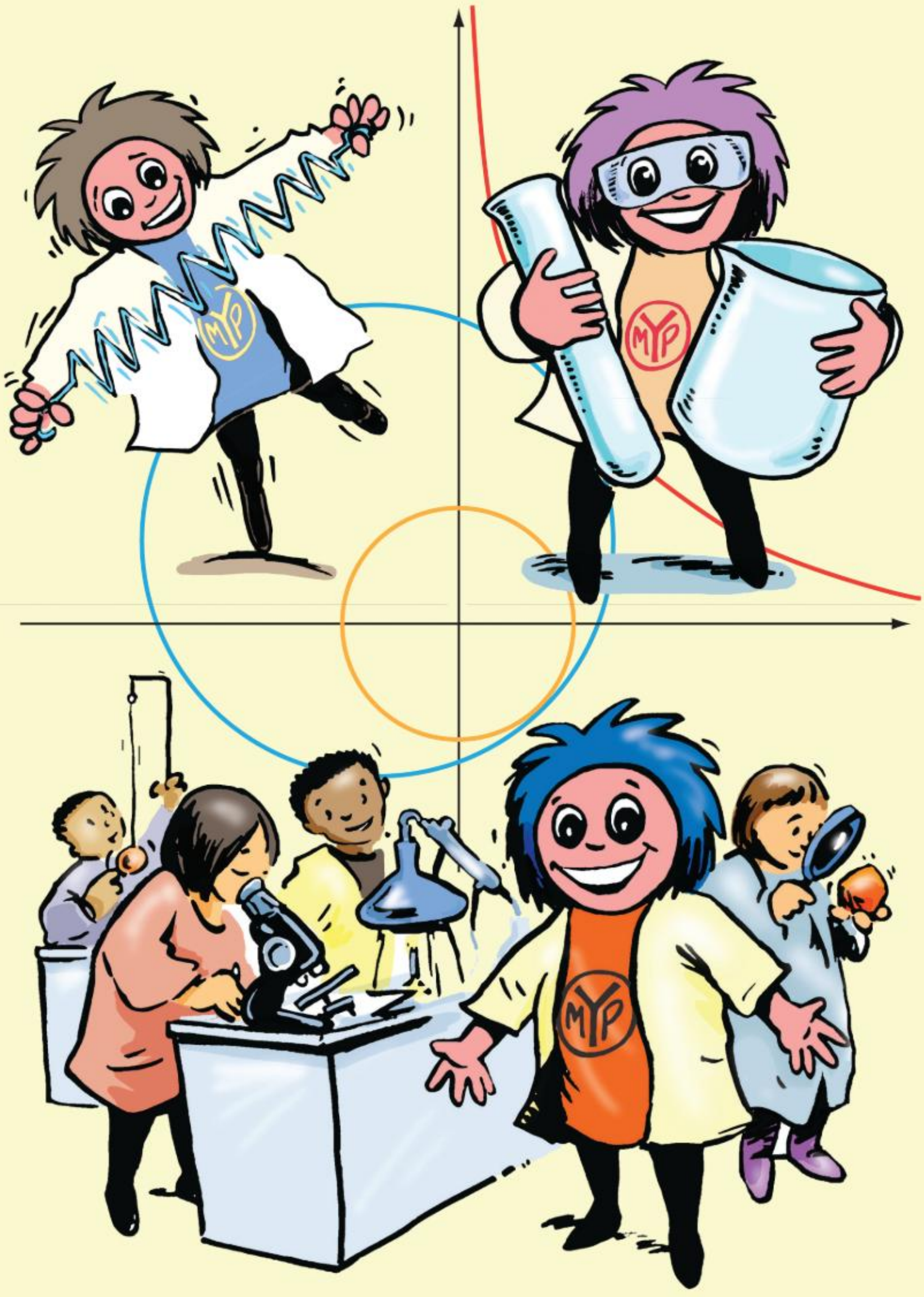
Investigations for MYP Sciences

FOR USE WITH THE
I.B. PROGRAMME

2nd EDITION

Christopher Talbot, Cesar Reyes, David Fairley

MYP



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INVESTIGATIONS
FOR MYP SCIENCES

FOR USE WITH THE INTERNATIONAL BACCALAUREATE MYP PROGRAMME

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Foreword

This volume contains student instruction sheets for 10 Chemistry, 10 Biology, 10 Physics and 10 Earth and Space Investigations which are suitable as 'open-ended' Design Investigations for the MYP Sciences Programme. A 'stimulus' photograph is included for each investigation. It will either be a photograph of some of the apparatus or chemicals likely to be used in the investigation, or an everyday object that has some connection to the theme of the practical.

The Student Sheets have a small amount of relevant background information to initiate student's thinking or interest. However, they do not give explicit information about relevant variables to select, measure or control. The instructions do not tell students how to collect, process and analyse data. The student instruction sheets do include a general aim, for which students have to formulate a research question and hypothesis.

However, as a science teacher you must carry out your own risk assessment and comply with your own local or national rules, guidelines or regulations. Your students must be informed of the safety rules and regulations in your school before they engage in practical work relating to these Investigations. A list of materials: chemicals and apparatus is provided. Note that an individual student may not need to use all of the equipment since the materials list may provide for several different methods. Additional equipment and chemicals may be requested by students but you will need to check their proposed method before letting students commence practical work in the laboratory. Relevant safety instructions have been provided and must be clearly communicated and understood by students. Some practicals carry greater risks than others. Hence, you may not wish to carry out some practicals, unless the class is small, well behaved and experienced in practical techniques.

Your own professional judgement is critical: do not carry out practical work unless you are familiar with the proposed method and have assessed the risks and hazards and checked them against your school's regulations, guidelines or laws. The Teaching Notes have been written to allow non-specialist teachers to confidently and successfully introduce Investigations outside their own discipline. They include relevant background theory, the expected relationship between the variables and a suggested method, as well as likely issues to be included in an evaluation and suggestions for extension work.

Acknowledgements

We would like to thank Dr Richard Harwood (former Deputy Headmaster of Aiglon College, Switzerland), Mr Bernard Taylor (former IB Physics Teacher at Anglo-Chinese School (Independent), Singapore) and Mr Unnikrishnan Pandarathil (former Teacher of IB Physics at Overseas Family School, Singapore) for their helpful review work. We also acknowledge the support and camaraderie of current and former colleagues at OFS: Sheela Thomas, Sara Hornseth-Bates, Leo Don, Don Brown, Lorne Schmidt, Christine Clement, Kishanda Vickneson, Jon Homewood, Alison Martin, Saengdao Philavane, Laurence van Koninckxloo, Deborah Rogozinski, Vicky McKnight, Debbie Marinelli, Jason Brough and Adele Querzoli.

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The authors

Singapore

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Chris taught IB Chemistry, IB Biology, IGCSE Coordinated Sciences and MYP Science in the High School of the Overseas Family School and College, Republic of Singapore, where he was formerly Science Curriculum Area Leader. He graduated with honours in Biochemistry from the School of Biological Sciences, University of Sussex in the United Kingdom. He also holds an Advanced Certificate in Molecular Biology from Birbeck College, University of London in the United Kingdom. He has a Masters degree in Life Sciences (Chemistry) from the National Technological University (NTU) in Singapore. He is the author of the Student Guides to Internal Assessment for the IB Chemistry, Physics and Biology Diploma programmes. He is also the author of the Practice Examinations for Chemistry and Biology (IBID Press) and was a contributing author and proof-reader for the IB Biology Text. He has had many Chemistry and Biology articles published in School Science Review and is serving a five year term as an Editorial Associate.

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Cesar teaches IB Physics, MYP Science and IGCSE Coordinated Sciences in the High School of the Overseas Family School and College, Republic of Singapore. Previously, he taught at Port Moresby International School in Papua New Guinea, where he was the Deputy Principal for Academics and the IB Coordinator. He also taught at the University of the Philippines and the De La Salle University in the Philippines. He graduated with a degree in Physics from the University of the Philippines. He completed his Diploma in Teaching from St. Scholastica's College in Manila and he studied for a Masters in Physics at the De La Salle University. Cesar has been teaching the IB Diploma Physics Programme for the last eight years. He is the author of the Student Guide to Internal Assessment for the IB Physics programme.

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The three authors have been involved in the development of MYP Science assessment tasks and participated in internal moderation exercises at the Overseas Family School, Singapore since the introduction of the MYP Programme in 1997. They have attended a number of regional MYP Conferences.

Editor Profile

David Greig has worked very closely with all three authors as Editor in developing Volumes of Investigations for both the MYP Sciences and Diploma Science subjects. He is the principal consultant of 'S.T.A.R.', a graduate of the University of Adelaide and a very experienced science teacher, editor and author. The team would be pleased to receive comments and suggestions from MYP Science colleagues and can be contacted via the publisher.

Alby

The character on the front cover and throughout the books is the mascot for the IA Handbook and Investigations for the MYP Sciences.

His/her name is Alby and he is named after Albert Einstein. How many times do Alby and his friends appear in the MYP Science Guide? Why did the authors and editor choose Albert Einstein? You probably think it is because Einstein is considered by many scientists to be one of the greatest scientists of all time. He developed many new areas of theoretical physics, notably relativity and quantum theory, for which he was awarded the Nobel Prize in Physics in 1921.

However, we chose him because he embodies many of the characteristics of the MYP Learner Profile. For example, when Einstein was aged five, his father showed him a pocket compass. Einstein realised that there must be something in the space, previously thought to be empty, that was moving the needle and later said that this experience made 'a deep and lasting impression'. He also taught himself mathematics, science and philosophy. Einstein was clearly an enquirer, a thinker and knowledgeable from a young age.

Einstein was also clearly open-minded and principled. He was born a German Jew, but attended a Catholic school and lived in Switzerland and Italy. Later he moved to America and became an American citizen. He was also active in politics.

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HEALTH AND SAFETY SYMBOLS

Laboratories can be hazardous places. Often scientists, Science teachers and students handle equipment and materials which can be dangerous to their health and safety. Throughout these Investigations you will see a number of symbols and warnings which will represent particular hazards. For each of these we will briefly describe the hazard and indicate what precautions you should take to avoid damage and/or what responses are appropriate. In all cases, of course, you should seek advice and assistance from the teacher or laboratory technician.

A biohazard is any organism or body fluid which could possibly cause illness or disease in your body. This particularly includes micro-organisms.

A flammable substance is one which will readily burn in air. It may be a solid, liquid or gas. If you are using such a substance it is vital that there are no sparks or naked flames which could ignite it. It is vital that you know what to do in the event of fire. This may include the use of fire extinguishers and evacuation procedures.

A radioactive substance is one which emits particles or 'radiation'. This radiation is known to cause damage to cells and may also be cancer causing. If you are using radioactive substances it is vital that you wear protective clothing, use metal tongs and listen carefully to instructions given by your teacher or laboratory technician.

Sharp instruments are often used in Science and particularly in Biology, to cut sections through plant or animal tissue. These instruments, which include scalpels and razor blades are very sharp and obviously will also cut through your tissues. When using these instruments it is essential that you always cut away from your body and preferably onto a cutting board. It is also important to be very careful when carrying these instruments and also ensure they are placed on the workbench in a safe place.

When certain chemicals are mixed together they can become explosive. An explosion is caused by rapid expansion of gas in a confined space and can be very dangerous. Sometimes it is important to ensure that the space is not confined and sometimes it is important to conduct these reactions behind a protective screen.

It is often necessary to protect your hands from heat, chemicals or other hazards and gloves will be made available for these situations. The type of glove needed will depend on the particular hazard and your teacher will provide further advice. In some cases you will be advised to dispose of the gloves after use and in other cases to wash and dry them carefully.

Your eyes are the most vulnerable and easily damaged external part of your body. This is why they must be protected if you are using solids and liquids which could get into them. Whenever you are heating things or using corrosive liquids, and in other cases as instructed by a teacher, you should wear safety goggles. You should also do this if possible even if you wear spectacles to correct your vision. In the event that something gets in your eye you should immediately make use of the eyewash facility in the laboratory as instructed and then notify your teacher.

Some chemicals, which are used in a laboratory, are corrosive. This means that they can react with and 'eat away' materials like the bench, your books, clothing and skin. It is essential that you handle these materials, which are usually liquids, with care. Always tip from the container with the label uppermost, never add water to concentrated acid and never have your face anywhere near the container. It is usually advisable to wear both safety goggles and gloves. If protective aprons are available you should also wear one.

As a general rule, 12 or 24 volt *electrical* appliances are unlikely to cause serious injury. However, 'mains' voltage (110V or 240V or higher) can cause serious injury or death. The appliances you use should be regularly tested and certified safe. If you notice sparks or smell insulation burning, turn the power off immediately and notify staff. Be particularly careful not to allow water to get into any appliance as it may cause a short circuit.

ELECTRICITY

Some chemicals are *poisonous* and should not be inhaled or ingested. It will be necessary to use a fume cupboard when using poisonous gases or volatile liquids. They could make you very ill and you may require medical assistance. It is vital that you listen to instructions, follow them carefully and notify your teacher immediately if there is accidental exposure to poisonous or toxic substances.

POISON

Lasers are very intense beams of light. They are capable of causing burns to the skin and permanent damage to the eyes. It is essential that these are only ever used under the supervision of a teacher and in a situation where people can not see the beam directly or when it is reflected from a shiny surface. Sunglasses or welding masks do not provide sufficient protection and special 'laser glasses' must be used where there is a risk.

LASER

UV light is harmful to skin and especially eyes. Do not expose these areas directly to a UV light source. If it is not avoidable, sunscreen can be applied to the skin and special goggles should be worn.

UV

There are other *dangers* or hazards as well, for example carrying heavy or hot objects. This may also include chemicals which are not poisonous but which may smell unpleasant or irritate the skin. Whenever you see this icon more information will be provided in the adjacent text about the specific danger.

DANGER

In Science and particularly in Biology, there are situations when ethics and ethical issues need to be considered in experimental work. This is particularly the case when human volunteers are being used, not just for experimental work but also when they are being surveyed to collect personal information. In these cases a consent form should be used to explain the nature of their involvement and to get their approval. Ethics will also be an issue whenever animals are used in experimentation or when they are collected in the field. They should not be exposed to conditions that are outside their natural range of tolerance and wild animals must be released back where they were sampled with the minimum of disturbance.

ETHICS

The environment and environmental issues become important when hazardous substances are used or produced during an experiment. Their disposal must result in minimal impact on the environment. In field work the protocol that is used must reflect practices that minimise the impact of the investigation on the site.

ENVIRONMENT

IMPORTANT NOTE

Although every care has been taken in preparing and trialling these investigations, absolutely no responsibility or liability whatsoever can be accepted for any damage or accident which may occur for whatever reason during the conduct of any of these activities. The Safety Warnings and Icons are advisory only and are not intended to be exhaustive or exclusive. It is a strict condition of sale that safety in the laboratory is the responsibility of the staff and students doing the laboratory work and not the author, editor or publisher of this work.

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INTRODUCTION

Photosynthesis is a vitally important process occurring in green plants. Plants absorb carbon dioxide and water and in the presence of light and appropriate enzymes form glucose within chloroplasts and excess oxygen is released as a by-product. Plants are eaten by many animals and the majority of living organisms require oxygen for respiration. Plants are known as producers and are at the start of almost every food chain.

The summary word and symbol equations for photosynthesis are:

carbon dioxide + water → glucose + oxygen

$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the rate of photosynthesis.

MATERIALS

YOU WILL BE PROVIDED WITH

Water plant (*Elodea*)
Thermometer
Clamp stand
Rubber tubing
Kettle
Lamp (e.g. 60 W)
Gas syringe
Aluminium foil
(Data logger interface)
Spatula
Metre rule
Distilled water

Boiling tube
Large beaker 500 cm^3
Retort stand and clamp
Glass trough
Ice cubes
Scalpel
Rubber tubing
Coloured filters e.g. blue, red etc. (from a ray box)
(Dissolved oxygen sensor and light sensor)
Stopwatch
Test tubes
Light meter (lux meter) (if available)

Sodium hydrogencarbonate solution: 0.1 mol dm^{-3}

Sodium hydrogencarbonate (solid)

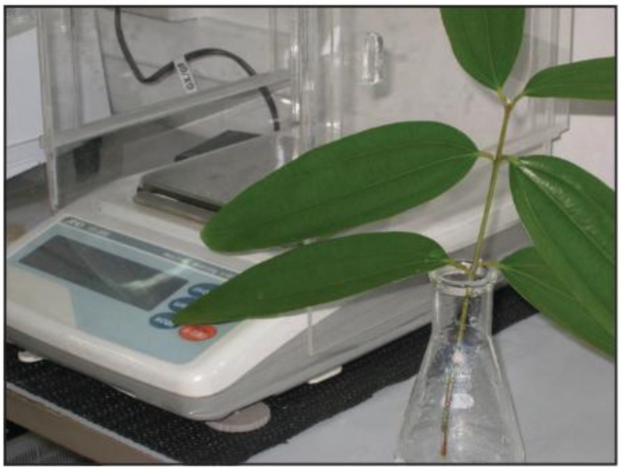
SAFETY

Glasses must be worn when cutting. Scalpels should not be carried from one table to another.

INTRODUCTION

The evaporation of water from the leaves of plants via the stomata and in stems via lenticels is known as transpiration. Transpiration has an important cooling effect on the plant's leaves and water provides support in non-woody plants.

It is also responsible for maintaining the transpiration stream inside the plant which carries water and dissolved mineral salts within the xylem vessels.



AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the rate of transpiration.

MATERIALS

YOU WILL BE PROVIDED WITH:

Heat source

Transparent and black plastic bags

Lamps

Conical flasks

Oil

Scissors

Leafy shoots

Vaseline

Electronic balance

Boiling tubes

Hair dryer

Fan

Electronic stopwatch

Lamp

Ruler

Hygrometer (to measure humidity)

Anhydrous cobalt(II) chloride paper

Squared paper

Potometer (if available; but it is not necessary)

SAFETY

Be careful when using scissors and glassware.

INTRODUCTION

Osmosis is a form of diffusion. Osmosis is defined as the diffusion of water molecules down a concentration gradient across a partially permeable membrane. Water molecules move from a dilute solution into a more concentrated solution.

Cell membranes in living cells are partially permeable; artificial membranes, such as 'Visking' tubing, can also be prepared so they are partially permeable. Osmosis plays an important role in keeping plant tissues firm (turgid).

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the extent of osmosis in potatoes.

MATERIALS

YOU WILL BE PROVIDED WITH:

Fresh potatoes (three varieties)

Scalpel

Measuring cylinder

Spatula

Cork borer

Sodium chloride, NaCl

Sucrose

Glucose

Distilled water

Potato peeler

Ruler

Beaker

Blotting paper

Potato peeler

Electronic balance

Plastic boards

SAFETY

Glasses must be worn when cutting. Scalpels should not be carried from one table to another. Your teacher will demonstrate how to use the cork borer safely.

INTRODUCTION

The surface area-to-volume ratio is the amount of surface area per unit volume of an object, such as a cell. The ratio between the surface area (supply of nutrients and oxygen) and volume of cells (demand for nutrients and oxygen) in organisms has an enormous impact on their biology since large animals cannot rely upon diffusion for the exchange of soluble chemicals. Hence, large complex multicellular animals have evolved lungs and circulatory systems.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect diffusion rate.

MATERIALS

YOU WILL BE PROVIDED WITH:

Beakers

Stop clocks

Boiling tubes

Scalpels

Tiles

Petri dishes

2 M hydrochloric acid

2 M ethanoic acid

Agar that has solidified with a few drops of phenolphthalein

N.B. The agar cubes contain phenolphthalein which is colourless in acidic solution and pink in basic solutions.

SAFETY

Glasses must be worn when cutting the agar and using acid.

Scalpels should not be carried from one table to another.

INTRODUCTION

Many of the commercial uses of micro-organisms are based on the process of fermentation. The best known and mostly widely used fermentation reaction is the anaerobic respiration of glucose by yeast (a single-celled fungus). Since one of the products is ethanol, this process is known as alcoholic fermentation. It is used to make alcoholic drinks, such as wine, and for baking bread. Carbon dioxide is a by-product of alcoholic fermentation.

AIM

To design, carry out and evaluate an experiment to investigate one of the variables that affect the rate of respiration in yeast.

MATERIALS

YOU WILL BE PROVIDED WITH:

250 cm^3 beaker
Delivery tube
Spatula
Yeast
Thermometer
Glucose
Fructose
Sucrose
Gas syringe
Beaker
Lime water
Rubber tubing
5 cm^3 syringe
Plastic tubing

Measuring cylinder
Bung
Water bath or kettle
Boiling tubes
Electronic balance
Starch
Boiled water (does not contain dissolved air)
Cooking oil
Stop watch
Test tubes
Spirit marker
Three way tap
1 cm^3 pipette (×2)
Graduated pipette or syringe (10 cm^3)

Length of 1 mm bore capillary tubing, 11 cm long and flame polished at both ends
Dropping pipette

SAFETY

Avoid contact with yeast powder; do not breathe in the yeast powder.

INTRODUCTION

All of the chemical reactions that occur inside living cells are controlled by enzymes. All enzymes are proteins, and they act as biological catalysts – they speed up chemical reactions without themselves being affected by the reaction. The molecules that react in enzyme-controlled reactions are termed substrates and form enzyme-substrate complexes.

Catalase occurs in many plant and animal tissues, including potato and fresh liver. It breaks down toxic hydrogen peroxide, formed as a by-product of various biochemical reactions, into water and oxygen.

These are the word and symbol equations for the reaction:

hydrogen peroxide → water + oxygen

$2H_2O_2 \rightarrow 2H_2O + O_2$

AIM

To design, carry out and evaluate an experiment to investigate one of the variables that affect the rate of decomposition of hydrogen peroxide by catalase.

MATERIALS

YOU WILL BE PROVIDED WITH:

Potatoes and/or fresh liver
Knife or scalpel
Detergent solution
Kettle
Measuring cylinder
Stop watch
Rubber tubing
Electronic balances
Scalpel
Potato peeler
Thermometer
Beaker
Ceramic tile
Cork borer
Conical flask with side arm and bung
Gas syringe
Water bath (if available)
15% by volume hydrogen peroxide solution

SAFETY

Disposable gloves must be worn if fresh liver is to be used as the source of catalase. Hydrogen peroxide is an irritant - safety glasses must be worn. It is harmful if swallowed.

GLOVES
GOGGLES
SHARP
CORROSIVE

INTRODUCTION

A seed develops from an ovule after fertilization. It consists of a tough coat or testa enclosing an embryo which is made up of a plumule, a radicle and one or two cotyledons. In favourable conditions the seed can grow and become a fully independent plant, bearing flowers and seeds during its life cycle.

Seeds require a number of factors for germination. A number of chemicals, including those from seeds, may stop germination occurring. Some seeds are very susceptible to acid rain which is formed from sulfur dioxide and contains sulfuric acid.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the germination of seeds.

MATERIALS

YOU WILL BE PROVIDED WITH:

Tomatoes

Filter paper

1% agar

Cress seeds

Polythene bags

Sellotape

Empty plastic drinks bottles

Pestle and mortar

Bean seeds

Cress seeds

Petri dishes and lids

Beaker

Bird seeds

Measuring cylinder

10 or 20 cm^3 gas syringe

Scissors

Filter paper

2 M sulfuric acid

Access to sulfur dioxide gas (*under teacher supervision and discretion)*

SAFETY

If you need to use sulfur dioxide in your experiment ask the teacher to introduce the gas. Sulfur dioxide is a toxic gas and an irritant to the eyes and lungs. Wear eye protection.

INTRODUCTION

The function of the heart during exercise is to pump sufficient blood to the muscles to allow them to function effectively when you exercise. This means providing them with the glucose and oxygen required for aerobic respiration and removing the excretory products, urea and carbon dioxide, and the excess heat produced during respiration. One measure of fitness is how quickly your heart rate returns to the resting rate after exercise.

The maximum rate that your heart can beat per minute tends to decrease with age, and this can be roughly estimated using the following empirical relationship:

[Maximum heart rate per minute] = [220] minus [your age in years].

The anaerobic threshold is approximately 85% of maximum heart rate.

AIM

To design, carry out and evaluate an experiment to investigate the effect of exercise on heart rate.

MATERIALS

YOU WILL BE PROVIDED WITH:

Heart rate monitor

Exercise equipment, for example, a rowing or cycling machine that displays duration, instantaneous power and average power.

If access to a gym is not possible then your heart rate can be monitored using a finger placed lightly on top of an artery in the neck or wrist.

A controlled and well defined amount of exercise can be used in the place of gym equipment.

SAFETY

WARNING: Do not participate in this investigation if you are feeling unwell or taking medication. Stop if you are feeling very tired or unwell. Do not exceed your maximum heart rate for your age.

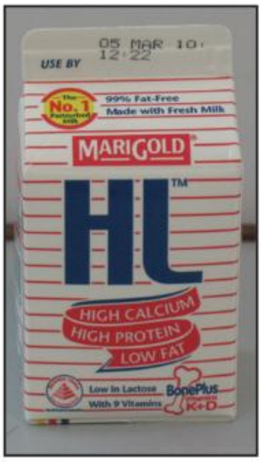
INTRODUCTION

Milk is a very nutritious and versatile food. People enjoy drinking milk in its natural form and also use it to make a wide range of food products, including cream, butter, yoghurt, cheese, and ice cream. People drink the milk produced from a variety of domesticated mammals, including goats, sheep, camels, reindeer, buffaloes, and llamas, although the major source for commercial production and consumption is from cows. Milk is composed of water, protein, lactose and fat which is dispersed throughout the milk in globules.

The relative densities of milk can be determined by measuring the time taken for droplets of milk to sink through a solution of copper(II) sulfate. The droplets are held intact due to the formation of a layer of copper proteinate at the surface.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the density of milk.



MATERIALS

YOU WILL BE PROVIDED WITH:

Two droppers or teat pipettes

Two measuring cylinders (100 cm^3)

Stopwatch

0.1 mol dm^{-3} copper(II) sulfate

Milk samples: skimmed, semi-skimmed and full fat (different brands)

SAFETY

Copper(II) sulfate solution is harmful if swallowed and irritating to eyes and skin. Safety glasses must be worn at all times.

INTRODUCTION

Reaction time is the ability to respond quickly with proper posture and control to a stimulus such as sound or sight. In many sports, maximum speed is rarely reached or needed, but a fast reaction is often necessary. A fast reaction time may save your life when you are driving by allowing you to react quickly to an event, such as when braking a car, or dodging a braking car!

One simple approach to measuring reaction times involves dropping a ruler between the fingers and thumb of the subject who has to grip it as soon as he or she sees it move. The speed of the subject's reaction is a function of the distance the ruler falls before it is arrested.

The reaction time (s) can be established from the following equation:

$$t = \sqrt{\frac{2d}{g}},$$

where g represents the acceleration due to gravity (9.80 m/s^2) and d represents the distance measurement from the ruler (in metres).

There are two much more accurate ways to measure reaction time:

Find and use a website such as <http://www.phy.ntnu.edu.tw/ntnujava/index.php?topic=137>

OR start two identical stopwatches simultaneously by pressing their start buttons together. Now if one person (observer) presses the stop button, the sound will be a stimulus for the second person (subject) to press the stop button on the other stopwatch and the difference will be the reaction time.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the reaction time of humans.

MATERIALS

YOU WILL BE PROVIDED WITH

Metre rules

2 electronic stopwatches

Bathroom scales (to measure mass of students)

SAFETY

This activity could be harmful and affect your health. Any plan involving food or drink must be approved by your Teacher.

INTRODUCTION

'Acid rain', which causes corrosion of buildings and death of trees and freshwater fish, is caused by the gases sulfur dioxide and nitrogen dioxide. These gases are released into the atmosphere when fossil fuels, such as coal and fuel oil, are burnt. These fuels contain small quantities of sulfur and when the fuels burn, the sulfur reacts with the oxygen in the air to form sulfur dioxide. The polluting gases come from a variety of sources including chimney smoke (particularly from factories), and car exhausts. These gases are soluble in water and react to ultimately form sulfuric and nitric acids. These then react with stonework and metals, such as iron.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the rate of a reaction involving dilute acid.

MATERIALS

YOU WILL BE PROVIDED WITH:

Gas syringe
Delivery tube and bung
Ruler
Clamp stand
Rubber tubing
Burette
Pestle and mortar
2 M ethanoic acid
Kettle
Glass trough
Digital balance
Copper(II) oxide
2 M hydrochloric acid, HCl
2 M copper(II) sulfate solution

Conical flasks
Electronic stopwatch
Fine sand paper
Measuring cylinders
Glass trough
Boiling tubes
2 M nitric acid, HNO_3 (aq)
Marble chips (calcium carbonate)
Magnesium ribbon
Magnesium powder
Copper
Zinc

SAFETY

Safety glasses must be worn at all times during the investigation. Dilute acid is corrosive – if it comes into contact with skin or eyes, then the affected area must be washed with a stream of cold water. Disposable gloves should be worn during the practical. Copper(II) sulfate solution is harmful if swallowed and irritating to eyes and skin. Copper(II) oxide is harmful.

CORROSIVE
GLOVES
GOGGLES

INTRODUCTION

Neutralisation occurs when an acid reacts with a base to form a salt and water only. Acid rain in lakes and in soil is often neutralised by adding calcium oxide or calcium hydroxide. Many toothpastes and chewing gums are alkaline and help to neutralise the acids produced by bacteria respiring sugars in your mouth. When neutralisation occurs there are changes in pH, concentration, conductivity and temperature which can be measured when an alkali is progressively added to an acid, or vice versa.

AIM

To design, carry out and evaluate an experiment to investigate the reaction between a dilute acid and a dilute alkali (soluble base).

MATERIALS

YOU WILL BE PROVIDED WITH:

Funnel
Burette
Conical flask
0.1 M sodium hydroxide
0.1 M sulfuric acid
0.1 M nitric acid
0.1 M ammonia
Universal indicator solution
Thermometer
Conductivity probe and meter
1 M sodium hydroxide
Burette stand

Pipette and filler
White tile
Measuring cylinder (25 cm^3)
1 M sulfuric acid
Distilled water
0.1 M hydrochloric acid
0.1 M ethanoic acid
pH probe and meter (and data-logger if available)
Temperature probe (and data-logger if available)
1 M hydrochloric acid
Two insulated styrofoam or polystyrene cups
A range of commercial antacids

SAFETY

Safety glasses must be worn at all times during the investigation. Dilute acid and alkali are corrosive – if they come into contact with skin or eyes, then the affected area must be washed with cold water.

GOGGLES CORROSIVE

INTRODUCTION

The element iron comprises over 5% of the Earth's crust. It is commonly used to construct machine tools, cars, the hulls of large ships, and structural components for buildings and bridges. Huge amounts of money are spent globally on the prevention of rusting, which can rapidly weaken and damage iron. Rusting is an oxidation reaction that involves the formation of hydrated iron(III) oxide. Ferroxyl indicator can be used to show where rusting is occurring: a blue colour confirms that rusting is taking place.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the rusting of iron.

MATERIALS

YOU WILL BE PROVIDED WITH:

Iron nails

Fine sand paper

Conical flask

Kettle

Metal scissors

Polish

Paint

Sodium chloride

Zinc foil and copper foil

Test tubes with rubber stoppers or corks

Cotton wool

Measuring cylinder (25 cm^3)

Distilled water

Vegetable oil

Ferroxyl indicator

Petroleum jelly

Petri dishes

Pipette

Balance capable of weighing to at least 0.01 g

Anhydrous calcium chloride (drying agent: absorbs water vapour)

SAFETY

FLAMMABLE CORROSIVE
GOGGLES GLOVES

Wear safety glasses and gloves. Calcium chloride may be harmful if it is swallowed. Eye contact: Immediately flush the eye with plenty of water. If irritation persists call for medical help. Skin contact: Wash off with water. Solid $K_3Fe(CN)_6$ is an irritant to the eyes. Phenolphthalein is also an irritant to the eyes and skin and is dissolved in alcohol (flammable). Care is needed when using paints and polishes.

INTRODUCTION

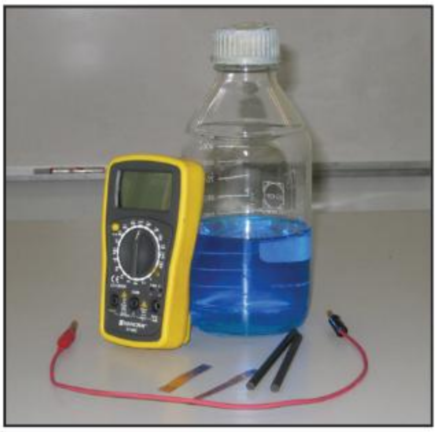
Copper is a very important metal, widely used in cables, wires and in the formation of alloys, such as brass and bronze. Copper can be produced in a very pure form by electrolysis of copper(II) sulfate solution - unreactive impurities drop to the bottom of the solution. Copper(II) sulfate solution can be electrolysed with inert carbon (graphite) electrodes and reactive copper electrodes. The change in electrodes results in different products.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the electrolysis of copper(II) sulfate solution.

MATERIALS

YOU WILL BE PROVIDED WITH:



- Milliammeter (or multimeter)
- Beaker
- Crocodile clips and leads
- Fine sand paper
- 2 M copper(II) sulfate solution
- Electronic balance
- Propanone (for degreasing electrodes)
- Power supply
- Copper electrodes
- Stopwatch
- Carbon electrodes
- Ignition tubes
- Wooden splints

SAFETY

Copper(II) sulfate solution is poisonous. Safety glasses must be worn. Propanone is poisonous, highly flammable and irritating to the eyes. The vapours may cause drowsiness and dizziness.

INTRODUCTION

When humans and other mammals get hot, they sweat. Sweat is released from the sweat pores that lie in the skin's surface. Sweat consists of water with small amounts of urea and dissolved salts. The physiological role of sweat is to cool us down. When water evaporates, it removes heat energy from the surface of our skin. Plants lose water via the stomata (pores) on the underside of leaves. This process is known as transpiration and plays an important role in keeping plants cool. Other molecular liquids, such as propanone and the alcohols, undergo rapid evaporation at room temperature.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the evaporation of a volatile liquid or series of volatile liquids.

MATERIALS

YOU WILL BE PROVIDED WITH:

Electronic balance

Propan-1-ol

Beakers

Thermometer

Propanone

Methanol

Burette

Clamp stand

Conical flasks

Pentan-1-ol

Ethanol

Distilled water

Kettle

Stopwatch

Small portable fan

Butan-1-ol

Pipette

Measuring cylinders

Watch glasses

SAFETY

Work in a well-ventilated laboratory. Safety glasses and gloves must be worn at all times during the practical. Bunsen burners are not to be used at any time during this practical. Any heating must be done using a water bath. All alcohols are toxic with methanol being the most toxic. It is toxic by inhalation, contact with the skin and if swallowed. Medical attention must be sought if this occurs.

FLAMMABLE POISON
GOGGLES GLOVES

INTRODUCTION

Ethanol and the other alcohols can be used as fuels. Ethanol is prepared from sugar cane by fermentation which is catalysed by enzymes from yeast. Ethanol can also be mixed with petrol (gasoline) to form what has been called 'Gasohol'. Most such common blends contain 10% ethanol mixed with petrol (gasoline). This is done in countries that have to import crude oil, but have a suitable climate for growing sugar cane.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the heat released by the combustion of alcohols.

MATERIALS

YOU WILL BE PROVIDED WITH:

Spirit burner with wick
Thermometer
Electronic balance
Propan-2-ol
Ethanol
Methanol
Propan-1-ol
Butan-1-ol
Screen
Clamp stand and clamp
Electronic stopwatch
Large glass beaker
Pentan-1-ol
Hexan-1-ol
Matches
Butan-2-ol
Copper calorimeter with wooden cover with holes for stirrer and thermometer

SAFETY

All of the alcohols are toxic and highly flammable. Eye protection must be worn at all times.

INTRODUCTION

Water is a very good solvent and will dissolve a wide range of substances. It is an especially good solvent for salts. A solution which contains as much solute as can be dissolved at a particular temperature is called a saturated solution. If any more solute is added to a saturated solution, the extra salt (solute) remains undissolved. The solubility of a salt (solute) is the mass of a salt (solute) which dissolves in 100 g (100 cm^3) of water at a particular temperature to form a saturated solution.

Salts are ionic compounds formed when the hydrogen of an acid is replaced by a metal ion. Salts of hydrochloric acid are called chlorides, salts of nitric acid are called nitrates and salts of sulfuric acid are called sulfates.

Rock salt from the Dead Sea

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the solubility of a salt in water.

MATERIALS

YOU WILL BE PROVIDED WITH:

Boiling tubes
Burette
Thermometer
Test tube holder
Beaker
Electronic balance
Potassium chloride
Distilled water
Magnesium chloride
Sodium nitrate
Spatula
Clamp stand
Bunsen burner
Measuring cylinder
Potassium nitrate
Sodium chloride
Ethanol
Magnesium nitrate
Ammonium chloride
Magnesium sulfate

SAFETY

Safety glasses must be worn at all times. Naked flames (Bunsen burners) must not be used if ethanol is used as a solvent. The heating must then be done with a water bath provided by your teacher. Assume that all of the salts are harmful and toxic if swallowed.

FLAMMABLE
POISON
GOGGLES
GLOVES

INTRODUCTION

Many salts are soluble in water and dissolve to form an aqueous solution. The ionic lattice breaks down and the ions become surrounded by water molecules. Aqueous solutions of ionic compounds are conductors of electricity due to the presence of mobile positive and negative ions. The conductivity of a solution can be measured with a sensitive ammeter or conductivity probe and meter.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the conductivity of a salt in aqueous solution.

MATERIALS

YOU WILL BE PROVIDED WITH:

Ammeter

Bulb

Crocodile clips and leads

Spatula

Potassium chloride (KCl)

Sodium chloride (NaCl)

Magnesium chloride ($MgCl_2$)

Power pack

Measuring cylinder

Glass beaker (100 cm^3)

Distilled water

Electronic balance

(Multimeter - if available)

Calcium chloride ($CaCl_2$)

Conductivity probe and meter (if available)

SAFETY

Wear safety glasses and treat all the chemicals as harmful and toxic. In order to perform a safe experiment, the voltage should be kept low. Never work with electrical equipment if your hands or clothing are wet.

Chemistry Investigation 9

The reaction between sodium thiosulfate and dilute acid

INTRODUCTION

When sodium thiosulfate and a dilute acid are mixed together, they react to give a precipitate of sulfur. The reaction is relatively slow and a yellow precipitate of sulfur gradually forms after the chemicals are mixed. Sulfur dioxide is also released. The gas is acidic and is used as a food preservative. The rate of a reaction can be followed by monitoring and measuring any variable that changes during a chemical reaction. In this case the rate can be monitored by measuring the length of time for a cross on a piece of paper beneath the reaction flask to disappear from view. The rate is inversely proportional to the reaction time.

AIM

To design, carry out and evaluate an experiment to investigate a variable that affects the rate of reaction between sodium thiosulfate and dilute acid.

MATERIALS

YOU WILL BE PROVIDED WITH:

Measuring cylinders

Thermometers

Gas syringe

2 M hydrochloric acid

1 M ethanoic acid

Electronic stopwatch

Electronic balance

0.5 M sulfuric acid

Kettle

Burette

Light meter and data-logger (if available)

Beakers

pH probe and meter

Conductivity probe and meter (if available)

1 M sulfuric acid

20 g/dm³ sodium thiosulfate solution

Distilled water

0.1 M sodium thiosulfate solution

0.5 M hydrochloric acid

Ice

Pipette

SAFETY

You must wear safety glasses at all times during the practical. You must work in a well ventilated laboratory and not smell the sulfur dioxide released during the reaction. If you suffer from severe asthma and are working in a poorly ventilated laboratory you must not participate in this investigation. Skin contact with sodium thiosulfate solution should be avoided.

INTRODUCTION

Metals react with a wide range of substances. All metals react with oxygen and chlorine; the more reactive metals react with water. Metals also react with metal ions in a displacement reaction. A displacement reaction happens when a more reactive metal displaces a less reactive metal from a solution of its salt. The metal that does the displacement is a better reducing agent than the metal in the form of its ions. Electrochemical cells (simple batteries) can also be used to establish the relative reactivity of metals.

AIM

To design, carry out and evaluate an experiment to establish a metal reactivity series.

MATERIALS

YOU WILL BE PROVIDED WITH:

Magnesium ribbon

Copper foil

Lead foil

Iron

Zinc

1 M zinc nitrate solution

1 M copper(II) nitrate solution

1 M lead(II) nitrate solution

1 M iron(II) nitrate solution

1 M magnesium nitrate solution

2 M hydrochloric acid

2 M sodium chloride solution

Saturated potassium nitrate solution

Fine sandpaper

Spotting tile

Scissors

Teat pipettes

Aluminium

Wires, leads

Voltmeters

Filter paper

Silver coated wire

0.05 M silver nitrate solution

1 M aluminium nitrate solution

several lemons and potatoes

SAFETY

You must wear safety glasses and gloves at all times during the practical. All of the solutions are poisonous and harmful if swallowed. Solutions of silver nitrate are very dangerous to the eyes and blacken the skin. Seek medical treatment if ingested. Lead and potassium compounds are also toxic when ingested.

GLOVES GOGGLES POISON CORROSIVE

INTRODUCTION

The temperature of an object tells us how hot (or cold) it is. Temperature is measured by a thermometer, usually in degrees Celsius (°C). Temperature is a measure of the average kinetic energy of the particles (atoms, ions or molecules) present in the substance. The greater the average kinetic energy, the faster the particles move and the higher the temperature of the substance. Heat passes from a body at a higher temperature to one at a lower temperature. Thermos flasks are used to prevent the transmission of heat and hence keep hot water at a high temperature for a long period of time.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the rate of cooling of water.

MATERIALS

YOU WILL BE PROVIDED WITH:

Thermometer

Retort stand

Tripod stand and gauze

Copper can calorimeter

Tin (painted black)

Tin (painted silver)

Tin (painted white)

Kettle

Beakers

Stop watch

Styrofoam cups

Beakers

Boiling tubes

Measuring cylinders

Cotton wool

Aluminium foil

Data-logging interface and temperature sensor (if available)

Electric fan (if available)

SAFETY

An electric kettle is a much safer source of hot water than a Bunsen burner, tripod and gauze. However, immersion heaters also get hot and must be handled with care.

INTRODUCTION

There are many occasions in everyday life when fluids, such as water, have to flow through pipes. A knowledge and understanding of fluid flow is an important aspect of engineering. Liquids flowing through pipes possess viscosity, an internal frictional force which opposes motion when they flow. Physics models of fluid flow are based on the assumption that when a liquid travels slowly through a pipe the flow is steady and smooth.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the flow of a liquid through a capillary tube.

MATERIALS

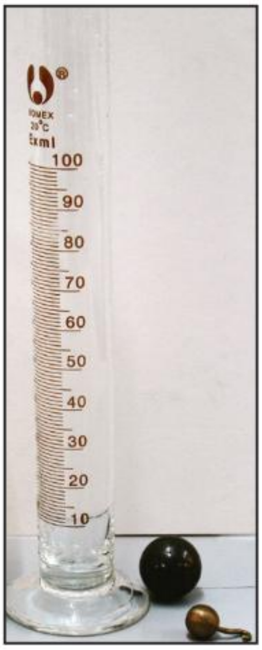
YOU WILL BE PROVIDED WITH:

Burette
Beaker
Metre rule
Ethanol
Glycerol
Distilled water
Capillary tube
Retort stand
Stop watch
Thermometer
Magnet

SAFETY

Ethanol is poisonous and flammable – naked flames must not be present in the laboratory. Safety glasses must be worn. Ethanol is irritating to skin. Wash contaminated skin promptly with soap or mild detergent and water. Ethanol is irritating to eyes and can be damaging if a large amount is splashed into eyes. Wash eyes promptly with plenty of water, while lifting the eye lids. Continue to rinse for at least 15 minutes, and get medical attention. If ethanol is swallowed seek medical attention.

INTRODUCTION



When a skydiver jumps from a plane he or she accelerates to a constant speed, known as the terminal velocity. S/he continues falling at constant velocity until s/ he opens his/her parachute - s/he will then fall at a lower constant velocity until they reach the ground. A similar effect is observed when a small dense object falls through a liquid. Free fall describes any motion of a body where gravity is the only or most important force acting upon it, at least initially.

The viscosity, η, of a liquid is given by the following formula:

$$\eta = \left[\frac{2R^2(\rho_b - \rho_f)g}{9v}\right]$$

where, R = radius of ball bearing (m); ρ_b = density of ball bearing (kg/m^3); ρ_f = density of liquid (kg/m^3), g = acceleration due to gravity (m/s^2) and v = terminal velocity (m/s). The units of viscosity are Pascal seconds (Pa.s).

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the free fall motion of an object through a liquid.

MATERIALS

YOU WILL BE PROVIDED WITH:

Metal paper clips
Burette
Rubber bands
Retort stand and clamp
Distilled water
Chinagraph pencil
Thermometer
Sodium chloride (solid)

Metal balls (of different sizes and/or different metals)
Stopwatch
Light gates and data-logger (if available)
Tall measuring cylinder
Glycerol
Light vegetable oil
Kettle
Magnet

SAFETY

Glycerol will irritate eyes, so eye protection should be worn. Glycerol is generally regarded as a safe material for which no special handling precautions are required. However, it is flammable. It also feels oily, so may be a slipping hazard if spilled on the floor. Eye and skin contact: immediately flush the eye with water. If irritation persists, call for medical help.

FLAMMABLE

GOGGLES

INTRODUCTION

Ball-based games, such as table tennis, tennis and basketball, all rely upon the fact that all balls bounce to some degree when they hit a solid surface. However, balls from different games bounce differently when dropped onto the same surface. For example, baseballs have less bounce than tennis balls or golf balls.

Bouncing balls obey the law of conservation of momentum: momentum before a collision equals the momentum after the collision. Bouncing balls also obey Newton's Third Law of Motion: the falling ball exerts a force on the solid surface; the surface exerts an equal but opposite force on the ball.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affects the bounce of a ball.

MATERIALS

YOU WILL BE PROVIDED WITH:

Golf balls

Squash balls

Metre rule

Set squares

Video camera (if available)

Tennis balls

Stop watch

Cricket balls

Adhesive tape

Clamp stand

Snooker or billiard balls

Rubber balls

Ping pong (table tennis) balls (of various grades)

Access to various surfaces e.g. sand, rubber, concrete, steel plate etc.

SAFETY

Wear eye protection if small balls are being dropped long distances.

GOGGLES

INTRODUCTION

Everyday items are full of springs; they are present in systems from door catches, bed mattresses, chairs, toys, clocks, watches to car suspensions. Springs are also used in Newton meters or spring balances used to measure small forces in the laboratory. Engineers must understand the behaviour of springs when they are stretched.

Robert Hooke, a contemporary of *Isaac Newton*, was one of the first scientists to study the behaviour of springs. A spring is made of an elastic material that changes in shape, or deforms, when a force is applied to it.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the stretching of an elastic material.

MATERIALS

YOU WILL BE PROVIDED WITH:

Springs (helical)	Rubber bands
50 gram hanger	Slotted masses (50 g)
Metre rule	Light metal bars
Clamp stand	Plastic bags
G-clamp	Springs (pre-tensioned)
Set square	Large flat headed nail

SAFETY

Students should be aware of the dangers of the spring snapping and large masses landing on their hands or feet. Eye protection is recommended.

DANGER GOGGLES

INTRODUCTION

A pendulum is a weight suspended from a pivot so it can swing freely. Pendulums have been used for hundreds of years as timing devices. Pendulums are used to regulate pendulum clocks. Seismometers have inertial masses that are suspended on springs. They are free to move in three dimensions.

The Italian scientist *Galileo Galilei's* (1564-1642) interest in pendulums happened after he observed a swinging bronze burner in the cathedral at Pisa. He used his pulse to measure the short periods of time that the burner swung for. The period of a pendulum is defined as the time for one oscillation, that is: 'there and back again'.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the period of a simple pendulum.

MATERIALS

YOU WILL BE PROVIDED WITH:

Thread/string

Plasticine

Ruler

Clamp stand

Electronic balance

Pendulum bobs (brass masses with hooks)

Electronic stopwatch

Protractor

Metre rule

G-clamp

SAFETY

Put a towel or blanket on the floor to prevent damage should the mass fall. Avoid large amplitude oscillations.

INTRODUCTION

All conductors provide some resistance when an electric current flows through them. Resistance results in the change of some electrical energy into heat energy. Resistance can be calculated from the voltage and current. A good conductor has a low resistance. Resistance in electrical circuits can be dangerous – it can lead to fires, or it can be useful – high resistance wires are used in hair dryers and electrical heaters. Electrical resistance was first studied in the late 1820s by *Georg Ohm*.

AIM

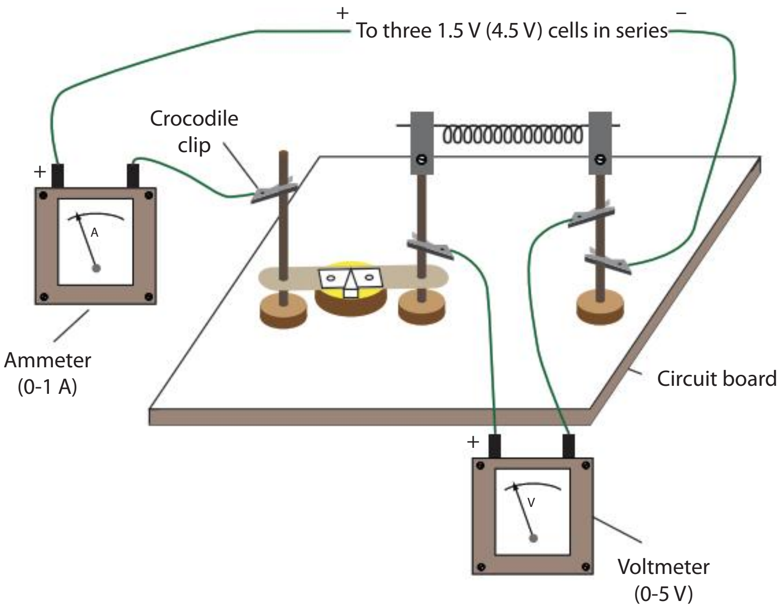
To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the resistance of a wire.

MATERIALS

YOU WILL BE PROVIDED WITH:

Metal cutters
Ammeter
Thermometer
Voltmeter
Clamp stand
Metre rule

Copper wire (different dimensions)
Nickel wire (different dimensions)
Nichrome wire (different dimensions)
Wires with crocodile clips
Constantan wire (different dimensions)
Sellotape



SAFETY

In order to perform a safe experiment, the voltage should be kept low (3V) so the chance of overheating is low. Never work with electrical equipment if your hands or clothing are wet.

ELECTRICITY GOGGLES

INTRODUCTION

Light undergoes bending, (or refraction) when the light waves move between transparent media, such as air and water, or glass and air. Refraction is responsible for the apparent shallower depth of water and occurs in lenses (found in optical instruments such as glasses, the telescope and the microscope), including the lens in the human eye. Early work on the refraction of light was carried out by the Dutch mathematician *Snell*, French philosopher *Descartes* and *Ibn Sahl*, (now Baghdad, Iraq) 984 A.D., six centuries before either of the Europeans did their work.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the refraction of light.

MATERIALS

YOU WILL BE PROVIDED WITH:

Rectangular glass block

Power supply (for ray box)

A3 white paper

Pins

Ray box with single slit and 'barrel'

Convex lens

Protractor

Soft wooden board

SAFETY

Do not shine light beams directly into your eyes in a darkened room.

Take care if you are using pins.

INTRODUCTION

A cantilever is a beam supported at one end. Cantilevers are widely found in construction, notably in cantilever bridges and balconies. Temporary cantilevers are often used in construction. The partially constructed structure creates a cantilever, but the completed structure does not act as a cantilever. In cantilever bridges, the cantilevers are usually built as pairs, with each cantilever used to support one end of a central section. The simplest example of a cantilever is a 'diving board' used by divers.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the deflection of a simple cantilever ('diving board').

MATERIALS

YOU WILL BE PROVIDED WITH:

Metre ruler

Masses

Metal ruler

G clamp

Protractor

SAFETY

Be careful of a snapping ruler. Wear safety goggles.

DANGER GOGGLES

INTRODUCTION

An electric current flowing through a wire generates a weak magnetic field. A strong magnetic field can be made by coiling the wire around a piece of 'soft' iron. The magnetic field surrounding the iron is similar to that of a bar magnet. This simple electromagnet is also called a solenoid. An electromagnet is a type of magnet whose magnetic field is produced by the flow of electric current. The magnetic field disappears when the current ceases. Electromagnets are used in electric bells, relays (a switch operated by an electric current), circuit breakers, loudspeakers and microphones. Very powerful electromagnets are used in high speed magnetic-levitation trains.

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the strength of an electromagnet.

MATERIALS

YOU WILL BE PROVIDED WITH:

Clamp stand and clamp

Permanent bar magnet

Transparent plastic bags

Paper clips

Variable resistor (rheostat)

Wire strippers and cutters

Sellotape

Ammeter (preferably digital)

Iron filings

Staple wires

Soft iron core (or a six inch nail)

Insulated wire (preferably single stranded)

Blu tac®

Electronic balance (measuring to two decimal places or more)

SAFETY

In order to perform a safe experiment, the voltage should be kept low so the chance of the coil overheating is low. Also the power supply should be switched off between experiments. Never work with electrical equipment if your hands or clothing are wet.

INTRODUCTION

The chemical and physical properties of substances are strongly influenced by their structure at the atomic, molecular and/or ionic level, and in order to understand the properties of substances it is necessary to know about their bonding and structure. In most solids, the atoms, ions or molecules are arranged into a regular three-dimensional pattern (known as a lattice); such solids are described as crystalline. The shape, distribution and size of the crystals also have an important role in controlling the properties of substances.

Igneous rocks, such as granite are formed by the cooling of magma. Magma is a mixture of molten and semi-molten solids found beneath the surface of the Earth. The rate at which molten rock (magma) cools affects the size of the crystals that form within the solid rock.

Some crystals in rocks are large

Some crystals in rocks are small

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the crystallization of salol.

MATERIALS

YOU WILL BE PROVIDED WITH:

Boiling tubes

Bunsen burner

Boiling tube holder

Thermometer

Hand lens

Cling film

Access to a fridge

Kettle

Crushed ice

Boiling tube rack

Heat proof mat

Spatula

Glass rod

Microscope (with eye piece reticule)

Salol (phenyl-2-hydroxybenzoate)

Dry ice (if available)

Lead(II) iodide (to only be used by teacher)

SAFETY

Salol may be harmful if swallowed and may cause irritation. **Eye contact:** salol is irritating to eyes. It can be damaging if a large amount is splashed into eyes. Wash eyes promptly with plenty of water, while lifting the eye lids. Continue to rinse for at least 15 minutes, and get medical attention. If salol is swallowed seek medical attention. Disposable gloves must be worn.

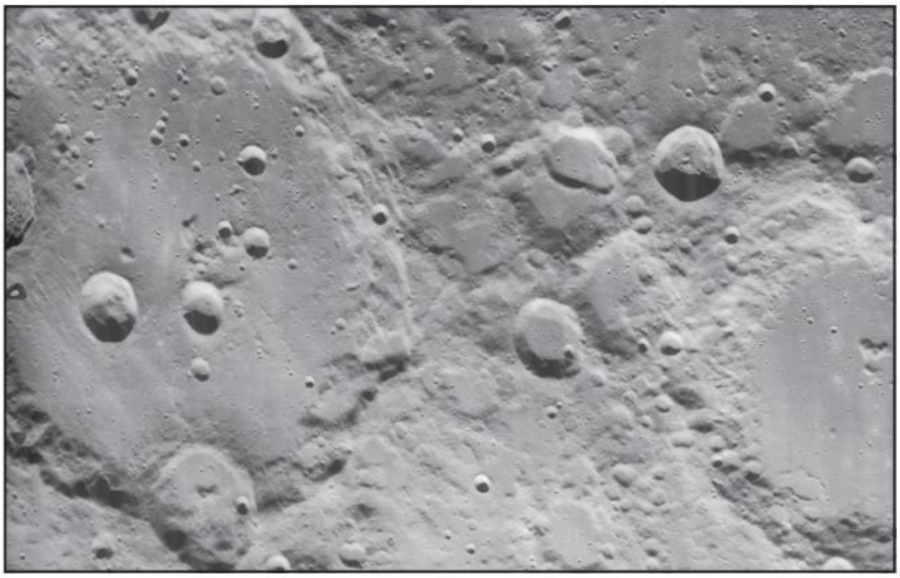
GLOVES

GOGGLES

POISON

INTRODUCTION

Every year, hundreds of tonnes of cosmic dust are estimated to enter the Earth's atmosphere. Less frequently, larger fragments of comets or asteroids intercept Earth, such as the object that produced an "air burst" over Chelyabinsk Oblast, Russia, causing injuries to over 1000 people in February 2013. There is an inverse relationship between the size of an object and the frequency with which such objects strike the Earth. Stony meteorites with a diameter of 100 m are estimated to impact the Earth with an average frequency of around one every 5000 years, producing an impact energy equivalent to approximately 40 million tonnes of TNT and a crater over 1 kilometre across. The Chixulub crater, buried underneath the Yucatán Peninsula in Mexico and implicated in the extinction of the dinosaurs, is over 180 km wide and 20 km deep and was caused by an impactor over 10 km in diameter.



Some of the craters on the Moon

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the formation of impact craters.

MATERIALS

YOU WILL BE PROVIDED WITH:

Balls (of different sizes and/or different materials)

Retort stand and clamp

Modelling clay

Soil

Large plastic tray

Rulers (1 m and 30 cm)

Sand

Flour

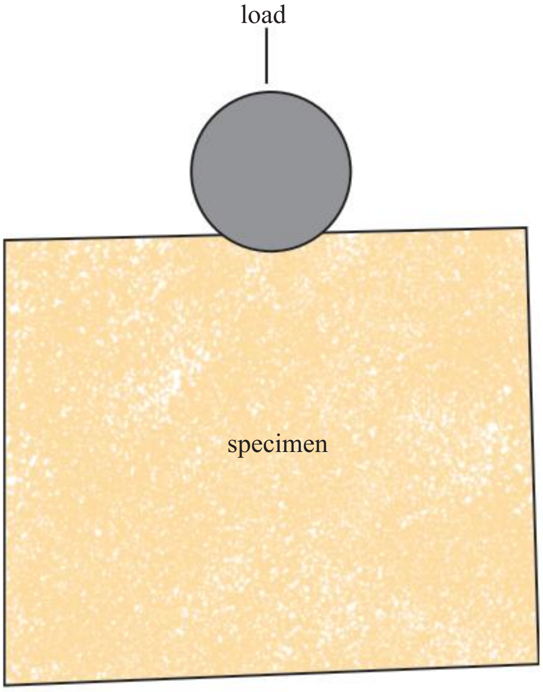
SAFETY

Wear eye protection to avoid dust in the eyes.

INTRODUCTION

The hardness of a substance or material is an important physical property. A substance can only be scratched by a substance harder than itself. Diamond is one of the hardest known substances and it is used in dentist drill tips, mining drills and to cut other diamonds. Hardness can be measured by a scratch test or by pushing a metal ball onto the surface of a specimen under a known load, for a fixed time. See adjacent Figure.

The size of the indentation left in the specimen surface when the load is removed is then measured under a suitable low power microscope. The hardness is defined as the applied load divided by the contact area between the metal ball and the specimen, that is, the maximum cross-sectional area of the curved surface of the indentation. Hardness may also be expressed on the Brinell scale.



AIM

To design, carry out and evaluate an experiment to investigate the hardness of a range of substances and to determine whether hardness is independent of load for different materials. A device to test hardness could be constructed but must be surrounded by a plastic safety screen.

MATERIALS

YOU WILL BE PROVIDED WITH:

Emery paper
10 kg loads
Travelling microscope
Steel rule
5 kg loads
70%-30% brass
Sand paper
Foam rubber
Plastic safety screen
Candle
Copper
60%-40% brass
Small steel balls of different sizes

Variety of substances for hardness testing

Low power microscope (with a scale in the eye piece)

SAFETY

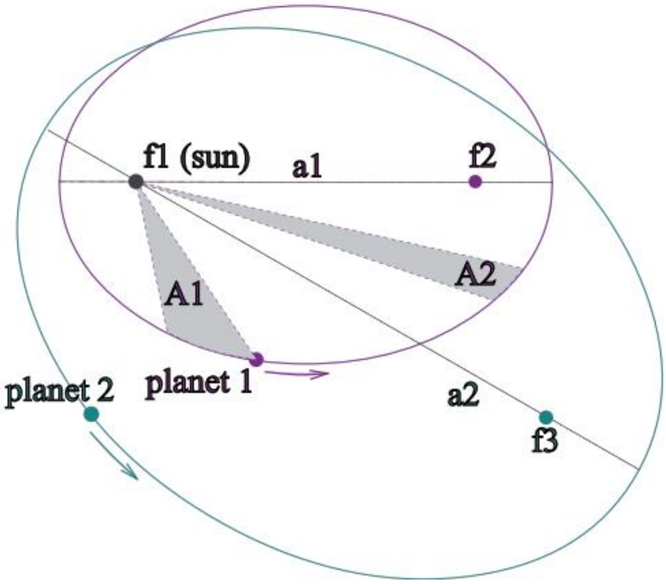
Be careful that fingers are not placed in the hardness machine when a load is applied. Safety glasses must be worn during hardness testing.

INTRODUCTION

The solar system consists of a star (the Sun) around which orbit eight planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Pluto ceased to be a planet in 2006 – it is now designated as a dwarf planet, or more specifically a plutoid.

A model solar system can be constructed that models the relative sizes of the Sun and the planets and models the relative distances of the planets from the Sun.

According to Kepler's first law, the orbit of each planet is an ellipse, with the Sun at one focus. Kepler's second law states that a line drawn from the Sun to any planet sweeps out equal areas in equal times.



A diagram illustrating Keplers Laws

The orbits of the planets obey Kepler's third law: the square of the period (T) of orbit for each planet is equal to the cube of its semi-major axis (r), provided the Earth's period and semi-major axis are used as the units of time and distance. The semi-major axis of a planet is its average distance from the Sun.

Mathematically $T^2/r^3 = k$. If T is in years and r is astronomical units (AU) where 1 AU is the average distance from the Sun to the Earth, then k=1. Put simply, Kepler's third law states that the period squared is proportional to the average distance from the Sun cubed (in any consistent units).

The data for the orbits and the semi-major axes of the planets can be obtained from astronomy books or the Internet. Kepler's laws are a consequence of the gravitational force that exists between two objects.

AIMS

To build a model solar system (to scale) and analyse planetary data.

MATERIALS

YOU WILL BE PROVIDED WITH:

Tape measure
Metre rule
Sellotape
Styrofoam balls
Felt-tip markers
Access to the Internet
Access to a spreadsheet
Roll of toilet paper (for marking out scale distances)
Steel rule
Newspaper
Sticky labels

INTRODUCTION

The amount of solar energy reaching the Earth's surface in one hour is greater than the total amount of energy used by human beings in one year. Solar energy is therefore a major source of renewable energy and is captured using a variety of passive and active solar technologies. Passive techniques include orienting buildings towards the Sun and selecting materials with suitable thermal insulation properties. Active solar technologies include the use of mirrors to focus solar energy for water heating and the use of photovoltaic cells. A solar cell, or photovoltaic cell (PV) is a device that converts light into electricity using a phenomenon called the photoelectric effect.

Solar cells in use on a farm

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables that affect the performance of a solar cell.

MATERIALS

YOU WILL BE PROVIDED WITH:

Photovoltaic cell

Leads/wires

Thermometer

30 cm ruler

Protractor

Clear plastic tray with lid

Aluminium pie pan

Colour filters or cellophane

Flashlight (or ray box kit or light bulb)

Retort stand and clamp

Multimeters

Crocodile clips

Cardboard

Hair dryer (or warm water bath)

1 m ruler

SAFETY

Ensure that the power supply is switched off before adjusting any leads to light bulbs. Never work with electrical equipment if your hands or clothing are wet. Students should not be wearing metal jewellery and water taps should not be turned on.

INTRODUCTION

Pure water has a pH of 7.0. Normal rain is slightly acidic (pH = 5.6) due to the presence of dissolved carbon dioxide, which reacts with water to form weak carbonic acid.

$$CO_2(g) + H_2O(l) \leftrightarrows H_2CO_3(aq) \leftrightarrows H^+(aq) + HCO_3^-(aq)$$

In the presence of oxides of nitrogen and sulfur (SO_2 and NO_x), the pH of rainwater can drop below 5.6, at which point it is referred to as “acid rain”. The principal contributor of these oxides to the atmosphere is human sources; such as electricity generation using fossil fuels, factories and motor vehicles. In the United States acid rain with a pH as low as 4.3 has been measured.

Some effects of acid rain

AIM

To design, carry out and evaluate an experiment to investigate one or more of the variables associated with acid rain.

MATERIALS

YOU WILL BE PROVIDED WITH:

Sodium sulfite (or sodium metabisulfite)

$6 M H_2SO_4$

Ziploc plastic bags

24-well wellplate

Universal indicator or a pH meter

Sodium nitrite (or potassium nitrite)

pH reference solutions (pH 2 to 7)

Plastic transfer pipettes/droppers

Microscope

Potassium iodide

A supply of *Blepharisma* or *Volvox* organisms

SAFETY

6 M sulfuric acid is corrosive and should be handled very cautiously. SO_2, NO and NO_2 are toxic gases and should be prepared in a fume cupboard and not be allowed to escape into the laboratory. This experiment should not be done by anyone who has a sensitivity to sulfites or has an asthmatic condition. Sulfites have been shown to cause severe asthma attacks in a few sensitive individuals.

GLOVES GOGGLES

CORROSIVE POISON

INTRODUCTION


Cornpops are an example of a bioplastic

Plastics belong to a group of molecules called polymers, which are large molecules made of repeating units called monomers. Most plastics contain between 500 and 20,000 or more repeating units. They are usually unreactive, stable and resist decomposition.

Plastics can be produced by covalently bonding together monomers in a reaction called polymerisation. There are two types of polymerisation: addition and condensation polymerisation.

Most plastics are made from crude oil (petroleum).
Molecules present in crude oil can be made to undergo a controlled chemical reaction to make polymers that can be processed into plastics. Pollutants are produced during the process and the world's crude oil supply is limited.

Chemists have been searching for new 'greener' ways of making plastics. One approach uses plants as the raw material instead of crude oil (petroleum). This type of plastic is known as a bioplastic and is prepared by converting the sugar or starch present in plants into plastic.

Plasticity is the ability of a material to deform permanently without breaking or rupturing.

AIM

To prepare and investigate the properties of a bioplastic.

MATERIALS

YOU WILL BE PROVIDED WITH:

Grater	0.1M hydrochloric acid
Beakers	0.1M sodium hydroxide
Pestle and mortar	Potatoes
Large watch glass	Distilled water
Bunsen burner	Food colouring
Heat proof mat	Propane-1,2,3-triol (glycerol)
Gauze	Universal indicator
Stirring rod	Teat pipette
Petri dish	Measuring cylinders (10 cm^3 and 25 cm^3)
White tile	Tea strainer

SAFETY

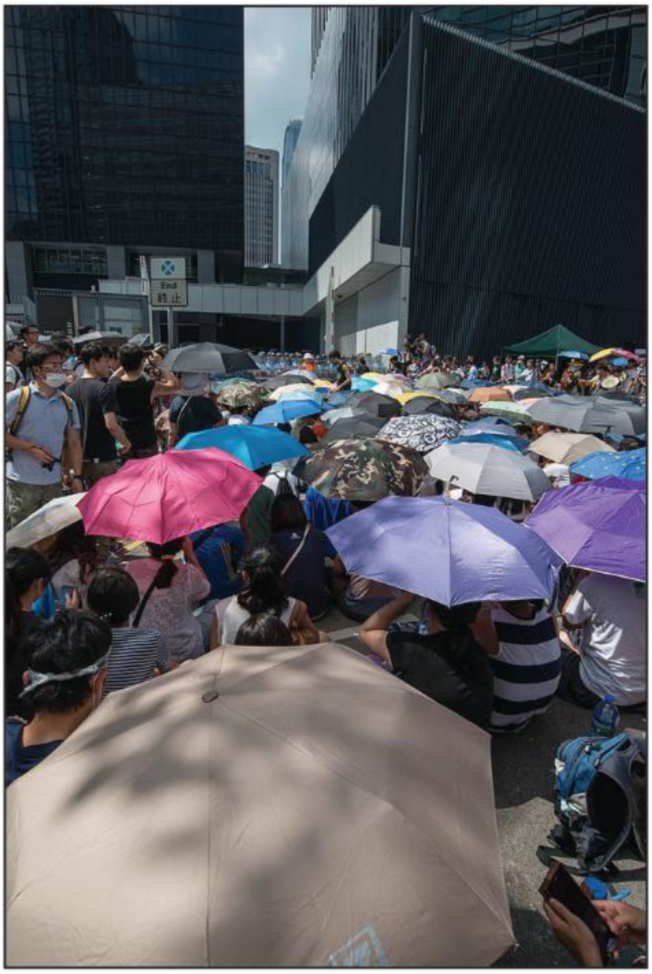
Eye protection must be worn at all times. Any acid or alkali must be washed off immediately if it comes into contact with skin.

CORROSIVE GOGGLES

INTRODUCTION

An umbrella or parasol is designed to protect against rain or sunlight. A parasol is an item designed to provide protection from the Sun; an umbrella usually refers to a device more suited to provide protection from the rain. Often the difference is the material; some parasols are not waterproof.

Examine the material of a variety of umbrellas under a microscope; some of them have holes or pores. Given the presence of pores, find out how it is possible for the umbrella to keep out the rain. The surface of an umbrella is described as discontinuous since it contains pores.



Umbrellas in use

AIM

To investigate a factor that affects the performance of an umbrella.

MATERIALS

YOU WILL BE PROVIDED WITH:

Umbrellas (made of different materials and with different designs and shapes) AND/OR various umbrella fabrics

Plastic drain pipe

Glass tubes (of various sizes and lengths)

Light microscope (with eye piece graticule)

Conical flasks (of different sizes)

Measuring cylinders (of different sizes)

Plastic bags (impermeable to water)

Sealant

Plasticine

SAFETY

Do not attempt the experiment outside during a rain storm.

INTRODUCTION

Carbon dioxide (CO_2) is a colourless gas that is present in our atmosphere due to natural and man-made sources. Carbon dioxide and other greenhouse gases in the upper atmosphere, such as water vapour (H_2O), ozone (O_3), methane (CH_4), dinitrogen monoxide (N_2O) and chlorofluorocarbons (CFCs) absorb and trap heat energy and hence act like a global blanket. The Sun warms the surface of the Earth and the radiation normally radiates back out into space. Because low levels of carbon dioxide are naturally present in the Earth's atmosphere, a certain amount of this 'greenhouse effect' is normal and beneficial.

Islands will be affected by a rise in sea levels

However, the widespread combustion of fossil fuels and increased deforestation has resulted in larger concentrations of carbon dioxide. Some of the heat energy ends up trapped in the atmosphere. This phenomenon is known as the 'greenhouse effect'. In the past century, the amount of carbon dioxide in our atmosphere has increased by more than 20% and has reached a point where scientists are concerned that global warming, an increase of the Earth's average temperature is occurring. *John Tyndall* has studied the heat absorbing powers of gases, including carbon dioxide.

AIM

To simulate and investigate global warming.

MATERIALS

YOU WILL BE PROVIDED WITH:

Two 750 cm^3 glass containers with opaque plastic lids

Fine dried sand and soil

Modelling clay

A cork

Two mercury thermometers

Two alcohol thermometers

Source of carbon dioxide or carbon dioxide generator (Kipp generator/Kipp's apparatus) (metal carbonate and dilute acid)

SAFETY

Wear safety glasses when handling chemicals. If a mercury thermometer is broken or breaks in use, inform the teacher immediately.

DANGER GOGGLES

INTRODUCTION

Coagulants are often added to river water to help remove turbidity (cloudiness). The substances normally used are salts, such as iron(II) chloride, iron(II) sulfate, and hydrated potassium aluminium sulfate, which is known commercially as alum. Water treatment plants are concerned with determining the dose of coagulant required to clarify polluted water and to determine the pH at which this occurs.

Small scale natural water treatment in Cambodia

Large scale water treatment in Spain

AIM

To perform a small scale investigation of waste water treatment.

MATERIALS

YOU WILL BE PROVIDED WITH:

Digital pH meter or data logger with pH probe

Conductivity meter or data logger with conductivity probe

Turbidity meter or spectrophotometer or colorimeter

Flocculator SW1 or milk shake mixer

0.1 mol dm^{-3} sodium hydroxide

0.1 mol dm^{-3} hydrochloric acid

Magnetic stirrer

Alum, iron(II) chloride, iron(II) sulfate

Calcium oxide (lime)

SAFETY

Wear safety glasses and gloves when handling chemicals and waste water.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

- Water plant (*Elodea*)
- Thermometer
- Clamp stand
- Stopwatch
- Kettle
- Lamp (e.g. 60 W)
- Gas syringe
- Aluminium foil
- (Data logger interface)
- Metre rule
- Light meter (lux meter) (if available)
- Boiling tube
- Large beaker (500 cm^3)
- Retort stand and clamp
- Glass trough
- Ice cubes
- Scalpel
- Rubber tubing
- Coloured filters e.g. blue, red etc. (from a ray box)
- (Dissolved oxygen sensor and light sensor)
- Test tubes

CHEMICALS REQUIRED

Sodium hydrogencarbonate solution: 0.1 mol dm^{-3}

Sodium hydrogencarbonate (solid)

Distilled water

SAFETY

Students should be shown how to use a scalpel safely. Glasses must be worn when cutting. Scalpels should not be carried from one table to another.

SHARP

GOGGLES

SUGGESTED RESEARCH QUESTION

To determine the effect of dissolved carbon dioxide concentration on the rate of photosynthesis in the aquatic plant, *Elodea*, as measured by average oxygen production per minute. (There are other possibilities).

SUGGESTED VARIABLES

The independent variable is the dissolved carbon dioxide concentration (as measured by the sodium hydrogen carbonate concentration in moles or grams per cubic decimetre) and the dependent variable is the number of bubbles of oxygen in a fixed time interval, for example, five minutes. Controlled variables are light intensity (as measured by the distance of the light away from the plant (or actual light intensity reading)); colour of light (via the use of filters) and the temperature of water.

BACKGROUND THEORY

In the presence of light and carbon dioxide, green plants photosynthesize and produce oxygen.

The overall word equation describing photosynthesis is: water + carbon dioxide → glucose + oxygen

The process of photosynthesis is a complex multi-step process controlled by a number of enzymes. The light required for this process is absorbed by a green pigment called chlorophyll. The most effective lights for photosynthesis are blue and red lights.

For aquatic plants (hydrophytes), such as *Elodea*, carbon dioxide can be provided in the form of a solution of sodium hydrogencarbonate. The rate of oxygen production (as bubbles or in the solution) can be used as a measure of the rate of reaction.

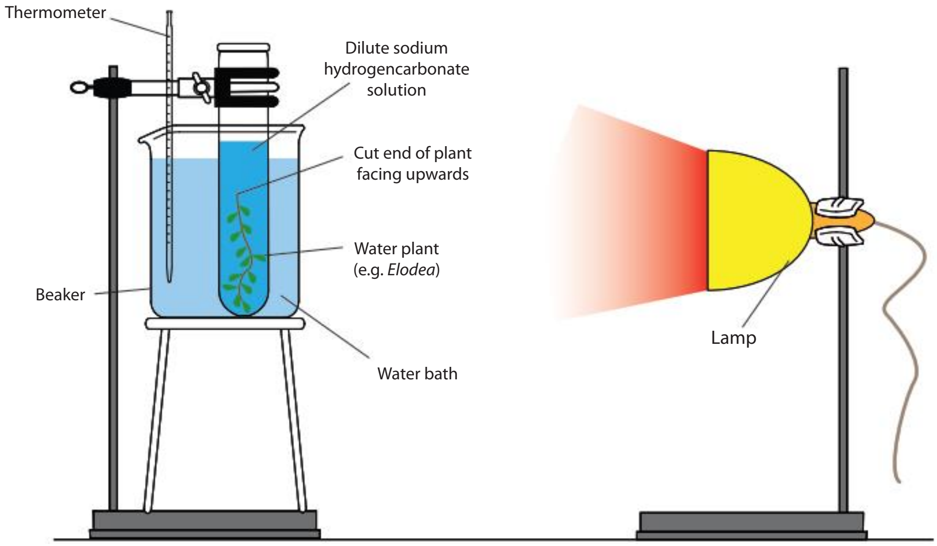
In photosynthesis any factor which is in short supply, so that it reduces the rate of the process from its possible maximum, is described as a limiting factor. Changing the limiting factor increases or decreases the rate of photosynthesis, but changes to the other factors have no effect.

SUGGESTED METHOD

Take a water plant and make a clean sloping cut across the bottom of the stem (between the shoots). Immerse the cut end of the plant facing upwards. You might need to tie a small mass to the plant to keep it submerged in a boiling tube containing 0.1 mol dm^{-3} sodium hydrogencarbonate solution. Chlorinated tap water should not be used in this experiment.

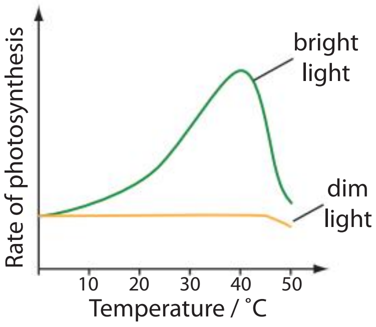
Place a powerful lamp close to the plant, for example, 10 cm away, to ensure that bubbles of oxygen-enriched air are released at regular intervals. Allow some time, for example, 3 – 5 minutes, for the plant to adapt to the conditions before counting the bubbles over a fixed interval of time. Alternatively, the gas can be collected and measured in a small gas syringe. Repeat the experiment using sodium hydrogencarbonate concentrations ranging from 0.1 mol dm^{-3} down to 0.01 mol dm^{-3}.

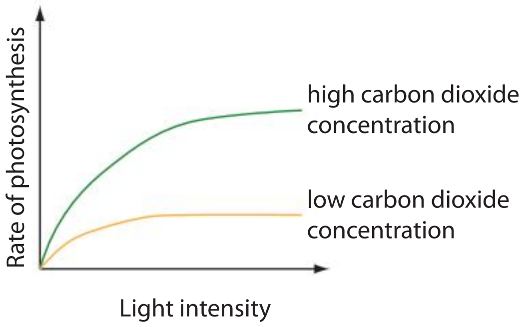
Alternatively, the light intensity can be varied by moving the lamp to a range of different distances. The light intensity obeys an inverse square law, so halving the distance quadruples the intensity.



GRAPHICAL RELATIONSHIP

Increasing dissolved carbon dioxide levels increases the rate of photosynthesis up to the carbon dioxide saturation point where further increases in the dissolved carbon dioxide level has no effect (due to light being a limiting factor). Students should plot a graph of sodium hydrogencarbonate concentration in moles per cubic decimetre (mol dm^{-3}) or grams per cubic decimetre (g dm^{-3}) (x axis) against rate of bubble production or total volume of oxygen (y axis). A similar graph will be obtained if light intensity is chosen as an independent variable, except that at very high light intensities chlorophyll will be decomposed and the rate of photosynthesis will decrease. Light intensity could be measured if a light meter is available, otherwise the independent variable is the distance to the lamp.





EVALUATION

Students should be aware of the assumption involved in bubble counting, i.e., all the bubbles have identical volumes. The aluminium foil (if used correctly) acts like a mirror and reflects the unused light which missed *Elodea's* leaves and which would otherwise pass right through the water and out of the tube. This extra reflected light, will improve the rate of photosynthesis and make the student's task of bubble counting easier. Issues related to biological variability and control of variables, for example, temperature (unless it has been chosen as an independent variable) should also be discussed by students. Random errors in the concentration and time measurements should also be recognised. The higher light intensities should be quite accurate but the smaller light intensities would be less accurate because the light spreads out - the *Elodea* will also receive background light from other experiments. High light intensities may also lead to heating of the water surrounding the *Elodea* - this could be reduced by positioning a large beaker of water between the lamp and the plant.

SUGGESTED EXTENSION WORK

There are several possible independent variables for this investigation. The investigation could be extended to include other species of hydrophytes (e.g. *Hydrilla*). It can also be data-logged. Photosynthesis investigations may also be carried out using immobilised algae suspended in sodium alginate.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Potometer (if available; but it is not necessary)

Transparent and black plastic bags

Lamps

Conical flasks

Oil

Scissors

Leafy shoots

Vaseline

Squared paper

Balance capable of weighing to at least 0.001 g

Boiling tubes

Hair dryer

Fan

Electronic stop watch

Scalpel

Ruler

Hygrometer (to measure humidity)

Anhydrous cobalt(II) chloride paper

Heat source

SAFETY

Be careful when using scissors and glassware.

SUGGESTED RESEARCH QUESTION

To determine the effect of wind velocity on the transpiration rate in a leafy privet shoot as determined via the loss of water in fifteen minutes as measured by an electronic balance. (There are other possibilities).

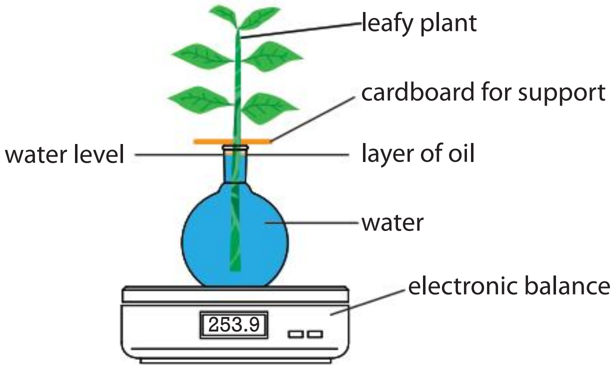
SUGGESTED VARIABLES

The independent variable is wind velocity and the dependent variables are time and total mass (if a simple potometer employing an electronic balance is used). The controlled variables will be the species of the plant, light intensity, soil water concentration, the number of leaves and size of leaves of the plant as well as the number of stomata and aperture size of stomata.

BACKGROUND THEORY

Transpiration is the loss of water via evaporation through the stomata of the leaves of plants. Transpiration cools plants and enables the flow of water and dissolved mineral salts through xylem vessels. In living plants the following factors affect the rate of transpiration: light intensity, humidity, air movement and temperature.

Light does not affect evaporation, but in daylight the stomata of the leaves are open. At night, when the stomata close, transpiration is greatly reduced. If the air is humid, i.e., contains a high concentration of water vapour, it can accept very little further water vapour from the plant and so the transpiration rate is reduced. In dry air, the diffusion of water vapour from the leaf interior to the atmosphere will be rapid.



The relative rates of transpiration can be related to the water vapour concentration gradient between the inside and outside of the leaf. In still air, the region around a transpiring leaf will become saturated with water vapour. There will be no concentration gradient and no more water vapour will escape from the leaf. In moving air, the water vapour near the stomata will be removed from the leaf as it diffuses out. This will maintain a concentration gradient and hence maintain a high rate of transpiration. Warm air can hold more water vapour than cold air. Hence, evaporation or transpiration will take place more rapidly into warm air.

SUGGESTED METHOD

Since transpiration is the loss of water vapour, the rate of transpiration can be measured by weighing a plant at intervals to establish how much mass of water has been lost. The rate of transpiration is traditionally measured using a potometer, but these are not usually available as class sets. Students may of course see diagrams of potometers in text books and could be encouraged to construct their own using a capillary tube, syringe and a three way tap.

A simple potometer can be constructed by placing a healthy leafy shoot into a flask and covering the surface with a thin film of oil (to prevent evaporation of the water). Transpiration can then be demonstrated by placing the apparatus onto a precise electronic balance. The total mass will decrease with time. A rate as measured by mass of water lost per unit time can then be readily calculated. A fan and a hair dryer can be used to vary the wind speed and temperature of the air. To change the humidity, the shoot can be enclosed in a transparent plastic bag. The humidity will soon increase as the water vapour which has been transpired will not be able to leave the bag and so will stay around the plant thereby increasing the humidity. A change in conditions may take 10 minutes before it produces a new, steady rate of mass loss.

GRAPHICAL RELATIONSHIP

Separate graphs could be drawn with rate of transpiration (mass per unit time) (y axis) versus air temperature, wind speed or humidity (x axis). The rate of transpiration should increase with increasing air temperature and wind speed, but decrease with increasing humidity. The best way to compare water loss of different shoots (for example, of different species) is on the basis of unit leaf area (estimated using squared paper). The water loss can then be expressed in terms of mass per unit area per unit time.

EVALUATION

Students may realise that more time should have been allowed between experiments to allow the plant to fully equilibrate before the next experiment was started. This would have reduced the number of anomalies caused by the sudden exposure of the plant to completely different conditions when the previous effects of the last experimental conditions had not had time to wear off.

It is often difficult for students to change just one environmental condition without changing another. For example the lamps that may be used to give the leaves the maximum possible light intensity in the experiment will also have the effect of slightly heating up the leaves. This could cause the rate of transpiration to increase.

There are a number of limitations of a potometer that students should identify. Not all of the water taken up will be transpired; some will be used in photosynthesis (as a reactant and solvent) and some may be absorbed by cells to increase their turgor (firmness). However, these quantities are very small compared with the volume of water transpired.

Some students may choose to do their experiments outside the laboratory. This should not be discouraged, but these may result in uncontrolled variables and hence unreliable results. A control experiment should also be carried out. The experiment should be repeated without a plant. There should be little or no water loss.

There may be a general deterioration in the results as the experiments progress. As the experiments were carried out the water would have warmed up to room temperature. This will have caused bubbles to form in the xylem as the air leaves the solution. These air bubbles could have caused a loss of cohesion tension in the leaves, which may have led to cavitation in the xylem. This cavitation would have reduced the number of working xylem vessels in the stem and could account for the reduced rate of uptake that may be seen in later experiments.

SUGGESTED EXTENSION WORK

There are several possible independent variables for this investigation. Students could also smear the upper surfaces of the leaves with vaseline and measure the rate of water loss. They could then compare the effect of smearing the lower surfaces too. They could also investigate the effect of removing the roots of the plant.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Fresh potatoes (three varieties)
Ruler
Measuring cylinder
Spatula
Cork borer
Scalpel
Plastic boards
Beaker
Blotting paper
Electronic balance

CHEMICALS REQUIRED

Sodium chloride, NaCl
Glucose
Sucrose
Distilled water

SAFETY

Students should be shown how to use a scalpel safely. Glasses must be worn when cutting. Scalpels should not be carried from one table to another. The safe use of a cork borer should be demonstrated.

SHARP

GOGGLES

SUGGESTED RESEARCH QUESTION

To determine the concentration of cell sap in potato cells via a weighing method. Alternatively, to determine the relationship between the mass of a potato cube and the concentration of the surrounding sugar solution once equilibrium has been reached.

SUGGESTED VARIABLES

The independent variable is the concentration of salt or sugar solution and the dependent variable is the mass of the potato piece. The controlled variables include the variety of potato (although will this will have little effect), surface area of the potato, temperature of the surrounding solution and the time for immersion before measurements are recorded.

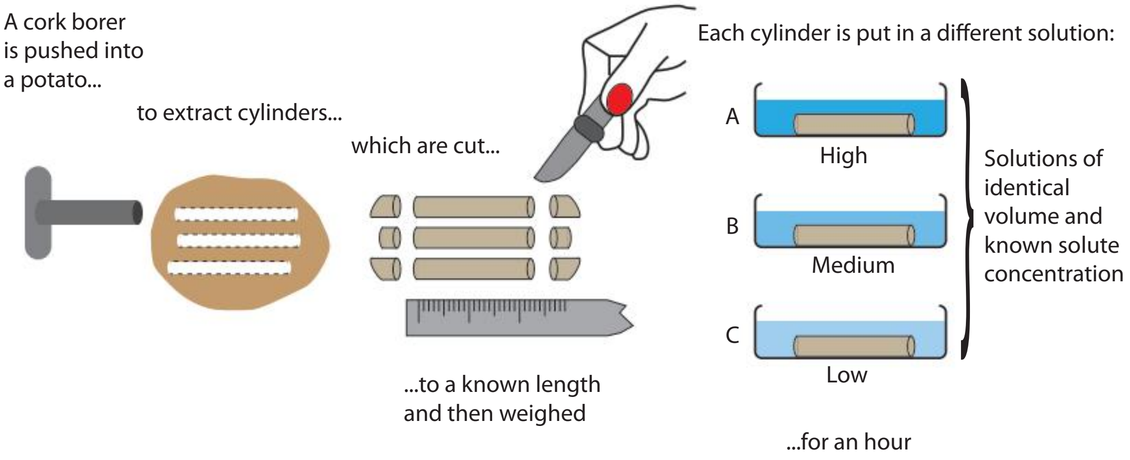
BACKGROUND THEORY

Osmosis is the diffusion of water across a selectively permeable membrane from a dilute solution to a concentrated solution. The level of the concentrated solution will increase or, if it is confined in an enclosed space, such as a cell, its pressure will increase.

If the sugar or salt solution is more concentrated than the cell sap of the potato cells then the cells will lose water by osmosis. The cells will lose their turgor and will become flabby. They will become shorter and lose mass. If the sugar or salt solution is less concentrated than the cell sap of the potato cells then the cells will gain water by osmosis. The cells will increase their turgor and will become firmer. They will become longer and gain mass. If the concentrations of the cell sap and the surrounding solution are the same then no overall change (in mass or length) occurs: the two rates of water diffusion are equal.

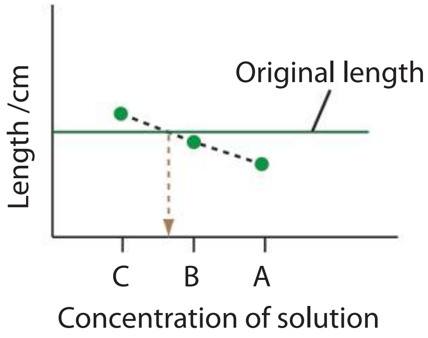
SUGGESTED METHOD

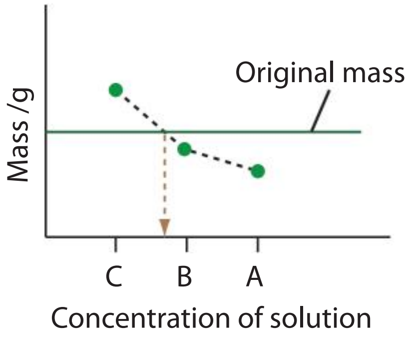
Students should use the cork borer to extract potato cylinders from one of the three varieties of potato available. The peel of the potato should be removed since it is impermeable. These can then be cut to a fixed length using a ruler and a scalpel. Alternatively a blade can be used to cut cubes and other shapes of potato tissue.The students should then fully immerse them in various solutions of at least 5 known concentrations for a fixed length of time, ideally until equilibrium is reached. They should then be re-weighed on an electronic balance and/or their length measured. If the experiment is to be left for more than 24 hours, the test-tubes should be placed in a refrigerator or the potato will ferment and decompose.



GRAPHICAL RELATIONSHIP

Graphs of concentrations of solution (*x* axis) and mean length or mass (*y* axis) should be drawn. The graphs should be smooth curves. At the point where the graph cuts the line indicating the original length or mass the average solute concentration of potato cells may be determined.





SUGGESTED EXTENSION WORK

There are several possible independent variables for this investigation. The effect of solute concentration could also be investigated with a different type of plant tissue, for example, transverse sections of dandelion stems. Mass can be measured again, but another dependent variable is the direction and extent of curvature of the stem. The curvature will increase with the salt or sugar solution concentration.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Beakers

Stop clocks

Boiling tubes

Scalpels

Tiles

Petri dishes

Agar that has solidified with a few drops of phenolphthalein

Electronic balances

CHEMICALS REQUIRED

2 M hydrochloric acid

2 M ethanoic acid

SAFETY

Glasses must be worn when cutting. Scalpels should not be carried from one table to another.

CORROSIVE GOGGLES SHARP

SUGGESTED RESEARCH QUESTION

To determine the relationship between the surface area to volume ratio of a phenolphthalein stained agar cube and the time taken for the cube to change from pink to colourless.

SUGGESTED VARIABLES

The independent variable is the surface area to volume ratio of the cube. The dependent variable is the time taken for the cube to turn from pink to colourless. Controlled variables are the volume and concentration of hydrochloric acid, temperature of the surroundings and preparation and composition of agar.

BACKGROUND THEORY

One factor that controls the rate of diffusion is the surface area. The greater the surface area, the faster the rate of diffusion. For simple diffusion there is a directly proportional relationship between the surface area and the rate of diffusion. The rate of simple diffusion also varies with concentration and temperature. Increases in concentration and temperature both lead to an increase in the diffusion rate. There is a linear relationship between the concentration and the diffusion rate and an exponential relationship between the temperature and the diffusion rate.

SUGGESTED METHOD

Students should cut agar cubes of known and precise dimensions from the gel, for example, a 10 mm cube. They should then place a fixed volume, for example 10 cm^3 of dilute hydrochloric acid in a boiling tube. Students should start the timer as soon as the acid and the cube meet - time how long it takes for each cube to change colour from pink to colourless. This will take several minutes.

Students should repeat the experiment with a wide range of larger cubes of known dimensions which are placed in a known volume of acid for a fixed length of time. Students should measure the dimensions of the cubes and calculate the surface areas and volumes. The surface area to volume ratios should also be calculated. Students should plot a graph of time (x axis) against surface area to volume ratio (y axis).

GRAPHICAL RELATIONSHIP

Students should plot a graph of time (y axis) against surface area to volume ratio (x axis). For extension work students could vary the temperature of the hydrochloric acid or the concentration of acid (via dilution).

EVALUATION

Students should be aware of the relatively large random errors present in the measurements of the cubes. The acuity of the student in judging when the colour change is complete should be noted. Short times have a large random uncertainty.

SUGGESTED EXTENSION WORK

For extension work, students could vary the temperature or the nature or concentration of acid (via dilution). They could also change the shape of the cubes to various cuboids. It is also interesting to 'carve' the agar into the shapes of various cells (e.g red blood cells, epithelial cells, palisade mesophyll cells) and investigate diffusion rates.

Day/Date of lesson ____________________ **Period** ____________

Teacher ________________________________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

250 cm^3 beaker

Delivery tube

Spatula

Yeast

Thermometer

Stop watch

Test tubes

Dropping pipette

Rubber tubing

5 cm^3 syringe

Plastic tubing

Measuring cylinder

Bung

Water bath or kettle

Boiling tubes

Gas syringe

Electronic balances

Graduated pipette or syringe (10 cm^3)

Spirit marker

Three way tap

1 cm^3 pipette (×2)

Beaker

Length of 1 mm bore capillary tubing, 11 cm long and flame polished at both ends

CHEMICALS REQUIRED

Glucose, fructose, sucrose

Starch

Boiled water (does not contain dissolved air)

Cooking oil

Limewater

SAFETY

Avoid contact with yeast powder; do not breathe in the yeast powder.

SUGGESTED RESEARCH QUESTION

To determine the rates of carbon dioxide production (as measured by change in volume per unit time) from glucose and fructose using brewer's yeast.

SUGGESTED VARIABLES

The independent variable is the type of carbohydrate; the dependent variable is the total volume of carbon dioxide. The controlled variables are the mass and strain (species) of yeast, the mass of the carbohydrate and the volume and temperature of water it is dissolved in.

BACKGROUND THEORY

Respiration is the process by which useful energy is produced from glucose inside living cells. There are two types of respiration: aerobic respiration which requires molecular oxygen and anaerobic respiration which does not require molecular oxygen. Aerobic respiration releases a significantly larger amount of useful energy than anaerobic respiration. Both types of respiration occur in a number of enzyme-controlled steps.

Aerobic respiration in all living organisms can be summarised by the following word equation:

glucose + oxygen → carbon dioxide + water

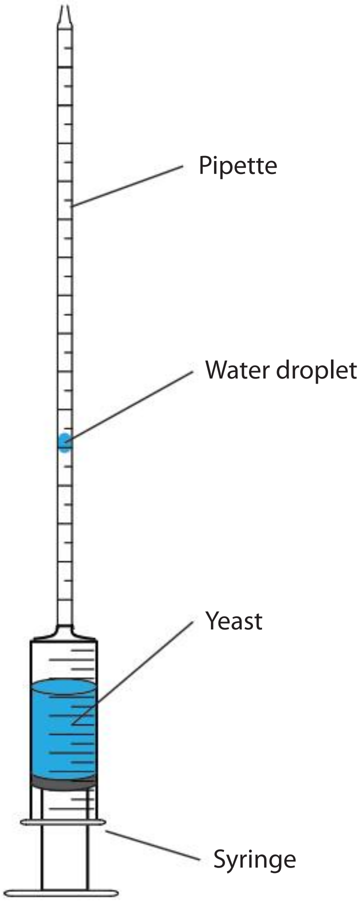
The process of anaerobic respiration in yeast is known as fermentation and can be summarised by the following word equation:

glucose → ethanol + carbon dioxide

The carbon dioxide is given off as bubbles and the number given off in a known time can be used to estimate the rate of the reaction.

SUGGESTED METHOD

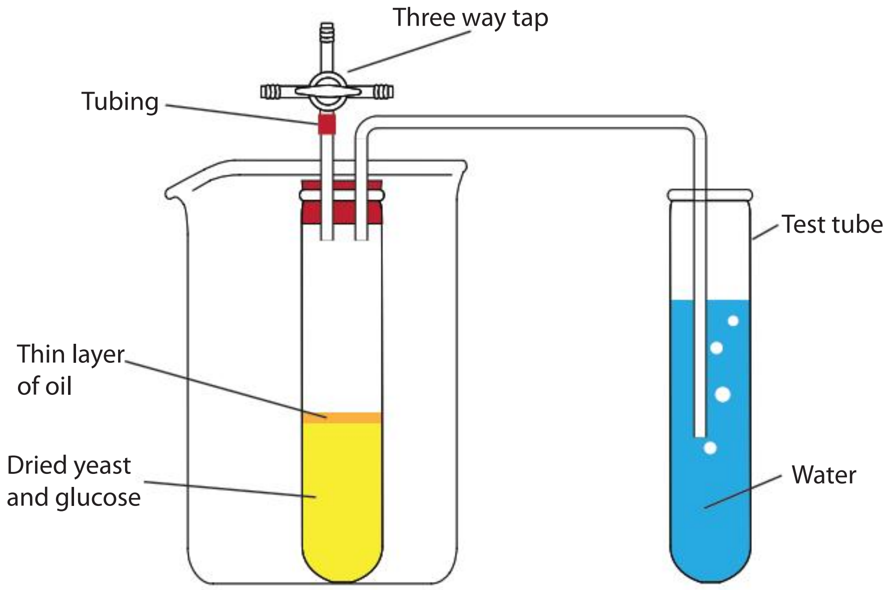
One possible approach involves volumetric measurements of yeast carbon dioxide production by recording displacement of a water droplet in a pipette. The apparatus (a very simple respirometer) consists of a syringe and one or two 1 cm^3 pipettes held together by short lengths of plastic tubing. The principles of its operation are very simple: the yeast suspension is placed into a syringe, and the carbon dioxide released by the cells pushes a small water droplet up the pipette, which allows the volume of carbon dioxide to be measured at different times over a period of 10 - 20 minutes.



Weigh out 1.0 g of glucose and place it in a 50 cm^3 flask. Add 10 ml of boiled (to remove air) distilled water to the flask and gently swirl until the glucose is completely dissolved. Using a 10 cm^3 pipette, transfer 10 cm^3 of the yeast suspension into the flask. Allow the yeast suspension to incubate for five minutes, with occasional swirling. Take up exactly 3 cm^3 of the yeast suspension into a syringe. Invert the syringe and draw 1 cm^3 of air above the liquid.

Complete the assembly of the respiration apparatus (do not forget the water droplet), and place it into your test tube rack. As soon as the water droplet reaches the zero cm^3 mark, begin taking measurements at suitable time intervals. Students can mark measurements using either the top or the bottom of the droplet, but they must be consistent. Students may need to decrease the time interval between measurements to one minute or less as the rate of carbon dioxide production increases.

An alternative apparatus is shown below. Use a graduated pipette or syringe to place 10 cm^3 of glucose solution in the tube. As students release this solution into the tubes they should keep the tip of the pipette in contact with the inside of the tube so that the liquid runs down the tube without splashing and introducing air. They should swirl the tube gently to mix the yeast and glucose solution but they should not shake it and so introduce air. Use a dropping pipette to cover the surface of the solution in each tube with a thin layer of oil. Check that the taps are open (pointing upwards) and then fit the rubber bungs securely into each tube.



Place the tube in the water bath so that its delivery tube is dipping into the water in the test-tube. Leave the boiling tubes to acquire the temperature of the water bath for a minute, then close the taps (pointing downwards). Bubbles of carbon dioxide may then be observed and counted.

GRAPHICAL RELATIONSHIP

Graphs should be plotted of volume of carbon dioxide gas (y axis) against time (x axis) for glucose and fructose. Separate lines should be plotted for different temperatures. Part of the graph should be linear - the gradient over the linear region will be the rate of fermentation.

SUGGESTED EXTENSION WORK

In addition to the temperature there are a number of other possible independent variables including: concentration of glucose (a suitable range is 0 to 5%), nature of substrate (glucose, sucrose and fructose), concentration of sodium chloride (0 to 10% salt), ethanol concentration (a suitable range is 0 - 10%), presence of sorbitol or salt, pH (a suitable and safe range is 2 to 7) and variety or strain of yeast.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

- Potatoes (and/or fresh liver)
- Knife or scalpel
- Detergent solution
- Kettle
- Measuring cylinder
- Stop watch
- Rubber tubing
- Scalpel
- Electronic balances
- Potato peeler
- Thermometer
- Beaker
- Ceramic tile
- Cork borer
- Conical flask with side arm and bung
- Gas syringe
- Plastic board
- Water bath (if available)

CHEMICALS REQUIRED

15% volume hydrogen peroxide solution

SAFETY

Students should be shown how to use a scalpel or knife safely. Glasses must be worn when cutting and using hydrogen peroxide (irritant to eyes and skin and harmful if swallowed). Scalpels should not be carried from one table to another. Metals, metal oxide powders and organic compounds should not be in the vicinity during the practical.

GLOVES GOGGLES SHARP CORROSIVE

SUGGESTED RESEARCH QUESTION

To determine the relationship between the temperature and the rate of reaction (as measured by foam height) between catalase (from potato tissue) and aqueous hydrogen peroxide.

SUGGESTED VARIABLES

The independent variable is the temperature of the hydrogen peroxide solution. The dependent variable is the height of the foam in a specified time period. The controlled variables are the number and surface area of potato pieces, the variety of potato, pH, the volume and concentration of hydrogen peroxide, the amount and type (brand) of detergent and immersion time. Ideally, the same potato should be used to cut the pieces.

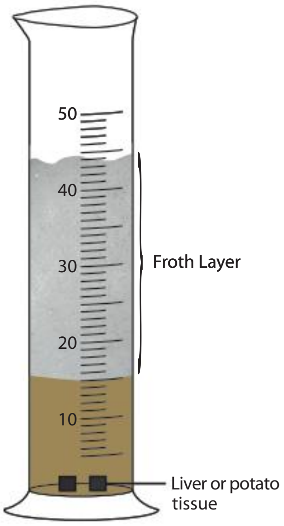
BACKGROUND THEORY

Enzymes are biological catalysts which increase the rate of a reaction without undergoing a permanent chemical change (i.e., they are not used up in the reaction). They are proteins. Enzymes form a temporary 'complex' with the chemical they are acting upon, called the substrate, before forming and releasing the product(s). Enzymes work within a narrow range of temperatures and pH values. At extreme values the protein loses it shape and hence biological activity - a process called denaturation.

Hydrogen peroxide will decompose naturally at a very slow rate to form oxygen gas and water:

$2H_2O_2\ (aq) \rightarrow 2H_2O\ (l) + O_2\ (g)$

If the enzyme catalase is added to the hydrogen peroxide then the breakdown is very rapid. Catalase can be found in most living organisms as hydrogen peroxide is toxic and is a by-product of respiration. Potatoes and liver cells are rich sources of catalase. Cutting through the potato skins to expose the cells inside allows catalase to escape from the cut cells and to react with hydrogen peroxide. Adding cut potatoes to a sample of aqueous hydrogen peroxide results in an accelerated rate of decomposition.

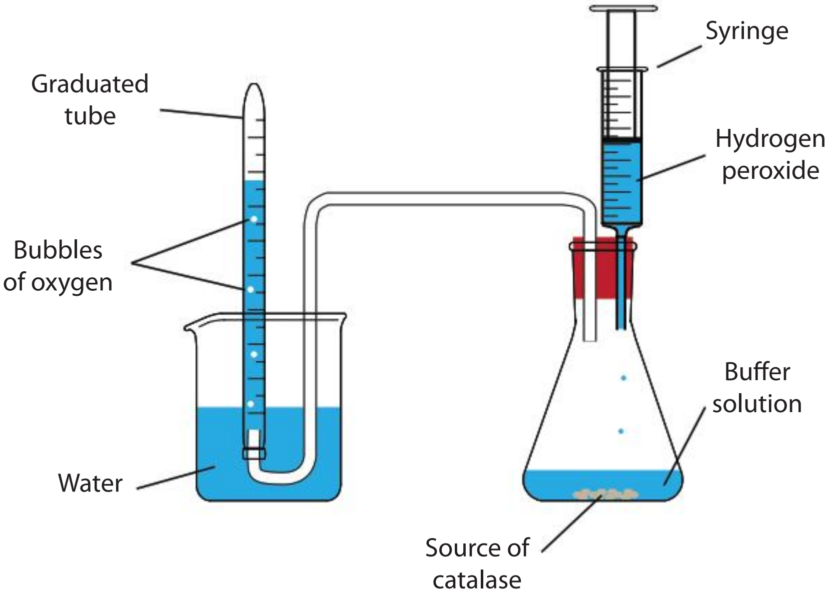


SUGGESTED METHOD

One simple approach is to put a fixed volume of hydrogen peroxide (of known concentration) into a measuring cylinder with a few small drops of detergent and then add a small number of potato pieces - flat discs work best or cubes of liver. The potato discs or liver cubes need to be of fixed and known dimensions. The height of the foam can be measured after a suitable short period of time. Students need to make sure that the catalase (liver or potato) is at the required temperature.

An alternative method is to perform the reaction in a sealed conical flask with a delivery tube connected to a graduated tube/measuring cylinder or eudiometer (if available). The oxygen gas can be collected and its total volume measured using a gas syringe, eudiometer or graduated tube. The hydrogen peroxide is added using a syringe.

The reaction vessel could also be connected to an electronic pressure sensor and a data logger could be used to record the changes in gas production in the reaction vessel.



GRAPHICAL RELATIONSHIP

A graph of temperature of hydrogen peroxide along the *x*-axis and height of foam (estimate of oxygen produced) on the *y*-axis should be drawn. Average data results should be used. A smooth curve should be drawn. An exponential relationship should be observed up to the optimum temperature followed by a sharp downward curve.

EVALUATION

Students should be aware of the inherent variation in biological materials, such as potato tissue. Different portions of potato may contain different amounts of catalase since it may not be evenly distributed throughout the potato. Students should also consider the accuracy to which they can dilute the hydrogen peroxide (if concentration is their independent variable), including; drips, pipettes leaving different amounts in the tip, parallax error (minimal), gradual decomposition of the hydrogen peroxide and impurities in the beaker including water (after being washed out). The height of foam may not be proportional to the amount of oxygen produced since not all the oxygen produced may produce foam.

SUGGESTED EXTENSION WORK

There are several possible independent variables for this investigation, e.g. surface area of potato, and concentration of hydrogen peroxide. The experiment could be improved by students extracting catalase and using a water bath (to control the temperature of the solution) or a buffer (to control the pH). Catalase extracts are obtained by combining equal amounts (by mass) of plant or animal material and deionised water in a blender, although a food processor or juicer also works well. Alternatively, the potato can be ground up using a mortar and pestle and then mixed with water. The extracts are filtered through cheesecloth. (Glass wool can be substituted).

Students can also investigate different vegetable and animal sources for catalytic activity, for example: leeks, carrots, liver, blood (horse), apricots contain catalase; tomatoes, rhubarb and citrus fruits do not contain detectable levels of catalase. Fruits typically have much lower catalase activity, perhaps due to their higher acidity. This may result in some fruits having greater susceptibility to damage by oxidation. (Able students can also investigate the effect of methanol, ethanol and ethanoate ions - all of which act as inhibitors).

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

- Tomatoes
- Petri dishes and lids
- Beaker
- Polythene bags
- Sellotape
- Plastic drinks bottles
- Pestle and mortar
- Bean seeds and bird seeds
- Portable lamp
- 1% agar
- Cress seeds
- Measuring cylinder
- 10 or 20 cm^3 syringe
- Scissors
- Filter paper

CHEMICALS REQUIRED

- Propanone
- 2 M hydrochloric acid
- 2 M sulfuric acid
- Sodium sulfite
- 1 M hydrochloric acid

SAFETY

Do not let students generate their own sulfur dioxide gas. Sulfur dioxide is a toxic gas and an irritant to the eyes and lungs. Sulfur dioxide may be prepared on a small scale in the fume cupboard by reacting a small amount of sodium sulfite with 1 M hydrochloric acid. Students must wear eye protection.

POISON GOGGLES

SUGGESTED RESEARCH QUESTION

To determine the relationship between the number of cress seeds that germinate and the concentration of sulfur dioxide.

SUGGESTED VARIABLES

The independent variable is the concentration of sulfur dioxide. The dependent variable is the number of cress seeds that germinate. The controlled variables are the number of cress seeds, the volume of the polythene bag and the surrounding air temperature and light intensity.

BACKGROUND THEORY

Before they can begin germination, seeds need a supply of water. This softens the testa or seed coat and allows the radicle to grow and push its way out. Water activates the enzymes which convert the starch stored in the cotyledons or endosperm into soluble sugars which are then transported in solution to the growing regions. At this stage seeds also need a supply of oxygen. This gas is necessary for aerobic respiration, from which the seed derives its energy for all the chemical processes which contribute to growth. Seeds will not start to germinate if the temperature is too low. The minimum temperature needed varies with the species of seed. Only a small number of species of plants have seeds which need light to begin germination. Once the cotyledons (seed leaves), or plumule, are above ground, light is needed for photosynthesis.

The exudate of tomato seeds contains a water-soluble inhibitor which prevents cress seeds germinating. The inhibitor is likely to be abscisic acid. The activity of the exudate would, obviously, depend on how the extract was made, but it is also likely to contain sugars and it might also affect the pH of the extract. Sugars could enable microbial growth on the cress and pH too might affect the germination. Students could germinate cress seeds in sugar concentrations equivalent to those in tomato juice and see if the sugars alone inhibit germination.

SUGGESTED METHOD

Petri dishes are lined with about 5 g of cotton wool and saturated with 20 cm^3 of distilled water. Fifty cress seeds are spread evenly over each. Both dishes are placed in polythene bags of known volume. One bag is 'fluffed up' and sealed with sellotape - this is the control. The other bag is 'fluffed up' and injected with a known volume of sulfur dioxide to represent the atmosphere polluted with acid rain. A gas syringe is used to collect and inject the sulfur dioxide gas. An alternative method is to use two plastic drinks bottles. A layer of cotton wool can be inserted using a glass stirring rod. Water followed by fifty cress seeds are added. Sulfur dioxide is injected and the bottles sealed. The cress seeds should be allowed to grow in a warm, sunny position for one week.

Students should examine the cress seeds after several days and count the number of seeds with a broken seed casing, either with some growth or with just the white inner parts of the seed showing. Ideally, students should also measure growth.

GRAPHICAL RELATIONSHIP

The students could pool their results and plot bar charts of group number (horizontal axis) versus number of germinations (from fifty seeds) (or plant length or mass) for the control cress seeds and the cress seeds exposed to sulfur dioxide gas. The bar chart should indicate that seeds grown under control conditions germinate better than those exposed to sulfur dioxide.

EVALUATION

Student should be aware that much of the variation in the results is due to the random errors in the preparation and collection of sulfur dioxide gas as well as biological variation in the cress seeds.

SUGGESTED EXTENSION WORK

Students could repeat the existing investigation with different species of seeds to see if certain species are more tolerant of acid rain pollution than others. Students could also vary the concentration of sulfur dioxide to determine a critical concentration below which no effect on growth can be found. The quantity of water applied to the cotton wool, the surrounding air temperature and light intensity could all be varied as independent variables.

The role of cotyledons (seed leaves) in the germination and growth (over a week) of bean seeds could be investigated. The testa can be carefully removed and the cotyledons (or some fraction) of them removed. The cotyledons do not contribute structurally to the embryo plant but are essential for its continued growth beyond a rudimentary stage as can be seen by comparing the week-old embryo with any of the others having some cotyledon. It seems likely therefore that the cotyledons supply essential substances such as nutrients or growth stimulators to the embryo. Since the cotyledons are bulky and the growth is proportional to the amount of cotyledon available, their role as a nutrient reserve is very likely.

If seeds are germinated within a roll of aluminium foil, which is then stood vertically in a nutrient solution, the growth of the root can be accurately measured over time.

Day/Date of lesson ______________ **Period** __________

Teacher ______________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Stopwatch

Access to exercise equipment in a gym (for example, a rowing or cycling machine that displays duration, instantaneous power and average power.)

SAFETY

WARNING: Do not allow students to participate in this investigation if they are feeling unwell or taking medication. Stop if they are feeling very tired or unwell. Do not allow them to exceed the maximum heart rate for their age.

DANGER

SUGGESTED RESEARCH QUESTION

To examine the heart rate of a rower as he or she exercises aerobically to maintain a series of constant power outputs.

SUGGESTED VARIABLES

The independent variable is the power output during rowing; the dependent variable is the heart rate. The controlled variables are the air temperature, clothing and the make of rowing machine. The physiological condition of the exercising student is assumed to be unchanged between tests.

BACKGROUND THEORY

An athlete will eventually reach a point where he or she can no longer improve on his/her power output and/or his/her heart rate. During exercise the metabolic rate of the muscles increases and generates a rising demand for oxygen. The pacemaker of the heart can be increased (via the sympathetic nerve) or slowed down (via the vagus nerve). Blood flow (cardiac output) is determined by the volume delivered by each heart beat (stroke volume) and the number of beats per minute (heart rate). During exercise both stroke volume and heart rate increase. The presence of the hormone adrenaline increases the heart rate. High levels of carbon dioxide will decrease the heart rate and dilate the peripheral blood vessels. During exercise the breathing rate and tidal volume both increase so more oxygen is supplied to the blood in the lungs.

If insufficient oxygen is present at high power outputs the rower will have insufficient oxygen in his muscles and the cells switch to anaerobic respiration. The resulting lactic acid will build up in the muscle, making contraction more difficult. It is generally triggered at approximately 85% of maximum heart rate. An oxygen debt will be created and the rower will feel pain. The lactic acid will be converted back into pyruvic acid once sufficient oxygen is supplied to the muscle cells.

SUGGESTED METHOD

The subject needs to warm up so the 'resting' heart rate can be recorded. This can be used a base level to which the exercising student has to recover before embarking on any of the exercises or tests. The subject can then row at given power outputs for a fixed period of time. The maximum heart rate and power output should be recorded.

GRAPHICAL RELATIONSHIP

A line graph should be drawn of maximum heart rate (y axis) versus power output (x axis). The relationship will not be linear and the rate of increase of heart rate is smaller for larger power output values. A linear graph can be obtained by plotting $\log_{10}$ (maximum heart rate) versus $\log_{10}$ (power output).

EVALUATION

Students should note that lower power values, because they require minimal exertion, were the hardest to keep constant. Recovery times become longer after the bursts of higher power rowing. The exercise is assumed to be aerobic, but at high power output the person rowing (or doing other exercise) may be respiring anaerobically or a mixture of the two.

SUGGESTED EXTENSION WORK

Another very good indicator of cardio-vascular fitness is 'recovery time' which is variously defined. Students could devise and conduct an experiment, or series of experiments to investigate a factor(s) that may affect recovery time.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Two droppers or teat pipettes

Two measuring cylinders (100 cm^3)

Stopwatch

CHEMICALS REQUIRED

0.1 mol dm^{-3} copper(II) sulfate

Milk samples: skimmed, semi-skimmed and full fat (different brands)

SAFETY

Copper(II) sulfate solution is harmful if swallowed and irritating to eyes and skin. Safety glasses must be worn at all times.

SUGGESTED RESEARCH QUESTION

To discover the relationship between the fat content of skimmed and semi-skimmed milk and the time taken for a droplet to sink through a solution of 0.1 mol dm^{-3} copper(II) sulfate.

SUGGESTED VARIABLES

The independent variable is the fat content of the milk; the dependent variable is the time taken for a droplet to sink through a solution of 0.1 mol dm^{-3} copper(II) sulfate. Controlled variables include the concentration and temperature of copper(II) sulfate solution, the volume of milk droplet; the depth of sampling, the freshness of the milk (time between opening and testing).

BACKGROUND THEORY

The composition of milk affects its density. The higher the amount of fat relative to proteins in the milk sample, the lower its density. The relative densities of different samples and types of milk can be determined by measuring the time taken for their droplets to sink through a solution of copper(II) sulfate.

In fresh milk, the fat droplets are uniformly dispersed, but when milk is allowed to stand the droplets rise to the top of the milk and form a layer of cream. Milk can be treated to prevent the formation of a cream layer. This type of milk is known as homogenised milk and is prepared by forcing milk under pressure through very small holes. The fat is broken down into smaller droplets which remain evenly dispersed and the milk has the same composition throughout. Homogenised milk is whiter, more opaque (cloudy), and more viscous than unhomogenised milk with the same fat content.

SUGGESTED METHOD

Fill the two measuring cylinders with copper(II) sulfate solution. Release a drop of the milk sample just below the surface of the copper(II) sulfate solution. Record the time taken for the drop to fall between the 100 and 10 cm^3 marks. Repeat and average the results.

GRAPHICAL RELATIONSHIP

A bar chart should be drawn of brand of milk versus average time for the drop to fall a fixed distance. A line graph could be drawn if a range of milks (of known fat composition) were tested.

EVALUATION

Students should be aware of random and systematic errors present in the manual timing. A taller measuring cylinder should be used so the times are longer and the effect of the errors reduced. Random errors in the size of the milk drop and its position of release should also be noted.

SUGGESTED EXTENSION WORK

The density of various brands of milk could be calculated from accurate measurements of the mass and volume of milk samples. It is assumed that changes in the fat content are responsible for changes in the density of the milk samples.

Day/Date of lesson ______________ **Period** __________

Teacher ______________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Metre rulers

Electronic stopwatches

Bathroom scales (to measure mass of students)

SAFETY

You are not allowed to take large quantities of food or drinks, such as coffee or coca cola beforehand.

SUGGESTED RESEARCH QUESTION

To discover the relationship between the average reaction time of male and female students aged between 14 and 15 years old.

SUGGESTED VARIABLES

The independent variable is the gender and the dependent variable is the average reaction time for three trials. The controlled variable is the age of the students. Uncontrolled variables might include illness, fatigue, distraction, height, mood, muscular tension, vision and drugs/medication.

BACKGROUND THEORY

Cells in the retina detect the movement of the falling ruler (the stimulus), the optic nerve then sends impulses to the cerebral cortex of the brain. The visual cortex sends an impulse to the motor cortex and the motor cortex of the brain sends an impulse to the spinal cord. The spinal cord sends an impulse to the hand/finger muscles which contract to catch the ruler.

In almost every age group experiments have shown that men have faster reaction times than women, perhaps because of the greater involvement of men in sports, driving and computer games. Reaction times are shortest in the late twenties and then increase slowly with age. Shorter people have faster reaction time because shorter people have a shorter transit time for stimuli initiated in the brain.

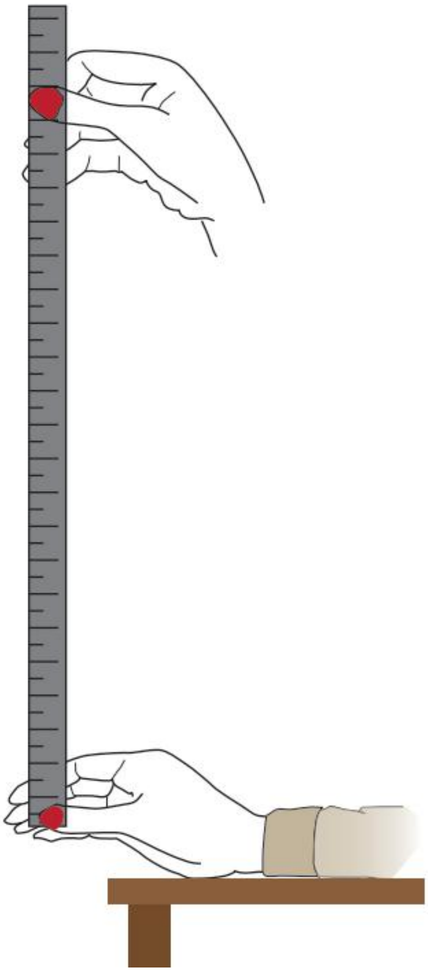
SUGGESTED METHOD

The subject marks a pencil line down the centre of his thumb-nail and sits sideways at a bench or table with the forearm resting flat on the bench and the hand over the edge (see Figure over). The student holds a ruler vertically between the subject's first finger and thumb with the zero opposite the line on the thumb but not quite touching either the thumb or fingers. The subject watches the zero mark and, as soon as the experimenter releases the ruler, the subject grips it between finger and thumb to stop it falling any further. The distance on the ruler opposite the mark on the thumb is recorded. This is repeated a number of time times and the average distance calculated. This distance can be converted to a time by the use of the equation in the student instruction sheet.

Two other, more accurate methods are briefly described in the Student sheets.

GRAPHICAL RELATIONSHIP

A bar chart should be plotted of average reaction time for a sample of male students versus the average reaction time for a sample of female students.



EVALUATION

The students should recognise that the sample size is relatively small and many of the potentially important controlled variables are not controlled. The speed of impulse conduction is so rapid that very large differences in distance would be needed to produce a measurable difference in reaction time by this crude method.

SUGGESTED EXTENSION WORK

The experiment could be repeated with the same student but this time the student lets the ruler rest lightly against the thumb or fingers, with closed eyes, and grips the ruler as quickly as possible after he or she feels it begin to fall. The average class results will probably not show any significant difference (at the 5% level of confidence if analysed statistically) between the reaction times. These are likely to be in the region of 0.2 seconds in both cases.

Students could also repeat the experiment to investigate the effect of left versus right hand. The left hemisphere is regarded as the verbal and logical brain, and the right hemisphere is thought to govern creativity, spatial relations, face recognition, and emotions, among other things. Also, the right hemisphere controls the left hand, and the left hemisphere controls the right hand. Students could also investigate the effect of direct vision versus peripheral vision. The fastest reaction time comes when a stimulus is seen by the cone cells in the retina (when the student is looking right at the stimulus). If the stimulus is picked up by rod cells (around the edge of the eye), the reaction is slower.

Students may also use the ‘two-stopwatch’ method to test right and left or sight and sound stimuli. This method produces much more consistent and accurate results. Some websites convert reaction time to braking distance (see Student sheets) and this could lead good students to investigate this mathematically.

Day/Date of lesson ________________ **Period** __________

Teacher ________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Gas syringe

Delivery tube and bung

Ruler

Clamp stand

Rubber tubing

Burette

Pestle and mortar

Kettle

Conical flasks

Electronic stopwatch

Fine sand paper

Measuring cylinders

Glass trough

Boiling tubes

Gas syringe and rubber delivery tube

Glass trough

Digital balance capable of weighing to at least 0.01 g

SUGGESTED CHEMICALS

Magnesium ribbon

2 M nitric acid, HNO_3 (aq)

Marble chips (calcium carbonate)

2 M copper(II) sulfate solution

Magnesium powder

2 M ethanoic acid

Zinc

Copper

Copper(II) oxide

2 M hydrochloric acid, HCl (aq) (students should dilute the acid as appropriate)

SAFETY

Safety glasses must be worn at all times during the investigation. Dilute acid is corrosive – if it comes into contact with skin or eyes, then the affected area must be washed with cold water. Iron should not be supplied to students since iron sulfide impurities generate the very poisonous gas, hydrogen sulfide. Calcium is too reactive and should not be given to students. The magnesium must only be reacted with acid - it must not be heated directly. Powdered magnesium is dangerous if blown into a Bunsen burner flame. Any heating of dilute acid must be done using a water bath. Copper(II) sulfate solution is harmful if swallowed and irritating to eyes and skin. Copper(II) oxide is harmful.

CORROSIVE

GLOVES

GOGGLES

SUGGESTED RESEARCH QUESTION

To determine the relationship between the rate of reaction (as measured by the time for completion) and concentration for the reaction between magnesium and hydrochloric acid. (There are other possibilities).

SUGGESTED VARIABLES

The concentration of the hydrochloric acid is an independent variable and the time (for the reaction to go to completion) is the dependent variable. Controlled variables are the volume and temperature of hydrochloric acid and the mass and total surface area of magnesium.

BACKGROUND THEORY

Magnesium reacts with dilute acid to release hydrogen gas: $Mg\ (s) + 2H^{+}\ (aq) \rightarrow Mg^{2+}\ (aq) + H_2\ (g)$. Calcium carbonate reacts with dilute acid to release carbon dioxide gas:

$CO_3^{2-}\ (aq) + 2H^{+}\ (aq) \rightarrow CO_2\ (g) + H_2O\ (l)$.

The relative rate of a chemical reaction can be explained by reference to simple collision theory. If a solid reactant is broken down into smaller pieces the rate of reaction increases. The rate increase happens because smaller pieces of the same mass of solid have a greater surface area compared with larger pieces of the solid. Therefore, there is more chance that a reactant particle will hit the solid surface and react (in the same amount of time). When gases or liquids are heated, the particles gain kinetic energy and move faster. The increased speed increases the frequency of collisions between reactant molecules and the reaction rate increases. In addition heated molecules have a greater average kinetic energy, and so, at higher temperatures, a greater proportion of them have the required activation energy to react. It is important to remember that any discussion of factors affecting the rate of a reaction must refer to the number of collisions in a given amount of time.

If concentration is chosen as the independent variable then a quantitative prediction supported by a quantitative explanation could be expected, e.g. if the concentration of acid is halved, then students may predict the rate will be halved (assuming the reaction is first order). Quantitative predictions for changes in surface area are difficult to verify because of the difficulties in producing a series of marble chips whose surface areas can be measured and be related one to another, e.g.×2, ×4 etc. Your School's MYP Science course may not include the mole concept. It is, therefore, acceptable for students to describe the concentration in terms of the ratio of the volume of water to the volume of 2 M hydrochloric acid. Some prior teaching of how to perform a serial dilution will probably be required.

Able students should realise the effects of changes in surface area, however, this provides a challenging investigation for able students, because of the difficulty in measuring the surface areas and the difficulty in reproducing identical surface areas in order to repeat the results.

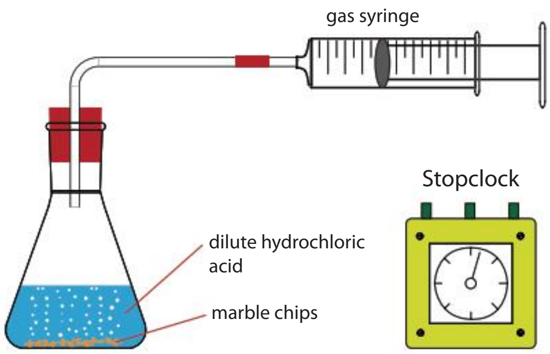
Reaction temperature is also very difficult to control since the reaction between magnesium and hydrochloric acid is very exothermic. A simple water bath, for example, a beaker of water can be employed in an effort to maintain a reasonably constant temperature.

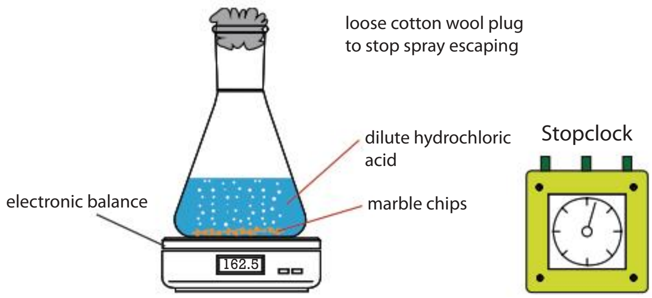
SUGGESTED METHOD

There are a variety of methods for measuring the rate of reactions that produce gas. The simplest approach is to use 1/time (reciprocal of seconds, s^{-1}) (for completion of reaction) as a measure of the average rate during the reaction. Students may use an electronic balance and an open flask (with some cotton wool in the neck to prevent acid spray splashing on the balance) to follow the loss in mass (due to release of gas) or a sealed gas syringe to record increase in total gas volume. Students using a gas syringe or balance will be able to plot graphs that will allow instantaneous rates to be obtained from gradients. Alternatively, the gas produced might be collected by downward displacement of water in an inverted measuring cylinder.

Be aware that students will often plan to measure the time taken for calcium carbonate to fully react and the products dissolve into solution, not realising that this will not work if the acid is the limiting reagent.

Note that as hydrochloric acid is diluted below approximately 1 mol dm^{-3} that the time taken for the reaction to go to completion is on the order of several minutes. Therefore students should either work at concentrations between 1 M and 2 M, or set up multiple test tubes simultaneously to expedite data collection.





GRAPHICAL RELATIONSHIP

Graphs of concentration (*x* axis) versus rate: change in mass or volume per unit time (*y* axis) may be directly proportional (provided the reaction is first order). A graph of temperature of acid (*x* axis) versus rate (*y* axis) should be exponential, provided a wide range of temperature is studied. A graph of surface area (*x* axis) versus rate (*y* axis) will be linear, provided surface area can be calculated.

EVALUATION

Students should be aware of random errors present in their measurements of mass, volume and time. Temperature can be controlled using a thermostatically controlled water bath. It is difficult to control the temperature of the reaction between magnesium and hydrochloric acid because it is significantly exothermic.

SUGGESTED EXTENSION WORK

Students could repeat the experiment using a different strong acid or a weak acid or choose another independent variable for the set of reactants. The most able students could try to establish a rate law. The students could perform the reaction between magnesium and dilute acid in the presence of copper(II) sulfate solution – the copper formed (via a displacement reaction) slows the reaction down as unreactive copper is deposited onto the surface of the magnesium.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Funnel

Burette

Conical flask

Burette stand

Pipette and filler

White tile

Measuring cylinder (25 cm^3)

Styrofoam or polystyrene cup

pH probe and meter (and data-logger if available)

Temperature probe (and data-logger if available)

Conductivity probe and meter (and data-logger if available)

CHEMICALS REQUIRED

0.1 M nitric acid

0.1 M sodium hydroxide

0.1 M ammonia

Distilled water

0.1 M sulfuric acid

0.1 M hydrochloric acid

0.1 M ethanoic acid

Universal indicator solution

A range of commercial antacids, ideally a single pure chemical, (e.g., milk of magnesia)

SAFETY

Safety glasses must be worn at all times during the investigation. Dilute acid and alkali are both corrosive – if they come into contact with skin or eyes, then the affected area must be washed with cold water. Universal indicator may be harmful if swallowed and may temporarily mark skin.

CORROSIVE

GOGGLES

GLOVES

SUGGESTED RESEARCH QUESTION

To investigate the change in temperature as 25.0 cm^3 of 0.1 M hydrochloric acid is neutralised by 50.0 cm^3 of 0.1 M sodium hydroxide.

SUGGESTED VARIABLES

The independent variable is the volume of sodium hydroxide and the dependent variable is the temperature of the solution. The controlled variables are the equipment used, the concentrations and starting temperatures of the acid and alkali solutions.

THEORY

Neutralisation is the reaction between an alkali and an acid to form a salt and water only. It is an exothermic reaction: heat is released from the chemicals into the surroundings. The reaction between sodium hydroxide (a strong alkali) and hydrochloric acid (a strong acid) can be described by the following equations:

$NaOH\ (aq) + HCl\ (aq) \rightarrow NaCl\ (aq) + H_2O\ (l)$; $H^+\ (aq) + OH^-\ (aq) \rightarrow H_2O\ (l)$

The equivalence point is when stoichiometric amounts of acid and alkali are present, for example, 25 cm^3 of 0.1 M NaOH and 25 cm^3 of 0.1 M HCl - there is only sodium chloride and water present.

During this neutralisation the temperature rises up to the equivalence point. The temperature then decreases since addition of further acid involves no chemical reaction. A similar graph is obtained if higher concentrations of acid and alkali are used, but the two lines will meet at a higher peak.

If conductivity is monitored then there will be a decrease down to the equivalence point since two ions are replaced by one ion and a molecule. The conductivity will rise after the equivalence point as excess hydrochloric acid (hydrogen and chloride ions) is added to the sodium chloride solution.

The pH changes abruptly near the equivalence point since a relatively small change in hydrogen ion concentration causes a large change in pH. A symmetrical curve centred around the equivalence point is obtained due to the logarithmic nature of pH. $pH = -\log_{10}[H^+\ (aq)]$.

SUGGESTED METHOD

Stand an insulated (or styrofoam) cup in a beaker for support. Using a pipette and safety filler, transfer 25 cm^3 of the sodium hydroxide solution into the cup, and measure the steady temperature. Using the burette, add a small portion (2–4 cm^3) of dilute hydrochloric acid to the solution in the cup, noting down the actual volume reading. Stir by swirling the cup and measure the highest temperature reached. Immediately add a second small portion of the dilute hydrochloric acid, stir, and again measure the highest temperature and note down the volume reading. Continue in this way until there are enough readings to decide the maximum temperature reached during this experiment. You will need to add at least 30 cm^3 of the acid.

EVALUATION

Students should be aware of random errors present in all the measurements of volume including those present in the technician's preparation of the solutions. Sodium hydroxide absorbs carbon dioxide from the atmosphere, thereby reducing its stated concentration. The main concern in this experiment is the heat loss. If possible a lid should be used. More reliable results can be achieved using two polystyrene cups (one inside the other).

SUGGESTED EXTENSION WORK

Students could follow the pH during neutralisation using indicator solution or, preferably using a pH probe and meter. The conductivity could also be monitored using a conductivity probe and meter. Students could also investigate the volume of acid required to neutralise different commercial antacids.

Day/Date of lesson ________________ **Period** __________

Teacher ________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Iron nails

Fine sandpaper

Conical flask

Petri dishes

Balance capable of weighing to at least 0.01 g

Kettle

Metal scissors

Test tubes with rubber stoppers or corks

Cotton wool

Measuring cylinder (25 cm^3)

Pipette

CHEMICALS REQUIRED

Sodium chloride

Distilled water

Polish and paint

Anhydrous calcium chloride (drying agent: absorbs water vapour)

Ferroxyl indicator (10 cm^3 of 0.5 mol dm^{-3} $K_3Fe(CN)_6$ + 5 drops of phenolphthalein + 20 cm^3 of 0.1 mol dm^{-3} NaCl)

Zinc foil and copper foil

Vegetable oil

Petroleum jelly

SAFETY

Students must wear safety glasses and gloves. Calcium chloride may be harmful if it is swallowed.

Eye contact: Immediately flush the eye with plenty of water. If irritation persists call for medical help.

Skin contact: Wash off with water. Small amounts of calcium chloride can be disposed of in normal laboratory waste, unless local rules prohibit this. Solid $K_3Fe(CN)_6$ is an irritant to the eyes. Phenolphthalein is also an irritant to the eyes and skin and is dissolved in alcohol (flammable). Care is needed when using paints and polishes. No Bunsen burners should be used.

SUGGESTED RESEARCH QUESTION

To find the relationship between the concentration of aqueous sodium chloride solution and rate of rusting as measured by the increase in mass. (To find out the effects of zinc and copper on the rate of rusting of iron. To find the conditions under which rusting occurs).

SUGGESTED VARIABLES

The independent variable is concentration of sodium chloride solution; the dependent variable is the mass of rust. Controlled variables include mass, purity and surface area of iron (though this is difficult to measure), nature of surrounding air and time of exposure.

BACKGROUND THEORY

Many metals corrode because they react with oxygen to form oxides. The rusting of iron is a corrosion process and involves the reaction between iron, oxygen and water to form hydrated iron(III) oxide (rust). Both oxygen and water must be present for rusting to occur.

The rusting of iron is actually a complex electrochemical process involving an anode (a piece of metal that readily gives up electrons), an electrolyte (a liquid that conducts electricity) due to the presence of mobile ions and a cathode (a piece of metal that readily accepts electrons). Rusting consists of the following reactions:

$Fe \rightarrow Fe^{2+} + 2e^{-}$; $O_2 + 2H_2O + 4e^{-} \rightarrow 4OH^{-}$; $Fe^{2+} + 2OH^{-} \rightarrow Fe(OH)_2$; $4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3.H_2O + 2H_2O$

Following these reactions can be achieved by using ferroxyl indicator, a mixture of potassium hexacyanoferrate(III) and phenolphthalein, often dissolved in sodium chloride solution. The yellow hexacyanoferrate(III) ion complexes to iron(III) ions forming a deep blue colour:

$[Fe(CN)_6]^{3-} (aq) + Fe^{2+} (aq) \rightarrow Fe[Fe(CN)_6]^{-} (aq)$

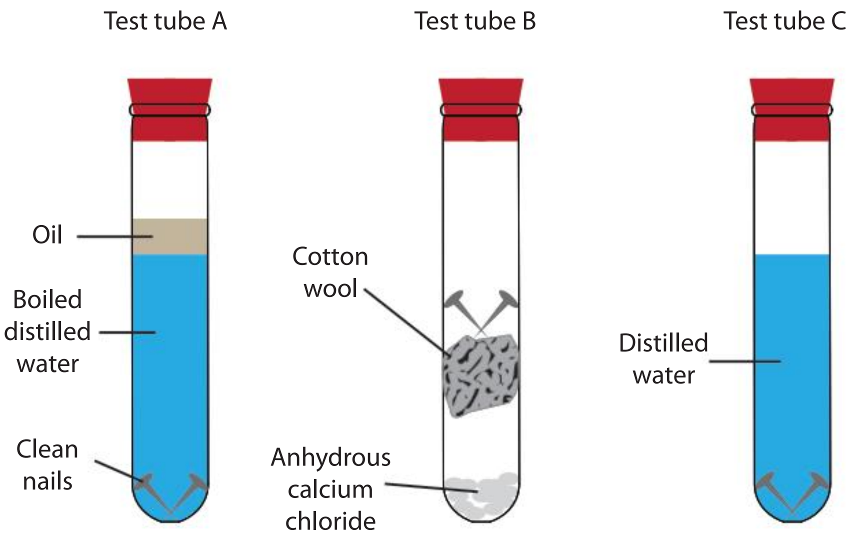
(yellow) (blue)

Formation of hydroxide ions is identified by using phenolphthalein indicator. It turns pink in the presence of hydroxide ions.

The presence of sodium chloride or other ionic substances makes the water a better electrolyte (conductor) and increases the rate of corrosion. The presence of copper (in physical contact with the iron) will promote rusting; zinc will inhibit rusting since zinc lies above iron in the reactivity series and corrodes preferentially. (Zinc acts as a sacrificial anode).

SUGGESTED METHOD (TO ESTABLISH THE CONDITIONS FOR RUSTING)

An obvious investigation is for students to prove that oxygen and liquid water are both necessary for rusting. Students could also investigate the effect of sodium chloride (at different concentrations) on the rate of rusting. Students could also attach pieces of copper (less reactive than iron) and zinc (more reactive than iron) to measure their effect on the rate of rusting. Copper will promote rusting; zinc will inhibit rusting. Students could also weigh the amount of rust gained by the iron under different conditions and calculate rates of rusting.



GRAPHICAL RELATIONSHIP

Students could plot scatter graphs of rust mass (*y* axis) against time (*x* axis) under different conditions.

EVALUATION

There should be no rusting in test tube A since boiling removes the dissolved oxygen and the oil should prevent entry of oxygen from the atmosphere. However, the boiled water is still likely to contain some dissolved oxygen and some rusting will be observed. Anhydrous calcium chloride is a drying agent (dessicant). Test tube B therefore contains dry air and the nails should not rust significantly. Test tube C contains water and dissolved oxygen and hence displays the most rust. This is a long term investigation - the test tubes will need to be observed over a period of days to weeks. Students should recognise that for a perfectly fair test the nails should be identical in nature and be equally cleaned. All tubes are assumed to be air tight.

SUGGESTED EXTENSION WORK

The presence of other metals in physical contact with the iron could also be investigated. The rate of rusting could also be determined by measuring the mass of rust produced at regular intervals. Students should recognise the need to reweigh the nails when dry, and the risk of admitting moisture (water vapour) and/or oxygen (air) if the stoppers are removed to periodically reweigh the nails.

Students can use ferroxyl indicator to determine which parts of the nail undergo the greatest rusting. This is often where the iron was placed under stress or strain. They can also use the ferroxyl indicator to investigate the rate of corrosion when a second metal is placed in contact with the iron or when different electrolytes are used.

Day/Date of lesson ____________ **Period** ________

Teacher ________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

- Milliammeter (or multimeter)
- Beaker
- Crocodile clips and leads
- Fine sandpaper
- Ignition tubes
- Electronic balances
- Power supply
- Copper electrodes
- Stopwatch
- Carbon electrodes
- Wooden splints

CHEMICALS REQUIRED

2 M copper(II) sulfate solution

Propanone (for degreasing electrodes)

SAFETY

Copper(II) sulfate solution is poisonous and irritating to skin and eyes. Safety glasses must be worn. Propanone is poisonous, highly flammable and irritating to the eyes. The vapours may cause drowsiness and dizziness.

FLAMMABLE CORROSIVE GOGGLES GLOVES

SUGGESTED RESEARCH QUESTION

To find the relationship between the mass of copper produced at the cathode and the quantity of electricity consumed during the electrolysis of copper(II) sulfate using carbon electrodes.

SUGGESTED VARIABLES

The time for which a constant current flows is the independent variable; the mass of copper deposited at the cathode (negative electrode) is the dependent variable. Controlled variables include the volume and concentration of copper(II) sulfate solution, nature and dimensions of the electrodes (and the distance between them), the current passed and the temperature.

BACKGROUND THEORY

The electrolysis of copper(II) sulfate solution using inert carbon electrodes can be described by the following half equations:

Anode (positive electrode): $4OH^- (aq) \rightarrow 2H_2O (l) + O_2 (g) + 4e^-$

Cathode (negative electrode): $Cu^{2+} (aq) + 2e^- \rightarrow Cu (s)$

The electrolysis of copper(II) sulfate using copper electrodes can be described by the following half equations:

Anode (positive electrode): $Cu (s) \rightarrow Cu^{2+} (aq) + 2e^-$

Cathode (negative electrode): $Cu^{2+} (aq) + 2e^- \rightarrow Cu (s)$

The concentrations of the copper(II) sulfate solution remains unchanged but copper atoms are transferred from the anode to the cathode. Hence, the anode dissolves and the cathode becomes copper plated. Any impurities present in the copper will dissolve or sink to the bottom of the electrolytic cell.

The number of electrons passed through the electrolytic circuit is directly proportional to the time and current. Hence simple ionic theory (Faraday's first law) predicts that doubling of the current or doubling of time (with constant conditions) should produce a doubling in the mass of copper deposited on the cathode or a doubling in the mass of copper lost from the anode.

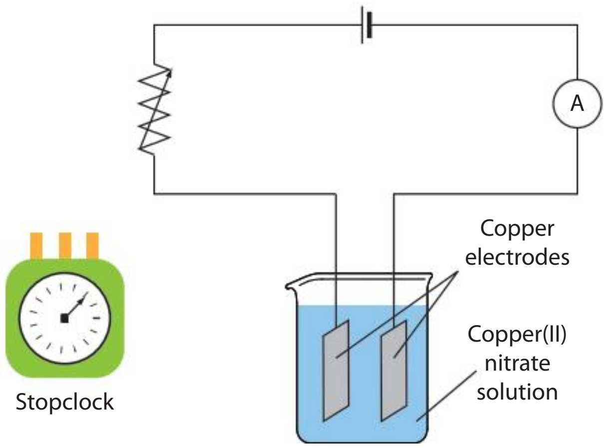
The quantity of electricity is not usually measured in numbers of electrons, but in coulombs, one coulomb being passed when a current of one ampere flows for one second.

Number of coulombs = current (A) × time (s) (1 A = 1 C/s)

The results of experiments where current and time are varied are expressed by Faraday's first law of electrolysis: the mass of a substance dissolved or produced at an electrode is proportional to the quantity of electricity which passes through the electrolyte.

SUGGESTED METHOD

A series circuit should be constructed containing a variable resistor, a power supply and an ammeter. The rheostat should be adjusted so that a small current (0.1 A to 0.2 A) flows. Carbon electrodes in a holder can be used or copper electrodes can be bent over the side of a beaker containing the electrolyte copper(II) sulfate or nitrate. Alternatively, an electrolytic cell with carbon electrodes entering from the bottom can be used. Students will find that the copper plating will fall off the cathode if large currents are used and if the cathode is not thoroughly cleaned and degreased. Masses of copper at the cathode can be measured against time (or current for a fixed length of time).



GRAPHICAL RELATIONSHIP

A linear graph will be obtained for a plot of time (x axis) against mass of copper deposited (y axis). A linear graph will also be obtained for a plot of current (x axis) against mass of copper deposited (y axis).

EVALUATION

It is very likely that non-linear results will be obtained at high current levels or long periods of time due to loss of deposited copper from the cathode.

SUGGESTED EXTENSION WORK

The experiments can be repeated with the electrolysis of silver nitrate and the results compared. Capable students might be encouraged to calculate the number of moles of electrons, n_e, which have passed through the circuit and hence the mass of copper expected. This can be compared with the experimental values.

$n_e = \frac{It}{F}$; where I is the current in amps, t is the time in seconds and F is the Faraday constant.

$n(Cu^{2+}) = \frac{n_e}{2}$ since $Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$; $m(Cu) = n(Cu^{2+}) \times M(Cu)$, where m represents the mass of copper (in grams) and M the molar mass of copper.

Day/Date of lesson ____________________ **Period** ____________

Teacher ________________________________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

- Beakers
- Thermometer
- Small portable fan
- Burette
- Conical flasks
- Kettle
- Stopwatch
- Pipette
- Measuring cylinder
- Watch glass
- Balance capable of weighing to at least 0.001 g

SUGGESTED CHEMICALS

- Pentan-1-ol
- Propan-1-ol
- Propanone
- Butan-1-ol
- Ethanol
- Distilled water
- Methanol

SAFETY

Do not let students drink the alcohols or smell them strongly. Work in a well-ventilated laboratory. Safety glasses and gloves must be worn at all times during the practical. Bunsen burners are not to be used at any time during this practical. Any heating must be done using a water bath. Methanol is toxic by inhalation, contact with the skin and if swallowed. Medical attention must be sought if this occurs.

SUGGESTED RESEARCH QUESTION

To compare the relationship between the evaporation rates of methanol, ethanol, propan-1-ol, butan-1- ol and pentan-1-ol (at constant temperature), as measured by their mass loss from an open beaker after a fixed time interval, and their molecular mass.

SUGGESTED VARIABLES

The change in mass of the alcohol is the ultimate dependent variable. The nature of the alcohol (specifically, the molecular mass) is the independent variable. Controlled variables include time for evaporation, initial volume (or mass) of alcohol (or other volatile liquid), temperature, wind speed and pressure of surrounding air and surface area of beaker.

BACKGROUND THEORY

Evaporation is the process by which fast moving molecules at a liquid's (or solid's) surface escape and form a gas. It occurs at all temperatures between the freezing point and boiling point of the liquid. In any liquid the molecules are closely packed but freely moving. The average speed at which the molecules move depends on their temperature. In hotter liquids the molecules move at higher average speeds and the evaporation rate is consequently higher. When fast moving molecules are near the surface, they can escape into the gas above the liquid's surface. As increasing numbers of the most energetic molecules evaporate to form gas, the average kinetic energy of the remaining molecules decreases, so the liquid cools (until heated by the surroundings) and gaseous molecules return to liquid form. This sets up an equilibrium.

The rate of evaporation can also be increased by the presence of wind speed, which removes gas molecules, or increasing the surface area over which evaporation can occur. Evaporation is an endothermic process: work is done in separating molecules and overcoming or breaking the attractive forces operating between adjacent molecules. The rate of evaporation varies with the boiling point (or molecular mass) of the liquid: the lower the boiling point (or molecular mass), the weaker the intermolecular forces and the greater the evaporation rate.

SUGGESTED METHOD

Place a small known volume of ethanol in an open beaker (of known mass) and place into the centre of the pan of an electronic balance with a high degree of precision. The mass of the ethanol can be determined by difference. Start the stopwatch and stop after a suitable time interval. Record pairs of readings of total mass and time at suitable intervals. Students will need to carry out some initial experiments to find suitable times for significant evaporation, and hence mass loss, to occur.

GRAPHICAL RELATIONSHIP

The students should obtain a directly proportional relationship between the remaining mass of the liquid (y axis) against time (x axis). A line of best fit with a negative gradient should be obtained. The more volatile liquid will have a larger gradient.

EVALUATION

Students should be aware of the random errors present in the mass readings and the possibility of a systematic error known as a zero error. Students should also be aware of the difficulty in controlling variables, such as air temperature and wind speed.

SUGGESTED EXTENSION WORK

Alternative investigations may involve determining the effect of temperature on the evaporation rate. A graph of the mass of the liquid (y axis) against the temperature (x axis) should be an exponential curve. Other independent variables that could be investigated include surface area of container and, less preferably, wind speed (in relative terms, for example, slow, medium and fast settings).

Day/Date of lesson ____________________ **Period** ____________

Teacher ________________________________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

Spirit burner with wick

Screen

Thermometer

Screen (to protect from draughts)

Glass beaker

Matches

Clamp stand and clamp

Electronic stopwatch

Copper calorimeter with wooden cover with holes for stirrer and thermometer

Electronic balance

CHEMICALS REQUIRED

Methanol

Ethanol

Propan-1-ol

Butan-1-ol (Print formulas on the bottles)

Pentan-1-ol

Hexan-1-ol

SAFETY

Do not give students fuels, such as kerosene, ether and petrol to investigate. Show students how to safely burn a small quantity of alcohol in a spirit burner and how to use the cap to extinguish the flame. Eye protection must be worn at all times.

FLAMMABLE GOGGLES

SUGGESTED RESEARCH QUESTION

To determine the relationship between the number of carbon atoms in a simple alcohol and its heat of combustion (in joules per gram or kilojoules per mole). Less able students may investigate the relationship between the heat released and the mass or volume of liquid fuel.

SUGGESTED VARIABLES

The number of carbon atoms (or molecular mass) of the alcohol is the independent variable and the temperature change in a fixed mass of water is the proximate dependent variable (the ultimate dependent variable is the heat of combustion). Controlled variables include: mass of water, size and type of calorimeter (including insulation), distance between the flame and the calorimeter and temperature rise.

BACKGROUND THEORY

The combustion of alcohols is an exothermic process and heat is released to the surroundings (air). The heat of combustion is the energy change when a substance undergoes complete combustion in excess air. For liquid fuels it can be found using a metal calorimeter and a spirit burner. The heat from a spirit lamp can be transferred to a known volume and hence mass of water inside a metal calorimeter. The quantity of heat transferred can be calculated from the following expression:

Heat energy (in joules) = mass of water (in kg) × 4200 (J/kg/°C) × temperature rise (°C).

4200 (J/kg/°C) is the specific heat capacity of water, the energy needed to raise the temperature of 1 kg of water by 1 °C. The amount of alcohol burnt can be found by weighing the spirit burner before and after a reasonable temperature rise has been obtained. The heat of combustion can then be scaled up to heat released per gram or kilogram. Alternatively, the mass of alcohol can be converted into an amount (in moles) using the molecular mass before it is 'scaled up' up into J/mol or kJ/mol.

The bond energy is the energy needed to break one mole of covalent bonds (in the gaseous state). Covalent bonds exist within molecules and are formed from the sharing of one or more electron pairs. Bond energies are measured in kilojoules per mole or kJ/mol.

When a chemical reaction takes place bonds are broken: heat energy is absorbed from the surroundings. New bonds are then formed between the atoms and heat energy is released to the surroundings. If the heat energy released is greater than the heat energy absorbed, then the reaction is exothermic. However, if the heat energy released is less than the heat energy absorbed, then the reaction is endothermic.

Bond energy values can be used to calculate a theoretical heat change for a chemical reaction:

Heat change = Total heat energy absorbed by breaking bonds in reactants - total heat energy released by making bonds in products.

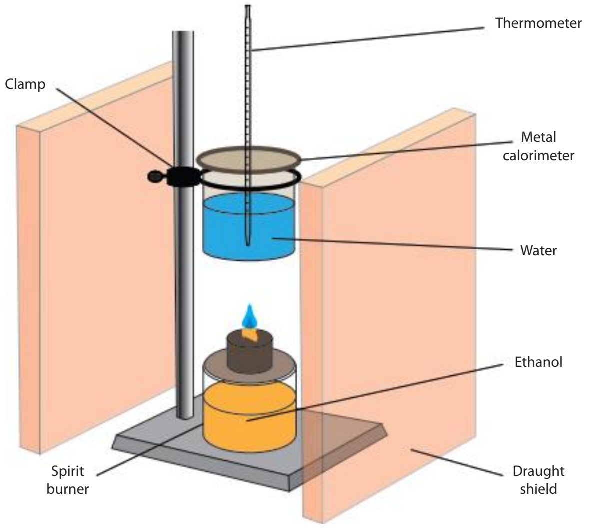
A positive value for the heat change indicates that the overall reaction is endothermic; a negative value for the heat change indicates that the overall reaction is exothermic.

If bond energy calculations are performed for alcohols then they must refer to the combustion of one mole of alcohol. Fractional numbers may be needed for some complete combustion equations for the alcohols. This is not an issue since coefficients in balanced equations refer to amounts in moles, for example, $\frac{1}{2}O_2$ (g) refers to a half a mole of gaseous oxygen molecules. A series of such calculations will lead to a series of heats of combustion that increase by a constant amount, due to the progressive addition of $-CH_2-$ as the alcohol homologous series is ascended.

Students should recognise the advantages of expressing heat changes in kilojoules per mole rather than in kilojoules per unit mass or volume. The mole is directly related to the number of molecules (via the Avogradro constant), whereas equal masses or equal volumes will contain different number of molecules due to a difference in molecular mass and density.

SUGGESTED METHOD

A known volume of distilled water should be poured into the calorimeter and the temperature recorded. A weighed spirit burner should be filled with an alcohol and reweighed. It should be lit and placed underneath the metal calorimeter fitted with a lid and preferably an insulating shield (see Figure). The alcohol should be allowed to burn for several minutes and a significant temperature rise, for example, about 20 °C should be recorded. The water should be stirred. Obviously, the water should not be allowed to boil: heat energy would be lost as latent heat (of vaporization) and there would be no rise in temperature.



To measure heats of combustion for a range of five alcohols including repeats will take well in excess of an hour. Groups of students could be assigned one or two alcohols to measure and data shared amongst members of the class.

GRAPHICAL RELATIONSHIP

The heats of combustion for the alcohols will show an approximate linear relationship with the number of carbon atoms. The connection between the structures of the alcohols and their enthalpies of combustion can be explained in terms of bond breaking and bond making from the balanced combustion equations for one mole of alcohol. The heats of combustion for each alcohol can be calculated by subtracting the energy released from making -O-H and C=O bonds from the energy absorbed in breaking -C-H, C-C, -O-H and O=O bonds. Calculated (or literature) values could be plotted on the same graph for comparison. Literature values from the Nuffield Book of data are: ethanol -1367 kJ mol^{-1}, propan-1-ol, -2021 kJ mol^{-1} and butan-1-ol, -2676 kJ mol^{-1}. These can be converted to values of kJ/g by dividing the enthalpy change by the molar or molecular mass.

EVALUATION

Students would be expected to comment on the huge heat loss (to the calorimeter and surrounding air) and incomplete combustion, as shown by soot (unburnt carbon) formation. Improvements would include more precise temperature measurements (since this is the major source of random error - but insignificant compared to the two main systematic errors: soot production and heat loss), use of oxygen, rather than air, and better insulation to retain more heat within the calorimeter and better circulation of air. Heat loss to the calorimeter can be calculated if the heat capacity of the calorimeter is known. Students performing a bond energy calculation should compare their experimental value for heat change with a calculated or theoretical value for a heat change. Students could also investigate to find the structure of a commercial calorimeter, e.g. a bomb calorimeter. They should find out how it is designed to minimize heat loss.

SUGGESTED EXTENSION WORK

Extension work could include extending the investigation from liquid alcohols to liquid hydrocarbons, for example, alkanes. There will be safety issues with this. Students could also investigate the effect, if any, of isomerism: straight chain versus branched isomers, for example, propan-1-ol versus propan-2-ol.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

- Boiling tubes
- Burette
- Thermometer
- Test tube holder
- Beaker
- Electronic balances
- Spatula
- Clamp stand
- Bunsen burner
- Measuring cylinder

CHEMICALS REQUIRED

- Potassium nitrate
- Ammonium sulfate
- Sodium chloride
- Distilled water
- Ethanol
- Magnesium nitrate
- Magnesium chloride
- Ammonium chloride
- Sodium nitrate(V)
- Magnesium sulfate

SAFETY

Safety glasses must be worn at all times. Naked flames (Bunsen burners) must not be used if ethanol is used as a solvent. The heating must then be done with a water bath provided by your teacher. Potassium salts are toxic by ingestion; potassium nitrate is an oxidising agent.

SUGGESTED RESEARCH QUESTION

To determine the relationship between the solubility of sodium chloride (as measured by the mass of sodium chloride) which dissolves in 100 g (100 cm^3) of water and the temperature of the water. To establish a solubility curve for sodium chloride in water.

SUGGESTED VARIABLES

The independent variable is the temperature of the water; the dependent variable is the mass of sodium chloride that dissolves in 100 g (100 cm^3) of water. The controlled variables are the volume of water, the degree (if any) of stirring and the length of time for complete dissolution.

BACKGROUND THEORY

A solution consists of a solute dissolved in a solvent and, if the solvent is water then an aqueous solution is formed. A saturated solution is a solution which contains as much solute as can be dissolved at the temperature concerned, in the presence of undissolved solute. The solubility of a solute in a solvent at a particular temperature is the mass of the solute required to saturate 100 grams of solvent at that temperature.

The solubility of most ionic substances in a given solvent increase as the temperature is increased, although for some substances, the change in solubility is relatively small. (By contrast the solubilities of gases dissolved in water decrease with increasing temperature). By cooling solutions of different concentrations and determining the temperatures at which they become saturated, a graph of solubility can be drawn.

SUGGESTED METHOD

Find the mass of a boiling tube, add about 4.00 g of potassium nitrate and find the mass again. Add 10.0 cm^3 of distilled water using a burette. Heat the mixture gently (with a Bunsen burner), with shaking, until the crystals dissolve. Hold the tube up to the light and allow the solution to cool, stirring continuously with a thermometer. Note the temperature at which crystals first appear. The reading can be checked by re-heating to just dissolve the crystals and allowing the solution to cool again. Add 2.5 cm^3 of distilled water and repeat the experiment to find the new temperature of crystallisation. Continue until at least five readings have been taken.

The solubility of a substance is usually expressed in grams of solute per 100 grams of water. (Students should assume that 1 cm^3 of water has a mass of 1 g).

For example: 10 g of water dissolves 4.00 g of potassium nitrate(V)

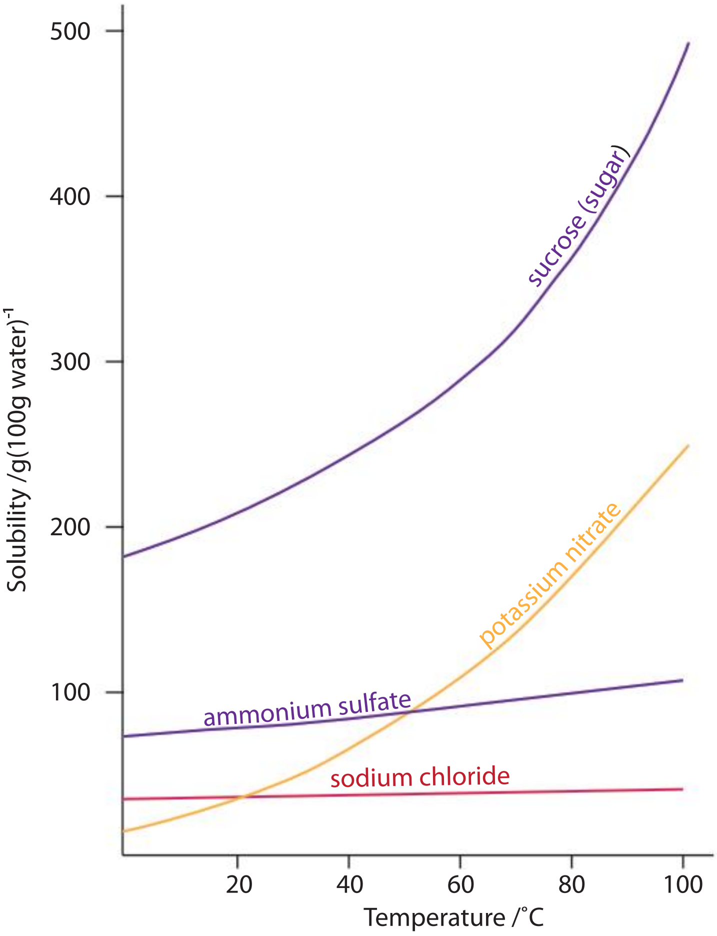
Hence, 100 g of water dissolves 4.00 × 10 g = 40.0 g of potassium nitrate(V)

Students should tabulate their results using a table something like this:

Mass of salt / g	Volume of water / cm^3	Solubility / g (100 g water)$^{-1}$	Temperature / °C

GRAPHICAL RELATIONSHIP

A graph of the solubility of potassium nitrate(V) against temperature should be plotted. Temperature should be on the *x* axis and solubility/ g (100 g water)$^{-1}$ should be on the *y* axis. A smooth curve should be drawn through the points. The solubilities of salts in water increase as the temperature is raised, although for some substances, such as sodium chloride, the change is small.



EVALUATION

Students should be aware of random errors present in the measurements of the mass of the potassium nitrate and the volume of distilled water. Students should be aware that distilled water is not pure and contains dissolved carbon dioxide. Students are likely to account for the increase in solubility with temperature on kinetic grounds: the water molecules move faster and dissolving occurs more quickly. A correct explanation (but ignoring entropy) to account for the increase in the amount of potassium nitrate dissolved is to invoke a shift in the equilibrium to favour the endothermic forward reaction. However, it should be noted that some dissolution reactions, for example, for calcium chloride, are exothermic in the forward direction.

SUGGESTED EXTENSION WORK

Students could establish solubility curves for a range of ionic salts and look for any patterns. They may predict that ionic salts with high molar masses are likely to be less soluble. However, the solubility of ionic compounds depends on the charges and relative sizes of the ions.They could also repeat the experiments with ethanol. This is a less polar solvent than water and will lead to a decrease in solubility. The ethanol molecules are larger and carry a weaker dipole than water molecules - hence they solvate ions more slowly. Students could investigate the supersaturation of hydrated sodium thiosulfate. If students have several solubility curves then they can investigate the separation of soluble substances by fractional crystallisation.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Ammeter

Bulb

Crocodile clips and leads

Spatula

Power pack

Measuring cylinder

Glass beaker (100 cm^3)

(Multimeter - if available)

Conductivity probe and meter (if available)

Balance capable of weighing to at least 0.001 g

Distilled water

SUGGESTED CHEMICALS

Potassium chloride (KCl)

Sodium chloride ($NaCl$)

Magnesium chloride ($MgCl_2$)

Calcium chloride ($CaCl_2$)

SAFETY

Wear safety glasses and treat all the chemicals as harmful and toxic. In order to perform a safe experiment, the voltage should be kept low. Never work with electrical equipment if your hands or clothing are wet.

ELECTRICITY GOGGLES POISON CORROSIVE

SUGGESTED RESEARCH QUESTION

To find the relationship between the conductivity of a solution (as measured by its current) and the concentration (molarity) of sodium chloride in water (at constant temperature).

SUGGESTED VARIABLES

The independent variable is the concentration (molarity) of sodium chloride. The dependent variable is the electric current. The controlled variables are the volume, temperature and nature of the solvent.

BACKGROUND THEORY

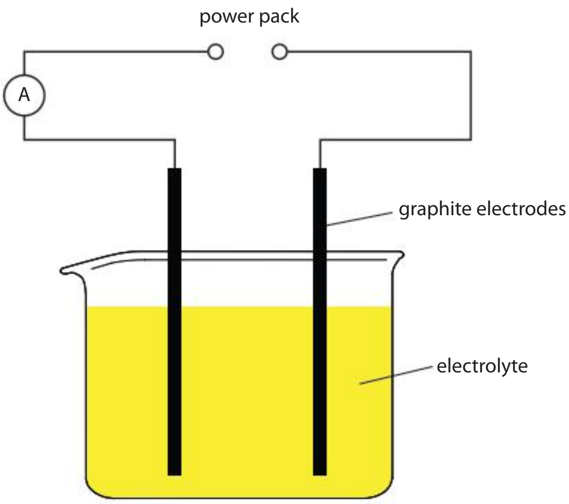
Pure water does not conduct electricity (due to the low concentration of hydroxide and hydrogen ions), but any soluble salt, acid or alkali will contribute to the conduction of electricity. An ionically conducting solution is called an electrolyte solution and the compound, which releases the ions as it dissolves, is called an electrolyte.

Conductivity is a measure of the ability of a substance to conduct an electrical current. In liquids, the presence of free ions (positive and negative charges) is necessary for conductivity. When two electrodes, one positively charged and the other negatively charged, are introduced into a liquid containing free ions, the positive and negative ions will move in opposite directions (toward oppositely charged electrodes). This movement of charged particles constitutes an electric current through the liquid.

A strong electrolyte is a compound that will completely dissociate into ions in water. Correspondingly, a weak electrolyte dissolves only partially. The conductivity of an electrolyte solution depends on the concentration of the ionic species and behaves differently for strong and weak electrolytes.

SUGGESTED METHOD

Pour 300 cm^3 of distilled water into a 500 cm^3 beaker. Connect inert electrodes (for example, graphite) into an external circuit containing a power pack or battery and a sensitive ammeter. Alternatively, introduce a conductivity probe and sensor. Meter readings should be recorded as small, well stirred masses are introduced into the solution.



GRAPHICAL RELATIONSHIP

Students will find that the current will increase with increasing amounts of sodium chloride, due to the increasing ion concentrations. A linear relationship will be observed at low ion concentrations. Students should plot a graph of current (*y* axis) against mass or molarity of sodium chloride (*x* axis).

EVALUATION

The most able students will make comparisons, on a molar basis, between the Group 1 and Group 2 chlorides, by comparing the number of ions released by each formula unit. The more able students will also realise that the concentration of ions decreases with time due to the action of electrolysis.

SUGGESTED EXTENSION WORK

This investigation could be readily performed using a data-logger interfaced with a conductivity probe and meter. This apparatus could also be used to follow and record the changes in conductivity that occur during neutralisation.

Day/Date of lesson ____________ **Period** ____________

Teacher ____________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

Measuring cylinders

Thermometers

Gas syringe

Electronic stopwatch

Electronic balance

Pipette

Electronic balances

Beakers

pH probe and meter

Conductivity probe and meter (if available)

Kettle

Burette

Light meter and data-logger (if available)

CHEMICALS REQUIRED

2 M hydrochloric acid

1 M ethanoic acid

Ice

0.1 M sodium thiosulfate

Distilled water

1 M sulfuric acid

20 g/dm^3 sodium thiosulfate solution

0.5 M hydrochloric acid

0.5 M sulfuric acid

SAFETY

You must wear safety glasses at all times during the practical. You must work in a well ventilated laboratory and not smell the sulfur dioxide released during the reaction. If you suffer from severe asthma and are working in a poorly ventilated laboratory students must not participate in this investigation. Skin contact with sodium thiosulfate solution should be avoided.

GLOVES GOGGLES POISON CORROSIVE

SUGGESTED RESEARCH QUESTION

To find the relationship between the concentration of the sodium thiosulfate solution and its reaction with hydrochloric acid, as measured by the time taken for sulfur to obscure a cross underneath a conical flask.

SUGGESTED VARIABLES

The concentration of the sodium thiosulfate solution is the independent variable; the time for the sulfur precipitate to obscure a cross is the dependent variable. The concentration and volume of the hydrochloric acid, the dimensions of the conical flask, the temperature of the solutions and the nature of the cross are all controlled variables.

BACKGROUND THEORY

When sodium thiosulfate and a dilute acid are mixed together they react, via a redox reaction, to give a precipitate of sulfur according to the following equation:

$Na_2S_2O_3\ (aq) + 2HCl\ (aq) \rightarrow 2NaCl\ (aq) + SO_2\ (g) + H_2O\ (l) + S\ (s)$

The net ionic equation is:

$S_2O_3^{2-}\ (aq) + 2H^+\ (aq) \rightarrow SO_2\ (g) + H_2O\ (l) + S\ (s)$

These equations are found in many text books, but are not correct and potentially misleading (see Evaluation). Any of the following variables could, in principle, be monitored in order to determine rate: pH (there will be an increase since a strong acid is consumed), gas volume (or pressure) and, possibly, mass loss (but sulfur dioxide is very soluble in water, so no bubbles are seen as the reaction takes place). In practice the most effective method is to perform the reaction in a conical flask standing on a piece of paper marked with a cross. Provided that the same depth of solution is used each time, it will always require the same mass of sulfur to make the solution cloudy enough to obscure the cross.

If the mass *m* is produced in time *t*, then the average rate of production of sulfur from the beginning of the reaction to time *t* will be *m*/*t*.

Since *m* is constant, average rate $\alpha\ \frac{1}{t}$

for example, if the rate (s^{-1}) doubles, the time (s) is halved.

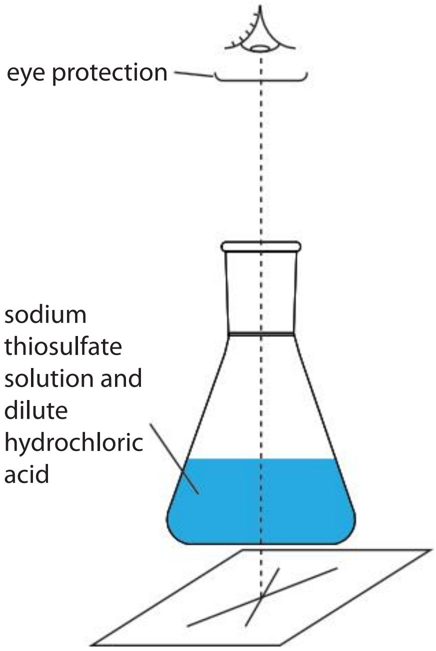
When the temperature of the thiosulfate or acid solution is raised the ions will move around at higher average speeds and hence have higher average kinetic energies. More of the collisions will be effective and involve ions with combined kinetic energies equal to or greater than the activation energy barrier. The number of collisions per unit time will also be increased, but this is a less important contribution to the large increase in rate. In many reactions when the temperature is increased by ten degrees Celsius the rate is doubled because the number of effective collisions is doubled. This relationship does not apply to all reactions at all temperatures, but is exhibited by this reaction.

If the concentration of either reactant is doubled then the rate may be doubled (provided that neither reactant is present in large excess). This is due to the increase in the frequency of collisions - the speed and hence kinetic energy of the ions is unchanged.

SUGGESTED METHOD

Using separate labelled measuring cylinders, measure 40 cm^3 of sodium thiosulfate solution (mass concentration 20 g/dm^3) and 10 cm^3 of 2 M hydrochloric acid. Place a conical flask on a piece of paper marked with a cross and pour in the thiosulfate solution. Add the acid and simultaneously start an electronic stopwatch. Stir the mixture well and then look vertically down through it at the cross. Stop the clock when the cross is obscured and record the time. Rinse the conical flask and stirring rod thoroughly and then with a little distilled water and repeat the experiment, using in turn 30, 25, 20, 15 and 10 cm^3 of sodium thiosulfate solution, but topping up to 40 cm^3 of distilled water, so that the depth of the solution and the concentration of hydrochloric acid remains constant. The effect of temperature could be investigated by starting with the most dilute of these sodium thiosulfate solutions and warming to different temperatures over a Bunsen burner before adding to the hydrochloric acid (which has also been heated to the same temperature).

GRAPHICAL RELATIONSHIP



A graph should be drawn of volume of sodium thiosulfate solution ('concentration') on the *x* axis against 1/time (s^{-1}) on the *y* axis. This straight line graph is preferable to a curved graph of volume of sodium thiosulfate solution ('concentration') on the *y* axis against time (s) on the *x* axis. Ideally the volumes of thiosulfate solution should be converted to concentrations in moles per cubic decimetre. A linear graph with a line of best fit going through the origin is expected.

EVALUATION

Students should be aware of random errors in measurements of volume and systematic errors in time measurement (due to reaction time). The reaction is exothermic and, ideally, the temperature should be controlled by performing the reaction in a thermostatted water bath. The difficulty in judging the exact 'end point' should also be noted. The equations given previously are present in many texts. However, sulfur dioxide is not the only product and small amounts of H_2S are also produced. The reaction may also be described by the following half equations:

$S_2O_3^{2-} + 6H^+ + 4e^- \rightarrow 2S + 3H_2O$; $2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2e^-$

SUGGESTED EXTENSION WORK

More reliable results may be obtained if a light intensity probe and data-logger are used to measure when the mixture goes cloudy. The effect of changing the acid concentration and the temperature of the reaction mixture using the same method are all possible extension work. 0.1 M sodium thiosulfate solution and 0.5 M hydrochloric acid in equal volumes are solutions that are suitable for an investigation into the effect of temperature. The solutions can be heated in test tubes using a water bath.

An exponential graph of rate against temperature is expected, provided the temperature range is sufficiently wide. A graph of the natural logarithm of the rate versus the reciprocal of the absolute temperature (in kelvin) will be linear. The effect of different acids may be investigated, but the strong acids of the same concentration will give very similar results since the anion from the acid is a spectator ion - only the hydrogen ion reacts with the thiosulfate ion. Students could try and establish a rate law for the reaction. Sources suggest that the order of reaction is between zero and first depending on the concentration of acid. Students could also investigate the effect of iron(II) ions on the reaction: they act as a catalyst. Students could identify the gases generated during the reaction.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Fine sandpaper
Spotting tile
Scissors
Teat pipettes
Wires
Leads
Voltmeter
Filter paper
Balance capable of weighing to at least 0.001 g

SUGGESTED CHEMICALS

Magnesium ribbon
Lead foil
Zinc
1 M zinc nitrate solution
1 M magnesium nitrate solution
1 M iron(II) nitrate solution
2 M sodium chloride solution
0.05 M silver nitrate solution
2 M sodium chloride solution
Copper foil
Iron
Aluminium
1 M copper(II) nitrate solution
1 M lead(II) nitrate solution
2 M hydrochloric acid
Saturated potassium nitrate solution
1 M aluminium nitrate solution

SAFETY

You must wear safety glasses and gloves at all times during the practical. All of the solutions are poisonous and harmful if swallowed. Solutions of silver nitrate are very dangerous to the eyes and blacken the skin. Seek medical treatment if ingested. Lead and potassium compounds are also toxic when ingested.

GLOVES GOGGLES
POISON CORROSIVE

SUGGESTED RESEARCH QUESTION

To establish a reactivity series for copper, lead, iron and zinc using metal ion displacement reactions.

BACKGROUND THEORY

Any metal will displace one lower in the reactivity series from aqueous solutions containing its ions. This is because atoms of the higher metal have a greater tendency to donate electrons and the ions of the one lower down are more easily discharged (or reduced), that is, they more readily accept electrons.

For example, iron reacts with copper(II) sulfate solution. Iron atoms donate electrons to copper(II) ions in solution. This gives iron(II) ions in solution and deposits copper atoms on the iron:

$Fe\ (s) + CuSO_4\ (aq) \rightarrow FeSO_4\ (aq) + Cu\ (s)$ or $Fe\ (s) + Cu^{2+}\ (aq) \rightarrow Fe^{2+}\ (aq) + Cu\ (s)$

Students will have a hypothesis based upon the reactivity series and perhaps reference to reducing power, that is, ability to lose electrons. They should write equations: word equations and symbol equations. The most able students will write ionic equations derived from half equations.

SUGGESTED METHOD

The order of reactivity can be established using displacement reactions. If the metal is more reactive than the metal in solution, this metal displaces ('pushes out') the less reactive metal from the solution. Students will test each metal with every other metal ion (in the form of its nitrate - a spectator ion) and look for signs of displacement, for example, a colour change. These results can be recorded in a grid with names of nitrates across the top and names of metals down the side. A tick ✓ can be used to show reactivity and a cross X to show no reaction.

Alternatively, and preferably, pairs of metal electrodes can be inserted into an electrolyte solution, with a salt bridge between them, and the potential difference (voltage) between them measured. In each case the positive electrode is the least reactive metal of the pair.

Copper(II) nitrate and aluminium nitrate solutions are both slightly acidic and the magnesium will react to form hydrogen. It is a side reaction. The displacement reactions may be slow so students need to leave the metal immersed in a metal ion solution for several minutes before recording their observations.

GRAPHICAL RELATIONSHIP

A bar graph could be drawn with bars representing pairs of metals and their voltages (or average voltages). The bars should be in drawn in order or decreasing order of voltage. The relative positions of the metals in the reactivity series could be indicated by means of numbers with 1 being the most reactive.

EVALUATION

Students should be aware bubbles are evidence of a side reaction involving the displacement of hydrogen ions by a reactive metal. Aluminium nitrate and copper(II) nitrate solutions are both acidic due to hydrolysis of hydrated metal ions and release of hydrogen ions. Students should also consider the purity of the metal surfaces. Random errors in the voltage readings should also be noted.

SUGGESTED EXTENSION WORK

Hydrochloric acid could also be used to further confirm the reactivity series established by metal displacement reactions involving hydrogen ions. The students could extend their study to include other metals, including aluminium. Anomalous reactions will be observed with aluminium due to the presence of its unreactive oxide layer. A reactivity series can also be established by constructing electrochemical cells (simple batteries) and measuring their voltages. The greater the difference in reactivity of two metals, the greater the cell voltage.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Thermometer

Retort stand

Tripod stand and gauze

Copper can calorimeter

Tin (painted black)

Tin (painted silver)

Tin (painted white)

Kettle

Beakers

Stop watch

Styrofoam cups

Beakers

Boiling tubes

Measuring cylinders

Cotton wool (for insulation)

Aluminium foil

Data-logging interface and temperature sensor (if available)

Electric fan (if available)

SAFETY

An electric kettle is a much safer source of hot water than a Bunsen burner, tripod and gauze. However, immersion heaters also get hot and must be handled with care.

SUGGESTED RESEARCH QUESTION

To find the relationship between the surface area of water and its rate of cooling in air at 25 °C for equal volumes of water.

SUGGESTED VARIABLES

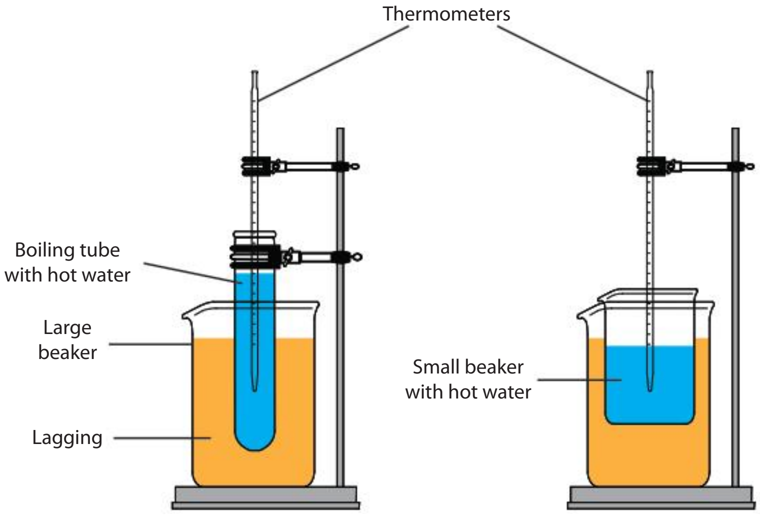
Exposed surface area of the water is the independent variable. Temperature and time are proximate (intermediate) variables and the rate of cooling is the ultimate dependent variable. Controlled variables are volume of the water, the initial temperature of the water, the temperature of the surrounding air and wind speed (if any).

BACKGROUND THEORY

Newton's law of cooling states that the rate of change of the temperature of an object is proportional to the difference between its own temperature and the temperature of its surroundings. The surface area of the exposed water determines its rate of cooling, not its total volume. A larger exposed surface area of water allows a greater amount of evaporation and convection of air above the hot water to occur.

SUGGESTED METHOD

Fixed volumes of water at the same temperature should be added to the boiling tubes and beakers. A thermometer or temperature sensor should be inserted into the samples of water. Cotton wool lagging may be added to reduce the heat loss. The temperature of the two samples of water should be recorded against time. See diagram opposite.



GRAPHICAL RELATIONSHIP

A graph, known as a cooling curve graph, should be drawn of temperature (vertical axis) against time (horizontal axis). A graph with decreasing gradient will be obtained that will level out at room temperature. Alternatively, the temperature change for a fixed cooling time could be determined. This experiment can be used to calculate average cooling rates in degrees Celsius per second (°C/s). The flattening curve shows that the rate of heat loss is lower as the temperature falls. A subsequent graph of cooling rate (or temperature change) versus surface area should be produced.

EVALUATION

Students should be aware of random errors in the temperature, volume and surface area measurements. Improvements in the accuracy and precision of these readings may be increased by the use of a data-logger and temperature sensor. The results should be repeated and averaged to increase the accuracy.

SUGGESTED EXTENSION WORK

This experiment could be readily modified so data-loggers are used to collect and analyse the raw data. The painted tin cans could be used to demonstrate how colours affect the rate of cooling. The use of an air-conditioned laboratory allows the surrounding air temperature to be controlled. The effect of impurities in the water, such as sodium chloride, could also be investigated. The addition of salt speeds up the cooling process and the solution will cool to room temperature faster than pure water. This is because the specific heat capacity of salt solution is less than that of pure water. The water could be replaced with the more volatile ethanol. The electric fan could be used to investigate the effect of wind velocity on the rate of cooling.

Day/Date of lesson ________________ **Period** __________

Teacher ________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Burette

Beaker

Metre rule

Thermometer

Capillary tube

Retort stand

Stopwatch

Magnet

CHEMICALS REQUIRED

Ethanol

Glycerol

Distilled water

SAFETY

Ethanol is poisonous and flammable – naked flames must not be present in the laboratory. Safety glasses must be worn. It can be irritating to the skin - wash contaminated skin promptly with soap or mild detergent and water. Ethanol is irritating to eyes - can be damaging if a large amount is splashed into eyes. Wash eyes promptly with plenty of water, while lifting the eye lids. Continue to rinse for at least 15 minutes, and get medical attention. If ethanol is swallowed seek medical attention.

RESEARCH QUESTION

To find the relationship between the height of the water in the burette and the time taken for the water to flow out of the burette. (Other liquids could also be tested).

SUGGESTED VARIABLES

The initial height of the water column is the independent variable; the time for the water to reach the lower graduation mark on the burette is the dependent variable. The diameter and length of the burette, capillary diameter, nature of the liquid and its temperature are controlled variables.

BACKGROUND THEORY

Pressure is defined as the force acting normally (i.e., at right angles) per unit surface area. The pressure on a surface can be calculated from the formula:

$$\text{pressure} = \frac{\text{normal force}}{\text{area}}$$

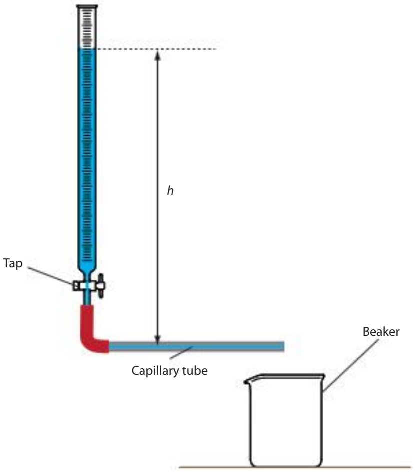
The pressure at the base of a liquid column is found from the following expression:

$P = h \times \rho \times g$, where h represents the height of liquid above the base, g represents the gravitational field strength and ρ represents the density of the liquid.

The pressure in a liquid is therefore proportional to the height of liquid above that level and the density of the liquid. The pressure is independent of the area. Simple models of fluids assume that the fluid is incompressible and that it suffers no friction as it moves through the pipe. The rate of flow (volume per second) of a liquid through a pipe is given by the equation:

Rate of Flow = $\frac{\pi P a^4}{8L\eta}$ where P represents the pressure differences between the two ends of the capillary tube, L the length of the tube, a is the radius of the tube and η is the coefficient of the viscosity. Hence, $\frac{P}{L}$ is the pressure gradient.

This formula (Poiseuille's formula) is applicable to the steady flow of a liquid.



SUGGESTED METHOD

Students should ensure that the capillary tube is horizontal. Water should be poured into the burette until the meniscus is at the zero mark. The height of the water above the capillary tube, h, should be measured and recorded. The tap of the burette should be opened and the stopwatch started. The time and corresponding height should be recorded. Stop the stopwatch when the water reaches the lowest graduation mark on the burette.

GRAPHICAL RELATIONSHIP

A graph should be plotted of starting height against time. An exponential graph is obtained showing that the water drains rapidly initially since the pressure is high. A linear graph is obtained if the logarithm of height is plotted against time.

EVALUATION

It is important that the rate of flow of liquid should be small and that the flow is not turbulent. Students should note the importance of recording the temperature of the liquid because viscosity varies with temperature. It is also necessary to ensure there are no air bubbles since they will cause the flow of water to become turbulent. The uncertainties in the measured times become proportionately larger as the measured times get shorter.

SUGGESTED EXTENSION WORK

Water can be replaced with another liquid of different viscosity, or repeated with water at different temperatures. However, students should be aware that the heated (or cooled) liquid will cool down or (heat up) once it is placed into the burette. The length of the capillary tube and its diameter can also be varied. Poiseuille's formula indicates that the rate of flow is directly proportional to the pressure gradient $\frac{P}{L}$ and the rate of flow is proportional to a^4, where a is the radius of the tube.

Day/Date of lesson ____________ **Period** ____________

Teacher ____________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

Metal paper clips
Burette
Rubber bands
Retort stand and clamp
Distilled water
Chinagraph pencil
Thermometer
Metal balls (of different sizes and/or different metals)
Stopwatch
Light gates and data-logger (if available)
Tall measuring cylinder
Kettle
Magnet

CHEMICALS REQUIRED

Light vegetable oil

Glycerol

Sodium chloride (solid): to change the density (and hence viscosity) of the water

SAFETY

Glycerol will irritate eyes, so eye protection should be worn. Glycerol is generally regarded as a safe material for which no special handling precautions are required. However, it is flammable. It also feels oily, so may be a slipping hazard if spilled on the floor. Its properties will change if it is allowed to absorb water vapour from the atmosphere so it must be kept in a closed container. Waste engine oil is carcinogenic and must not be used. Students should not be allowed to heat liquids, such as alcohols, with a naked flame. A water bath or steam bath must be used under the supervision of the teacher. **Eye and skin contact:** immediately flush the eye with water. If irritation persists, you may need to call for medical help.

FLAMMABLE
GOGGLES
DANGER

SUGGESTED RESEARCH QUESTION

To find the relationship between the terminal velocity of a steel ball bearing in free fall and the viscosity of various liquids.

SUGGESTED VARIABLES

The independent variable is the viscosity of the liquid. The proximate dependent variables are the distance and time once terminal velocity has been reached. The ultimate dependent variable is the terminal velocity. The controlled variables are the volume of liquid used, the dimensions of the measuring cylinder or burette and the distance the steel ball bearing was allowed to drop before times were taken.

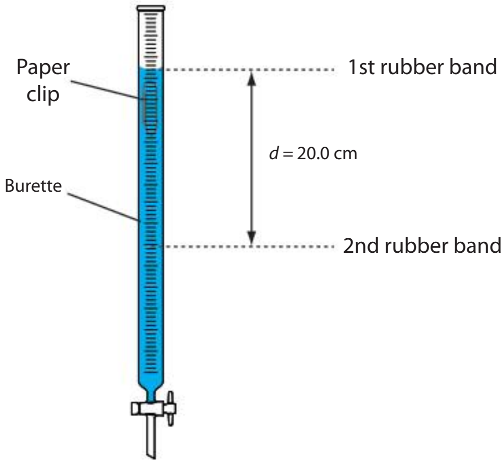
BACKGROUND THEORY

When the ball bearing is released from rest, there is no frictional force and the resultant force is equal to the weight. The velocity of the ball bearing increases while the frictional force is less than the weight. Terminal (maximum) velocity is reached when the frictional force equals the weight. The resultant force is zero and so there is no acceleration. This illustrates Newton's first law of motion: an object travels in a straight line at constant speed unless acted upon by an unbalanced force.

A lower temperature will result in a higher viscosity and hence a lower terminal velocity. Denser objects need a greater distance before they reach their terminal velocity. The upthrust they experience is initially less than their weight, so they need a larger resistive force before they can reach the balanced force condition.

SUGGESTED METHOD

Students should fill the burette with water (or another liquid). Rubber bands (or a chinagraph pencil) should be used to mark two points that are a distance of at least 20 cm apart. Students should release a paper clip or ball bearing and record the time taken for it fall through the distance. Students will find that the falling object will rapidly reach its terminal velocity, where the downwards weight force exerted by the object is matched by the upthrust or buoyancy of the liquid.



Students will have to ensure that the ball bearing or other object falls through the liquid for a sufficient length of time so that it likely reaches its terminal velocity. This can be achieved by careful observation involving a number of trials. A magnet can be used to retrieve the ball bearing.

GRAPHICAL RELATIONSHIP

The terminal velocity can be calculated from the expression: velocity = distance/time. An approximately linear relationship is expected between the frictional force, F, and the terminal velocity, v. Frictional force F is equal to the weight of the ball bearing since the net force operating on the ball bearing is zero.

EVALUATION

Students should place the ball-bearings in a dish of the same liquid before use. This reduces the occurrence of air bubbles, which will affect the motion of the ball bearings. Chinagraph pencil lines have a thickness; it might be better to use coloured adhesive tape and try to start/stop the stop clock as the bottom of the ball bearing reaches the top edge of the tape. Automated measurements using data-logged light gates is a useful suggestion, but these measurements must also be assessed for errors.

SUGGESTED EXTENSION WORK

Extension work can involve using balls of different diameter or different materials. The viscosity of the liquid can be calculated using the formula on the student instruction sheet.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Stop watch

Metre rule

Set squares

Video camera (if available)

Tennis balls

Golf balls

Adhesive tape

Clamp stand

Snooker or billiard balls

Rubber balls

Table tennis (Ping pong) balls (of various grades)

Access to various surfaces e.g. sand, rubber, concrete, steel plate etc.

SAFETY

Wear eye protection if small balls are being dropped long distances.

GOGGLES

SUGGESTED RESEARCH QUESTION

To find the relationship between the height of the bounce of a ping pong ball (40 mm diameter) and the type of surface it lands on (at a temperature of 25 °C).

SUGGESTED VARIABLES

The independent variable is the nature of the surface that the ping pong ball lands on. The dependent variable is the vertical height of the bounce which the ping pong ball undergoes. The controlled variables in this investigation are the air temperature and pressure (negligible effect), the dimensions and nature of the ping pong ball as well as the height of the release and the release technique.

BACKGROUND THEORY

The ability of a ball to rebound from a surface is determined both by the nature of the surface and the nature of the ball. The maximum height will occur upon rebound when minimal energy is converted into some other form such as heat, sound or a permanent change in shape (deformation), but this is not possible in practice.

The material with the highest modulus of elasticity would deform the least and minimise the amount of energy lost to the surface. Steel plate has a high modulus of elasticity and hence would allow the ping pong ball to bounce highest.

At a certain height, the ball will reach terminal velocity and hence undergo its maximum deformation (change of shape) upon contact with the surface. Additional increases in drop height will not increase the deformation. Therefore, there is a limit to the amount of energy that can be stored and its shape change produced by the impact.

SUGGESTED METHOD

Balls should be released onto a flat surface from alongside a vertically clamped ruler. The vertical height of the bounce should be recorded visually from its alignment (of either the top or bottom surface of the ball) with the ruler.

GRAPHICAL RELATIONSHIP

A bar chart should be drawn of height of bounce (vertical axis) against type of surface (horizontal axis) or a line graph of height versus modulus of elasticity of surface.

EVALUATION

Students should be aware of measurement errors from an inability to accurately judge the height of the bounce. If the investigation is performed outside then students should be aware of the difficulty of controlling variables, such as wind speed. Students should reject data that involves the ball moving off the vertical – this will occur due to wind or an uneven surface.

Students should be aware that the ball may reach its terminal velocity. For example, a table tennis ball is likely to attain terminal velocity in its fall very quickly, as its weight is very small compared with its surface area.

SUGGESTED EXTENSION WORK

A video camera could also be used to extend this experiment. The camera could be lined up with the ruler and the ball could be dropped from the appropriate height. The advantage of using a video camera is that the frames could be examined and replayed many times to measure a more accurate height. This means that the results will be more accurate than a measurement of the ball bouncing back 'by eye' and so a conclusion can be more justified.

Students could also measure subsequent bounces and find out whether a bouncing ball displays exponential decay. Accurate measurements could be obtained using a data-logger connected to a sound sensor or light gate. The bounce heights of balls (made from different materials) on a fixed surface could also be determined.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Springs (helical)
50 gram hanger
Metre rule
Clamp stand
G-clamp
Set square
Plastic shopping bag
Rubber bands
Slotted masses (50 g)
Light metal bars
Plastic bags
(Springs – pre-tensioned)
Large flat headed nail
Scissors

SAFETY

Students should be made aware of the dangers of the spring snapping and large masses landing on their hand or foot. Eye protection is recommended.

SUGGESTED RESEARCH QUESTION

To determine how the extension (increase in length) of a steel spring varies with the force applied.

SUGGESTED VARIABLES

The independent variable is the force applied (in Newtons) or the load (also accept mass) and the length of the spring wire is the proximate dependent variable. The extension (new length – original length) is the ultimate dependent variable. Controlled variables: type of spring, the temperature of the metal and the stiffness of the metal.

BACKGROUND THEORY

When a small force is applied to a spring made from wire, its length increases. Its original length is restored when the force is removed. This can be explained by picturing the bonds that hold adjacent atoms together as acting like small perfect springs.

The relationship being studied is known as Hooke's law: 'The deformation of a material is proportional to the force applied to it (provided the elastic limit is not exceeded)'. In the context of loading a wire or spring, the deformation is equivalent to the increase in length.

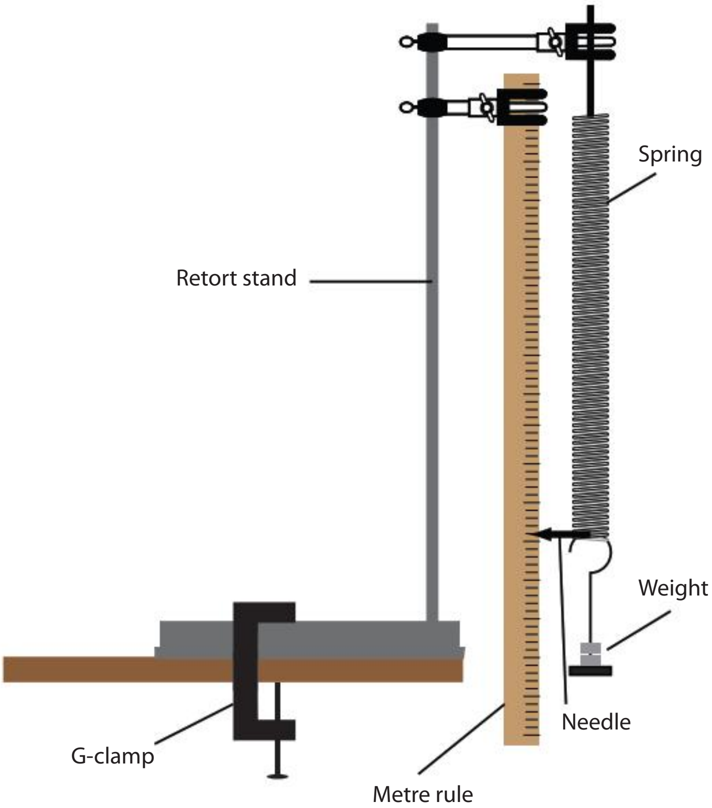
Hooke's Law states that the restoring force of a spring is directly proportional to a small displacement. In equation form, $F = kx$ where k is a constant called the spring constant and is a measure of the stiffness of the spring. Since the spring exerts a force in the opposite direction to the applied force, Hooke's law may be stated as: $F = -kx$

This is sometimes called a 'restoring force' because the spring exerts its force in the direction opposite to the displacement - hence the minus sign).

SUGGESTED METHOD

Clamp the retort stand to the table with a G-clamp. Suspend the spring over the edge of the table from the retort stand. Position a metre rule from a second clamp and align it in an upright position next to the spring. Attach a needle to the bottom of the spring. Measure and record the position of the needle. Place a mass on the hanger and record the new position of the needle. Record the value of the mass and calculate the force exerted on the spring (gravitational field constant = 9.8 N/kg).

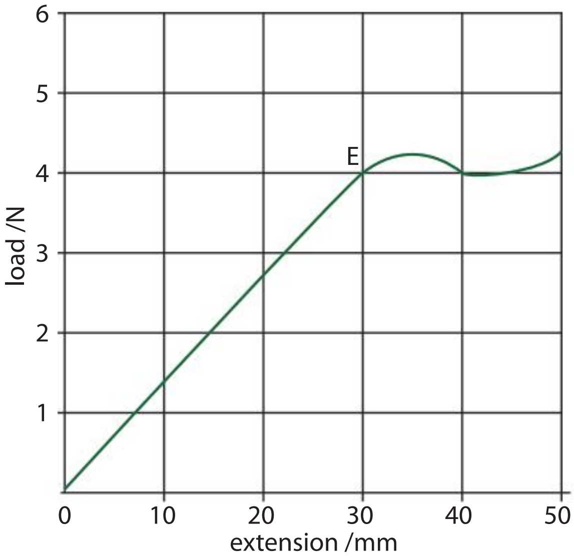
The students should measure the length of the spring accurately. They should then progressively add masses to the hanger and measure the new length of the spring. The students should calculate the extension of the spring: new length of spring – length of unstretched spring.



GRAPHICAL RELATIONSHIP

Students should plot a graph of load (*y* axis) against extension (*x* axis) with the line going through the origin (0,0). The gradient of the line will give the spring constant, *k*: a measure of the stiffness of the spring. Students will find with a very large load that the spring becomes permanently deformed. This is known as the elastic limit (E) and when larger loads are added the extension will no longer be proportional to the load.

Plastic behaviour or plastic deformation has occurred. However, students should then find for small loads that the extension is directly proportional to the load or mass. This is known as Hooke's Law.



EVALUATION

Improvements should be centred on improving the precision of the mass and length measurements. For example, the use of a metre rule with more divisions combined with the use of a magnifying glass. They should also check on the actual masses of the masses used (instead of assuming they are exactly 50 g), especially if they are old and chipped. A precise electronic balance should be used for this purpose. Students should be aware of parallax error and how it can be minimised. Students should also be aware of the importance of repeating and averaging to reduce random measurement errors. They should draw lines of best fit through their data; ideally a spreadsheet, such as Excel, could be used. Students may obtain a graph that is initially curved before the linear region (Hooke's law); this is probably due to the fact that in the early stages of the experiment some of the turns of the spring are pressing against each other.

SUGGESTED EXTENSION WORK

Extension work may involve the use of two springs, either in series or in parallel, or replacing the spring with a rubber band. Springs in series: the extension of each spring when a mass is added to the lower one is the same as if each spring were supporting the mass separately. The total extension is therefore double what it would be with just one spring.

Springs in parallel: each spring, in effect, carries half the mass so it stretches less far. The extension of each spring when the mass is added to the middle of a light bar connecting them is half the extension it would be if it were supporting the full mass on its own. Students could also be given some pre-tensioned springs – they will coil up tight when not loaded. A minimum force must be applied to make them begin to stretch. As a result they do not produce directly proportional results, but they do produce a linear relationship. A rubber band or length of plastic does not obey Hooke's law. Instead it will exhibit a phenomenon known as elastic hysteresis. This means that the force extension-curve for loading the rubber band does not overlap the curve obtained when the masses are unloaded from the rubber band. The area between the two curves equates to the difference in work done bewteen loading and unloading the rubber band.

Day/Date of lesson ________________ **Period** __________

Teacher ________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

- Thread/string
- Plasticine
- Ruler
- Clamp stand
- G-clamp
- Pendulum bobs (brass balls with hooks)
- Electronic stopwatch
- Protractor
- Metre rule
- Electronic balance

SAFETY

Put a towel or blanket on the floor to prevent damage should the mass fall. Avoid large amplitude oscillations.

SUGGESTED RESEARCH QUESTION

To determine the relationship between the period of a simple pendulum and its length. (There are other possibilities).

SUGGESTED VARIABLES

The length is an independent variable and the period is the dependent variable. Controlled variables are the mass of the bob, surface area of the bob and angle of release.

BACKGROUND THEORY

A simple pendulum consists of a 'bob' (mass) attached to string so that it can swing in a regular repeating pattern which eventually stops. When a pendulum is displaced (pushed) from its resting equilibrium position, it is subject to a restoring force due to gravity, that will accelerate it back towards the equilibrium position. The period is the time taken for the simple pendulum to complete one oscillation: from the resting position and back to the starting position or one complete to and fro motion.

When the pendulum is at the top of its swing it is momentarily stationary. It has zero kinetic energy and maximum gravitational potential energy. As the pendulum falls the potential energy is transformed to kinetic energy. The speed increases as the pendulum falls and reaches a maximum at the bottom of the swing. Here the speed and kinetic energy are a maximum, and the potential energy is a minimum. As the pendulum rises the kinetic energy is transformed back to potential energy. The speed of the pendulum decreases and falls to zero as it reaches the top of its swing, with the potential energy a maximum again. A small amount of energy is lost due to air resistance as the pendulum swings. This means the amplitude of each swing is slightly smaller than the one before, the amplitude decreases progressively.

There are two forces acting on the pendulum bob. Gravity tries to pull the bob downwards but this is resisted by the tension in the string. As there are only two forces they can only be balanced when they are in opposite directions. This only occurs when the pendulum is in the middle of its swing, so for the rest of the time the two forces are unbalanced; hence the bob swings back and forth.

The following relationship describes (in an approximate manner) the behaviour of an ideal simple pendulum (a point mass suspended by a weightless string):

$T = 2\pi\sqrt{\frac{l}{g}}$, where T represents the period (s); l represents the length of the pendulum, m represents the mass of the bob and g represents the gravitational field constant (N/kg).

This equation suggests the following relationships:

- The mass of the bob of the pendulum has no effect on the period
- The angle of release has no effect on the period provided amplitudes are small (less than 10 degrees) (since $\sin\theta \approx \theta$ for small angles)
- The length of the string does affect the period

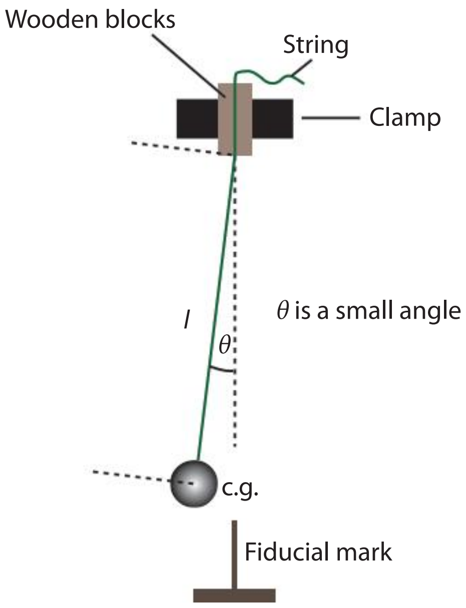
The equation can be rearranged to make g the subject:

$$g = \frac{4\pi^2 l}{T^2}$$

This allows students to calculate a value of g and compare with the accepted value of 9.81 N/kg.

SUGGESTED METHOD

You will need to demonstrate to students the definition of one period, i.e. the time taken for the simple pendulum to complete one oscillation: from the resting position and back to the starting position. You could comment on the relative shortness of the period (and hence the inaccuracy of the measurement). Students should realise that they need to record the time for a fixed number of oscillations and then calculate the average period. It is important for students to check that the pendulum is swinging in a single plane before measurements are started. The size of swing should also be kept small since the period of the pendulum is independent of the displacement of angle (provided it is relatively small). The clamp should not be allowed to move.



To measure the period of oscillation, a fiducial mark can be introduced. This is a line used as a reference for starting and ending an oscillatory motion. The fiducial mark should be a vertical line or a long thin rod placed at the centre of the oscillatory motion; preferably behind the pendulum bob. This will help to determine the exact moment the bob passes through the mark.

Because of the large uncertainty in measuring the period of one oscillation it is advisable for students to time 5 or 10 oscillations and divide. A suitable compromise needs to be found between minimising the timing error and the decrease in amplitude due to air resistance. A video camera could be used to film the pendulum and the period determined by playing the video back frame by frame.

GRAPHICAL RELATIONSHIP

Students should plot a smooth curve of average period (y axis) against length of pendulum (x axis). The gradient of the graph decreases as the length increases. This shows that the rate of increase of time per swing decreases as the length increases. The graph can be made linear by plotting the average period (y axis) against the square root of the length (x axis). A line of best fit should be drawn – a value for g can be calculated from the gradient.

If students are investigating the mass of the bob or angle of release they should realise that there will be 'scatter' in their results due to random uncertainties. The data points in these graphs should not be joined 'dot to dot'. Students often assume that any sensibly selected independent variable will always have an effect upon the dependent variable. Many may decide to investigate the effect of the mass of the bob, which yields an unexpected (counter-intuitive) result: the mass has no effect on the period of the pendulum. Proving that there is no link between two variables can be just as significant as finding one. The period is also independent of the angle of release, but only for small angles.

EVALUATION

During the motion of the pendulum the string is subject to various tension forces, and consequently errors are introduced due to the accompanying flexing of the string.

Students should realise that the largest error is present in the timing and that improvements should be focussed on increasing the accuracy of the timing, perhaps via the use of a fiducial mark (if not used) or a light gate and a data-logger. An alternative might be a very high speed digital video camera that could accurately record the position of the bob and the elapsed time.

A small error is introduced by assuming that the motion of the pendulum is simple harmonic motion. A real pendulum only approximates to simple harmonic motion. There is some friction in the string where it moves on the metal rod and some air friction. Friction with air or air resistance is greatest when the bob is large and light. The pendulum is said to exhibit damped simple harmonic motion.

There will also be variation in human reaction time when manually operating a stopwatch. Another difficulty is deciding where the centre of the bob is. Students should recognise that it may not be possible to accurately measure the period of a pendulum with a short length since it will be swinging very quickly.

SUGGESTED EXTENSION WORK

Extension work could involve the two other independent variables: angle of release and mass of bob. There is an alternative way that a pendulum can swing. Instead of swinging backwards and forwards in a single plane it is possible to make the pendulum swing in a horizontal circular path. It would be interesting to investigate how the time for each revolution of this conical pendulum changes with the length and to compare this with the simple pendulum.

For a conical pendulum, it can be shown that $t = 2\pi\sqrt{\frac{l\cos\theta}{g}}$ for small angles, θ, $\cos\theta \approx 1$ and the period, t, of a conical pendulum is equal to the period of the simple pendulum of the same length, l. Also, the period for small angles is approximately independent of the angle of the swing.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Constantan wire

Ammeter

Thermometer

Voltmeter

Clamp stand

Metre rule

Copper wire (different dimensions)

Nickel wire (different dimensions)

Nichrome wire (different dimensions)

Wires with crocodile clips

Metal cutters

Sellotape

SAFETY

In order to perform a safe experiment, the voltage should be kept low (5V) so the chance of overheating is low. Also the power supply should be switched off before changing the length of the wire. Never work with electrical equipment if you hands or clothing are wet. Students should not be wearing metal jewellery and water taps should be not switched on.

SUGGESTED RESEARCH QUESTION

To determine the effect of length (or cross-sectional area) on the resistance of a wire.

SUGGESTED VARIABLES

Length is the independent variable. The current and the voltage are proximate (intermediate) variables and the resistance is the ultimate dependent variable.

BACKGROUND THEORY

The relationship between the current and voltage is the basis of the definition of resistance. The resistance of a conductor is the ratio of the voltage across it to the current flowing through it.

$$\text{Resistance, } R\ (\Omega) = \frac{\text{Potential difference across the wire } (V)}{\text{Current through the wire } (I)};\ R = \frac{V}{I}.$$

Ohm's law states that the current through a metallic conductor, maintained at constant temperature, is directly proportional to the potential difference between its ends: $I \propto V$

Conductors with a constant value for the ratio $\frac{V}{I}$ are said to obey Ohm's law and are described as ohmic conductors. Ohm's law is only obeyed at constant temperature so students (unless they control the temperature of the wire) will obtain non-linear results if large currents are used.

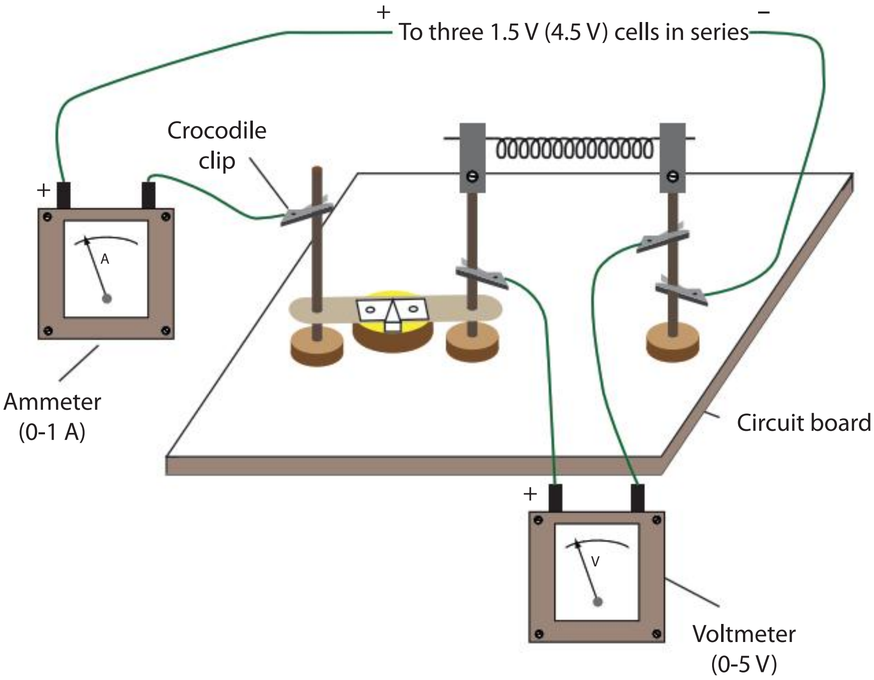
One ohm is the resistance of a conductor through which the current is 1 ampere when the potential difference between its ends is 1 volt. The resistance of a conductor depends on its dimensions (length and cross sectional area) and the material from which it is made.

$R = \rho \frac{l}{A}$ where R is the resistance in ohms, ρ is a constant dependent on the type of metal called the resistivity (units of ohm metres) and l is the length of the wire (in metres) and A is the cross-sectional area (square metres). Hence resistance is directly proportional to length and inversely proportional to cross-sectional area.

SUGGESTED METHOD

The circuit should be set up something like this:

The voltmeter measures the potential difference across the wire. The ammeter measures the steady current flowing through. The rheostat should be adjusted so that the current flowing in the circuit is kept below 1 A.



A long wooden board with a metre ruler attached and banana sockets at each end facilitates easy measurement of change in resistance with length. One test lead from the voltmeter can be connected at one end of the ruler, and the other lead quickly moved along in 10 cm increments, for example.

Wire is available in different diameters. Each diameter has an associated SWG (standard wire gauge) number. A table of SWG numbers and diameters is given below:

Diameter/mm	0.711	0.559	0.457	0.376	0.315	0.274	0.234	0.193
SWG number	22	24	26	28	30	32	34	36

GRAPHICAL RELATIONSHIP

Students should calculate values of resistance from voltage and current readings. They should plot resistance against length (or other appropriate independent variable, such as cross-sectional area). A plot of resistance versus length will be linear, but a plot of resistance against cross-sectional area will be an inverse relationship. This graph can be converted to a linear relationship by plotting resistance against the reciprocal of the cross-sectional area.

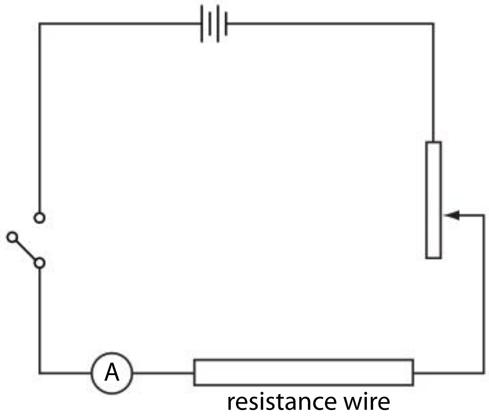
EVALUATION

Students should be aware of random errors present in their voltage and current readings - caused by random noise in the circuits and power pack and heating (unless a water bath is used). Students should check the two meters for zero errors (a form of systematic error). Voltage and current readings should be taken simultaneously. Students should recognise the role of the rheostat controlling the current in the circuit and hence the temperature of the wire, and also recognise the need to allow the wire to cool before taking duplicate readings. The accuracy of the measurements could be checked by switching off the power pack and checking the resistance readings by using the multi-meter as an ohm-meter.

SUGGESTED EXTENSION WORK

Extension work could involve investigating the effect of another independent variable, for example, cross-sectional area. Students could determine the effect of temperature on resistance by measuring the voltage-current characteristics of a light bulb versus that of a nichrome wire heating coil immersed in a water or oil bath. The heating coil should yield a linear graph of voltage versus current (it is an Ohmic conductor). The voltage-current plot for the light bulb is curved as the resistance of the bulb increases with temperature (it is a non-Ohmic conductor).

The resistivity law is that $R = \rho l / A$ where R is the resistance of a wire of length l, cross-sectional area A and made of a material whose resistivity is ρ (units of ohm metres). Logically, R is proportional to l, and R is also proportional to l/A so ρ is a proportionality constant which depends only on the material of which the wire is made and not on the wire's length, cross-sectional area, or shape. One test of the resistivity law could be to measure the resistance (R) of various lengths (l) of a certain gauge (diameter or cross-sectional area) and kind (material) of wire. A linear plot of R versus l should reveal that R is proportional to l and, according to the law, the slope of this plot should be ρ/A. If the diameter of the wire is measured, from which the area (A) of the wire may be calculated, then from the slope of R versus l, ρ could be found.



Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Rectangular glass block	Ray box with single slit and 'barrel'
Convex lens	Power supply (for ray box)
Rectangular perspex block	Rectangular glass block
A3 white paper	Protractor
Soft board	Pins

SAFETY

Do not shine light beams directly into your eyes in a darkened room. Take care if you are using pins.

DANGER SHARP

SUGGESTED RESEARCH QUESTION

To find a relationship between the angles of incidence and the angles of refraction by obtaining a set of readings for the angles of incidence and refraction as a light ray passes from air into glass.

SUGGESTED VARIABLES

The angle of incidence is the independent variable and the dependent variable is the angle of refraction. The controlled variables are the material of the block and the width of the incident ray.

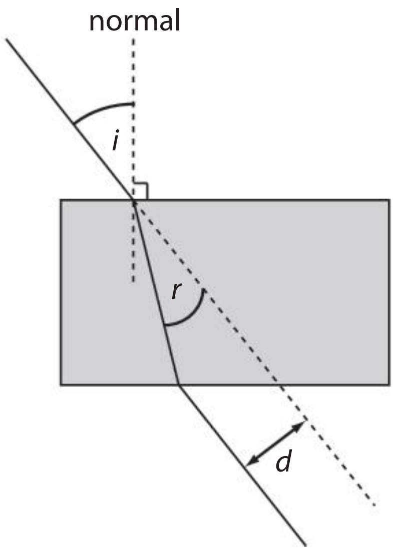
BACKGROUND THEORY

Refraction is the bending of a wave when it enters a medium where its speed is different. The refraction of light when it passes from a less optically dense medium to a more optically dense medium bends the light ray toward the normal to the boundary between the two media.

The amount of bending depends on the indices of refraction of the two media and is described quantitatively by Snell's Law:

$\frac{\sin i}{\sin r}$ = refractive index, where i and r are the angles of incidence and refraction.

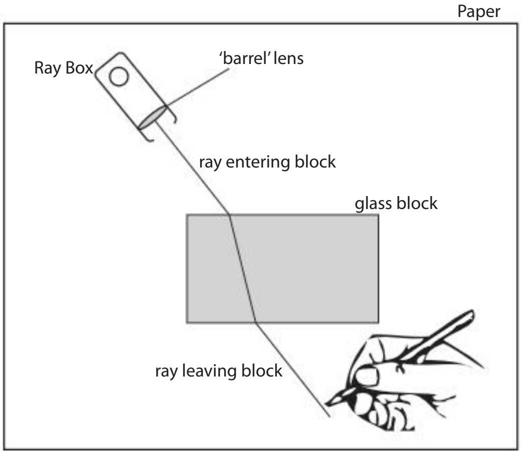
Students should be familiar with the reflection and refraction of light. Ideally, some simple experiments involving reflection in a plane mirror should have been done. They need to be familiar with the concept of the normal and the trigonometric sine ratio.



SUGGESTED METHOD

Students should place the glass block on the paper and draw around it to mark its position. They should angle the ray so that it goes through the block. They should mark the incident and refracted paths from the block using a pencil. (The positions of light rays can also be marked by the use of four pins). They should then join up the lines to show the path of the light ray inside the block. The angles of incidence (*i*) and refraction (*r*) should be measured with a protractor.

Students should measure the angle of incidence (*i*), the angle of refraction (*r*) and the distance between the paths of the rays entering and leaving the block (*d*).



GRAPHICAL RELATIONSHIP

A graph of *r* (or *d*) against *i* should be plotted. This will be non-linear, but a linear plot will be obtained if sin *i* (*y* axis) is plotted against sin *r* (*x* axis). The gradient of the line will be equal to the refractive index of the glass (Snell's Law).

EVALUATION

Students should recognise the random error associated with measuring the angles of incidence and refraction, and the uncertainty resulting from the divergence of the incident ray.

SUGGESTED EXTENSION WORK

The refractive index could be determined using a similar method for blocks of other transparent materials, for example, perspex. Students could use a triangular prism and the dependence of index of refraction on wavelength could be investigated.

The refractive index, η, is defined as: c / c_m, where c represents the velocity of light in a vacuum and c_m represents the velocity of light in the medium. $\eta_1 \sin\theta_1 = \eta_2 \sin\theta_2$.

For example, for glass η = 1.5, the speed of light in a vacuum is 3×10^8 m/s

$$\eta_g = \frac{c}{c_g} = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

The frequency does not change as a wave moves into a second medium.

Since the speed of light in a medium can be calculated, $\eta = \frac{c}{c_m} = \frac{f \times \lambda}{f \times \lambda_m} = \frac{\lambda}{\lambda_m}$.

If the wavelength in air is known, then the wavelength in the medium can be calculated.

Day/Date of lesson ____________________ **Period** ____________

Teacher ________________________________ **Room** ____________

No. of students/groups ____________

APPARATUS REQUIRED (PER GROUP)

Metallic metre ruler

G clamp

Masses

Protractor

SAFETY

Be careful of a snapping ruler.

DANGER GOGGLES

SUGGESTED RESEARCH QUESTION

To find the relationship between the mass of the load placed onto a cantilever and its depression from the horizontal.

SUGGESTED VARIABLES

The load (or displacement of load from the fulcrum) is the independent variable. The distance of depression from the horizontal is the dependent variable. Controlled variables would be the position of the load and the dimensions and nature of the cantilever and the surrounding conditions, for example, air temperature (though this is not likely to have a significant effect).

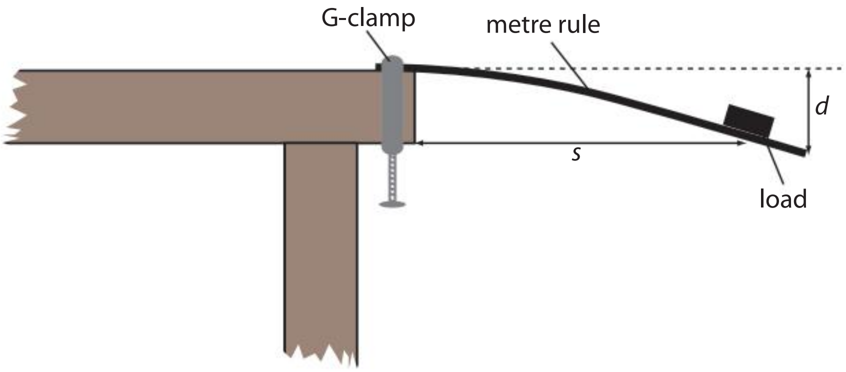
BACKGROUND THEORY

A cantilever is a beam supported rigidly at one end and free to deform at the other end. This experiment is a version of Hooke's law which states that the stress is directly proportional to strain. The further masses ('weights') are from the attached end, the larger the moment {force (N) multiplied by distance (m)} is about the supported end. So the further out they are, the more deflection will occur.

The placement of the load is the more significant factor. The temperature slightly affects the length of the cantilever since the hotter it is the longer the cantilever will become thereby slightly increasing the cantilever arm of the load. If the temperature becomes sufficiently high enough it can affect the internal strength of the material and weaken it, thereby causing more deflection.

SUGGESTED METHOD

Attach a metre ruler to a table using a G clamp as shown below. Place a mass on the ruler so that the metre rule deviates from the horizontal. Students will then record a series of measurements to establish the relationship between the distance from clamp and the depression from the horizontal. Alternatively, the distance from the fulcrum can be kept fixed, and the depression measured as a function of the load.



GRAPHICAL RELATIONSHIP

A graph of depression (horizontal axis) against load (vertical axis) will be linear (up to the elastic limit). A graph of depression versus distance from fulcrum will also be linear.

EVALUATION

Students should be aware that the wood of the metre rule has an elastic limit and will give rise to non-linear results at high loads. The measurements will have random errors.

SUGGESTED EXTENSION WORK

The results should be repeated and averaged. Different materials could be used for the cantilever, for example, metals and different types of plastic. Students could also measure the period of oscillation (T) of a simple cantilever as a function of length (l). T^2 is proportional to l. The period may be very difficult to measure but a high speed video camera could possibly be used.

Day/Date of lesson ________________ **Period** __________
Teacher __________________________ **Room** __________
No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

- Clamp stand and clamp
- Permanent bar magnet
- Transparent plastic bags
- Paper clips
- Variable resistor (rheostat)
- Wire strippers and cutters
- Sellotape
- Ammeter (preferably digital)
- Iron filings
- Staple wires
- Soft iron core (or a six inch nail)
- Insulated wire (preferably single stranded)
- Blu-tac®
- Electronic balance (measuring to two decimal places (or more)

N.B. The bar magnet can be fixed to the pan of the electronic balance with Blu-tac®, *however the balance is a delicate instrument and excessive force must not be used.*

SAFETY

In order to perform a safe experiment, the voltage should be kept low so the chance of the coil overheating is low. Also the power supply should be switched off between measurements. Never work with electrical equipment if your hands or clothing are wet. Students should not be wearing metal jewellery and water taps should be not turned on.

SUGGESTED RESEARCH QUESTION

To find the relationship between the current in the coil and the strength of an electromagnet.

SUGGESTED VARIABLES

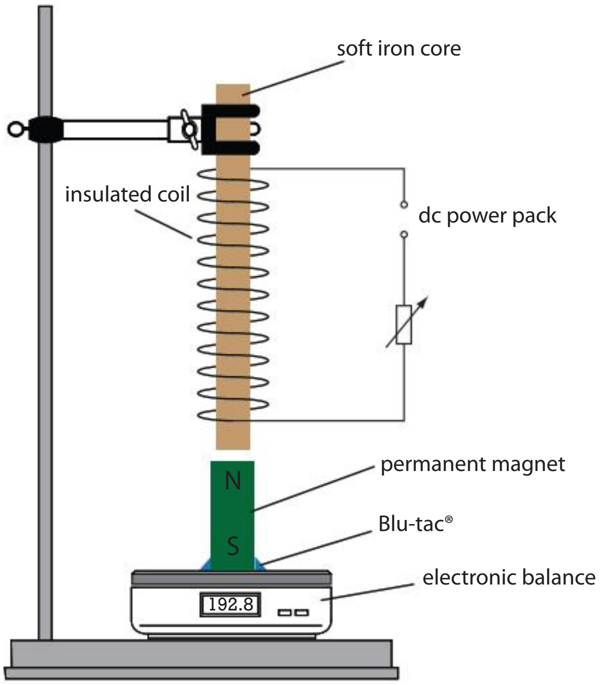
The independent variable is the current in the coil of the electromagnet. The proximate dependent variable could be: the mass of paper clips or iron filings picked up by the electromagnet or, preferably, the change in the mass reading of a magnet mounted on the pan of an electronic balance when it interacts with the electromagnet. This leads to the ultimate dependent variable, the strength of the electromagnet. The controlled variables are the number of loops in the coil, the temperature of the coil and the nature and cross-sectional area of the core.

BACKGROUND THEORY

A current flowing in a wire produces a magnetic field around it. The magnetic effect of a current was discovered by Oersted in 1820. He noticed that the needle of a compass deflected from magnetic north when placed near a current-carrying wire. A solenoid is a long coil containing a large number of closely-wound turns of insulated copper wire. The magnetic field produced by a current-carrying solenoid is similar to the magnetic field produced by a bar magnet. If a soft iron rod (called a core) is placed inside a solenoid, the strength of the magnetic field becomes very large because the iron core is magnetized as the result of a process called induction (the individual magnetic 'domains' in the iron core align with the direction of the magnetic field inside the solenoid, thereby strengthening the field).

The strength of the magnetic field of an electromagnet is directly proportional to the current flowing in the coil and the number of turns in the coil. After a certain value of current and number of turns is reached, further increases do not make the electromagnet stronger. The iron core is said to be magnetically saturated since all the domains are aligned. The challenge in this activity is how to accurately measure the strength of the electromagnet.

SUGGESTED METHOD



An electromagnet can be constructed by winding a length of insulated wire around an iron core (e.g. six inch nail). Single strand insulated wire is recommended as it winds easily around the nail and it is easy to remove the insulation on the ends of the wire. The electromagnet should be connected in series with an ammeter and a rheostat. The rheostat enables the current to be changed and ensures that the coil of the electromagnet will not get overly hot. The "strength" of the electromagnet can be measured by determining the number or mass of paper clips picked up, however this can be unreliable if the magnetic field produced is weak. Alternatively the mass of iron filings picked up could be determined, although this can be messy. A better method is to mount the electromagnet in a clamp stand a short distance (5 – 10 mm) from a permanent bar magnet mounted vertically on an electronic balance. The bar magnet can be fixed to the pan of the electronic balance with Blu-tac®, however students will need to be reminded that the balance is a delicate instrument and excessive force must not be used. As the current is changed the mass reading on the balance will increase or decrease (depending on the alignment of the pole of the electromagnet with the pole of the bar magnet (opposite poles attract and like poles repel). Should the student decide to use the number of loops as the independent variable, s/he must start with a large number of loops (i.e. 30) and increment it by twenties to get a significant change in the strength. This prevents the students from using a large current to obtain a reasonable electromagnet strength.

GRAPHICAL RELATIONSHIP

If the balance is tared (zeroed) before measurements are taken then the mass readings can be converted to forces in newtons by using $F = mg$ ($g = 9.8$ N/Kg). A graph of force (y axis) versus current or number of loops (x axis) will be linear.

EVALUATION

Possible sources of errors for this investigation may include: the iron core becoming magnetically saturated, a large current heating up the wire and heating up the iron core and irregular and loose winding of the wires. There will also be random errors in the balance readings of mass.

SUGGESTED EXTENSION WORK

The investigation can be extended by changing the polarity of the bar magnet on the electronic balance (students should investigate whether the forces are equal and opposite). If the current has been changed, then the effect of the number of loops of the coil or the nature of the core material are other independent variables that might be investigated.

Day/Date of lesson ______________ **Period** __________

Teacher ______________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Boiling tubes
Bunsen burner
Boiling tube holder
Thermometer
Hand lens
Cling film
Kettle
Boiling tube rack
Heat proof mat
Spatula
Glass rod
Microscope (with eye piece graticule)
Access to a fridge

Chemicals required

Salol (phenyl-2-hydroxybenzoate); dry ice (if available); lead(II) iodide (teacher demonstration only)

SAFETY

Salol may be harmful if swallowed and may cause irritation.

Eye contact: Salol is irritating to eyes. It can be damaging if a large amount is splashed into eyes. If this occurs, wash eyes promptly with plenty of water, while lifting the eyelids. Continue to rinse for at least 15 minutes, and get medical attention. If salol is swallowed seek medical attention. Disposable gloves must be worn.

POISON GLOVES GOGGLES

SUGGESTED RESEARCH QUESTION

To find the relationship between the crystal size of salol and its rate of cooling and the temperature at which crystals form.

SUGGESTED VARIABLES

Crystal size is the dependent variable. Temperature of the glass slide is the independent variable (this determines the rate of cooing). The pressure on the slide, the mass or volume of the molten salol, and the time before observing/measuring crystals are controlled variables.

BACKGROUND THEORY

The salol crystals provide a model to represent the size of crystals as a function of cooling. The largest crystals of salol are formed from the slowest cooling melt and the smallest crystals from the fastest cooling melt. Igneous rocks show a similar behaviour. Coarse-grained rocks, like granite, are formed by slow cooling at depth, whereas volcanic rocks, like basalt, are fine-grained and the lava has cooled quickly.

Directional solidification refers to a process by which a liquid is transformed (by freezing) into a solid through the application of a temperature gradient (a temperature difference over a specified distance such as 10°C/cm) in which heat is removed in one direction. The heat travels down the temperature gradient from hot to cold. A container of liquid will turn to a solid in the direction the temperature is lowered. If this liquid has a solute (something dissolved in the liquid) present, typically some of the solute will be rejected into the liquid ahead of the liquid/solid interface. However, not all of the solute can be contained in the solid as it forms; the remaining solute is pushed back into the liquid near the interface. This phenomenon has many important consequences for the solid, including how much of the solute eventually ends up in the solid.

SUGGESTED METHOD

Salol is melted in a boiling tube in a hot water bath. The melting point of salol is 41.5 °C. A few drops of the melt are placed, using a glass rod, onto two clean slides – one that has been cooled in a freezer and one that has been warmed in a water bath (and then dried).

Each sample should then be covered by another clean slide at the same temperature. The crystals can be observed by using a hand lens or a microscope. The crystals that form on the cooled slide should be smaller than those on the warmed slide. The experiment can then be repeated with glass slides of different temperatures.

Another slide at the same temperature should be used to cover the salol on the slides – this makes the rate of cooling more uniform and prevents crystals growing vertically upwards towards the observer and thus appearing smaller in cross section than they actually are. The size of crystals can be measured using the eye piece graticule, or a digital microscope (if available).

GRAPHICAL RELATIONSHIP

A graph should be drawn of crystal size (vertical axis) against temperature of glass slide (horizontal axis). A smooth curve should be drawn through the data points.

EVALUATION

Students should be aware that once a pair of slides of different temperatures are prepared and then removed, speed is necessary to ensure there is a significant difference in temperature between them once the salol is placed on them.

Students should be aware that a range of different crystal sizes will be formed at a specific temperature. Sometimes this activity doesn't work because the liquid salol can 'supercool' and cool down to room temperature without crystallising. This can be avoided by adding a speck of dust or a tiny seed crystal to act as a nucleation site.

SUGGESTED EXTENSION WORK

The experiment could be repeated with slides at the same temperature but covered in cling film. Different sets of masses could be added to the slides to simulate pressure.

This experiment could be readily modified so hot saturated solutions of lead(II) iodide solutions are cooled at different rates. The solution that cools faster will produce smaller crystals. **This should only be done as a teacher demonstration**.

This can be introduced in a qualitative way by the following activity. Half fill a boiling tube with water and add a small measure of lead(II) iodide. Heat over a Bunsen flame until the liquid starts to boil, then quickly tip the contents into another clean boiling tube. Cool this second tube and its contents immediately under a stream of cold water from the tap. Leave the original tube to cool down. The contents of both tubes should be examined after about 15 minutes.

It is likely that the first tube (the one that cooled at room temperature) will contain some undissolved lead(II) iodide and students may object that this experiment is not a fair test. In fact, the undissolved solid may tend to promote crystallization by acting as seed crystals. Students could design a better experimental procedure in which they pour a little of the saturated solution into each of two boiling tubes, leaving the undissolved solid in the original tube to be disposed of (by the teacher).

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Balls (of different sizes and/or different materials)

Retort stand and clamp

Modelling clay

Soil

Large plastic tray

Rulers (1m and 30 cm)

Sand

Flour

SAFETY

Wear eye protection to avoid dust in the eyes.

SUGGESTED RESEARCH QUESTION

To find the relationship between the height that a brass ball is dropped from and the diameter of the impact crater it produces in a tray of sand.

SUGGESTED VARIABLES

The independent variable is the height that the brass ball is dropped from. The dependent variable is the diameter of the impact crater produced in a tray of sand. The controlled variables are the diameter and the density of the brass ball (impactor), the release angle of the brass ball (vertical), the density of the impacted surface (sand), and acceleration due to gravity.

BACKGROUND THEORY

The diameter of an impact crater for an impactor striking the Earth's surface depends on the kinetic energy of the impacting body, the local acceleration due to gravity, a variable called the 'crater collapse' factor, the density of the impactor and the density of the target surface. The size of an impact crater is given by the equation below:

$$D=0.07Cf\left(E_K \cdot \frac{\rho_a}{\rho_t}\right)^{\frac{1}{3.4}}$$

where D is the crater diameter, Cf is the crater collapse factor (= 1 for craters ≤ 3 km and 1.3 for craters ≥4 km), E_K is the kinetic energy of the impactor (in kilotonnes TNT equivalent), ρ_a is the density of the impactor and ρ_t is the density of the target rock. The formula suggests that the diameter of an impact crater will increase with increasing kinetic energy of the impactor, but according to a 'power law' relationship, rather than linearly. The kinetic energy of the falling mass can be determined as follows:

$h = \frac{1}{2} at^2$ (which can be rearranged to solve for t)

$v = at$ (where a = acceleration due to gravity)

$E_K = \frac{1}{2} mv^2$

SUGGESTED METHOD

Balls should be released from alongside a vertically clamped ruler into a basin containing sand. The diameter of the impact crater should be measured with a short ruler. The sand should be smoothed over in between trials.

Students will have to ensure that the impact produces a reasonably circular impact crater and discard any data where the crater is anomalously shaped or not clearly visible.

GRAPHICAL RELATIONSHIP

A scatter graph should be plotted of impact crater diameter against height of drop (or alternatively the height could be converted to a velocity or kinetic energy, as detailed in the background theory). A smooth curve should be fitted to the data. More capable students could use software to fit a power law curve to the data.

EVALUATION

Students should recognise the limitations of extrapolating their results to real impact events involving much larger objects (up to kilometres in diameter) impacting with the Earth's crust.

SUGGESTED EXTENSION WORK (IF APPLICABLE)

Extension work can involve using balls of different diameters or different materials and target surfaces of different densities. A video camera could be used to view the dynamics of an impact in slow motion, including into water. The ratio of crater diameter to crater depth could also be investigated.

Day/Date of lesson ________________ **Period** __________

Teacher ___________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Emery paper
Sand paper
10 kg loads
Foam rubber
Low power microscope (with a scale in the eye piece)
Travelling microscope
Plastic safety screen
Steel rule
Candle
5 kg loads
Copper
70%-30% brass
60%-40% brass
Small steel balls of different sizes
Variety of substances for hardness testing

SAFETY

Be careful that fingers are not placed in the hardness machine when a load is applied. Safety glasses must be worn during hardness testing.

SUGGESTED RESEARCH QUESTION

To investigate the relationship between the hardness of a material and the applied load. Alternatively, to test the hardness of a number of materials or substances and relate it to their structure, bonding and crystal size. To establish if hardness is independent of load for a given material.

SUGGESTED VARIABLES

Hardness may be a dependent variable. The load is the independent variable. The controlled variables are loading time, dimensions and material of the specimen, surrounding temperature and size and composition of the steel ball.

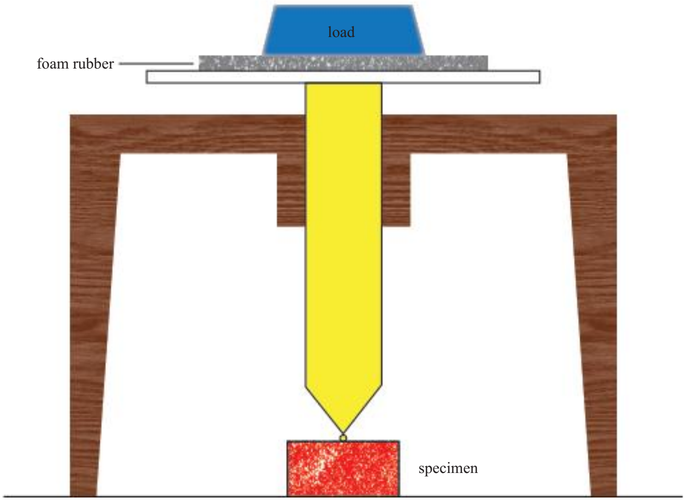
BACKGROUND THEORY

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force (load) is applied. Some materials, such as metals and alloys, are harder than others. Macroscopic hardness is generally characterized by strong bonding or strong intermolecular forces but the behaviour of solid materials under force is complex; therefore, there are different measurements of hardness. These measurements include: scratch hardness, indentation hardness, and rebound hardness. Hardness is dependent on ductility, strain, strength, toughness and viscosity.

SUGGESTED METHOD

Specimens of a suitable size, for example, 1.5 - 2.0 cm diameter and 1.0 cm length, are, if necessary, ground smooth (using emery paper) on one flat face. The other flat face should be as parallel as possible to the smooth (ground) face.

One of the specimens, for example pure copper, should then be placed in the hardness machine with the ground face uppermost and horizontal. Alternatively, a piece of material cut from a strip of 3 mm or more in thickness can be used. A load (initially 10 kg but more may be required) should then be placed gently on the loading platform of the hardness machine. See adjacent Figure.



Care must be taken to avoid any form of shock loading because this will result in larger and possibly distorted indentations. To reduce shock a piece of foam rubber can be placed on the loading platform. The load should be applied for a fixed and short period of time, for example 30 seconds.

The indentation produced after a short period of time (to be established by the student and kept constant) is measured with a travelling microscope, or under a low power microscope with a scale in the eye piece which can be calibrated, for example against the millimetre divisions on a steel rule.

The indentations should be circular and several measurements should be made of the diameter from different points on the circumference. For each specimen six indentations should be made and measured, and the hardness calculated.

The process is then repeated with similarly shaped specimens of the same material, but with different loads. The indentation diameter should be measured at least three times for each applied load. Since the ball is spherical, the Brinell hardness scale may be used by students. However, the large size of indentation and possible damage to the test-piece limits its usefulness.

GRAPHICAL RELATIONSHIP

A graph should be drawn of hardness (vertical axis) against load (horizontal axis). A bar chart can be drawn to compare the hardness of different substances.

EVALUATION

If the circular indentations do not show up clearly against the bright metal surface, the contrast can be improved by holding the ground surface in a candle flame before making the indentations, in order to deposit a thin layer of soot. When indentations are made on this surface they should show up more clearly.

SUGGESTED EXTENSION WORK

Scratch hardness may also be used to assess materials. A scratch can be made by loading a pointed indenter and then moving this slowly across this surface. The width of the scratch line gives a measure of its hardness.

Day/Date of lesson ______________ **Period** __________

Teacher ______________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Tape measure	Steel rule
Metre rule	Newspaper
Sellotape	Sticky labels

Access to the Internet

Access to a spreadsheet

Roll of toilet paper (for marking out scale distances)

Styrofoam balls

Felt-tip markers

SUGGESTED RESEARCH QUESTION

To verify Kepler's third law.

SUGGESTED VARIABLES

Orbital radius in astronomical units is the independent variable and orbital period in years is the dependent variable.

BACKGROUND THEORY

Kepler's third law - sometimes referred to as the law of harmonies - compares the orbital period and radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The comparison being made is that the ratio of the squares of the periods, to the cubes of their average distances from the Sun is the same for every one of the planets.

SUGGESTED METHOD

Students can make a solar system model out of many types of materials. The one issue they should keep in mind is scale; they will need to represent the very different distances from the Sun as well as different planetary diameters. One of the easiest materials to use for planets is Styrofoam balls. They are inexpensive, lightweight, and they come in a variety of sizes.

Object	Diameter	Approximate Size	Possible Object of Approximate Size
Sun	1,390,000 km	69.5 cm	70 cm exercise ball
Mercury	4,880 km	2.5 mm	Small pebble
Venus	12,104 km	6 mm	Bead or large ball bearing
Earth	12,756 km	6.5 mm	Bead or large ball bearing (should be slightly larger than Venus)
Mars	6,794 km	3.5 mm	Small pebble or ball bearing
Jupiter	142,984 km	7.1 cm	Baseball
Saturn	120,526 km	6 cm	Tennis ball
Uranus	51,118 km	2.6 cm	Large marble "shooter" or super ball
Neptune	49, 532 km	2.5 cm	Same as Uranus, but should not be larger
Pluto	2,274 km	1 mm	Poppy seed or small grain of sand

GRAPHICAL RELATIONSHIP

A graph should be drawn of period squared (T^2) (vertical axis) against r^3 (horizontal axis). A curve of best fit should be drawn. A log-log plot can also be constructed for displaying the data: log T (vertical axis) against log r (horizontal axis).

This could be used to formatively assess the data processing aspect of Criterion C only – it could not be used to assess all of Criteria B and C.

EVALUATION

Students should understand the vastness of space and the need for a logarithmic scale (if appropriate). Students could also research the distinction between planets and dwarf planets.

Students should appreciate that Kepler's laws are empirical laws based on observations. They can be used to predict where and when a planet could be found, but the theory behind the laws was not understood until Newton. Kepler's third law can be applied to comets, such as Halley's comet.

SUGGESTED EXTENSION WORK

- Students could investigate the distances between stars and between galaxies, and the size of the observable universe.
- Students could also be encouraged to make and study other simple models related to the Earth and its geology.
- Tectonic plates could be modeled with plasticine; a model volcano (baking soda, food dye and vinegar) could be constructed under supervision (with appropriate safety measures) and convection currents in the mantle can be modeled using potassium manganate(VII) gently heated in water.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Photovoltaic cell	Multimeters
Leads/wires	Crocodile clips
30 cm ruler	Hair dryer (or warm water bath)
Protractor	1 m ruler

Flashlight (or ray box kit or light bulb)

Clear plastic tray with lid

Aluminium pie pan

Digital thermometer

Colour filters or cellophane

Cardboard

Retort stand and clamp

SAFETY

Ensure that the power supply is switched off before adjusting any leads to light bulbs. Never work with electrical equipment if your hands or clothing are wet. Students should not be wearing metal jewellery and water taps should not be switched on.

SUGGESTED RESEARCH QUESTION

How does the distance between the light source and the solar cell affect the voltage?

SUGGESTED VARIABLES

The distance between the flashlight and the solar cell controls the intensity of light falling on the cell and is the independent variable. The voltage across the solar cell is the dependent variable. The wavelengths emitted by the light source, the temperature of the solar cell, the surface area of the solar cell that is illuminated and the angle between the solar cell and the light source are controlled variables. The ambient lighting conditions also need to be carefully controlled.

BACKGROUND THEORY

Photons from a light source hit a solar panel and are absorbed by semiconducting materials, such as silicon. Electrons acquire energy from the photons and are promoted from the 'valence band' (lower energy level) to the 'conduction band' (higher energy level) of the semiconductor. The electrons flow in one direction (DC current) to a metal contact and are returned to the valence band of the semiconductor.

Light intensity varies as the inverse square of the distance from the light source, i.e. a doubling of distance results in a four-fold drop in light intensity. The intensity of solar energy striking a solar cell displays a diurnal and seasonal variation because the angle between the Sun and solar cell changes with the seasons and the time of day. The voltage-current characteristics of a solar cell will depend on the wavelength of the incident light because of the correlation between wavelength and energy (shorter wavelength corresponds to higher energy radiation). There is a minimum energy required to promote an electron across the band gap of the semi-conductor. The temperature of a solar cell also affects the performance of the cell.

SUGGESTED METHOD

The experiment is best performed in a darkened room. Place a flashlight in the jaws of a clamp and attach to a retort stand. Attach a 1m ruler to the stand so that the height of the flashlight above the solar cell can be determined. Connect the wires of the solar cell to the leads of a multimeter (set up to measure a DC voltage of 1V or less). Turn on the flashlight and position it so that the light hits the centre of the solar cell perpendicularly from above. Record the (open-circuit) voltage of the solar cell for a range of heights of the flashlight.

GRAPHICAL RELATIONSHIP

A graph of voltage (y-axis) versus height of the flashlight (x-axis) should be drawn. A smooth curve should be drawn through the data points .

EVALUATION

More capable students should compare their experimental data with that expected based on an inverse-square relationship between voltage and height. An inverse-square relationship between the height of the flashlight and the voltage may not be evident if the flashlight contains a lens to focus the light or if too narrow a range of heights is measured.

SUGGESTED EXTENSION WORK

By placing a light bulb and ammeter in series with the solar cell, voltage could be replaced by current as the dependent variable. By connecting a rheostat in series with the solar cell it should be possible to measure the voltage-current characteristics of the solar cell from open-circuit (i.e. voltmeter only attached to the solar cell) to short-circuit (i.e. an ammeter only attached to the solar cell). The effect of the angle between the light source and the solar cell on either voltage or current could be investigated.

The effect of wavelength on the voltage-current characteristics of the solar cell could be determined by placing layers of coloured cellophane over the flashlight or alternatively using a ray box kit with coloured filter slides. Using opaque cardboard to cover different percentages of the surface of the solar cell could also be used to vary the intensity of light striking the solar cell. By using a piece of opaque card with a hole cut in it the location of the spot where light reaches the solar cell could be varied and its effect on either voltage or current (or both) investigated. The temperature of the solar cell could be varied by placing it in a clear plastic tray (with a lid) and punching a hole in the lid for the leads to protrude through. The temperature of the solar cell could then be varied over a range by placing the plastic tray into an aluminium pie can (or similar) containing ice water or hot water.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Sodium sulfite (or sodium metabisulfite)

Sodium nitrite (or potassium nitrite)

Potassium iodide

6 M H_2SO_4

pH reference solutions (pH 2 to 7)

Universal indicator or a pH meter

A supply of *Blepharisma* or *Volvox* organisms

"Zipper" plastic bags (pint and quart sizes)

Plastic transfer pipettes/droppers

Plastic container with lid

24-well wellplate

Microscope

SAFETY

6 M sulfuric acid is corrosive and should be handled very cautiously. SO_2, NO and NO_2 are toxic gases and should be prepared in a fume cupboard and not be allowed to escape into the laboratory. This experiment should not be done by anyone who has a sensitivity to sulfites or has an asthmatic condition. Sulfites have been shown to cause severe asthma attacks in a few sensitive individuals.

SUGGESTED RESEARCH QUESTION

What is the relationship between volume of pollutant gas and the pH of water?

SUGGESTED VARIABLES

The number of droppers of gas bubbled into a small volume of water is the independent variable. Depending on the age and ability of the students, the volume of gas or moles of gas could be used as the independent variable. The pH of the water is the dependent variable. The volume and temperature of the water, the procedure for preparing the pollutant gas and the size of the plastic dropper used to collect the gas are controlled variables.

BACKGROUND THEORY

Sulfur dioxide can be prepared by the reaction of sulfuric acid with sodium sulfite to produce sodium sulfate, water and sulfur dioxide.

$$H_2SO_4(aq) + Na_2SO_3(s) \rightarrow Na_2SO_4(aq) + H_2O(l) + SO_2(g)$$

Sulfur dioxide reacts with water to produce sulfurous acid, a weak acid.

$$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$$

Nitric oxide, NO, can be prepared by the reaction of sulfuric acid with sodium (or potassium) nitrite.

$$H_2SO_4(aq) + 3NaNO_2(s) \rightarrow Na_2SO_4(aq) + H_2O(l) + NaNO_3(aq) + 2NO(g)$$

Nitric oxide reacts with oxygen and water to form nitrous acid, HNO_2, a weak acid. The reaction is thought to proceed as follows:

$$4NO(g) + O_2(g) + 2H_2O(l) \rightarrow 4HNO_2(aq)$$

When exposed to oxygen, NO is converted into nitrogen dioxide, NO_2.

$$2NO(g) + O_2(g) \rightarrow 2NO_2(g)$$

Oxygen can be generated via the catalytic decomposition of hydrogen peroxide.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

Nitrogen dioxide reacts with water to produce both nitric and nitrous acids, HNO_3 and HNO_2, a strong and a weak acid respectively.

$$2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)$$

SUGGESTED METHOD

Sulfur dioxide can be prepared by placing 1.5 g of sodium sulfite (sodium metabisulfite) in the bottom corner of a 1 pint heavy duty zipper bag. Fill a plastic dropper (transfer pipette) with 6 M sulfuric acid and place the dropper in the plastic bag with the sodium sulfite. Smooth out the bag so it contains a minimum amount of air and then seal the bag. With the bag sealed, slowly squeeze the contents of the dropper onto the sodium sulfite, which will produce a sealed plastic bag partially filled with SO_2 (*see Figure 1*). In order to get a pipette full of the gas, squeeze the bulb of a clean, dry plastic dropper to expel the air inside, then keep squeezing the bulb whilst slowly pushing the tip of the dropper against the zip seal at one corner of the plastic bag. With practice it is possible to push the pipette tip so that the seal opens around it. Push the tip all the way into the bag and release the bulb so that gas enters the pipette, then withdraw the pipette. As the tip leaves the bag, carefully reseal along the “zip” strip. The gas can then be bubbled into a small volume of water in a well plate or small beaker and the pH can be determined, either using a pH meter, or by comparing the colour of universal indicator with a series of pre-prepared reference solutions.

Nitric oxide can be prepared by repeating the procedure using 1.5 g of sodium nitrite (or potassium nitrite) in place of sodium sulfite. To generate nitrogen dioxide (*see Figure 2*), place 0.5 g of solid potassium iodide in a 1 pint heavy duty zipper bag and fill a dropper with 6% hydrogen peroxide solution.

Seal the bag and place it inside a larger (1 quart) heavy duty zipper bag containing 1.5 g of sodium nitrite (or potassium nitrite) and a dropper containing 6 M sulfuric acid. Seal the larger bag. Without opening either bag, generate oxygen in the smaller bag by slowly squeezing the dropper so that hydrogen peroxide drips onto the potassium iodide. Generate nitric oxide in the outer bag by squeezing the 6 M sulfuric acid onto the sodium nitrite. When the reaction is complete, without opening the larger bag, open the smaller bag containing oxygen. The larger bag now contains mostly NO_2, which can then be bubbled into water in the same manner as SO_2 above.

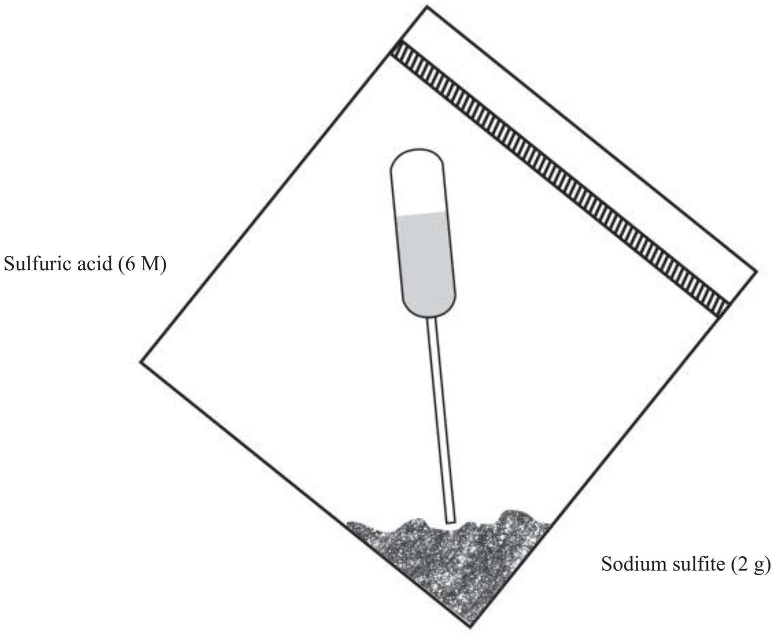


Figure 1. The zipper bag setup for generating sulfur dioxide

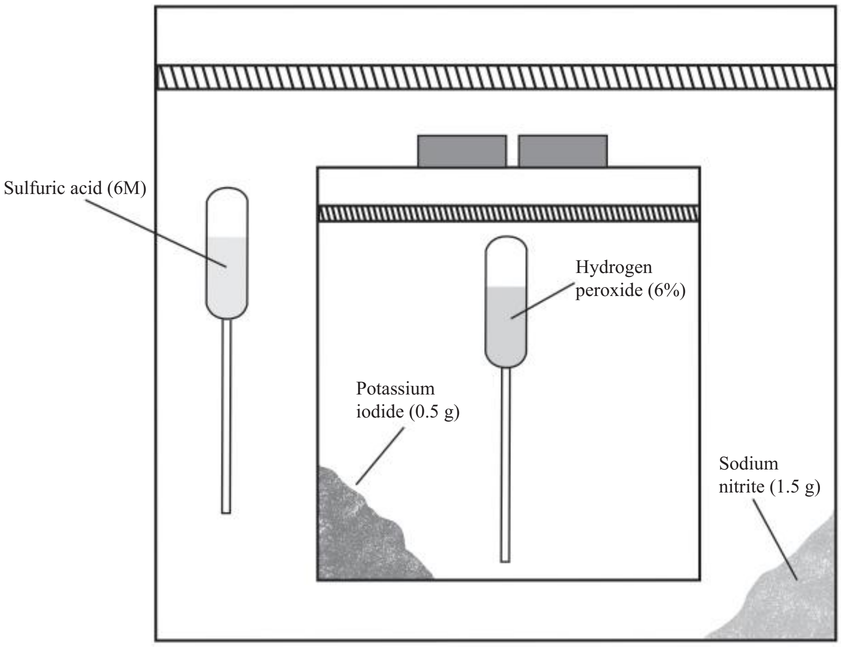


Figure 2. The complete assembly for generating nitrogen dioxide

GRAPHICAL RELATIONSHIP

A graph of pH (*y*-axis) versus the number of droppers of gas (or volume of gas or moles of gas) (*x*-axis) should be drawn. A smooth curve should be drawn through the data points.

EVALUATION

Students should recognize that the relationship between pH and the volume of gas is non-linear since the pH scale is a logarithmic scale (each step downwards on the scale represents a 10-fold increase in the concentration of aqueous H^+ ions). If a log scale is used on the *x*-axis the graph should become linear. Students should consider the effectiveness of bubbling the gas directly into water as a model of acidification of lake water, where the gas would only be absorbed at the surface. Bubbling the gas directly into the water creates a greater surface area of contact, and hence the pH will drop more rapidly than if the gas had been "puffed" over the surface. Students could comment on the likely purity of their gas sample (which will decrease as the plastic bag is opened more and more times) and should recognize sources of error inherent in the procedure, e.g. in measuring the volume of gas and in squirting the gas above the water.

SUGGESTED EXTENSION WORK

The effect of 'acid rain' on items composed of metal or calcium carbonate could be investigated by creating an acid rain chamber, a plastic container e.g. a 2 litre plastic ice cream container with a clear lid. Items such as strips of metal (magnesium, zinc, iron, tin, copper etc.) marble chips, egg shells or snail shells can be placed in the container and a small beaker containing sodium sulfite or sodium nitrite placed in one corner of the container. With the container in a fume cupboard 6 M H_2SO_4 can be added to the beaker and the lid quickly replaced on top of the container. Over a period of days or weeks the items can be observed for qualitative changes, or the mass of each item could be measured as a function of time. The "acid rain" can be replenished by replacing the sulfite (or nitrite) and sulfuric acid as required.

The effect of acid rain on living organisms could be investigated by placing some *Blepharisma* or *Volvox* culture into a clear plastic well plate, placing the well plate on the stage of a microscope and adjusting the magnification and focus so that the organisms are clearly visible. *Blepharisma* is a genus of unicellular ciliated protists found in fresh or salt water, identified by their red or pink colour. *Volvox* is a type of green algae found in fresh water, which moves using a flagellum. The movement of the *Blepharisma or Volvox* should be observed and qualitatively described before and after a puff of NO_2 or SO_2 gas is squirted above the water (do not bubble gas through the water) in the well plate.

CLEAN UP

Open the bags containing any unused SO_2 or NO_x in the back of the fume cupboard and allow the gases to be vented into the hood. After the gases have been vented from the bags, fill the bags completely with water and carefully pour the water down the sink.

Day/Date of lesson ____________ **Period** ________

Teacher ____________________ **Room** ________

No. of students/groups ________

APPARATUS REQUIRED (PER GROUP)

Grater
Beakers
Pestle and mortar
Large watch glass
Bunsen burner
Heat proof mat
Gauze
Petri dish
Teat pipette
Universal indicator paper
Measuring cylinders (10 cm^3 and 25 cm^3)
0.1M hydrochloric acid
0.1M sodium hydroxide
Potatoes
Distilled water
Food colouring
Propane-1,2,3-triol (glycerol)
Stirring rod
White tile
Tea strainer

SAFETY

Eye protection must be worn at all times. Any acid or alkali must be washed off if it comes into contact with skin.

SUGGESTED RESEARCH QUESTION

To establish the effect of adding a 'plasticiser' on the physical properties of a plastic made from potato starch.

SUGGESTED VARIABLES

The amount of plasticiser is the independent variable and the degree of plasticity is the dependent variable. Controlled variables are the temperature and the method of preparation (including volumes of different chemical and concentrations).

BACKGROUND THEORY

Making a plastic from potato starch

Starch is made of long chains of glucose molecules covalently bonded together. It contains two polymers: amylose, which is straight-chained and amylopectin which is branched (and similar to glycogen). When starch is dried from an aqueous solution it forms a film due to hydrogen bonding (weak intermolecular forces) between the chains.

However, the amylopectin inhibits the formation of the film. Reacting the starch with hydrochloric acid breaks down the amylopectin, forming a more satisfactory film. This is the product that can be made without propane-1,2,3-triol. The straight chains of the starch (amylose) can line up together and areas of the film can become crystalline, which causes the brittleness.

Students should be able to see a difference in the two films. The film without the propane-1,2,3-triol is far more brittle, the one with it shows more plastic properties. Adding propane-1,2,3-triol makes a difference due to its hygroscopic (water attracting) properties. Water bound to the propane-1,2,3-triol enters between the starch chains and stops the crystalline areas from forming, preventing the brittleness and resulting in more plastic properties, thus acting as a plasticiser.

SUGGESTED METHOD

Extracting the starch

1. Grate about 100 g of potato. The potato does not need to be peeled, but it should be clean.
2. Put the potato into the mortar and add about 100 cm^3 of distilled water to the mortar, and grind the potato carefully.
3. Pour the liquid off through the tea strainer into the beaker, leaving the potato behind in the tea strainer.
4. Repeat the second and third steps twice.
5. Leave the mixture to settle in the beaker for 5 minutes. Decant the water from the beaker, leaving behind the white starch which should have settled in the bottom.
6. Put about 100 cm^3 of distilled water in with the starch and stir gently. Leave to settle again and then decant the water, leaving the starch behind.

Making the plastic film

1. Put 22 cm^3 of water into the beaker and add 4 g of the potato starch slurry from the previous step (or 25 cm^3 water and 2.5 g of commercial potato starch), 3 cm^3 of hydrochloric acid and 2 cm^3 of propane-1,2,3-triol.
2. Put the watch glass on the beaker and heat the mixture using the Bunsen burner. Bring it carefully to the boil and then boil it gently for 15 minutes. Do not boil it dry. If it looks like it might, stop heating.
3. Dip the glass rod into the mixture and dot it onto the indicator paper to measure the pH. Add enough sodium hydroxide solution to neutralise the mixture, testing after each addition with indicator paper. You will probably need to add about the same amount as you did of acid at the beginning (3 cm^3).
4. You can then add a drop of food colouring and mix thoroughly. Pour the mixture onto a labelled petri dish or white tile and push it around with the glass rod so that there is an even covering. Repeat the process, but leave out the propane-1,2,3-triol.
5. Label the mixtures and leave them to dry out. It takes about one day on a radiator or sunny windowsill, or two days at room temperature. Alternatively, use a drying cabinet. It takes about 90 minutes at 100 °C.
6. Loads can be attached to the dry sample to see if they obey Hooke's law (refer to Physics Investigation 5) and establish at what load plastic deformation occurs. This occurs at loads beyond the elastic limit.

GRAPHICAL RELATIONSHIP

A graph should be drawn of the mass or volume of plasticiser (horizontal axis) against the load before the bioplastic is permanently deformed.

EVALUATION

Students should consider the reproducibility of their results (i.e. precision). If literature values can be sourced they could compare the elastic limit of their bioplastic with other types of plastic. Variables that are likely to have affected the quantity and quality of their bioplastic, e.g. temperature, mixing, time of reaction, drying time etc. should also be discussed.

SUGGESTED EXTENSION WORK

Students could explore whether the source of starch makes any difference to the quality of their bioplastic, e.g. cornstarch, pea starch or sugar cane bagasse (the fibrous matter that remains after sugar cane is crushed to extract the juice). Some further research into bioplastics based on cellulose, lignin, or plant protein could be carried out.

Day/Date of lesson ______________ **Period** __________

Teacher ______________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

Umbrellas (made of different materials and of different designs and shapes)

Plastic drain pipe

Glass tubes (of various sizes and lengths)

Light microscope (with eye piece graticule)

Conical flasks (of different sizes)

Measuring cylinders (of different sizes)

Plastic bags (impermeable to water)

Sealant

Plasticine

SAFETY

Do not attempt the experiment outside during a rain storm.

SUGGESTED RESEARCH QUESTION

To establish the effect that varying the head of water (water pressure) has on the ability of an umbrella to prevent the passage of water. Alternatively, to establish whether there is a maximum pore size above which the umbrella lets water pass through.

SUGGESTED VARIABLES

The head of water (water pressure) is the independent variable and the water resistance (as measured by the volume of water that passes through the umbrella) is the dependent variable. Controlled variables are the temperature, volume and nature of the liquid, and the material and its pore size, the number of holes per unit area and the total surface area.

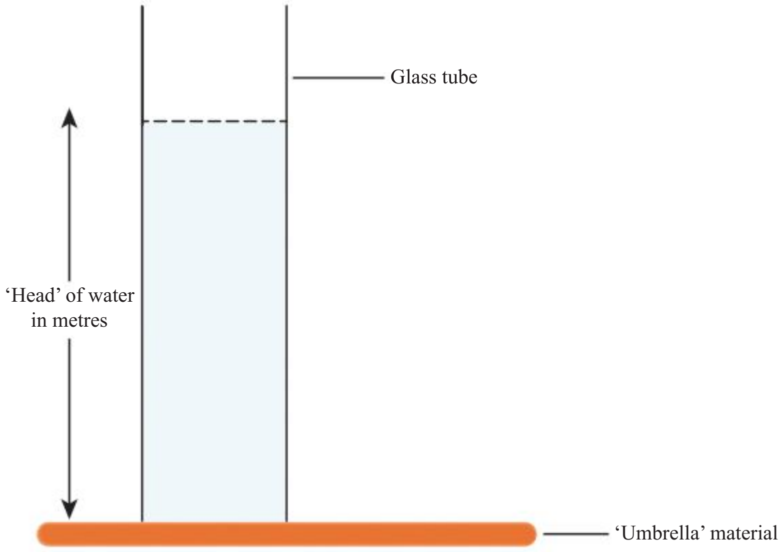
BACKGROUND THEORY

The fabric or the material from which an umbrella is made is tough and weather proof. It might be made from canvas, acrylic, vinyl or another synthetic fibre. The fabric may be chemically coated to make it even more durable, stain and water resistant.

Air vents or pores in the fabric allow for exchange of air and for stability in the case of strong winds. Surface tension prevents water passing through the small pores.

SUGGESTED METHOD

A simple example of how the head of water (water pressure) can be varied is shown below. A large graduated tube is ideal. Alternatively, known volumes of water could be dropped from different heights onto an umbrella. The material - tube connection needs to be very well sealed.



GRAPHICAL RELATIONSHIP

A graph should be drawn of the water height or height dropped from (vertical axis) against the volume or mass of water (horizontal axis) that passed through the umbrella material. The resistance of the material would presumably be inversely related to the volume of water flowing in unit time.

EVALUATION

It may be difficult to obtain accurate and precise results. Large amounts of water may be needed and repeated data collection will be necessary. The results may be dependent on whether the material has been soaked. If the flow rate was fast, the head of water could not be considered to be constant; surface tension effect would presumably be significant. The diameter of the tube may have an influence, if it is small.

SUGGESTED EXTENSION WORK

The investigation could be repeated (with suitable safety precautions) with water at different temperatures and with small volumes of liquids of varying polarity, such as ethanol and propanone (acetone). Umbrellas could be pricked with needles of different sizes to establish the maximum hole size that lets water pass through the umbrella.

The aerodynamic response of umbrellas to wind could also be investigated and used to see if an umbrella can be designed to prevent high wind speeds and being turned inside out. This can be done with commercial umbrellas or with student-designed and made umbrellas.

Day/Date of lesson ________________ **Period** __________

Teacher __________________________ **Room** __________

No. of students/groups __________

APPARATUS REQUIRED (PER GROUP)

YOU WILL BE PROVIDED WITH:

Two 750 cm^3 glass containers with opaque plastic lids

Fine dried sand

Fined dried soil

Modelling clay

Cork

Two mercury thermometers

Two alcohol thermometers

Source of carbon dioxide or carbon dioxide generator (Kipp generator/Kipp's apparatus) (metal carbonate and dilute acid)

SAFETY

Wear safety glasses when handling chemicals. If a mercury thermometer is broken inform the teacher immediately.

SUGGESTED RESEARCH QUESTION

To investigate the absorption of thermal energy by carbon dioxide and air.

SUGGESTED VARIABLES

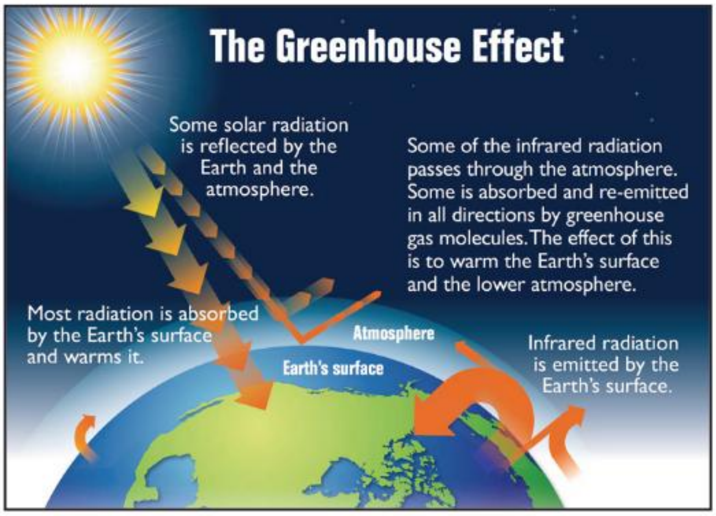
The nature of the 'atmosphere' within the container is the independent variable and the temperature of the atmosphere is the dependent variable. Controlled variables are the exposure to solar energy, time of exposure to the Sun, mass and nature and surface area of the sand and the dimensions and nature of the container.

BACKGROUND THEORY

Carbon dioxide is present in the atmosphere at a concentration of about 400 parts per million. This means about 400 out of one million molecules or atoms in the air are carbon dioxide. Carbon dioxide is present at a relatively low concentration in the air, but is a potent greenhouse gas.

The 'greenhouse effect' occurs because greenhouse gases, such as carbon dioxide, let solar energy (including shortwave infrared radiation) pass through the atmosphere. The Earth absorbs sunlight or solar energy, warms then reradiates heat energy (as long wave infrared radiation). Some of the outgoing long wave radiation is absorbed by greenhouse gases, such as carbon dioxide, in the atmosphere. This heats the atmosphere which in turn re-radiates long wave radiation in all directions. Some of it makes its way back to the surface of the Earth. Refer to the Figure overpage.

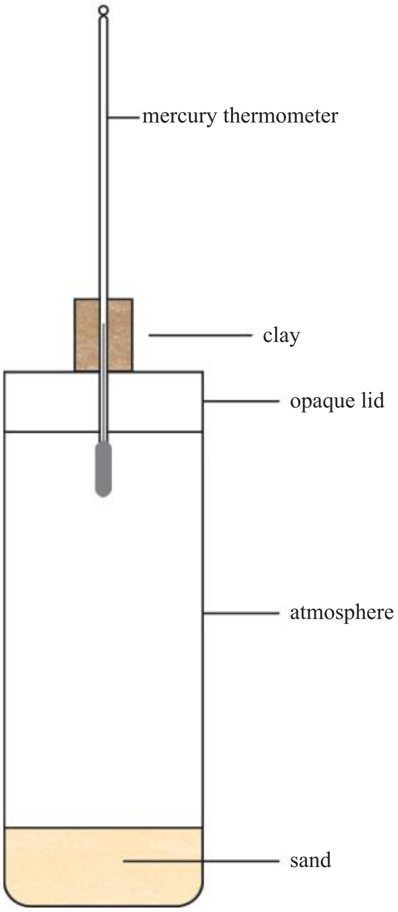
A significantly higher temperature is expected in the container with carbon dioxide, but this may not be observed. Assuming the glass (or plastic containers) do transmit sufficient infrared from the Sun (or infrared lamps), the pure CO_2 atmosphere increases infrared absorption, directly heating it faster than the air. This seems analogous to John Tyndall's original experiment, except that Tyndall measured the amount of transmitted (non-absorbed) radiation, whereas the bottle experiment indirectly measures the absorption via its heating of the gas.



SUGGESTED METHOD

Two transparent glass containers are filled with the same mass of sand (or soil). Although sand reflects more light than soil, it is easier to dry and manipulate. The containers should have different 'atmospheres': one of carbon dioxide and one of air. The containers can then be left out to be heated by solar energy from sunlight. A mercury thermometer is inserted through a hole in the lid of each container and placed well above their bases. The thermometer can be kept in place and the exit sealed with modeling clay. The two glass containers can be placed on a cork mat (a thermal insulator) to avoid heat loss through the base.

Light bulbs cannot be used since more than 90% of the radiation emitted by a typical light bulb is in the infrared range and glass is opaque to most of this radiation. Infrared lamps can be used if available.



GRAPHICAL RELATIONSHIP

A scatter graph should be drawn of temperature (vertical axis) versus time in minutes (horizontal axis) during both the day and at night.

EVALUATION

Because carbon dioxide has a greater density than air, it reduces heat transfer by suppressing convection and, near the sand, this could cause a small increase in temperature not related to the 'greenhouse effect'.

Considerably more reliable results are obtained if the mercury in the thermometer is protected from direct sunlight and if the containers are kept away from draughts and surfaces that could unevenly reflect sunlight on to them. There will also be stronger convective cooling from draughts.

However, the path length for a bottle of pure carbon dioxide is relatively small and perhaps cannot trap a significant fraction of re-radiated infrared radiation, or perhaps it is only trapped by absorption at the container walls, in which case how does infrared enter from the lamp? Perhaps it heats the bottle wall which then radiates inwards.

If the bottles are still warming at the end of the experiment, the dominant effect may be differences in heating rate by gaseous infra-red absorption. Even in equilibrium, heat loss would be via conduction, convection and radiation from the outer walls of the bottle, a poor model for the atmospheric 'greenhouse effect' and global warming. However, the experiment should demonstrate infrared absorption by greenhouse gases.

SUGGESTED EXTENSION WORK

The investigation could be repeated (with suitable safety precautions) with other gases, for example, helium, dinitrogen oxide, nitrogen etc. Plastic bottles can also be used assuming they do transmit infrared radiation. The presence of water vapour may affect the results and the experiment could be repeated in the presence of silica gel to remove water vapour. This is also a suitable experiment for data-logging. The experiment could also be repeated with different sized containers and the amount of sand varied.

A more sophisticated experiment could use two open-topped aquariums heated by downward pointing infrared lamps. A 'pure' CO_2 atmosphere in one aquarium (generated by the addition of sodium hydrogen carbonate) would be retained only because of its greater density. The 'pure' CO_2 should absorb more of the infra-red component in the atmosphere, while the control set-up absorbs more at the surface. Differences in temperature increase might then depend on conduction and convection from the differentially heated surfaces, causing a delay in heating the air.

Day/Date of lesson ____________ **Period** ________

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APPARATUS REQUIRED (PER GROUP)

Digital pH meter or data logger with pH probe

Conductivity meter or data logger with conductivity probe

Turbidity meter or spectrophotometer or colorimeter

Flocculator SW1 or milkshake mixer

0.1 mol dm^{-3} sodium hydroxide

0.1 mol dm^{-3} hydrochloric acid

Magnetic stirrer

Alum, iron(II) chloride, iron(II) sulfate

Calcium oxide (lime)

SAFETY

Wear safety glasses and gloves when handling chemicals and waste water.

SUGGESTED RESEARCH QUESTION

To determine the dose of coagulant required to clarify a known mass or volume of waste or river water. To determine the pH at which this occurs.

SUGGESTED VARIABLES

The dose of a specified coagulant within the container is the independent variable. Controlled variables are the volume or mass of waste or river water, composition of waste or river water, temperature of waste or river water, stirring rate, stirring time, settling time and time before measurements are recorded and the chemical nature of coagulant.

BACKGROUND THEORY

Turbidity in water is due mainly to the presence of colloidal clay and silt particles. Because of their similar surface electrical charges, the colloidal particles repel and remain in suspension.

By adding a coagulant such as alum it is possible to destabilize the colloidal particles as a result of changing the ionic environment in which the particles exist. Alum is a metal salt and it produces a spongy mass of insoluble metal hydroxide which covers the colloidal particles. Many waters are naturally alkaline due to the presence of hydrogencarbonate ions or produced by adding lime (calcium oxide) to the water. This is termed 'coagulation' and the spongy mass is termed a 'floc' when it becomes visible.

The floc is gently stirred to cause further aggregation, this is called 'flocculation' resulting in larger particles which have a reasonable settling out velocity. This period of flocculation followed by a settling out time, called sedimentation, produces clearer and cleaner water.

The reactions can be described by the following simplified equations:

$Al_2(SO_4)_3\ (aq) + 6H_2O\ (l) \rightarrow 2Al(OH)_3\ (s) + 3H_2SO_4\ (aq)$

$3H_2SO_4\ (aq) + 3Ca(HCO_3)_2\ (aq) \rightarrow 3CaSO_4\ (s) + 6CO_2\ (g) + 6H_2O\ (l)$

that is overall:

$Al_2(SO_4)_3\ (aq) + 3Ca(HCO_3)_2\ (aq) \rightarrow 2Al(OH)_3\ (s) + 3CaSO_4\ (s) + 6CO_2\ (g) + 6H_2O\ (l)$

SUGGESTED METHOD

The investigation may be carried out in two parts. Firstly, the waste water of fixed volume or mass is dosed with various concentrations of alum (or another coagulant) to find the optimum dose and secondly, using a constant dose the experiment is repeated to find the best pH.

Samples of river water can be treated with varying amounts of chemicals, followed by flocculation and a period of settling. Measurements are made of pH, turbidity and conductivity. The experiment can be repeated with new samples of the same river water at different pH values, each now containing the same amount of coagulant (for example, alum). The pH adjustment can be made by the dropwise addition of very dilute (0.1 mol dm^{-3}) hydrochloric acid or sodium hydroxide while stirring. Measurements of pH, turbidity and conductivity can be recorded again.

A suggested method is using 300 cm^3 of river water, with varying volumes of 100 ppm alum solution added up to 300 cm^3. Distilled water is added to maintain a constant volume of 600 cm^3. Three hours stirring and 16 hours settling time is recommended. Tap water can be used as a comparison.

GRAPHICAL RELATIONSHIP

A scatter graph should be drawn of the turbidity (vertical axis) versus the volume or mass of coagulant. If pH is varied the turbidity should be plotted against pH on a scatter graph.

EVALUATION

Students should recognize and discuss the impact of some of the critical variables involved in the experiment, for example, sufficient stirring time to ensure complete flocculation of the particulates in the water, sufficient settling time to allow the floc to settle as a sediment, whilst keeping the total volume of water constant to ensure fair measurements of the turbidity.

SUGGESTED EXTENSION WORK

The investigation could be repeated with a variety of waste and river waters and coagulants.