Kimbolton Fireworks

Fireworks
An explosive business

RONALD LANCASTER

GCSE key words
Combustion
Oxidation
Compounds
Flame tests

Above: *Kimbolton Fireworks gained first prize at an international fireworks and music competition in Cannes in 2001. Displays on three barges 300 m out to sea were synchronised by a computer on the promenade.*

Fireworks have been known for many hundreds of years. What gives them their particular colour or effect? How are they made and how are they set off? This article includes some basic chemistry relevant to your GCSE science course — with an explosive twist.

Fireworks are an explosive combination of colour and noise. Whistles, bangs and humming noises combined with many different kinds of light effects give pleasure and delight to thousands of people all over the world. Although fireworks were invented hundreds of years ago they have developed as science has progressed, particularly over the last 200 years.

Mary Evans Picture Library

Left: *The Gunpowder Plot in 1605 was a famous but unsuccessful attempt to blow up the king and parliament, still celebrated with fireworks made from gunpowder.*

IN THE BEGINNING

Many people think that fireworks came from the Far East, but this is only part of the story. It was the West which taught the East how to make modern fireworks.

Gunpowder was, undoubtedly, discovered in China. The people who made it were not looking for gunpowder but for the 'elixir of life'. They mixed together various salts, some of which must have been nitrates, with charcoal, honey and eventually sulphur, and found that this mixture caught fire readily.

By AD 800 gunpowder had been produced in a form similar to that we use today. It is pretty certain that Arabs brought it to Europe in the thirteenth century. This mixture of potassium nitrate, charcoal and sulphur has a long history, but the Chinese did not use it in weapons, instead they made it into firecrackers. The powder was packed into bamboo tubes and thrown on to the fire so that it exploded and scared away evil spirits. Such crackers are still made today, and are traditionally covered in red paper, which has a spiritual significance.

Nitrates contain the group (NO_3^-).

12 g of charcoal (about 6 cm^3) when completely burnt produces 24 000 cm^3 of gas. If this expansion occurs quickly enough it can be used to propel shells or to cause an explosion.

INTRODUCING COLOURS

Potassium chlorate is $KClO_3$, potassium perchlorate is $KClO_4$.

Fireworks as we know them today are a comparatively recent invention. Some were made with gunpowder before 1800, but they could only burn gold or white and consisted mainly of rockets, bangers and gold or white fountains. The charcoal and the sulphur burn in the oxygen provided by the potassium nitrate (an oxidising agent) to provide golden flames. By-products include gases such as carbon dioxide and sulphur dioxide and some solid potassium compounds. It is mainly the charcoal which produces the gold colour.

The best blue 'stars' were originally made with an easily-decomposed pigment called Paris green. It was made by boiling arsenic oxide with copper sulphate and then precipitating the pigment with ethanoic acid. It is impossible to buy this pigment today because of its toxicity.

Nitrates of barium and strontium provided some other colours, but the discovery of potassium chlorate (another oxidising agent) by Berthollet in 1794 changed everything. By 1820 European firework makers were producing fine coloured fireworks, but they were very dangerous because potassium chlorate is an unstable compound and, when mixed with sulphur, can spontaneously combust. It did this many times, causing serious accidents, before the more stable potassium perchlorate came into use to supply the oxygen.

BOX 1 FLAME TESTS

Flame tests are used to show whether certain metal ions are present in a compound. A tiny sample of compound on a piece of platinum (or nichrome) wire is placed in a non-luminous bunsen flame. The energy of the flame causes electrons in the metal ion to rise to higher energy levels, and as they fall back to their original level they give out specific frequencies of light.

Metal ion	Colour
Lithium	Deep red
Sodium	Persistent yellow-orange
Potassium	Lilac
Rubidium	Red
Caesium	Blue
Calcium	Orange-red
Barium	Pale green
Copper(II)	Blue-green

Deliquescence is when a chemical absorbs water from the atmosphere.

Many street lights contain sodium — hence their colour.

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BOX 2 CONGREVE ROCKETS

Around the end of the eighteenth century rockets experienced a brief revival as a weapon of war. Indian rocket barrages were used against the British in 1792 and again in 1799. These caught the interest of an artillery expert, Colonel William Congreve, who set out to design rockets for use by the British military.

Congreve rockets were highly successful in battle. They were used by British ships to pound Fort McHenry in the 1812 war against the USA, and this inspired Francis Scott Key to write the line 'the rockets' red glare,' in his poem that later became 'The Star-Spangled Banner' — the US national anthem.

It was not long before the isolation of magnesium and aluminium (due to the development of electrochemistry) allowed manufacturers to produce brilliant silver fireworks. More recently titanium has become available and has the same effect.

The range of colours used to be restricted to red, blue, green, yellow and white. High temperature flames have now been developed with the addition of either magnesium or magnesium–aluminium alloy, known as magnalium alloy, which corrodes much less easily than magnesium alone. These have made possible intermediate colours such as citron (between green and yellow), turquoise (between green and blue) and rich oranges and violets.

HOW IT WORKS

Colour occurs in the flame due to the formation of halides, but these are unstable and only exist in the flame itself. The best colour emitters are strontium(I) chloride (SrCl) which produces red, copper(I) chloride (CuCl) for blue and barium(I) chloride (BaCl) for green. Sodium atoms produce yellow quite powerfully, and traces of sodium can overwhelm any other colour present. Blue has always been the most difficult colour to produce because the copper chloride molecule is easily destroyed in high-temperature flames.

Most coloured fireworks consist of four main components with a number of additives. The oxidising agent potassium perchlorate provides the oxygen, the fuel is normally a gum resin such as shellac from India or gum yacca (acaroid resin) from Australia. The colouring agent is the insoluble salt of the appropriate metal. Insoluble salts are chosen to avoid chemical reactions which produce deliquescence. In addition there is the halogen donor and sometimes starches to slow down the burning rate or to act as an adhesive for making pellets which burst as stars.

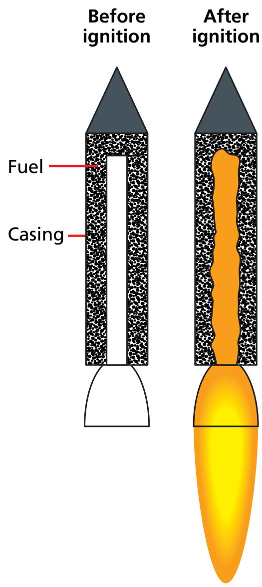

Figure 1 How a rocket works.

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Above: Kimbolton Fireworks setting up a display on the Thames.

INTO THE AIR

There are four main kinds of fireworks: rockets, roman candles, fountains and shells, but there are literally hundreds of variations of each type.

Rockets have been made for a few hundred years, not only for pleasure but also as weapons (Box 2). The gas produced in the rocket motor issues from the end with great force and the flight of the rocket is guided with a stick, fins or additional stabilising jets (see Figure 1). The payload of stars is ejected at the apex of their flight, but rockets cannot carry large payloads.

Shells are packages of paper — either compressed papier-mâché spheres or paper cylinders bound with cord (see Figure 2). They are propelled into the air by a lifting charge of gunpowder. The mortars from which shells are fired can be made of paper, polyethene or fibreglass. In earlier times steel was used, but this is dangerous if the mortar bursts. In about 1926, Aoki in Japan developed the modern chrysanthemum shell which has produced some of the most innovative shell patterns in recent years.

The roman candle is a very English kind of firework and consists of a long narrow tube. Stars or small bombettes are fired out of the tube at intervals, using some form of delay mechanism between each shot.

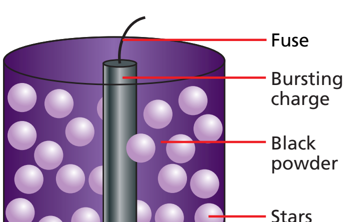

Figure 2 The structure of a simple shell.

BOX 3 SAFETY

All fireworks are potentially dangerous. They must be handled only as instructed on the packaging. No attempt should be made to 'investigate' or dismantle any firework. Do not attempt to make your own fireworks — it is dangerous and illegal.

SETTING OFF

Large firework displays require a lot of skill and time to set up. Many displays are now fired with electric matches which are expensive, but allow multiple firing alongside pyrotechnic delay systems. Computer-fired systems are also available at considerable expense but they do not always work well in poor weather conditions. A good, experienced operator can fire perfectly well by hand without electricity.

Fireworks continue to give pleasure to many people, whether in large public displays or your own back garden. As they are partly based on good old blackpowder it is doubtful whether modern science will be able to enhance them further — but only time will tell.

Below: The Reverend Ronald Lancaster, with some of his products.

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*The Reverend **Ronald Lancaster** taught chemistry and religious studies for many years and is now managing director of Kimbolton Fireworks, the UK's principal manufacturer of display fireworks.*