Fireworks are one of the most spectacular outdoor shows. They produce amazing bursts of colors that take a variety of shapes. But how do they work? How do they burn into so many colors and patterns? And why, if not handled properly, can they cause serious injuries or even death?

**What’s inside a firework?**

The source of most fireworks is a small tube called an aerial shell that contains explosive chemicals. All the lights, colors, and sounds of a firework come from these chemicals.

An aerial shell is made of gunpowder, which is a well-known explosive, and small globs of explosive materials called stars (Fig. 1). The stars give fireworks their color when they explode. When we watch fireworks, we actually see the explosion of the stars. They are formed into spheres, cubes, or cylinders that are usually 3–4 centimeters (1–1½ inch) in diameter.

Figure 1. Structure of an aerial shell. The black balls are the stars, and the gray area is gunpowder. The stars and the powder are surrounding a bursting charge, which also contains black powder.

Each star contains four chemical ingredients: an oxidizing agent, a fuel, a metal-containing colorant, and a binder. In the presence of a flame or a spark, the oxidizing agent and the fuel are involved in chemical reactions that create intense heat and gas. The metal-containing colorant produces the color, and the binder holds together the oxidizing agent, fuel, and colorants.

At the center of the shell is a bursting charge with a fuse on top. Igniting the fuse with a flame or a spark triggers the explosion of the bursting charge and of the entire aerial shell.

**How fireworks explode**

The explosion of a firework happens in two steps: The aerial shell is shot into the air, and then it explodes in the air, many feet above the ground.

To propel the aerial shell into the air, the shell is placed inside a tube, called a mortar, which is often partially buried in sand or dirt. A lifting charge of gunpowder is present below the shell with a fuse attached to it. When this fuse, called a fast-acting fuse, is ignited with a flame or a spark, the gunpowder explodes, creating lots of heat and gas that cause a buildup of pressure beneath the shell. Then, when the pressure is great enough, the shell shoots up into the sky.

After a few seconds, when the aerial shell is high above the ground, another fuse inside the aerial shell, called a time-delay fuse, ignites, causing the bursting charge to explode. This, in turn, ignites the black powder and the stars, which rapidly produce lots of gas and heat, causing the shell to burst open, propelling the stars in every direction.

During the explosion, not only are the gases produced quickly, but they are also hot, and they expand rapidly, according to Charles’ Law, which states that as the temperature of enclosed gas increases, the volume increases, if the pressure is constant (Fig. 1). The loud boom that accompanies fireworks is actually a sonic boom produced by the expansion of the gases at a rate faster than the speed of sound!

If the stars are arranged randomly in the aerial shell, they will spread evenly in the sky after the shell explodes. But if the stars are packed carefully in predetermined patterns, then the firework has a specific shape—such
Fireworks’ safety

Fireworks are a lot of fun to watch, but they are illegal in some states. The illegal amount of fireworks—which include the “every sock” and “M-80”—can be found in some stores or on the black market. In some states, it is illegal to purchase fireworks if you are not a resident of that state. Also, regulations require that consumer fireworks are only allowed in some states on the Black Market and in some counties in the United States. Some fireworks contain more than the limited amount of 5 milligrams. For this reason, they are illegal in some counties in the United States. Some fireworks contain more than the limited amount of 5 milligrams. For this reason, they are illegal in some counties in the United States.

Knowing the rules and regulations is important. According to Conkling, fireworks that are publicly available in stores are legally available in 41 of the 50 U.S. states. So, you may not be able to purchase fireworks in your state does not allow it. Also, regulations require that consumer fireworks should have no more than 50 milligrams (about 1/500th of an ounce) of gunpowder. This may seem like a tiny amount, but it can cause serious injuries. “You would be surprised by how powerful these fireworks can be,” says Doug Goyen, president of Zambelli Fireworks, one of the largest fireworks companies in the United States.

More often, light from fireworks is produced by luminescence. When fireworks explode in the sky, the gunpowder reactions create a lot of heat, causing the metallic substances present in the shell into the air and the debris to disperse in the air. The timing of the two fuses is important. The fast-acting fuse ignites first, propelling the shell into the air, and then the time-delay fuse ignites to cause the aerial shell to explode when it is high in the sky.

The fast-acting fuse ignites first, propelling the shell into the air, and then the time-delay fuse ignites to cause the aerial shell to explode when it is high in the sky. If the shell is not high enough, the shell will not emit light. These metallic substances are actually metal salts, which are dispersed in the air.

Fireworks are a lot of fun to watch, but they should be handled with great care because they can be dangerous. “When using fireworks, care even more damage. Also, regulations require that consumer fireworks should have no more than 50 milligrams of gunpowder. This may seem like a tiny amount, but it can cause serious injuries. “You would be surprised by how powerful these fireworks can be,” says Doug Goyen, president of Zambelli Fireworks, one of the largest fireworks companies in the United States.

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Despite people's attention to safety, accidents still happen. Most injuries are caused by the mishandling of firecrackers. When they burn, they can reach temperatures of up to 1,000 °C (1,800 °F). Many people, especially children, are burned by them.

Accidents involving fireworks occur every year. They cause field and house fires and result in injuries and deaths. Many of the accidents involve young people. For instance, in 2009, a 17-year-old boy in Latrobe, Pa., lost his right hand and leg after an M-80 firework exploded in his lap.

Another case involved teenagers who were playing with fountain fireworks—aerial fire-works that shoot up tall fountains of sparks—on the front porch of a duplex home in St. Paul, Minn., when a fire broke out. The flames burned through the second floor and reached the roof, resulting in nine people being displaced from their homes.

Because of the danger associated with consumer fireworks, the American Academy of Pediatrics recommends that children and young adults avoid them altogether and attend local aerial fireworks demonstrations instead. Taylor says watching aerial fireworks can be very moving. “One of the grandchil-dren of the founder of Zambelli Fireworks was known for saying, ‘Grandpa, I like your fireworks because I can feel them in my heart,’” he says. “That’s so true! It’s really an emotional experience.”

How did you become a pyrotechnic chemist?

I was interested in all kinds of science as a child, and eventually, chemistry became my focus. I went to graduate school at Johns Hopkins University, Baltimore, Md., to pursue a Ph.D. in physical organic chemistry. The topic of my thesis (unusual reaction mechanisms involving “nonclassical” pathways) doesn’t have much to do with what I do now, but it taught me the discipline of doing research and recording observations.

In 1969, I went on to teach undergraduate chemistry at Washington College, Chestertown, Md., which is where I pursued my undergraduate studies. Soon after that, I was approached by a fireworks company that wanted to hire me for a side project on developing chemical compositions for fireworks that are safe to carry and store. I became really interested in the chemistry of fireworks.

Later, the U.S. Army asked me if I was interested in working on some military pyrotechnic applications involving the production of brightly colored smoke for signaling purposes, and my pyrotechnic chemistry career shot off. Nowadays, I do training seminars for people interested in anything that explodes—from people who design and manufacture fireworks to people who dispose of bombs.

How do you make sure that fireworks are safe?

Mainly, you don’t want compounds that explode as they fall on the ground. It’s important to develop stable compounds that ignite only in the sky. Fireworks were invented hundreds of years ago, and we have learned through the centuries to avoid certain chemicals and mixtures that are too easy to ignite accidentally. There is also a big push now to make fireworks as environmen-tally friendly as possible.

Do you have any advice for students who want to become pyrotechnic chemists?

Take as many chemistry and physics classes as you can while in school. These classes will give you the background you need to understand the chemical reactions that take place in fireworks and other pyrotechnic devices. Also, don’t experiment on your own with explosive materials! There are many easy ways to make explosives, but that does not mean they are safe.

—Christen Brownlee

SELECTED REFERENCES


