Theresa Lau

Fireworks: A Contribution of Chemistry to Celebrations and Festivities

Introduction

Fireworks can be seen in the night sky during major holidays around the world. Their colorful explosions and booming noises have made them synonymous with celebrations everywhere. Following the discovery of gunpowder in the 9th century, the invention of fireworks quickly followed, and they made their way around the world to become established as a frequent conclusion to a night of festivities.

A Brief History

While there is no exact date for the discovery of gunpowder, its invention is credited to the Chinese. In the process of looking for the elixir to immortality, Chinese Taoist alchemists accidentally discovered gunpowder when they heated a mixture of sulfur, saltpeter (potassium nitrate), honey, and arsenic sulfide, which resulted in an explosion. The earliest records of this discovery were recorded in a Taoist text dated near 800 A.D. Through further experimentation, charcoal replaced honey and other materials to make more powerful and louder explosions. The alchemists also found that if the gunpowder was ignited in a container with an open end, the explosion would result in flames, sparks, and smoke, a sight known today as fireworks.

Because the explosions were frightening, so the Chinese set off gunpowder in bamboo sticks to scare off evil spirits during holidays and happy events such as Lunar New Year, weddings, coronations, and births. These became known as firecrackers,

which soon came to signify a celebration. During the Tang dynasty (618-907 A.D.), Tang emperors were known to put on magical fireworks displays. The fireworks were also used in warfare to scare the enemy. Eventually, the use of gunpowder shifted to inflicting harm on the enemy, usually in the form of crude bamboo rockets and cannons.

By the 13th century, the Arabs had learned of gunpowder, and the news spread quickly to Europe. Roger Bacon, a Franciscan monk, became one of the first Europeans to study and write about this new discovery. A warfare revolution occurred in Europe, further spurred by the development of metallurgy, thus creating the earliest form of modern warfare.

The Italians were fascinated with fireworks and were the first to develop fireworks into an art form. They developed aerial shells to launch fireworks that exploded at high altitudes. They were the undisputed masters of fireworks through the 17th century. Thanks to advances in chemistry in the 1830s in southern Italy, pyrotechnicians were able to obtain color in fireworks by adding a metallic salt and chlorinated powder to the firework composition. These methods are essentially the same as those used today to make colored fireworks.

The Chemistry of Fireworks

Aerial fireworks, the kind seen in the sky on holidays and celebrations, have six main components: gunpowder, color elements, the main fuse, the time-delay fuse, the firework container, and the launch tube, which is separate from the firework itself. The main fuse and the time-delay fuse are lit simultaneously, although they lead to different parts of the firework. The main fuse leads to one section of gunpowder. Its combustion

creates heat and rapidly expanding gas that propels the firework high into the sky when the gas escapes the launch tube. The time-delay fuse is calculated to reach the main compartment just as the firework reaches its maximum height. The main compartment contains more gunpowder and metallic salts give fireworks color. The time-delay fuse sets off the main explosion that results in colorful lights across the sky. A schematic diagram of a typical spherical firework shell is displayed in Figure 1.

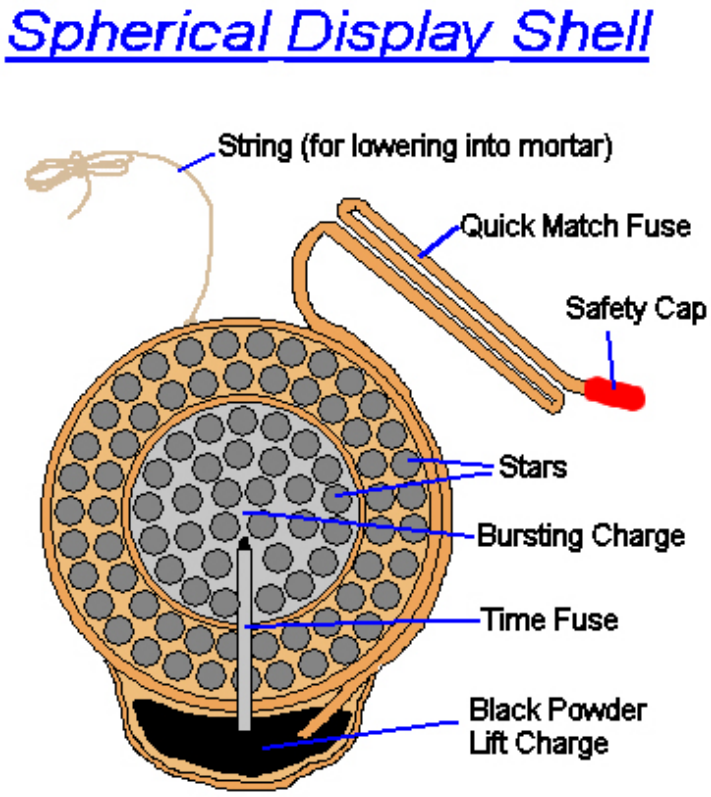


Figure 1. A simple schematic of a spherical firework shell from www.pyrouniverse.com.

The reactions that take place in the firework are oxidation-reduction reactions. Oxidizers provide the oxygen needed to burn the reducing agents, which provide the heat to burn the coloring agents and produce the energy of the explosion. The most common oxidizers are nitrates, chlorates, and perchlorates, while the reducing agents are sulfur and carbon.

Of the three common oxidizers, nitrates are the most common, as they are a major component of gunpowder (as potassium nitrate, or saltpeter). The chemical reaction is:

$$2\ KNO_3 \rightarrow K_2O + N_2 + 2.5\ O_2$$

Because not all of the oxygen is released in this reaction, the reaction is not as explosive as that of other oxidizers and is more controlled. Nitrates are usually used to propel the firework into the sky. Because the reaction does not provide enough heat to burn the reducing agents, nitrates are only used in the lift charge.

Chlorates were discovered by the Italians to produce a higher temperature when burned and are thus more explosive oxidizers. With higher temperatures, more intense colors and spectacular explosions were possible. The reaction is:

$$2\ KClO_3 \rightarrow 2\ KCl + 3\ O_2$$

Because all the oxygen atoms are released, chlorates are better oxidizers than nitrates. The disadvantage of chlorates, however, is that they are more unstable than nitrates and more dangerous to handle. The instability comes from the chlorine atom, which is only bonded to three oxygen atoms, when it could bond to four. The remaining unpaired electron on the chlorine atom makes it extremely reactive, resulting in very fast explosions.

Perchlorates are more commonly used today because they are more stable than chlorates and provide more oxygen than either chlorates or nitrates. The reaction is:

$$KClO_4 \rightarrow KCl + 2\ O_2$$

Not only are all the oxygen atoms released, but each perchlorate produces more oxygen than chlorate. Perchlorates are more stable because the chlorine atom is bonded to the

maximum number of oxygen atoms, and therefore the potassium is bonded not to the chlorine atom, but to an oxygen atom, which is far less reactive.

The reducing agents sulfur and carbon are both found in gunpowder (the carbon comes from charcoal). Their reactions,

$$O_2\,(g) + S(s) \rightarrow SO_2\,(g)$$

$$O_2\,(g) + C\,(s) \rightarrow C0_2\,(g)$$

produce much heat. The heated gas products rapidly expand, resulting in the explosion characteristic of fireworks.

The heat from the reaction also serves to burn the metallic salts that give fireworks their color. Different metallic salts emit different colors when burned. The heat excites the electrons in the atoms, which emit photons (light) when the electrons fall back into their normal energy state. Each metallic salt emits light of different wavelengths, resulting in different colors for use in fireworks. The colors produced by metallic salts are listed in Table 1 along with examples of corresponding common metallic salts used in practice.

Color	Metallic Salt	Examples
Red	Lithium salts (red) Strontium salts (bright red)	Li_2Co_3 $SrCO_3$
Orange	Calcium salts	$CaCl_2$
Yellow	Sodium salts	NaCl
Green	Barium compounds + Chlorine producer	$BaCl_2$
Blue	Copper compounds + Chlorine producer	CuCl
Purple	Mixture of strontium and copper compounds (for a mix of red and blue)	
Silver	Aluminum, titanium, magnesium	

Table 1. Burning metallic salts produces colors in fireworks.

Fireworks not only come in a variety of colors, but they also come in many different shapes and sizes. The shapes come from how the metallic salts are packaged and patterned in the main compartment. The reaction times of the salts also contribute to the shape of the firework. For example, the raining effect of fireworks is produced by slow and controlled reactions. Some common shapes and effects of fireworks can be seen in Table 2.

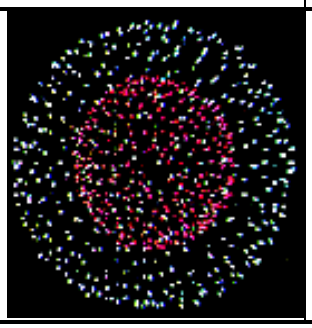
Shape	Peony	Willow	Palm Tree	Spider
Example				

Table 2. Names and shapes of different firework effects.

Fireworks Today

While fireworks were originally used to scare away evil spirits, today they represent a time of celebration. Often, fireworks are used celebrate the beginning of something momentous (like the New Year or the Olympics), or it can be used to commemorate holidays. The sonic boom and the explosion of colors in the sky invoke a sense of awe that keeps fireworks popular around the world.

New Year's Eve is one of the most common holidays around the world to be celebrated with fireworks. Independence days are celebrated with fireworks, like Independence Day in the United States or Canada Day in Canada. Victoria Day

celebrates the birthday of Queen Victoria and Queen Elizabeth II; it is the only other holiday in Canada when the public is allowed to buy and set off fireworks. Bastille Day in France celebrates the start of the French Revolution in 1789.

In England, fireworks and burning effigies commemorate the day that Guy Fawkes and his conspirators tried to blow up Parliament with gunpowder in 1605 (often referred to as the Gunpowder Plot). The Ryogoku Fireworks Festival in Japan dates from 1733, when a famine led to a ceremony to a water god that included fireworks to drive away disease. Diwali, or the Festival or Lights, is the most popular festival in India and celebrates the triumph of good over evil. At night, windows are lit with candles and lamps while fireworks are set off.

Today, China remains the world's largest exporter of fireworks. The fireworks industry has been growing in the United States with an industrial revenue of $930 million in 2007 and a consumption of 265.5 million pounds of fireworks (of which only approximately six million pounds were produced domestically).

As enjoyable as fireworks are, recent climate changes have caused growing concerns about the pollution released from fireworks and the possible environmental toxins present in the colorants. The variability in the construction of fireworks makes the pollution from fireworks difficult to measure, although some have argued that pollution from fireworks is insignificant compared to that from burning fossil fuels. Efforts to create more environmentally friendly fireworks include using compressed air to launch fireworks and an electronic timer instead of a time-delay fuse. Disneyland pioneered such fireworks in 2004. Safety concerns have also limited the sale of consumer fireworks in most countries around the world due injuries, fires, and even deaths caused by the

production or usage of fireworks. Despite these limitations, professional displays of fireworks are still enjoyed around the world.

Conclusion

Fireworks are an integral part of many cultures and societies today. Although the purpose and use of fireworks has evolved since its conception, fireworks now transcend language and culture barriers; words are not needed to enjoy explosions of color in the sky. Through chemistry, fireworks have developed into an art form (competitions are held in many countries) that brings enjoyment to millions of people worldwide.

References

"Bastille Day." http://en.wikipedia.org/wiki/Bastille_Day.

"Fireworks." http://dopamine.chem.umn.edu/chempedia/index.php/Fireworks

"Fireworks." http://en.wikipedia.org/wiki/Fireworks

"Fireworks Industry Facts & Figures." http://www.americanpyro.com/industry.html

"Gunpowder." http://en.wikipedia.org/wiki/Gunpowder

"History of Gunpowder." http://epicfireworks.wordpress.com/tag/gun-powder/

"History of Fireworks." http://www.pyrouniverse.com/history.htm