Fireworks have been used worldwide in celebrations for over hundreds of centuries. The beauty and artistry of making these spectacular night shows come alive has a rich history in art as well as science. The history of fireworks can be traced back to the Chinese with the advent of gunpowder. Around the 9th Century the Chinese discovered black powder with the accidental mixture of saltpeter, charcoal and sulfur. The Chinese then used this mixture in rockets and firebombs. This simple use of gunpowder would change the way battles were fought, and with a little experimenting, fireworks were created and used in celebrating both military victories and peace (Bianco and Willis p 338). In 1540, Vannoccio Biringuccio, an Italian metallurgist, published a book on how to combine different metals to produce different types of explosives and fireworks (Bianco and Willis p 338). Interestingly enough, advances made in the chemistry of applying different elements at various heats have produced amazing colors; however the use of gunpowder has not changed over the centuries. The production of a firework’s intense color, sound and pattern is a craft that entails chemistry, physics and artistic value.

In the making of fireworks, many basic principles of both physics and chemistry are employed. Energy transformation, in each phase of the mechanics of fireworks, is evident in the release of bright light, sound and heat. Fireworks can be classified as both a high and low explosive. A high explosive involves extreme temperatures resulting in detonation. Detonation is a “rapid rearrangement of atoms, which sets off a rapid change of events,” (KABOOM! film). Detonation occurs during the second phase of a firework explosion, which produces a loud sound and bright light. A low explosive is one that burns at a very fast rate due to its confinement upon ignition but does not detonate. Three things are needed to initiate explosive: ignition source, fuel source and oxygen. The potential energy held in each firework is shown in a beautiful display of kinetic energy moving through the air once the source is ignited. A chemical reaction within the firework itself produces more oxygen, which then adds to both the combustion and heat needed to emit the various colors while at the same time producing velocity, acceleration and immense sound.

The basic components of fireworks include the following: fuel, oxidizing agents, reducing agents, color agents, binding agents and stabilizers. Extreme safety goes into the production and delivery of fireworks as the stability of the dry chemicals can be very dangerous if handled incorrectly. The firework is carefully fabricated into a shell made of paper. The following components are what make up a firework. These include the shell, a primary/main fuse as the outside ignition source, the lift charge, launch tube/mortar, black powder, stars (special containers that house the mixtures of compounds), time-delay fuse and a break. When ready for display, the firework is then placed into a mortar tube in the ground. The placement of the mortar shell and its size in relation to the firework are equally important in order to get the desired effect. The purpose of the mortar shell is similar to the reactions of a cannonball in a cannon as explained by Newton’s Third Law of Motion requiring equal and opposite force. The firework is shot through the air vertically as the lift charge is ignited (Bianco and Willis p 339). The fuel source, black powder (gunpowder) once ignited from a quick burning fuse, supplies the lift charge that produces heat and gas. This effect allows the trapped energy in the contained shell to push against the tube, which supplies the kinetic energy to set the firework in motion. The black powder mixture of 75% potassium nitrate (salt peter), 15% charcoal, and 10% sulfur is still used today. This lift charge can set the firework into the air as high as 1,000 feet (Nova Online par 3). The main fuse when ignited is what sets the lift charge into motion. The main fuse also has a secondary fuse on a time delay which is buried deep in the shell which houses the oxidizing agents, color agents and binding agents. Black powder can also be found within each of the separate charges, also known as breaks or compartments, attached by the slow burning delay fuses. The breaks are used to separate the compartments and colored ‘stars’ from each other. Due to the time delay fuse, each compartment is lit in succession, perfectly timed in order that the break occurs at the peak height of the trajectory. The ‘stars’ are packed with different chemical compounds of color and binding agents that when vaporized allow for spectacular light emissions.
Many chemical reactions occur within the firework once ignited. The most important reactions are oxidations and reductions. The oxygen need to supply the reaction is not from the surrounding air but from “oxidizers that produce the oxygen required to burn the mixture of reducing agents and to excite the atoms of the light-emitting compounds” (Shakhashiri par 10). Because the firework is self-contained, the amount of released oxygen results in very high temperatures often over 3,000 degrees Celsius (Bianco and Willis 341). The various light emitted from the fireworks are the product of incandescence (bright or white light spectrum from high temperature) and atomic/molecular emission that produces brilliant colors from the absorption of energy (Bianco and Willis 341). Specially crafted ‘stars’ are placed in the compartments of the firework which enclose the chemical compounds that are carefully mixed to generate particular colors. The heating of metal salts is used to emit particular colors that produce the special effects and color configurations. To completely understand the importance of this reaction one must understand oxidation. During oxidation, atoms lose their electrons to form bonds with other atoms in order to form a more stable reaction process. This is considered an exothermic reaction, one that produces heat. What happens during this process of electron transfer has everything to do with how the elements absorb energy and give off light and specific colors. As explained by Shakhashiri:

The energy absorbed by an atom rearranges its electrons from their lowest energy state, called the ground state, up to a higher energy state, called an excited state. The excess energy of the excited state is emitted as light, as the electrons descend to lower-energy states, and ultimately the ground state.

The amount of energy released is varied by the wavelength of light. With a higher frequency and thus a shorter wavelength, the higher energy produces colors in the end of the electromagnetic light spectrum, such as violet blue. Orange/red colors would then be produced from lower energy and longer wavelengths of the electromagnetic spectrum (Shakhashiri par 4).

(Adapted from: http://scifun.chem.wisc.edu/CHEMWEEK/fireworks/fireworks.htm)

The chemical composition, temperature of heat created by oxidation and the configuration of the ‘stars’ in the compartments all contribute to the success of the firework display. According to Shakhashiri, the most common oxidizers include nitrates, chlorates and perchlorates while sulfur and carbon, when combined with the oxygen are the reducing agents most used to produce the energy of the explosion (par 10). The reducing agents are necessary to produce the gases that either speed up or slow down the oxidation reaction. The stabilizers/regulators used to control the burn are often cornmeal and the metals used (Gerling, Brockert, and McConnell par 6). Binding agents are found within the ‘stars’ to keep the mixture together. Several different binding agents are used including Elmer’s all-purpose glue or a starchy compound with shellac dampened by alcohol (Gerling, Brockert, and McConnell par 7). The combinations for colors are numerous. The following chart demonstrates the most common elements used for the color productions of fireworks.

<table>
<thead>
<tr>
<th>Color</th>
<th>Compound</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>strontium salts, lithium salts</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lithium carbonate, Li₂CO₃ = deep red</td>
<td>650</td>
</tr>
<tr>
<td></td>
<td>strontium carbonate, SrCO₃ = bright red</td>
<td>650</td>
</tr>
<tr>
<td>Orange</td>
<td>calcium salts</td>
<td>670</td>
</tr>
<tr>
<td></td>
<td>calcium chloride, CaCl₂</td>
<td></td>
</tr>
<tr>
<td>Yellow</td>
<td>sodium salts</td>
<td>610-620</td>
</tr>
<tr>
<td></td>
<td>sodium chloride, NaCl</td>
<td></td>
</tr>
</tbody>
</table>
Green  |  barium compounds + chlorine producer  
      |  barium chloride, BaCl₂  

Blue   |  copper compounds + chlorine producer  
      |  copper(I) chloride, CuCl  

Purple |  mixture of strontium (red) and  
      |  copper (blue) compounds  

Silver |  burning aluminum, titanium, or magnesium  

http://scifun.chem.wisc.edu/CHEMWEEK/fireworks/fireworks.htm

Sound waves are also created during the explosion of fireworks. Whistle sounds in the past were created from the compound of potassium picrate, but are not favored anymore due to the difficulty of handling the material (Lancaster 248-249). Empty spaces are used to resonate sounds within the explosion of the firework. Fireworks which create a humming sound are constructed in such a way that the gas upon combustion escapes out of a tube and causes the tube to rotate on its own axis (Lancaster 251).

The many majestic scenes created by celebratory fireworks are both a work of art and science. The chemistry involved in creating the colorful display enhances the artistic design of the firework. With the understanding of the chemical reactions and physical science involved in producing a spectacular firework show, one can appreciate the energy conservation theory from start to finish of a single firework. The beauty of light, energy, sound and motion bring the world of physical science alive in theory and practice.

Works Cited


An easy-to-understand introduction to the science of fireworks: how do they get into the sky and where do all the different colors come from? The word “firework” comes from the Greek word pyrotechnics, which means, very appropriately, “fire art” or “fire skill”; there’s certainly no shortage of art and skill in modern firework displays! Photo: A summer firework display in Swanage, England. A single firework can involve dozens of separate explosions. Home Â» Minerals Â» Fireworks. The Art and Science of Fireworks Displays. Art, Chemistry, Physics and Math Light Up the Fourth of July! Article by: Hobart M. King, Ph.D., RPG. Colorful fireworks: The color of a fireworks burst is created by adding metallic compounds that flame with a known color to the stars within a fireworks shell. This photo shows fireworks bursts with a variety of color. Photographer was Kurume-Shimin. Photo used here under a Creative Commons license. Aerial fireworks display: The vibrant colors in a fireworks display are made possible by minerals. Each color streak in the d Fireworks are synonymous with celebration in the twenty-first century. But pyrotechnicsâ€”in the form of rockets, crackers, wheels, and bombsâ€”have exploded in sparks and noise to delight audiences in Europe ever since the Renaissance. Here, Simon Werrett shows that, far from being only a means of entertainment, fireworks are a work of art and science. Acknowledgments. Notes.