Colour

Teacher Notes

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Colour

Why focus on G&T and higher achievers?

Within the education system every child has the right to develop their learning so as to maximise their potential.

These exercises are designed to give students 'enthuse and enrich' activities that although related to the curriculum are in fact taking the learning experience to the next level whilst also showing chemistry in a familiar context. This has been found to be a successful model for not only improving learning but also for raising levels of motivation. Higher achieving students can find the restraints of the standard curriculum to be demotivating leading to underachievement.

The different activities are designed to improve a number of skills including practical work/dexterity, thinking/analysis skills, literacy, research activities, use of models and teamwork. Students should also gain confidence through the activities and improve the ability to express themselves.

Some of the activities would appear to be complex for KS3, however at this stage in their learning high achieving students are open to new concepts and are ready to explore issues without pre-conceptions. They are keen to link ideas and develop concepts and understanding. It can prove to be an uplifting experience.

Introduction

Exploring the colour of substances allows for a better understanding of reactions and properties. By understanding what is causing the colour or the change of colour gives an insight of what is happening at even the electron level.

Colour can also be used as a means of both qualitative and quantitative analysis. Aspects of these properties are explored through flame colours and linked to atomic absorption and emission spectroscopy. Many areas of chemistry are covered in this topic from analysis, redox, electrode potential, transition metals to surfactant properties.

This programme is designed to develop students understanding of these topics from basic concepts to higher level thinking. It also aims to show that understanding how aspects of chemistry link together gives fuller understanding of the chemical processes as a whole. Working through the activities will also develop thinking and research skills.

Topic	Type of activity	Summary	Timing (mins)	KS3	KS4	KS5	Page
An introduction to colour	Practical	This is a circus of experiments that explores some of the fundamental principles of the topic.	60	√	√		9
Flame tests	Demonstration	A dramatic illustration of the basis of atomic spectroscopy.	10	√	√	√	13

Flame colours	Practical	An opportunity for students to explore emission spectra, line spectra and qualitative analysis.	30	√	√	√	15
Dyeing	Demonstration	Linking bonding, properties of polymers and dyestuffs this fun experiment has many applications.	30	√	√	√	17
Synthesis of azo dyes	Practical	A microscale practical that explores the chemistry of azo dyes and their synthesis.	20		√	√	21
Oxidation states of vanadium	Demonstration	A broad ranging demonstration looking at transition metals, redox, electrode potential and colour.	30			√	23

The first activity, a circus of experiments, looks at some of the basic principles of the topic, linking together a wide range of applications. These include showing links between physics and chemistry. Individual experiments can be used in isolation to help illustrate particular topics. For example the multicoloured milk works well with an introduction to surfactants.

Flame colours can be investigated on two levels, the first is a dramatic demonstration of the how electrons can be excited to higher energy levels by heat and then emit that energy at a series of characteristic wavelengths of visible light. This allows for both qualitative, under controlled conditions, and quantitative analysis. The second is a class practical where students can gain hands on practice and also extend the activity by exploring line spectra of, in this case, metal ions.

There are many different types of polymers with different properties. There are also many chemically different dyestuffs. This activity investigates, in a fun way, how they interact. Students are genuinely intrigued by the fact that what to all intents and purposes is a white cloth can emerge as a multicoloured flag. This also links to the next activity which is more key stage 5, or possibly year 11, whereby students can synthesise an azo dye. This is an intriguing synthesis as most require elevated temperatures to proceed, whereas this synthesis needs to be kept cold!

An activity ideally suited to key stage 5 is that of exploring the oxidation states of vanadaium. It links together several key aspects of chemistry in order to understand and explain the colour changes. These include transition metal chemistry, redox, and electrode potentials.

Aims and objectives

The aims and objectives of these activities are:

- Developing questioning skills through problem solving.
- Exploring the use of models to expand understanding

- Develop practical skills and dexterity.
- Promote independent learning.

Chemistry topics:

- Sources of colour
- Surfactants
- Chromatography
- Redox
- Equilibria
- Dyes
- Polymers
- Synthesis
- Transition metals
- Electrode potentials

These exercises can be used with key stages 3, 4, and 5 as indicated on the *Possible Routes*.

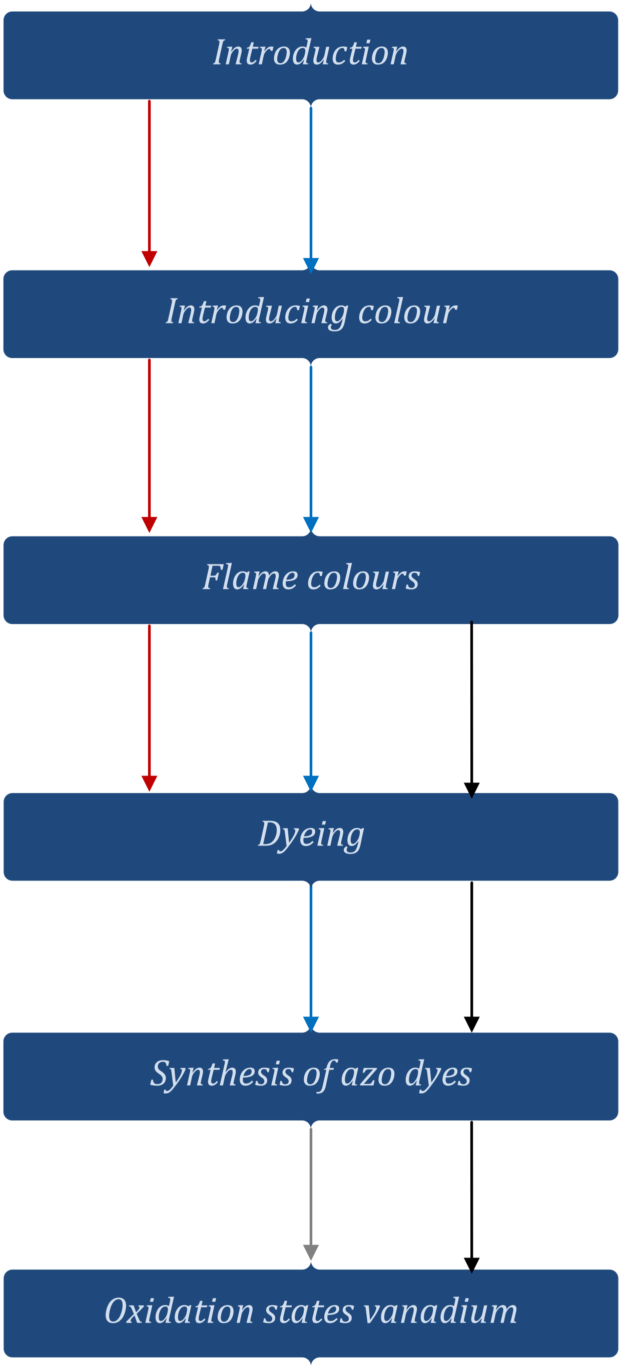
These activities have proved very successful with key stage 3 students who have followed the prescribed pathway and have been stimulated into further independent learning.

At key stage 4 this activity enhances understanding of key industrial processes such as the Haber and Contact Processes.

As well as developing key concepts and understanding, these exercises provide a reinforcement and revision tool for a number of topics from the A level syllabus.

At all levels there is promotion of questioning skills, independent learning and research skills.

Possible routes



Introduction

Introducing colour

Flame colours

Dyeing

Synthesis of azo dyes

Oxidation states vanadium

The introduction leads into a circus of activities exploring colour, linking between chemistry and physics.

Both a demonstration and a class practical looking at the colours produced by metal ions leads into analysis and spectroscopy.

Dyeing explores the differing properties of polymers and dyestuffs in this dramatic demonstration.

Dyestuffs are further explored in an unusual microscale synthesis of an azo dye.

The oxidation states of vanadium links many different aspects of chemistry in this thought provoking demonstration.

Key

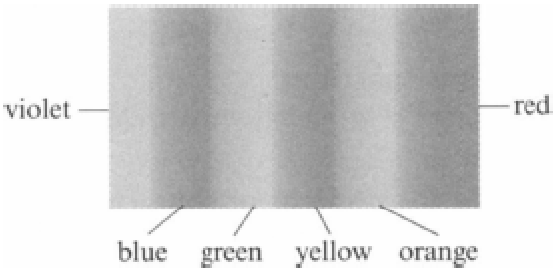
🟥→	KS3 G&T
🟦→	KS4
⬛→	KS5
🟩→	Yr 9 G&T

Explaining colour

The simplest atoms are hydrogen atoms, they have just one electron. Imagine twirling a weight round on the end of a piece of elastic; if you twirl more quickly, the elastic will stretch and the weight will get further away from your hand. Suppose that the electron takes in some energy from somewhere. It will start to move more quickly. As it starts to move more quickly, it will move further away from the nucleus. The further the orbit is from the nucleus, the more the energy associated with the electrons in it. Now imagine that you shine some white light through a sample of hydrogen. White light is made up of light of lots of different wavelengths. Light is a form of energy - the shorter the wavelength, the greater the energy of the light. Red light has the longest wavelength (least energy) of visible light and violet has the shortest wavelength. If the electron absorbs red light, it will move a little away from the nucleus; if it absorbs violet light, it will move further away. There seems no obvious reason why an electron should absorb light of one wavelength rather than another.

As white light passes through the hydrogen gas, the electrons in some atoms would absorb red, those in others orange or yellow or green or blue or violet. When the white light reached the other side of the sample of hydrogen, some of each colour would have been absorbed; the intensity of each colour would have been reduced, but they will all still be there (unless there was so much hydrogen that all the light has been absorbed). So if you were to pass the light through a prism and shine it on to a screen, you would expect to see a full spectrum from red to violet.

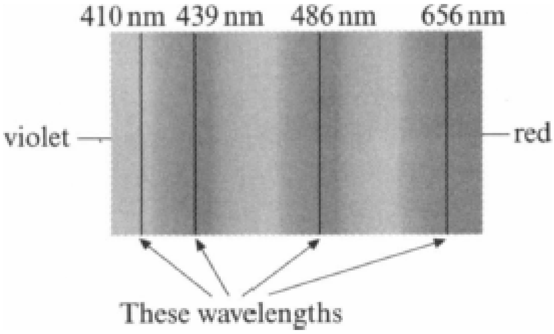
The visible spectrum



In fact, that isn't what you see. Most of the colours come through the sample totally unchanged. Some of the wavelengths, on the other hand, have totally disappeared. There are gaps in the spectrum where these wavelengths have been taken out.

Absorption spectra

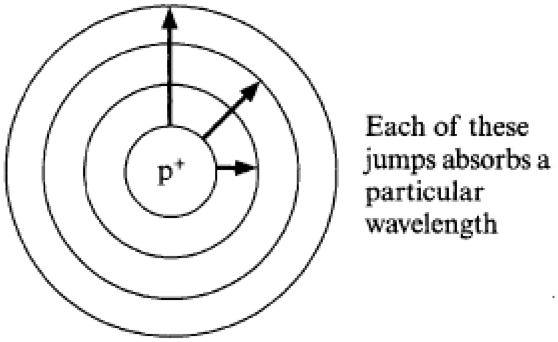
As noted above, if you pass white light through hydrogen and then view the spectrum, you will find that most of the different colours are still there; they haven't been absorbed at all. But some very specific wavelengths have been totally absorbed; they don't come through, and are represented by black lines in the spectrum shown below.



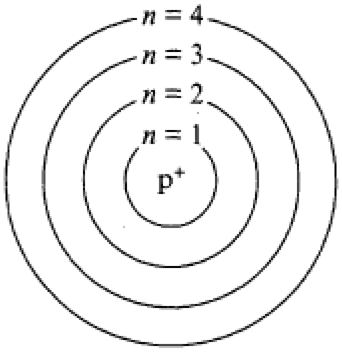
The same sort of thing happens with all other elements when made into vapours. They absorb a few specific wavelengths and allow the rest to pass through. This sort of spectrum is called an absorption spectrum. Each element absorbs a particular set of wavelengths. You can identify the different elements by seeing which wavelengths are absorbed, *i.e.* by seeing what the absorption spectrum looks like. This sort of analysis is called spectroscopy. The instruments used to carry it out are called spectroscopes.

Why do elements only absorb certain wavelengths?

Because only certain orbits exist within an atom, only specific wavelengths of light are absorbed. Electrons can only absorb light with a wavelength that exactly corresponds to the energy change involved in each movement of the electrons between these orbits.



The electrons in each of these orbits possess a particular amount of energy, so the orbits are called energy levels. The word 'quantum' means 'a particular amount', so movement to each of the energy levels involves a specific quantum of energy; each energy is thus given a principal quantum number, represented by the letter *'n'*.



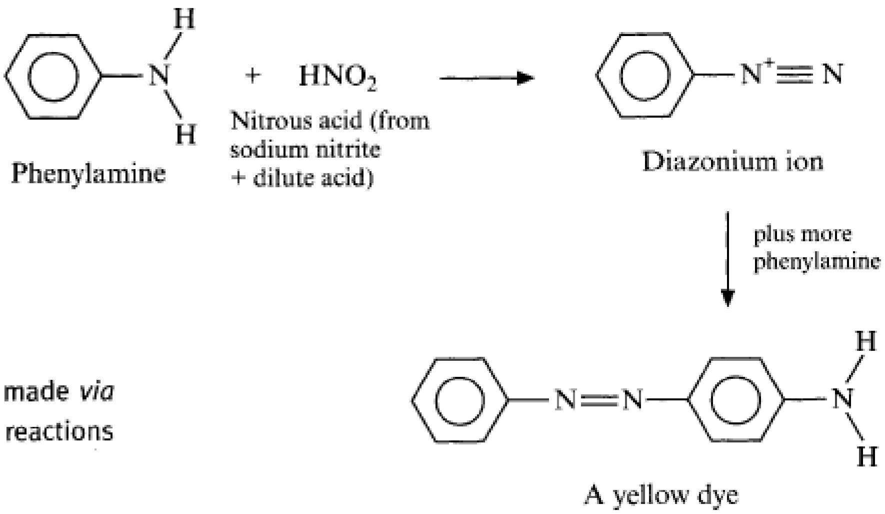
For quantum number n

All the transition metals tend to have coloured compounds, and the colour depends on the oxidation number of the metal. Unfortunately, there is no systematic way of working out the possible oxidation numbers of the transition metals, although it is quite easy to work out the *maximum* oxidation number. The colours on the other hand are a bit easier. Iron(II) compounds tend to be green and iron(II1) compounds tend to be brown, for example - but even that is not universally true.

Colour changes

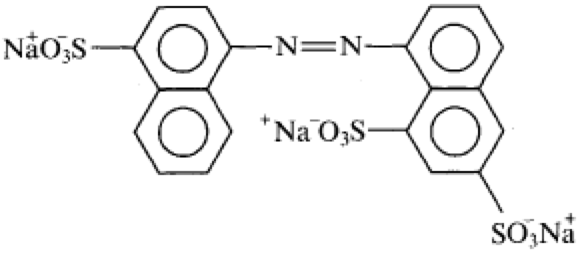
Many chemicals are coloured, and the intensity of the colour of their solutions will vary with concentration; so as the reaction proceeds and products are formed, colour intensity can be monitored using a colorimeter to determine the rate.

Some of the amines that contain aromatic groups are often used as starting points for making highly coloured 'azo' dyes. Some are used (controversially) as food dyes and some as dyes for cloth. This 'diazotisation' reaction must be done at about 5 ^{o}C as the nitrous acid made from the sodium nitrite and dilute hydrochloric acid decomposes easily above about 10 ^{o}C.

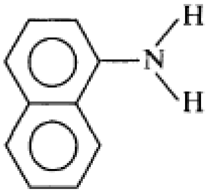


Azo dyes can be made *via* 'diazotisation' reactions

Another coloured dye is Ponceau red (E124), which is used in colouring tinned fruit.



Ponceau red (E124)



1-Aminonaphthalene
or
1-Naphthylamine

The first activity introduces the fundamental ideas about colour. The starting amine for this compound was 1 –aminonaphthalene (shown above). The ionic SO_3^- Na^+ groups on the dye makes it more water soluble, which is necessary for a food dye. Azo dyes have been linked with allergic reactions *(e.g.* asthma) in some people.

The first activity presents an introduction to colour. Chromatography links well to separation techniques and the later activities show the link between physics and chemistry.

Multicoloured milk can be used as an introduction to surfactants.

The traffic light activity can be used on many levels:

- An example of a chemical change as the colour changes.
- Illustration of a redox reaction.
- The fact that oxygen dissolves in water.

- How an equilibrium can be affected by changing the concentration of one compound.
- The fact that glucose is a reducing agent, being a reducing sugar!

Activity 1: An introduction to colour

Teacher Notes

Key [PS] – per student [PG]-per group

Chromatography

Materials required

- large circle of filter paper [PS]
- plastic or paper bowl [PS]
- selection of felt tip pens [PG]
- selection of stencils [PG]
- beaker of cold tap water [PG]

1. Choose a stencil pattern and colour-in the dots using a selection of colours, or design your own using a series of dots.
2. Rest the circle of filter paper on a bowl.
3. Dip your finger in the beaker of cold tap water to get a drop on the end and let it fall onto one of the coloured dots. Repeat this for all the dots.
4. Watch what happens to the colours and ask the students to describe what they see. Explain how colours that we see can be made up from a series or other colours. Explain how this method can be used to identify inks in forensic science.

Bubbles

Materials Required

- 20 cm length of garden wire [PS]
- plastic or paper bowl [PG]
- small amount of diluted washing up liquid [PG]
- beaker of cold tap water [PG]

1. Empty half a beaker of cold tap water into a paper bowl and place it in the middle of the table.
2. Add some washing up liquid.
3. Take a length of garden wire and carefully twist it into a looped shape.
4. Dip it into the bubble mixture to get a film and then hold it up to the light and observe.

Discuss with the students what's happening. Where else do they see similar effects?

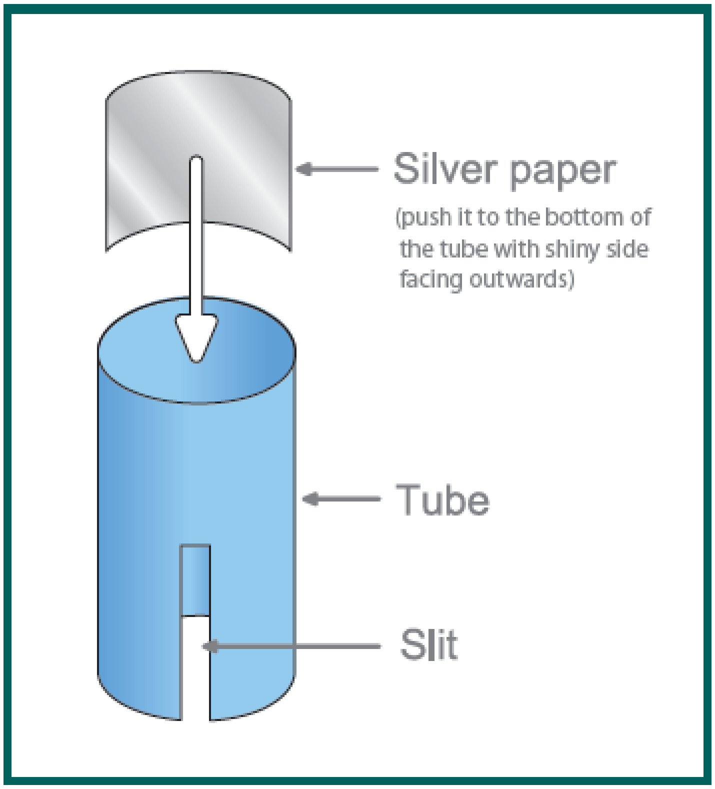
Scatter tubes

Materials Required

- piece of card (dark coloured, 1/8 A4) [PS]
- piece of silver prism paper (~3 cm square)
- roll of tape [PG]
- pair of scissors [PG]
- small torch [PG]

1. Take the piece of card and bend it to make a short fat tube.
2. Stick it in place using tape.
3. Cut an opening in the tube at one end by making two slits, lifting the flap and cutting it off.
4. Fix the piece of silver paper on the inside of the tube at the back opposite the opening.
5. Stand the tube on a white surface and shine the torch through the opening and look down the top of the tube.
6. Record your observations and discuss the results.

How do these compare with those in the bubble experiment?



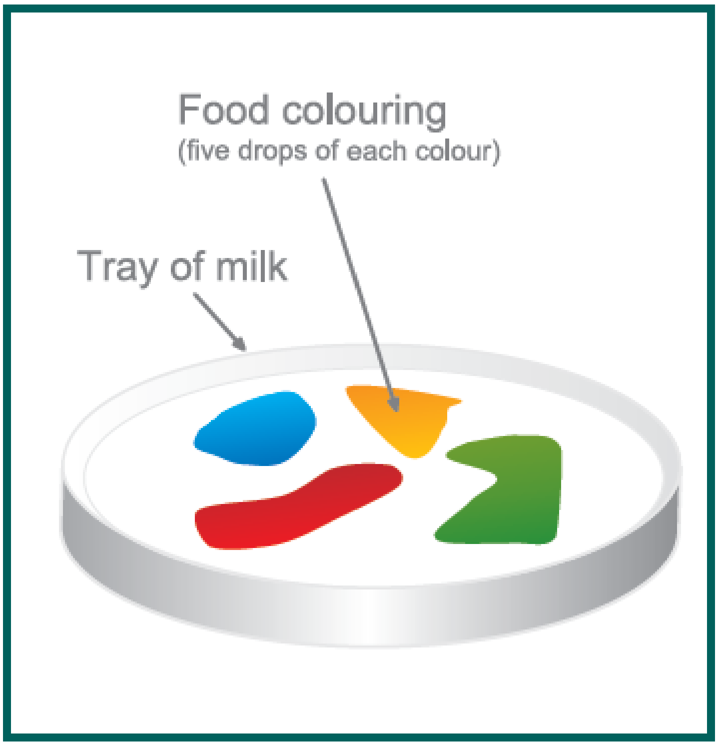
Multi-coloured milk

Materials Required

- piece of card (dark coloured, 1/8 A4) [PS]
- piece of silver prism paper (~3 cm square)
- roll of tape [PG]
- pair of scissors [PG]
- small torch [PG]

1. Pour the milk into a clean shallow tray so that it covers the bottom. Make sure there are no traces of washing up liquid in the tray.
2. Add five drops of one food colouring on top of each other in one quarter of the tray.
3. Repeat with the other colours so you have four separate puddles of colour in the milk.
4. Add one drop of diluted washing up liquid to the centre of the tray and watch what happens. Can the students suggest why this happens?
5. Add a further drop of washing up liquid onto each colour and observe.

Discuss possible reasons for the observations. Explain how surface tension works using examples the students will understand – e.g. pond skaters, flour etc. Explain that milk is made of fat and water. The food colouring mixes with the water. The washing up liquid breaks the surface tension of the fat and water and allows the colours to mix together making swirl patterns.



Traffic light demonstration

Materials Required

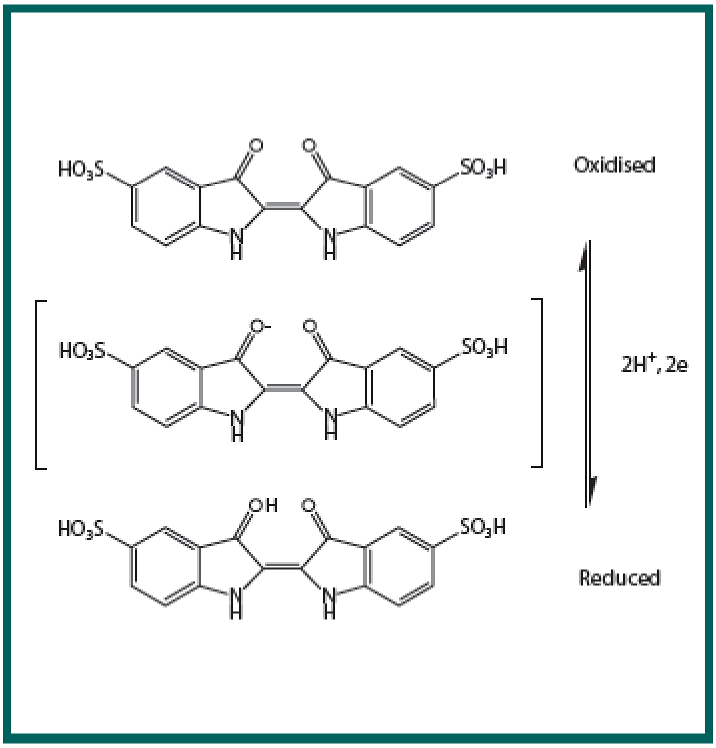
- 2 x 1 dm^3 beakers
- 250 cm^3 beaker
- stirring rod
- 750 cm^3 of warm water (~ 60°C from kettle)
- 12 g of glucose
- 6 g of sodium hydroxide pellets (corrosive)
- 0.04 g of indigo carmine indicator
- kettle

Wearing goggles dissolve the sodium hydroxide pellets in 250 cm^3 of cold tap water with stirring.
Dissolve the glucose in 750 cm^3 of warm water (~ 60 °C).
Add the indicator to the glucose solution and mix together until all the solution is dark blue.

When the class is watching, pour in the sodium hydroxide solution and watch what happens.
Pour the whole solution slowly from a height into the other large beaker.

Why does the colour change?

The sodium hydroxide makes the solution basic. The glucose acts as a reducing agent with the indigo carmine behaving as an indicator in the redox process. Indigo carmine can exist in oxidised, reduced and intermediate forms. Each form has a slightly different structure which means that each structure absorbs a different frequency of light; hence the three different colours – red, yellow and green. When the mixture is first poured into the beaker the indicator is in its green oxidised form – this is where the reaction mixture is most exposed to oxygen in the air. The colours then change through red and on to yellow as the indigo carmine is reduced.



Student can be made aware of the colour emitted from atoms due to the excitation of electrons by activity 2. They can appreciate that the energy absorbed results in the promotion of an electron to a higher energy level and upon relaxation to a lower energy they can emit that energy at a wavelength visible to the naked eye. This can also be used for qualitative analysis and as the foundation of explaining atomic spectra which in turn can be used quantitative.

The light produced by both the demonstration and the class practical is of a high intensity and can be used to show characteristic line spectra. This can be achieved with hand held spectrometers and even with simple homemade versions consisting of a black box containing a diffraction grating (a CD will also work!).

Activity 2: Flame colours – a demonstration

Teacher notes

This demonstration experiment can be used to show the flame colours given by alkali metal, alkaline earth metal, and other metal, salts. This is a spectacular version of the 'flame tests' experiment that can be used with chemists and non-chemists alike.

It can be extended as an introduction to atomic spectra.

Lesson organisation

This experiment must be done as a demonstration. It takes about ten minutes if all is prepared in advance.

Preparation includes making up the spray bottles and conducting a risk assessment.

Your employer's risk assessment must be customised by determining where to spray the flame to guarantee the audience's safety.

Procedure

HEALTH & SAFETY: Carry out the whole experiment in a well ventilated area you have previously shown to be safe. Wear eye protection. Ensure that the spray can be safely directed away from yourself and the audience. Ensure there are no smoke detectors near the experiment and avoid spraying near a heat sensor.

a) Darken the room if possible.
b) Light the Bunsen and adjust it to give a non-luminous, roaring flame (air hole open).
c) Conduct a preliminary spray in a safe direction away from the Bunsen flame. Adjust the nozzles of the spray bottles to give a fine mist.
d) Choose one spray bottle. Spray the solution into the flame **in the direction you have rehearsed**. Repeat with the other bottles.
e) A spectacular coloured flame or jet should be seen in each case. The colour of the flame depends on the metal in the salt used.
f) As an extension, students can view the flames through hand-held spectroscopes or diffraction gratings in order to see the line spectrum of the element. (Diffraction gratings work better. A better way to produce a steady source of light is to use discharge tubes from the Physics Department – with a suitable risk assessment.)

Teaching notes

The colours that should be seen are:

sodium – yellow-orange (typical ‘street lamp’ yellow)
potassium – purple-pink, traditionally referred to as ‘lilac’ (often contaminated with small amounts of sodium)
lithium – crimson red
copper – green/blue
calcium – orange-red (probably the least spectacular)
barium – apple green
strontium – crimson

The electrons in the metal ions are excited to higher energy levels by the heat. When the electrons fall back to lower energy levels, they emit light of various specific wavelengths (the atomic emission spectrum). Certain bright lines in these spectra cause the characteristic flame colour.

The colour can be used to identify the metal or its compounds (eg sodium vapour in a street lamp). The colours of fireworks are, of course, due to the presence of particular metal salts.

Web links

Flame colours gives a simple explanation of flame colours in terms of excited electrons. (http://www.chemicalconnection.org.uk/chemistry/topics/view.php?topic=3&headingno=5)

Flame tests gives another slightly different version, involving establishing some flame colours and then using them to identify unknowns. (http://www.creative-chemistry.org.uk/activities/flametests.htm)

Flame colours – a demonstration

Technician

Apparatus and chemicals

Eye protection

Trigger pump operated spray bottles (see note 1)
Bunsen burner
Heat resistant mat(s)
Hand-held spectroscopes or diffraction gratings (optional)

Samples of the following metal salts (no more than 1 g of each) (see note 2):

Sodium chloride (**Low hazard**)
Potassium chloride (**Low hazard**) (see note 3)
Lithium chloride (**Harmful**) (see note 3)
Copper sulfate (**Harmful, Danger to the environment**).

Ethanol (**Highly flammable**), approx 10 cm^3 for each metal salt.
or IDA (industrial denatured alcohol) (**Highly flammable, Harmful**)

Technical notes

Sodium chloride is **Low hazard**. Refer to CLEAPSS Hazcard 47B.
Potassium chloride is **Low hazard**. Refer to CLEAPSS Hazcard 47B.
Lithium chloride is **Harmful**. Refer to CLEAPSS Hazcard 47B
Copper sulfate is **Harmful, Danger to the environment**. Refer to CLEAPSS Hazcard 27C.
Ethanol is **Highly flammable**. IDA (industrial denatured alcohol) is **Highly flammable, Harmful**. Refer to CLEAPSS Hazcard 40A.

1 Spray bottles of the type used for products such as window cleaner should be used.
These piston-operated spray bottles should be emptied, cleaned thoroughly and finally rinsed with distilled water. Ideally, one bottle is needed for each metal salt. **Never** use spray bottles with a rubber bulb - **the flame may flash back into the container**.

2 The chlorides of metals are the best but other salts also work. Make a saturated solution of each salt in about 10 cm^3 ethanol. To do this, add the salt to the ethanol in small quantities, with stirring, until no more will dissolve – often only a few mg of salt will be needed. Place each solution in a spray bottle and label the bottle. The solutions can be retained for future use. They can be stored in the plastic bottles for several weeks at least without apparent deterioration of the bottles.

3 Potassium iodide and lithium iodide can be used instead. As a general rule, chlorides are usually suggested as they tend to be more volatile and more readily available. These two are in fact a little more volatile than the chloride, and potassion iodide is certainly likely to be available (refer to CLEAPSS Hazcard 47B). Other metal salts (e.g. those of calcium and barium) can also be used provided an appropriate risk assessment is carried out. Barium chloride is toxic but gives a different colour (refer to CLEAPSS Hazcard 10A), while calcium chloride (**Irritant**) and strontium chloride (**Irritant**) are different again (refer to CLEAPSS Hazcard 19A).

Activity 3: Flame Tests – class practical

Introduction

The main problems with the normal method of performing flames tests are:

- The need to use conc. HCl – presenting as it does a considerable hazard that often deters teachers from using the procedure in years 9 – 11
- The problem of contamination of wires
- The cost of regularly renewing wires

This alternative method does away with the need for conc. HCl to be used and also avoids the cost and contamination problems associated with the uses of nichrome or platinum (!) wires. The use of a circus arrangement for the procedure also makes classroom management much easier than if every pair/three have to collect and test all the solutions at their own workstation.

The intensity of colour produced is sufficient, in a darkened room, to enable line spectra using a spectrometer, even a homemade one!

Procedure

In advance of the lesson a supply of wooden splints need to be thoroughly soaked in the solutions below for at least 24 hours.

The splints can be pre-labelled with a pencil before soaking in order to save confusion during the practical.

A series of boiling tubes should be half-filled with approx 0.5M solutions (preferably chlorides – but nitrates or sulfates are fine as alternatives) containing cations such as:

Li^+	Ca^{2+}	K^+	Ba^{2+}	Cs^+
Na^+	Sr^{2+}	Rb^+	Cu^{2+}	Pb^{2+}

Each 'station' around the lab then consists of a boiling tube of one of the above solutions in a rack (labelled with name and symbol of cation plus appropriate hazard warnings), with as many pre-soaked splints as there are working groups in the set immersed in the solution. A Bunsen burner, heat resistant mat and container for disposal of used splints will also be needed. One station could be set up with distilled water as a control and another with a solution labelled as 'unknown' if wanted.

Holding a soaked splint in a blue flame then reveals the flame colour.

Instructions should focus on the need to watch the splint carefully, so that it is not held in the flame long enough to burn and burners could be clamped at an angle if desired (BEWARE DIRECTION OF FLAME!) to avoid contamination by dripping round mouth of burner.

This activity can also be adapted to be part of a Crime Scene Investigation which proves very popular with key stage 3 students (and even primary students!). It can be used as part of the analysis of the potential poison.

Activity 4: Dyeing – three colours from the same dye-bath

Introduction

We are familiar with the colour of our clothing. This is achieved by using a variety of dyes. The dyes used can be chemically very different and different dyes will react with a range of polymers to give a wide variety of colours.

It is possible to link together the properties of polymers and their ability to react with different classes of dyes and this can be illustrated in the following fun demonstration.

Different dyes bond to fabrics in different ways.

Acid dyes (eg “blue”) bond to basic groups in the amide linkages of wool, silk & nylon.

Direct dyes (eg “red) bond by hydrogen bonding in cellulose based cotton, viscose and rayon.

Disperse dyes (not used here) are insoluble in water and are absorbed as solid solutions to hydrophobic fabrics such as polyesters.

Using this information it is possible to creates flags of different nations from apparently white fabric when emerging from a dye bath.

Teacher notes

Samples of different fabrics are placed in a single dye bath containing three dyes. The materials emerge dyed different colours, illustrating how dyeing involves specific chemical interactions between the dye and the molecular nature of the fibre.

Lesson organisation

This is likely to be performed as a teacher demonstration, in the context of the topic of organic dyestuffs, either as an introductory attention-grabber, or later in the topic to stimulate discussion of the chemical interactions involved in dyeing. If the materials for the demonstration have been fully prepared, the demonstration itself should take around 30 minutes. The demonstration can be scaled up as required for larger audiences.

An alternative method whereby an apparently white rectangle of fabric is dipped in a dye bath and emerges as a flag composed of different colours. This merely requires the sewing together of the appropriate white fabrics in the required pattern to give the colours of a flag when dipped in a solution of mixed dyes.

Procedure

Wear eye protection

a) If the dye bath has yet to be prepared, dissolve 0.02 g of each of the red and yellow dyes and 0.03 g of the blue dye in 200 cm^3 of water in a beaker, add a few drops of dilute hydrochloric acid and heat to boiling.
b) Place a sample of cotton, cellulose acetate and either wool, silk or nylon in the dye bath and simmer gently for about 10 minutes.

c) Remove the fabrics with forceps or tongs, rinse under running water, and hang up on the 'clothes line'. Cotton will be dyed red, acetate yellow and wool, silk or nylon blue-green. (Some of the yellow direct dye will take to these materials as well as the blue acid dye.)

d) Try other materials as well if desired. Polyester will be dyed yellow and polyester/cotton will become orange.

e) Now examine the effect of the dyes individually. Make three dye baths, the first containing 0.02 g of red dye in 200 cm^3 of water, the second containing 0.02 g of the yellow dye in 200 cm^3 of water and the third containing 0.03 g of the blue dye in 200 cm^3 of water. Add a couple of drops of hydrochloric acid (2 mol dm^{-3}) to each dye bath and heat to boiling.

f) Place a sample of each fabric in each dye bath and treat as before, ie simmer for 10 minutes, remove the samples and rinse. Typical results are shown in the table.

Dyes	Silk	Wool	Nylon	Cotton	Acetate	Polyester	Polycotton
Mix	olive-green	olive-green	olive-green	red	yellow	yellow	orange
Red	pale orange-red	pale orange-red	pale orange-red	red	almost white	pink	pink
Blue	blue	blue	blue	very pale blue	white	white	almost white
Yellow	orangey	orangey	orangey	pale yellow	bright yellow	bright yellow	bright yellow

Teaching notes

Different dyes bond to fabrics in different ways.

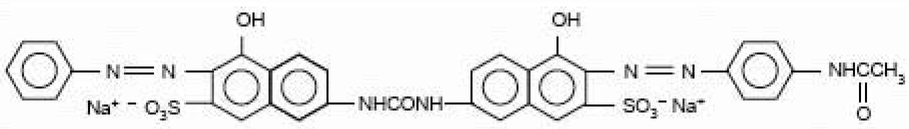
- Acid dyes contain acidic –CO_2H and –SO_3H groups which bond to the basic –NH groups in the amide linkages of wool, silk and nylon.

- Direct dyes bond by hydrogen bonding and take well to cellulose-based fibres such as cotton, viscose and rayon which have many –OH groups.

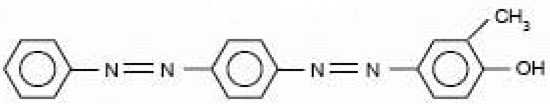
- Disperse dyes are not water-soluble. They exist in the dye-bath as a fine suspension (hence the name), and are absorbed as a solid solution by hydrophobic fabrics such as polyesters.

After the demonstration, students who have already studied the chemical structures of different types of fibre could be asked to predict the effects on other fabrics, for example on silk and nylon, which are polyamides like wool. They could also be asked to predict the effect of the dyes on a mixed fabric, such as cotton-polyester. They may now be able to offer a possible explanation for some odd effects in washing machine accidents, where labels and trim may emerge a different colour to the rest of the garment.

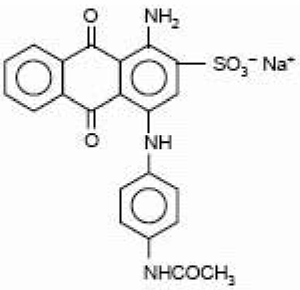
The structures of the dyes used in this experiment are:



Direct red 23



Disperse yellow 7



Acid blue 40

This demonstration could be followed up by various investigations, for example:

1 Devising mixed dye-baths to produce different colours to the ones demonstrated using the chemical principles fabrics described above.

2 Investigating the effect on the colours produced in different fabrics of:

- mordants such as salt or alum (**Low hazard**) refer to CLEAPSS Hazcards 47B or 2B
- pH of the dye bath
- time in the dye bath
- temperature of the dye bath

3 How fast (resistant to washing out) are the dyes to a variety of treatments?

A good account of which types of dyes dye which fabrics is given in The Essential Chemical Industry, p 42. University of York: The Chemical Industry Education Centre, 1989.

Kemtex Educational Supplies (see website address below) provide kits of dyes and fabrics for similar demonstrations.

Web Links

Kemtex Educational Supplies (http://www.kemtex.co.uk) provide a range of information sheets about dyes and dyeing, and related processes such as transfer printing, as well as supplying a wide range of dyes to school Art & Design and Textile Departments.

The University of Regensburg, Germany (http://www.uni-regensburg.de/Fakultaeten/nat_Fak_IV/Organische_Chemie/Didaktik/Keusch/D-Video-e.htm), provides a wide range of video clips of chemistry experiments at an advanced level, including a number relating to dyes and dyeing.

Dyeing – three colours from the same dye-bath

Technician notes

Apparatus and chemicals

Eye protection

Beakers (400 cm^3), 4
Large watch glasses or petri dishes, 4
Tongs or forceps
Scissors
Sample tubes, stoppered, 6
Bunsen burner
Tripod
Gauze
Heat resistant mat
String and paper clips, crocodile clips or clothes pegs (see note 3)

Access to:

Top pan balance

For one demonstration:

Samples of the following fabrics in white (see note 2):
wool, silk, nylon, cotton, polyester, cellulose acetate (‘triacetate’), polyester/cotton mix.

Dyes:
Acid blue 40, 0.06 g (**Low hazard**)
Disperse yellow 7, 0.04 g (**Irritant**)
Direct red 23, 0.04 g (**Irritant**)

For all three dyes refer to CLEAPSS Hazcard 32 and see notes 3 and 4
Hydrochloric acid, 2 mol dm^{-3} (**Irritant**), small quantity

Technical notes

Hydrochloric acid, (**Irritant**). Refer to CLEAPSS Hazcard 47A and Recipe Book sheet 43

1 Prepare a ‘clothes line’ using string between laboratory stands, long enough and with enough ‘pegs’ (crocodile clips, paper clips or miniature clothes pegs) to hang out the dyed fabric samples.

2 About 100 cm^2 of each fabric, or a few cm of thread will be sufficient. As a minimum, samples of cotton, either polyester or cellulose acetate, and either wool, silk, or nylon are required. White nylon, 100%, can be difficult to obtain and it may be necessary to try a second-hand clothes shop. Cut four strips of each fabric (about 4 cm x 4 cm is suitable). Each fabric should be easily identifiable in some way, for example by cutting different shapes.

3 Preparing the dye samples:

Bottles should be opened in a fume cupboard. The dilute solutions are low hazard but will stain skin and clothes. Protective gloves (preferably nitrile) should be worn. Weigh out into stoppered sample tubes, two samples of 0.02 g of each of the red and yellow dyes, and two samples of 0.03 g of the blue dye. Label each sample tube. These dyes are available from Philip Harris Ltd (www.philipharris.co.uk) or from Kemtex Educational Supplies (http://www.kemtex.co.uk - see link to Dyes for Salters Advanced Chemistry).

4 If the teacher requires the dye bath to be made ready before the lesson, dissolve 0.02 g of each of the red and yellow dyes and 0.03 g of the blue dye in 200 cm^3 of water in a beaker, add a few drops of the hydrochloric acid and heat to boiling.

Additional

It is also possible to create a flag by sewing together the appropriate white fabrics (from the chart above) that will form the different colours of a flag.

The properties of dyestuffs can be further investigated in this microscale synthesis of an azo dye. It explores the whole process of synthesis with the unusual twist of working at low temperatures.

Activity 5: The microscale synthesis of azo dyes

Teacher notes

In this experiment students prepare an azo dye and use it to dye a piece of cotton. The synthesis is unusual in that whereas most organic syntheses require ambient or elevated temperature, this synthesis requires low temperatures.

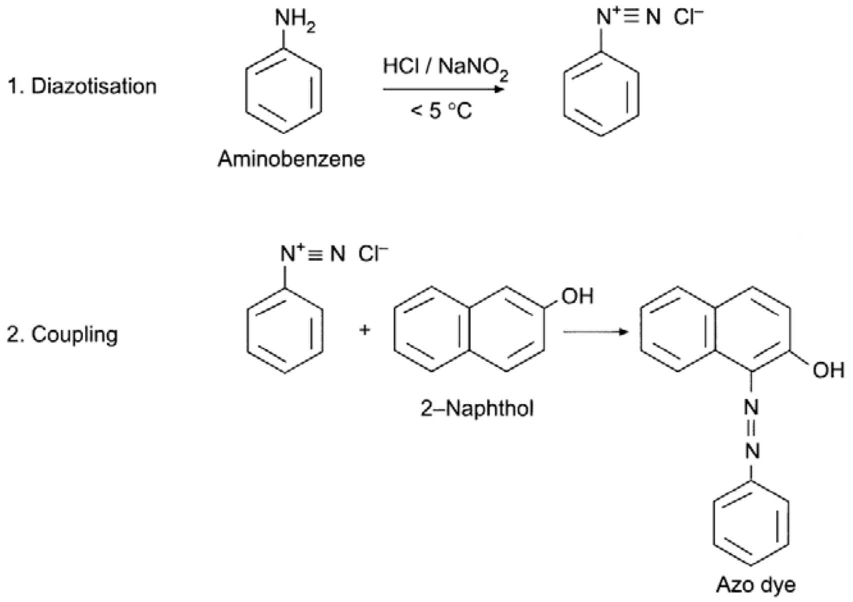
(An alternative to this experiment is recommended by CLEAPSS in L195 *Safer Chemicals, Safer Reactions* using ethyl 4-aminobenzenecarboxylate, used as a local anaesthetic to the skin (Benzocaine))

The experiment will take approximately 20 minutes.

Chemicals

- Ice
- Aminobenzene (aniline) (Toxic) See CLEAPSS *Hazcard* 4A
- Hydrochloric acid (Corrosive) see CLEAPSS *Hazcard* 47A
- Sodium nitrile (Oxidising and Toxic) see CLEAPSS *Hazcard* 93
- 2-Naphthol (Harmful) See CLEAPSS *Hazcard* 70.
- Sodium hydroxide solution (2 mol dm^{-3}) (Corrosive)
- Ethanol (Highly flammable) Refer to CLEAPSS *Hazcard* 40
- Urea (low hazard) see CLEAPSS *Hazcard* 35

The reactions are:



Instructions

Wear googles (not safety spectacles), wear disposable nitrile gloves.

1. Put eight drops of aminobenzene in a 10 cm^3 beaker and add 30 drops of deionised water followed by 15 drops of concentrated hydrochloric acid. Swirl the beaker and then put it in an ice bath.

2. Weigh 0.15 g of sodium nitrite into another beaker and add 1 cm^3 of deionised water. Cool the beaker in the ice bath. Add one spatula of urea this prevents side reactions occurring).

3. Mix the contents of the two beakers together and keep in the ice bath.

4. Weigh 0.45 g of 2-naphthol into another beaker and add 3 cm^3 of sodium hydroxide solution. Swirl to dissolve.

5. Take a piece of cotton cloth 2 x 2 cm^2 and, using tweezers, dip it into the 2-naphthol solution. Allow the solution to completely soak the cotton.

6. Dip the cloth completely into the diazonium salt solution. A red dye forms in the fibres, dyeing the cloth.

7. Take the cloth out, wash it under the tap and leave to dry

Teaching notes

The orange-red azo dye forms in the fibres of the cotton, dyeing the cloth. The melting point of 1-phenylazo-2-naphthol is 133 ^{o}C.

The urea decomposes excess HNO_2 formed and prevents many side reactions from occurring. A better ‘red’ dye is usually produced.

References

S. W. Breuer, Microscale practical organic chemistry. Lancaster: Lancaster University, 1991.

The microscale synthesis of azo dyes

Technician notes

Apparatus (per group)

- Safety goggles
- Disposable nitrile gloves
- Three 10 cm^3 beakers
- Thermometer
- Tweezers.
- Access to a fume cupboard

Chemicals (per group)

- Ice
- Aminobenzene (aniline) (Toxic) See CLEAPSS *Hazcard* 4A
- Hydrochloric acid (Corrosive) see CLEAPSS *Hazcard* 47A
- Sodium nitrile (Oxidising and Toxic) see CLEAPSS *Hazcard* 93
- 2-Naphthol (Harmful) See CLEAPSS *Hazcard* 70.
- Sodium hydroxide solution (2 mol dm^{-3}) (Corrosive)
- Ethanol (Highly flammable) Refer to CLEAPSS *Hazcard* 40
- Urea (low hazard) see CLEAPSS *Hazcard* 35

Higher level thinking can be developed in the following activity which brings together transition metal chemistry, oxidation states, redox, electrode potentials with colour changes. It should begin to allow students to predict the course of a redox reaction. This is particularly applicable to key stage 5.

Activity 6: The oxidation states of vanadium

Teacher Notes

Topic

Transition metals – the colours of different oxidation states. redox reactions and electrode potentials.

Timing

Up to half an hour.

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Description

Zinc is used to reduce a yellow solution of ammonium vanadate(V) to a mauve solution containing vanadium(II) ions. The intermediate oxidation states of vanadium(IV) (blue) and vanadium(III) (green) are also seen.

Method

Before the demonstration

Make up a 0.1 mol dm^{-3} solution of ammonium metavanadate (**toxic**) by dissolving 11.7 g of solid in 900 cm^3 of 1 mol dm^{-3} sulphuric acid (**irritant**) and making up to 1 dm^3 with deionised water. This yellow solution is usually represented as containing VO_2^+(aq) ions (dioxovanadium(V) ions) in which vanadium has an oxidation number of +5.

The demonstration

Place 500 cm^3 of the ammonium metavanadate solution in a 1 dm^3 conical flask and add about 15 g of powdered zinc (**highly flammable**). This will effervesce and give off hydrogen on reaction with the acid.

The solution will immediately start to go green and within a few seconds will turn pale blue, the colour of the VO^{2+}(aq) ion in which the vanadium has an oxidation number of +4. The short-lived green colour is a mixture of the yellow of V^V and the blue of V^{IV}. The blue colour of VO^{2+} is similar to that of the Cu^{2+}(aq) ion. Over a further fifteen minutes or so, the colour of the solution changes first to the green of V^{3+}(aq) ions and eventually to the mauve of V^{2+}(aq) ions. The green of V^{3+}(aq) is the most difficult to distinguish.

If desired, decant off a little of the solution at each colour stage, filter it to remove zinc and stop the reaction and place in a petri dish on the overhead projector to show the colour more clearly.

When the reaction has reached the mauve stage, filter off a little of the solution into a boiling tube and add acidified potassium permanganate solution dropwise. This will re-oxidise the vanadium through the +3 and +4 oxidation states back to V^V. Take care with the final few drops to avoid masking the yellow colour of vanadium(V) with the purple of permanganate ions.

Visual tips

A white background is vital if the colour changes are to be clearly seen. If desired, prepare solutions containing V^{IV} and V^{III} beforehand for comparison. This is recommended for teachers who are not familiar with these colours.

This can be done as follows:

V^{IV}: take a little of the original ammonium metavanadate solution in a test-tube and add approximately 1 mol dm^{-3} sodium thiosulphate solution dropwise until no further colour change occurs and a light blue solution is obtained. If too much thiosulphate is added, the solution will gradually go cloudy due to the formation of colloidal sulphur by reaction of the excess thiosulphate with acid but this will not affect the blue colour of V^{IV}.

V^{III}: take a little of the original ammonium metavanadate solution in a test-tube and add a spatula-full of powdered tin. Leave this for about five minutes and then filter off the tin to leave a green solution containing V^{3+}(aq) ions.

Teaching tips

This demonstration can be used as an introduction to the idea that different oxidation states of transition metal ions often have different colours and that electrode potentials can be used to help predict the course of redox reactions (via the ‘anticlockwise rule’ or otherwise). While waiting for the reaction to go to completion, some of the reactions can be discussed.

The oxidation states of vanadium

Technician notes

Apparatus

- One 1 dm^3 conical flask.
- Filter funnel.
- Boiling tube.
- Dropping pipette.
- Four petri dishes (optional).
- Access to an overhead projector (optional).
- Test-tubes and rack (optional).

Chemicals

The quantities given are for one demonstration.

- 11.7 g of **ammonium metavanadate** (ammonium vanadate(V), NH4VO3) (Toxic) See CLEAPSS Hazcard 9B
- 15 g of zinc powder (Highly flammable) See CLEAPSS Hazcard 107
- 100 cm^3 of approximately 0.25 mol dm^{-3} **potassium permanganate** [potassium manganate(VII) KMnO4] (Solid: Oxidising & Harmful; Solution-low hazard) see CLEAPSS Hazcard 81. In 1 mol dm^{-3} sulphuric acid (Irritant) see CLEAPSS Hazcard 98A and CLEAPSS Recipe Book sheet 98.
    - Dissolve 4 g of potassium permanganate in 100 cm^3 of 1 mol dm^{-3} sulphuric acid.
- About 1 g of powdered tin (optional).
- About 10 cm^3 of approximately 1 mol dm^{-3} sodium thiosulphate solution
- (optional). Dissolve about 25 g of sodium thiosulphate-5-water in 100 cm^3 of water.
- 1 dm^3 of 1 mol dm^{-3} **sulphuric acid** (Irritant) see CLEAPSS Hazcard 98A and CLEAPSS Recipe Book sheet 98

Glossary

absorption spectrum	The absorption spectrum is primarily determined by the atomic and molecular composition of the material.
anion	An ion with more electrons than protons, giving it a net negative charge.
azo dye	Azo dyes are compounds containing the functional group R-N=N-R', in which R and R' are either an aryl or alkyl group.
cation	An ion with fewer electrons than protons, giving it a positive charge.
emission spectrum	The spectrum of electromagnetic radiation emitted by an atom or a compound's molecules when they are returned to a lower energy state.
ionisation	The process of converting an atom or molecule into an ion by adding or removing charged particles such as electrons.
redox	A process that involves reduction and oxidation.
spectrometer	An instrument used to measure properties of light over a part of the electromagnetic spectrum.

Royal Society of Chemistry
Education Department

Registered Charity Number: 207890

Burlington House
Piccadilly, London
W1J 0BA, UK
Tel: +44 (0)20 7437 8656
Fax: +44 (0)20 7734 1227

Thomas Graham House
Science Park, Milton Road
Cambridge, CB4 0WF, UK
Tel: +44 (0)1223 420066
Fax: +44 (0)1223 423623

Email: education@rsc.org
www.rsc.org/education