Lesson Plan

Classic Candle Experiment

Brief description

Students will find this classic experiment fun to do and amazing to watch but trickier to explain. A lit candle is covered with an inverted jar in a saucer of water, the flame expires and water rises up into the jar. Students test their explanations by experimenting with different candles, jars and bottles. They will also realise that prior knowledge can lead to plausible but incorrect conclusions.

Duration: 45 - 70 minutes

Year level:	Middle to upper primary
Topics:	States of matter (solid, liquid, gas), thermal expansion, air pressure, vacuums, misconceptions in science
Preparation:	10 to 20 minutes (depending on availability of materials)
Extensions:	Science: Teacher Demonstration 8: Hot air expands Science: Teacher Demonstration 11: Leaping Candle Flame *(Teacher Demonstrations 8 & 11 are available online in PDF format)*

Overview

Whole class	Perform Teacher Demo 1 (see Teacher Notes), discuss small group activities, worksheet, and safety precautions and allocate groups and jobs	(10 – 15 min)
Small groups	Experiment with various candle sizes and different shapes of bottles and jars to test test scientific explanations of observations	(20 – 35 min)
Whole class	Class discussion of the activity: • discuss the correct scientific explanation • discuss the common misconception described in the Teacher Notes • perform Teacher Demo 2 (see Teacher Notes) to clarify and/or help overcome remaining misconceptions	(15 – 20 min)

Planning for safety:

The risks associated with this lesson are easily managed by implementing a few simple safety precautions and behaviour rules. Students are likely to suggest many of these precautions themselves. Allowing them to do so in a discussion prior to the activity may help foster more positive attitudes towards, and closer adherence to the agreed behaviour rules and safety precautions. Please refer to the safety notes on page 8 for suggested safety precautions. You should always consider the individual circumstances of your students and classroom when planning lessons – please consult your science coordinator or principal for further guidelines.

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Materials and equipment

Collect a selection of approximately 15 to 20 jars and bottles with different shapes and sizes (students can bring most of these from home). For safety, and to minimise the total number required, groups should only collect one jar or bottle at a time and these should be returned to the store before proceeding with the next one.

Qty / group	Description
1[1]	Clear glass bottles and jars – various shapes and sizes
1[2]	Cake, normal and large candle per group (cut to size)
1	Shallow plate or saucer
1	Jug (or softdrink bottle) filled with water
1	Funnel
1	Marker pen and sticky tape
3 – 5	Drops of food colour
1[3]	Lighter (teacher to light candles only)
1	Damp tea-towel (for wiping up and safety)

[1] EG: Glass juice bottles (small and large) / Coffee jars / Wine bottles / Glass softdrink bottles / Vases / Decanters

[2] Cut long candles to approximately the same length as birthday candles

[3] Teacher only lights candles when groups are ready to commence

Preparation

To minimise preparation time, ask students to bring as many of these items from home over several days prior to the lesson. Cut long candles in half. Collect approximately 15 to 20 glass bottles and jars of various shapes and sizes, buckets (or ice cream containers) and candles and store in a convenient classroom location. Photocopy sufficient quantities of the student worksheet (Page 11).

Objectives

This activity presents opportunities for the introduction or reinforcement of science concepts and for students to practice their science skills and to instil positive attitudes. The objectives below are suggestive only – please consult your curriculum documentation and consider your students' situation in your planning.

Prior knowledge and common misconceptions

A common misconception (the 'consumed oxygen' misconception) is likely to arise during this activity as students attempt to explain their observations. Discussing this misconception in a positive and supportive environment can instil positive attitudes towards science, conceptual development, and may help students become more open minded and able to accept new evidence and information. A teacher demonstration to help correct and overcome this misconception is provided on page 9 in the Teacher Notes.

Objectives continued...

Science skills

Students will:

- **Observe** that the candle flame gradually diminishes before expiring
- **Infer** that the candle flame diminishes and expires because it consumes oxygen inside the jar or bottle
- **Observe** that the candle flame burns longer in larger jars or bottles
- **Infer** that the candle flame burns longer in a larger jar or bottle because there is more air and therefore more oxygen available
- **Infer** that the candle flame heats the air inside the jar or bottle and that the air cools after the flame expires
- **Observe** bubbles escaping from the bottom of the jar or bottle (not always noticeable with small jars or bottles with wide necks)
- **Infer** that the escaping bubbles result from expansion of the air inside the jar due to heating by the candle flame
- **Observe** that the water level rises very slowly (if at all) as the candle flame diminishes, and rises quickly after the flame has completely expired
- **Infer** that the water level rises due to contraction of the cooling air inside the jar – the contraction of the cooling air creates a partial vacuum (a region of lower pressure) inside the jar and the higher external pressure forces air into the jar in order to equalise the pressure inside and outside the jar
- **Record** and describe their observations using appropriate scientific language and/or diagrams

Science concepts

- a flame is the result of a chemical reaction which consumes fuel (in this case, candle wax) and oxygen and produces heat and other gases – a fire expires if either the fuel or oxygen runs out
- thermal expansion – gases expand when heated and contract when cooled
- gases move from regions of high pressure to regions of low pressure until the pressure in both regions is equal
- a vacuum is a region of lower than atmospheric pressure

Positive attitudes

Students will

- identify and observe the safety precautions discussed prior to the activity
- discover that a plausible explanation for an observed effect may not necessarily be correct
- appreciate that misconceptions can arise from sound reasoning and accurate prior knowledge
- recognise that incorrect yet plausible explanations and misconceptions can be difficult to correct
- work cooperatively in small groups and ensure everyone has sufficient opportunities to see and understand the activity
- handle all equipment and water carefully and responsibly
- dispose of waste responsibly (eg pour waste water onto plants or garden beds instead of down the sink)

Procedure

Teacher Demonstration 1 – Whole Class (10–15 min)

- Demonstrate the Classic Candle Experiment (see Teacher Notes page 5) – students will enjoy seeing each step of this demonstration – allow plenty of time for students to make predictions
- Discuss the objectives you have chosen for this activity, such as:
- Discuss the safety precautions you have taken during the demonstration and ask the students to suggest further precautions they should take during this activity (see safety notes on page 8) to establish a set of behaviour rules for the lesson and write these on the board if desired
- Allocate groups and jobs (allocating job badges will minimise classroom traffic and the risk of accidents and spills)

Experimenting with candles, bottles and jars – Small Groups (15–20 min)

- All group members read the worksheet instructions
- Equipment Manager collects materials required for activity from science store
- Teacher adds food colouring to water when the saucer or plate is ready (to minimise the risk of stained carpets / hands / clothes)
- Teacher lights candle when the group has prepared the equipment and all members are ready to observe the experiment (students do not light candles)
- Group members discuss and record observations and decide what to try next (different candle / bottle / jar)
- Equipment manager aerates the bottle or jar by filling it to the brim with water (if possible, this should be done outside to minimise the candle smoke odour in the classroom)
- Repeat the experiment with a different candle, bottle or jar

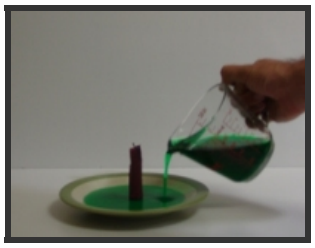
Discussion – Whole Class (10–15 min)

- Discuss each group's observations and conclusions – ask each group's Communication Officer to report their conclusions
- Perform Teacher Demo 2: Cooling Air Contracts – this will help students overcome the common 'consumed oxygen' misconception
- Discuss observations which support and/or contradict the correct explanation and the common misconception
- Discuss the reason misconceptions were reached (ie most students probably knewthat fires consume oxygen but may not have known that heating air causes it to expand and that cooling air contracts)

Teacher Notes

Teacher Demo 1: The Classic Candle Experiment

Note: the bottle must be aerated before repeating the experiment to replace the consumed and remove the carbon dioxide – filling the bottle to the brim with water and emptying will ensure the air contains the same amount of oxygen each time.



1 Secure a candle to the saucer with BluTak and add coloured water (adding detergent to the water makes the escaping air bubbles more visible and longer lasting)

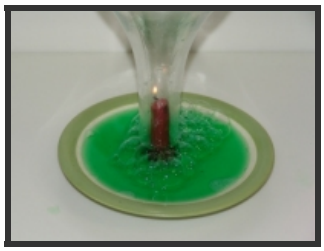
Your students will appreciate seeing every step of this demonstration including the addition of detergent and food colour into the water prior to pouring into the saucer

2 Carefully cover the candle with the inverted bottle or jar

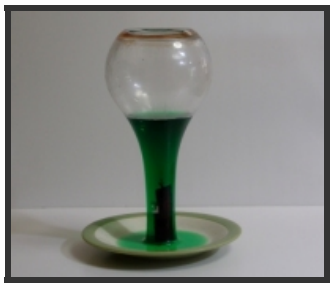
For best visual results, use a bottle with a narrow neck and a large volume (clear wine bottles or wine decanters work well for the demonstration)

3 The candle flame will gradually diminish in size as it consumes the oxygen inside the bottle

The time taken for the candle to expire depends on the size and shape of the bottle



4 Heat produces by the candle's flame causes the air inside the bottle to expand – some of this expanding air is forced out of the bottle which can be observed as it bubbles through the water (adding detergent to the water reinforces this observation)



5 When the candle flame expires, the remaining air in the bottle begins to cool – a cooling gas contracts creating a partial vacuum (a region of lower than atmospheric pressure) – the higher external pressure forces water into the bottle until the external and internal pressures are equalised

The height to which the water rises depends on the shape of the bottle and the volume of the candle

6 Aerate the bottle and prepare the candle

Before repeating the experiment, aerate the bottle by filling it to the brim with water and emptying – the candle wick will absorb a small amount of water and may need to be blown dry before repeating the experiment

Scientific explanation

The thermal expansion and contraction of the air inside the bottle is the principal effect in this demonstration. Heat produced by the candle flame causes the air inside the bottle to expand. Some of the expanding air escapes via the mouth of the bottle which can be observed as bubbles escaping from larger jars and accompanied by a glugging sound. The candle flame gradually consumes oxygen and when the oxygen level becomes too low to sustain the flame[1], it expires and the air inside the bottle begins to cool down again. The cooling gas inside the bottle contracts creates a partial vacuum (ie the pressure inside the bottle is lower than the pressure outside the bottle). The higher external pressure forces water up into the bottle[2] until the internal and external pressures are equal.

[1] Not all of the available oxygen in the bottle is consumed – how much is consumed depends partly on the height of the candle

[2] Note: it is tempting to say that the resulting vacuum "sucks" water into the bottle, however physicists avoid the use of the word "suck" because gases exert pressure from areas of high pressure towards areas of low pressure

The 'consumed oxygen' misconception

Most children know that fires consume oxygen and the most likely explanation they will offer is that the candle's flame consumes all of the oxygen leading to a decrease in the total volume of gas inside the bottle. This explanation seems so plausible to most people that it has even been propagated by science teachers and published in science textbooks. The misconception attracted the attention of New Scientist magazine (No2136, 30 May 1998) after three students wrote in seeking a better explanation for their observations, which directly contradicted the oxygen consumption explanation given by their teacher. The editor wrote:

> *"It will come as a shock to millions of schoolchildren and many teachers that this classic experiment is a sham"*

The following observations directly conflict with the 'consumed oxygen' explanation:

1) *if oxygen consumption was the principle effect, the water should start rising steadily from the instant the candle is covered and stop as soon as the flame expires but instead, the water rises most rapidly* after *the flame expires – flame consume oxygen but produce carbon dioxide and water vapour so the total volume of gas does not change significantly*[3]
2) *the air bubbles escaping from the jar or bottle are evidence of the fact that the air in the jar or bottle is expanding, not contracting (air expands when it is heated)*

[3] In reality there is a tiny reduction in the total volume due to the consumption of oxygen, but it is so small compared to the thermal expansion and contraction effect that it is totally negligible. Candle wax is a form of hydrocarbon. When it burns, oxygen (from air) reacts with the wax to form two new gases; carbon dioxide and water vapour. Some of the carbon dioxide would dissolve into the water and most of the water vapour would condense back into liquid water. The result is a tiny reduction in the total gas volume which is negligible compared to the amount of gas expelled from the bottle due to the heating and resulting expansion of the air.

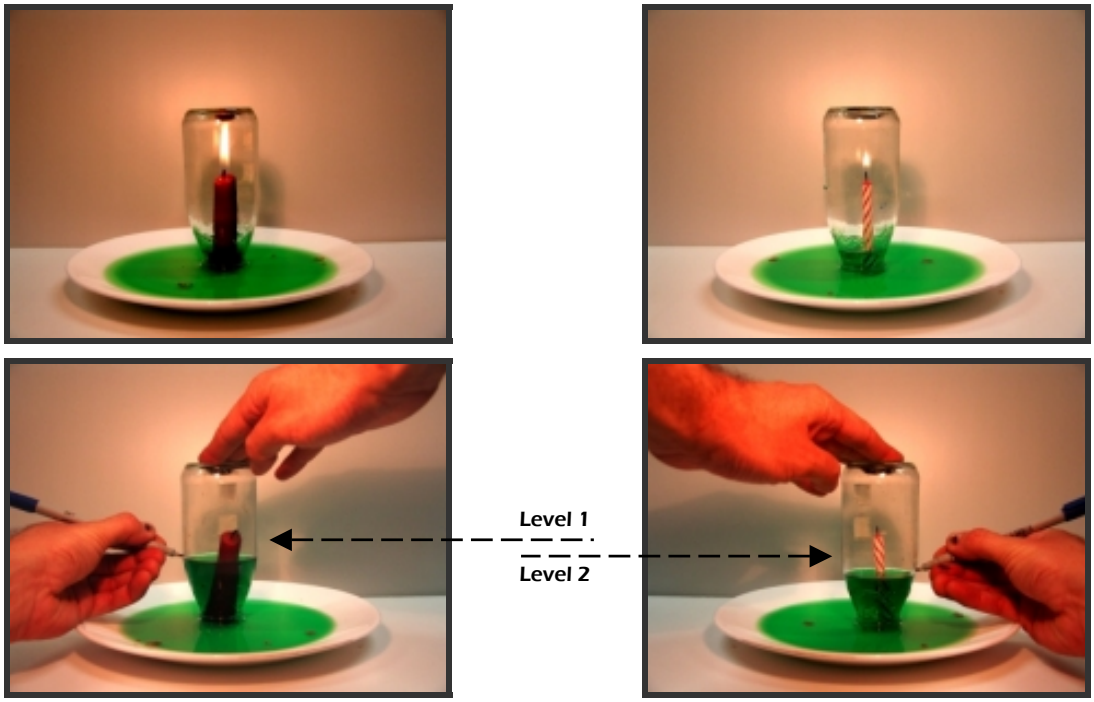
Considering that reaching this misconception demonstrates a synthesis of scientifically accurate prior knowledge (that fires consume oxygen), it is important that students are praised for reaching it. A discussion about this misconception, its dissemination by science teachers and proliferation in textbooks and how we easily jump to plausible but wrong conclusions can even play a constructive role for students (and teachers) in keeping an open and inquisitive mind. Performing Teacher Demonstration 2 (see page 9) may also help students overcome this misconception and reinforce the fact that heating gases expand and cooling gases contract.

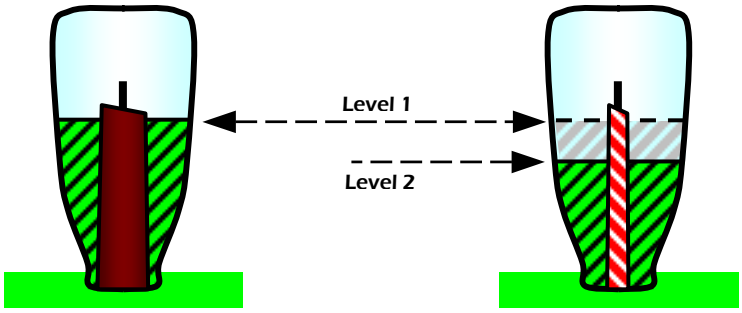
Variations due to candle thickness

The height to which the water rises varies with candle thickness because thicker candles have a larger volume. The difference will be more noticeable in bottles with a narrow neck than wide mouth jars and if the diameter of the thicker candle is close to the inner diameter of the neck of the bottle.

Small bottle with standard candle

Small bottle with cake candle

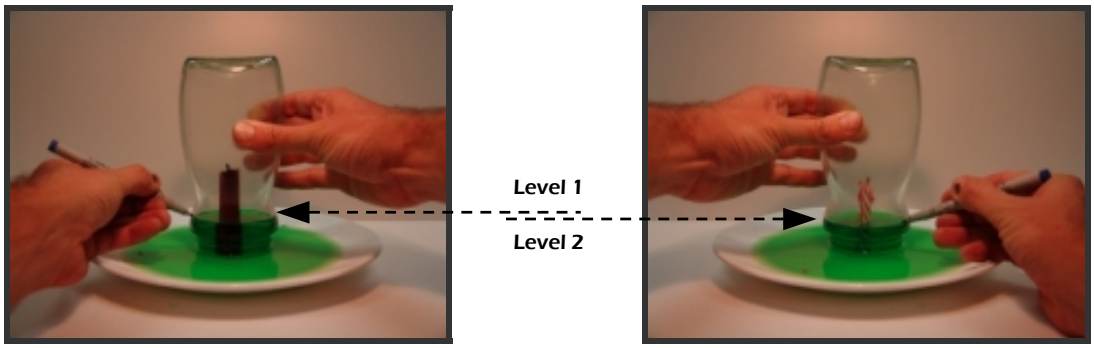




An equal volume of water rises to a greater height because the larger candle takes up more space and reduces the available volume inside the bottle

Wide jar with standard candle

Wide jar with cake candle



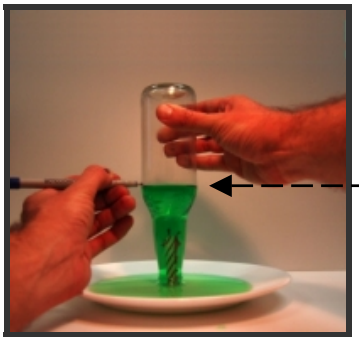
Height difference is less noticeable with the same candles in wide mouthed bottles and jars – a much thicker candle would result in a larger difference in the levels

Variations due to bottle shape

A candle will burn longer in a larger bottle because it contains more oxygen. A large bottle with a long, narrow neck (eg the decanter illustrated on the previous page or a wine bottle) allows the escaping air to be observed more readily than wide mouthed jars. The height to which the water rises varies with the shape of the jar or bottle. An equal volume of water will rise higher in a bottle with a long, narrow neck than in a bottle with a short wide neck.

Small bottle with long, narrow neck

Large bottle with wide neck



Level 1

Level 2

Safety notes

The following precautions will minimise the risk of spills or accidents. Please consider your students' individual needs and classroom situation when planning this lesson and consult your science advisor or principal if you have any reservations.

If possible, jars and bottles should be aerated outside the classroom.
Classroom should be well ventilated during activity to minimise candle odours.
Check the sensitivity of smoke detectors with grounds keeper prior to the lesson.

To minimise risk of accidents:

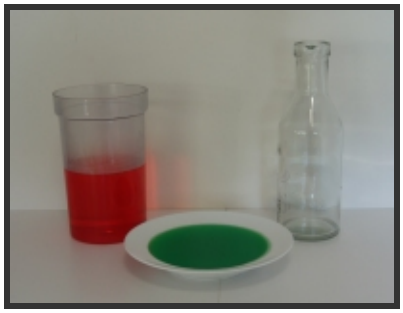
All group members agree to work cooperatively
Clear workstations of all unnecessary items and materials
Only one glass jar or bottle at the workstation at one time
Only the teacher lights the candle when the experiment is ready
Keep a damp tea-towel at each work station to smother candle flame if necessary
Use the damp tea-towel to mop up minor spills

To minimise classroom traffic:

One person per group (Equipment Manager) leaves workstation to collect/return materials
One person per group (Communication Officer) leaves workstation to ask for assistance

Teacher Demo 2: Cooling air contracts

This demonstration may help to overcome the common misconceptions about the role of oxygen consumption in the Classic Candle Experiment. In this demonstration, the bottle is heated by hot water before being set upside down in a plate of water. As the air inside the bottle cools, water rises into as in the Classic Candle Experiment.

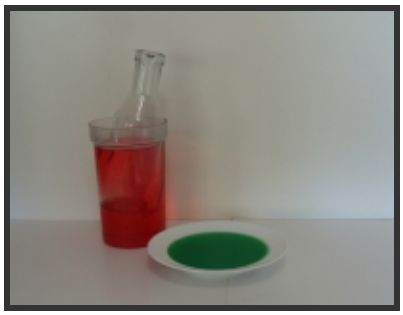


1 Use a bottle with a long narrow neck

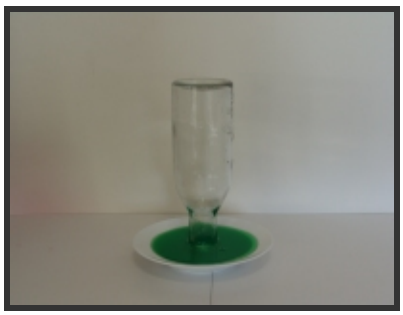
Fill a plate or saucer with coloured water

Fill a large jar with hot water – hotter water will produce a better visual result

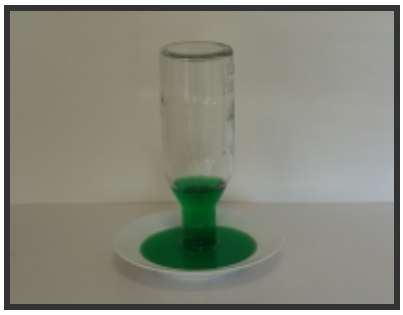
Safety note: wear a glove or use a tea-towel to handle the bottle if you are using very hot water



2 Submerge the bottle in the hot water and wait for approximately 20 or 30 seconds



3 Stand the inverted bottle in the saucer of water



4 The water will rise slower than it does in the Candle Experiment – the height to which the water rises will depend on the water and room temperatures, and how long you left the bottle in the water, and may be higher or lower than the height obtained in the Candle experiment with the same bottle

The Candle Experiment

**This classic experiment is amazing to watch but tricky to explain.
Even some textbooks have jumped to conclusions and got it wrong!
Try experimenting with it to see if you can figure out what's going on.**

Objective

Use your observation skills to notice as many things as you can. Try to formulate a scientific explanation for your observations. You can test some of your ideas by using different sized candles, bottles and jars.

Materials required

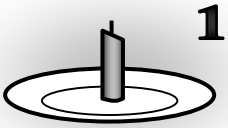
Candles (various sizes)
Jars and bottles (one at a time per group)
Funnel
Damp towel (for safety)
Saucer or plate
2 litres of water (in jug or bottle)
Food colour

Safety Notes

Please observe the following simple safety precautions during this experiment:

- *Only allow the teacher to light the candle when the experiment is ready*
- *Never leave a burning candle unattended*
- *Collect one jar or bottle at a time to minimise the amount of glassware on your workstation*
- *Take care not to bump the table while the jar or bottle is balanced on it*
- *If a lit candle is accidentally knocked over, cover it with the damp tea-towel*
- *Report any accidents or spills to the teacher immediately*

Procedure



1 Secure a candle to the plate using sticky putty (make sure the candle fits into the jar or bottle you are using)

2 Pour water into plate and add a few drops of food colour

3 Light the candle

4 Cover the candle with an upside down glass, jar or bottle and watch what happens next

5 When you are ready to start over, carefully tilt the jar or bottle to slowly empty it back into the plate.

Aerate the jar or bottle by filling it to the brim with water, then emptying it again. This procedure removes all the air in the bottle and replaces it with fresh air. If possible, aerate your bottle outside to reduce the amount of candle smoke (and smell) in the classroom.

Experimenting and investigating

Try experimenting with different candles, bottles and jars. Write down all the things you can notice happening during the experiment. Record your results and ideas in your science journal and consider the questions below.

What effect does the size of the candle have on how high the water rises?
What effect does the size of the bottle or jar have on how high the water rises?
What effect does the shape of the bottle or jar have on how high the water rises?
For each of these observations, write down what you think is happening.
Can you think of ways to test your ideas? (it's okay to have more than one for each observation)
Do all your observations support your explanation? If not, why?
Do you think you could prove your explanation?