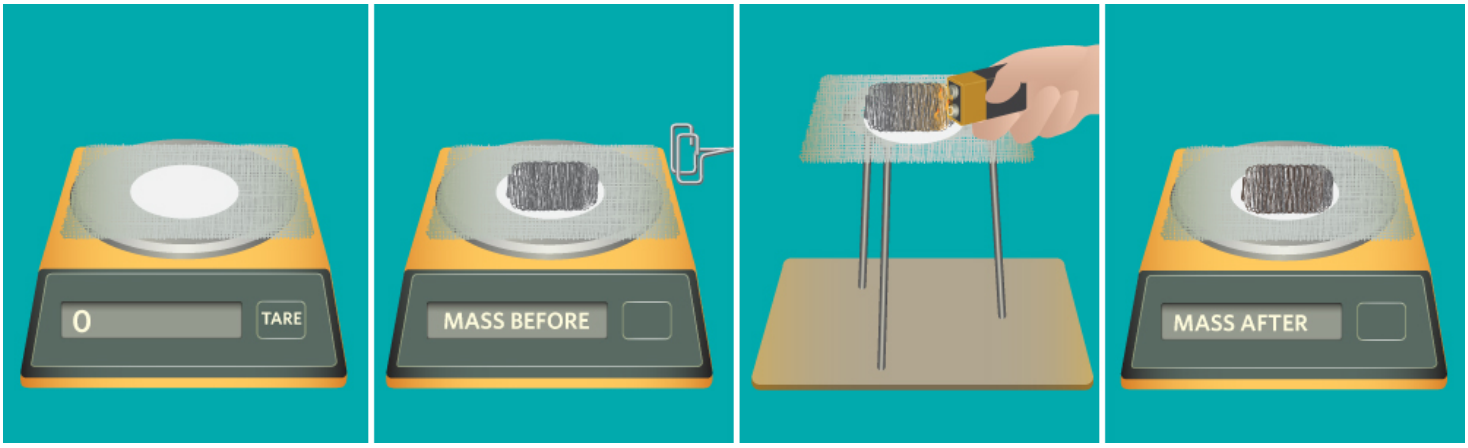


Procedure for Part I.

Procedure

Part I – Combustion of charcoal

1. Brush any dirt, dust or contaminating chemicals from the gauze mat into a chemical discard container, as directed by your teacher.
2. Place the gauze mat on the mass balance and tare, or zero, the reading.
3. Using the tongs, place a chunk of charcoal onto the gauze mat. Record its initial mass and your observations of it in the Results table.
4. Set up the tripod on the fireproof mat on a cleared bench. Use the tongs to transfer the gauze mat along with the charcoal to the tripod. Heat the charcoal with the hand-held butane kitchen lighter for a couple of minutes or until it starts to burn.
5. Watch closely what happens and record your observations in the Results table.
6. After the chemical reaction has stopped, return the gauze mat and reaction products to the mass balance and record the final mass reading in the Results table.
7. Record your final observations of the reaction products and then dispose of them into a chemical discard container, as directed by your teacher.



Procedure for Part II.

Part II – Combustion of steel wool

1. Brush any dirt, dust or contaminating chemicals from the gauze mat into a chemical discard container, as directed by your teacher.
2. Place the gauze mat on the mass balance and tare, or zero, the reading.
3. With clean hands, tease apart the steel wool into a loose ball and place onto the gauze mat. Record its initial mass and your observations of it in the Results table.
4. Very lightly touch the 9 V battery to the steel wool then gently but quickly pull it away.
5. Watch the display! Record your observations in the Results table.
6. After the chemical reaction has stopped, return the gauze mat and reaction products to the mass balance and record the final mass reading in the Results table.
7. Record your final observations of the reaction products and then dispose of them into a chemical discard container, as directed by your teacher.

Results

Question 1

Record: Use the project space below to present your results. You should construct a table of results that best suits the data from *both* parts of the experiment but you may also include photos, videos or other evidence.

Discussion

Question 2

Compare: Calculate the change in mass of the charcoal due to combustion in the air. Give your answer:

1. as the change in mass (final mass - initial mass) in grams, and
2. as the percentage change = ($\frac{change\ in\ mass}{initial\ mass}$ x 100)%.

Question 3

Compare: Calculate the change in mass of the steel wool due to combustion in the air. Give your answer:

1. as the change in mass (final mass - initial mass) in grams, and
2. as the percentage change = ($\frac{change\ in\ mass}{initial\ mass}$ x 100)%.

Question 4

Explain: Use your understanding of the law of conservation of matter and the chemical equations for these two reactions to account for the calculated changes in mass.

Question 5

Evaluate: Identify some limitations of the experimental design that prevented you from collecting more reliable and accurate data. How would you improve the design to obtain more accurate results in future?

Conclusion

Question 6

Conclude: Write a concluding statement that addresses the aims of the experiment.

Career: Chemical Reactions

Brought to you by Edith Cowan University

Pavel Jungwirth always knew he wanted to be a scientist. Growing up in Prague with a family of scientists, it seemed to be the most natural choice. In school, he enjoyed studying languages and history but there was never any serious competition.

At the Academy of Sciences of the Czech Republic, Pavel studies salts. For the past ten years he's been investigating how and why different salts chemically react with proteins. He also spends his time studying the many different reactions between water and salt ions in the human body using clever computer simulations.

Together with Philip Mason, Pavel is one of the scientists who came up with the missing piece of the puzzle of why sodium explodes in water. They pondered the problem as they spent a number of Saturday afternoons setting off sodium explosions on a balcony. It was only when they got hold of a special high-speed camera – rented for $1000 a week – that they captured the crucial evidence to support their theory.

Besides blowing up chemicals, most of Pavel's time at work is spent working on experiments with his students. Conducting actual experiments is extremely fun, he says, but computer simulations are just as fun.

As enjoyable as they may be, Pavel doesn't spend all his time on experiments – he also enjoys reading and cooking. And when he gets to go outdoors, he is an avid hiker and skier.

Question 1

Consider: Chemical reactions are everywhere, so chemists who can understand them are in demand in many different areas of life. For example, in medicine they are needed to explain the chemical reactions that keep our bodies alive or allow them to respond to medicines. In industry, chemists are needed to help design and test a wide range of products from dishwashing detergents to rechargeable phone batteries, while environmental chemists study how pollutants affect living things, air, soils and rivers.

Imagine that you've just finished a chemistry degree at university and now need to decide how to apply your knowledge. Which area would you choose to specialize in, and why?

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