Demonstrating chemistry, part 1: From element origins to chemical reactions

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A wide range of chemistry demonstration reactions, with the linking theme 'making useful products', is presented in this and a subsequent article. Most are suitable for the full ability range of 14–16 year-olds.

ABSTRACT
The notion 'chemical reaction' distinguishes chemistry from other sciences and is an important preliminary to developing sound understanding of the subject. The idea that 'a chemical reaction produces new products' is also important. Many sound points on these themes can be presented using demonstration reactions. Practical details for a wide range of such reactions are given here, with descriptions of music and illustrations designed to help illuminate and engage an audience. The reactions are presented as a series of interconnected sections which, taken together, show how chemists seek to control chemical reactions in order to produce the everyday products we take for granted. In this article, demonstrations to illustrate the origins of the chemical elements, that elements exist in finite quantities, that chemical reactions involve breaking and making chemical bonds and examples of chemical reactions are presented. A subsequent article will provide demonstrations to help with teaching the mole, controlling chemical reactions, introducing entropy and making new products.

Developing sound understanding of a 'chemical reaction' is an essential preliminary to further study of chemistry. One strategy that can assist pupils in developing their understanding is to present demonstration reactions using this as the background theme. This article and its partner each describe a number of reactions in four different sections. The papers together present a strategy for developing pupils' understanding that chemistry involves making useful products from the chemical elements available on Earth, and that the elements are conserved and rearranged in the process. The content of the sections and the reactions themselves may be used individually. The authors have presented all eight sections sequentially in a demonstration lecture lasting approximately 1 hour and 20 minutes.

The purpose of the articles is to give teachers in schools clear instructions for demonstration reactions, together with ideas and information supporting their use in the laboratory. Thus, the articles go beyond 'normal' texts presenting instructions for demonstrations alone. We anticipate this format will be useful to beginning teachers, colleagues working outside their specialism and experienced chemistry teachers seeking new approaches. For ease of reference, we have tabulated full details of the demonstrations and other material used to provide illustration and atmosphere.

1 Chemistry starts in the stars

Table 1 describes a dramatic sequence illustrating that chemistry begins in space. A picture of the Orion nebula shows large red areas. Red is the spectral colour of hydrogen, that is hydrogen gas lit by starlight. Hydrogen was present after the Big Bang, which many

Table 1 Chemistry starts in the stars: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
Chemistry starts in the stars A sequence using music and pictures as a starting point for discussion about the origin of the chemical elements	1. Show a slide/transparency of an area of space where star formation is taking place, such as the Orion nebula. 2. Darken the room before the audience enters. 3. Play music as the audience enters. 4. Allow the audience to look at the picture and listen to the music without comment. 5. Maintain the darkness, stop the music and discuss the picture.	**Resources** Room with blackout, or which can be darkened. Picture of the Orion nebula or similar; an automatically changing slide sequence of nebulae could also be used. Slide projector or overhead projector. Music player. Music suggestions: *Allegri Misere* Holst, *The Planets* Strauss, *Also sprak Zarathustra*

cosmologists believe was responsible for the origins of the universe. Hydrogen is the starting material for other chemical elements: within the nebula, new stars, which can be seen as bright spots, are being ‘born’. Starbirth begins where gravity draws stardust together, building up very strong forces. Eventually the forces become so strong that hydrogen atoms fuse together into helium atoms. The fusion process continues, increasing pressure within the star. Eventually the pressure is too great to sustain, and the star explodes making a supernova. The Earth is thought to be left over from a supernova. Within the debris left by a supernova processes continue, forming more chemical elements. These processes mean that everything in and on the Earth including ourselves is made from stardust – the hydrogen atoms which were present when the Big Bang occurred.

2 The chemical elements

Table 2 describes resources and demonstrations used to illustrate that the chemical elements exist in finite quantities and that matter cannot be destroyed. Chemists convert matter in natural substances to products that we use. A globe is a good starting point for showing this, introducing the fact that the Earth comprises a mixture of solids, liquids and gases. The Earth can be presented as the leftover from a supernova, a star explosion. The Earth has a solid core made from iron, covered with a hot, thick, viscous liquid and then a thin solid coating on the surface. The surface of the Earth itself is covered two-thirds with water and one-third with solid material. The surface is surrounded by a thin envelope of a gas mixture we call the ‘atmosphere’ – anyone who has travelled more than 5 miles (8 km) to school has travelled further than the depth of most of the Earth’s atmosphere! A container of Lego bricks provides a good illustration of the chemical elements: the set of bricks is a finite resource – none of the components can be destroyed and many different combinations are possible. What chemists do is to control how the bricks stick together; for example, making two-element compounds and others that are much more complicated. Scientists have organised the chemical elements into a pattern we recognise as the Periodic Table. This provides a structural backbone against which chemical reactions can be carried out.

During the formation of the Earth, a number of two-element compounds were made, mainly by chemical reaction with atmospheric oxygen. Examples include aluminium oxide (ruby), silicon dioxide (quartz and sand) and carbon dioxide. The demonstration reaction involving aluminium foil shows how reactive this metal really is! The equations for the reactions involved are:

for the removal of the oxide layer:

$$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$$

for the effervescence observed after the removal of the oxide layer:

$$2Al + 2NaOH + 6H_2O \rightarrow 2NaAl(OH)_4 + 3H_2$$

Table 2 The chemical elements: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
The chemical elements Illustrate what was left after the supernova using a globe of the Earth, a wave bottle and samples of rocks. Describe Lego bricks as ‘elements’. The bricks are in finite supply. Show the Periodic Table as the way chemists organise the elements.	1. Spin the globe when talking about the Earth comprising solids, liquids and gases. 2. Hold up and name rocks as compounds, stressing element names. 3. Tilt the wave bottle to illustrate the oceans. 4. Hold the gas cube in the air to illustrate the atmosphere. **Lego bricks and Periodic Table** 1. Tip out the Lego bricks. 2. Show the Periodic Table. 3. Play ‘*The Elements*’ song, offering a memory test!	**Resources** Globe of the Earth. Samples of rocks: e.g. marble, sandstone, coal, sand, calcite, gypsum. Wave bottle: 1. Fill a large fizzy drink bottle (label removed) with 2/3 water, 1/3 paraffin. 2. Add food colour to make a strong blue. Replace the top tightly. Gas cube: 12 x 1 metre rods joined to make a cube of air. Lego blocks – in a Lego container/bucket. Periodic Table – on a board or in the background. Music player – tape/CD of *The Elements* by Tom Lehrer.
Solid carbon dioxide experiment Demonstrate the behaviour of solid carbon dioxide by adding solid lumps to alkaline liquids, producing bubbles and clouds of fog. The carbon dioxide dissolves slowly causing the indicators to change colour. *(continued)*	Wearing thermal protection gloves and eye protection, add solid carbon dioxide to each cylinder. **Extension** Place a piece of solid carbon dioxide in a disposable latex, surgical-type glove (standard rubber gloves will not stretch sufficiently), tie up and hang somewhere to expand – this shows the contrast between solid and gas densities.	**Chemicals and equipment** 4 x 500 cm^3 measuring cylinders. Solid carbon dioxide (DANGER – risk of burns). Indicators, e.g. universal, methyl red, bromothymol blue, methyl orange. Dilute (0.1 mol dm^{-3}) sodium hydroxide solution (IRRITANT). (Note: If NaOH is less than 0.05 mol dm^{-3}, it is low hazard; if 0.5 mol dm^{-3} or more, it is CORROSIVE. If corrosive, chemical splash goggles are needed; otherwise safety spectacles can be used.) Indicators made up in ethanol are FLAMMABLE. Thermal protection gloves and (for extension) disposable latex glove. **Preparation** 1. Fill the cylinders with distilled water. 2. Add a few drops of one indicator, using a different one for each cylinder. 3. Add dilute sodium hydroxide to each cylinder until the alkaline colour of the indicator is seen.

Table 2 (*continued*) The chemical elements: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
The real reactivity of aluminium Although reactive, aluminium has wide use in everyday settings. Its apparent inertness is due to a coating of aluminium oxide. In this reaction, the oxide layer is removed and the true reactivity is revealed.	1. Immerse the foil in sodium hydroxide solution for about 1 min, until it begins to effervesce. 2. Remove with tweezers and rinse with distilled water by squirting the surface from the wash bottle. 3. Transfer the foil to the second dish containing the mercury(II) chloride. 4. After about 1 min remove the foil. 5. Rinse the foil as in step 2. 6. Leave the foil exposed on the watchglass.	**Chemicals and equipment** Protective gloves. Chemical splash goggles. Tweezers. 2 x large dishes. Wash bottle with distilled water. 10 x 10 cm square aluminium foil. 200 cm^3 1 mol dm^{-3} sodium hydroxide solution (CORROSIVE). 200 cm^3 1% mercury(II) chloride solution (TOXIC). Mercury salts are toxic by absorption through the skin. **Disposal** Leave the foil in a beaker of sodium hydroxide solution until completely dissolved. Do not place the foil in the refuse. Add an excess of concentrated sodium hydroxide solution to the mercury(II) chloride solution. Filter off the mercury hydroxide precipitate. Store the precipitate for professional disposal in a sealed container.

3 Inside chemical reactions: breaking and making chemical bonds

Chemical reactions involve the rearrangement of particles of chemical elements by breaking and making chemical bonds. Pupils often think that energy is ‘stored’ in chemical bonds, an idea reinforced by everyday phrases such as ‘high-energy foods’ and those taught in science lessons such as ‘a fuel is an energy store’. Pupils can be helped to understand that breaking chemical bonds requires energy and that formation of chemical bonds releases energy. The processes of bond breaking and bond making enable rearrangements of chemical elements to take place, resulting in the formation of one or more new products which did not exist previously. No material is destroyed: everything is reorganised into new structures. Lego bricks can be used to illustrate these points: no bricks can be taken away, but many different arrangements of the bricks are possible by breaking apart and rebuilding. Table 3 describes two reactions that can be used to help explain the principles behind bond breaking and bond making.

Combustion of fuels such as butane provides a good illustration. Most combustion reactions need to be started by the input of a relatively small amount of energy, used to break bonds between particles in the reagents. The particles of reagents rearrange to form new substances. Energy is released when new bonds form; in the case of carbon-based fuels the main compounds formed are carbon dioxide and water. When the quantity of fuel is large, sufficient energy is released to sustain car motion and produce electrical power on a huge scale.

Realising that energy is released when chemical bonds form can be difficult for pupils. One reaction that helps explain this is the solidification of hydrated sodium ethanoate. This can be prepared in a liquid form and cooled to the point where crystallisation will occur very rapidly when the liquid is poured into a vessel containing seeding points, such as small crystals. The liquid solidifies so rapidly that it can be poured to form a rising stack of solid, like a stalagmite, in the dish. What is also special about this change is that, as the solidification occurs, heat is emitted from the stalagmite – this can easily be felt within a few centimetres. A chemical handwarmer shows the same effect. Pupils understand the point behind this when they succeed in making the link to the bonds being made when a liquid changes to a solid. Discussing the behaviour of water freezing to ice will help.

Table 3 Inside chemical reactions: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
Combustion of a fuel – butane Fuel and oxygen react to make carbon dioxide, water vapour and some carbon. A spark is needed to ignite the reactants. The reaction is exothermic. Molecular models can be used to show where the energy comes from. The fuel–oxygen system releases energy when chemical bonds are made.	1. Dim the lights. 2. Light the cigarette lighter. 3. Introduce the term 'chemical reaction' – in this case combustion. 4. Go through the steps in the reaction – spark needed to start, flame, light, heat, gases produced. 5. Show molecular models: reactants bag 1 – spark gives energy to break bonds; products bag 2 – energy released when new bonds form product molecules. 6. Nothing has been taken away – matter cannot be destroyed.	Cigarette lighter. **Molecular models** Reactants bag 1: butane (lighter fuel), oxygen gas. Products bag 2: carbon dioxide, water. Use transparent plastic bags. Make sure the same numbers of atoms of each element are in each bag.
Sodium ethanoate stalagmite A supersaturated solution crystallises rapidly to form a stalagmite. The change is exothermic, due to the formation of new chemical bonds.	1. Explain that the demonstration shows energy is released when chemical bonds form. 2. Hold the dish steady in one hand. 3. Pour the solution slowly, trying to make the liquid land on one spot only. 4. Invite the audience to feel the heat coming from the stalagmite. 5. Show how a chemical handwarmer works on the same principle – pass this around.	**Chemicals and equipment** 250 cm^3 beaker. 25 cm^3 measuring cylinder. Large flat-bottomed dish. Hot-plate. Watchglass or clingfilm to cover beaker. 250 g sodium ethanoate.3H$_2$O. Chemical handwarmer bought from a camping/outdoor shop. **Preparation** *At least one hour before:* 1. Place sodium ethanoate in the beaker with 25 cm^3 water. 2. Heat gently until the solid has dissolved. 3. Remove from the heat. 4. Cover the beaker. 5. Leave the beaker *undisturbed* in the place where it will be used until needed. 6. The solution is ready to pour when the beaker is gently warm to the fingers. 7. Place a few tiny crystals in the dish. **Disposal** The stalagmite can be washed down the sink with water.

4 Examples of chemical reactions

Table 4 describes four reactions illustrating different points about chemical reactions; each would make a pleasing introduction to chemistry.

The 'Traffic light' reaction is a good one to use alongside others, as the fluctuations in colour can act as a deliberately placed distraction to test observation skills. To start the reaction, a pupil may be invited to shake the flask, so everyone can see the colour change. The demonstration is a nice addition to an open evening display – for this, the stopper can be secured firmly with tape and the flask labelled 'SHAKE ME!' to provide a pleasing surprise for visitors.

The reaction between sugar and concentrated acid needs care – not just in the use of concentrated acid and the fumes produced, but in explanation, because

Table 4 Chemical reactions: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
The 'Traffic Light' reaction – an oscillating reaction This is a redox reaction. Glucose in alkaline solution reduces an indicator. Oxygen, introduced by shaking the flask, oxidises the indicator. The indicator is indigo carmine and the colour changes to red, then green, and then to yellow when left to stand. The cycle can be repeated many times.	1. Shake the flask vigorously. 2. Leave the flask to stand. 3. Repeat the shaking. 4. Ask the audience to let you know when the colour changes back. **Extension** Have a range of flasks with different indicators: methylene blue (5 cm^3 of a 0.1% solution in ethanol) gives blue and colourless; phenosafranine (6 drops of a 0.2% aqueous solution) gives pink and colourless; Resazurin (4 drops of a 1% aqueous solution) gives pale blue and purple/pink.	**Chemicals and equipment** Chemical splash goggles. 1 x 1 dm^3 conical flask with stopper. 1 x 500 cm^3 measuring cylinder. 6 g sodium hydroxide (CORROSIVE). 10 g glucose 4 cm^3 1% (aqueous) indigo carmine made fresh to avoid deterioration **Preparation** 1. Dissolve the sodium hydroxide in 300 cm^3 water (CORROSIVE solution 0.5 mol dm^{-3}). 2. Immediately before the demonstration add the glucose and the indicator. 3. Stopper the flask. Goggles only need to be worn during the preparation stage. **Disposal** Wash down the sink with water.
Sugar and concentrated sulfuric acid – dehydration The acid removes water from sucrose producing a black spongy carbon column rising up the beaker. *(continued)*	1. Explain that we are seeing dehydration – removing water from a substance. Check for asthmatics. If there are any, either conduct the demonstration in a fume cupboard or have asthmatics at least 3 metres away. 2. Add 20 cm^3 acid to the sucrose. 3. The reaction will not start immediately. Do not add more acid. 4. Steam, heat and small amounts of sulfur dioxide (TOXIC and CORROSIVE) will be given off as the reaction proceeds. If not done so before, remove the beaker to a fume cupboard when the carbon column has formed.	**Chemicals and equipment** 1 x 100 cm^3 beaker. Access to fume cupboard. 50 g sucrose. *Fresh* concentrated sulfuric acid (CORROSIVE) in a bottle with a graduated pipette stopper. Heatproof mat. **Preparation** Weigh out the 50 g sucrose into the beaker. Place the beaker on the heatproof mat. **Disposal** Allow reaction products to cool. Transfer to a bucket containing water and neutralise with dilute alkali. Leave to stand for at least an hour. Place the neutralised carbon column in the refuse and wash the liquid down the sink.

Table 4 (*continued*) Chemical reactions: demonstrations and resources.

Demonstration	*Procedure*	*Technical details*
The reaction between potassium iodide and lead(II) nitrate Two clear colourless solutions are mixed producing a yellow precipitate of lead(II) iodide and potassium nitrate solution. The change is dramatic for those not expecting it!	1. Say that reactions are sometimes surprising – what may happen if these two are mixed? 2. Pour the contents of one flask into the other, swirl. **Extension or alternative** Carry out a solid phase reaction, mixing the two solids in a screw-top jar with a few drops of water.	**Chemicals and equipment** 2 x 500 cm^3 conical flasks. 1 x 100 cm^3 measuring cylinder. 20 g lead(II) nitrate (TOXIC). 20 g potassium iodide. **Preparation** 1. Measure 100 cm^3 water into each flask. 2. Add lead(II) nitrate to one flask and potassium iodide to the other. 3. Cover the tops of the flasks with clingfilm until needed. 4. Label the flasks discreetly. **Disposal** Filter off the lead(II) iodide. Store in safe place for eventual collection by a licensed waste contractor.
Ammonium dichromate(VI) volcano Sparks are seen when a small heap of ammonium dichromate is ignited. Steam and a large volume of chromium(III) oxide are produced in a decomposition reaction.	1. Introduce decomposition as another type of chemical reaction. 2. Place the flask on the tripod and gauze and heat strongly. Dim the lights in the room if possible. 3. Stop heat when the 'volcano' erupts.	**Chemicals and equipment** Goggles. Neoprene or rubber gloves. 1 x 1 dm^3 conical flask. Bunsen, tripod, gauze and heatproof mat. Pestle and mortar. Desiccator with silica gel. Glass funnel. Cardboard tube, e.g. inside of kitchen roll. Mineral wool, e.g. Rocksil (IRRITANT). 3 g ammonium dichromate(VI) (EXPLOSIVE and TOXIC). **Preparation** 1. Taking care to avoid skin contact or inhalation of fine dust, grind the ammonium dichromate(VI) in the pestle, in a fume cupboard while wearing gloves. 2. Leave in desiccator for 2 days. 3. Just before the demonstration, fit the funnel to the cardboard tube and place the tube into the flask. Pour the solid into the flask through the funnel to make a conical heap. 4. Remove the cardboard and plug the flask with mineral wool. (Although the products are all LOW HAZARD, it is possible that some undecomposed ammonium dichromate(VI) may be carried into the atmosphere with the product and hence inhaled. The mineral wool plug prevents this.) **Disposal** Place the chromium(III) oxide in a sealed plastic bag in the refuse.

pupils may too easily use this to confirm their thinking that acids 'burn', whereas alkaline substances are 'safe'. However, it is a very good demonstration, as a rising column of hot steaming carbon produced from innocent white sugar is very dramatic. When performing the demonstration, ensure that any asthma sufferers are seated at least 3 m away to avoid triggering any attacks. The acid acts as a powerful dehydrating agent, removing water from the sugar. The sugar is a carbohydrate made from carbon, hydrogen and oxygen. Addition of the acid causes bonds to be broken in the sugar and acid molecules, and rearrangement results in the formation of water together with a mixture of other products.

The lead(II) nitrate and potassium iodide reaction is another excellent 'surprise' reaction. As described, a yellow crystalline precipitate forms when the two clear, colourless solutions are mixed together. Ask pupils to explain where the yellow 'stuff' comes from and lead them towards the answer that new bonds form between the particles in the two liquids to give the yellow product. The particles are too small to be seen, but we can see the effects of the new bonds forming.

The ammonium dichromate(VI) volcano is a 'classic' demonstration that many may remember from their own school days. It is a good example of a decomposition reaction, in which one compound is broken down to make others. Pupils can be invited to suggest how they know a chemical reaction has occurred: observing the colour change from orange to green and the production of sparks are two significant signs. In terms of bonds, pupils can be helped to realise that heat breaks bonds in the original substance and that particles are rearranged to make new products.

Conclusion

Although it is relatively easy to show a range of different chemical reactions, pupils also need to know that chemistry is most useful when the products are needed for a specific reason. In order to make products effectively and efficiently, chemists need to know exactly how much of each reagent is needed, and to be able to control the ways in which these are combined. These are basic components of a chemist's 'toolkit' for understanding how chemical reactions really 'work'. The second article, to follow in June 2005, will describe demonstration reactions to illustrate these and other related points.

Sources

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■ Health and safety

Note that none of the reactions described are 'banned' by UK legislation and all may be carried out safely in a standard school science laboratory. Advice about disposal is included; information on specific hazards associated with the use of specific chemicals is readily available to members through the CLEAPSS School Science Service (www.cleapss.org.uk). In UK law, risk assessments are the employer's responsibility. Teachers must consult their employer's risk assessments and consider whether modification is necessary for the specific situation in their class, room or school.

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