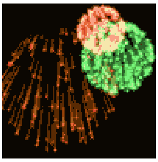
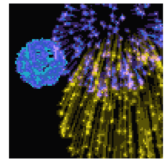


Fireworks!

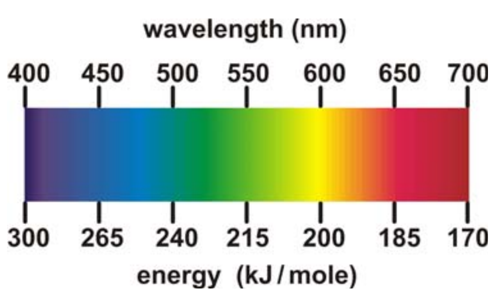


Tonight as you watch the aerial fireworks show as part of the Gialamas Company's Concert in the Park festivities, you may wonder how all the impressive colors and sounds are produced. People everywhere enjoy the fantastic explosions and the brilliant light displays of fireworks. However, these spectacles are much more than just a form of entertainment. Each firework launched into the sky is a precisely formed assembly of chemicals and fuel, carefully calibrated to produce a particular effect – a red chrysanthemum spray accompanied by a powerful explosion, or a blue strobe, for example. Understanding how the contents of a firework produce the impressive variety of colors, forms, and sound intensities requires only a simple understanding of chemical reactions.

Fireworks generate three very noticeable forms of energy: a tremendous release of sound, bright light, and heat. The tremendous booms heard at ground level are the result of the rapid release of energy into the air, causing the air to expand faster than the speed of sound. This produces a shock wave, a sonic boom.

The colors are produced by heating metal salts, such as calcium chloride or sodium nitrate, that emit characteristic colors. The atoms of each element absorb energy and release it as light of specific colors. 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 emitted is characteristic of the element, and the amount of energy determines the color of the light emitted. For example, when sodium nitrate is heated, the electrons of the sodium atoms absorb heat energy and become excited. This high-energy excited state does not last for long, and the excited electrons of the sodium atom quickly release their energy, about 200 kJ/mol, which is the energy of yellow light.

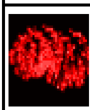
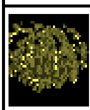
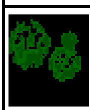
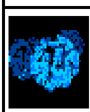
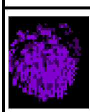
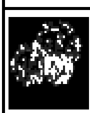
The amount of energy released, which varies from element to element, is characterized by a particular wavelength of light. Higher energies correspond to shorter wavelength light, whose characteristic colors are located in the violet/blue region of the visible spectrum. Lower energies correspond to longer wavelength light, at the orange/red end of the spectrum.



The colors you see exploding in the sky are produced by the elements with the characteristic emissions listed in the following table. In making fireworks, the metal salts are put into stars, small clay or dough-like lumps or cubes 3 to 4 cm in diameter. Stars consist of a blend of oxidizing agent, reducing agent, coloring agent (metal salt), and binders. When ignited, the stars produce both sound and light effects. The appearance of a firework is determined by its stars, which are made by hand and carefully packed into cardboard compartments within the firework shell, where they await ignition by a time-delay fuse.

From lift-off to color release, a carefully choreographed sequence of events takes place, producing the desired effect. The power needed to lift each firework into the air is provided by the highly exothermic combustion of black powder, a slow-burning combination of 75% potassium nitrate, 15% charcoal, and 10% sulfur. Said to have first been used in China about 1000 years ago, the recipe for black (or coal) powder has undergone little change since then. This formulation explodes at a rate of about 3 meters per second, classifying it as a low explosive. In fact, when it burns in the open air, black powder's heat and gas dissipate quickly. The key to firework's success is to trap the heat and gas in the bottom of the shell, which is positioned in a launch tube or mortar, until the trapped gas pressure builds to such a force that, when it escapes, it hurls the firework high into the air.

A firework is ignited by lighting the main fuse. That simultaneously starts both the

	Color	**Compound**	**Wavelength (nm)**
	**red**	**strontium salts, lithium salts** **lithium carbonate, Li_2CO_3 = deep red** **strontium carbonate, $SrCO_3$ = bright red**	**650**
	**orange**	**calcium salts** **calcium chloride, $CaCl_2$**	**670**
	**yellow**	**sodium salts** **sodium chloride, NaCl**	**610-620**
	**green**	**barium compounds + chlorine producer** **barium chloride, $BaCl_2$**	**590**
	**blue**	**copper compounds + chlorine producer** **copper(I) chloride, CuCl**	**500-535**
	**purple**	**mixture of strontium (red) and copper (blue) compounds**	**420-460**
	**silver**	**burning metallic aluminum, titanium, or magnesium**	**all**

fast action fuse, which quickly carries the flame down to the lift charge, and the time delay fuse, which continues to burn upward toward the cardboard compartments containing the stars, even as the firework is hurtling skyward.

Fireworks are classified as both a low and a high explosive. The initial lift charge that sends the firework into the sky is a low explosive. The burning charge undergoes rapid decomposition, but not detonation. The firework can be thought of as flying through the air powered by a fast burning wick. Where the wick ends, it meets the high explosive components of the firework. In this second stage there is an instantaneous detonation producing both a loud explosion and a bright flash of color.

The black powder lift-charge is calculated to exhaust itself precisely when the slow-burning, time-delay fuse reaches the first compartment packed with light-producing stars and black powder. This happens when the firework is at the very apex of its upward flight. Simultaneously the fuse sets off sound-producing explosives and detonates the stars, initiating color emission. If the timing of the fuses is off, however, the firework may detonate early, too close to the ground, or late, when the firework is falling back to earth.

Chemistry of Fireworks

The sights and sounds of each explosion are the result of several chemical reactions – oxidations and reductions – taking place within the firework as it ascends into the sky. Oxidizers produce the oxygen required to burn the mixture of reducing agents and to excite the atoms of the light-emitting compounds. Various oxidizers are used in both the black powder and the stars. Commonly used oxidizers are nitrates, chlorates, and perchlorates. The reducing agents, sulfur and carbon, combine with the oxygen from the oxidizers to produce the energy of the explosion.

The most commonly used oxidizers are nitrates, the major component of black powder. Nitrates are composed of nitrate ions (NO_3^-) with metal ions. The most common oxidizer is potassium nitrate, which decomposes to potassium oxide, nitrogen gas, and oxygen gas.

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

When reacting, nitrates release two of their three oxygen atoms. Because the oxidation does not result in the release of all available oxygen, the reaction is not as vigorous as that of other oxidizers and is more controlled. This is why nitrates are used as the major component of black powder. In fireworks their main purpose is to provide the initial thrust to power the package into the sky and to ignite each bundle of stars. Instead of nitrates, chlorates or perchlorates are usually used in star explosions, because their reactions produce a temperature high enough to energize many of the more colorful metal salts.

The oxygen released by nitrates and other oxidizers in the star compartments immediately combines with the reducing agents to produce hot, rapidly expanding gasses. The most common reducing agents are sulfur and carbon (charcoal) – standard components of black powder – which react with oxygen to produce sulfur dioxide and carbon dioxide respectively:

$$O_2(g) + S(s) \longrightarrow SO_2(g)$$

$$O_2(g) + C(s) \longrightarrow CO_2(g)$$

The reactions that produce these gases also release a great deal of heat energy, so no only are the gases produced rapidly, they are hot and rapidly expanding gases. This adds to the explosive force of the reaction.

Firework Safety

Fireworks are used so frequently today in celebrations that it is easy to forget that they are dangerous explosives. Every year more than 8,000 people in the U.S. suffer injuries caused by the personal use of fireworks. Nearly half of the victims are children. A third of the injuries are caused by illegally obtained fireworks, and burns account for half the injuries. (An ordinary sparkler burns at a temperature of more than 1000°C!)

The National Fire Protection Association (*www.nfpa.org*) enforces stringent safety regulations for large fireworks displays. Spectators must be kept at least 840 feet from the launch area (that's based on the height and burst diameter of the largest shells). Shells may not be launched if winds are stronger than 20 miles per hour, because they could be blown off course. Nevertheless, many accidents occur with unregulated, informal neighborhood displays, when spectators attracted to the activities stand dangerously close to the launch area.

Fireworks manufacturers also go to great lengths to ensure safety, but even so, more than 20 workers were killed in firework plants in the U.S. between 1970 and 1995. Safety regulations require that buildings be separated by concrete blast walls and that roofs be weakened to ensure that any explosion travels upwards rather than outwards. In addition, most fireworks are still made by hand because metal machinery could produce sparks or static electricity which would ignite the explosives.

Many animals are terrorized by the noise of fireworks, and people are urged to leave their pets at home when they go to fireworks displays. Sadly, there are reports of dogs that have run away from the noise, and some were lost.

Wisconsin Initiative for Science Literacy

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