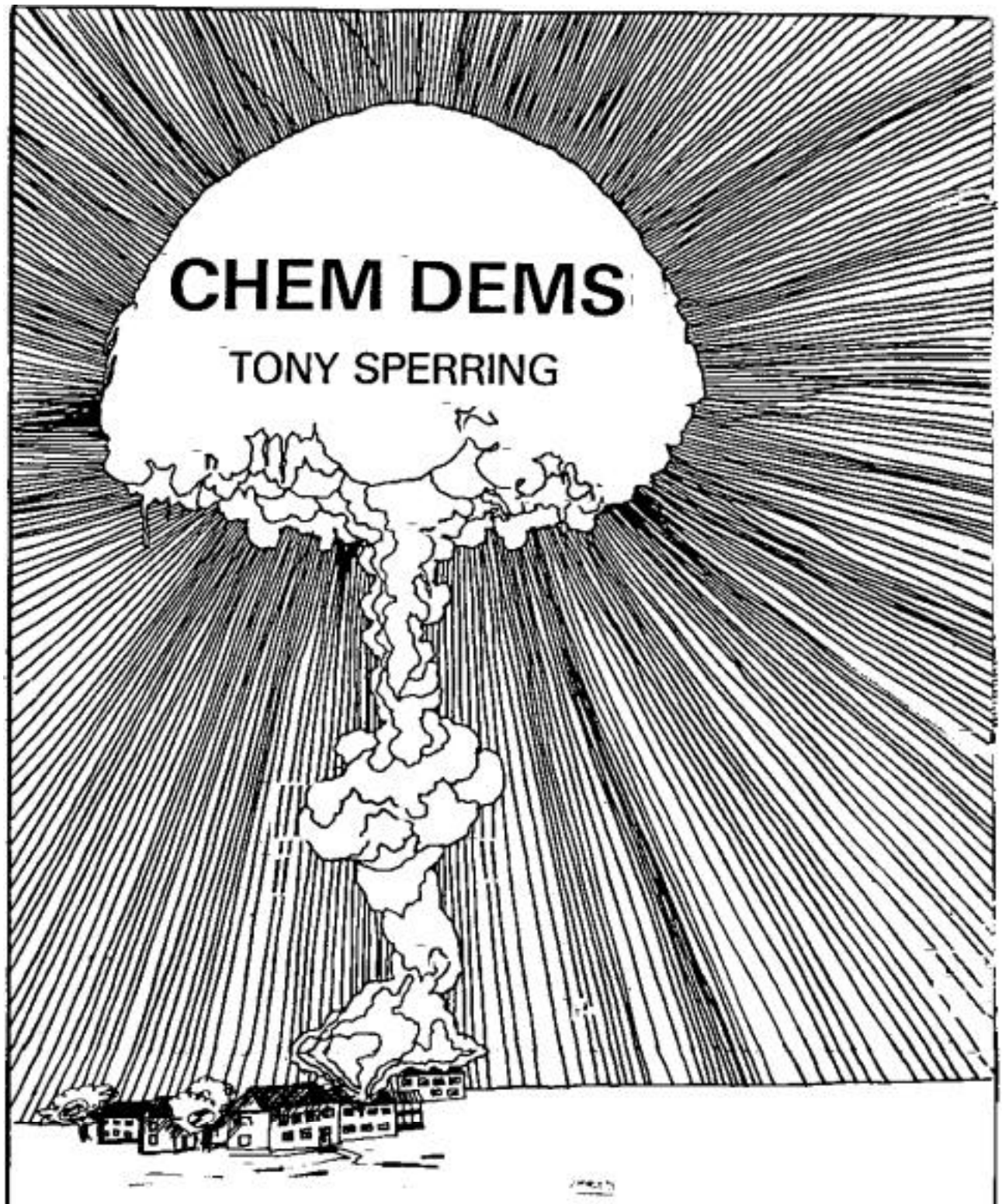
CHEM DEMS

TONY SPERRING



Science Teachers Association of NSW

CHEM DEMS

Chemistry Demonstrations for Secondary Schools and Colleges

by

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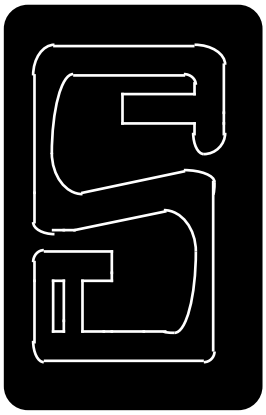

STANSW

In memory of Kevin Trainor, an inspiring teacher and a good friend, who first showed me many of these demonstrations and who taught me that:

It is not important to teach interesting things, but it is important to make interesting those things that ought to be taught.

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Copies of this book may be obtained from:

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Preface

Of all the sciences taught in the high school, Chemistry is probably the easiest to teach badly. Too often the subject has been allowed to degenerate into a dull litany of obtuse facts and indigestible abstractions, divorced from everyday experiences and contexts, and devoid of wonder. Yet experience and educational research indicate that the mere cataloguing of "important" facts and the force-feeding of inscrutable theories is the surest way to turn all but the most resilient student right off the subject. Too many students of traditionally constructed courses emerge from their experiences of chemistry with, at best, little regard for the subject and its role in their lives, or at worse an aversion for all things "chemical".

But there is another side to Chemistry — it can be interesting, it can be shown to be relevant, it can be fun. All it takes is an awareness of what interests children (of all ages), some imagination, a bit of flair – and the right recipes. This is a book of recipes, and a few ideas. It has been written in the belief that the elements of entertainment – colour and movement, mystery and excitement, pyrotechnics and the elements of surprise (we'll leave sex and violence to the biologists) – can be used to capture the attention and stimulate the interest and engagement of students. By exciting in our students a sense of wonder we are better able to promote a desire to learn more about the world of energy and substance—which goes by the name "Chemistry".

Safety first

A word of caution. As with much of Science, there are safety issues which must be recognised and addressed. Many chemicals are toxic or pose other dangers. The substances and reactions described here can involve an element of danger which, if not recognised and guarded against, can result in tragedy. In Queensland a young teacher killed himself and one of his students in attempting to manufacture a rocket, using a potassium chlorate and sulfur propellant in a metal pipe. In New South Wales a teacher and some students ended up in hospital when a model volcano exploded. These events were predictable, and therefore avoidable.

It is assumed that, as a practicing science teacher, you will be aware of the OH & S protocols at your place of work and standard safety practices e.g. the dangers of powdered oxidising agents (like potassium nitrate), the folly of grinding or impacting mixtures of solid chemicals (like potassium nitrate and sulfur), the precautions that need to be taken with corrosive acids, caustic alkalis, the toxic compounds of heavy metals or carcinogenic aromatic compounds, and so on.

Not all the chemicals or demonstrations in this collection are necessarily permitted in all schools. Different states and systems have differing regulations regarding the use of chemicals and the conduct of certain experiments. You should consult the regulations that govern science teachers in your state or system. In N.S.W. public school and TAFE teachers should consult the NSW Department of Education & Training safety manual:

Chemicals Safety in Schools **. NSW Department of Education and Training, Sydney, 2000 (Revised 2002)**

In particular, note that some of the substances included in these demonstrations are now classified "Category X" and are "banned in DET schools". Where these substances have been used, a note has been made in the Ingredients list and the Safety Notes for the demonstration. A full list of banned chemicals is given in Appendix H of the Chemical Safety In Schools package.

The dangers and safety precautions associated with any chemical can be found in the MSDS (Material Safety Data Sheets) resource, a copy of which is included on CD-Rom in the Chemical Safety in Schools for NSW schools. MSDS data is widely available on the internet.

A variety of Internet sites have chemical safety data (search for MSDS or Material Safety Data Sheets). Some good sites are:

- MSDS-Search: http://www.msdssearch.com/DBLinksN.htm
- Oxford University Physical and Theoretical Chemistry laboratory (http://physchem.ox.ac.uk/MSDS/)
- Hazardous Chemical Database (University of Akron) (http://ull.chemistry.uakron.edu/erd/)

Other internet sites which deal with chemical safety can be found http://alex.edfac.usyd.edu.au/Methods/Science/ScienceWWW.html

An attempt has been made to summarise any known hazards associated with each demonstration—but it is stressed that these precautions are **in addition to standard safety practice and common sense, and assume that you will exercise your professional responsibilities as a teacher.**

DISCLAIMER

The inclusion of a demonstration, procedure or a chemical in this collection does not imply that it is permitted by either individual schools or school systems in New South Wales or elsewhere in Australia. Teachers should check with the latest policy documents and occupational health and safety regulations applicable to their state, system or school in order to ensure compliance with these before trying a demonstration or using a chemical.

The Demonstrations

What started as a collection of less than twenty spectaculars has grown into a collection of about a hundred. An attempt has been made to arrange them in groups according to central themes but, because many of the demonstrations are multi-faceted and can be used in a variety of contexts, this division is to some extent arbitrary. The two appendices attempt to give some guide to the possible uses of each demonstration.

It has been found over long years of experience that Murphy's Law is often at work where demonstrations are concerned. All the recipes have been tried repeatedly and work — most of the time! Inevitably there is an element of subjectivity and serendipity involved in some formulations — a "moderate" flame, a "light" colour, "rapid" stirring and similar descriptions are examples. Take the advice offered in an old Arabic proverb: "Put your faith in Allah (but tie your camel to a tree)". Try it out for yourself first, according to the recipe, and then decide on whether the scale needs to be modified, how the demonstration should be timed, and what sort of prefacing and prompting is necessary to ensure the optimum impact. But above all remember that safety should not be sacrificed for spectacle.

Organisation

The demonstrations have been grouped into 9 main classes: States of Matter, Atomic Structure and Chemical Bonding, Chemical Equilibrium, Chemical Energy, Redox, Rates of Reaction, Polymers, Tricks and Paradoxes, and Miscellany. As many chemical processes involve a number of concepts, such a division is to some extent arbitrary. Therefore, to assist the teacher in selecting an appropriate demonstration for a particular purpose, two appendices have been included: Appendix A contains a brief description of each demonstration, whilst Appendix B summarises the main concepts and topics that each demonstration involves.

Finally, if you know of any demonstrations that could be included in this collection, or of better ways to do the ones herein, don't hesitate to let me know.

Tony Sperring
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Section 1: STATES OF MATTER

Liquid densities
Fascinating freon
Supersaturated magic
Colourful chromatography
Iodine extraction
Recrystallisation
The fountain
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Absorbing experiences
Gel diffusions
Crystal forms
A crystal garden
The sunset demonstration
Aniline magic
Heron's siphon
Foams
"Quickies"

LIQUID DENSITIES

Six different liquids are added to a cylinder to show different densities and miscibilities.

CONCEPTS - USES

Motivation
Solubility
Density
Miscibility

MATERIALS

Mercury (10-30mL)
Freon (or chloroform or carbon tetrachloride) – 20-30mL : ***Carbon tetrachloride is an X-Category chemical in NSW*** .
Ether – 20-30mL (alternative - hexane): ***Ether is an X-Category chemical in NSW*** (substitute with hexane or another hydrocarbon)
Ethanol (or methylated spirits) – 20-30mL
Copper sulfate – 0.1M made up in saturated sodium chloride solution – 20-30mL
Iodine – several crystals
Olive oil (or any vegetable oil) – 10-20mL
Sudan III or Sudan IV (Optional)
Measuring cylinder – 250mL (or 100mL)
Dropper


SAFETY NOTES

Take care with flammable ether and toxic mercury and carbon tetrachloride.
Ether and Carbon tetrachloride are X-Category chemicals in NSW .

PREPARATION

- Prepare the 0.1M copper sulfate solution by dissolving 2.5g of $CuSO_4 . 5H_2O$ and 36g of NaCl per 100mL of solution.

- Colour the ether (brown) and the freon/$CHCl_3$/CCl_4 (pink) with some iodine crystals. If there is no ether use hexane (or cyclohexane) coloured pink with some iodine.

- Colour the oil (e.g. red) with an oil soluble dye like Sudan III or Sudan IV.

PROCEDURE

- Pour the following liquids into the measuring cylinder (in any order): mercury, aqueous $CuSO_4$, freon (or $CHCl_3$ *or* CCl_4).

- Carefully add the ethanol (or methylated spirits) to the top of the aqueous layer using a dropper/pipette to minimise mixing.

- Carefully add the vegetable oil at the aqueous-alcohol interface using a dropper/pipette.

OBSERVATIONS

- The following layers should form in sequence (top to bottom):
  Ether (brown) or hexane (pink)
  Alcohol (colourless initially)
  Vegetable oil (red)
  Aqueous $CuSO_4$(blue)
  Freon (pink)
  Mercury (silver)

- Observe for diffusion in the upper layers.

FASCINATING FREON

Coloured freon is boiled under water forming immiscible liquid-vapour bubbles.

CONCEPTS - USES

Motivation
Phase changes
Equilibrium
Le Chatelier's principle
Solubility
Kinetic molecular theory

MATERIALS

Freon (or chloroform) – 50mL.
Iodine – about 0.5g.
Sodium thiosulfate – several crystals.
Conical flask – 500mL.
Tripod and bunsen.

SAFETY PRECAUTIONS

No special precautions (unless chloroform is used - avoid vapour and skin contact).

PREPARATION

- Dissolve just sufficient iodine in about 150–250mL of freon (or chloroform) to produce a dark pink colour, in a large conical flask.

- Add water almost to the top of the flask.

PROCEDURE

- Stand flask on a tripod and place a bunsen with a very low flame under one corner/edge of the flask.

- Allow flame to gently heat the flask in one spot.

OBSERVATIONS

- The freon will eventually boil gently, forming bubbles of vapour which will rise in the aqueous layer.

- Some freon bubbles will consist of vapour and (pink) liquid.

- With careful heating the "double" bubbles will rise to the surface of the water, lose some of the vapour and sink back to the bottom of the flask.

- Bubbles can be seen to circulate through the aqueous phase, rising up one edge and descending the opposite edge flask.

- Some bubbles will hover in the aqueous layer, and by other bubbles as they rise and fall (an analogy of molecular movement).

COMMENTS - VARIATIONS

- The system can be kept (stoppered) and re-used many times.

- Over time, a yellow-gold colour may develop in the aqueous phase as iodine dissolves and reacts in the aqueous phase (to form the tri-iodide ion):

$$I_2(\text{freon}) \rightleftharpoons I_2(aq)$$

$$3I_2(aq) + 3H_2O(l) \rightleftharpoons 5I^-(aq) + 6H^+(aq) + IO_3^-(aq)$$

$$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq)$$

- The yellow I_2 or I_3^- colour can be removed by the addition of a small amount of sodium thiosulfate:

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-}$$

- Addition of too much thiosulfate will also decolourise the freon layer as the iodine freon/water equilibrium is disturbed (Le Chatelier's principle).

SUPERSATURATED MAGIC

When a crystal is added to a clear solution it rapidly crystallises forming a solid mass and releasing heat.

CONCEPTS - USES
Science Fairs, Motivation
Supersaturation
Crystallisation and solubility
Energy reversibility

MATERIALS
Sodium acetate (hydrated) – 250 to 400g.
Large flask (eg. Florence flask) – 750mL to 1L.
Rubber stopper (to fit flask).

SAFETY NOTES
No special precautions.

PREPARATION
- Place 250g to 400g of the sodium acetate crystals into a clear, dry flask. Ensure no foreign matter is allowed entry.

- Use a low flame or a hotplate to gently heat the flask until the solid "melts" (in fact, dissolves in its own water of crystallisation). During the heating, place an inverted beaker over the mouth of the flask.

- Allow the solution to cool overnight after inserting the rubber stopper. Do not jar the solution when handling it.

PROCEDURE
- Remove the stopper and add several crystals of sodium acetate to the cool solution.

OBSERVATION
- When the crystal hits the solution crystallisation will commence sometimes jarring the mixture or even simply removing the stopper will trigger the formation of crystals.

- The clear, colourless solution will quickly be transformed into a white, opaque, solid mass.

- Heat will be given out in the process (heat of crystallisation).

COMMENTS
- The solution - crystallisation is a reversible process:

$$NaC_2H_3O_2.3H_2O(s) + \text{Heat} \rightleftharpoons Na^+(aq) + C_2H_3O_2^-(aq) + 3H_2O(l)$$

- The solution process is endothermic, the recrystallisation is exothermic.

- The normal solubility of sodium acetate is 100g/100mL.

- The mixture can be kept for many years if sealed and free from contamination.

VARIATION
- If the process is performed in a petri dish on an overhead projector, crystals are seen to grow rapidly.

COLOURFUL CHROMATOGRAPHY

Food dyes are separated into their coloured components on paper (in about 40 minutes).

CONCEPTS - USES
Motivation
Physical separation
Mixtures and compounds
Chromatography
Solubility

MATERIALS
Chromatography paper (preferably square sheets)
Melting point tubes
Sodium citrate – 2.5g
Ammonia – 250mL of 1.5M
Food dyes (supermarket)
Large jar or tall beaker (1L)
Glad wrap

SAFETY NOTES
No special precautions.

PROCEDURE

- Choose food dyes from the supermarket which have a range of colours. Check that some are mixtures (each 5-digit number is a colour index - C.I. - code for a pure dye compound). Include colours like green, brown, dark red.

- Cut a piece of chromatography about 20cm square, such that it will fit into the jar/beaker when rolled into a cylinder (no overlap) .

- Draw a pencil line about 3cm from the bottom edge of the paper (figure 1).

- Use different melting point tubes to place small (3–5mm maximum diameter) spots of the different food dyes, at 3–5cm spacings, along the pencil line. Allow the spots to dry and then apply more of each dye to get a concentrated spot (figures 1 and 2).

- Prepare the solvent by dissolving 2.5g of tri-sodium citrate in 250mL of 1.5M ammonia (alternatively make 2.5g of tri-sodium citrate and 25mL of concentrated ammonia up to 250mL with water).

- Place about a 2cm depth of solvent into the jar/beaker and cover with glad-wrap (or a lid), and allow 5 minutes to achieve a suitable equilibrium vapour pressure.

- Staple the chromatography paper into a cylinder, trying not to overlap the edges.

- Place the paper cylinder into the jar/beaker and cover. Allow to stand undisturbed for up to an hour.

- Remove paper when the solvent has almost reached the top of the paper and allow it to dry.

- Compare the food dyes to determine:

  (i) which are mixtures;
  (ii) which dye compounds are common to different food dye mixtures (identical dyestuffs will travel the same distance on the paper);
  (iii) the correspondence between the chromatogram and the label C.I. numbers.

- As the solvent moves up the paper the spots will move and those which are mixtures will begin to separate into two or more components.

COMMENTS

- Food dyes permitted in Australia are listed in each of the following:

Hansenn, M., (1992). *New Additive Code Breaker,*. Melbourne: Lothian.

Selinger, B., (1998) *Chemistry in the Marketplace.* (5th edition), Sydney: Harcourt Brace Jovanovich.

IODINE EXTRACTIONS

A blue solution and a yellow solution are mixed to produce a green solution. When shaken with one solvent the green solution forms two immiscible layers (yellow and blue). When shaken with a different solvent it produces a purple colour before separating into two immiscible layers (blue and pink).

CONCEPTS - USES

Motivation. Science Fairs
Phase equilibria
Immiscibility and solubility
Physical separation
Energy of solvation
Extraction
Polarity and non-polarity

MATERIALS

Iodine solution (in aqueous alcohol) – tincture of iodine.
Freon (or chloroform)
Ether: ***Ether is an X-Category chemical in NSW*** . Substitute with Hexane (or a hydrocarbon mixture such as petrol or kerosene)
Separating flasks (2) – 250mL or larger
Copper sulfate solution – 0.2M
Beakers
White background (stage)

SAFETY NOTES

Ether is very flammable. ***Ether is an X-Category chemical in NSW*** .

PREPARATION

- Dilute some tincture of iodine to produce about 150mL-200mL of a deep golden solution.
- Set up a retort stand and retort ring to fit the separating flasks.

PROCEDURE

- Mix equal volumes of the diluted iodine solution and 0.2M copper sulfate (about 200mL each) in a large beaker to produce a green solution.
- Pour one-third of the mixture into each of the two separating flasks, retaining the other third for comparison.
- Add about 80–100mL of ether (or substitute hydrocarbon) to one flask, stopper and shake (venting the vapours to release any build up of pressure). Allow to stand.
- Add about 80-100mL of freon to the second separating flask, stopper and shake. Allow to stand.

OBSERVATIONS

- The ether extraction should produce two layers, one blue (the lower, aqueous layer) and one either yellow (the upper, ether layer) or pink (if a hydrocarbon is used). With care in the dilution of the original iodine solution, and the selection of volumes of solution to be used, the final ether layer will appear the same colour as the original iodine solution if ether is used.
- The freon extraction should initially produce a purple colour, during the shaking, which should separate on standing to give an upper (aqueous) blue layer and a lower (freon) pink layer.

COMMENTS

- Iodine, a non-polar substance, is more soluble in the non-polar freon and the slightly polar ether, than in water (which is highly polar)
- Copper (II) ions are soluble in water but not in non-polar solvents.

RECRYSTALLISATION

A black powder is boiled and filtered whilst hot to produce a black residue and a blue-green solution. On cooling the solution forms white crystals which are filtered from the blue solution.

CONCEPTS - USES
Motivation
Solubility principles
Chemical bonding
Physical separation
Pure substances and mixtures

MATERIALS
Aspirin powder (or salicylic acid or benzoic acid) - 10g
Carbon powder (eg charcoal) - 1g
Copper sulfate - 2g
Conical flasks (250-500mL) - 2
Filter funnel
Tripods and bunsen burners - 2
Ice
Buchner funnel and flask
Filter paper
Boiling chips

SAFETY NOTES
Take care with boiling solutions.

PREPARATION
- Mix the three powders to produce a homogeneous mixture. (Alternatively, these can be mixed in front of the class and "unmixed" in the demonstration). Crush all lumps.
- Set up two bunsens (with tripods and gauzes) side by side, and bring about 400mL of water to the boil in a beaker.
- Flute a large piece of filter paper to fit the funnel.

PROCEDURE - OBSERVATIONS
- Place several teaspoon amounts of the black mixture (and several boiling chips) into a conical flask with about 100–150mL of hot water and just bring to the boil. Turn down the flame to a simmer.
- Place about 10mL of hot water into the second conical flask (with boiling chips), sit the filter funnel and fluted filter paper in it, and bring the water just to the boil on the second bunsen. The steam should heat the filter funnel. Use a dropperful of boiling water to wet the filter paper.
- With both solutions kept near boiling point, filter the black mixture in small amounts. Ensure that neither solution boils dry nor cools. The filtrate should be clear and blue, or blue-green. Charcoal will be retained in the filter paper.
- Cool the filtrate in an ice-bath (or, if time permits, set it aside to cool slowly to produce long, needle-like crystals). A white crystalline mass of aspirin (or salicylic acid or benzoic acid) will form provided not too much water was used in the first step.
- Filter the aspirin using a buchner apparatus and water aspirator. The filtrate will be blue.
- Evaporate the filtrate to dryness to give blue crystals of copper sulfate.

COMMENTS

- Charcoal (carbon) is insoluble in water, hot or cold. The aspirin (or salicylic/benzoic acid) is insoluble in cold water but soluble in hot water. Copper sulfate is water soluble.

- This demonstration illustrates the following:
  (i) a mixture, an organic compound, and an element;
  (ii) solubility and bonding - carbon is non-polar covalent, aspirin is a polar covalent substance, copper sulfate is an ionic substance;
  (iii) physical v chemical change (eg aspirin can be charred by heating to illustrate a chemical breakdown to form carbon).

- Copper and salicylic acid form a blue-green complex.

THE FOUNTAIN DEMONSTRATION

A flask “sucks up” a coloured liquid in a fountain and the liquid changes colour.

CONCEPTS - USES

Gas pressure
Air pressure
Solubility of gases

MATERIALS

Hydrogen chloride gas - can be generated by the action of concentrated sulfuric acid on sodium chloride.
Universal indicator
Florence or round bottom flask (500mL)
Rubber stopper with two holes
Piece of tapered glass tubing to fit Florence flask
Piece of rubber tubing 4"–6" long
Clamp dropper
Large beaker
Retort stand and clamp

SAFETY NOTES

- *If HCl is to be generated by reaction do so in a fume cupboard and exercise great care with concentrated sulfuric acid. (About 50mL of concentrated H_2SO_4 poured down a thistle funnel onto about 5-10g of sodium chloride in a gas generating apparatus will produce sufficient HCl to fill a 500mL flask).*

- *There is the risk of an implosion if the flask is cracked or weakened. This can be minimised by ensuring that water does not enter the flask until the clamp is released.*

PREPARATION

- Fill a dry Florence flask with hydrogen chloride gas and stopper tightly.

- Fit the two hole stopper with a long piece of glass (see diagram) attached to the rubber tubing and a dropper filled with water.

- Insert the fitted stopper into the flask and clamp it above a beaker containing water and a suitable indicator (e.g. Universal indicator). Place the rubber tubing into the water and undo the clamp.

PROCEDURE

- Squirt the water from the dropper into the flask. A quick shake may be necessary.

OBSERVATIONS

- Water should spurt into the flask and change colour as it does so. This should continue until much of the flask contains a coloured solution.

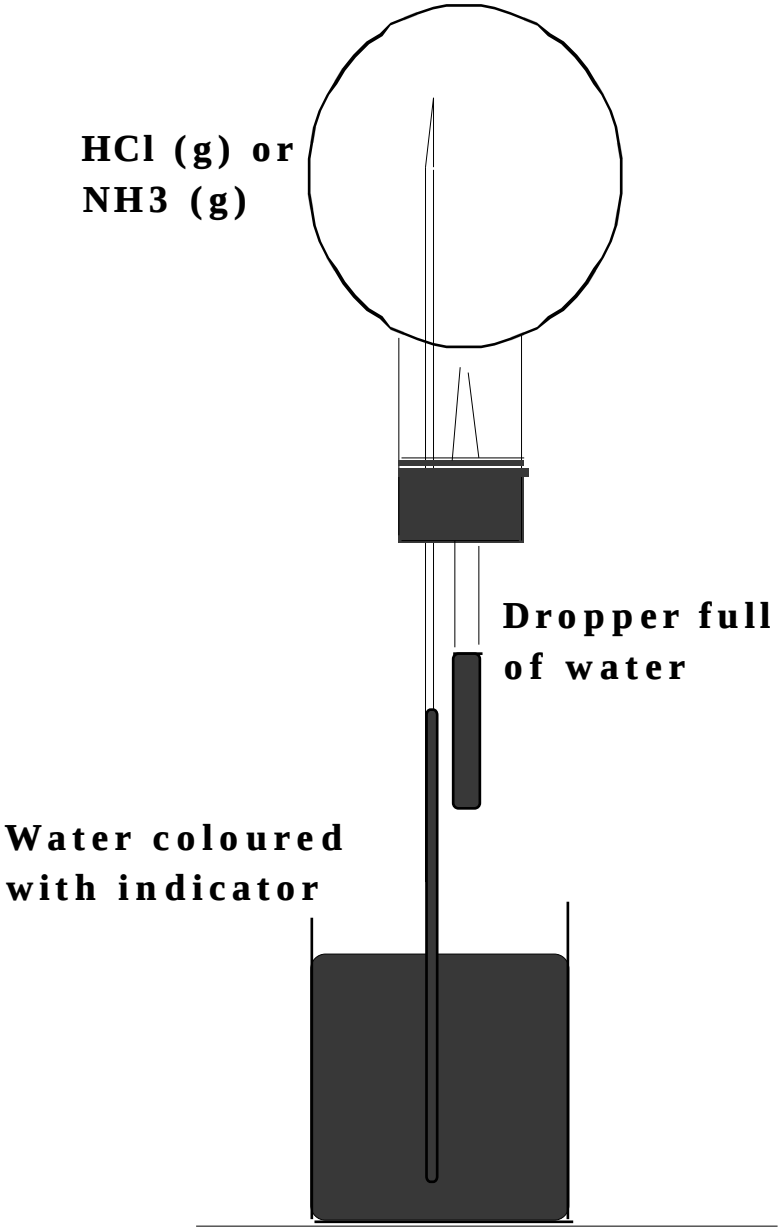
COMMENTS

- The initial volume of water will dissolve much of the HCl gas (to form hydrochloric acid). This greatly reduces the pressure inside the flask and the air pressure forces water into it as a result.

- Equation: $HCl(g) + H_2O(aq) \rightarrow H_3O^+(aq) + Cl^-(aq)$

- Failure may be due to (i) not having an anhydrous gas , (ii)a wet flask to begin with or (iii)an ineffective seal between the rubber stopper and the glassware

- Alternative gases may be used, provided they are very water soluble. Ammonia is more difficult to prepare in the anhydrous state but will work well if it is relatively dry. It can be generated by warming concentrated ammonia solution.



ANOTHER FOUNTAIN

As above, except process is started by heating the flask to expel air.

CONCEPTS - USES

Motivation. Science Fairs
Air Pressure
Kinetic Molecular Theory
Heat and expansion

MATERIALS

Large Florence or Round-bottom flask - 750mL.
Large beaker - 500mL to 1L.
Rubber stopper with 1 hole.
Glass tubing (to fit rubber stopper) - 20 to 30cm.
Rubber tubing (optional) - about 30cm.
Clips/clamps for rubber tubing (optional) - 2.
Retort ring or bosshead and clamp.
Retort stand.
Sodium hydroxide solution- about 50mL of 2M.
Phenolphthalein indicator.
Bunsen, tripod and gauze.

SAFETY NOTES

Check that flask is not cracked as there is the danger of an implosion. Take care, when inverting the hot flask, that the stopper does not come loose.

PREPARATION

- Use a piece of glass tubing that has one end drawn to a narrow orifice (about $^{1}/_{3}$–$^{1}/_{2}$ normal diameter, but not too narrow). Carefully insert the glass tubing into the stopper so that, when it is placed into the flask, the orifice of the glass tubing is about 5cm from the base of the flask.

- Set up the retort stand so that the flask can be inverted above the beaker and held in position.

- Place about 30-50mL of 2M NaOH into the flask. Swirl to wet all the inside surface.

- Mix 1–2mL of phenolphthalein with 500–600mL of water in a large beaker and stand the beaker on the base of the retort stand.

- For Method B, attach a burette clamp to a piece of rubber tubing and attach it to the end of the glass tubing.

PROCEDURE - OBSERVATIONS

Method A

- Swirl the alkali solution around the flask to fully wet the surface and then discard.

- Carefully invert the flask and place it in the retort ring (clamp) above the beaker so that the glass tubing (or the attached rubber tubing) reaches to the bottom of the beaker .

- Heat the flask evenly with a moderate flame. Bubbles of air will be seen coming from the tubing. Continue heating for 2–3 minutes to remove as much air as possible.

- Stop the heating and allow the flask to cool. Within 1–2 minutes the colourless solution will move up the tubing and enter the flask. As it enters the flask a pink-red colour is seen as the liquid enters the flask in a fountain.

Method B:

- Bring the solution of 2M NaOH just to the boil in the open flask. Turn off the bunsen and then insert the rubber stopper (with clamp on rubber tubing open).

- When hot air/steam is no longer attempting to leave the flask, tighten the clamp on the rubber tubing. (If this is done too soon the internal pressure will loosen the stopper, releasing hot alkali).

- Invert the flask and place it in the retort ring, with the bottom of the rubber tubing reaching to the bottom of the beaker.

- Loosen the clamp on the rubber tube. Within about a minute the colourless solution will enter the flask in a stream, turning bright red-purple in the process.

ADSORBING EXPERIENCES

A solid when added to coloured solutions removes the colour from solution.

CONCEPTS-USES
Adsorption
Surface effects
Physical separation
Solubility

MATERIALS
Methyl (crystal) violet - 0.1% solution
Aluminium hydroxide - 10g
Congo red - 0.2g
Methylated spirits or ethanol - 20 mL
Filtration apparatus
Beakers or conical flasks

SAFETY NOTES
No special precautions.

PREPARATION
- If Aluminium hydroxide is not available it may be prepared from a mixture of solutions of alum - $KAl(SO_4)_2$ - and sodium hydroxide. This may be prepared in situ or before hand (filter and dry in an oven).

PROCEDURE
- Place half a rice grain amount of methyl violet into a beaker or conical flask with sufficient water to produce an intensely violet solution. Swirl the solution around the container and then discard it, and rinse the container until the washings are colourless.

- Draw attention to the slight colour sheen on the surface of the glass, then add 20-30mL of methylated spirits (or ethanol) and swirl to produce a violet solution.

- Place a rice-grain amount of congo red into a beaker/flask with sufficient water to produce a red solution.

- Add several teaspoon amounts of aluminium hydroxide (or equal amounts of Al^{3+} (aq) and OH^- (aq) to produce a precipitate in situ) and bring to the boil for 1–2 minutes. Filter (at the pump preferably) to give a colourless filtrate and a red precipitate.

COMMENTS
- Methyl violet is adsorbed onto the glass and will resist dissolution in water, but is soluble in ethanol. Glacial acetic will also dissolve methyl violet.

- Congo red is adsorbed by aluminium hydroxide (which is the basis of the mordanting process in dyeing where certain dyes which do not “take” directly to fibres will take to the insoluble “lakes” formed upon pre-treatment of the fabric with a mordant, like alum).

GEL DIFFUSIONS

Solutions diffuse through a gel at different rates. Solutions and/or products of reaction are coloured.

CONCEPTS-USES

Motivation
Kinetic Molecular theory
Molecular size
Colloids
Diffusion

MATERIALS

Gelatine - 20g
Iodine solution (eg tincture of iodine) - 5mL
Starch sol - 1%
Potassium iodide - 5g
Copper sulfate solution - 0.1M x 10mL
Ammonia solution - 1M X 10mL
Iron (II) Sulfate solution - 0.1M x 10mL
Potassium ferricyanide solution - 0.25% x 10mL
Test tubes

SAFETY NOTES

No special precautions.

PREPARATION

- Prepare a 5% solution of gelatine containing 1% potassium iodide (eg dissolve 2g of KI in 150mL of water, bring it to the boil and add to it a mixture of 10g gelatine and 50mL water which has been standing 24 hours).

- Pour the hot gelatine sol into:
  (a) a long piece (eg 25cm) of glass tubing, stoppered at both ends (with corks), leaving about 2cm space at the top–allow to cool and set;
  (b) two large test-tubes to half fill them–allow to cool and set.

- Prepare the following “solutions” so that they are of equivalent colour intensities:
  (a) $Cu(NH_3)_4^{2+}$ by mixing 0.1M Cu^{2+} (aq) with sufficient 1M NH_3 to dissolve any precipitate that may initially form;
  (b) $KFeFe(CN)_6$ by mixing 1% $K_3Fe(CN)_6$ with an equal volume of 0.1M Fe^{2+}(aq) to give a deep blue sol of Prussian blue.

- Once the gel has set in the long tube, remove the bottom cork and then remove a 2cm plug of gel (eg use a cork borer). Fit a cork to both ends of the tube.

PROCEDURE

- Place a small amount of I_2 (aq) into one end of the tube containing the gel (and re-cork) and a small amount of starch sol in the other end (re-cork) an set aside for a day or so.

- Into the separate test-tubes and gel place either $Cu(NH_3)_4^{2+}$ or the Prussian blue sol and set aside.

OBSERVATIONS - COMMENTS

- As iodine is a much smaller molecule than starch, it will diffuse more speedily and thus the black starch/iodine ring will appear closer to the starch end of the tube.

- As $Cu(NH_3)_4^{2+}$ is a 'smaller' molecular species than the colloidal Prussian blue—$KFeFe(CN)_6$—it will diffuse more rapidly than the latter.

CRYSTAL FORMS

Different crystals are observed to form from hot, saturated solutions.

CONCEPTS - USES

Motivation. Science Fairs
Crystal shapes
Crystallisation and solubility

MATERIALS

Ammonium chloride - 10g (per 10mL)
Potassium nitrate - 10g (per l0mL)
Potassium chromate - 10g (per 10mL): ***Potassium chlorate is an X-Category chemical in NSW***.
Potassium chlorate - 2g (per 10mL)
Some of: Sodium hydrogen sulfate - 5g
Ammonium nitrate - 25g
Copper sulfate - 5g
Potassium ferricyanide - 10g
Iron (II) ammonium sulfate - 5g
Watch glasses
Beakers and test tubes
Bunsen
Microscope (optional)

SAFETY NOTES

Care with oxidising agents (potassium chlorate, nitrates).
Potassium chlorate is an X-Category chemical in NSW .

PREPARATION

- Prepare hot saturated solutions of each salt and maintain the temperature of each just below the boiling point.

- Set up microscope(s) if available.

- Amounts for l0mL of hot saturated solutions of each salt:
  - NH_4Cl - more than 3.9g
  - KNO_3 - more than 3.8g
  - K_2CrO_4 - more than 6.5g
  - $KClO_3$ - more than 1g
  - $NaHSO_4$ - more than 2.9g
  - NH_4NO_3 - more than 21g
  - $CuSO_4$ - more than 2.2g
  - $K_3Fe(CN)_6$ - more than 4.9g
  - $(NH_4)_2Fe(SO_4)_3$ - more than 2.5g

PROCEDURE

- Pour about 2mL of each hot, saturated solution into a watch glass and observe. Use a microscope if available.

OBSERVATIONS

- As solutions cool, crystals will appear and will grow.
- Different shapes will be observed

e.g. NH_4Cl dendrites K_2CrO_4 - “fluffy” clusters
NH_4NO_3 - needles KNO_3 - needles
$KClO_3$ - thin plates $NaHSO_4$ - needles

A CRYSTAL GARDEN

Plant-like, coloured shapes grow slowly from different seed crystals in a solution of waterglass.

CONCEPTS - USES

Motivation, Science Fairs
Solubility
Precipitation
Crystal formation

MATERIALS

Sodium silicate solution (Waterglass); Crystals of some of the following:

Cobalt (II) Nitrate.
Iron (III) nitrate (or chloride).
Magnesium nitrate (or sulfate).
Manganese (II) sulfate.
Large beaker or glass jar.

SAFETY NOTES

No special precautions.

PREPARATION

- Dilute the sodium silicate solution 1 to 4 with hot water, stirring well as the two are mixed.

PROCEDURE

- Place the diluted sodium silicate solution in a beaker/jar to a depth of about 10–12cm and allow to stand.
- Drop in a large crystal of each different compound so that they are evenly spaced at the bottom of the beaker/jar.
- Cover the beaker/jar and leave overnight.

OBSERVATIONS

- A “Crystal garden” of different silicates, with characteristic colours will have formed.

COMMENTS

- Equations:

$2Co^{2+} + SiO_4^{2-} \rightarrow Co_2SiO_4$ (red/violet)

$Mn^{2+} + SiO_4^{2-} \rightarrow MnSiO_3$ (pink)

$Fe^{3+} + SiO_4^{2-} \rightarrow FeSiO_3$ (green)

$Mg^{2+} + SiO_4^{2-} \rightarrow MgSiO_3$ (white)

THE SUNSET DEMONSTRATION

An off-white precipitate is slowly formed in a flask producing a Tyndall beam when in front of a projector. The transmitted light slowly changes colour from white ? yellow ? orange ? red ? black.

CONCEPTS - USES

Explanation of red sunset
Reflection of light by particles
Colloids
Tyndall Effect

MATERIALS

Sodium Thiosulfate crystals - 20g (approx)
Water - 1 litre
Dilute (2M) HCl - 20 mL (approx)
Florence flask (or substitute) - 1 litre
35 mm projector
Screen or white wall.

SAFETY PRECAUTIONS

Sulfur dioxide is produced in the reaction. Take care that the fumes are not inhaled when disposing of the solution.

PREPARATION

- Dissolve about 20g of sodium thiosulfate per litre of water and place in a 1 litre Florence flask (or a large beaker).

- Arrange projector so that its light is thrown onto a wall or screen that is easily observable and so that the light path is observable by the class.

- Place a support for the Florence flask in front of the lens of the projector so that all the light shines through the flask.

PROCEDURE

- Stand flask in front of lens.

- Add about 20ml of dilute HCl and shake. A precipitate of colloidal sulfur slowly forms. As it forms the beam of light becomes more noticeable as it passes through the mixture (Tyndall effect). As more sulfur forms the light passing through and being seen on the screen changes hue from pale yellow to yellow, then to orange, and then red ending with darkness.

EXPLANATION

Chemically: $2HCl + Na_2S_2O_3 \rightarrow S + SO_2 + H_2O + 2NaCl$

Colloidal sized particles can scatter light. Thus they show a strong Tyndall effect. As they more effectively scatter blue light, they allow red light to pass through the dispersion preferentially.

Colloidal particles in the air close to the horizon block and scatter the blue light whilst permitting red light (of longer wavelength) to pass through. Thus as the sun approaches the horizon more and more of the blue light is reflected (blocked) and the sun and sky appear redder.

ANILINE MAGIC

An orange (or red) liquid forms globules when added to water. Addition of a reagent causes the oil to disappear. Subsequent addition of another reagent produces an opaque (colloidal) dispersion.

CONCEPTS - USES

Motivation. Science fairs
Solubility
Density
Structure of molecules
Polarity and non-polarity of molecules
Solutions, suspensions and colloidal dispersions

MATERIALS

Aniline - 5mL : ***Aniline is an X-Category chemical in NSW*** .
Oil soluble dye (optional)
Concentrated hydrochloric acid - 5mL
Sodium hydroxide (4M) - 20mL
Measuring cylinder (eg 250mL)
Stopper
Acetic anhydride (optional)
Beaker

SAFETY NOTES

Take special care with aniline - it is toxic and carcinogenic. Acetic (ethanoic) anhydride is corrosive to skin and gives off acrid fumes
Aniline is an X-Category chemical in NSW .

PREPARATION

If the aniline is fresh, and not dark in colour, it can be coloured with a small amount of an oil-soluble dye (eg. Sudan III).

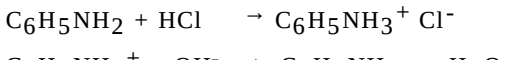
- Fit a tall (250mL–500mL) measuring cylinder with a stopper.

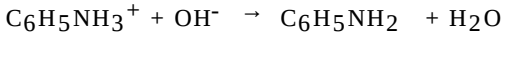
PROCEDURE

- Fill a measuring cylinder with water to within 7cm of the top, and set against a white background.
- Pour about 5mL of aniline into the flask. The aniline should form globules of oil which are denser than water. Stopper the flask.
- Gently swirl the flask to produce interesting shapes in the aniline globules. Invert the flask to show aniline disperses but does not dissolve, and the globules coalesce again on standing to form a dense layer of the oil.
- Add 5mL of concentrated hydrochloric acid to the flask, stopper and invert to mix thoroughly. The aniline should disappear as it dissolves.
- Add about 15–20mL of 4M sodium hydroxide and mix by inverting. A cloudy turbidity should be produced in the mixture as the aniline forms a colloidal dispersion.

COMMENTS

- Aniline is poorly soluble in water. Addition of HCl produces the salt anilinium chloride, which is water soluble. Subsequent addition of a base re-forms the aniline as microscopic (colloidal) droplets, giving an emulsion.



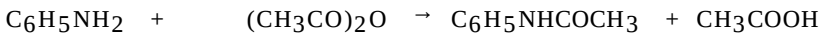


FURTHER ACTION

- Carefully mix about 2mL of aniline with about 5mL of acetic anhydride. Note the heat produced.

- Pour this mixture into about 100mL of cold water and stir well with a glass rod. White crystals of acetanilide should form.

- Aniline and acetic anhydride are used to synthesise the drug acetanilide (a precursor to the paracetamol family of analgesics).



aniline	acetic anhydride	acetanilide	acetic acid

- Acetanilide is quite soluble in acetic anhydride but poorly soluble in water.

HERON'S SIPHON

Water is added to a can producing an apparently continuous stream of water from one can to another.

CONCEPTS - USES

Motivation. Science fairs
Problem solving skills
Pressure (Pascal's principle)
Scientific methods/processes

MATERIALS

Thistle funnel (or filter funnel)
Glass tubing
Rubber tubing
Large Cans (5L) – 2
Rubber stoppers (2 holed) – 2
Coloured water

SAFETY NOTES

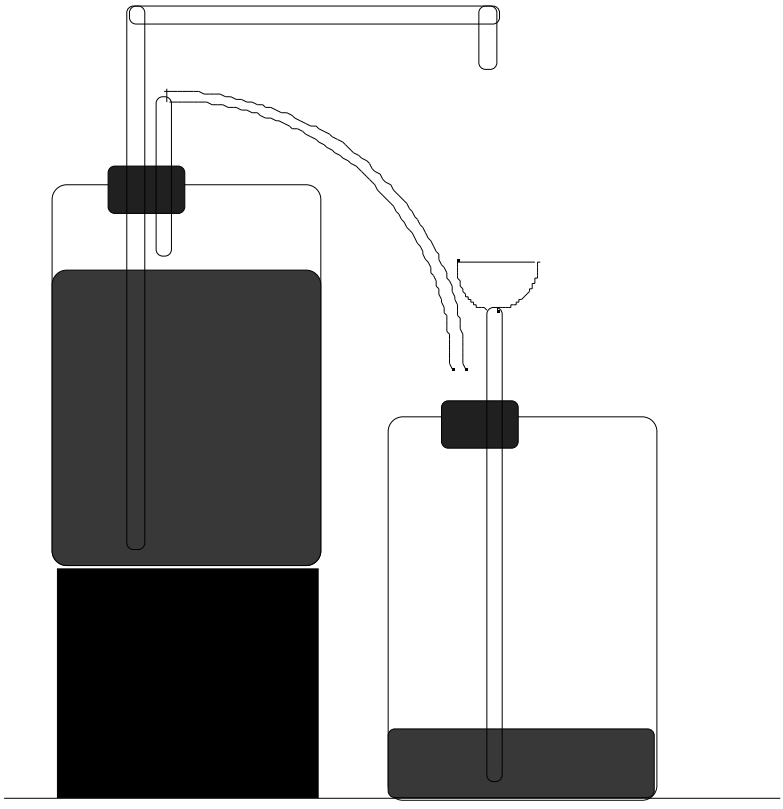
No special precautions.

PREPARATIONS

- Bend a piece of glass tubing to the following shape and approximate dimensions.
- Bore two rubber stoppers with two holes to fit the glass tubing and thistle funnel (see diagram).
- Connect glass tubing, thistle funnel and rubber tubing (as in diagram).
- Add coloured water to each can to the levels indicated. Ensure that the apparatus is air tight.
- Have about 1 litre of the coloured water in reserve for the demonstration.
- Set the cans up as shown in the diagram.

PROCEDURE

- Pour coloured water into the thistle funnel until the water siphons into the funnel from the other can.



OBSERVATIONS

- Water will siphon (apparently in a cycle) for about 5-10 minutes, depending on the capacity of the cans (until the water in the full can had been transferred to the lower can and the levels are equal).

COMMENTS

- This can be used as an exercise in deductive reasoning. Ask the students to draw a diagram of the internal (hidden) states of each can at the start of the operation. If students "jump" to conclusions before enough time has passed for the siphon to cease working, the point can be made that patience and observation over a reasonable period of time is a necessary part of the scientific approach.

FOAMS

Solutions are mixed to form a number of foams.

CONCEPTS - USES
Colloids
Effervescent reactions
Acid-base reactions

MATERIALS
Aluminium sulfate - 35g
Sodium bicarbonate - 30g
Egg albumin - 1 egg
Laundry detergent powder - 1g
Beakers

SAFETY NOTES
No special precautions.

PREPARATION
- Solution A: Mix 1g of a laundry powder detergent and 7g of aluminium sulfate and grind to a fine powder before dissolving in about 50mL of water.
- Solution B: Dissolve about 5g of sodium bicarbonate in 50mL of water.
- Solution C: Dissolve 25g of aluminium sulfate (or an equivalent amount of “alum”—potassium aluminium sulfate) in 100mL of water.
- Solution D: Dissolve 25g of sodium bicarbonate in about 150mL of tepid water and slowly add the white of an egg with stirring and gentle heating. Cool the solution and collect the top 100mL of the solution.

PROCEDURE
- Quickly pour solution A into solution B. A stable foam should quickly form.
- Quickly pour solution D into solution C. A stable foam should form.

COMMENTS
- The reactions are due to the acidity of Al^{3+}

$$Al(H_2O)_6^{3+} \rightarrow Al(H_2O)_5\,OH^{2+} + H^+$$

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

QUICKIES

AIR PRESSURE #1

Needs
- 250-500mL Florence or conical flask
- 7cm filter paper
- Retort stand, boss head and clamp.

Method
- Fill the flask to overflowing with water.
- Slide the piece of filter paper across the top of the water ensuring that no air bubbles are allowed to form.
- Invert the flask and carefully clamp it upside down in a secluded spot.

Observation
- The air pressure acting upwards (not just downwards as many students think) supports the weight of the water.
- If left undisturbed the water will slowly evaporate and be replaced by air in the flask until the pressure inside the flask exceeds the external air pressure.

AIR PRESSURE #2

Needs
- Aluminium “pop top” can with araldite used to enable a rubber stopper to form an air-tight seal when inserted.
- Rubber stopper to fit hole in can.
- Tripod, bunsen, gauge.

Method
- Place about 10mL of water in the can and bring to boil.
- After water has boiled in the can for a minute or so, turn off the bunsen and insert the stopper into the hole. Push it in tightly to ensure an efficient seal.
- Allow can to cool undisturbed.

Observation
- Within a minute or so the can will buckle noisily and be crushed by the external air pressure.

AIR PRESSURE #3

Needs
- 1 boiled egg (shelled)
- Tripod, bunsen, gauze.

Method
- Heat the “empty” flask for about half a minute.
- Turn off the bunsen and place the egg onto the flask opening so that it seals it (pointy end downwards).

Observation
- As the flask cools the external air pressure will force the egg into the flask.

IODINE PHASE CHANGES

Needs
- Solid iodine crystals
- 500–750mL flask
- Stopper
- Bunsen
- Freon or alcohol

Method
- Place several small pieces of iodine in the flask and insert the stopper loosely.
- Shake the flask and listen for the sound of the solid iodine.
- Wave flask into and out of a moderate bunsen flame until iodine can no longer be heard and iodine has sublimed.
- Cool the flask under a stream of cold water.
- Observe the tiny iodine crystals on the walls of the flask.
- Add alcohol (or freon) to dissolve the iodine.

Observation
- Small pieces of iodine sublime to fill the flask with a purple vapour.
- Some iodine may momentarily melt and run along the inside of the glass showing the liquid phase.
- Upon cooling the purple colour is all but removed as the iodine forms fine solid crystals on the glass
- The alcohol dissolves the iodine to form a brown solution (Freon forms a pink-violet solution).
- All phases of a substance-gaseous, liquid, solid and solution can be observed in this sequence.

AMMONIUM CHLORIDE SUBLIMATION

Needs
- Solid ammonium chloride.
- Evaporating basin.
- Tripod and bunsen.

Method
- Heat a small amount (e.g. 3–5g) of NH_4Cl moderate flame.

Observation
- The solid will sublime and upon cooling in the air, form white wisps of smoke.

CHALK CHROMATOGRAM

Needs
- Piece(s) of white chalk
- Food dye or dark coloured ink
- Beaker, watch glass (or Gladwrap)
- Methylated spirits

Method
- Place an intense spot of an ink or dye about lcm from the base of a piece of chalk.
- Place a 0.5cm depth of alcohol into a beaker.
- Stand chalk in beaker and cover.

Results
- Coloured spot(s) will move up chalk and separate.

SUPERSATURATION #1

Needs
- Sodium thiosulfate crystals (hypo)
- 500–700mL flask

Method
- Use a gentle flame or a hotplate to heat the crystals gently until they dissolve in their own water of crystallisation. Cover with a small beaker and stand overnight to cool undisturbed.
- If crystals are uncontaminated, a supersaturated solution will be formed.
- Add a crystal of sodium thiosulfate to the cool solution.

Observation
- The clear colourless solution is quickly transformed into a solid, white, opaque mass. Heat is given out.
- Footwarmers in old trains contained crystals of 'hypo'.

SUPERSATURATION #2

Needs
- Sodium sulfate crystals - 100g
- Beakers

Method
- Dissolve 100g of sodium sulfate crystals in 120mL of water in a clean beaker, warming.
- Place the warm solution into 2 separate beakers, cover and cool. Do not disturb.

Observation
- When cool, lift the cover of one beaker and jar or tap the beaker. Crystallisation should occur.
- Add a "seed" crystal of sodium sulfate to the second beaker. Crystallisation begins at once.

SUPERSATURATION #3

Needs
- One (or both) of: lead iodide (0.86g), benzoic acid (11.8g)
- 250–500mL flasks (or beakers)
- Bunsen, tripod, gauze

Method
- Dissolve the indicated weight of the solid in 200mL of boiling water.
- Allow to cool or use iced water to cool the flask(s).

Observation
- Crystals will form. For PbI_2 yellow leaflets soon appear giving a "golden rain" appearance in the sun. For benzoic acid–fine white crystals appear.

PHYSICAL v CHEMICAL CHANGE #1

Needs
- 0.5M copper sulfate
- 0.2M potassium chromate
- Dilute iodine solution (tincture of iodine)
- Beakers or test tubes

Method
- Dilute some iodine/alcohol solution (tincture of iodine) until it is the same colour as 0.2M potassium chromate.
- Mix equal volumes of blue $Cu^{2+}(aq)$ and yellow $I_2(aq)$ to produce a green mixture - a physical change.
- Mix equal volumes of blue $Cu^{2+}(aq)$ and yellow $CrO_4^{2-}(aq)$ to produce a mustard coloured precipitate of $CuCrO_4$ - a chemical change.

Results
- The physical change produces no new substance - the properties of the mixture (eg colour, solubility) are those of the mixed components.
- The chemical change produces a new substance whose properties (eg. colour, solubility) are different to those of the reagents.

CHEMICAL v PHYSICAL CHANGE #2

Needs
- Sucrose (about 5g)
- Naphthalene (or mothball) or menthol (about 1g)

Method
- Heat each solid separately in a test tube fitted with a 10cm piece of glass tubing.

Observation
- The sucrose chars (forming carbon) and releases steam - a chemical change which does not spontaneously reverse on cooling.
- The naphthalene melts and then boils producing a noticeable odour - a physical change which is reversed on cooling (note crystals in tube).

Alternatively
- Heat solids in evaporating basins with inverted funnel standing on basin.

BOILING BY COOLING

Needs
- Florence or round bottom flask
- Retort ring and stand
- Ice
- Rubber stopper to fit flask
- Bunsen, tripod, gauze

Method
- Half fill the flask with water (coloured with food dye if desired) and boil it for a minute.
- When water ceases boiling, place the stopper loosely in the mouth of the flask to enable internal pressure to equal atmospheric pressure, then insert the stopper firmly.
- Invert the flask and stand in a retort ring (or clamp it).
- Place a block of ice on the flask (or cool it with wet palm of the hands after allowing it to cool a little).

Results
- The water in the flask will boil.

BOILING BY SUCTION

Needs
- Side arm flask (or test tube)
- Vacuum pump (eg water aspirator)
- Ether (or acetone or methanol): ***Ether is an X-Category chemical in NSW.***
- Stopper for flask

Method
- Place some of the ether in the flask and firmly stopper it (if acetone or methanol are used it may be necessary to slightly warm the flask on a hotplate).
- Attach to the pump and evacuate.

Results
- The liquid should boil.

SEPARATION BY ADSORPTION

Needs
- Activated charcoal (about 5–10g)
- Solution of methylene blue (or methyl violet)
- Conical flask (250–500mL)
- Filtration apparatus

Method
- Shake 1–2 teaspoons of activated charcoal with about 150mL of solution containing 2-3 drops of the dye for at least 1 minute.
- Filter.

Observation
- Filtrate will be clear and colourless.

Variations
- Decolourise soft drinks (e.g. Orange, Lime, Cola) or brown vinegar using 2–3 teaspoons of activated charcoal

SALT “GLUE”

Needs
- A small block of ice
- Beaker of water
- Salt (NaCl)
- Piece of cotton/wool thread or string

Method
- Moisten one end of thread and lie it across block of ice floating on some water.
- Place moist thread across the ice and sprinkle it with salt.
- Wait for a moment and then pull thread.

Results
- Thread will be attached to ice, which can be lifted from beaker.

SELECTIVE ADSORPTION

Needs
- Kaolin
- One of: methylene blue, methyl violet, crystal violet
- One of: methyl orange, tartrazine (food additive-102) cochineal (food additive-120)

Method
- Prepare a solution of any two dyes, one from each group above (eg. methylene blue + cochineal).
- Add a teaspoon of kaolin, shake well, and allow to stand.

Result
- Kaolin will absorb some dyes (eg. first group) but not others (eg. second group).
- The colour of the solution will change as a result of the selective absorption of one of the dyes.

DENSITY

Needs
- Methylated spirit
- Olive (or vegetable) oil
- Sudan III dye (optional)
- Measuring cylinder (100–250mL)

Method
- Half fill the cylinder with water.
- Carefully pour a layer of methylated spirits onto the water layer.
- Add several crystals of Sudan III (or any oil-soluble dye) to about 10mL of a vegetable oil to colour it.
- Add 0.5mL of coloured oil to the measuring cylinder.

Result
- The coloured oil will be suspended at the (invisible) interface of the alcohol and water.

SECTION 2: ATOMIC STRUCTURE AND CHEMICAL BONDING

Conservation of matter
Green fire
Coloured fireworks
Fireworks II
“Quickies”

CONSERVATION OF MATTER
(The Copper cycle)

A sequence of reactions, starting with copper metal, in which the indestructibility of elements (i.e. atoms) is shown.

CONCEPTS - USES

Atomic theory of matter
Elements and compounds
Law of conservation of matter
Element production

MATERIALS

Copper powder (preferred) - or wire or sheet
Copper compounds. At least:
- Copper sulfate
- Copper carbonate
- Copper oxide
- Copper nitrate

Sodium hydroxide - dilute (eg 2M)
Sulfuric acid - dilute (eg 2M)
Nitric acid - concentrated or dilute (2M)
Zinc powder
Ammonia solution - dilute (eg 2M) or concentrated
Hydrochloric acid - concentrated
Drinking straw
Atomiser spray bottles (several)
Beakers and test tubes
Bunsen burner or Mekker burner
Nichrome (or platinum) wire (for flame testing)

SAFETY NOTES

Take care with concentrated nitric acid and the brown fumes of nitrogen dioxide produced when it reacts with copper.

PREPARATION

- Prepare about 50mL 0.1M or 1% solutions of the soluble copper salts e.g. $CuSO_4$, $Cu(NO_3)_2$ and place into separate atomiser spray bottles.

PROCEDURE - OBSERVATIONS

1: Flame test for copper

- Set the Mekker (or bunsen) burner flame to a semi-luminous state (air hole half open).

- Use the drinking straw to blow a small (one-quarter teaspoonful) amount of copper powder into the flame to produce a green colour. Alternatively strongly heat some (old) copper wire (or sheet or gauze) in the flame to produce a green flame colour. Tell students this is a test for the element copper.

- Blow a small amount of the insoluble copper compounds (eg CuO, $CuCO_3$) into a semi-luminous flame and note the green colours. (The black CuO can be called “Tenorite” and the green $CuCO_3$ “Malachite” or “azurite” if their identity is to be revealed later).

- Spray solutions of the soluble copper salts - eg $CuSO_4$, $Cu(NO_3)_2$ - in semi-luminous flames to produce a green colour. The $CuSO_4(aq)$ can be called “chalcothinite solution” or “blue vitriol solution” if their identity is not to be revealed before testing.

- The nichrome (or platinum) wire may be used to heat small amounts of solid for flame tests (in a small loop).

2: Tests for aqueous copper ion

- Solutions of Cu^{2+} (aq) can be tested separately, with dilute or concentrated ammonia (to produce an intensely blue colour) and with concentrated hydrochloric acid (to produce a bright green solution).

3: Reaction of copper metal

- Dissolve about 0.5g of copper metal (powder or pieces) in 10mL concentrated nitric acid (avoid fumes of NO_2) in a fume cupboard or a flask attached to a water aspirator. When copper is dissolved add sufficient water to produce a blue solution. Alternatively, dissolve the copper in dilute nitric acid, with heating. On each case, copper nitrate solution is produced.

- Divide the solution into two parts and use one half in tests for:
  (i) the element copper (flame test);
  (ii) copper ions (NH_3 or HCl or both)

4: Reaction of copper nitrate

- Neutralise the excess acid in the remaining half of the solution by adding sodium hydroxide solution until a thick blue precipitate of $Cu(OH)_2$ is formed. Simultaneously add NaOH to some $Cu(NO_3)_2$(aq) prepared from the salt to show an identical reaction.

- Heat the $Cu(OH)_2$ suspensions strongly to form a black precipitate of CuO. The two can be combined if desired.

- Use the nichrome (or platinum) wire to heat small amount of the precipitate in a strong flame to test for copper (green flame).

5: Reaction of copper oxide

- Add sufficient sulfuric acid to the copper oxide mixture (and separately to a small amount of "tenorite" [copper oxide] powder) to dissolve it, using heat, to produce a blue solution. Divide this solution into two.

- Use one half of the solution to test for:
  (i) copper (flame test);
  (ii) copper ions (with conc. NH_3 and/or conc HCl).

6: Re-formation of copper metal

- Add just sufficient dilute sodium hydroxide to the remaining copper sulfate solution to neutralise the excess acid. (Test with blue litmus paper).

- Add a spatula amount of zinc powder and shake well. Brown-reddish copper metal should form and the blue colour should fade.

ALTERNATIVE PROCEDURE

1: Test "Malachite" for Copper

- Use a straw to blow some copper carbonate ("malachite") through a semi-luminous flame to produce a green (copper) colour.

2: Reactions of "malachite"

- Dissolve some copper carbonate in dilute sulfuric acid, with mild heating. The powder effervesces and will dissolve to form a blue solution. Test the blue solution for
  (i) copper (spray into a flame);
  (ii) copper ions (conc. NH_3 and/or conc. HCl)

- Heat a small (spatula) amount of copper carbonate in a strong flame to produce a black powder (copper oxide). Test the powder for copper (blow some through a flame).

- Treat the copper oxide as in step #5.

COMMENTS

- These reactions demonstrate the point that, whereas compounds (and thus molecules) are destroyed in chemical reactions elements (and thus atoms) are not. Chemical changes therefore involve re-arrangements of atoms to form different molecular (or ionic) combinations.

- The main reactions are

(a) Tests for Cu^{2+} (aq)

$$Cu^{2+} + 4NH_3 \rightarrow Cu(NH_3)_4^{2+}$$

$$Cu^{2+} + 4Cl^- \rightarrow CuCl_4^{2-}$$

(b) Reactions

$$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2NO_2 + 2H_2O$$

(conc.)

$$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$$

(dilute)

$$Cu^{2+} + 2OH^- \rightarrow Cu(OH)_2$$

$$Cu(OH)_2 \rightarrow CuO + H_2O$$

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

$$Cu^{2+} + Zn \rightarrow Cu + Zn^{2+}$$

$$CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$$

$$CuCO_3 \rightarrow CuO + CO_2$$

GREEN FIRE

A colourless liquid burns with a bright green flame.

CONCEPTS - USES

Motivation. Science Fairs
Atomic spectra
Atomic structure
Incandescence

MATERIALS

Boric acid (boracic acid) - 5g
Methanol - 25mL
Evaporating basin
Taper
Laboratory mat

SAFETY PRECAUTIONS

Methanol is toxic and flammable.

PREPARATION

- Shake about 5g of boric acid with about 25mL of methanol, in a flask or test tube.

PROCEDURE

- Place the solution into an evaporating basin, sitting on a laboratory mat. Darken the room.
- Ignite the vapours.

OBSERVATIONS - COMMENTS

- The methanol burns with a bright green flame, due to the emission spectrum of boron.

COLOURED FIREWORKS

Solid mixtures are ignited to produce different coloured flames.

CONCEPTS - USES

Motivation. Science Fairs
Energy of reaction
Atomic spectra
Atomic structure
Incandescence

MATERIALS

Potassium chlorate: ***Potassium chlorate is an X-Category chemical in NSW.***
Sucrose
Strontium salt (e.g. strontium chloride)
Barium or copper salt (e.g. barium chloride or copper sulfate)
Calcium salt (e.g. calcium chloride)
Sodium salt (e.g. sodium chloride)
Concentrated sulfuric acid
Dropper
Laboratory mats

SAFETY NOTES 

- ***. Potassium chlorate is an X-Category chemical in NSW*** *. It is very dangerous. It should not be ground, impacted or mixed with concentrated sulfuric acid.*

- *Take care with concentrated sulfuric acid.*

- *Perform the demonstration(s) in a well ventilated room, outdoors or in a fume cupbaord.*

- *Do not store any leftover sugar-chlorate mixture: flush down the sink.*

PREPARATION

- Grind about 10g of sucrose to a fine powder. Place it into a clean, dry beaker.

- Place about 10g of potassium chlorate into a clean, dry beaker and gently crush any lumps, using a finger or a bakelite spatula. BE CAREFUL NOT TO GRIND THE COMPOUND!

- Mix the sucrose and the potassium chlorate, by shaking the powders together in one of the beakers. Divide this mixture, which is potentially very reactive, into equal portions in dry test tubes (or small beakers).

- Add about 1g of one each of the following metal salts to successive test tubes, and mix well by shaking:
  (1) strontium salt
  (2) sodium salt
  (3) calcium salt
  (4) barium or copper salt

PROCEDURE

- Pour the sugar-chlorate mixtures onto separate laboratory squares well clear of all equipment and chemicals.

- Darken the room and then ignite each mound by adding one or two drops of concentrated sulfuric acid WITH CARE (holding the dropper at arm's length).

OBSERVATIONS

- The mounds of powder will ignite with a flare, and give off light of a colour which is characteristic of the metal contained in the mixture, as follows:

(1) strontium - crimson
(2) sodium - orange
(3) calcium - red
(4) barium (or copper) - green
(5) potassium - lilac

COMMENTS

- The colours are characteristic for each metal, resulting from the emission of energy due to the excitation of electrons from one electron energy level to a higher one, and subsequent return to the ground state.

FIREWORKS II

Variation on Coloured Fireworks.

CONCEPTS - USES

Motivation. Science fairs
Energy
Atomic spectra
Redox reactions

MATERIALS

Potassium chlorate: ***Potassium chlorate is an X-Category chemical in NSW.***
Sucrose
Charcoal
Sulfur
Strontium nitrate(or chloride)
Copper sulfide
Copper sulfate
Copper oxide
Mercury (I) chloride
Barium nitrate(or chloride)
Sodium chloride
Potassium nitrate
Antimony sulfide


SAFETY NOTES

Treat potassium chlorate with great care: Do not grind! Potassium chlorate is a strong oxidiser, and most mixtures are dangerous if mistreated. ***Potassium chlorate is an X-Category chemical in NSW*** *. Mercury (I) chloride is toxic.*

PREPARATION

The following mixtures of finely powdered chemicals (by volume) will, when ignited, produce flames of the colour indicated. DO NOT GRIND $KClO_3$! Keep the amounts to a minimum (eg. 5g total, at most).

Chemicals	Ratio	Colour
• Strontium salt • Potassium Chlorate • Sucrose or Charcoal/sulfur	1 1 1	Crimson
• Copper sulfate • Potassium Chlorate • Sulfur	1 1 1	Purple
• Copper sulfate • Potassium Chlorate • Sucrose	1 1 1	Blue-green
• Copper sulfide • Copper oxide • Mercury I chloride • Potassium chlorate • Sucrose or Charcoal/sulfur	3 1 2 6 2	Blue
• Sodium chloride • Potassium Chlorate • Sucrose or Charcoal/sulfur	3 4 1	Yellow-orange

• Antimony salt	1	Brilliant white
• Potassium nitrate	6	
• Sulfur	1	

PROCEDURE

- Place a small amount of each mixture (sufficient to cove a 20¢ coin in a small mound) onto a flame-proof mat.

- Ignite each mixture using a lighted taper on the end of a metre rule.

- The mixtures will flare and produce a flame that has a distinctive colour.

COMMENTS

- Potassium chlorate and potassium nitrate are strong oxidising agents. Charcoal, sulfur and sucrose are all reducing agents.

- The distinctive colours are characteristic of certain metals which undergo incandescence when they are heated. The incandescence produces a colour which corresponds to electron transitions from an excited state to a lower energy state.

- Colours may be observed through a spectroscope which will often reveal individual lines in an elements atomic spectra.

QUICKIES

POLARITY OF WATER

Needs
- Tap
- Perspex rod (or glass rod)
- Ebonite rod
- Piece of flannel or wool
- Piece of silk

Method
- Allow water to run from a tap in a thin, continuous stream.
- Charge the perspex (or glass) rod, with a positive charge, by rubbing it with silk.
- Hold the charged rod near the stream of water.
- Charge the ebonite rod, with a negative charge, by rubbing it with wool (or flannel).
- Hold the charged rod near the stream of water.

Results
- In each case the stream of water will be attracted to the rod, as it is a polar liquid.

Variations

Try polar liquids (e.g. alcohols, acetone) and non-polar liquids (eg. freon, hexane) running from burettes.

Section 3: CHEMICAL EQUILIBRIUM

Colourful equilibria
Iron equilibria
Iron (III) equilibria
Colourful copper complexes
Colourful cobalt equilibria
Competing equilibria
Copper complex equilibria
Cobalt-Alcohol equilibria
Bicarbonate equilibrium
See Section 10 “Quickies” for other examples

COLOURFUL EQUILIBRIA

A series of reagents are mixed to produce and dissolve precipitates of different colours.

CONCEPTS - USES

Motivation. Science Fairs
Reversible equilibria
Competing equilibria
Shifting the equilibrium position
Colourful changes

MATERIALS

Hydrochloric acid - 0.100M and 1M
Sodium hydroxide - 0.105M (plus phenolphthalein indicator)
Iron (III) chloride - 0.01M in 0.01M Hydrochloric acid
Potassium (or ammonium) thiocyanate - 0.03M
Silver nitrate - 0.01M
Sodium (or potassium) iodide - 0.1M
Freon (or chloroform)
Starch
Sodium (or potassium) cyanide - 0.1M : ***Sodium (or Potassium) cyanide is an X-Category chemical in NSW.***
Sodium nitrite - 0.1M optional
Sodium fluoride - 0.5M

SAFETY PRECAUTIONS

Take special care with the highly toxic chemicals (thiocyanate, fluoride, cyanide, nitrite). As small amounts of dangerous hydrogen cyanide gas are produced in the reaction, adequate ventilation is advisable. ***Sodium (or potassium) cyanide is an X-Category chemical in NSW.***

PREPARATION

10mL of each of the following solutions (except freon or chloroform) are required:
(1) 0.100M HCl
(2) 0.105M NaOH (+ phenolphthalein)
(3) 0.01M $FeCl_3$ in 0.01M HCl
(4) 0.03M KCNS (or 0.1M NH_4CNS)
(5) 0.5M NaF
(6) 0.01M $AgNO_3$
(7) 0.05M NaCN in 0.05M $NaNO_2$
(8) 0.1M NaI (or KI)
(9) 1M HCl
(10) Freon (or chloroform) - 100mL
(11) 1% starch solution

PROCEDURE

- Add exactly 10mL of each of the solutions to a large beaker in order (1 to 11), stirring well each time and observing the reactions that occur in each case.

OBSERVATIONS

- Solution 1 - colourless
- Solution 2 added = pink solution results
- Solution 3 added = colourless solution results
- Solution 4 added = dark red solution results
- Solution 5 added = colourless solution results
- Solution 6 added = white precipitate results
- Solution 7 added = colourless (or light pink) solution results
- Solution 8 added = pinkish-yellow suspension results

- Solution 9 added = orange suspension results
- Solution 10 added = orange suspension with a lower pink layer results
- Solution 11 added = blue-black suspension with a pink layer results.

REACTIONS

The equations for the equilibrium reactions involved are:

(1) + (2): $HPh + OH^- \rightarrow Ph^- + H_2O$

(Mix) + (3) : $Ph^- + H^+ \rightarrow HPh$

(Mix) + (4) : $Fe^{3+} + SCN^- \rightarrow FeSCN^{2+}$

(Mix) + (5) : $FeSCN^{2+} + 6F^- \rightarrow FeF_6^{3-} + SCN^-$

(Mix) + (6) : $Ag^+ + Cl^- \rightarrow AgCl$

(Mix) + (7) : $AgCl + 2CN^- \rightarrow Ag(CN)_2^- + Cl^-$

(Mix) + (8) : $Ag(CN)_2^- + I^- \rightarrow AgI + 2CN^-$

(Mix) + (9) : $3I^- + 2NO_2^- + 4H^+ \rightarrow 2NO + H_2O + I_3^-$

(Mix) + (10): $I_3^- + Freon \rightarrow I_2(freon) + I^-$

(Mix) + (11): $I_3^- + Starch \rightarrow Starch\text{-}I_2 + I^-$

COMMENT

- Most solutions will keep for extended periods, though aqueous iodine solutions will slowly oxidise to produce iodine, giving the solution a yellow colour over time. (Addition of a small amount of sodium hydroxide will retard this).

- Solution (7), the cyanide/nitrite mixture, tends to decompose slowly due to the following reaction:

$$3CN^- + 5NO_2^- + H_2O \rightarrow N_2 + 3CO_3^{2-} + 2OH^-$$

- As sodium and potassium cyanide are not permitted in many schools, solution (7) may be omitted from the sequence.

IRON EQUILIBRIA

A solution, when poured from one beaker to the next in sequence, undergoes a series of colour changes.

CONCEPTS - USES

Motivation. Science Fairs
Equilibrium
Competing equilibria
Equilibrium law
Transition metal chemistry

MATERIALS

Iron III chloride (or sulfate or nitrate) - 0.2g/100mL.
Potassium (or ammonium) thiocyanate - 0.2g/100mL.
Potassium ferrocyanide - $K_4Fe(CN)6$ - 1g/100mL.
Tannic acid - 0.2g/100mL.
Salicylic acid - 0.2g/100mL.
EDTA - 2g /100mL.
6 beakers (600–800mL size).

SAFETY NOTES 

Most compounds are toxic, especially thiocyanates.

PREPARATION

- Place 600mL of 1% Fe solution into one beaker (#1).

- Into the successive beakers place separately and in order:

    - #2 - 20mL of 0.2% salicylic acid
    - #3 - 20mL of 0.2% potassium thiocyanate
    - #4 - 20mL of 0.2% tannic acid
    - #5 - l00mL of 1% potassium ferricyanide
    - #6 - l00mL of 2% EDTA

- Stand beakers against a white background.

PROCEDURE

- Pour all but 100mL of the solution from beaker #1 into #2. Swirl.
- Pour all but 50mL of beaker #2 into beaker #3. Swirl.
- Continue pouring solution into successive beakers, leaving about 40–50mL in each beaker.

OBSERVATIONS

- The different beakers will contain different coloured solutions as follows:
    #1 : Pale yellow
    #2 : Purple
    #3 : Dark Red
    #4 : Blue-black
    #5 : Blue
    #6 : Green

COMMENTS

- Iron III forms a variety of complex ions or co-ordinated species.
- The species which predominate in each solution are:

  #1: $Fe(H_2O)_6^{3+}$

  #2: $Fe(C_7H_5O_3)(H_2O)_4^{2+}$

  #3: $Fe(SCN)(H_2O)_5^{2+}$

  #4: $Fe(C_{76}H_{51}O_{46})_3$

  #5: $Fe\ Fe(CN)_6$

  #6: $Fe\ EDTA^-$

- The equilibrium reactions are in sequence:

$$FeCl_3 + 6H_2O \rightleftharpoons Fe(H_2O)_6^{3+} + 3Cl^-$$

$$Fe(H_2O)_6^{3+} + C_7H_6O_3 \rightleftharpoons Fe(C_7H_5O_3)(H_2O)_5^{2+} + H_2O + H^+$$

$$Fe(C_7H_5O_3)(H_2O)_5^{2+} + SCN^- \rightleftharpoons Fe(SCN)(H_2O)_5^{2+} + C_7H_5O_3^-$$

$$Fe(SCN)(H_2O)_5^{2+} + 3C_{76}H_{52}O_{46} \rightleftharpoons Fe(C_{76}H_{51}O_{46})_3 + 3H^+ + SCN^- + 5H_2O$$

$$Fe(C_{76}H_{51}O_{46})_3 + Fe(CN)_6^{3-} \rightleftharpoons FeFe(CN)_6 + 3C_{76}H_{51}O_{46}^-$$

$$FeFe(CN)_6 + EDTA \rightleftharpoons Fe\ EDTA^- + Fe(CN)_6^{3-} + 4H^+$$

IRON (III) EQUILIBRIA

A solution when poured into seemingly empty beakers in succession produces a variety of colours.

CONCEPTS - USES

Motivation. Science Fairs
Equilibrium
Colour
Transition metal chemistry

MATERIALS

Iron (III) chloride (or nitrate) - 3g
Ammonium (or potassium) thiocyanate - 2g
Tannic acid - 1mL of saturated solution
Oxalic acid - 10mL of saturated solution
Beakers (6 x 250mL)
White background

SAFETY NOTES

Thiocyanates and oxalic acid are very toxic.

PREPARATION

- Dissolve 3g of $FeCl_3.6H_2O$, or an equivalent amount of any soluble iron (III) salt, in 10mL of water and place 15 drops of this solution into beaker 2.
- Dissolve 2g of ammonium (or potassium) thiocyanate in 10mL of water and place 2 drops only of this solution into beaker 3, and 10 drops into beaker 4.
- Prepare about 5mL of a saturated solution of tannic acid, and place 12 drops of this solution into beaker 5.
- Prepare 10mL of a saturated solution of oxalic acid(or sodium oxalate) and place all of this solution into beaker 6.

PROCEDURE

- Line the beakers up in order 1'6 on a white background.
- Half fill the empty beaker (beaker 1) with water.
- Pour the contents of beaker 1 into beaker 2 to produce a pale yellow solution of $Fe^{3+}(aq)$.
- Pour the yellow solution into beaker 3 to produce an orange solution of dilute $FeSCN^{3+}(aq)$.
- Pour the contents of beaker 3 into beaker 4 to produce a dark red solution of more concentrated $FeSCN^{2+}(aq)$.
- Pour the contents of beaker 4 into beaker 5 to produce a black solution of Fe(III) tannate.
- Pour the contents of beaker 5 into beaker 6 to produce a yellow solution of $Fe_2(C_2O_4)_3(aq)$.

COMMENTS

- The reactions are:

  $Fe^{3+} + SCN^- \rightarrow FeSCN^{2+}$

  Fe^{3+} + tannic acid $\rightarrow$ Fe (III) tannate

  $2Fe^{3+} + 3H_2C_2O_4 + 5H_2O \rightarrow Fe_2(C_2O_4)_3.5H_2O + 6H^+$

COLOURFUL COPPER COMPLEXES

A blue solution produces a variety of colours and precipitates when mixed with other reagents.

CONCEPTS - USES

Motivation, Science Fairs
Colourful reactions
Equilibrium
Complexes
Transition metal chemistry

MATERIALS

Copper sulfate - 1M
Salicylic acid (or sodium salicylate) - 5g
Oxalic acid (or sodium oxalate) - 5g
Potassium iodide - 5g.
Cream of tartar (Potassium hydrogen tartrate) or Rochelle's salt (Sodium Potassium Tartrate 5g
Ethylennediamine- 5mL
Aniline - 5mL : ***Aniline is an X-Category chemical in NSW***
Ammonia - 2M
EDTA - 5g
Hydrochloric acid - concentrated
Beakers or test tubes

SAFETY NOTES

Oxalic acid is toxic. Aniline is toxic and carcinogenic. ***Aniline is an X-Category chemical in NSW***

PREPARATION

- Prepare about 10–50mL of 10% solutions of each reagent except for 2MNH_3 and 2M $CuSO_4$ and conc. HCl, and ethylennediamine and aniline which can 5% and 1% respectively.

PROCEDURE - OBSERVATIONS

- Mix equal amounts of $CuSO_4$(aq) and each of the other reagents in turn to produce the following colours:

  (1) Cu^{2+} + EDTA - blue solution.
  (2) Cu^{2+} + NH_3 - dark blue solution.
  (3) Cu^{2+} + Oxalic acid - pale blue suspension.
  (4) Cu^{2+} + iodide - olive brown suspension.
  (5) Cu^{2+} + Cream of tartar - turquoise solution.
  (6) Cu^{2+} + salicylic acid - dark green solution.
  (7) Cu^{2+} + ethylennediamine - dark blue solution.
  (8) Cu^{2+} + aniline - lime green suspension.
  (9) Cu^{2+} + HCl - lime green solution.

- Treat some of the original mixtures as follows:

i. (Cu^{2+} + Salicylic) + EDTA - navy blue solution.

ii. (Cu^{2+} + Oxalic) + EDTA - blue solution.

(Cu^{2+} + Oxalic) + Salicylic - olive green suspension.

iii. (Cu^{2+} + I^-) + EDTA - emerald green solution.

(Cu^{2+} + I^-) + ethylennediamine - purple solution.

iv. (Cu^{2+} + ethylennediamine) + EDTA - blue solution.

(Cu^{2+} + ethylennediamine) + Salicylic - dark green solution.

(Cu^{2+} + ethylennediamine) + Oxalic - pale blue suspension.

v. (Cu^{2+} + HCl) + NH_3 - dark blue solution.

(Cu^{2+} + HCl) + EDTA - blue solution.

COMMENTS

- Most of the compounds supply a ligand for the formation of complex ions and co-ordination compounds. Ligands differ in their stability constants so that some complexes are more stable than others.

- The complexes which form are (in turn):

$Cu(H_2O)_6^{2+}$

(1) $CuEDTA^{2-}$

(2) $Cu(NH3)_4^{2+}$

(3) $Cu(C_2O_4)_2$

(4) $CuI + I_2$ (due to redox reactions)

(5) $Cu(C_4H_4O_6)_2^{2-}$

(6) $Cu(C_7H_5O_3)_2$

(7) $Cu(C_2H_8N)_2^{2+}$

(8) $Cu(C_6H_5NH_2)_4^{2+} + Cu(OH)_2(s)$

(9) $CuEDTA^{2-}$

COLOURFUL COBALT EQUILIBRIA

A pink solution changes to a blue colour upon heating, and returns to pink on cooling. Addition of various reagents gives colour changes and a precipitate.

CONCEPTS - USES

Motivation
Equilibrium
Le Chatelier's principle
Solvation
Complex ion formation
Transition metal chemistry

MATERIALS

Cobalt (II) chloride
Concentrated hydrochloric acid
2-propanol (iso-propyl alcohol)
Acetone
Silver nitrate - 0.1M

SAFETY NOTES

Acetone and 2-propanol are flammable.

PREPARATION

- Prepare a solution of 1g $CoCl_2.6H_2O$ in 10mL 2-propanol. Then add distilled water dropwise until the deep-blue solution just turns pink. This is "Cobalt solution #1".

- Prepare another solution of cobalt (II) by dissolving about 10g of $CoCl_2.6H_2O$ in 20mL of water. This is "Cobalt solution #2".

PROCEDURE - OBSERVATIONS

- In a large test tube (or flask) heat cobalt solution #1 until the colour changes from pink to blue. Cooling the solution reverses the colour change. If the solution is in a test tube it can be placed into a beaker of ice water after heating, so that the top (hot) part of the test tube will be blue whilst the bottom (cool) part will be pink.

- Place some cobalt solution #2 into a flask or test tube. Add about 10mL of concentrated hydrochloric acid, so that the pink solution turns blue.

- Divide this solution into two.

- Add distilled water to one half of the mixture, and note the colour change from blue to pink.

- Add 0.1M $AgNO_3$ dropwise to the other half of the mixture, and note both the appearance of a precipitate and the colour change from blue to pink.
- Into a test tube containing some of cobalt solution #2 , carefully pour 10mL of acetone on top of the solution so as to avoid mixing, and observe the blue layer on top of a lower pink layer.

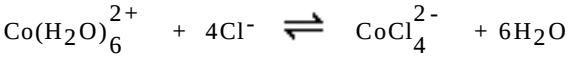
COMMENTS

- The essential equilibria are:

  For cobalt solution #1

$$Co(H_2O)_6^{2+} + 4Cl^- + \text{Alcohol} + \text{Energy} \rightleftharpoons CoCl_4^{2-} + \text{Alcohol}.6H_2O$$

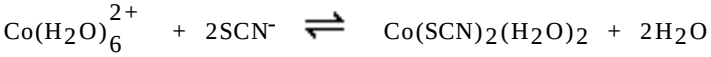
For cobalt solution #2



- Adding heat energy shifts equilibrium #1 to the right, removing energy shifts it to the left.
- Concentrated HCl shifts equilibrium #2 to the right.
- Excess water shifts equilibrium #2 to the left.
- Adding Ag^+ removes Cl^- (as AgCl) and so shifts equilibrium #2 to the left.
- Adding acetone removes water (through hydrogen bonding) and so shifts the equilibrium to the right.

VARIATION

- Mix about 2g of $CoCl_2$ with 2g KSCN to produce a deep blue solid.
- Dissolve the solid in about 10mL of ether to get a blue solution.
- Add 15mL of water, which forms a pink layer below the ether.
- Equation:



COMPETING EQUILIBRIA

A series of precipitates are produced and dissolved as a silver ion solution is mixed, in turn, with a sequence of reagents.

CONCEPTS - USES

Equilibrium
Shifting the equilibrium position
Competing equilibria
Solubility equilibria

MATERIALS

Silver nitrate - 8.5 g (per 100 mL).
Sodium carbonate - 1.1g.
Sodium hydroxide - 4.0 g or 1.0 M solution.
Sodium chloride - 5.9 g.
Ammonia (3M)
(Potassium cyanide - 6.5 g) – optional: ***Potassium cyanide is an X-Category chemical in NSW***
Potassium bromide - 11.9g.
Sodium thiosulfate - 12.4 g.
Potassium iodide - 16.6g.
Sodium sulfide - 2.40g

SAFETY PRECAUTIONS

No special precautions apart from those associated with working with cyanide solutions (deadly poison - do not mix with acids). ***Potassium cyanide is an X-Category chemical in NSW***

PREPARATION

- 10 mL of each of the following solutions are required (for convenience 100 mL of each can be prepared using the amounts listed above):

0.5 M $AgNO_3$	3.0 M NH_3
0.1 M Na_2CO_3	1.0 M KBr
1.0 M NaOH	0.5 M $Na_2S_2O_3$
1.0 M NaCl	1.0 M KI
1.0 M KCN	1.0 Na_2S

PROCEDURE

- Place 10 mL of each solution in order, into separate 25 mm test tubes.
- Mix solutions stepwise, saving half of each mixture at each step (i.e. mix 10 mL $AgNO_3$ + 10 mL Na_2CO_3, divide into 2 x 10 mL portions, then set one aside and add 10 mL of NaOH to the other 10 mL portion etc.)

OBSERVATIONS

- Step 1: $AgNO_3$ + Na_2CO_3 → White Ag_2CO_3
- Step 2: (1) + NaOH → Brown Ag_2O
- Step 3: (2) + NaCl → White AgCl
- Step 4: (3) + NH_3 → Colourless $Ag(NH_3)_2^+$
- Step 5: (4) + NaBr → Cream AgBr

- Step 6: (5) + $Na_2S_2O_3$ → Colourless $Ag(S_2O_3)_2^{3-}$
- Step 7: (6) + AgI → Yellow AgI
- Step 8: (7) + KCN → Colourless $Ag(CN)_2^-$
- Step 9: (8) + Na_2S → Black Ag_2S

COMMENTS

- Each system is an equilibrium one involving Ag^+ ions. As each successive reactant is added the preceding equilibrium is disturbed and a new one established.

Equations

(i) $Ag^+ + CO_3^{2-} \rightleftharpoons Ag_2CO_3(s)$

(ii) $Ag^+ + 2OH^- \rightleftharpoons Ag_2O(s) + H_2O$

(iii) $Ag^+ + Cl^- \rightleftharpoons AgCl(s)$

(iv) $Ag^+ + 2NH_3 \rightleftharpoons Ag(NH_3)_2^+(aq)$

(v) $Ag^+ + Br^- \rightleftharpoons AgBr(s)$

(vi) $Ag^+ + 2S_2O_3^{2-} \rightleftharpoons Ag(S_2O_3)_2^{3-}(aq)$

(vii) $Ag^+ + I^- \rightleftharpoons AgI(s)$

(viii) $Ag^+ + 2CN^- \rightleftharpoons Ag(CN)_2^-(aq)$

ix) $2Ag^+ + S^{2-} \rightleftharpoons Ag_2S(s)$

- The K for each successive reaction gets progressively smaller.

COPPER COMPLEX EQUILIBRIA

Colour changes are produced when a series of reagents are added to a blue solution in succession.

CONCEPTS - USES

Equilibrium
Transition metal chemistry
Co-ordination complexes

MATERIALS

Copper sulfate - 0.2M (about 200mL)
Potassium bromide - about 5g
Sodium sulfate - about 5g
Hydrochloric acid - concentrated
Beakers and test-tubes
Ice
Bunsen burner

SAFETY NOTES

No special precautions.

PROCEDURE

- Note the blue colour of the copper sulfate solution, due to the $Cu(H_2O)_6^{2+}(aq)$.
- Add some crystals of KBr to the blue solution to produce a green solution of $CuBr_6^{2-}(aq)$.
- Add some crystals of Na_2SO_4 to the green $CuBr_4^{2-}$ solution to reform the blue $Cu(H_2O)_6^{2+}$.
- Add concentrated HCl to the previous solution and form green $CuCl_4^{2-}$.
- Place the green solution of $CuCl_4^{2-}$ in an ice bath to form blue $Cu(H_2O)_6^{2+}$.
- Heat the blue solution from the previous step to form green solution $CuCl_4^{2-}$.

COMMENTS

- The equilibria are:

$$Cu(H_2O)_6^{2+} + 4Br^- \rightleftharpoons CuBr_4^{2-} + 6H_2O$$

$$Cu(H_2O)_6^{2+} + 4Cl^- \rightleftharpoons CuCl_4^{2-} + 6H_2O$$

- As each of the above reactions is endothermic, heating the mixture shifts the equilibria to the right, and cooling shifts the equilibria to the left.

COBALT - ALCOHOL EQUILIBRIA

A pink solution produces different colours (pink to violet) when added to different amounts of alcohol. Addition of water reverses the colour change.

CONCEPTS - USES

Transition metal chemistry
Co-ordination complexes
Equilibrium

MATERIALS

Cobalt (II) chloride - 13g
Ethanol
Beakers (250mL x 6)

SAFETY NOTES

No special precautions.

PREPARATIONS

- Prepare 2M $CoC1_2$ by dissolving 13g of cobalt (II) chloride in 50mL of water.

PROCEDURE

- Add 5mL of 2M $CoCl_2$ to each of the following in 250mL beakers, against a white background:

(i) 50mL water - beaker 1
(ii) 25mL ethanol - beaker 2
(iii) 50mL ethanol - beaker 3
(iv) 75mL ethanol - beaker 4
(v) 100mL ethanol - beaker 5

- After observing the different colours, slowly add 50mL of water to beaker 5 (and then, in succession beakers 4 to 2).

OBSERVATIONS

- The colours which will initially be observed are:

(i) beaker 1 - rose pink
(ii) beaker 2 - cherry red
(iii) beaker 3 - magenta
(iv) beaker 4 - purple
(v) beaker 5 - violet

- Addition of water will change the colour progressively from violet through purple, magenta and red to a light rose pink.

COMMENTS

- The equilibrium involves the replacement of water molecule ligands in the cobalt complex by ethanol molecules:

$$Co(H_2O)_6^{2+} \rightleftharpoons CoCl_4^{2-}$$

- Overall:

$$\underset{\text{(pink)}}{2Co(H_2O)_6Cl_2} \rightleftharpoons \underset{\text{(blue)}}{Co(CoCl_4)} + 12H_2O$$

BICARBONATE EQUILIBRIUM

A colourless solution bubbles and turns pale pink when attached to a suction pump.

CONCEPTS - USES

Motivation
Equilibrium
Le Chatelier's principle
Acid-base equilibria
Acid-base reactions

MATERIALS

Sodium bicarbonate - saturated solution
Phenolphthalein indicator
Side arm flask
Vacuum pump or water aspirator

SAFETY NOTES

No special precautions.

PREPARATION

- Saturated sodium bicarbonate is made by dissolving 16g of $NaHCO_3$ per 100mL of water.
- Add 5 drops of phenolphthalein indicator to the solution, in a side arm flask. If the solution is coloured, add 2M HCl dropwise to discharge the colour.
- Stopper the flask.

PROCEDURE

- Reduce the pressure in the flask using a vacuum pump or water aspirator.

- The solution should bubble and then turn a pink colour.

COMMENTS

- The equilibrium is shifted to the right, producing more OH^- which changes the indicator colour, as the carbon dioxide is removed:

  $$HCO_3^- \rightleftharpoons OH^- + CO_2$$

- Phenolphthalein is pink at a pH above 8.3.

- The colour can be discharged with dilute acid:

  $$H^+ + HCO_3^- \rightarrow H_2CO_3$$

  $$H^+ + OH^- \rightarrow H_2O$$

Section 4: CHEMICAL ENERGY

The Rocket
Freezing mixture
Exploding can
Thermite reaction
Volcano reaction
Nitrate flash
Permanganate fire
The Roman candle
Touch powder
Gun cotton
Purple fumes
Electrochemical energy
Chemiluminescence
“Quickies”

THE ROCKET

A plastic bottle is launched by a loud explosion when a flame is applied.

CONCEPTS - USES

Motivation. Science Fairs
Explosion of hydrogen
Combustion
Exothermic reaction
Redox reactions
Activation energy

MATERIALS

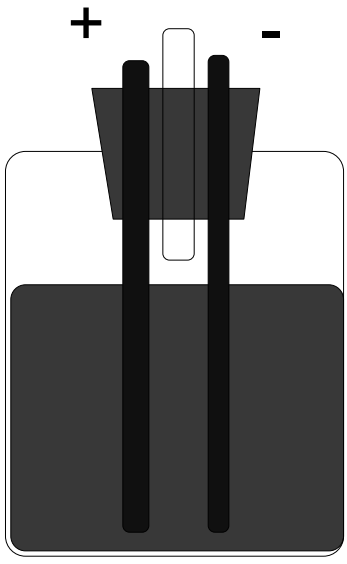
A plastic orange juice bottle (about 300mL)
A hydrogen/oxygen generator (see below)
12 volts D.C.
Sulfuric acid (2M) - about 200 mL
A taper on the end of a metre rule

SAFETY NOTES

- *Take care that no flames are about as the hydrogen/oxygen mixture is being generated.*
- *The explosion produces a flame, a loud noise, and launches the plastic bottle into the air. Take care to ignite it at a safe distance (using a metre rule).*
- *A 300mL volume will be sufficient. Larger volumes may produce excessive noise.*

PREPARATION

The hydrogen/oxygen generator consists of two electrodes (carbon or lead) in a bottle containing 2M sulfuric acid, and with one orifice enabling the gas mixture to be collected (by displacing water from the plastic orange juice bottle). As an added safety precaution it may be as well to use a plastic bottle for the generator.



- Generate a mixture of H_2/O_2 by passing a 12 volt direct current through the sulfuric acid. Collect the gas mixture in a 250-300mL plastic bottle by the downward displacement of water (in a pneumatic trough). When the bottle is full of gas, stopper it.

- Attach a taper to the end of a metre rule (or similar).

PROCEDURE

- Place the bottle, mouth down, in a tripod stand (or a retort ring) such that there are no delicate lights on the ceiling immediately above it.

- Dim the lights, remove the stopper and place the lighted taper under the bottle (standing well back).

OBSERVATIONS

- The gas mixture will explode with a visible flash and a piercing “bang”, launching the plastic bottle into the air and probably hitting the ceiling).

COMMENTS

- This demonstration is probably best done towards the end of a lesson and also only after warning the teachers of nearby classes!

- The reaction demonstrates the importance of the activation energy barrier which must be overcome before reaction can occur. The hydrogen-oxygen mixture is, of itself, kinetically stable (because it will not react spontaneously) but thermodynamically unstable (because a large exothermic reaction will occur when the activation energy has been supplied).

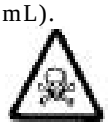
- Equation: $2H_2 + O_2 \rightarrow 2H_2O$

FREEZING MIXTURE

Two solids when mixed in a flask freeze a pool of water "gluing" the flask to a board, also forming a solution and a gas.

CONCEPTS - USES
Endothermic reaction
Entropy and reaction

MATERIALS
Ammonium thiocyanate - about 10g.
Barium hydroxide - about 15g.
Conical flask (250 mL) fitted with rubber stopper
Piece of masonite board (or similar) - about 6" x 6"
Cool water (about 20 mL).



SAFETY NOTES
Ammonium thiocyanate and barium hydroxide are poisonous. Ammonia gas is produced during reaction (though not in dangerous amounts).

PREPARATION
- Into a dry 250 mL conical flask (or similar) place about 10g of ammonium thiocyanate. Fit a rubber stopper so that the flask can be inverted (optional).
- Place about 10-12g of barium hydroxide in a 25mm test tube (or a small dry beaker).
- Cool some water in the fridge (especially if it is a warm day).

PROCEDURE
- Place a small pool of (cool) water onto the masonite board (or onto a bench top).
- Pour the barium hydroxide powder into the conical flask and swirl the flask until a slurry forms. Ammonia fumes can be detected at this stage.
- Place the (stoppered) flask into the pool of water and allow it to stand there.

OBSERVATIONS
- Within a minute the water should freeze and bond the flask to the board (or the desk).

COMMENTS
- If the flask is frozen onto a board the board can be up-ended and the flask will be held to it.
- The reaction clearly demonstrates that the increase in entropy in going from two (ordered) solids to a salt solution and a gas, compensates for the increase in enthalpy due to reaction.

Equation:

$$(NH_4)_2SCN(s) + Ba(OH)_2(s) \rightarrow Ba(SCN)_2(aq) + 2H_2O(l) + 2NH_3(g)$$

EXPLODING CAN

A can of gas explodes, ejecting the lid.

CONCEPTS - USES

Combustion of natural gas
Detonation of an explosive mixture
Rates of reaction
Stoichiometric ratio and rate of reaction.

MATERIALS

A tin can with lid (about 1000cc capacity) and holes
Piece of bunsen-size rubber tubing.

SAFETY NOTES

The lid of the can will be ejected with some force so ensure that the can is well away from students and not sited beneath a light. Ensure that the can is filled with gas before lighting to avoid the risk of a premature detonation.

PREPARATION

- Place the can on a tripod.
- Attach the rubber tubing to the gas tap and connect it to the hole in the bottom of the can.
- Place the lid on the can firmly.
- Turn on the gas and allow it to fill the can for a couple of seconds.
- Light the gas coming out of the hole in the lid, with a taper. If the gas tap is turned on full the flame will be about 12"–18" in size.
- Turn off the gas and then detach the rubber tubing from the hole in the can. The flame should increase in size.
- Stand back. (The lights may be turned off.)

OBSERVATIONS

- The flame will slowly die down and then there will be an explosion, ejecting the lid high into the air.

COMMENTS

- As the gas burns, air enters the can through the hole in the bottom until an explosive (near stoichiometric) mixture is obtained.

- Equation:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- The reaction is similar to that responsible for explosions in coal mines.

THERMITE REACTION

Molten iron and intense heat are produced when a powdered mixture is ignited in a tin can.

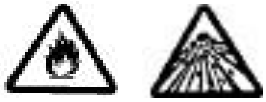
CONCEPTS - USES

Exothermic reactions
Activation energy
Reduction of an oxide by an active metal
Activity Series of metals
Element production

MATERIALS

Aluminium powder - 12 to 50g*
Iron (III) oxide - 12 to 50g
Sucrose - 2 g (approx)
Potassium Chlorate - 1 g (approx): ***Potassium chlorate is an X-Category chemical in NSW***
Magnesium ribbon - 10 mm length (approx)
Tin can - 450 g size.
Tripod stand
Sand in bucket or pneumatic trough

* The Aluminium powder must be of Laboratory Reagent Standard (e.g. BDH). Normal "Aluminium Powder" is often well oxidised and thus significantly impure.



SAFETY NOTES

- *The reaction generates a great deal of heat and produces molten iron. It is best done outdoors or in a sturdy fume cupboard. Chemical Safety in Schools states that total mass of the reaction mixture should not exceed 25g.*

- *The trigger mixture contains Potassium chlorate, a very powerful oxidising agent which will detonate if it is ground (in a mortar and pestle) or if it is heated with certain reducing agents. Exercise scrupulous care with this substance. Keep it well away from concentrated sulfuric acid.* ***Potassium chlorate is an X-Category chemical in NSW***

- *In preparing the sugar/$KClO_3$ "trigger" ensure that you grind the pure sugar first and then mix gently with the $KClO_3$ to produce only enough of the mixture to cover a 20c piece. Flush excess mixture down the sink with copious amounts of water.*

PREPARATION

- Use an old coffee can with a lid (or similar) to mix equal amounts (about 50g of each is more than sufficient) of the aluminium powder and the iron (III) oxide.

- Pour the mixture into the tin can, which has had a hole punched into its base and covered with some cello tape, and place the can on a tripod stand above the sand trap.

- Pour the trigger mixture into a small heap onto the top of the Fe_2O_3/Al mixture and stand the piece of magnesium ribbon upright in it.

- See diagram (next page).

PROCEDURE

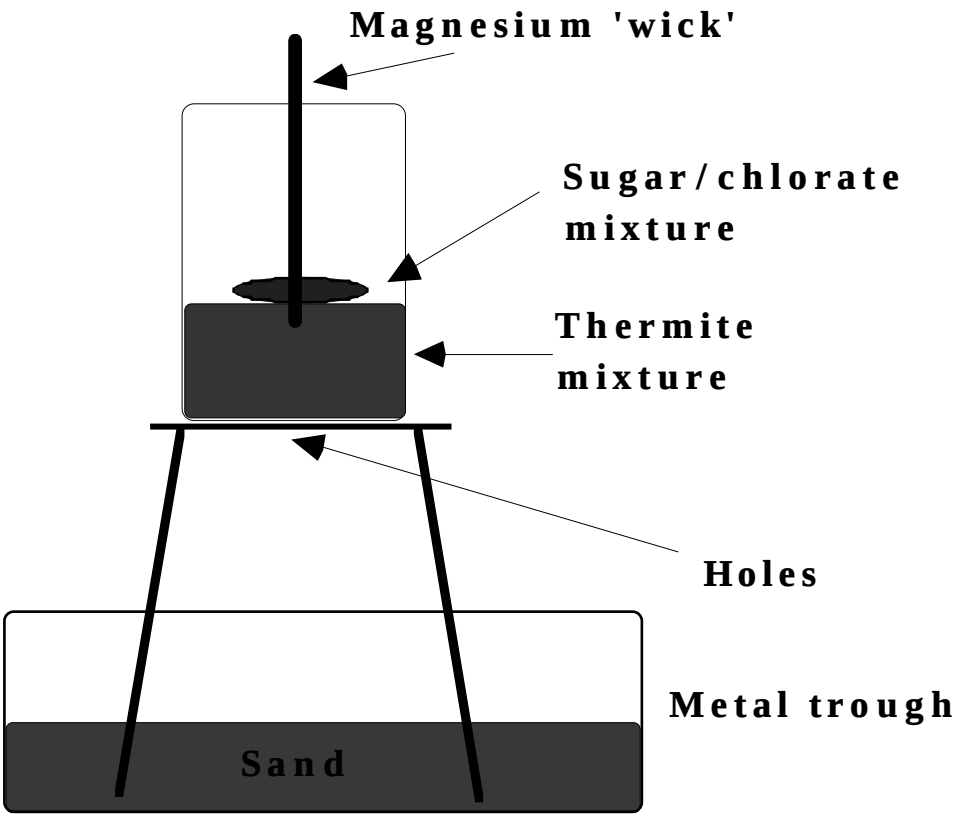
- Darken the room (if it is done indoors).

- Light the magnesium wick with a bunsen flame.

- Stand back.

OBSERVATIONS

- The magnesium will burn and ignite the trigger mixture which will flare with a lilac flame.
- The trigger reaction will initiate the thermite, reaction producing intense heat and, usually, a stream of molten iron which will pour through the hole and collect in the sand.



COMMENTS

Equation: $2Al + Fe_2O_3 \rightarrow 2Fe + Al_2O_3 + HEAT$

- As iron melts at 1540^{o}C the reaction generates temperatures in excess of this.
- This reaction was (and still is) used to mend fractures in railway lines.
- The reaction is a simple model for the reduction of ores to extract a metal.

THE VOLCANO REACTION

An orange powder on a flat surface ignites slowly to form a volcano-like mound of powder, and gives off a flame.

CONCEPTS - USES

Motivation. Science Fairs
Decomposition reaction
Exothermic reaction
Simulation of volcano shape
Redox reactions
Decomposition reaction

MATERIALS

Ammonium dichromate
Magnesium ribbon
Laboratory mat

SAFETY NOTES

- *Handle ammonium dichromate and chromium oxide powder with care as chromium compounds are carcinogenic. Reaction generates heat.*

- *Under no circumstances should other chemicals be mixed with the ammonium dichromate to "better" simulate a volcano. Ammonium dichromate is a powerful oxidising agent: in 1977 a model volcano exploded as a result of $(NH_4)_2Cr_2O_7$ being mixed with sulfur..*

PREPARATION

- A tray will be needed to collect the product of the reaction.

PROCEDURE

- Place 50-100g of ammonium dichromate in a mound on top of a laboratory mat, standing on a tray.

- Insert a 5-8cm length of magnesium ribbon into the top of the mound as a wick.

- Darken the room and light the magnesium (with a bunsen flame).

OBSERVATIONS

- The magnesium will burn brightly and ignite the ammonium dichromate, which will burn slowly forming dark green powder (chromium III oxide) which forms the shape of a volcano. The reaction gives off an orange flame.

COMMENTS

- The product forms a light powder - ensure that there are no draughts in the room.

- Reaction is a redox decomposition - chromium is reduced from +VI state to +III state whilst nitrogen is oxidised from -I state to 0 state.

- Equation:

$$(NH_4)_2Cr_2O_7 \rightarrow Cr_2O_3 + N_2 + 4H_2O$$

NITRATE FLASH

A white powder is ignited by several drops of water.

CONCEPTS - USES

Motivation. Science Fairs
Exothermic reaction
Oxidising agents
Redox reactions
Explosive mixtures

MATERIALS

Ammonium nitrate - about 5g
Zinc dust - about 5g
Ammonium chloride - about 0.5g
Laboratory mat
Dropper


SAFETY NOTES

- *Ammonium nitrate is explosive when ground. Treat carefully.*
- *The mixture of ammonium nitrate with any reducing agent is dangerous.*
- *Avoid inhaling zinc dust.*

PREPARATION

- In a dry beaker carefully mix equal amounts of zinc dust and ammonium nitrate (about 5g each) with a small amount of ammonium chloride. Use immediately—do not store!

PROCEDURE

- Place the mixture on a laboratory mat and darken the room.

- Carefully ignite the mixture with a drop of water. The mixture will flare.

COMMENTS

- The strong oxidising agent, ammonium nitrate, oxidises the reducing agent, zinc. Ammonium chloride acts as a catalyst.

- Equation:

$$NH_4NO_3 + Zn \rightarrow ZnO + N_2 + 2H_2O$$

PERMANGANATE FIRE

CONCEPTS - USES

Motivation. Science Fairs
Redox reactions
Oxidising agents
Exothermic reactions
Energy content of substances

MATERIALS

Potassium permanganate (solid)
Glycerol
Sucrose
Mortar and pestle
Laboratory mats

SAFETY NOTES

- *Powdered mixtures, especially of oxidising agents with oxidisable materials should not be ground or impacted. Do not leave any of this mixture unattended or stored.*

- *The mixture will flare - be careful.*

PREPARATION

- In a clean, dry mortar and pestle, carefully grind about a teaspoonful of potassium permanganate (for each reaction).

PROCEDURE - OBSERVATIONS

- On a laboratory mat, carefully pour the powdered potassium permanganate into a mound shape. Use a pen or test tube to impress a small divot into the top of the mound. Turn off lights.

- Using a dropper, place 1-2 drops of glycerol into the divot. Stand well clear. The permanganate will burst into flames within a few seconds.

- Mix equal amounts of powdered permanganate and finely powdered sugar with care in a clean, dry beaker. Pour the mixture into a dry laboratory mat, as before.

- Ignite the mixture using 1 drop of water.

COMMENTS

- Potassium permanganate is a powerful oxidant. Glycerol and sucrose are reductants which react exothermically with strong oxidants.

- Equation 1:

$$14KMnO_4 + 4C_3H_8O_3 \rightarrow 7Mn_2O_3 + 5CO_2 + 16H_2O + 7K_2CO_3$$

- Equation 2:

$$12KMnO_4 + C_{12}H_{22}O_{11} \rightarrow 6Mn_2O_3 + 6CO_2 + 11H_2O + 6K_2CO_3$$

THE ROMAN CANDLE

A powdered mixture erupts from a test tube with a flash when heated strongly.

CONCEPTS - USES

Motivation. Science Fairs
Exothermic reaction
Activation energy
Synthesis reaction
Chemical and physical changes
Redox reactions

MATERIALS

Zinc powder - about 2-5g
Sulfur powder - about 2-5g
Crucible
Tripod and clay triangle
Bunsen burner

SAFETY NOTES

- *The reaction mixture flares violently when heated. Take care.*
- *Avoid breathing any dust or smoke produced by the reaction*

PREPARATION

- The reaction should preferably be done in a crucible, though it can be done in a test tube with care (although the test tube usually breaks during the reaction). Set the crucible on a tripod (in a clay triangle) above a bunsen burner.
- CSIS recommends that this demonstration be done outdoors.

PROCEDURE

- Mix equal volumes (about 2g sulfur and about 3g zinc) of powdered sulfur and powdered zinc intimately, and place into the crucible (or a pyrex test tube clamped at an angle and pointing along the bench AWAY FROM THE AUDIENCE OR ANY MATERIAL THAT MAY BE DAMAGED).

- Heat the mixture strongly, standing well back.

OBSERVATIONS

- After an induction period the mixture will suddenly flare, producing a bright flash and some smoke.

- If the reaction is done in a test tube the tube will probably break because of the heat generated. Some of the product and unreacted reactants will be expelled onto the bench, up to a metre or more in distance at times.

COMMENTS

- This is a spectacular demonstration of activation energy in an exothermic reaction. It also makes a mess of the bench and any books left within the firing range.

- The reaction is a redox one which synthesises a compound from its two constituent elements.

- Equation:

$$Zn + S \rightarrow ZnS$$

TOUCH POWDER

A piece of filter paper holding a small amount of solid detonates when touched.

CONCEPTS - USES

Motivation. Science fairs
Chemical stability
Decomposition reaction
Energy

MATERIALS

Iodine - 10 g
Concentrated ammonia - 40 mL
Filter paper
Filtration apparatus
Metre rule and feather

SAFETY NOTES 

This demonstration is banned in NSW public Schools .

The dry touch powder (nitrogen triiodide) is extremely explosive when dry. Do not store or handle when dry! Take great care and do not prepare large amounts!

PREPARATION

- Place 5-10 g of iodine crystals into a small beaker and add about 40 mL of concentrated ammonia. Stir until precipitation of NI_3 ceases.

- Filter the solution, discarding the liquid with copious quantities of water, and ensuring that the precipitate remains damp at all times that it is to be handled.

- Carefully scrape a small amount of the WET nitrogen triiodide, just sufficient to cover a 10¢ coin, onto separate pieces of filter paper.

- Set the filter paper(s) to dry in a safe, secluded place, supported on a wire gauze on a tripod.

PROCEDURE

- The touch powder can be detonated, when it is dry, by stroking it with a feather (or similar object) on the end of a metre rule.

- The NI_3 will detonate with a very loud explosion which is safe as long as the amounts are kept small and the solid is unconfined.

COMMENTS

- The nitrogen triiodide is formed as follows:

  $2NH_3 + 3I_2 \rightarrow 2NI_3 + 3H_2O$

- Nitrogen triiodide is an unstable compound which decomposes very easily:

  $2NI_3 \rightarrow N_2 + 3I_2$

GUN COTTON

A white substance ignites and disappears in a flash when lit.

CONCEPTS - USES

Motivation. Science Fairs
Redox reactions
Nitration and Esterification reaction
Energy
Exothermic reaction
Instability of some compounds
Semi-synthetic polymer

MATERIALS

Cotton wool.
Concentrated sulfuric acid - 10mL.
Concentrated nitric acid - 10mL.
Beaker - 100mL.
Stirring rod.
Ether (optional) - 10mL.
Ethanol (optional) - 10mL.
Watch glass (optional).

SAFETY NOTES

Dry gun cotton will detonate easily. Handle with care. Take care with concentrated acids. Alcohol-ether solvent is flammable.

PREPARATION

- Carefully mix equal volumes (10mL) of concentrated sulfuric acid and concentrated nitric acid in a beaker.
- Warm the solution to 50°C and then immerse a wad of cotton wool in the solution. Use a glass rod to remove air bubbles and saturate the fibres. Allow to stand for 4 minutes only.
- Remove the cotton wool and rinse in a beaker of cold water until the rinse water is no longer acidic.
- Squeeze the cotton dry and spread out on a piece of filter paper to dry in a safe place where it will not be disturbed.

PROCEDURE

- Carefully handle the cellulose nitrate or “gun cotton” with tongs.
- Place a small piece of gun cotton onto a wire gauze and ignite with a long burning taper.
- Dissolve some gun cotton in a 50-50 mixture of ethanol and ether. Pour some of the syrupy solution into a watch glass and allow the solvent to evaporate.

OBSERVATIONS

- When ignited the gun cotton will disappear in a flash and a puff of smoke.
- Gun cotton can be detonated if jarred/impacted - Be careful!
- A film of cellulose nitrate - old photographic film base-should form on the watch glass.

COMMENTS

- Nitrate esters, like other nitrated organic molecules (eg. TNT, nitroglycerine), are unstable because of the high proportion of oxygen present in the molecules, leading to “internal” oxidation/combustion.

PURPLE FUMES

A powder gives off violet fumes when a drop of water is added.

CONCEPTS - USES

Motivation. Science Fairs
Synthesis reaction
Energy
Exothermic reactions

MATERIALS

Aluminium powder - about 5g
Iodine - about 5g
Laboratory mat
Dropper

SAFETY NOTES

- *The reaction is exothermic.*

- *The reaction produces copious iodine fumes. Do not inhale. Do in a fume cupboard or in the open air with students upwind.*

PREPARATION

- Grind the iodine to a fine powder.

PROCEDURE - OBSERVATIONS

- In a dry beaker, mix equal amounts (about 5g each) of aluminium powder and iodine powder, and place the mixture in a small mound on a laboratory mat.

- Ignite the mixture with a drop of water. As the reaction produces heat, purple iodine fumes will appear.

COMMENTS

The water provides a greater surface contact between the reactants. Once reaction begins, the heat of reaction vaporises some of the iodine, forming purple fumes.

Equation:

$$2Al + 3I_2 \rightarrow 2AlI_3$$

$$I_2(s) \rightarrow I_2(g)$$

ELECTROCHEMICAL ENERGY

A flash globe “goes off” when two pieces of metal are immersed in a liquid.

CONCEPTS - USES

Science Fairs. Motivation
Electrochemistry
Energy
Conversion of chemical energy to electrical, heat, and light energy.

MATERIALS

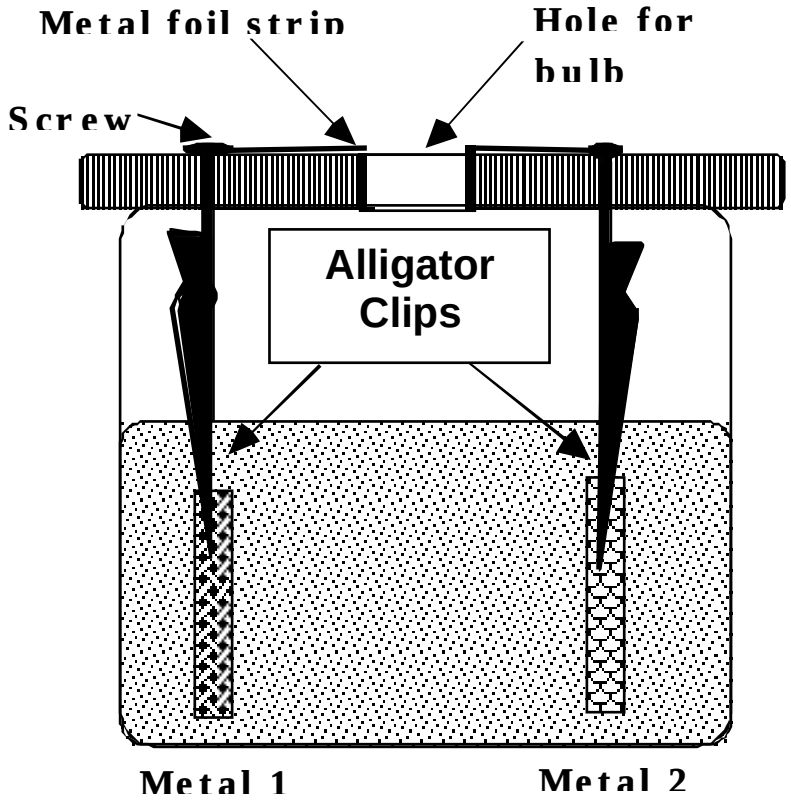
Photoflash bulb with two terminals (eg. Sylvania FBlb)
Bulb holder with electrical contacts - see below.
Piece of magnesium ribbon.
Piece of another metal strip (eg copper)
2M sulfuric acid.
Beaker.

SAFETY NOTES

No special precautions.

PREPARATION

- Bulb holder: cut a hole in a piece of wood or plastic that is just large enough to hold the light bulb. Use metal foil (eg copper, tinfoil) to make contact between each side of the hole and two alligator clips which are screwed into the holder.



- Fit a photo bulb into the socket so that it makes electrical contact with the copper on both sides of the hole.

- Attach a 7–8cm length of magnesium ribbon to one of the alligator clips and another metal to the other one.

- Place 50mL of 2M H_2SO_4 into the beaker.

PROCEDURE

- Darken the room and place the apparatus so that it rests on the beaker and the two metal strips are immersed in the acid.

OBSERVATIONS

- As soon as the metals make contact with the acid, the photo bulb flashes.
- The magnesium can be seen reacting with the acid.
- The photo bulb will be too hot to touch.

COMMENTS

- Reaction includes the following:

$$Mg \rightarrow Mg^{2+} + 2e$$

$$2H^{+} + 2e \rightarrow H_2$$

$$2H^{+} + Mg \rightarrow Mg^{2+} + H_2$$

CHEMILUMINESCENCE

A series of solutions mixed in a darkened room produce, after an induction period, a red luminescence followed by a vigorous effervesce, accompanied by a glowing green luminescence. The liquid overflows its container and gets quite hot.

CONCEPTS - USES

Motivation. Science Fairs
Steps in a reaction
Rates of reaction
Luminescence
Light and heat energy given out due to reaction
Different energies involved with different steps in a reaction

MATERIALS

Luminol (5-Amino-1, 2, 3, 4,-tetrahydro-1, 4-phthalazinedione or 5-Amino-2, 3-dihydro-1, 4-phthalazinedione)**- 0.05g
Pyragallol - 5g
Formalin (Formaldehyde) - 50 mL
Potassium carbonate - 112 g
30% Hydrogen Peroxide (100 volume) - 150 mL
The quantities can be scaled down by as much as 1/5 if necessary.
1 L beaker (or similar)
5 L beaker or large trough.

** The Luminol can be purchased from chemical suppliers who stock either Merck chemicals (Merck 820071) or Sigma chemicals (Sigma A8511) Though expensive (it comes in 1g or 5g lots) one gram will be sufficient for at least 20 full scale demonstrations. (Do not confuse "luminol" with "luminal").

SAFETY NOTES 

- *30% hydrogen peroxide is corrosive to the skin. Formalin fumes should be avoided - it is a suspected carcinogen.*
- *During the course of reaction the mixture will effervesce and overflow the beaker. Thus a 5 L beaker or large trough is necessary to catch the overflow.*
- *The mixture gets moderately hot (about 80°C) during reaction.*
- *If spilt the mixture should be cleaned up quickly as it will blister paint work*

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PREPARATION

In separate (150 mL) beakers place the following:
50 mL of 10% Pyrogallol (5g in 50 mL H_2O)
50 mL of Formalin
50 mL of alkaline 0.1% Luminol (0.05 g in 50 mL 2M NaOH)
100 mL of saturated Potassium carbonate (112g in 100 mL)*
150 mL of 30% Hydrogen peroxide.
Darken the room, the darker the better.
*N.B. This solution must be cool - make up the day before and cover.

PROCEDURE

Darken the room and add the solutions to the 1L beaker (standing inside the larger beaker or trough) in the order above.

OBSERVATIONS

- The solution will initially luminesce a deep red colour.

- After some time the red glow will fade and the solution will begin to effervesce.

- As the effervescence increases the solution will glow a blue-lilac colour and overflow the inner beaker. This step can vary in time from several seconds to a few minutes.

- Heat is given out sufficiently to raise the temperature to about 80ºC or more.

- After it ceases luminescence the solution, still effervescing slightly, is a pale green colour.

COMMENTS

Few chemical demonstrations can match this for spectacle. The reactions are complex and beyond the scope of high school students. The system is a redox one

QUICKIES

SUGAR: ENERGY FOOD

Needs
- Powdered sucrose
- Powdered potassium permanganate

Method
- Mix equal amounts (about 5g) of powdered sucrose and $KMnO_4$ in a dry beaker.
- Place mixture on a dry laboratory mat.
- Add several drops of water.

Observation
- The mixture ignites.

COMBUSTION OF IRON (STEEL WOOL)

Needs
- Piece of steel wool
- Metal tongs
- Bunsen
- Gas jar of oxygen (optional)

Method
- Tease out a handful of steel wool to about a 10cm length.
- Hold in a bunsen flame in the dark.
- (Optional) - Place into a gas jar of oxygen.

Observation
- The steel wool burns giving off sparks and forming black iron oxide.
- In pure oxygen a shower of sparks is produced.

COMBUSTION OF SULFUR

Needs
- Fume cupboard
- Sulfur powder (about 1–2g)
- Deflagrating spoon
- Gas jar of oxygen
- (Optional) - Universal indicator, a flower, acidified $KMnO_4$

Method
- Fill the end of the deflagrating spoon with sulfur.
- Heat the sulfur until it melts and starts to burn - in fume cupboard.
- Place burning sulfur into oxygen in dark room.

Observation
- The sulfur burns with a bright blue flame.
- Fumes of sulfur dioxide are produced.

Optional
- Test SO_2 with a solution of indicator (acidic colour forms).
- Place a flower or coloured fabric in the SO_2 (it bleaches).
- Pour a dark pink solution of acidified $KMnO_4$ into the SO_2 (colour disappears).

COMBUSTION OF RED PHOSPHORUS

Needs
- Red phosphorus
- Deflagrating spoon
- Gas jar of oxygen

Method
- As for sulfur.

Observation
- A brilliant white flame is produced.
- Phosphorus pentoxide as acidic (test with universal indicator) .

MAKING MATCHES

Needs
- Potassium chlorate (0.5g) : ***Potassium chlorate is an X-Category chemical in NSW***
- Sulfur (0.5g)
- Laboratory mat
- Long taper

Method
- With care, crush some $KC1O_3$ with a clean vulcanite spatula to remove any lumps. DO NOT GRIND!
- Gently mix some sulfur with the $KC1O_3$ in a dry test tube by shaking.
- When homogeneous, pour the mixture onto a laboratory mat.
- Ignite with a taper held at arm's length.

Results
- The mixture will flare as it ignites.
- Match heads contain $KC1O_3$ and antimony trisulfate (Sb_2S_3).

AN ELECTRIC LEMON

Needs
- Lemon
- Galvanised roofing nail
- Copper nail
- Leads with alligator clips
- Voltmeter

Method
- Soften the lemon manually.
- Connect the nails to the poles of a voltmeter (galvanised to negative; copper to positive).
- Insert nails into lemon.

Result
- A current should be measurable.

Section 5: RATES OF REACTION

Catalytic mechanism
Autocatalysis
Autocatalysis II
Iodate clock
Coloured clock reactions
Double clock
Versatile clock
The Patriotic clock
The Cinnamon clock
Rainbow reaction - the Spectral clock
The Golden clock
The Chemiluminescent clock
Cyclic iodine clock
Oscillating reaction I
The Belousov clock (Oscillating reaction II)
Oscillating reaction III
Oscillating reaction IV
Oscillating reaction V
Oscillating reaction VI
“Quickies”

CATALYTIC MECHANISM

A hot cherry-red solution turns green and effervesces vigorously before returning to its original colour.

USES - CONCEPTS
Motivation
Steps in a reaction
Catalysis
Mechanism of catalysis and regeneration of catalyst
Redox reactions

MATERIALS
Sodium potassium tartrate (Rochelle's Salt) - 7g
Cobalt (II) Chloride - 5 mL of 1% solution
Hydrogen peroxide (6%) - 10mL
Tall beaker - at least 300mL capacity
Tripod and bunsen
White background

SAFETY NOTES
No special precautions

PREPARATION
- Dissolve 7g of Rochelle's salt in about 60mL of water and place in the tall beaker.
- 1% Cobalt (II) Chloride solution can be prepared by dissolving 1g of Cobalt (II) chloride in 100mL of water.
- 6% hydrogen peroxide is "20 volume".

PROCEDURE
- Just bring the Rochelle's salt solution to the boil. Remove the bunsen.
- Against a white background add 10mL of hydrogen peroxide.
- Then add sufficient 1% $CoCl_2$ to give a distinct pink colour.

OBSERVATIONS
- On adding the peroxide the solution may effervesce vigorously. As the reaction reaches its peak the solution should turn green.
- When effervescence has virtually ceased the pink colour of the Co^{2+} should return.

COMMENTS
- The Co^{2+} catalysis the reaction. The catalysis involves the formation of an intermediate species in which the pink $Co^{2+}(aq)$ species is changed to a green complex.
- When reaction nears completion the original catalyst is regenerated. This clearly makes the point that a catalyst does take part in a reaction, but is not used up by the overall reaction (any change to the catalyst during some step of the reaction is reversed before the reaction is complete).
- Equation. The overall reaction is the oxidation of tartrate ion to carbon dioxide:

$$C_4H_4O_6^{2-} + 5H_2O_2 + 2H^+ \rightarrow 4CO_2 + 8H_2O$$

AUTOCATALYSIS

A purple solution changes colour (to pink then gold and finally colourless) at different rates.

CONCEPTS - USES

A colourful reaction
Oxidation states
Colour and oxidation state
Catalysis
An autocatalysed reaction
Redox reactions

MATERIALS

Oxalic acid (mono hydrate) - 10g (per 500 mL).
Potassium permanganate - about 0.04g (per 200 mL).
Concentrated sulfuric acid - 15 mL (or equivalent amount of 4M H_2SO_4)
Manganese (II) sulfate - small amount of solid.
Several 250 mL beakers.

SAFETY NOTES

- *Care with concentrated H_2SO_4*
- *Oxalic acid is poisonous if ingested.*

PREPARATION

- 200 mL of 0.001M $KMnO_4$ (0.04g).

- 500 mL of Oxalic Acid solution (10g) acidified with 15 mL concentrated H_2SO_4.

PROCEDURE

- Mix solutions back and forth twice and then divide the solution into four equal parts against a white background.

- One will act as a standard. The colour should slowly change and fade over a period of 4-5 minutes (Initial changes are slowly perceived).

- Heat one on a strong bunsen and compare the rate of change of colour with the one at room temperature.

- Add a small amount (just visible) of manganese (II) sulfate solid to one beaker and compare the effect of this catalyst on the colour change.

- Add 10 mL of concentrated H_2SO_4 to the fourth and compare the effect on the colour change.

OBSERVATIONS

- All solutions will undergo a visually pleasing colour change from dark purple to purple to red to orange to gold to yellow to colourless, at varying rates.

COMMENTS

- The overall reaction is catalysed by Mn^{2+}. Since Mn^{2+} is a product of reaction, the reaction is self-catalysed.

- Equation:

$$5C_2H_2O_4 + 2MnO_4^- + 6H^+ \rightarrow 2Mn^{2+} + 10CO_2 + 8H_2O$$

- Acid should increase the rate of the reaction.

AUTOCATALYSISII

Addition of a colourless liquid to the top of a blue solution produces a colour change (to yellow) that moves slowly down a measuring cylinder.

CONCEPTS - USES

Motivation. Science fairs
Redox reactions
Catalysis
Rates of reaction
Diffusion

MATERIALS

Potassium chlorate - 4g : ***Potassium chlorate is an X-Category chemical in NSW.***
Sodium sulfite - 12.5g
Bromophenol blue indicator - about 0.005g solid or 10mL of solution.
Sulfuric acid - 2M
Measuring cylinder
Beaker.

SAFETY NOTES

Potassium chlorate is a powerful oxidiser. ***Potassium chlorate is an X-Category chemical in NSW.***

PREPARATION

- In a beaker dissolve the following in 50mL water: 4g $KClO_3$, 12.5g Na_2SO_3 and about 0.005g of solid bromophenol blue indicator (or 10 mL of solution).

- Dilute 4mL of 2M sulfuric acid to 50mL with water, and then add this diluted acid to the other solution to produce a dark blue solution.

- Fill a measuring cylinder with the blue solution (to the 100 mL mark).

PROCEDURE

- Carefully, to minimise stirring, add a few millilitres of 2M sulfuric acid (use a dropper) to the top of the blue liquid in the cylinder.

OBSERVATIONS

- A yellow colour will form at the top of the blue column. Gradually the yellow colour will move down the cylinder over a period of minutes.

- Using a thistle funnel, with care, it is possible to add a layer of 5mL of 2M sulfuric acid at the bottom of the blue solution so that diffusion occurs from top and bottom.

COMMENTS

- The reaction is a redox one in which chlorate, in acidic conditions, oxidises the sulfite ion and produces protons which change the colour of the acid-base indicator from blue to yellow.

- As the oxidation occurs only in acidic conditions, and as the reaction produces H^+, it is autocatalysing:

$$H^+ + SO_3^- \rightarrow HSO_3^-$$

$$ClO_3^- + 3HSO_3^- \rightarrow Cl^- + 3SO_4^{2-} + 3H^+$$

Bromophenol blue + H^+ → “Bromophenol yellow”.

IODATE CLOCK REACTION

After an induction period of 6–10 seconds, a colourless mixture of two reagents instantly turns blue-black.

CONCEPTS - USES

Motivation. Science Fair
Steps in a reaction
Rates of reaction
Rate determining step in a reaction
Variation of reaction rate with temperature and concentration

MATERIALS

Potassium iodate - 2.1 g (per litre).
Sodium sulfite (anhydrous, AR grade) - 1.3 g (per L)
Starch (preferably not “Soluble Starch”)
Dilute sulfuric acid (e.g. 2 M).
2 x 250 mL beakers (or larger)—more as required.
Stopwatch (optional).
White background (optional).

SAFETY NOTES

Neither chemical is considered dangerous (though both can be poisonous if ingested).

PREPARATION

- Solution A: 2.1g KIO_3 per litre
  10 mL of 2M H_2SO_4
  20 mL of 1% starch “solution”

- Solution B: 1.3g Na_2SO_3 per litre.
  (Solution B must be made up within 6 hours of use as it easily oxidises).

- Starch “solution” is prepared by pouring a slurry of about half a teaspoon measure of starch into about 200 mL of boiling water. Soluble starch gives unsatisfactory results as often as not.

- The Iodate/acid solution can be prepared well in advance if the starch is omitted. It is stable for many months.

PROCEDURE

- Place equal amounts of A and B in separate beakers (e.g. 100 mL)

- Quickly pour solutions back and forth twice to ensure thorough mixing and place the mixture against a white background (or hold it in the air).

OBSERVATION

- After an induction period (of from 3-10 sec) the colourless solution will instantly turn black.

COMMENTS

- At different temperatures the rate of reaction is different (cooling is advisable to heating as the reaction tends to proceed too quickly when warmed).

- Varying the concentration of either species can effect the rate. This is easily done by diluting one of the solutions by say, a factor of a half.

- The steps in the reaction are:

(i) $IO_3^- + 3SO_3^{2-} \rightarrow I^- + 3SO_4^{2-}$ (Rate determining slow step)

(ii) $IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O$ (Fast)

(iii) $I_2 + SO_3^{2-} + H_2O \rightarrow 2I^- + SO_4^{2-} + 2H^+$ (Fastest)

(iv) I_2 + starch → black coloured complex.

The delay in the appearance of the black iodine-starch complex is due to removal of I_2 by SO_3^{2-} in step (iii). Only when all the SO_3^{2-} is used up will the I_2 react with the starch (itself a very fast step).

<u>Overall</u> $2IO_3^- + 5SO_3^{2-} + 2H^+ \rightarrow I_2 + 5SO_4^{2-} + H_2O$

The reaction is a redox one.

COLOURED CLOCK REACTION
(Formaldehyde Clock)

A mixture of two colourless solutions turns pink in an instant after an induction period of several seconds. Different indicators can produce different colour changes at different rates.

CONCEPTS - USES

Motivation. Science Fairs
Steps in a reaction
Rates of reaction
Change of pH during reaction

MATERIALS

Sodium metabisulfite - 20 g (per litre).
Sodium sulfite (anhydrous) - 3 g.
Formalin (Formaldehyde) - 90 mL.
Indicator(s) - e.g. phenolphthalein, universal.
250 mL beakers (2 or more).
White background.

SAFETY NOTES

Formalin is toxic and its fumes should be avoided – it is a suspected carcinogen.

PREPARATION

- Solution A:
  20 g $Na_2S_2O_5$
  3 g Na_2SO_3
  1000 mL water.

  Then dilute this solution by 4 to give Solution A. Further dilutions will slow the rate of the reaction.

- Solution B:
  90 mL formalin
  910 mL water.

PROCEDURE

- Mix equal volumes of A and B thoroughly (after adding about 2 mL of indicator solution to one of them).

- Stand against a white background.

- As a variation repeat after heating one solution to about 20°C above water temperature. This should double the rate of reaction.

OBSERVATIONS

- If mixed thoroughly a homogenous colour change should occur after an initial induction period. With phenolphthalein the change is from colourless to red; with universal indicator a sequence of colour changes occurs, at differing rates.

- With insufficient mixing the colour change occurs in splotches (itself an interesting phenomenon).

- The colour change is not as sharp as with the iodate clock, though still reasonably rapid. Dilution will increase the induction period.

COMMENTS

The reaction mechanism is:

(i) $HCHO + HSO_3^- \rightarrow CH_2OSO_3^-$ [Slow]

(ii) $HCHO + H_2O + SO_3^{2-} \rightarrow CH_2OSO_3^- + OH^-$ [Fast]

(iii) $OH^- + HSO_3^- \rightarrow SO_3^{2-} + H_2O$ [Slow]

(iv) OH^- + indicator → Colour change. [Fast]

- Colour change will occur due to production of OH^-. However the OH^- is not "available" for reaction with the indicator until the HSO_3^- has been used up.

DOUBLE CLOCK REACTION
(The Landolt or Old Nassau reaction)

Two colourless solutions, when mixed in a variety of ratios produce different results, notably slow appearance of an orange colour followed by a flash to black.

CONCEPTS - USES

Motivation. Science Fairs
Rates of reaction
Steps in a reaction

MATERIALS

Potassium iodate - 4.5g (per litre)
Sodium metabisulfite - 6.0 g (per litre)
Mercury (II) chloride - 0.6g (per litre)
Starch (preferably not "Soluble Starch")
Several 250 mL beakers (at least 2)
Stopwatch (optional)
White background (preferable)

SAFETY PRECAUTIONS

- Mercury (II) chloride ($HgCl_2$) is an extremely toxic chemical.
  It was once called "corrosive sublimate of mercury" and has been known since the time of the Borgias as a poison.

- Sodium metabisulfite releases sulfur dioxide gas when it reacts with an acid.

PREPARATION

- Solution A:
  4.5 g KIO_3 per litre (1 L is sufficient; less will do in cases where the reaction is done only once).

- Solution B:
  6.0 g $Na_2S_2O_5$ per litre.

  0.6g $HgCl_2$ per litre.

  20mL of 1% starch solution.
  (Solution B must be made up within several hours of its use).

PROCEDURE

- Place exactly equal volumes of solutions A and B into 250 mL beakers then mix back and forth twice (quickly).

- Place against a white background.

OBSERVATIONS

- After an induction period of 5–10 seconds the colourless solution will turn orange (HgI_2), swiftly though not instantaneously.

- After another interval of a few seconds the orange colour will fade. It may be possible to just see an instantly colourless solution before the mixture flashes black. More often the colour will appear to change instantly from orange to black.

FURTHER INVESTIGATION

- Each step can be isolated by varying the proportion of A and B mixed together. It is then possible to time each visible step, and to demonstrate the dependence of the progress of a reaction on relative concentrations of reactants.

- The results for different proportions of A and B are summarised below.

SOLUTION A	SOLUTION B	OBSERVATION
50 mL	150 mL	(i) colourless induction (ii) orange colour (iii) colourless
95 mL	105 mL	(i) colourless induction (ii) orange colour (iii) colourless (iv) black ring appears at surface
150 mL	50 mL	(i) colourless induction (ii) black flash

The mechanism of the reaction is:

(a) $IO_3^- + 3HSO_3^- \rightarrow I^- + 3SO_4^{2-} + 3H^+$ [Slow]

(b) $5I^- + IO_3^- + 6H^+ \rightarrow 3I_2 + 3H_2O$ [Slow]

(c) $I_2 + HSO_3^- + H_2O \rightarrow 2I^- + SO_4^{2-} + 3H^+$ [Fast]

(d) $Hg^{2+} + 2I^- \rightarrow HgI_2$ [Fast]

(e) I_2 + Starch $\rightarrow$, ') Black complex. [Fast]

- Note that the metabisulfite ion produces the bisulfite ion by a reaction with water.

VARIATION

- Increasing the concentration of both reactants increases the intensity of the colour developed in the first step of the sequence, and decreases the time of the reaction steps (to a couple of seconds when concentrations are double the original recipe).

THE VERSATILE CLOCK REACTION

Mixture of three colourless solutions produces a blue-black colour (in an instant) after a variable induction period. Rate of appearance of colour can be varied by changes in proportions, temperature and catalysts.

CONCEPTS - USES

Motivation. Science Fairs
Rates of reaction
Catalysis
Reaction mechanism
Steps in a reaction
Redox reactions

MATERIALS

Potassium (or sodium) peroxydisulfate (or potassium persulfate) - ($K_2S_2O_8$) - 54g per litre
Potassium iodide - 33.2g per litre
Sodium thiosulfate - 2.48g per litre
Starch - 1% solution
Transition metal ion solutions e.g. -
Cu^{2+} , Zn^{2+} , Mn^{2+} , Fe^{2+} , Fe^{3+} , Co^{2+}, Ni^{2+} - O.1M each
Beakers
Stopwatch

SAFETY NOTES

No special, precautions.

PREPARATION

- Solution A:
  32.2g Potassium iodide
  1000 mL water

- Solution B:
  54g Potassium peroxydisulfate (or 47.6g sodium Peroxydisulfate)
  1000 mL water.

- Solution C:
  2.48g sodium thiosulfate
  100mL of 1% starch
  900 mL of water

PROCEDURE

Part 1: Concentration and rate

- Mix the following combinations of solutions, A, B and C, by firstly combining solutions A and C in one beaker, and mixing this solution with solution B (diluted as indicated). Mix back and forth to ensure thorough mixing. Start timing once solutions are mixed.

Trial	Solution A	Solution C	Solution B	[I-]	$[S_2O_8^{2-}]$
1	100 mL	50mL	100mL	0.080M	0.080M
2	100mL	50mL	60 + 40mL H_2O	0.080M	0.048M
3	100mL	50mL	20 + 80mL H_2O	0.080M	0.016M
4	60mL	50mL	100 + 40mL H_2O	0.048M	0.080M
5	20mL	50mL	60 + 80mL H_2O	0.016M	0.080M

Part 2: Catalysis

- Add 1mL of each metal ion in solution in turn to the following mix of solutions A, B and C and compare the time for reaction with that of trial #l in the previous part:

Solution A = 50mL^{+}
Solution B = 50mL
Solution C = 25mL^{+}
(NOTE: Mix A and C together first)

Part 3: Temperature

- Demonstrate the influence of T on rate by alternately heating or cooling solution B before mixing as in trial #1 above.

OBSERVATIONS

- After an induction period the clear and colourless mixture will turn blue-black in an instant.

COMMENTS

- The reaction sequence involves the oxidation of iodide to iodine, followed by its reduction back to iodide by thiosulfate. Thus, iodide ions are being recycled as the thiosulfate is gradually consumed. When all the thiosulfate has been used up, the iodine produced can react with the starch.

- The steps in the process are:

$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2 \quad \text{[Slow]}$$

$$I_2 + S_2O_3^{2-} \rightarrow S_2O_6^{2-} + 2I^- \quad \text{[Fast]}$$

- The rate law for the reaction is:

$$K = [I^-]\ [S_2O_8^{2-}]$$

THE PATRIOT CLOCK REACTION

A solution is added simultaneously to three separate beakers. After an induction period colours will suddenly appear in each beaker: red, white and blue in turn.

CONCEPTS - USES

Motivation. Science Fairs
Rates of reaction
pH change and reaction
Reaction mechanism
Steps in a reaction
Solubility product

MATERIALS

Sodium metabisulfite - 10g (per litre)
Sodium sulfite (anhydrous) - 1.5g
Formalin (Formaldehyde) - 45mL
Phenolphthalein indicator
Thymolphthalein indicator
Cadmium nitrate - about 2g
Beakers

SAFETY NOTES

Cadmium salts and formalin are toxic. Formalin (formaldehyde) fumes should be avoided – it is a suspected carcinogen.

PREPARATION

- Solution A: 10g sodium metabisulfite
  1.5g sodium sulfite
  1000mL of water

- Solution B: 45mL Formalin
  955mL water

PROCEDURE

- The reaction may be done in test-tubes or beakers against a white background. It is a variation of the Coloured Clock Reaction (Formaldehyde Clock).

- To three beakers (250-500mL size) add 75mL of solution A. To beaker #1 add 1mL of phenolphthalein, to beaker #2 add (and dissolve) about 2–2.5g of cadmium nitrate, and to beaker #3 add 1mL of thymolphthalein.

- To each beaker simultaneously and with vigorous stirring/mixing, add 75mL of Solution B.

OBSERVATIONS

- After an induction period of 5–10 seconds the following colours should appear suddenly:

  Beaker #1 : Red
  Beaker #2 : White
  Beaker #3 : Blue

COMMENT

- The reaction steps are:

$CH_2O + HSO_3^- \rightarrow CH_2OHSO_3^-$ (Slow)

$H_2O + CH_2O + SO_3^{2-} \rightarrow CH_2OHSO_3^- + OH^-$ (Slow)

$HSO_3^- + OH^- \rightarrow SO_3^{2-} + H_2O$ (Fast)

- Once the HSO_3^- ion is completely used up, the OH^- ion concentration rises rapidly so that the alkaline-sensitive indicators change colour and the Cd^{2+} ion is precipitated as $Cd(OH)_2$ past its Ksp value.

THE CINNAMON CLOCK REACTION

After an induction period a clear orange-brown mixture turns a light opaque yellow colour.

CONCEPTS - USES
Reaction kinetics
Rates of reaction
Solubility
Steps in a reaction
Reaction mechanism

MATERIALS
Cinnamaldehyde (oil of cinnamon) - about 10mL.
Acetone - 2mL.
Sodium hydroxide (2M) - 30mL.
Ethanol - 50mL.
Beakers (250mL).
Stopwatch (optional).

SAFETY NOTES
No special precautions.

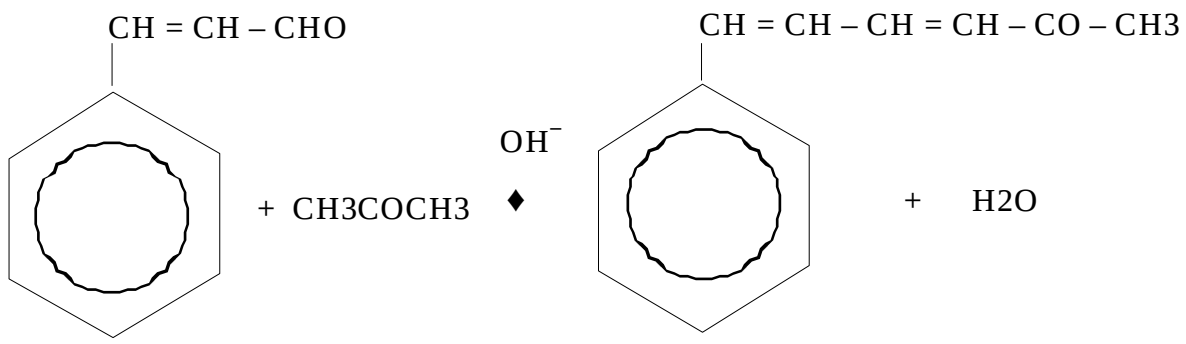
PREPARATION
Beaker A: 8.0mL cinnamaldehyde
50mL ethanol
30mL 2M sodium hydroxide

Beaker B: 2.0mL acetone

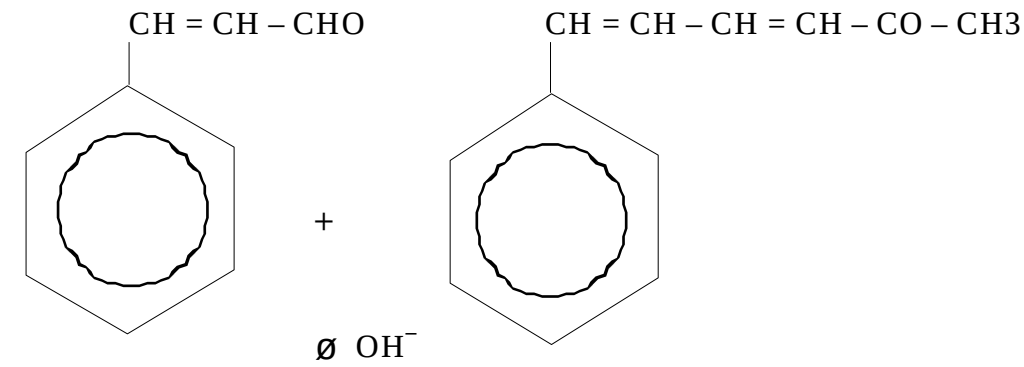
PROCEDURE
- Mix solutions thoroughly and set aside.
- Observe closely and patiently.

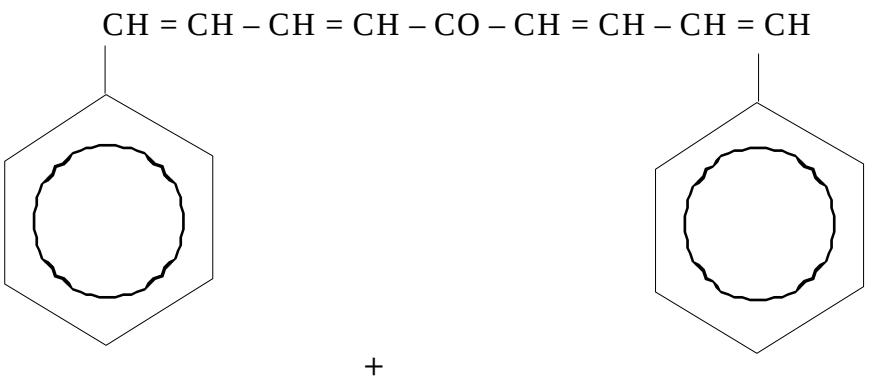
OBSERVATIONS
- After a delay of 30–90 seconds (depending on the temperature) the clear orange-brown mixture will turn a light yellowish, opaque colour as a precipitate forms.

COMMENTS
- Careful measurement can lead to reproducible results (to within 1–2 seconds).
- The reaction is a two step process, leading to the formation of dicinnamalacetone.
- Step 1 (Slow):



- Step 2 (Rapid):





- Benzaldehyde may be used instead of cinnamaldehyde, but the reaction is slower.

RAINBOW REACTION
(The Spectral Clock

Addition of reagent to a red solution causes it to gradually change colour (red ' orange ' yellow ' lime green ' green).

CONCEPTS - USES

Motivation. Science Fairs
Rates of Reaction
pH Changes in a reaction
Steps in a reaction

MATERIALS

Sodium thiosulfate - 0.372g per 500mL
Acetic acid - 0.10M (about 5mL)
Potassium iodide - 9.13g per 500mL
Hydrogen peroxide - 0.05M (or 0.12%)
Universal indicator.

SAFETY NOTES

Sulfur dioxide is produced in the reaction. Take care that the fumes are not inhaled when disposing of the solution.

PREPARATION

- Solution A is made by dissolving 0.372g of sodium thiosulfate crystals and 9.13g of potassium iodide separately in water and combining the solutions.
- In this mixture is added 4.0mL of 0.10M acetic acid and sufficient water to make a total volume of 500mL. This solution must be freshly prepared.
- 0.05M H_2O_2 is prepared by diluting 7.0mL of 6% H_2O_2 to 250mL with water. This solution must be freshly prepared.

PROCEDURE

- Measure 100mL of solution A into a large beaker (or conical flask) and add about 0.5mL of universal indicator solution.
- Against a white background add 50mL of the 0.05M H_2O_2 and swirl.
- Observe the progressive colour changes.
- The rate of reaction can be decreased by adding less of the H_2O_2 (e.g. try 40, 30, 20 and 10mL runs).

OBSERVATIONS

- The solution will go through a number of colour changes, as the pH increases, as follows:

Initial Colour :	Orange
Within 5 seconds	Yellow
10 seconds	Lime
20 seconds	Green
30 seconds	Aqua
60 seconds	Blue
90 seconds	Purple

- The reaction sequence is:

1. $H_2O_2 + I^- \rightarrow H_2O + IO^-$ (slow)
2. $IO^- + H^+ \rightleftharpoons HOI$ (fast)
3. $HOI + H^+ + I^- \rightarrow H_2O + I_2$ (fast)
4. $I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$ (fast)

- Reactions #1, 2 and 3 all act to reduce (H^+) and thus raise the pH.

THE GOLDEN CLOCK REACTION

Mixture of two colourless solutions produces a sudden change to yellow, after an induction period.

CONCEPTS - USES

Motivation. Science fairs
Reaction kinetics
Rates of reaction
Redox reactions
Solubility

MATERIALS

Sodium arsenite ($NaAsO_2$) - 2g
Glacial acetic acid - 11mL
Sodium thiosulfate - 20g
Beakers

SAFETY NOTES

Sodium arsenite is toxic. Dispose of solutions with care as hydrogen sulfide is produced.

PREPARATION

- Solution A: Dissolve 2g of sodium arsenite and then add 11mL of glacial (concentrated) acetic acid.

- Solution B: Dissolve 20g of sodium thiosulfate in 100mL of water.

PROCEDURE

- Mix the two solutions thoroughly by pouring A into B and then pouring the mixture back and forth several times. Allow to stand against a dark background.

OBSERVATIONS

- After an induction period of 15 to 20 seconds the mixture should suddenly turn golden.

COMMENTS

- The initial (rate-determining and unobserved) reaction is the slow formation of hydrogen sulfide. The reaction is probably the redox reaction:

$$10H^+ + 9S_2O_3^{2-} \rightarrow 2H_2S + 4S_4O_6^{2-} + 3H_2O$$

- Subsequently, the hydrogen sulfide reacts (in a fast reaction) to produce arsenious sulfide (a precipitation reaction):

$$2H^+ + 3H_2S + 2AsO_2^- \rightarrow As_2S_3 + 4H_2O$$

CHEMILUMINESCENT CLOCK REACTION

Mixture of a sequence of solutions (in a darkened room) leads to a colour change and then the emission of light.

CONCEPTS - USES
Motivation, Science Fairs
Rates of reaction
Energy transformation
Steps in a reaction

MATERIALS
Luminol (5 - Amino - 1, 2, 3, 4, - tetrahydro-1, 4-phthalazinedione or 5 - Amino - 2, 3-dihydro-1, 4-phthalazinedione)**-0.10g
Copper sulfate - 0.1M solution (about 10mL)
Potassium cyanide - 1g : ***Potassium cyanide is a X-Category chemical in NSW***
Ammonia - 1.5M solution (about 75mL)
Hydrogen peroxide (3%) - (about 210mL)
Hydrogen peroxide (30%) - (about 20mL)
Dimethylformanide - about 5mL
Conical flask
Pneumatic trough

SAFETY NOTES 

Potassium cyanide is toxic as is dimethylformamide (an eye and skin irritant). ***Potassium cyanide is a X-Category chemical in NSW.*** *30% hydrogen peroxide is corrosive.*

PREPARATION
- Solution A: 0.25g $CuSO_4.5H_2O$ dissolved per 10mL of water.
- Solution B: 10mL of concentrated NH_3 made up to 100mL with water.
- Solution C: 1.0g KCN dissolved per 50mL of water.
- Solution D: 0.10g of luminol dissolved in 5mL of dimethylformamide.
- A darkened room, a large beaker or conical flask (e.g. 570-100mL) and a pneumatic trough or tray, to collect any overflow, are required.

**Luminol: See “Chemiluminescence” demonstration for purchasing details.

PROCEDURE
- In a large beaker (or flask), standing in a pneumatic trough, place 10mL of solution A ($CuSO_4$) and add 75mL of solution B (NH_3) to produce a dark blue solution. Swirl to dissolve any precipitate.
- Slowly add solution C (KCN) until the dark blue colour just disappears (about 15mL) and then add a little excess water.
- Darken the room (work by candlelight if necessary).
- Add about 1.5–2.0mL of solution D (luminol), swirl and then when the room is darkened quickly pour 15.0mL of 3% hydrogen peroxide into the beaker and swirl vigorously to ensure mixing.

OBSERVATION
- After an induction period the mixture will change colour, luminesce and effervesce.

COMMENTS

- The luminol is incidental to the clock reaction, serving as an indicator of the oxygen gas formed by the decomposition of hydrogen peroxide:

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

- The reaction is inhibited by the cyanide ion (CN^-) which must first be converted to the inactive cyanate ion (CNO^-), during the induction period, before the $Cu(NH_3)_4^{2+}$ ion is able to re-form and catalyse the peroxide decomposition.

- Variation. With more concentrated solutions of hydrogen peroxide large volumes of oxygen gas are released leading to a chemiluminescent fountain effect.

CYCLIC IODINE CLOCK REACTION

A mixture oscillates in colour from blue to brown.

CONCEPTS - USES

Motivation
Reaction kinetics
Entropy and order in a reaction
Oscillating reaction

MATERIALS

Malonic acid - 1.56g per 100mL
Manganese II sulfate - 0.445g per 100mL
Potassium iodate - 4.28g per 100mL
Sulfuric acid - 1M
Hydrogen peroxide - 4.5M (or 16%)
Starch solution - 3%.

SAFETY NOTES

Sulfur dioxide is produced in the reaction. Take care that the fumes are not inhaled when disposing of the solution.

PREPARATION

- Solution A : dissolve 1.56g of malonic acid and 0.445g of $MnSO_4.4H_2O$ in 100mL of water.
- Solution B i: dissolve 4.28g of potassium iodate in 50mL of water, adding 16mL of 1M sulfuric acid, and diluting to 100mL total volume.
- 4.5M hydrogen peroxide is made by diluting 51mL of 30% H_2O_2 to 100mL with water.
- 3% starch solution is made by mixing 3g of starch powder (do not use “Soluble Starch”) with about 20mL of water and then pouring this, with stirring, into about 100mL of boiling water. Boil for two minutes and cool.

PROCEDURE

- To 100mL of the 4.5M H_2O_2 add, in turn, 100mL of solution A, 100mL of solution B and about 5mL of starch solution. Shake well to ensure thorough mixing.
- Observe against a white background.
- Addition of either methanol or 2-propanol will increase the oscillation frequency but also bring the cyclic process to a halt sooner.

OBSERVATIONS

- The colour of solution oscillates in colour from blue to brown and gas bubbles are produced.

COMMENTS

- The main reactions involved in the overall catalytic decomposition of hydrogen peroxide are:

$$5H_2O_2 + 2HIO_3 \rightarrow 5O_2 + I_2 + 6H_2O$$

$$5H_2O_2 + I_2 \rightarrow 2HIO_3 + 4H_2O$$

- Nett reaction is: $2H_2O_2 \rightarrow 2H_2O + O_2$

VARIATION:

See “Oscillating reaction V” for alternative recipe.

OSCILLATING REACTION I

A mixture oscillates in colour between red and blue (or yellow and blue). Failure to continuously stir will produce patterns within the mixture.

CONCEPTS - USES

Motivation. Science Fairs
Spontaneous order from a chemical reaction
Non-equilibrium thermodynamics
Dissipative structures

MATERIALS

Potassium bromate - 100mL of 0.35M
Cerium (III) sulfate - 100mL of 0.004M
Malonic acid - 100mL of 1.2M
Sulfuric acid - 100mL of 1.5M
Ferroin indicator (optional)
Magnetic stirrer (optional)

SAFETY NOTES

No special precautions.

PREPARATION

- Ferroin is a redox indicator that will intensify the colour changes. It is available as a solution from chemical suppliers or can be made up as follows: dissolve 1.485g of 1,10-phenanthroline and 0.695g iron (II) sulfate crystals in 100mL water.

PROCEDURE

- Mix the solutions and stir gently. Observe after stirring ceases.

- Mix solutions continuously on a magnetic stirrer.

OBSERVATIONS

- After stirring, if left undisturbed, the system will spontaneously form stable shapes, alternating in colour between red and blue bands (in the absence of fermion the colours should alternate between blue and pale yellow).

- If stirred continuously on a magnetic stirrer the colour should oscillate, with increasing frequency, between red and blue. When stirring is stopped, banding will occur again.

COMMENT

- This reaction, termed the Zhabotinski reaction, and similar reactions were instrumental in the development of the theory of non-equilibrium thermodynamics, which deals with the spontaneous generation of ordered states in systems which are far from equilibrium (and thus not governed by the second law of thermodynamics).

- The reactions in sequence are:

$$Br^- + BrO_3^- + 2H^+ \rightarrow HBrO_2 + HOBr$$

$$Br^- + HBrO_2 + H^+ \rightarrow 2HOBr$$

$$BrO_3^- + HBrO_2 + H^+ \rightarrow 2BrO_2 + H_2O$$

$$2BrO_2 + 2H^+ + 2Ce^{3+} \rightarrow 2Ce^{4+} + 2HBrO_2$$

$$2HBrO_2 + 2HBrO_2 \rightarrow HOBr + BrO_3^- + H^+$$

$$4Ce^{4+} + BrCH(COOH)_2 + 2H_2O \rightarrow 4Ce^{3+} + HCOOH + 2CO_2 + 5H^+ + Br^-$$

VARIATIONS

- Oscillating reactions have been reported with other chemical systems. Some examples include:

  Bromate/ gallic acid/ sulfuric acid
  Bromate/ gallic acid/ nitric acid
  Bromate/ citric acid/ sulfuric acid/ manganese II

- Try the following on a magnetic stirrer at 35°C :
  0.04M potassium bromate
  0.04M citric acid
  0.01M manganese II sulfate
  0.5M nitric acid or 1M phosphoric acid or 3M H_3PO_4.

- Though colour is more intense at higher concentrations, the oscillations occur much more slowly (up to 20–30 minutes).

THE BELOUSOV CLOCK REACTION
(Oscillating Reaction II)

An alternative recipe for oscillating reactions I.

CONCEPTS - USES

Motivation. Science Fairs
Spontaneous order in a reaction
Non-equilibrium thermodynamics
Dissipative Structures
Reaction kinetics

MATERIALS

Malonic acid - 100mL of 0.55M
Potassium bromate - 2.1g per 50mL
Potassium bromide - 0.0060g per L
Cerium IV sulfate - 0.323g per 100mL
Sulfuric acid - 100mL of 6M.
Ferroin indicator solution
Magnetic stirrer.

SAFETY NOTES

No special precautions.

PREPARATION

- Ferroin indicator solution is a redox indicator which may purchased in solution or made up by dissolving 1.485g of 1,10-phenanthroline and 0.695g of iron II sulfate crystals in 100mL of water.

- Solution A is made by dissolving 5.72g of malonic acid (or propanedioic acid) in 100mL of water.

- Solution B is made by firstly, dissolving 0.060g of potassium bromide in 1 litre of water to produce stock KBr solution. To 50mL of this solution is added 2.09g of potassium bromate to make solution B.

- Solution C is made by dissolving 0.323g of cerium IV sulfate in 100mL of 6M $H_2 SO_4$.

PROCEDURE

- Place a large beaker (about 400–600mL) on a magnetic stirrer and add, in sequence:

  (i) 100mL of solution A (Malonic acid)

  (ii) 50mL of solution B (bromate-bromide)

  (iii) 50mL of solution C (cerium)

  (iv) 2.5 - 4mL of ferroin indicator.

- Stir against a white backdrop . The colour should oscillate from blue to red. Temperature will effect the oscillation period.

OBSERVATIONS

- The malonic acid is oxidised by the bromate ion, catalysed by the cerium IV ion. The periodic changes in the relative concentrations of Ce^{4+} and Ce^{3+} are shown by the colour changes of the indicator.

- The two essential steps in the reaction are

$$6Ce^{4+} + C_3H_4O_4 + 2H_2O \rightarrow CH_2O_2 + 2CO_2 + 6Ce^{3+} + 6H^+$$

$$10Ce3+ + 2BrO_3^- + 12H^+ \rightarrow 10Ce^{4+} + Br_2 + 6H_2O$$

- The net reaction is:

$$5C_3H_4O_4 + 6BrO_3^- + 6H^+ \rightarrow 5CH_2O_2 + 5CO_2 + 3Br_2 + 8H_2O$$

OSCILLATING REACTION III

A mixture of colourless solutions turns brown. After addition of other reagents, the colour will oscillate between red and blue (after a longish induction period).

CONCEPTS - USES

Motivation. Science fairs
Reaction kinetics
Thermodynamics
Redox reactions

MATERIALS

Sodium bromate - 7.5g
Sodium bromide - 1g
Malonic acid - 1g
Ferroin indicator - 10mL
Concentrated sulfuric acid - 3mL
Dishwashing detergent or hair shampoo - 1 drop

SAFETY NOTES

Sodium bromate is a strong oxidiser.

PREPARATION

- Solution A: Dissolve 7.5g of sodium bromate and 3mL of concentrated sulfuric acid in 100mL of deionised water. Alternatively dissolve $NaBrO_3$ in 27mL of 2M H_2SO_4(or 54mL of 1M H_2SO_4) and make up to 100mL with deionised water.

- Solution B: Dissolve 1g of sodium bromide (NaBr) in 10mL of deionised water.

- Solution C: Dissolve 1g of malonic acid in 10mL of deionised water.

- Ferroin indicator: Use as supplied or make up by dissolving 1.49g of 1,10 - phenanthroline and 0.70g of $FeSO_4.5H_2O$ in 100mL of deionised water.

PROCEDURE

- Mix the solutions in a beaker in the following order:
  (i) 30mL solution A
  (ii) 2.5mL solution B
  (iii) 5.0mL solution C

- A brown colour will form. When it disappears add, in turn, 5.0mL of ferroin and several drops of detergent/shampoo.

OBSERVATIONS

- After a period of up to 5 minutes or so, the colour of the solution will oscillate between red and blue.

COMMENTS

- The reactions are complex and include:
  (i) the reaction of bromate and malonic acid to produce bromomalate;
  (ii) the oxidation of ferroin (a redox indicator) from its reduced (red) form to its oxidised (blue) form;
  (iii) the reaction of bromide and malonic acid to form bromomalate;
  (iv) the reaction of bromomalate and oxidised (ferric) ferroin to form bromide;
  (v) the inhibition of the ferroin red to blue oxidation by the bromide ion.

- Reference: *Scientific American*, July 1978.

OSCILLATING REACTION IV

A mixture will effervesce, turn brown and then oscillate from brown to colourless for a period of several minutes.

CONCEPTS - USES

Motivation. Science fairs
Reaction kinetics
Redox reactions

MATERIALS

Malonic acid - 6g
Potassium (or sodium) bromate - 4g
Manganese (II) sulfate - 0.5g
Sulfuric acid - 50mL (concentrated) or 500mL of 2M
Magnetic stirrer
Large beaker (eg 60–800mL)

SAFETY NOTES

Potassium bromate ($KBrO_3$) is a strong oxidiser. Care with concentrated H_2SO_4.

PREPARATION

- Prepare 2M sulfuric acid by slowly and carefully dissolving 50mL of concentrated H_2SO_4 in 450mL of water. Alternatively, warm 2M H_2SO_4 to a temperature of 70–80°C.

PROCEDURE

- Add the following solids, in succession, to about 500mL of 2M H_2SO_4 on a magnetic stirrer (amounts are approximate):

  (i) 6g malonic acid
  (ii) 4g potassium bromate
  (iii) 0.5g manganese II sulfate

OBSERVATIONS

- The mixture will effervesce and then turn brown.
- After a short time (usually 10–30 seconds) the colour will begin to oscillate from brown to clear and colourless.
- Oscillations will continue for several minutes.

COMMENTS

- The reaction sequence is a complex one involving upwards of 20 chemical species and as many steps.
- The gas produced is carbon dioxide (in an oxidation reaction).
- The colour change is associated with the different oxidation states of manganese. Mn(II) is colourless, Mn(IV) is brown.
- Reference: *Scientific American*, March 1983.

OSCILLATING REACTION V

An alternate recipe for “Cyclic Iodine Clock”.

CONCEPTS - USES

Motivation. Science fairs
Thermodynamics
Reaction kinetics
Redox reactions

MATERIALS

Hydrogen peroxide - 30% (100 volume) - 40mL
Potassium iodate - 4.3g
Sulfuric acid (2M) - 4.5mL
Malonic acid - 1.56g
Manganese (II) sulfate - 0.34g
Starch - 0.05g
Beakers
Magnetic stirrer

SAFETY NOTES

Take care with concentrated hydrogen peroxide. It is corrosive.

PREPARATION

- Solution A: Dilute 40mL of 30% H_2O_2 to 100mL with water.

- Solution B: Dissolve 4.3g of KIO_3 in about 75mL of water, add 4.5mL of 2M H_2SO_4 (or 9mL of 1M H_2SO_4) and make up to 100mL with water. Stir well to dissolve.

- Solution C: Prepare a paste with about 0.05g of starch in a small volume of water and add it, with stirring, to 100mL of nearly boiling water. Stir well, remove from heat, and add 1.56g of malonic acid and 0.34g of $MnSO_4.H_2O$. Cool the solution.

PROCEDURE

- Mix the solutions in order A, B and C, in a large beaker on a magnetic stirrer against a white background.

OBSERVATIONS

- The colour will oscillate from light yellow to blue for a period of about 10 minutes.

COMMENTS

- The reactions are a complex series of redox reactions, involving the production of iodine and oxygen gas.

- See “Cyclic iodine clock” for alternative recipe.

OSCILLATING REACTION VI

A mixture will oscillate in colour from colourless to gold to blue over a period of 5–10 minutes. Purple vapours will also appear.

CONCEPTS-USES

Motivation, Science fairs
Rates of reaction
Reaction kinetics
Redox reactions
Energy
Thermodynamics

MATERIALS

Potassium iodate - 28.7g
Perchloric acid (70%) - 15.2g or Sulfuric acid
Malonic acid - 10.5g
Manganese (II) Sulfate - 2.3g
Vitex indicator or starch indicator - 1g
Hydrogen peroxide (100 volume) - 296.3g
Beakers, Magnetic stirrer (optional)


SAFETY NOTES

Take special care with perchloric acid and concentrated H_2O_2

PREPARATION

- Solution A
  Dissolve 28.67g of potassium iodate in about 700mL of warm water. Dilute (CARE!) 15.2g of perchloric acid by adding it to 50mL water and then add it slowly and with stirring to the fully dissolved KIO_3 solution. Make up to 1 litre.

- Solution B
  Dissolve 10.46g of malonic acid and 2.25g of manganese sulfate ($MnSO_4$. H_2O) in about 400 mL of water, add about 20mL of a 1% solution of Vitex (or starch) and make up to 500 mL.

- Solution C
  Make 296.3g of fresh 30%" or "100 volume" hydrogen peroxide up to 500 mL with water.

- Smaller volumes may be produced to conserve chemicals (eg ¼ scale).

PROCEDURE

- Into a large (eg 500 mL) beaker containing a magnetic stirrer add one part (e.g. 100mL) of B, one part (eg 100mL) of C and two parts (eg 200mL) of A whilst stirring constantly. If a magnetic stirrer is not available, thoroughly mix the solutions by pouring back and forth several times.

OBSERVATIONS

- A series of striking cyclic changes from colourless to gold to blue will occur over a period of 5-10 minutes.

- After some time purple vapours of iodine appear above the solution.

COMMENTS

- The mechanism of oscillating reactions is not well understood but they have formed the basis of the development of a theory of non-equilibrium thermodynamics where the entropy law does not apply.

- Perchloric acid may be substituted by 10.8g concentrated sulfuric acid.

QUICKIES

IODIDE FORMATION

Needs

- 0.1M potassium iodide
- 0.1M sodium persulfate (or peroxydisulfate) $Na_2S_2O_8$
- 1% starch solution
- Beakers

Method

- Mix equal volumes of $I^-(aq)$ and $S_2O_8^{2-}(aq)$.
- Mix equal volumes of $I^-(aq)$ and $S_2O_8^{2-}(aq)$ with a small amount of starch indicator.
- Observe each against white background.

Results

- Iodine slowly forms - in beaker #1 the colourless reactants gradually produce a pale yellow solution which slowly darkens to form a brown solution; in beaker #2 the colour change is noticed sooner as blue I_2 - starch appears and gradually darkens to give a black colour.

- Reaction is:

  $2I^- + S_2O_8^{2-} \rightarrow I_2 + 2SO_4^{2-}$

- For a slower reaction try

  0.05M I^- and 0.02M $S_2O_8^{2-}$

Section 6: REDOX REACTIONS

Blue bottle
Colourful cycle
The beating heart
Silver mirror
Blue printing
Colourful Vanadium
Colourful Manganese
Menthoids magic
Fire writing
“Quickies”

BLUE BOTTLE

A colourless solution will turn blue when shaken. Upon standing the blue colour will disappear. The cycle can be repeated many times.

CONCEPTS - USES
Motivation - Science Fairs
Redox reactions
Oxidation states
Colour and oxidation state
Reducing action of glucose
Oxygen solubility in water

MATERIALS
Glucose - 12g (Approx).
Sodium hydroxide - 12g
Methylene blue - 1mL of 1% solution.
Conical flask or Florence flask fitted with stopper (up to 1000mL size)
A white background

SAFETY NOTES
No special precautions

PREPARATION
- Dissolve 12g of glucose (powder) in a litre of water (volume is not critical).
- Within an hour of class time dissolve the sodium hydroxide in the glucose solution. Add about 1mL of methylene blue solution to produce a blue colour.
- Stopper the bottle.

PROCEDURE - OBSERVATIONS
- After the solution has been left to stand the blue colour will fade to yield a colourless solution.
- Shaking the flask will cause the solution to turn blue.
- The blue colour fades rapidly (depending on the degree of agitation when the flask was shaken) and returns on subsequent shakings.

COMMENTS
- On shaking, oxygen dissolves in the solution and reacts with methylene blue to give a blue colour (methylene blue in an oxidised form).
- On standing, alkaline glucose acts as a reducing agent and the methylene blue is reduced to a colourless oxidation state.

Equations: Me = Colourless Methylene blue

MeBl = Blue Methylene blue

(i) $O_2(g) \rightarrow O_2(aq)$ [Fast]

(ii) $O_2(aq) + Me(aq) \rightarrow MeBl(aq)$ [Fast]

(iii) $C_6H_{12}O_6(aq) + OH^-(aq) \rightarrow C_6H_{11}O_6^-(aq) + H_2O$ [Fast]

(iv) $C_6H_{11}O_6^-(aq) + MeBl(aq) \rightarrow Me(aq) + OH^-(aq) + C_6H_{12}O_6(aq)$ [Slow]

VARIATION

- The same effect can be produced by pouring the solution back and forth between two large beakers (from a height sufficient to agitate the mixture and dissolve air).

COLOURFUL CYCLE
(The Indigo Carmine Cycle)

A yellow solution will turn orange when gently shaken and green when vigorously shaken. Upon standing the green colour will change to orange and then to yellow. The cycle can be repeated many times.

CONCEPTS - USES

Motivation. Science Fairs
Redox reactions
Oxidation states
Colour and oxidation state
Reducing action of glucose
Oxygen solubility in water
Rates of reaction

MATERIALS

Glucose - 12g (approx).
Sodium hydroxide - 12 g
Indigo carmine - 50 mL of 2% alcohol solution.
Conical flask or Florence flask fitted with stopper - up to 1 000 mL size.
A white background.

SAFETY NOTES

No special precautions.

PREPARATION

- Dissolve 12g of glucose (powder) in a litre of water (volume is not critical).
- Within an hour of class time dissolve the sodium hydroxide in the glucose solution and add 50 mL (at least) of 2% indigo carmine solution to form a definite lime green solution.
- Stopper and allow to stand for 10–15 minutes during which time the colour should fade, through red-orange, to yellow.

PROCEDURE - OBSERVATIONS

- After the solution has been left to stand and equilibrate it should be yellow. Note that the reduced colour (yellow) is similar to the most oxidised colour (lime green). The difference is noticeable only with experience .
- Shake the flask slightly. (The solution should turn red-orange).
- If the solution is left to stand the red-orange colour should fade slowly to yield a yellow colour.
- If the solution is shaken vigorously, the yellow (or red-orange) colour will change to a lime green. When left to stand the colour should fade quickly from green to red-orange, and more slowly from red-orange to yellow.

COMMENTS

- The reaction mechanism is thought to be as follows:

Y = $C_{16}H_8N_2O_8S_2^{2-}$ (Yellow - reduced indigo carmine)

R = $C_{16}H_7N_2O_8S_2^{2-}$ (Red-orange - intermediate oxidation state)

G = $C_{16}H_6N_2O_8S_2^{2-}$ (Green - oxidised indigo carmine)

On Shaking

(i) $O_2(g) \rightarrow O_2(aq)$ [Fast]

(ii) $Y(aq) + {}^1/_2O_2(aq) \rightarrow R(aq) + OH^-(aq)$ [Fast]

(iii) $R(aq) + {}^1/_2O_2(aq) \rightarrow G(aq) + OH^-(aq)$ [Slow]

On Standing

(i) $G(aq) + OH^-(aq) + C_6H_{12}O_6(aq) \rightarrow R(aq) + C_6H_{12}O_7(aq)$ [Fast]

(ii) $R(aq) + OH^-(aq) + C_6H_{12}O_7(aq) \rightarrow Y(aq) + C_6H_{12}O_8(aq)$ [Slow]

- Glucose is acting as a reducing agent and oxygen in the air is the oxidising agent.
- Note that the steps of the reaction (in both directions) occur at different rates and also that, if a forward step is fast, the corresponding reverse reaction is slow (e .g. Y'R is fast, R'Y is slow).

* The reaction mixture takes a while to return to the (lime green) reduced state when it is first made up because of the amount of air introduced when the reagents are mixed. Also, if insufficient indigo carmine is added at the start, the colour of the highest oxidation state (green) will not be noticeably different to that of the reduced state (yellow). The secret is to add plenty of indicator and leave the mixture to stand undisturbed for enough time after making it up before testing that it has returned to the reduced state by gently swirling.

THE BEATING HEART
(The Mercury Heart)

A blob of mercury pulsates in a heart shape when touched with a nail in a solution.

CONCEPTS - USES

Motivation. Science Fairs
Redox reactions
Surface phenomenon
Electrochemistry

MATERIALS

Mercury
Iron nail
Sulfuric acid - 6M
Sulfuric acid - concentrated
Potassium dichromate - 0.1M
Watch glass - 8–10cm diameter
Retort stand and clamp

SAFETY NOTES  

Take the usual precautions with 6M and concentrated H_2SO_4 and with mercury.

PREPARATION

- Clean the nail and attach it to a clamp held in a retort stand.

- Place a pool of mercury - about 2cm in diameter - into the watch glass and add about 5mL of 6M H_2SO_4, so that all the metal is covered. Then add 1mL of 0.1M $K_2Cr_2O_7$.

- Position the nail so that it only just touches the very edge of the mercury.

PROCEDURE - OBSERVATIONS

- To start the demonstration, slowly add from 0.5mL to 2mL of concentrated sulfuric acid, dropwise, above the pool of mercury until it starts to vibrate. Do not add more acid than is necessary to start a rhythmical “beating” of the mercury.

- The position of the nail can be adjusted to change the amplitude of the beating.

COMMENTS

- The controlling factor is the number of electrons on the surface of the mercury, which affects the surface tension. The mercury has a lower surface tension, and therefore flattens, when there are few electrons, and has a higher surface tension, and adopts a spherical shape when there are many electrons. In the first stage the dichromate oxidises the iron nail and the mercury leading to a reduction of the number of electrons, and thus a flattening of the mercury. As the mercury flattens it touches the iron nail, which has a higher electrical charge, so that electrons flow from the nail to the mercury, which now adopts a spherical shape. The cycle repeats to give a beating effect.

SILVER MIRROR
(The Tollen's Silver Mirror Reaction)

A silver coating forms on glassware when a solution is heated strongly.

CONCEPTS - USES

Motivation. Science Fairs
Redox reactions
Test for strong reducing agents
Element formation by reduction reaction

MATERIALS

Silver nitrate solution - 0.1M
Ammonia solution - 0.5M or 1M
Sodium hydroxide solution - 1M or 2M
Glucose powder
Test tube and holder
Bunsen burner
Dropper

SAFETY NOTES

The "Tollen's reagent" formed from mixing silver nitrate, sodium hydroxide and ammonia must not be kept or allowed to dry as it forms explosive compounds. Always make fresh and discard after use.

PREPARATION

- Thoroughly clean the inside surface of a test tube by heating some sodium hydroxide solution in it to near boiling. Leave the hot solution in the test tube until ready for use.

- Dissolve about 1-2g glucose in 5mL of water.

PROCEDURE - OBSERVATIONS

- Pour the hot sodium hydroxide solution out of the test tube and then add 5mL silver nitrate solution, forming a brown precipitate (silver oxide).

- Using a dropper add JUST sufficient ammonia solution to dissolve the brown precipitate, forming the clear "Tollen's reagent".

- Add the glucose solution and heat, without shaking, over a moderate flame (or in a boiling water bath).

  - The solution should darken, forming a silvery mirrored finish on the inside surface of the test tube. The silver mirror should be observable when the test tube is emptied.

  COMMENTS

  - Tollen's reagent is a weak oxidising agent and glucose is a strong reducing agent, which react to form elemental silver.

  - Equations:

$$Ag^+(aq) + 2OH^-(aq) \rightarrow Ag_2O(s) + H_2O(l)$$

$$Ag_2O(s) + 2NH_3(aq) + H_2O(l) \rightarrow Ag(NH_3)_2^+(aq) + 2OH^-(aq)$$

$$2Ag(NH_3)_2^+(aq) + C_6H_{12}O_6 + H_2O \rightarrow 2Ag + C_6H_{12}O_7 + 4NH_3 + 2H^+$$

BLUE PRINTING

Light sensitive paper develops a blue colour upon exposure and treatment with a reagent solution.

CONCEPTS - USES

Motivation
Photochemical reactions
Redox reactions
Colour and oxidation state

MATERIALS

Potassium ferricyanide - about 20g (per 100mL)
Iron (III) oxalate (ferric oxalate) - about 20g (per 100mL)
Shallow trays (e.g. photographic trays) - 2
Paper (preferably fairly stiff)
Tracing paper

SAFETY NOTES

Chemicals are toxic.

PREPARATION

- Prepare sufficient 20% ferric oxalate and 20% potassium ferricyanide to give a 1–2cm depth of solution in each tray.

- Prepare light-sensitive paper in advance of the demonstration session by dipping sheet(s) of paper into the ferric oxalate solution, remove, and allow to dry in a dark place. These undeveloped sheets can be stored in opaque envelopes for future use.

PROCEDURE

- Draw a diagram or write a message onto a piece of tracing paper. Attach to a piece of the treated paper with paper clips and expose to strong light for at least 20 minutes.

- Place some opaque objects onto a piece of treated paper and expose to strong light for at least 20 minutes.

- Develop the papers by dipping, one after the other, into the developing solution (20% potassium ferricyanide). Within a few seconds the blue colour will develop. Remove the papers and carefully wash away the solutions with a most cloth.

- Allow prints to dry. Flatten under a heavy book for future use, if desired.

COMMENTS

- Ferric oxalate undergoes photochemical reduction to ferrous oxalate in the undeveloped paper:
  $Fe_2(C_2O_4)_3 \rightarrow 2FeC_2O_4 + 2CO_2$

- The developing solution reacts with iron II to produce a precipitate of Prussian blue:

  $Fe^{2+} + Fe(CN)_6^{3-} + K^+ \rightarrow KFeFe(CN)_6$

COLOURFUL VANADIUM

A yellow solution changes colour to blue, then green, then violet as it is heated with a piece of metal.

CONCEPTS - USES

Motivation
Transition metal chemistry
Oxidation states
Redox reactions
Colour and oxidation state

MATERIALS

Ammonium metavanadate - 2g
Sodium hydroxide - 1.5g
Sulfuric acid (2M) - 100mL
Mercury (II) chloride - 0.5g
Nitric acid - (concentrated) - 1mL
Zinc (granulated) - 50g

SAFETY NOTES

Take care with $HgCl_2$ - it is very toxic.

PREPARATION

- Zinc amalgam: Dissolve 0.5g $HgCl_2$ in about 60mL of water and add 1mL of concentrated nitric acid, in a 250mL flask. Then add 50g of granulated zinc, stopper and shake for a few minutes. Decant the solution and rinse the zinc amalgam several times with water before storing it under water in a sealed flask.

- Vanadium solution: Dissolve 1.5g of sodium hydroxide in about 40mL of water and add 2g of ammonium metavanadate (NH_4VO_3) and warm to dissolve it, stirring frequently. Add 100mL of 2M sulfuric acid and make up to 200mL with water.

PROCEDURE

- Place the zinc amalgam in a large (eg 1L) flask and add the vanadium solution. Stopper and note the yellow colour. Save a sample.

- Gently swirl the flask to produce a blue colour. Save a sample.

- Shake the flask again to produce a green colour and save a sample.

- Shake the flask vigorously and note the violet colour. Save a sample.

RESULTS

- The solution, originally yellow, will change colour to blue, green and then violet.

COMMENTS

- Zinc amalgam is a reducing agent.

- Vanadium can exist at a number of oxidation states, each characterised by different colours:

  V (+V) is yellow
  V (+IV) is blue
  V (+III) is green
  V (+II) is violet

- The reactions are in sequence:

  $Zn + 2VO_3^- + 8H^+ \rightarrow 2VO^{2+} + 2n^{2+} + 4H_2O$

  $Zn + 2VO^{2+} + 4H^+ \rightarrow 2V^{3+} + Zn^{2+} + 2H_2O$

  $Zn + 2V^{3+} \rightarrow 2V^{2+} + 2n^{2+}$

- The colour changes can be reversed using hydrogen peroxide.

COLOURFUL MANGANESE

A violet-pink solution reacts with a number of reagents to produce a variety of colours - pale pink, colourless, green and a brown precipitate.

CONCEPTS - USES

Motivation. Science fairs
Transition metal chemistry
Oxidation states
Redox reactions
Colour and oxidation state

MATERIALS

Potassium permanganate - 1g
Sulfuric acid - 2M
Sodium hydroxide - 2M
Sodium bisulfite - 0.5g
Beakers
White background

SAFETY NOTES

No special precautions.

PREPARATION

- Make a 0.2% solution of potassium permanganate by dissolving 1g in 500mL of water.
- Make a 0.01M solution of sodium bisulfite by dissolving 0.54g of $NaHSO_3$ in 500mL of water.

PROCEDURE - OBSERVATIONS

- Place 50mL of 0.1% $KMnO_4$ into each of four beakers.
- Add 15–20mL of 2M H_2SO_4 to beaker 1 and then progressively and slowly add $NaHSO_3$(aq) with stirring, to change the colour from purple to red to pink to colourless. Beaker 1 now contains Mn + II.
- Add 20mL of 2M NaOH to beaker 2 and add $NaHSO_3$ to form a green solution of MnO_4^{2-}, which is the Mn + VI state.
- To beaker 3 slowly add $NaHSO_3$ to produce a brown precipitate of MnO_2, the Mn + IV state.
- Beaker 4 will contain MnO_4^-, the Mn + VII state.

COMMENTS

The reactions are:

(i) $2MnO_4^- + H^+ + 5HSO_3^- \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$

(ii) $2MnO_4^- + 3OH^- + HSO_3^- \rightarrow 2MnO_4^{2-} + SO_4^{2-} + 2H_2O$

(iii) $2MnO_4^- + 3HSO_3^- \rightarrow 2MnO_2 + 3SO_4^{2-} + 3H_2O$

MENTHOIDS MAGIC

A medicinal pill dissolves in water forming a blue solution. Addition of a reagent produces a violet colour. Addition of another reagent changes the colour to pink. Shaking the pink solution re-forms the violet colour.

CONCEPTS - USES

Motivation
Colour and chemical reactions
Redox reactions
Dissolution of air (and oxygen) in water
Oxidation states
Colour and oxidation state
Reversibility of reactions

MATERIALS

Menthoids tablet - 1 (from a Pharmacy)
Sodium hydroxide - 20mL of 2M NaOH
Glucose - about 10g
Conical flask or Florence flask (500mL to 1000mL) fitted with stopper.
White background.

SAFETY NOTES

No special precautions.

PREPARATION

- Grind “Menthoids” tablet to a powder.
- Place powdered tablet into the bottom a dry stoppered flask

PROCEDURE - OBSERVATIONS

- Half fill the flask with tap water - A blue solution is formed.
- Swirl gently to dissolve the powder (avoid vigorous agitation).
- Add about 20mL of 2M NaOH - the blue solution will change colour to a dark blue/purple colour.
- Add about 5g of glucose powder, gently swirl to dissolve, and stopper. Stand undisturbed for several minutes. In time the solution will change colour to form a pink solution.
- Shake the pink solution gently—the colour will change from pink through purple to dark blue. Upon standing the colour changes back to pink.
- As a variation make up the mixture before class so that a pink solution in a sealed flask is all the students see. Shaking the flask will produce a colour change.
- The mixture is stable for several days but changes colour (pink to blue) more slowly as it ages. This, of itself, can be interesting as the mixture will not change colour immediately on shaking but will do so 5–15 seconds after it has been shaken.
- The less vigorously the solution is shaken, the sooner the colour change is reversed.

COMMENTS

- “Menthoids” contain phenolphthalein (pink in alkaline solutions) and methylene blue (blue in the presence of oxygenated water, colourless when it has undergone reduction).
- Glucose is a reducing agent which reacts with the methylene blue to reduce it to the colourless form. Shaking aerates the solution and oxidises the colourless (reduced) methylene blue to the coloured form (See “Blue Bottle” demonstration).

FIRE WRITING

Applying a glowing splint to a piece of paper produces a slow, fuse-like burning along a line.

CONCEPTS-USES
Motivation
Combustion
Energy
Redox reactions

MATERIALS
Potassium nitrate (or sodium nitrate) - about 5g
Small (camel's hair) paintbrush
Piece of paper

SAFETY NOTE
Potassium nitrate (or sodium nitrate) is an oxidiser. Handle carefully.

PREPARATION
- Prepare a concentrated solution of potassium nitrate by dissolving 5g or KNO_3 in a minimum volume of water (e.g. 20mL)

- Write a message or draw a diagram which is continuous on an unglazed piece of paper (not photocopy paper) and dry it.

PROCEDURE
- Use a glowing splint to ignite the writing which should burn slowly like a fuse.

COMMENTS
- Potassium nitrate is an oxidising agent. It oxidises the cellulose in the paper.

- The message is most obvious if the writing is kept fine rather than thick.

QUICKIES

SILVER CRYSTALS #1

Needs
- Copper wire
- 0.1M silver nitrate

Method
- Coil a piece of copper wire
- Suspend wire in 0.1M $AgNO_3$ in a darkened place.

Results
- After about an hour crystals of silver will form.
- Leave overnight for longer crystals (and a blue solution).
- Reaction is a displacement reaction:

  $2Ag^+ + Cu \rightarrow Cu^{2+} + 2Ag$

SILVER CRYSTALS #2

Needs
- 0.1M silver nitrate
- Mercury

Method
- Place a blob of mercury into the test tube and add 5-10mL of 0.1M $AgNO_3$.
- Stand undisturbed in a darkened place for about a day or two.

Results
- Beautiful crystals of silver will grow from the surface of the mercury.

LEAD CRYSTALS

Needs
- Zinc strip (1cm x 8cm)
- 0.1M lead nitrate (or lead acetate)

Method/Results
- As above
- $Zn + Pb^{2+} \rightarrow Pb + Zn^{2+}$

TIN CRYSTALS

Needs
- Iron wire (or nail)
- 0.1M tin chloride
- Test tube

Method/Results
- As above
- $Sn^{2+} + Fe \rightarrow Sn + Fe^{2+}$

MAKING COPPER

Needs
- 0.5M copper II sulfate
- Zinc powder or iron powder

Method
- Add a spatula amount of zinc (or iron) powder to a test tube full of aqueous copper II ions and shake.

Observation
- The blue colour will be removed from solution.

- Reddish copper powder will form as a sediment.

COLLOIDAL SULFUR

Needs
- 0.1M sodium thiosulfate
- 1M sulfuric acid
- Black background
- Test tubes or beakers

Method
- Mix 20mL with 2mL of acid and observe against a dark background.
- Repeat using 1M acid diluted successively to 0.5M, 0.25M, 0.1M.

Results
- A white/pale yellow colloidal precipitate of sulfur gradually forms.
- Rate of sulfur production decreases with acid concentration.

SULFUR SHOWER

Needs
- Sulfur powder
- Large beaker of water
- Dishwashing detergent

Method
- Cover the surface of a beaker of water with fine sulfur powder.
- Add a drop of detergent.

Result
- The sulfur particles cascade to the bottom of the beaker (as the detergent reduces the surface tension).

PEROXIDE DECOMPOSITION

Needs
- 30% hydrogen peroxide (i.e. “100 volume”)
- Potassium iodide - 1g
- Measuring cylinder
- Detergent or shampoo

Method
- Place about 20mL of H_2O_2 and 1mL of detergent into a measuring cylinder in a trough.
- Add about 1g of KI.

Result
- The mixture effervesces vigorously producing a foam.

- The steps in the reaction are:

$$H_2O_2 + I^- \rightarrow H_2O + IO^-$$
$$H_2O_2 + IO^- \rightarrow H_2O + O_2 + I^-$$

BLEACH DECOMPOSITION

Needs
- Laundry bleach (chlorine bleach)
- Cobalt (II) chloride - 5g or cobalt II nitrate.
- Flask

Method
- Add about 5g of $CoCl_2$ to about 100mL of bleach and swirl.

Result
- The mixture will effervesce, producing oxygen gas:

$$2ClO^- \rightarrow O_2 + 2Cl^-$$

- The black precipitate which forms is the unstable CO_2O_3.

- $CO(NO_3)_2$ can be used.

Section 7: POLYMERS

The Nylon rope trick
Instant resin
Phenol resin
Rayon
Polymer gel
The instant giant sausage
“Quickies”

THE NYLON ROPE TRICK

A continuous thread is pulled from the interface between two immiscible liquids.

USES - CONCEPTS

Motivation. Science Fairs
Polymerisation (condensation polymerisation) and polymers
Synthesis reaction

MATERIALS

Sebacoyl chloride (or Adipoyl chloride) - 2.2g (or 1.7g)
1,6-diaminohexane (Hexamethylene diamine) - 2.2g
Freon (or chloroform or 1, 1, 1-trichloroethylene) - 100mL Anhydrous sodium carbonate - 6.0g
250mL beakers
Glass rod
Tweezers/tongs
Retort stand and clamp

SAFETY NOTES

- *Sebacoyl (or adipoyl) chloride is corrosive. It reacts with water (and moisture in the air) to produce hydrogen chloride fumes. Old bottles have been known to explode because of the build-up of pressure inside containers.*
- *1,6-diaminohexane is caustic.*
- *Some recipes call for the use of carbon tetrachloride, whose use is forbidden in most schools. Freon is a safer alternative, Chloroform and 1, 1,,1-trichloroethylene are less safe.*

PREPARATION

- Dissolve exactly 2.2g of sebacoyl chloride (1.7g adipoyl chloride) in freon and stir vigorously with a stirring rod. Insufficient mixing results in an easily broken rope.

- Dissolve 6.0 g of anhydrous Na_2CO_3 and 2.2g of 1,6-diaminohexane in 50mL of water. Larger amounts of this solution may be prepared as a stock solution (with plastic stoppers - not glass ones).

- Attach a glass rod, horizontally, to a clamp on a retort stand and position it at the edge of the bench.

PROCEDURE

- Place the 100mL of sebacoyl chloride solution into a 250mL beaker positioned under the glass rod.

- Carefully pour the aqueous 1,6-diaminohexane solution on top of the other solution, forming two immiscible layers. Nylon forms at the interface.

- Use a pair of tweezers or tongs to grasp the nylon at the interface and draw it out of the solution carefully. A continuous rope should form, which should be led over the rod and placed into a large beaker on the floor beneath the rod.

- The weight of the nylon falling into the beaker on the floor should be sufficient to keep the nylon rope coming.

OBSERVATIONS

- The nylon forms as a white, opaque substance at the interface.

- The nylon should form a continuous rope as it is pulled from solution.

COMMENTS

- The nylon rope often breaks. This is usually caused by having too much sebacoyl chloride, either in the recipe or in the solution at the interface, due to poor mixing of the freon solution.

- Pulling the rope too quickly or too slowly may cause it to break. Try to avoid allowing large "blobs" of nylon to form, as they will put a strain on the rope.

EQUATIONS

Sebacoyl chloride is :

$Cl - CO -(CH_2)_8 - CO - Cl$

Adipoyl chloride is :

$Cl - CO -(CH_2)_4 - CO - Cl$

For sebacoyl chloride the reaction is:

$$Cl- CO- (CH_2)_8 - CO- Cl + H_2N(CH_2)_6NH_2 \rightarrow [- CO-(CH_2)_8 - CO - NH(CH_2)_6NH -]_n + nHCl$$

INSTANT RESIN

Addition of a liquid to another liquid, with stirring, produces (after a 5–15 second induction) a solid pink mass of resin.

CONCEPTS - USES

Motivation. Science Fairs
Polymerisation (Condensation polymerisation)
Polymers
Exothermic reaction
Thermosetting plastics

MATERIALS

Resorcinol - 10g
Formalin (Formaldehyde) - 40mL
Sulfuric acid - concentrated
Beaker - 250mL
Stirring rod

SAFETY NOTES

Handle concentrated sulfuric acid with care. Formalin (formaldehyde) is toxic; its fumes should be avoided as it is also a suspected carcinogen.
Reaction is exothermic and gives off acrid vapours - do in a fume cupboard.

PREPARATION

- Prepare about 10mL of 50% sulfuric acid by slowly and carefully adding 5mL of concentrated acid to 5 water. Allow to cool.

- Weigh 10g of resorcinol into a beaker.

PROCEDURE

- Place the beaker of resorcinol onto a laboratory mat (in a fume cupboard).

- Add about 40mL of formalin solution and stir to dissolve most of the solid.

- Carefully add 3mL–5mL of the 50% H_2SO_4, stir quickly and leave the stirring rod in the mixture. Stand back.

OBSERVATIONS

- After a variable induction period (usually a few seconds) the mixture should instantly polymerise to form a solid which is pink or red. You should be able to pick up the apparatus using the embedded rod. Sometimes the polymerisation is so rapid that it occurs as the mixture boils, forming solid resinous “splashes”, a frozen moment.

- The reaction is a condensation polymerisation forming a resorcinol-formaldehyde resin , similar to phenol-formaldehyde (PF) resin. The polymerisation occurs in three-dimensions (i.e. covalent bonding occurs in three dimensions) forming a cross-linked, thermosetting plastic.

PHENOL RESIN

A mixture is heated and a resin forms quickly.

CONCEPTS - USES

Motivation. Science Fairs
Polymerisation
Polymers
Condensation polymerisation
Catalysis
Resins
Thermosetting polymers

MATERIALS

Formalin (formaldehyde) - 25mL.
Phenol - 20g.
Acetic acid (concentrated) - 55mL
Hydrochloric acid (concentrated) - 25mL.
Sulfuric acid (concentrated) - 25mL.
Beaker.
Glass rod.
Fume cupboard.

SAFETY NOTES

A fume cupboard is essential as acid fumes (HCl) and formaldehyde are produced. Formalin is toxic and its fumes should be avoided – it is a suspected carcinogen.
Reaction is exothermic. Care with corrosive chemicals (phenol, concentrated acids).

PREPARATION

- Dissolve 20g phenol in a mixture of 25mL formalin and 55mL glacial acetic acid in a 250–500mL beaker.

PROCEDURE

- In a fume cupboard add about 25mL of concentrated HCl to the mixture and stir with a glass rod.
- With great care (to avoid spatters and fumes) quickly pour about 25mL of concentrated H_2SO_4 into the mixture, stir and stand back.

OBSERVATIONS

- A pink resin forms quickly and the mixture may bubble due to the heat of reaction and the release of gases (e.g. hydrogen chloride) and vapours.

COMMENTS

- The polymer is a phenol-formaldehyde (PF) resin. It is extensively cross-linked in a three dimensional covalent network and so is a thermosetting plastic.

RAYON

A solution injected (by syringe) into another forms a thin filament.

CONCEPTS - USES
Science Fairs
Polymers
Regenerated fibres

MATERIALS
Cellulose powder or filter paper.
Copper sulfate - 0.5M or 5g.
Concentrated ammonia.
Dilute hydrochloric (or sulfuric acid).
Sodium hydroxide - 2M.
Syringe (optional)
Beakers (250mL, 800mL or 1L)
Bunsen, tripod, gauze.

SAFETY NOTES
No special precautions.

PREPARATIONS
- Prepare Schweitzer's reagent as follows:

  (1) Boil 5g of copper sulfate in 100mL of water.
  (2) Slowly add 2M sodium hydroxide until precipitation is complete.
  (3) Decant, wash precipitate several times with water.
  (4) Dissolve the precipitate in the minimum amount of 4M ammonia (1 part conc. NH_3 with 3 parts water).

- Tear 2 x 11cm pieces of filter paper into small pieces (or use about 1–2g of cellulose powder) and dissolve in about 100mL of Schweitzer's reagent (about 10 minutes).

PROCEDURE
- Almost fill a large, tall beaker (800mL - 1L) with dilute acid (eg. 2M HCl)

Place cellulose/Schweitzer's reagent mixture into a syringe and slowly inject into the acid with a circular motion.

OBSERVATIONS
- A thin filament of silk-like fibre should be formed.

COMMENTS
- The fibre is "cuprammonium rayon", a regenerated form of cellulose.

POLYMER GEL
(A Polyvinyl Slime)

Two solutions are mixed to form a viscous gel that is able to flow slowly.

CONCEPTS - USES

Motivation. Science Fairs
Polymerisation and polymers
Chemical bonding
Gels and gelation

MATERIALS

Poly (vinyl alcohol) - Molecular Weight approx. 100,000
- 4g (per 100mL)

Borax - 4g (per 100mL)
Water soluble food colouring (e.g. Cochineal)
Beakers or (polystyrene cup)
Vulcanite spatula.

SAFETY NOTES

No special precautions.

PREPARATION

Prepare a 4% solution of the poly(vinyl alcohol) by slowly sprinkling 4g of the polymer powder onto the surface of 100mL of water in a 250–500mL beaker whilst stirring well with a broad stirrer (e.g. vulcanite spatula). Constant stirring is essential—failure to stir will result in a gluey mass of wet polymer. Moderate heat (to 90°C at most) will help dissolution, but do not overheat. The polymer solution should be a clear nearly colourless and somewhat viscous solution. If desired, add several drops of a food colouring.

- Prepare 100mL of a 4% borax ($Na_2B_4O_7.1OH_2O$) solution.

- Both solutions can be stored for some months.

PROCEDURE

- Pour 5–10mL of the borax solution into about 50mL of the polymer sol with rapid and vigorous stirring using a wide stirrer. Continue stirring until the mixture has gelled.

OBSERVATIONS

- A gel will form with the consistency of a very viscous “slime”.

- The material can be kneaded to form an elastic, semi-rigid solid which will flow and stretch under the influence of gravity. The gel can be stretched by slow pulling, or broken if pulled abruptly. Chunks of the gel can be reworked to form a single mass.

- When placed on a flat surface, the gel will flow to form a film. If placed into a container, it will assume the shape of the container.

COMMENTS

- The poly(vinyl alcohol) is a hydrophilic polymer similar to many natural gums because it contains hydroxyl groups along a polymer backbone. For a molecular weight of about 100,000 the average chain length of the macromolecules is about 4000–5000 carbon atoms. A typical fragment of the polymer chain would contain mainly (98%) 1, 3-diol sequence of hydroxyls with occasional 1, 2-diol units.

- The diol hydroxyls are able to interact with the borate ions leading to cross-linking of different polymer chains to form a three-dimensional network. Since these interactions involve hydrogen bonding, the cross-linking is not as strong as the covalent disulfide linkages in vulcanised rubber.

THE INSTANT GIANT SAUSAGE

A beaker/evaporating basin is heated strongly. Amidst a cloud of smoke a black column up to a metre long, suddenly appears.

CONCEPTS - USES

Motivation. Science Fairs
Polymerisation

MATERIALS

p-Nitroacetanilide - 10g
Concentrated sulfuric acid
Evaporating basin
Stirring rod
Bunsen burner
Tripod and gauze

SAFETY NOTES

Perform in a well ventilated area and do not breathe fumes. Take care with concentrated sulfuric acid. Avoid skin contact with p-nitroacetanilide.

PREPARATION

- Clamp the evaporating basin above a tripod and gauze .

PROCEDURE - OBSERVATION

- Place a heaped teaspoonful of p-nitroacetanilide into the evaporating basin and slowly add concentrated sulfuric acid, with stirring, until the mixture assumes the consistency of a thick paste. Use less acid rather than too much - several mLs is sufficient.

- Heat the mixture over a low flame and with careful stirring until the mixture begins to simmer. At this point stand back.

- The mixture will suddenly polymerise forming a large, black, sausage-shaped mass in an instant, with the evolution of some smoke. Avoid breathing the fumes, which contain sulfur oxides.

QUICKIES

CASEIN

Needs

- 100mL milk
- Vinegar, bunsen, gauze
- Formalin

Method

- Warm 100mL of milk to about 50°C and add acetic acid or vinegar until all the casein has been coagulated.
- Remove the casein and work with fingers until it forms a rubbery mass.
- Soak the casein overnight in formalin.

Results

- Casein, a protein polymer, is coagulated by acid and will harden in formalin to form a rigid plastic.

UREA-FORMALDEHYDE

Needs

- Urea - about 5g
- Formalin (formaldehyde) - about 10mL
- Test tube
- Concentrated sulfuric acid

Method

- Stir 5g of urea with 10mL of formalin until a saturated solution is formed.
- Add 1–2 drops of concentrated sulfuric acid.

Results

- The mixture suddenly hardens to form a cross-linked, thermosetting plastic.

Section 8: TRICKS AND PARADOXES

Magical beakers
Water to wine to milk
Burning hanky
Instant gel
The great glassware race

MAGICAL BEAKERS

A green liquid is poured from one beaker to another in a sequence, changing colour each time (green › lime › yellow › orange › red › blue › purple › green).

CONCEPTS - USES

Motivation. Science Fairs
Acid-base reactions

MATERIALS

7 large (600mL) beakers
Universal indicator (solution)
Hydrochloric acid - 1.0M
Sodium hydroxide - 1.0M
Buffer solution pH=7
Sodium hydrogen sulfate (bisulfate) - 1.0M
Eye-dropper

SAFETY NOTES

No special precautions.

PREPARATION

- Beakers must be clean and dry.
- Line up the beakers on a white background 1–7.
- Place 600mL of water coloured green with universal indicator into beaker #1.
- Place the following solutions in successive beakers:

Beaker #2 - 2 drops 1.0M HCl (or $NaHSO_4$)
Beaker #3 - 2 drops 1.0M HCl (or $NaHSO_4$)
Beaker #4 - 2 drops 1.0M HCl (or $NaHSO_4$)
Beaker #5 - 3 drops 1.0M NaOH
Beaker #6 - 1 drop 1.0M NaOH
Beaker #7 - 5mL of buffer 7 solution.

PROCEDURE - OBSERVATIONS

- Pour 500mL of the green solution from beaker 1 to 2. The solution in beaker #2 will initially turn pink but as the volume increases will change to orange and finally a lime-yellow.

- Pour 400mL of the lime-yellow solution from beaker 2 to 3. The solution will turn orange-yellow.

- Pour 300mL of the orange solution from beaker 3 to 4. The solution will turn red.

- Pour 200mL of the red solution from beaker 4 to 5. The solution will initially turn purple and then blue.

- Pour 100mL of the blue solution from beaker 5 to 6. The blue solution will turn purple.

- Pour half of the purple solution from beaker 6 to 7. The purple solution will turn green.

- Pour all of the green solution from 7 to 6 (green), then successively 6 to 5, 5 to 4, 4 to 3 etc. Each time the solution in the receptive beaker will turn green.

VARIATION

- Set up 6 beakers as follows:

Beaker #1 - 500mL water + Universal indicator
Beaker #2 - 4 drops 1.0M HCl (or $NaHSO_4$)
Beaker #3 - 4 drops 1.0M HCl (or $NaHSO_4$)
Beaker #4 - 8 or 9 drops 1.0M NaOH
Beaker #5 - 2 drops 1.0M NaOH
Beaker #6 - 10mL buffer solution 7

- Starting with beaker #1, pour all the green solution into the next beaker in the series. The colour should change from green to yellow, then red, then blue, then purple and finally end up green again.

VARIATION #2

Set up beakers as follows:

Beaker #1 - 400mL water + 3 drops 1M NaOH + Thymol Blue
Beaker #2 - 8 drops 0.1M $NaHSO_4$
Beaker #3 - 10 drops 0.1M $NaHSO_4$
Beaker #4 - 2mL 1M HCl
Beaker #5 - 5mL 1M HCl

- Pour all the solution from beaker #1 into the next beaker, and so on in sequence. The colour should change from blue to green, to yellow, to orange, to red. It may be necessary to vary the amounts slightly to account for different sized droppers or variations in concentrations. Non-volatile acids and bases are preferable to volatile ones.

WATER TO WINE TO MILK

A clear liquid turns a claret colour when poured into a wine glass. When the "wine" is poured back into the original container the colour disappears. When this solution is poured into a tumbler a white, milky liquid forms.

CONCEPTS - USES

Motivation. Science Fairs
Acid-base reactions
Precipitation reactions

MATERIALS

Sulfuric acid - 1M (or similar)
Sodium hydroxide (solid)
Phenolphthalein indicator solution
Barium chloride - saturated solution.
Wine glass
Drinking glass
Glass water pitcher

SAFETY NOTES

Barium salts are very toxic. Wash up well afterwards!

PREPARATION

- Fill the pitcher with dilute sulfuric acid and add about 1mL of phenolphthalein.
- Fill the wine glass with the acid and then establish the minimum number of pellets of sodium hydroxide that are necessary to produce a wine-red colour in the glass. Toss out this solution, dry the glass, and then add this number of pellets and allow to stand (e.g. overnight) until they have deliquesced (dissolved in moisture from the atmosphere).
- Rinse the drinking glass with saturated barium chloride solution, and leave about 5mL of the solution at the bottom.

PROCEDURE - OBSERVATIONS

- Pour the colourless "water" from the jug into the wine glass, forming "claret".
- Pour the "claret" back into the jug, reforming "water".
- Pour "water" from the jug into the drinking glass (vigorously in order to stir up the solutions), forming "milk".

COMMENTS

- The last step enables one to "correct" the biblical story so that it satisfies teetotallers!
- The red colour is produced because the sodium hydroxide in the wine glass neutralises the sulfuric acid, with a small amount of base in excess.

  Equation: $H_2SO_4 + NaOH \rightarrow Na_2SO_4 + 2H_2O$

- The disappearance of the red colour occurs because the excess base is, in turn, neutralised by the larger amount of acid in the jug.
- The white precipitate in the "milk" is barium sulfate.

  Equation: $BaCl_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2HCl(aq)$

  $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

BURNING HANKY

A handkerchief is soaked in a liquid, wrung dry and held in a bunsen flame. The handkerchief "burns" with a visible flame for a while. When the flame is extinguished the cloth is unaffected.

CONCEPTS - USES

Motivation. Science Fairs
Latent heat of vaporisation
Energy and change of state
Combustion
Ignition temperature and combustion

MATERIALS

Methylated spirit or ethanol
Clean cloth (e.g. handkerchief)
Beaker - 250mL or 500mL
Tongs

SAFETY NOTES

Keep "burning" cloth well clear of solvents.

PREPARATION

- Mix about 50mL of methylated spirit with an equal volume of water.

PROCEDURE - OBSERVATIONS

- Immerse the clean cloth in the alcohol-water mixture, remove and wring well to remove excess liquid.

- Turn out lights and hold the damp cloth in tongs, and then wave into a bunsen flame until it catches alight. Remove from bunsen flame and allow to burn for about 10 seconds.

- Extinguish the flame (e.g. under a large, upturned beaker) and examine cloth, which should not have been burnt.

COMMENTS

- The burning alcohol vaporises the water, effectively removing heat (latent heat of vaporisation of water) so that the cloth does not reach its kindling (ignition) temperature.

- As a variation, substitute the methanol-boric acid mixture described in "Green Fire" for the alcohol, to give a green flame.

INSTANT GEL

Two liquids are mixed to form a gel that sets in the container. When ignited the gel burns with a bluish flame leaving a white residue.

CONCEPTS - USES
Motivation
Formation of a gel
Solubility of salts

MATERIALS
Calcium acetate - 34g/100ml
Ethanol (or methylated spirits) - about 250ml
3 beakers

SAFETY NOTES
No special precautions.

PREPARATION
- Prepare a saturated solution of calcium acetate (34g per 100mL). An appropriate volume would be 100ml. Place this in a 500ml beaker (or larger).

- Place about 250ml of methylated spirits (or ethanol) in a beaker.

PROCEDURE
- Quickly pour the methylated spirits into the solution of calcium acetate.

- Then attempt to pour the contents of this beaker into another beaker

OBSERVATION
- The calcium acetate should form a gel that will solidify.

COMMENTS
- The calcium acetate and ethanol form a gel (a liquid dispersed in a solid), demonstrating that the calcium acetate is not soluble in ethanol (though soluble in water).

- The gel can be squeezed, to remove most of the alcohol, placed on an asbestos mat and lit (the alcohol will burn). This is sometimes called “burning snow”.

VARIATIONS
1. Place about 50mL of saturated $Ca(C_2H_3O_2)_2$ solution into an opaque container (eg. a tin can or a styrofoam cup) unseen by the students. From a height sufficient to cause complete mixing, pour in 200mL of methylated spirits or ethanol. Gel formation should be virtually instantaneous, enabling the container to be inverted to show that the liquid has “disappeared”.

2. Mix the solutions as above but in transparent beakers and with a glass rod (preferably with a flattened or bent end) in the beaker. The beaker-gel should be able to be lifted by the glass rod.

3. A slower gelation can be shown by diluting the saturated $Ca(C_2H_3O_2)_2$ by 20% (40mL + 10mL water) and pouring the solution into ethanol and mixing by pouring back and forth between two beakers.

4. The visibility can be improved by adding a food dye to either solution.

THE GREAT GLASSWARE RACE

Two contestants attempt to be the first to pour all of their sequence of beakers containing a coloured liquid, without spillage, into a "finish" beaker. Neither will succeed!

CONCEPTS-USES
Motivation
Solubility
Effervescent reactions
Careful laboratory techniques
Laboratory safety

MATERIALS
Methylated spirits - 100mL
Calcium acetate - 34g
Hydrochloric acid - 100mL of 1 Molar
Sodium bicarbonate - 10g
Beakers - 2 x 250mL; 2 x 150mL; 2 x 400mL
Conical flasks - 2 x 250mL*
Volumetric flasks - 2 x 250mL*
Measuring cylinders - 2 x 250
Filter tunnels - 2
Universal Indicator
(Sodium hydroxide - 0.1M)

SAFETY NOTE
Ensure that participants do not get acid or other chemicals on their skin or clothing.

PREPARATION
- Prepare 100mL of saturated calcium acetate (34g in 100mL water), add universal indicator and sufficient 0.1M sodium hydroxide to produce a dark blue colour (pH=9.5), and place into one of the 250mL conical flasks.

- Prepare 100mL of saturated sodium bicarbonate (10g in 100mL water), add universal indicator (to produce a dark blue colour) and place into the other 250mL conical flask.

- Place 100mL of 1M hydrochloric acid into one of the 250mL beakers.

- Place 100mL of methylated spirits (or ethanol) into the other 250mL beaker.

- Line the glassware up in the following order (before the lesson, preferably) so as to give two sets of glassware arranged in a straight line that is symmetrical about the centre of the line:

250mL conical flask 1 (+ calcium acetate) (COMPETITOR #1)
250mL volumetric flask 1 + funnel
150mL beaker 1
400mL beaker 1
250mL beaker 1 (+ methylated spirits)
250mL measuring cylinder 1

250mL measuring cylinder 2 (COMPETITOR #2)
250mL beaker 2 (+ hydrochloric acid)
400mL beaker 2
150mL beaker 2
250mL volumetric flask 2 + funnel
250mL conical flask 2 (+ sodium bicarbonate)

PROCEDURE

- Invite 2 students to compete in a "safe pouring" race. Draw their attention to the variety of glassware used in chemistry and the need to be able to handle each type efficiently and safely. Tell students that the aim of the race is to see who can transfer their liquid speedily **and** efficiently from the conical flask, via the other pieces of glassware **in turn**, into the measuring cylinder WITHOUT SPILLAGES. The "winner" will be the first person to reach the 195mL mark in the cylinder with minimum spillage. Tell them that the total volume of solution for each competitor is 200mL and solutions are to be poured at arm's length.

- At "Go" each student is to pour all his/her solution from one vessel to the next in line successively.

- When competitor #1 pours his (calcium acetate) solution into the final beaker a solid gel will form, preventing any transfer solution from the beaker to the measuring cylinder. Therefore he "loses" the race.

- When competitor #2 pours his (sodium bicarbonate) solution into the final beaker, a vigorous effervescence will spill much of the solution on the bench. Therefore he "loses" the race too!

COMMENTS

- The gel forms because calcium acetate, though soluble in water, is poorly soluble in alcohol and precipitates to form a liquid/solid matrix.

- The vigorous effervescence is due to:

$$HCl + NaHCO_3 \rightarrow NaCl + H_2O + CO_2$$

- Some "morals" can be drawn from the experience:

  + things aren't always what they seem;
  + it's easier to make a mess than to clean it up afterwards;
  + know what you are handling/mixing/etc before you do it;
  + scientists sometimes deliberately mislead the subjects of their study/the public "for a good cause"!
  + a safe technique is one which avoids danger even when unexpected things occur.

VARIATION

- Beakers can be used (in ascending order of capacity) with volumes of solution in each to total the capacity of each successive beaker.

- Use a dye to colour one sequence (#2) and an indicator to colour the other (#1).

Section 9: MISCELLANY

COLOURFUL QUICKIES

A variety (9) of different colourful test-tube reactions.

CONCEPTS - USES

Motivation. Science Fairs
Colourful chemical reactions

MATERIALS (Each can be done separately)

1. Lead nitrate solution 0.1M
   Potassium iodide solution 0.1M (fresh)
2. Mercury (II) nitrate solution 0.1M or mercury (II) chloride (0.5%)
   Potassium iodide solution 0.1M (fresh)
3. Potassium permanganate solution (0.1% in 1M H_2SO_4)
   Glucose crystals or Formalin solution
4. Copper (II) sulfate solution 0.1M
   Ammonia solution 2M
   Concentrated Hydrochloric acid
5. Potassium permanganate solution (0.1% in 1M H_2SO_4)
   Sodium sulfite or sodium thiosulfate
6. Potassium dichromate solution (0.1M in 1M H_2SO_4)
   Sodium sulfite or sodium thiosulfate
7. Iodine
   Ether (or hexane): ***Ether is a X-Category chemical in NSW*** .
   Freon (or chloroform)
8. Iron (III) nitrate (or sulfate) - 0.1M
   Potassium (or ammonium) thiocyanate - 0.1M
   Sodium fluoride
9. Potassium ferricyanide - approx 0.5
   Iron (II) sulfate (or iron II ammonium sulfate) - 0.1M

SAFETY NOTES

Some of the above compounds are toxic, especially mercury, lead and thiocyanate solutions. ***Ether is a X-Category chemical in NSW.***

PREPARATION

- For number 7, tie a large crystal of iodine onto the end of a piece of waxed cotton or fine string. (Sodium sulfite or thiosulfate solution will remove iodine stains).

PROCEDURE - OBSERVATIONS

- Each of the reactions involves one or more colour changes.

- For #1 mix equal amounts of the two colourless solutions to produce a golden precipitate.

- For #2 slowly pour the iodide solution into the mercury (II) solution, to produce an orange precipitate, which dissolves to give a colourless solution as more iodide is added.

- For #3, dilute the potassium permanganate solution until it is a reddish purple, and place it into a 100mL measuring cylinder. Then sprinkle some glucose powder onto the top. The colour should fade, from the top of the cylinder down, changing from red-purple to red, pink, orange, yellow and colourless. Alternatively, try touching the top of the solution with a glass rod that has been dipped in formalin. If the change is too slow, heat the solution.

- For #4, add the ammonia to an equal amount of copper (II) solution to change the light blue colour to dark blue. Then add concentrated hydrochloric acid to change the dark blue colour to lime green.

- For #5, sprinkle sodium sulfite (or thiosulfate) into the permanganate solution and shake. The purple colour should disappear. As a variation, dilute the permanganate solution so that it is less intense and pour it into an "empty" beaker containing some sodium sulfite (or thiosulfate) powder. Alternatively, generate some SO_2 by adding sodium sulfite to 2M hydrochloric acid in a flask. Then pour the gas (only) into a beaker or gas jar, and follow that with some diluted permanganate solution, which should lose its colour instantly, as it is poured into the beaker (gas jar).

- For #6, add some sodium sulfite (or thiosulfate) to the light orange solution of potassium dichromate and heat. (Alternatively, heat the dichromate solution first, then add the reducing agent). The colour should change from orange to green. If the solution turns brown, dilute the dichromate solution and try again.

- For #7, place freon (or chloroform), then water, then ether (or hexane) into a measuring cylinder. The layers should only be visible from close-up. Then dip the iodine (on a string) into each of the layers successively, jiggling slightly to produce a yellow (then brown) colour in ether (pink in hexane), no colour in water, and a pink (then purple) colour in freon (or chloroform). Alternatively, sprinkle finely ground iodine powder onto the top layer and let it sink to the bottom of the cylinder.

- For #8, mix equal volumes of the iron III solution and the thiocyanate solution to produce an intense red-black colour. If the iron III solution is sufficiently diluted it will appear to be colourless, giving a more spectacular effect. Then add sodium fluoride (solid or 0.1M solution) and the colour will disappear.

- For #9, mix equal volumes of the pale orange (or pale yellow if diluted sufficiently) potassium ferricyanide solution and the pale green (or colourless if diluted sufficiently) iron II solution. An intense blue precipitate (called Prussian blue) forms.

COMMENTS

- Equation 1: $Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$

- Equation 2: $Hg^{2+}(aq) + 2I^-(aq) \rightarrow HgI_2(s)$

  $HgI_2(s) + 2I^-(aq) \rightarrow HgI_4^{2-}(aq)$

- Reactions 3 and 5 involve the reduction of the permanganate ion, which is purple in solution, to produce the colourless manganese (II) ion. As the MnO_4^- concentration falls, the colour changes.

  Equation 3:

  $$2MnO_4^- + 5C_6H_{12}O_6 + 6H^+ \rightarrow 2Mn^{2+} + 5C_6H_{12}O_7 + 3H_2O$$

  Equation 5:

  $$2MnO_4^- + 5SO_3^{2-} + 6H^+ \rightarrow 2Mn^{2+} + 5SO_4^{2-} + 3H_2O$$

- Reaction 4 involves the replacement of the ligands in the copper complex ion.

  Equation 4 :

  $$Cu(H_2O)_6^{2+} + 4NH_3 \rightarrow Cu(NH_3)_4^{2+} + 6H_2O$$

  $$Cu(NH_3)_4^{2+} + 6Cl^- \rightarrow CuCl_6^{4-} + 4NH_3$$

- Reaction 6 involves the reduction of the orange dichromate ion to form green chromium (III).

  Equation 6 :

  $$Cr_2O_7^{2-} + 3SO_3^{2-} + 8H^+ \rightarrow 2Cr^{3+} + 3SO_4^{2-} + 4H_2O$$

- Reaction 7 involves the relative solubilities of iodine in non-polar solvents (freon and ether) and its relative insolubility in water.

- Reaction 8 involves the formation of some complex ions.

  Equation 8:

  $$Fe(H_2O)_6^{3+} + SCN^- \rightarrow FeSCN(H_2O)_5^{2+} + H_2O$$

  $$FeSCN(H_2O)_5^{2+} + 6F^- \rightarrow FeF_6^{3-} + SCN^- + 5H_2O$$

- Reaction 9 involves the precipitation of a salt, which has a formula that is the subject of dispute, being either $KFeFe(CN)_6$ or $Fe_3\ Fe(CN)_{6\ 2}$. A possibility is:

  $$K^+ + Fe^{2+} + Fe(CN)_6^{3-} \rightarrow KFeFe(CN)_6$$

COLOURFUL QUICKIES II

More colourful test-tube reactions.

CONCEPTS - USES
Motivation, Science Fairs
Colourful chemical reactions

MATERIALS (Each can be done separately)

1. Lead nitrate solution (0.1M)
   potassium chromate solution (0.1M)

2. Lead nitrate solution (0.1M)
   potassium chromate solution (0.1M)
   sodium hydroxide.

3. Nickel II chloride (or sulfate) solution (0.5M)
   concentrated ammonia.

4. Cobalt II chloride (or nitrate) solution (0.5M)
   concentrated hydrochloric acid.

5. Potassium dichromate (0.2M)
   Dilute sodium hydroxide (2M)
   Dilute Hydrochloric acid (2M)

6. Iron III sulfate (or chloride) (0.1M)
   potassium ferrocynanide (0.1M)
   sodium carbonate (1M)

7. Sodium arsenite or arsenic trioxide (0.15 M)
   sodium thiosulfate (0.8M)
   acetic acid (conc)

SAFETY NOTES
Some of the solutions are toxic.

PREPARATION

- Make up a sufficient quantity of each solution for a demonstration (e.g. 10mL if done in test-tubes; 50-100mL if done in beakers).

- For #7 dissolve about 1g of $NaAsO_2$ (or As_2O_3) and 5.5 mL of glacial acetic acid in water to a total volume of 50mL.

PROCEDURE-OBSERVATIONS

- For #1, mix equal amounts of the clear/colourless Pb^{2+} solution and the clear/yellow CrO_4^{2-} solution to produce a thick yellow precipitate which is the artist's pigment Chrome Yellow.

- For #2, mix equal amounts of the Pb^{2+} and the CrO_4^{2-} solutions to produce a yellow precipitate of $PbCrO_4$ in a beaker. Add a small amount of NaOH and boil the mixture gently to produce a colour change from yellow to orange and then to a brilliant red pigment (Chrome Red or Basic Lead Chromate).

- For #3, progressively add a small amount of concentrated ammonia to the green nickel (II) solution to produce a dark blue colour.

- For #4 add sufficient concentrated HCl to the pink solution of Co(II) to produce a blue colour. Then add excess water to produce the original pink colour.

- For #5, add dilute NaOH dropwise to the orange dichromate solution until it turns yellow. Then add dilute HCl dropwise to the yellow solution until it turns orange.

- For #6, mix equal volumes of the Fe (III) and the ferrocyanide solutions to produce a dark blue suspension. Add sufficient sodium carbonate solution to change the dark blue colour to an orange suspension.

- For #7 mix equal volumes of the arsenite and the thiosulfate solutions and stand against a white background. After about a 15 second induction period, a golden yellow precipitate forms.

COMMENTS:

- Equation 1: $Pb^{2+} + CrO_4^{2-} \rightarrow PbCrO_4$

- Equation 2: $2PbCrO_4 + OH^- \rightarrow PbCrO_4.PbO + 2H^+ + CrO_4^{2-}$

- Equation 3: $Ni(H_2O)_6^{2+} + 6NH_3 \rightleftharpoons Ni(NH_3)_6^{2+} + 6H_2O$

- Equation 4: $Co(H_2O)_6^{3+} + 4Cl^- \rightleftharpoons CoCl_4^{2-} + 6H_2O$

- Equation 5: $Cr_2O_7^{2-} + 2OH^- \rightarrow 2CrO_4^{2-} + H_2O$

  $2CrO_4^{2-} + 2H^+ \rightarrow Cr_2O_7^{2-} + H_2O$

- Equation 6: $4Fe^{3+} + 3Fe(CN)_6^{4-} \rightarrow Fe_4[Fe(CN)_6]_3$

  $Fe_4[Fe(CN)_6]_3 + 4CO_3^{2-} \rightarrow 2Fe_2(CO_3)_2 + 3Fe(CN)_6^{4-}$

- Equation 7: $2AsO_2^- + S_2O_3^{2-} + H_2O \rightarrow 2AsO_4^{3-} + 2S + 2H^+$

RAINBOW REACTIONS I

As a solution is progressively added to a red solution the colour changes through the colours of the rainbow.

USES - CONCEPTS

Motivation. Science Fairs
Colour changes in reaction
Neutralisation reactions
Acid-base titrations
pH and colour of indicators

MATERIALS

Boric acid - 2.90g (per 50mL solution)
Sodium hydroxide - 50mL of 2M
Universal Indicator solution
Burette (50mL) and beaker (250mL)
Magnetic stirrer (optional)

SAFETY NOTES

No special precautions.

PREPARATION

- Prepare 50mL of saturated boric acid (2.90g dissolved in 50mL water) and place into a 250mL beaker containing a magnetic stirring bar. Add sufficient Universal indicator solution to produce a rose-pink colour. Place the beaker onto the magnetic stirrer.

- Fill a burette with 2M NaOH and position it above the beaker .

PROCEDURE

- Start the motor of the stirrer so that it is stirring rapidly.

- Turn on the burette tap so that the NaOH enters at a steady rate (sufficient to empty the burette in about 60–90 seconds)

OBSERVATIONS

- The colour of the solution will change from red-pink to orange, then through yellow, lime green, emerald green, cyan and blue until it finally reaches purple.

- As the NaOH neutralises the weak acid the pH gradually increases.

- Equation: $H_3BO_3 + NaOH \rightarrow NaH_2BO_3 + H_2O$

  $NaH_2BO_3 + NaOH \rightarrow Na_2HBO_3 + H_2O$

  $Na_2HBO_3 + NaOH \rightarrow Na_3BO_3 + H_2O$

RAINBOW REACTIONS II

A purple liquid constantly stirred undergoes colour changes (all colours of the rainbow) after about 0.5mL of another liquid is added.

USES - CONCEPTS

Motivation. Science Fairs
A colourful reaction
Rate of reaction
Hydrolysis
Substitution reaction
Acid-base reactions
pH and reaction

MATERIALS

t-Butyl chloride (2-chloro-2-methylpropane) - about 2mL
Sodium hydroxide - 0.1M
Universal indicator solution
Selection of other indicators (optional) -
- Methyl red (or methyl orange)
- Bromocresol green
- Bromthymol blue
- Thymol blue
- Phenolphthalein

Beakers (250mL)
Droppers
Magnetic stirrer (optional)

SAFETY NOTES

No special precautions.

PREPARATION

- Prepare a solution with a pH of about 11-12 by adding 10 drops of 0.1M NaOH to 100mL water, in a 250mL beaker. Add sufficient indicator (starting with universal indicator) to produce a distinct colour.

PROCEDURE

- Place a magnetic bar into the solution, position on top of the stirrer and start the motor at a reasonably quick rate. Alternatively have a second 250mL beaker on hand to enable mixing to be done by pouring the solution back and forth between the two beakers.

- Add 15 drops of t-Butyl chloride to the solution and begin mixing, watching for the appearance of a colour change, and any subsequent changes.

OBSERVATIONS

- After about 40 seconds (with most indicators—some take up to twice as long) a colour change should be observable. For universal indicator the full range of colour changes (purple, blue, cyan, emerald green, lime green, yellow, orange, orange-red) should take about 2 minutes, with the changes in the middle being more rapid than those at either extreme.

- Different colour changes, and different induction times, can be achieved using different indicators. These changes are summarised in the table:

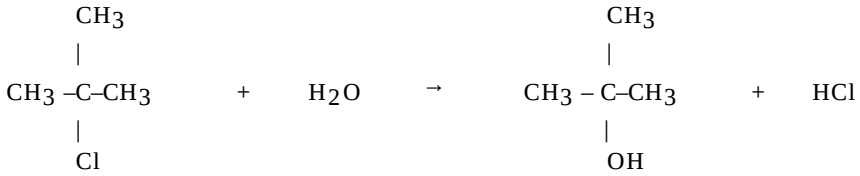
Indicator	Colour	Time (after start)
Methyl red	Yellow Orange Red	Initial 40 seconds 45 seconds
Bromthymol blue	Blue Green Yellow	Initial 40 seconds 45 seconds

Thymol blue	Blue Green Yellow	Initial 50 seconds 52 seconds
Phenolphthalein	Pink Pale pink Colourless	Initial 40 seconds 45 seconds
Bromocresol green	Blue Green Yellow	Initial 40 seconds 45 seconds
Bromphenol blue	Blue Green Yellow	Initial 75 seconds 80 seconds
m-Cresol purple	Violet Red Yellow	Initial 52 seconds 54 seconds

COMMENTS

- The reaction is an S_Nl reaction, i.e. a nucleophilic substitution reaction, in which the chlorine radical is replaced by an hydroxyl radical.

- Equation:



As H^+ ions are produced in solution in the reaction, the OH^- are gradually neutralised as the reaction proceeds, and eventually excess H^+ are produced. Thus the pH of the solution progressively falls as a result of reaction.

VARIATION

Make up two solutions: 0.1M 2-chloro-2-methylpropane (t-butyl chloride) in ethanol (1g per 100mL), and 0.01M sodium hydroxide.

- In one test tube (or beaker) put 5mL of 0.1M C_4H_9Cl and in another test tube (beaker) place 5mL 0.01M NaOH, 10mL water and a few drops of any one of the following indicators. Mix solutions back and forth once and observe for the colour change which occurs after an induction period.

- Indicators to use, and the colours they produce are:

  Methyl red - Yellow to red (about 6 seconds)
  Bromothymol blue - Blue to yellow (about 5 seconds)
  Thymol blue - Blue to yellow (about 10 seconds)
  Phenolphthalein - Red to colourless (about 11 seconds)
  Universal indicator - Purple to blue (instantly)
  Blue to green (about 8 seconds)
  Green to pink (about 10 seconds)

- With equal volumes of 0.1M C_4H_9Cl and 0.01M NaOH the colour changes with universal indicator were:

  Purple to blue: On mixing
  Blue to green: After 12 seconds, taking about 3 seconds.
  Green to yellow: After 15 seconds total, instantly.
  Yellow to orange: After 25 seconds total, gradually.

- Cooling the solutions greatly slows the reaction, increasing the induction period (e.g. with iced water, the methyl red change took over 50 seconds).

BLACK SUGAR

Addition of a liquid to a damp mass of sugar causes it to form a black mass that rises slowly up and out of the beaker. Alternatively, adding the liquid to a very wet suspension of sugar causes a black "eruption" of a lava-like material out of the beaker.

CONCEPTS - USES

Motivation. Science Fairs
Carbon content of sucrose
Dehydration of carbohydrates
Exothermic reactions
Chemical energy in sugar

MATERIALS

Sucrose (table sugar) - about 100g
Concentrated sulfuric acid - about 20mL
Beaker - 250mL (preferably narrow)
Glass stirring rod
Tray or laboratory mat

SAFETY NOTES

Take care with sulfuric acid. Reaction generates quite a bit of heat in the beaker. Do not use too much water to wet the sugar as a liquid solution of sugar will unexpectedly boil over when the acid is stirred in.

PREPARATION

- Place about 100g of sugar into the beaker and add just enough water to dampen it. Stir well so that the sugar is still a solid mass, but damp.

- Place about 20mL of the sulfuric acid into a small beaker, flask or test tube.

PROCEDURE

- With the beaker standing on a tray, quickly pour all the acid onto the sugar and stir it in. Stand clear.

OBSERVATIONS

- The sugar will blacken and char as soon as the acid hits it. As steam is produced the blackened mass of sugar should "grow" and be pushed up and out of the beaker.

COMMENTS

- Concentrated sulfuric acid is a powerful dehydrating agent. The heat of solution causes the sucrose to be decomposed to form steam and carbon.

- Equations

$$H_2SO_4\,(l) + H_2O(l) \rightarrow H_2SO_4(aq) + \text{Heat}$$

$$C_{12}H_{22}O_{11}(s) \rightarrow 12C(s) + 11H_2O(g)$$

VARIATION

- If more water is added to the sugar, to form a slurry, the carbon will erupt from the beaker and flow over the edges to form a black lava-like mass. BE CAREFUL when you add the acid - use a stirring rod to quickly stir the mix.

MAGIC BREATH

Inhaled air does not change the colour of a blue (or green) solution whereas exhaled air changes the blue colour to green then yellow (or green colour to yellow).

USES - CONCEPTS

Motivation. Science Fairs
Acidity of carbon dioxide
Carbon dioxide in exhaled air
Acid-base reactions
Neutralisation reaction

MATERIALS

Bromthymol blue indicator solution
Flask (conical, Florence or Drechsal) - 250mL size
Glass tubing or drinking straw
Drechsal bottles (2) and gas bubbling tubes (2) or
Side arm conical flasks fitted with one-hole stoppers and glass tubing (2)

SAFETY NOTES

No special precautions.

PREPARATION

- Prepare a solution of bromthymol blue in water which is just blue in colour (i.e. has a pH of 6.0) as follows:

  (i) add sufficient indicator to produce a grass-green colour
  (ii) add 0.1M ammonia (or 0.01M NaOH) dropwise with shaking until the colour just changes from green to blue.

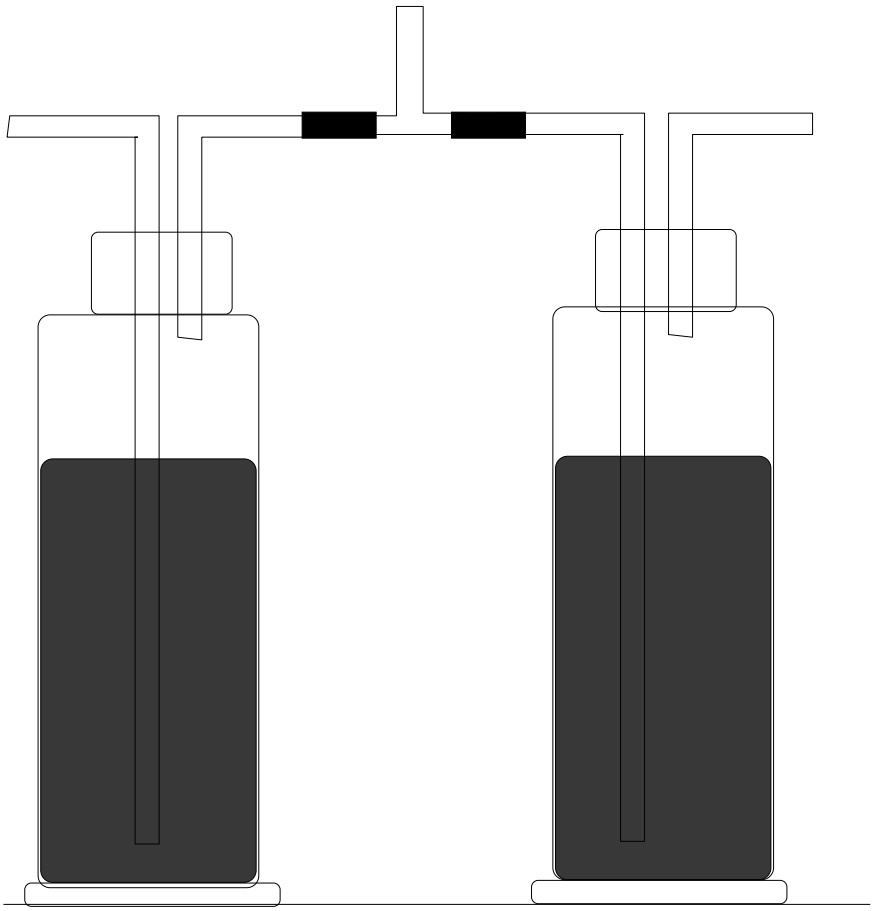
- As the demonstration of the colour change may be done using a test-tube and drinking straw, or on a larger scale using a conical flask (or similar apparatus), adjust the quantities accordingly.

- If the difference between inhaled and exhaled air is to be shown prepare the following apparatus, using either Drechsal bottles (from a Quickfit kit) or flasks, glass tubing and one hole stoppers (see diagram).

PROCEDURE

- For a colourful surprise simply blow air through the solution. The colour will change from blue, through shades of green, to yellow. One lungful should be sufficient for volumes of solution up to about 200mL.

- To show the difference in acidity (and thus carbon dioxide content) between inhaled air and exhaled air, breathe in a lungful of air through the T-junction connected to the illustrated apparatus, and then exhale.



OBSERVATIONS

- As the gas bubbles through the solution the colour changes from blue to yellow, progressively. Normal (inhaled) air will not cause a colour change.

COMMENTS

- As a variation, place some thymol blue and water (forming a green solution) into a conical beaker and exhale some “magic words” into the flask, several times. Then swirl the flask. The colour should change from green to yellow.

- Equations:

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$$

$$H_2CO_3(aq) + OH^-(aq) \rightarrow HCO_3^-(aq) + H_2O(l)$$

$$H_2CO_3(aq) \rightleftharpoons HCO_3^-(aq) + H^+(aq)$$

IODINE FROM KELP

The solution obtained by heating seaweed and dispersing the ash into water gives various tests for the presence of iodine.

CONCEPTS - USES
Redox reactions
Element formation
Physical and chemical changes

MATERIALS
Kelp or dried seaweed - about 2g
Hydrogen peroxide (20 volume) - about 10mL
Freon (or chloroform) - about 10mL
Silver nitrate (0.1M) - about 1mL
Starch solution
Sulfuric acid (2M) - about 1mL

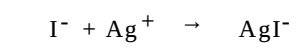
SAFETY NOTES
No special precautions.

PREPARATION
- If dried kelp ash is not available prepare some by thoroughly drying some seaweed in an oven (24 hours at 100°C). Crush the dried seaweed to a fine powder and then heat this strongly in a crucible for 5 to 10 minutes until an ash is left. (Use a fume cupboard).

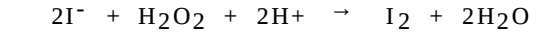
PROCEDURE
- Cover some of the kelp with 25mL of deionised water and boil gently.
- Filter the solution and cool it. The filtrate should be clear, perhaps with a pale yellow tinge.
- Test one half of the cool filtrate (for iodide ions) with silver nitrate solution.
- To the other half of the filtrate add 5–10 mL of hydrogen peroxide and 1mL of dilute sulfuric acid.
- Test half this (pale brown) solution with starch solution.
- Shake the remaining half of the solution with freon.

OBSERVATIONS
- The addition of silver nitrate to the filtrate should produce a creamy yellow precipitate (of silver iodide).
- Addition of hydrogen peroxide to the filtrate should produce a golden-brown colour in solution.
- Starch solution should produce a blue-black suspension when added to the golden-brown solution.
- When shaken with the golden-brown solution, the freon should turn pink-purple in colour.

COMMENTS
- The iodide ion is extracted from the seaweed and undergoes the following reactions:



$$I^- + Ag^+ \rightarrow AgI^-$$



$$2I^- + H_2O_2 + 2H^+ \rightarrow I_2 + 2H_2O$$

- The iodine is preferentially soluble in non-polar solvents (like freon, chloroform, carbon tetrachloride).

SYNTHESISING DYES

A number of solutions are mixed to produce brightly coloured precipitates of textile and food dyes.

CONCEPTS - USES

Motivation
Synthesis reactions
Organic condensation reactions
Colour and molecular structure
Azo dyes.

MATERIALS

Sodium nitrate - about 2g
2-naphthol - about 2g) At least one of these
N,N-dimethylaniline - about 3mL)
p-nitroaniline - about 1g)
Aniline - about 2g) At least one of these
Sulfanilic acid - about 3g)
Hydrochloric acid - concentrated and 2M
Sodium hydroxide - 2M
Sodium carbonate
Ice

SAFETY NOTES

All the organic compounds are toxic. Aniline and its derivatives are potentially carcinogenic.

PROCEDURE - OBSERVATIONS

1. Synthesis of Orange II

- Stir 1.2g of sulfanilic acid with 7.0mL of water and add 2M sodium hydroxide until the solution is just alkaline, and add 7.0mL of iced water and then 2mL of concentrated hydrochloric acid.
- Dissolve 0.5g of sodium nitrite in iced water and add it to the sulfanilic acid solution. Cool the solution to less than 5°C. This is solution A.
- Dissolve 1g of 2-naphthol in about 4mL of 2M sodium hydroxide and 100mL of water by warming. Add about 0.5g of anhydrous sodium carbonate and cool to below 5°C in an ice bath. This is solution B.
- Mix the two solutions when they are both below 5°C, and stir well.
- Orange crystals of the common dyestuff Orange II should form.
- The colour of this dye is pH dependant. Add 2M sodium hydroxide, with stirring, to change the colour.
- Variation: Aniline may be substituted for sulfanilic acid to give a different dye.

2. Synthesis of Methyl Orange

- Prepare a solution of sulfanilic acid and sodium nitrite (Solution A) as before. Cool it to below 5°C.
- Dissolve 1.5mL of N,N-dimethylaniline in 20mL of 2M hydrochloric acid, adding concentrated hydrochloric acid dropwise, if necessary, to assist dissolution. Cool to below 5°C. This is Solution B.
- Mix solutions A and B to form a red mixture.

- Add 2M sodium hydroxide, with stirring, until the mixture turns yellow. The methyl orange can be collected by filtration.

3. Synthesis of Para Red

- Dissolve 0.6g of p-nitroaniline in about 2mL of concentrated hydrochloric acid and dilute with about 60mL of water. Chill to below 5°C.

- Dissolve 0.6g of sodium nitrite in about 30mL of iced water and then pour this slowly, and with frequent cooling, into the p-nitroaniline solution to form Solution A. Cool to below 5°C.

- Prepare a solution of 2-naphthol as in Part 1. Cool to below 5°C. This is Solution B.

- Mix solutions A and B to form a red precipitate of the dyestuff Para Red.

COMMENTS

* The reactions involve two steps:

Step 1: DIAZOTISATION of aromatic amine.

$$Ar—NH_2 + HNO_2 \rightarrow Ar—N_2^+ + H_2O + OH^-$$

Step 2: Coupling of diazonium ion and a substrate.

$$Ar—N_2^+ + Ar—H \rightarrow Ar—N=N—Ar + H^+$$

* The dye molecules are extensively conjugated systems, leading to low energy $p \rightarrow p^*$ electronic transitions which absorb visible light.

QUICKIES

INSTANT SOLID

Needs
- Saturated calcium chloride solution
- 4M sulfuric acid

Method
- Quickly mix equal volumes of the two solutions against a dark background.

Observation
- The two clear and colourless liquids form a thick precipitate of calcium sulfate which solidifies in the test-tube (or beaker), forming a gel.

QUICK DECOMPOSITIONS

Needs
- One (or more) of: sucrose, lead nitrate, copper carbonate, mercury (II) oxide
- Test tubes, bunsen

Method
- Heat a small amount of the solid strongly.
- Decomposition will occur.

Observation
- For sucrose: black C, steam.
- For $Pb(NO_3)_2$: brown NO_2, orange PbO
- For $CuCO_3$: black CuO, invisible CO_2.

THE TRICOLOUR

Needs
- 1M ammonia
- Phenolphthalein (or alizarin red or phenol red)
- Saturated lead nitrate
- Saturated copper sulfate
- Beakers

Method
- Place 5 drops of indicator in beaker 1.
- Place 5-10 drops of saturated $Pb(NO_3)_2$ in beaker 2.
- Place 5-10 drops of saturated $CuSO_4$ in beaker 3.
- From the one large flask or beaker, at a height sufficient to give a good mixing, pour about 50-80mL of ammonia.

Results
- Different colours will be produced: #1 : Red #2 : White #3 : Blue

Variation
- Include a beaker containing 5-10 drops of a saturated solution of Fe^{2+} to produce a dark blue-greenish solution.
- Include a beaker containing 5 drops of cresolphthalein indicator to produce a purple solution.

WOHLER'S SYNTHESIS REVERSED

Needs
- Urea (100mL of 1M solution).
- Silver nitrate solution (0.1M)
- Conductivity apparatus
- Beakers

Method
- Test 1M urea for conductivity (non-electrolyte).
- Test 1M urea for ions, with several drops of Ag^+ (no precipitate therefore no ions).
- Boil 50mL of 1M urea for several minutes and repeat tests.

Result
- Boiled "urea" is an electrolyte (conducts a current) and forms a precipitate with Ag^+.
- Whereas Wohler synthesised urea from ammonium cyanate, the reaction has been reversed:

$$NH_2 - CO - NH_2 \rightleftharpoons NH_4^+ + OCN^-$$

$$Ag^+ + OCN^- \rightarrow AgOCN$$

BURNT BACON AND UNSATURATION

Needs
- Strip of bacon
- Metal tongs
- Flask/gas jar of bromine gas
- Bunsen

Method
- Cook the strip of bacon in a bunsen flame to a slight crisp.
- Place bacon in bromine flask and shake.

Results
- Bromine colour is removed rapidly.
- Cooking bacon converts glycerol to acrolein (propenol):

$$\begin{array}{l} CH_2 - CH - CH_2OH \\ \quad | \quad\ | \\ \quad OH \ \ OH \end{array} \rightarrow CH_2 = CH - CHO + 2H_2O$$

- Bromine reacts with double bonds in acrolein:

$$CH_2 = CH - CHO + Br_2 \rightarrow \begin{array}{l} CH_2 - CH - CHO \\ \quad | \quad\ | \\ \quad Br \ \ Br \end{array}$$

FREE RADICAL SUBSTITUTION

Needs
- Overhead projector
- Bromine (liquid)
- Hexane (or cyclohexane)
- Beakers
- Laboratory square
- Blue litmus paper

Method
- Dissolve bromine in the alkane to get an orange colour.
- Place equal amounts of alkane/Br_2 solution in beakers upon overhead stage.
- Place laboratory square under one of the beakers (control).
- Turn on OHP.

Result
- Bromine colour is removed from beaker exposed to light.
- Fumes of HBr are visible and can be tested with damp blue litmus paper.

$$C_6H_6 + Br_2 \rightarrow C_6H_5Br + HBr$$

A QUICK SAPONIFICATION

Needs
- Methyl salicylate (oil of wintergreen)
- 2M sodium hydroxide
- Beakers/test tubes

Method
- Pour 2M NaOH, with stirring, into methyl salicylate.

Results
- A thick white solid (sodium salicylate) is formed by saponification.

$$HOC_6H_4COOCH_3 + NaOH \rightarrow HOC_6H_4COO^-Na^+ + CH_3OH$$

APPENDIX A: THE DEMONSTRATIONS

STATES OF MATTER

Liquid densities: Six different liquids are added to a cylinder to show different densities and miscibilities.

Fascinating freon: Coloured freon is boiled under water forming immiscible liquid-vapour bubbles.

Supersaturated magic: When a crystal is added to a clear solution it rapidly crystallises forming a solid mass and releasing heat.

Colourful chromatography: Food dyes are separated into their coloured components on paper (in about 40 minutes).

Air Pressure #1: A piece of filter paper supports a flask full of water when it is upturned.

Air Pressure #2: An aluminium can collapses (due to air pressure) after heating.

Air Pressure #3: A boiled egg is forced into a flask after it is heated.

Iodine extractions: A blue solution and a yellow solution are mixed to produce a green solution. When shaken with one solvent the green solution forms two immiscible layers (top yellow, bottom blue). When shaken with a different solvent it produces a purple colour before separating into two immiscible layers (top blue, bottom pink).

Recrystallisation: A black powder is boiled and filtered whilst hot to produce a black residue and a blue-green solution. On cooling the solution forms white crystals which are filtered from the blue solution.

The fountain: A flask “sucks up” a coloured liquid in a fountain and the liquid changes colour.

Another fountain: As above, except process is started by heating the flask to expel air.

Adsorbing experiences: A solid when added to coloured solutions removes the colour from solution.

Iodine phase changes: Iodine is heated in a flask to produce a violet vapour, which cools to form fine crystals. The crystals dissolve in either alcohol (brown solution) or freon (pink solution).

Ammonium chloride sublimations: A white powder is heated to form fine wispy particles.

Gel diffusions: Solutions diffuse through a gel at different rates. Solutions and/or products of reaction are coloured.

Crystal forms: Different crystals are observed to form (under a microscope, if possible) from hot, saturated solutions.

A crystal garden: Plant-like, coloured shapes grow slowly from different seed crystals in a solution of waterglass.

Supersaturation #1: A crystalline substance dissolves when heated. Crystals re- form upon cooling (and heat is liberated).

Supersaturation #2: Jarring or seeding a clear solution produces crystals.

Supersaturation #3: Fine crystals form when solutions are cooled.

The sunset demonstration: An off-white precipitate is slowly formed producing a Tyndall beam when in front of a projector. The transmitted light slowly changes colour from white to yellow, orange and red.

Aniline magic: An orange (or red) liquid forms globules when added to water. Addition of a reagent causes the oil to disappear. Subsequent addition of another reagent produces an opaque (colloidal) dispersion.

Heron's siphon: Water is added to a can producing an apparently continuous stream of water from one can to another.

Foams: Solutions are mixed to form a number of foams.

ATOMIC STRUCTURE AND CHEMICAL BONDING

Conservation of matter: A sequence of reactions, starting with copper metal, in which the indestructibility of elements (i.e. atoms) is shown.

Green fire: A colourless liquid burns with a bright green flame.

Physical and chemical changes: Physical mixing of solutions is compared to chemical reaction involving precipitation.

Polarity of water: A stream of water is diverted by electrostatic attractions.

Coloured fireworks: Solid mixtures are ignited to produce different coloured flames.

Fireworks II: Variation on the above.

CHEMICAL EQUILIBRIUM

Colourful equilibria: A series of reagents are mixed to produce and dissolve precipitates of different colours.

Making matches: A solid mixture is ignited to produce a flame.

Boiling by cooling: A sealed flask of boiled-water is cooled, causing the water to boil again.

Boiling by suction: A warm liquid boils when attached to a vacuum pump (e.g. water aspirator).

Iron equilibria: A solution, when poured from one beaker to the next in sequence, undergoes a series of colour changes.

Iron III equilibria: A solution when poured into seemingly empty beakers in succession produces a variety of colours.

Colourful copper complexes: A blue solution produces a variety of colours and precipitates when mixed with other reagents.

Colourful cobalt equilibria: A pink solution changes to a blue colour upon heating, and returns to pink on cooling. Addition of various reagents gives colour changes and a precipitate.

Competing equilibria: A series of precipitates are produced and dissolved as a silver ion solution is mixed, in turn, with a sequence of reagents.

The tricolour: A colourless solution is poured into three separate beakers producing red, white and blue colours successively.

Copper complex equilibria: Colour changes are produced when a series of reagents are added to a blue solution in succession.

Silver crystals: Fine, needle-like crystals of silver form on a piece of wire in a solution overnight.

Lead crystals: As above.

Tin crystals: As above.

Cobalt-alcohol equilibria: A pink solution produces different colours (pink to violet) when added to different amounts of alcohol. Addition of water reverses the colour change.

Bicarbonate equilibria: A colourless solution bubbles and turns pale pink when attached to a suction pump.

CHEMICAL ENERGY

The Rocket: A plastic bottle is launched by a loud explosion when a flame is applied.

Instant solid: Mixture of two clear liquids produces a white gel.

Sugar energy food: Drops of water ignite a mixture of powdered solids.

Making copper: A grey powder, when added to a blue solution, removes the solution's colour and forms a reddish solid.

Freezing mixture: Two solids when mixed in a flask freeze a pool of water "gluing" the flask to a board, also forming a solution and a gas.

Exploding can: A can of gas explodes, ejecting the lid.

Thermite reaction: Molten iron and intense heat are produced when a powdered mixture is ignited in a tin can.

Chemical v physical change: Two white solids behave differently when heated - one melts, boils and then freezes on cooling; the other melts, decomposes and produces a black residue.

Quick decompositions: A variety of substances decompose on heating.

Separation by adsorption: The blue colour in a solution is removed by the addition of a black powder, followed by filtration.

The Volcano reaction: An orange powder on a flat surface ignites slowly to form a volcano-like mound of powder, and gives off a flame.

Nitrate flash: A white powder is ignited by several drops of water.

Combustion of steel wool: A piece of steel wool is burnt in a flame, and will then produce sparks in a gas jar of oxygen.

Combustion of sulfur: A powder burns with a bright blue flame in a gas jar of oxygen. The gas produced is acidic to indicators.

Combustion of red phosphorus: A solid burns with a bright white flame in a gas jar of oxygen. The gas produced is acidic to indicators.

Permanganate fire: A mound of black powder produces a violet-edged flame (after a brief induction period) when a few drops of liquid are added to it. A mixture of powders is ignited with a drop of water.

The Roman candle: A powdered mixture erupts from a test tube with a flash when heated strongly.

Touch powder: A piece of filter paper holding a small amount of solid detonates when touched.

Gun cotton: A white substance ignites and disappears in a flash when lit.

Purple fumes: A powder gives off violet fumes when a drop of water is added.

Electrochemical energy: A flash globe “goes off” when two pieces of metal are immersed in a liquid.

Chemiluminescence: A series of solutions mixed in a darkened room produce, after an induction period, a red luminescence followed by a vigorous effervescence, accompanied by a glowing green luminescence. The liquid overflows its container and gets quite hot.

RATES OF REACTION

Catalytic mechanism: A hot cherry-red solution turns green and effervesces vigorously before returning to its original colour.

Autocatalysis: A purple solution changes colour (to pink then gold and in finally colourless) at different rates.

Autocatalysis II: Addition of a colourless liquid to the top of a blue solution produces a colour change (to yellow) that moves slowly down a measuring cylinder.

Iodate clock: After an induction period of 6–10 seconds, a colourless mixture of two reagents instantly turns blue-black.

Coloured clock reactions: A mixture of two colourless solutions turns pink in an instant after an induction period of several seconds. Different indicators can produce different colour changes at different rates.

Double clock: Two colourless solutions, when mixed in a variety of ratios, produce different results notably slow appearance of an orange colour followed by a flash to black.

Iodine formation: Two colourless solutions are mixed to gradually produce a yellow (or blue) colour which slowly intensifies.

Colloidal sulfur: Two colourless solutions are mixed to gradually produce an off-white precipitate.

The versatile clock: Mixture of three colourless solutions produces a blue-black colour (in an instant) after a variable induction period. Rate of appearance of colour can be varied by changes in proportions, temperature and catalysts.

The patriotic clock: A solution is added simultaneously to three separate beakers. After an induction period colours will suddenly appear in each beaker: red, white and blue in turn.

The cinnamon clock: After an induction period a clear orange-brown mixture turns a light opaque yellow colour.

Rainbow reaction: Addition of a reagent to a red solution causes it to gradually change colour (red ’ orange ’ yellow ’ lime green ’ green).

The golden clock: Mixture of two colourless solutions produces a sudden change to yellow, after an induction period.

Peroxide decomposition: Addition of a small amount of a solid to a solution produces effervescence and a foam.

Bleach decomposition: Addition of a solid (or a solution) to a solution produces effervescence and a black precipitate.

Chemiluminescence clock: Mixture of a sequence of solutions (in a darkened room) leads to a colour change and then the emission of light.

Oscillating reaction I: A mixture oscillates in colour between red and blue (or yellow and blue). Failure to continuously stir will produce patterns within the mixture.

The Belousov clock: An alternative recipe for oscillating reactions I.

Oscillating reaction III: A mixture of colourless solutions turns brown. After addition of other reagents, the colour will oscillate between red and blue (after a longish induction period).

Oscillating reaction IV: A mixture will effervesce, turn brown and then oscillate from brown to colourless for a period of several minutes.

Oscillating reaction V: An alternate recipe for "Cyclic Iodine Clock".

Oscillating reaction VI: A mixture will oscillate in colour from colourless to gold to blue over a period of 5-10 minutes. Purple vapours will also appear.

REDOX REACTIONS

Blue bottle: A colourless solution will turn blue when shaken. Upon standing the blue colour will disappear. The cycle can be repeated many times.

Colourful cycle: A yellow solution will turn orange when gently shaken and green when vigorously shaken. Upon standing the green colour will change to orange and then to yellow. The cycle can be repeated many times.

Silver crystals: Needle-like crystals of silver form on a blob of mercury (overnight) in a solution.

Salt "glue": A sprinkle of salt "glues" a piece of cotton to an ice block.

The beating heart: A blob of mercury pulsates in a heart shape when touched with a nail in a solution.

Silver mirror: A silver coating forms on glassware when a solution is heated strongly.

Blue printing: Light sensitive paper develops a blue colour upon exposure and treatment with a reagent solution.

Colourful Vanadium: A yellow solution changes colour to blue, then green, then violet as it is heated with a piece of metal.

Colourful Manganese: A violet-pink solution reacts with a number of reagents to produce a variety of colours - pale pink, colourless, green and a brown precipitate.

Menthoids magic: A medicinal pill dissolves in water forming a blue solution. Addition of a reagent produces a violet colour. Addition of another reagent changes the colour to pink. Shaking the pink solution re-forms the violet colour.

Fire writing: Applying a glowing splint to a piece of paper produces a slow, fuse- like burning along a line.

POLYMERS

The Nylon rope trick: A continuous thread is pulled from the interface between two immiscible liquids.

Instant resin: Addition of a liquid to another liquid, with stirring, produces (after a 5-15 second induction) a solid pink mass of resin.

Phenol resin: A mixture is heated and a resin forms quickly.

Rayon: A solution injected (by syringe) into another forms a thin filament.

Polymer gel: Two solutions are mixed to form a viscous gel that is able to flow slowly.

The instant giant sausage: A beaker/evaporating basin is heated strongly. Amidst a cloud of smoke a black column up to a metre long, suddenly appears.

Casein: A liquid is added to warm milk forming a solid. The solid can be worked to form a rubbery mass or treated to harden it.

Urea-formaldehyde: Several drops of acid added to a solution suddenly form a solid.

TRICKS AND PARADOXES

Magical beakers: A green liquid is poured from one beaker to another in a sequence, changing colour each time (green ' lime ' yellow ' orange ' red ' blue ' purple ' green).

Water to wine to milk: A clear liquid turns a claret colour when poured into a wine class. When the "wine" is poured back into the original container the colour disappears. When this solution is poured into a tumbler a white, milky liquid forms.

Burning hanky: A handkerchief is soaked in a liquid, wrung dry and held in a bunsen flame. The handkerchief "burns" with a visible flame for awhile. When the flame is extinguished the cloth is unaffected.

Selective adsorption: A powder will adsorb (and remove) some colours from some solutions but not others.

Density: A coloured oil is suspended in a "blob" in a measuring cylinder of another liquid.

Instant gel: Two liquids are mixed to form a gel that sets in the container. When ignited the gel burns with a bluish flame leaving a white residue.

The great glassware race: Two contestants attempt to be the first to pour all of their sequence of beakers containing a coloured liquid, without spillage, into a "finish" beaker. Neither will succeed!

MISCELLANY

Colourful quickies: A variety (9) of different colourful test-tube reactions.

Colourful quickies II: More colourful test-tube reactions.

Wohler's synthesis reversed: A non-electrolyte is boiled to form an electrolyte.

A quick saponification: Two liquids are mixed to produce a thick white precipitate.

Rainbow reactions: As a solution is progressively added to a red solution the colour changes through the colours of the rainbow.

Burnt bacon and unsaturation: A strip of bacon will, after burning in a bunsen flame, discharge the colour from a gas jar of an orange gas.

Free radical substitution: Two orange liquids are placed on an overhead projector, but one is on a piece of opaque material. The one exposed to light forms white fumes (that change blue litmus to red) and loses its colour.

Rainbow reactions II: A purple liquid constantly stirred undergoes colour changes (all colours of the rainbow) after about 0.5mL of another liquid is added.

Sulfur shower: Adding a drop of a liquid to a beaker with a surface coating of a yellow powder causes the particles to cascade to the bottom of the beaker.

Black sugar: Addition of a liquid to a damp mass of sugar causes it to form a black mass that rises slowly up and out of the beaker. Alternatively, adding the liquid to a very wet suspension of sugar causes a black “eruption” of a lava-like material out of the beaker.

Magic breath: Inhaled air does not change the colour of a blue (or green) solution whereas exhaled air changes the blue colour to green then yellow (or green colour to yellow).

Iodine from kelp: The solution obtained by heating seaweed and dispersing the ash into water gives various tests for the presence of iodine.

Synthesising dyes: A number of solutions are mixed to produce brightly coloured precipitates of textile and food dyes.

APPENDIX B: MAJOR CONCEPTS AND OTHER FEATURES

The main concepts, ideas and features associated with each demonstration are indicated below. The columns are:

P.C.	=	Physical change (States of matter)
C.C.	=	Chemical change (Chemical reactions)
K.M.T.	=	Kinetic molecular theory
A.S.	=	Atomic structure/atomic theory
Bond.	=	Chemical bonding
Sol.	=	Solubility (including Colloids and Suspensions)
Eqm.	=	Equibilrium
En.	=	Energy
Red.	=	Oxidation-Reduction (Redox)
Org.	=	Organic chemistry
A-B	=	Acid-base chemistry
R.R.	=	Rates of reaction (reaction kinetics)

Demonstration	*PC*	*CC*	*KMT*	*AS*	*BOND*	*SOL*	*EQM*	*EN*	*RED*	*ORG*	*A-B*	*RR*
Liquid Density	x				x	x	x			x		
Fascinating freon	x		x		x	x	x			x		
Supersaturated magic	x					x	x	x				
Colourful chromatography	x				x	x	x			x		
Air pressure #1			x				x					
Air pressure #2			x				x					
Air pressure #3			x				x					
Iodine extraction	x				x	x	x			x		
Recrystallisation	x				x	x	x			x		
The fountain		x	x		x	x	x				x	
Another fountain		x	x				x				x	
Adsorbing experience	x				x	x	x					
Iodine phase changes	x		x		x	x	x			x		
Ammonium chloride subli	x		x		x			x				
Gel diffusions		x	x		x	x						
Crystal forms	x						x	x				
A crystal garden			x				x					
Supersaturation #1	x						x	x	x			
Supersaturation #2	x					x	x					
Supersaturation #3	x					x	x					
The sunset demonstration		x				x			x			x
Aniline magic		x			x	x	x				x	
Heron's siphon			x				x					
Foams		x				x						
Conservation of matter		x		x	x	x		x	x			x

Physical and Chemical cha		x			x	x	x					
Polarity of water				x	x	x						
Coloured fireworks		x		x				x	x			x
Fireworks II		x		x				x	x			x
Colourful equilibria		x			x	x	x					
Making matches		x						x	x			x
Boiling by cooling	x		x				x	x				
Boiling by suction	x		x		x		x	x		x		
Iron equilibria		x			x	x	x					
Iron III equilibria		x			x	x	x					
Colourful copper complexe		x			x	x	x					
Colourful cobalt equilibri		x			x	x	x	x		x		
Competing equilibria		x				x	x				x	x
The tricolour		x			x	x						
Copper complex equilibria		x			x	x	x	x				
Silver crystals		x				x	x		x			
Lead crystals		x				x	x		x			
Tin crystals		x				x	x		x			
Cobalt-alcohol equilibria		x			x		x					
Bicarbonate equilibrium		x					x				x	
The rocket		x						x	x			x
Instant solid		x				x						x
Sugar-energy food		x						x	x			x
Making copper		x						x	x			
Freezing mixture		x				x		x				
Exploding can		x						x	x			
Thermite reaction		x						x	x			
Chemical v physical chang	x	x	x		x			x		x		
Quick decompositions		x						x				
Separation by adsorption	x				x	x	x					
The volcano reaction		x						x	x			
Nitrate flash		x						x	x			x
Combustion of steel wool		x						x	x			x
Combustion of sulfur		x						x	x		x	x
Combustion of red phosph		x						x	x		x	x
Permanganate fire		x						x	x	x		x
The Roman candle		x						x	x			x
Touch powder		x			x			x	x			x
Gun cotton		x			x			x	x	x		x

Purple fumes		x						x	x			x
Electrochemical energy		x						x	x			x
Chemiluminescence		x						x	x			x
Catalytic mechanism		x						x	x			x
Autocatalysis		x						x	x			x
Autocatalysis II		x						x	x		x	x
Iodate clock		x							x			x
Coloured clock reactions		x							x	x	x	x
Double clock		x					x		x			x
Iodine formation		x					x		x			x
Colloidal sulfur		x				x	x		x			x
The versatile clock		x					x		x			x
The patriotic clock		x				x	x		x		x	x
The cinnamon clock		x				x	x		x	x		x
Rainbow reaction		x					x		x		x	x
The golden clock		x				x	x		x			x
Peroxide decomposition		x			x			x	x			x
Bleach decomposition		x				x		x	x			x
Chemiluminescent clock		x						x	x			x
Cyclic iodine clock		x					x		x			x
Oscillating reaction I		x					x		x			x
The Belousov clock		x					x		x			x
Oscillating reaction III		x					x		x			x
Oscillating reaction IV		x					x		x			x
Oscillating reaction V		x					x		x			x
Oscillating reaction VI		x					x		x			x
Blue bottle		x				x	x		x			
Colourful cycle		x				x	x		x			x
Silver crystals		x		x		x			x			
Salt glue	x				x			x				
The beating heart		x							x			
Silver mirror		x			x	x			x	x		
Blueprinting		x				x			x			
Colourful vanadium		x							x			
Colourful manganese		x				x			x			
Menthoids magic		x				x	x		x			
Fire writing		x						x	x			
The nylon rope trick		x			x	x				x		
Instant resin		x			x	x				x		x

Phenol resin		x			x	x				x		x
Rayon		x				x				x		
Polymer gel		x			x	x				x		
Instant giant sausage		x								x		x
Casein		x			x	x				x		
Urea-formaldehyde		x			x	x				x		x
Magical beakers		x				x	x				x	x
Water-wine-milk		x					x	x			x	x
Burning hanky	x	x	x			x		x	x	x		x
Selective adsorption	x				x	x	x					
Density	x				x	x				x		
Instant gel		x			x	x						
The great glassware race	x	x				x					x	
Colourful quickies		x				x	x		x		x	x
Colourful quickies II		x				x	x		x		x	x
Wohler reversed		x			x	x	x	x		x		
Quick saponification		x			x	x				x		x
Rainbow reactions I		x									x	
Burnt bacon		x			x			x		x		
Free radical substitution		x						x		x		x
Rainbow reactions II		x			x	x	x			x	x	
Sulfur shower	x		x		x	x						
Black sugar		x				x		x		x		
Magic breath		x				x	x				x	
Iodine from kelp		x			x	x	x			x		
Synthesising dyes		x			x	x		x		x		

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