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What happens when things burn?

Teachers' notes

Objectives

- To understand that today's accepted theory of burning is the combination of oxygen with other substances.
- To know that in the past many scientists believed the Phlogiston theory.

Outline

The investigation **What happens when things burn?** is intended to be a group activity that will investigate the 'Phlogiston Theory' of burning put forward in 1732 by George Stahl. Through making predictions, carrying out experiments, discussions and researching information, the students must decide whether to accept or reject the theory. Their decision must be supported by evidence. If the theory is rejected, a new theory of burning must be put forward.

Two different approaches to carrying out this investigation have been included.

- **Approach 1.** Different groups carry out different experiments and then pool the results.
- **Approach 2.** A thinking skills lesson, in which every student sees all the experiments.

Burning theories investigates burning, before looking back to see what 18th century chemists believed.

Teaching topics

The activity **What happens when things burn?** is not suitable for less able students who may find the investigation too confusing.

Burning theories is suitable for most students.

Either activity could be included when teaching about burning and the formation of compounds.

Look at the student worksheets before reading the rest of the teachers' notes.

Sources of information

M. E. Bowden, *Chemical Achievers: the human face of the chemical sciences*, Philadelphia: Chemical Heritage Foundation, 1997.

H. W. Salzberg, *From Caveman to Chemist: Circumstances and Achievements*, Washington: American Chemical Society, 1991.

W. H. Brock, *The Fontana history of chemistry*, London: Fontana Press, 1992.

B. Jaffe, *Crucibles: The story of Chemistry* (Fourth Revised Edition), New York: Dover Publications,1976.

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Approach 1: What happens when things burn?

Teaching tips

Lesson 1
Introduce the class to Phlogiston theory by handing out the student information sheets, **What happens when things burn?** and **About the chemists** and explain the task. This activity is suitable for high ability students.

Task
The task is to test out the Phlogiston theory and decide whether to accept it or reject it. The enquiry involves the students collecting data from a variety of sources such as doing their own experiments, finding out the results from other groups, and using **Burning – the fact cards**.

At the end of the enquiry, the students must come up with a firm conclusion, which should include their reasoning.

First demonstrate experiment B, smelting. Students could fill out the sheet while you do this.

Divide the class in half. One half could carry out experiment A in pairs, while the other half does experiment C.

Lesson 2
Hand out the **Burning interpretations table**. A few groups could present their results so that everyone may complete the interpretations table. The results should be discussed and they should decide if there is enough evidence to either support or reject the theory. State explicitly that a scientific theory is only valid if all the evidence fits it – if not we need to look for another theory.

It should be suggested that further evidence is still needed as the results are not conclusive. A possible way forward would be to investigate the work that other scientists, such as Black, Priestley and Lavoisier did (all are mentioned on the student information sheet). They should be looking for experiments in which samples were weighed before and after heating.

Hand out **Burning – the fact cards** and discuss the information in groups.

Some teachers may wish the class to find out their own information about burning theories and the people who thought them up. Many science CD-ROMS can be used for this.

By the end of the lesson each group must come to a firm conclusion, either accepting or rejecting the Phlogiston theory. They should be able to write a report stating their conclusion, explaining how they came to it, and where applicable putting forward a new theory.

In the final section of the lesson, today's accepted theory of combustion should be covered. It is important to make sure that the students do not go away with any new misconceptions. If there is time, go through the chemistry of experiments A-C. It is also worth pointing out that even though Priestley showed by experiment that metals combine with oxygen when they burn, the exact opposite of what the Phlogiston theory said, he still believed the Phlogiston theory when he died. He could not bring himself to reject such a well known theory even though it was completely wrong. Also note that instrumentation was not very good in the 18th century and not all chemists could agree if mass was lost or gained during the reactions.

Resources

- Class sets of student worksheets
  – What happens when things burn? (1)
  – About the chemists

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– Experiment A – Calcination
– Experiment B – Smelting
– Experiment C – Making alkali
– Burning interpretations table
– Burning – the fact cards

Experiment A (per group)

- Balance (measuring to 2 decimal places if possible)
- Magnesium ribbon 10–20 cm
- Heating crucible and lid
- Bunsen burner
- Heatproof mat
- Tripod
- Pipe clay triangle
- Tongs
- Safety glasses

Experiment B (Demonstration)

- Balance (measuring to 2 decimal places if possible)
- Combustion tube
- Bung fitted with a small glass tube
- Porcelain boat
- Copper(II) oxide
- Methane (natural) gas
- Bunsen burner
- Safety screen

Experiment C (per group)

- Balance (measuring to 2 decimal places if possible)
- Limestone chips
- Wire ring, or gauze (place the limestone chip near the edge and heat)
- Bunsen burner
- Heatproof mat
- Tongs
- Safety glasses
- Nails
- Watch glasses
- Dropper
- Universal Indicator paper or litmus paper.

Practical tips

Experiment A
Demonstrate the technique of lifting the lid a little, to allow access for the oxygen. The purpose of the lid is to minimize any loss of powder as smoke.

Students must wear safety glasses.

Experiment B
A pin hole test tube can be used and the experiment can be carried out without a porcelain boat.

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Experiment C
A sample of soft chalk (calcium carbonate) reacts better than a marble chip or limestone. Blackboard chalk is not always calcium carbonate. For this reaction to work well, the heat must be concentrated on the calcium carbonate. Balancing the chip on a small deflagrating spoon gives very good results.

Timing

2 hours 30 minutes for the whole activity.

Approach 2: What happens when things burn?

Teaching tips

In this approach the emphasis is on group work and discussions to enable the students to think through the difficult concepts. It is important that each student sees all the experiments so that they can process the information.

Hand out the student information sheets **What happens when things burn? (2)** and **Testing the Phlogiston theory**. Students should read through the sheets, complete the predictions table and then set up experiment C Making alkali.

While the limestone is being heated, demonstrate experiments A and B. It is useful to discuss the experiments while they are being demonstrated and write the start and finish masses on the board.

Students should return to experiment C and complete it.

The results table and questions 1–5 should be completed.

Students should discuss their results and try and complete the **Burning interpretations table**.

Hand out **Burning – the fact cards** to help students come up with an alternative model of burning.

In the final section of the lesson today's accepted theory of combustion should be covered. It is important to make sure that the students do not go away with any new misconceptions. If there is time, go through the chemistry of experiments A–C. It is also worth pointing out that even though Priestley showed by experiment that metals combine with oxygen when they burn, the exact opposite of what the Phlogiston theory said, he still believed the Phlogiston theory when he died. He could not bring himself to reject such a well-known theory even though it was completely wrong. Also note that instrumentation was not very good in the 18th century and not all chemists could agree if mass was lost or gained during the reactions.

Resources

- As approach 1 for experimental apparatus.
- Student worksheests
  – What happens when things burn? (2)
  – Testing the Phlogiston theory
  – Burning interpretations table
  – Burning – the fact cards

Practical tips

As approach 1

Timing

2 hours

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Burning theories

Teaching tips

Demonstrate to the class that fuels need oxygen to burn and this oxygen is taken from the air.

Students should then carry out their own experiment to find out what is made when a candle is burnt. More able students should be encouraged to use particle theory to help explain combustion.

Once you are sure that the students understand burning, explain that in the past scientists had a different view of burning. Introduce Joseph Priestly and Antoine Lavoisier as two chemists who played a major role in investigating burning. Their work led to the rejection of the Phlogiston theory and the acceptance of today's theory.

Resources

Demonstration

- Washing up bowl
- Gas jar
- Candle (15 cm)
- Plasticene

Class experiment (per group)

- Gas jar and lid
- Candle on a tray
- Heat-proof mat
- Limewater (0.02 mol dm^{-3})
- Blue cobalt chloride paper
- Safety glasses
- Student worksheets
  – Burning theories

Practical tips

Make sure that the candle is long enough to avoid the top getting wet. This will allow you to repeat the experiment if necessary.

Timing

1 hour

Adapting resources

Approach 1 and Approach 2 of **What happens when things burn?** are an example of how material can be adapted to suit the preferred learning style of the class.

Burning theories is an example of how similar material can be covered in a much less demanding way.

In all three cases the learning objectives are the same, and the materials could be modified further to meet the needs of individuals.

Opportunities for using ICT

- Data logging sensors to measure quantities such as humidity, temperature, light and oxygen levels can be used to monitor the burning process in the Burning theories demonstration.
- Use of CD-ROMs and the Internet to research 18th century scientists.
- Word processing to write up the enquiry.

Opportunities for key skills

These activities access the key skill of working together.

Communication skills are important in Approach 1, because each student will not complete all the experiments, but they will need to use the results.

Answers

Approach 1: What happens when things burn?

Experiment A – calcination

1. **(a)** The mass will decrease as Phlogiston is given off.
(b) It will become a powder as Phlogiston is given off.

2., 3. –

4. 1(a) – no, the mass has increased, 1(b) yes, a white powder has been formed.

5. 1(a) rejects the Phlogiston theory while 1(b) supports the theory.

6. Yes. Try repeating the experiment using a different metal such as copper, or repeat using a different amount of the metal to see if it still increases.

7. Keep heating and reweighing until there is no further change in mass.

Experiment B – smelting

1. It will turn into a metal because Phlogiston will be transferred from the natural gas to the ore. The metal ore will increase in mass because Phlogiston has been added to it.

2., 3. –

4. Tiny specks of copper have been made.

5. The results support the Phlogiston theory as a metal is made, but they reject the theory because the mass has decreased.

6. Yes, this is only one ore, it needs to be confirmed by others.

7. Phlogiston is a substance that can 'neutralise' the oxygen in the copper ore. It could be carbon.

Experiment C – making alkali

1. It will change into quicklime (CaO) which is alkaline because it will pick up Phlogiston from the air. This will mean that it loses some mass.

2., 3. –

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4. Yes, the mass, appearance and pH have all changed.
5. It supports the Phlogiston theory because it has turned into alkali, but it rejects the theory because its mass has decreased.
6. Yes.
7. Try heating another carbonate such as magnesium or copper carbonate.

Completed burning interpretations table

	Prediction using phlogiston theory	Experimental results	Interpretation supports or rejects phlogiston theory
A	Will form a powder Mass decreases	Powder formed Mass increases	Supports theory Rejects theory
B	A metal will form Mass increase	Metal formed Mass decreased	Supports theory Rejects theory
C	An alkali will form Mass increase	Alkali, pH = 11 Mass decreases	Supports theory Rejects theory

An interpretation of Burning - the fact cards

Card	Prediction using Phlogiston theory	Experimental results	Support for or rejection of Phlogiston theory
Black 1	It gains mass as it absorbs Phlogiston	Magnesia loses mass when heated	Rejects
Black 1	The product is alkali	The product is insoluble in water, not alkaline	Rejects
Black 2	It gains mass as it absorbs Phlogiston	Limestone loses 'fixed air'	Rejects
Black 2	It gains mass as it absorbs Phlogiston	Magnesia lost 'fixed' air	Rejects
Priestley 1	No reaction	A gas and liquid is produced	Rejects
Priestley 2		Discovers 'dePhlogistonated' air	
Lavoisier 1	Metals lose mass when they are heated	Metals gain mass when heated	Rejects
Lavoisier 2		Metals mass increases by the amount of oxygen they take from the air	Rejects
Lavoisier 3&4			New theory that explains the mass problems

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What happens when things burn? (2)

1. Fire is released, water and air escape, the earth or ashes are left behind.
2. Over 2000 years.
3. Particles of fire got stuck between the particles of the material being burnt.
4. Every material that burns has two parts, Phlogiston and ash. When materials burn, they give off Phlogiston.
5. It would make candles burn brightly and would keep mice alive twice as long as in ordinary air.
6. When things burn they join up with oxygen.
7. He knew that when metals burnt their mass increased. The Phlogiston theory said the opposite.

Approach 2: Testing the Phlogiston theory

1. There are several faults in the explanations. In smelting, you would expect both the carbon and the metal ore to give off Phlogiston as the theory says when things burn they give off Phlogiston. In making alkali, why should limestone pick up Phlogiston from the fire. Shouldn't it be losing it?
2. Decrease
3. Weigh the sample, heat it and weigh it again. Continue until there is no change in the mass.
4. Repeat the experiment and take an average of the results.
5. Yes, the mass, appearance and pH have all changed.

Burning interpretation table
See the interpretations table in Approach 1.

Burning theories

1. Level higher than at start.
2. Oxygen
3. Water, carbon dioxide, light and heat.
4. Fuel + oxygen $\rightarrow$ carbon dioxide + water

What happens when things burn? (1)

Deciding what happens when things burn

Imagine that you are a scientist in the 1780's and you are fascinated by burning. You want to understand what really happens when something burns. Your favourite explanation is the theory put forward by Georg Stahl in 1723.

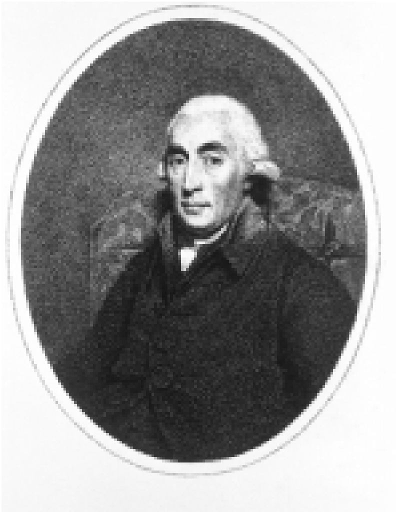
When materials burn they give off a substance called Phlogiston.

According to the theory 'Phlogiston' is a real substance with mass that could be transferred from one material to another. Stahl used his theory to explain the following reactions, which were all of great economic importance:

- **Calcination** A metal ore heated with charcoal turns into a metal because Phlogiston is transferred from the charcoal to the ore.
- **Smelting** When a metal is heated in the air it becomes a powder because it loses its Phlogiston.
- **Making alkali** When limestone is heated to high temperatures, it changes into quicklime, because it has picked up Phlogiston from the fire.

You can investigate the theory by looking at the results of these experiments.

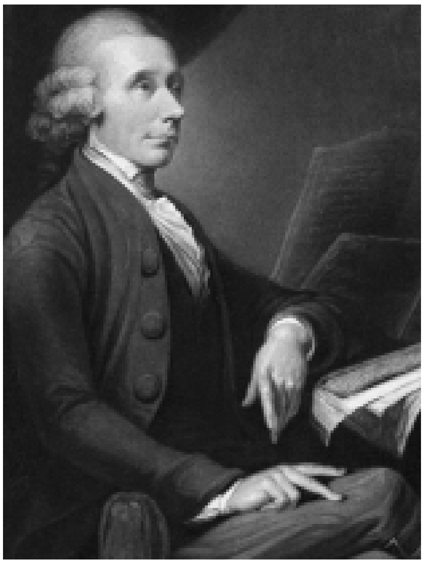
About the chemists



Joseph Black

(Reproduced courtesy of the Library & Information Centre, Royal Society of Chemistry.)

Joseph Black (1728–1799) was a doctor who later became an unsalaried professor of chemistry at the University of Edinburgh. His students paid a fee but his main income was from medicine. He was interested in the burning of limestone and believed in the Phlogiston theory.



Joseph Priestley

(Reproductions courtesy of the Library & Information Centre, Royal Society of Chemistry.)

Joseph Priestley (1733–1804) was an orphan from Yorkshire, who became a clergyman. Priestley enjoyed carrying out experiments and discovered that there are different types of 'air'.

Priestley publicly sympathised with the French Revolution. This caused him to be driven from his house and his library was burnt.

He went into exile in America, where with the help of his friend Benjamin Franklin, he settled. He believed in the Phlogiston theory until he died. The cartoon shows Joseph Priestley, 'Doctor Phlogiston', explaining away the Bible and other views.

Antoine Lavoisier with his wife, Marie.

(Reproduced courtesy of the Library & Information Centre, Royal Society of Chemistry.)

Antoine Lavoisier (1743–1794) was a Frenchman who studied law, but became interested in science, initially geology. He became a tax collector so that he could pay for his scientific experiments. He got married when he was 28 to a girl of 14, who became his laboratory partner. He put forward a new theory of combustion. Tax collectors were not popular in 1794 when he was guillotined.

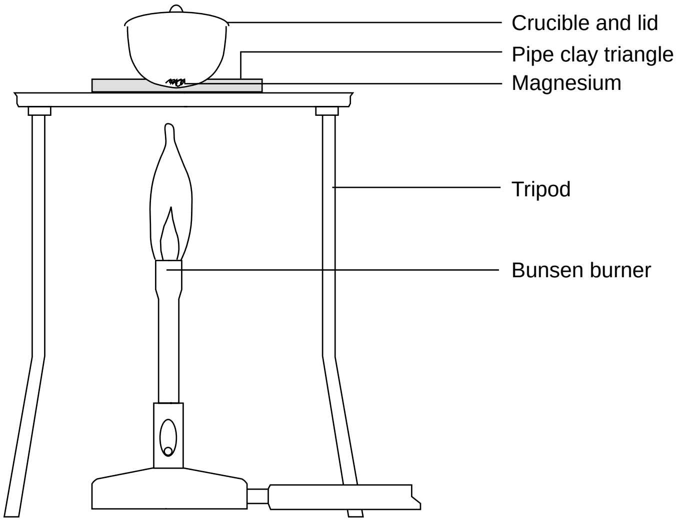
Experiment A – Calcination (burning metals)

Work in groups, and report back to the whole class:

1. When magnesium is heated in air it will burn. Using the Phlogiston theory predict what will happen to:

   (a) the mass of magnesium
   (b) the appearance of magnesium?

2. Carry out the experiment as described below.



Wear eye protection

- Clean a 10–20 cm length of magnesium ribbon with emery cloth to remove the oxide layer. Loosely coil it.
- Weigh a clean crucible and lid. Place the magnesium inside and reweigh.
- Heat the crucible for 5–10 minutes, lifting the lid a little from time to time with tongs. Ensure that as little product as possible escapes.
- Continue heating until glowing ceases.
- Cool the crucible and reweigh.

3. Carefully record your results in the table.
Mass of crucible + lid = g
Mass of crucible+lid+sample = g

	Appearance of sample	**Mass of sample / g**
Start		
End		
	Mass change/g	

4. Go back to question 1. Are your results the same as your predictions?

5. Do your results support or reject the Phlogiston theory?

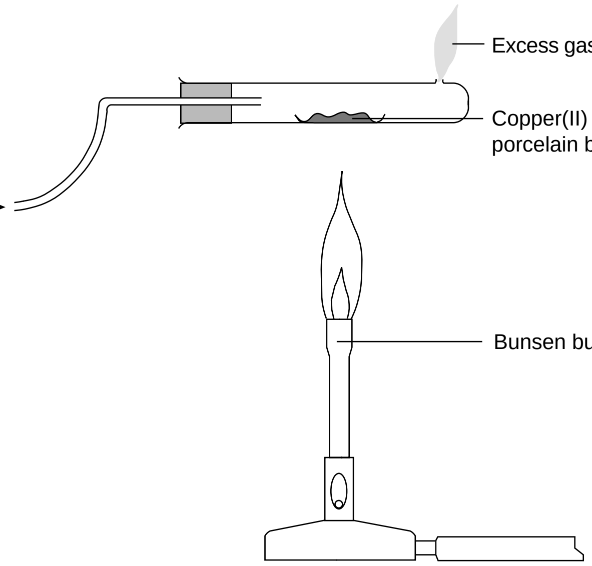
6. Do you think you need more evidence to reach a firm conclusion? Suggest how you could get more data.

7. How could you make sure all the Phlogiston has been lost?

Experiment B – Smelting

Heating a metal ore with charcoal or natural gas

1. When copper(II) oxide is mixed with methane and heated, it will burn. Using the Phlogiston theory predict what will happen.
2. Your teacher will demonstrate the experiment.



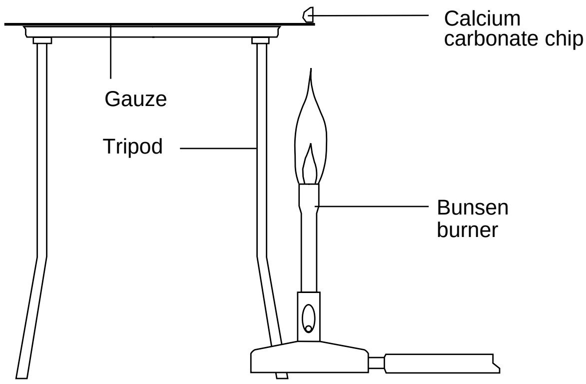
3. Record your observations

	Appearance of sample	Mass of sample / g
Start		
End		
	Mass change/g	

4. What can you deduce from your observations?
5. Do your results support or reject the Phlogiston theory?
6. Do you think you need more evidence to reach a firm conclusion?
7. Using the results from this experiment, what do you think Phlogiston is?

Experiment C –
Making alkali (heating limestone)

1. Using Phlogiston theory, predict what will happen when limestone, calcium carbonate is heated?
2. Carry out the following experiment.



- Take 2 limestone chips, which look similar and weigh them.
- Place one of the limestone chips on the gauze as shown in the diagram and heat it over the hottest Bunsen flame for 10 minutes.
- **Do not touch the chip – it is now corrosive.**
- Let it cool down for a few minutes and then use tongs to move the chip and reweigh it.

3. Carry out the following tests on both chips.

- Compare their appearances.
- Use a nail to see if they scratch easily. Make sure you hold the chip in the tongs.
- Place the chips on a watch glass, add two drops of water to each chip and test the solution with pH paper.

Record your observations in the table.

Test	**Unheated limestone chip**	**Heated limestone chip**
Appearance		
Mass / g		Before heating: After heating:
Does it scratch easily?		
Add water & then test with Universal Indicator paper		

4. Do you think that a chemical reaction has taken place? Give a reason for your answer.
5. Do your results support or reject the Phlogiston theory?
6. Do you think you need more evidence to reach a firm conclusion?
7. Suggest how you could obtain some more data.

Burning interpretations table

Experiment	Predictions using the Phlogiston theory	Experimental results	Interpretation supports (s) or rejects (r) the Phlogiston theory
(A) Calcination	What is formed?	What is formed?	
	Change in mass?	Change in mass?	
(B) Smelting	What is formed?	What is formed?	
	Change in mass?	Change in mass?	
(C) Making alkali	What is formed?	What is formed?	
	Change in mass?	Change in mass?	

Burning – the fact cards

Joseph Black (1)

Black worked with magnesia (magnesium carbonate) that was thought to be another form of lime. He found that when it was heated, it lost seven twelfths of its weight and changed into a new material that was insoluble in water and not alkaline. Black was puzzled because the magnesia must have absorbed a lot of phlogiston from the air and should have gone alkaline. Maybe the magnesia had lost something else?

Joseph Black (2)

Black carried out further experiments and discovered that magnesia did loose a gas when it was heated. This gas was known as 'fixed air'.

He also showed that when limestone was heated it did not absorb phlogiston but lost 'fixed air' (carbon dioxide).

Joseph Priestley (1)

Experiment

When mercury oxide was heated, the red solid decomposed and produced a colourless gas above the liquid mercury. When the gas was tested with the flame of the candle, the candle burned brightly. He had previously noted that other gases put out the flame.

Joseph Priestley (2)

Priestley found that the 'new air' would keep a mouse alive twice as long as ordinary air.

He called this 'new air' dephlogistinated air.

Antoine Lavoisier (1)

Lavoisier heard about Priestley's work and repeated it. He showed that Priestley's new gas was a component of air and that it combined with metals when they were heated. He called the new gas 'oxygen'.

Antoine Lavoisier (2)

Using sensitive scales he showed that when heated, mercury oxide lost weight as oxygen was released. He also proved that when a metal was heated in air, the metal would increase in weight by an amount corresponding to the amount of oxygen taken from the air.

Antoine Lavoisier (3)

The Law of Conservation of Matter

Matter is neither created or destroyed but is simply changed from one form into another.

Antoine Lavoisier (4)

Combustion is the combination of oxygen with other substances.

What happens when things burn? (2)

The ancient greeks thought everything was made from fire, water, air and earth.

In the 1600s, scientists thought that burning depended on air and that air was one single substance.

Robert Boyle heated tin in a sealed flask. When the seal was broken, the tin weighed more then before heating. Boyle thought the particles of fire had lodged between the particles of tin.

Georg Stahl (1660 – 1734) was a German scientist. He developed another idea. It was called the Phlogiston theory (from the Greek phlox = flame).

Joseph Priestly worked in England. He heated mercury in air, and make a red substance. When he heated the red substance he got a new gas.

Antoine Lavoisier was a French scientist, who worked with his wife. They worked on the problem of burning and knew the phlogiston theory wasn t quite right.

Lavoisier found that the sulfur gained weight when it burnt. He thought the air was combining with the sulfur. Joseph Priestley visited Lavoisier and helped him understand.

Read **What happens when things burn? (2)** and then answer the questions.

1. What was the Greeks theory of burning?

2. How long did their theory last?

3. What did Robert Boyle think about burning?

4. What was the Phlogiston theory?

5. What two things did Priestly find out about oxygen?

6. What was Lavoisier's new theory?

7. Why do you think Lavoisier rejected the Phlogiston theory?

Testing the Phlogiston theory

Thinking skills

Read through the information sheet **What happens when things burn? (2)**.

1. Sometimes scientists let their fondness for their theory affect their thinking. What are the faults in the Phlogiston theory explanations for the 3 experiments given at the bottom of the sheet?
2. The theory says that when a metal burns, it loses its Phlogiston. What would you expect to happen to the mass? (Increase/Decrease/No change)

Predictions for the three experiments

Calcination
Magnesium (a silvery metal ribbon) burns when heated in air.

Smelting
Copper ore (a black powder) changes when heated with charcoal or natural gas

Making alkali
Limestone (a white rock) changes into quicklime when heated in air.

Use the Phlogiston theory to make the following prediction:

Expt.	What will be formed? (Metal/alkali/powder)	What happens to the Phlogiston?	Change in mass? (Increase/decrease/ no change)
A			
B			
C			

Experiments

- You will do or see experiment A
- Your teacher will demonstrate experiment B
- You will do experiment C

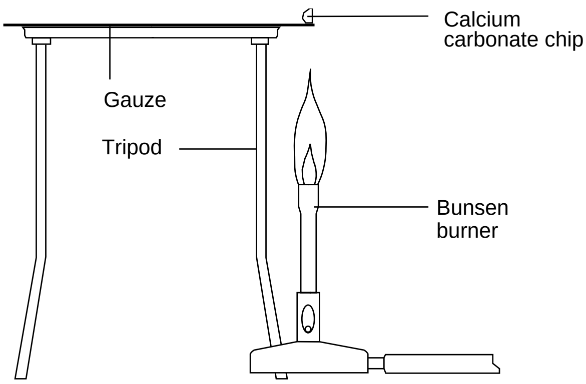
(A) Calcination (burning metals)

3. How would you make sure that all of the Phlogiston has been taken from the magnesium?

(B) Smelting (heating a metal ore with charcoal or natural gas)

4. What would you do to obtain more reliable results for the 'change in mass'?

(C) Making alkali (heating limestone)



- Place a limestone chip on the gauze as shown in the diagram and heat it over the hottest Bunsen flame for 10 minutes.
- **Do not touch the chip – it is now corrosive.**
- Let it cool down for a few minutes and then use tongs to move the chip onto the watch glass.
- Add drops of water to the chip and test the solution with pH paper.

5. Do you think that a chemical reaction has taken place? Give a reason for your answer.

Results

Expt.	**What is formed? (Metal/alkali/powder)**	**Change in mass? (Increase/decrease/no change)**
A		
B		
C		Decrease

Interpretations

- Use your Predictions table and Results table to fill in the Burning: Interpretations table. In groups, discuss whether each Prediction and Result either 'supports' or 'rejects' the Phlogiston theory.
- A scientific theory is only accepted if all of the evidence fits the theory. If you decide not to accept the theory, you will need to look at more evidence and think of a better theory.
- Ask your teacher for **Burning – the fact cards** which contain further evidence. Read the information and try to think of a better theory of burning. Make sure that you can clearly explain your new theory.

Burning interpretations table

Experiment	Predictions using the Phlogiston theory	Experimental results	Interpretation supports (s) or rejects (r) the Phlogiston theory
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(C) Making alkali	What is formed?	What is formed?	
	Change in mass?	Change in mass?	

Burning – the fact cards

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Joseph Black (2)

Black carried out further experiments and discovered that magnesia did loose a gas when it was heated. This gas was known as ‘fixed air’.

He also showed that when limestone was heated it did not absorb phlogiston but lost ‘fixed air’ (carbon dioxide).

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Experiment

When mercury oxide was heated, the red solid decomposed and produced a colourless gas above the liquid mercury. When the gas was tested with the flame of the candle, the candle burned brightly. He had previously noted that other gases put out the flame.

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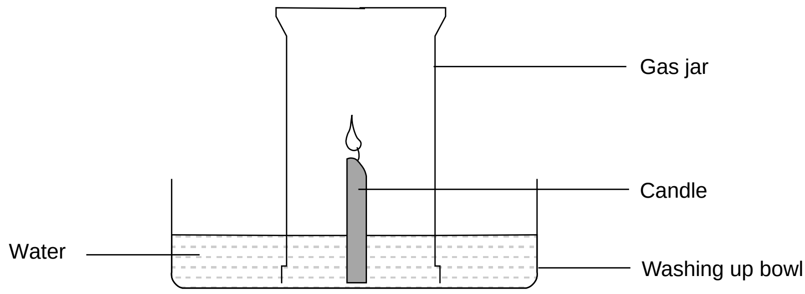
Antoine Lavoisier (4)

Combustion is the combination of oxygen with other substances.

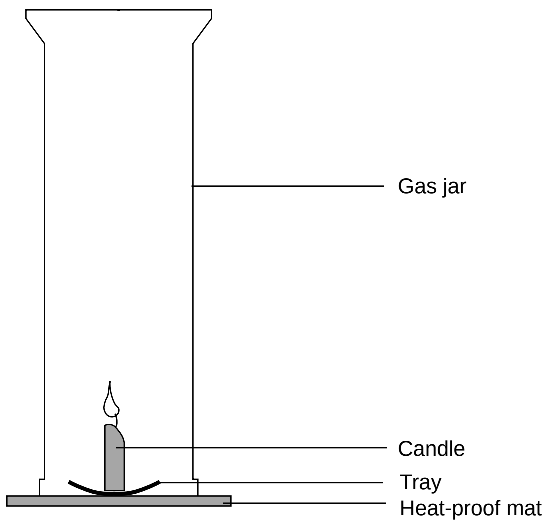
Burning theories

Your teacher will demonstrate the first experiment and then you can carry out the second experiment with a partner.



1. On the diagram, mark in the water level at the end of the experiment.

2. The water replaces ____________ gas, as the candle uses it up.



- Set up the experiment as shown in the diagram.
- When the candle goes out, remove the gas jar and put a lid on it.
- Add a piece of blue cobalt chloride paper. If it goes pink, water is present.
- Pour some limewater into the jar and swill it around. If the limewater goes cloudy, carbon dioxide is present.

3. When a candle burns it produces ______________ and

____________________________ gas. It gives out energy in the form of

___________________ and ____________.

4. Complete the word equation

Fuel + ___________ → ____________________ + __________