ChemHistory

Chemistry of the Lightbulb

Still a Bright Idea

By Brian Rohrig

With the flick of a switch, we are instantly bathed in visible light. When the power goes out and we scramble for candles and a flashlight, we realize how much we rely on the electric lightbulb. Few inventions have changed our lives as much as this remarkably simple, yet ingenious device.

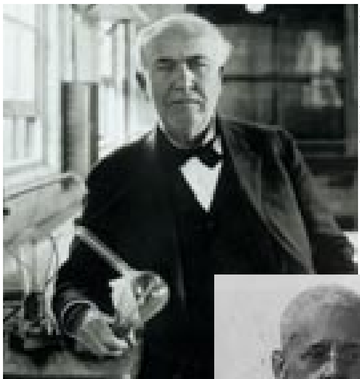
The fact is, we rely on the electric lightbulb. Few inventions have changed our lives as much as this deceptively simple, yet ingenious device.

With the flick of a switch, we are instantly bathed in visible light. When the power goes out, we scramble for candles and matches. But the charm of glowing firelight soon wears off, especially when sports events or homework are in the plans.

Edison's invention

Although Thomas Edison was not the first person to patent an electric lightbulb, he made so many improvements on its design that history generally gives him the credit. Without Edison's improvements, lightbulbs would last about as long as candles. In 1879, he constructed a lightbulb that glowed continuously for 40 hours, but he was determined to do better than that. By the end of 1880, his 1500-hour lightbulb was ready for public sale. A mere 25 years later, his electric bulb had forever transformed human life by illuminating homes and cities all over the world.

PHOTO ABOVE: PHOTODISC



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Thomas Edison

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Lewis Howard Latimer

These first lightbulbs were *incandescent*, as are most of the lightbulbs in your home today. Incandescence is the property of giving off visible light when heated. The hotter the object, the more energetic the light that is given off.

As you have probably observed, a piece of metal glows if its temperature gets high enough. As the temperature increases, the color of the emitted light changes from dull red, to orange, and at about 5800 °C, to white. A typical incandescent lightbulb operates at a temperature of about 2500 °C, where it glows with a yellow-white light.

Finding just the right filament was not an easy task. Using a simple trial-and-error approach, Edison experimented with thousands of different types of filaments. He was looking for one that would be both long-lasting and affordable.

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Although we talk about glowing lightbulbs, the actual glow comes from only one bulb component—a very thin wire called the filament. A typical 60-watt bulb contains about 2 meters of very thin tungsten wire only about 25 micrometers (1/1000 inch) thick. Look very closely at a clear unlit bulb, and you'll see that the filament is tightly wound into a double coil.

The first breakthrough came when Lewis Howard Latimer, the only African-American member of the Edison research team, developed an improved carbon-based filament that yielded an extended glow. He went on to design efficient production methods for manufacturing them in commercial quantities at reasonable cost.

Cost was a significant consideration for the lightbulb to catch on with the public. For example, Edison's team experimented with long-lasting platinum but rejected it for its price tag.

In 1910, William Coolidge of the General Electric Company developed a tungsten filament that is still in use today. Tungsten metal, with a melting point of about 3680 °C, proved to be both affordable and long-lasting.

How does a lightbulb light?

When electric current follows the metal pathway through an incandescent lightbulb, a tremendous amount of resistance is encountered as the electrons make their way through the very thin wire filament. Similar to students in a crowded lunch line, closely packed electrons generate friction—and that, in turn, produces heat. The thinner the wire, the more resistance the electrons encounter as they attempt to pass through. More resistance generates more heat until the wire reaches a high enough temperature to produce visible light.

Lightbulbs "burn out" when the filament breaks. At high temperatures, the tungsten metal, like other metals, *sublimes*. Sublimation is a process by which a solid is converted directly into a gas without first passing through a liquid phase—like old trays of ice cubes shrinking in your freezer.

In lightbulbs, the sublimated tungsten atoms are still sealed inside with nowhere else to go. Examine a burned-out lightbulb and you'll see a tungsten deposit on the interior surface of the glass—clearly visible as a black spot on top of the bulb. Even with its low sublimation rate at high temperatures, the tungsten filament finally wears thin and breaks. As a result, the circuit is broken. When the metal pathway breaks, electrons stop flowing, and the lightbulb ceases to glow.

Finding the right filament was only one hurdle for the early inventors. The second big problem came from the surrounding air—specifically oxygen.

We talk about "burning" lightbulbs, but the fact is that the filaments inside successful bulbs glow *without* burning. Edison found that for many filaments, the presence of oxygen caused the hot material to rapidly combust and break. Since glowing doesn't require any oxygen, Edison's early lightbulbs consisted of filaments mounted in a vacuum.

Although the vacuum solved one problem, it created another. Without any gas exerting pressure on the filament, the rate of sublimation increased. The tungsten atoms of the solid filament readily entered the gas phase at the high temperatures within the glowing bulb.

Argon to the rescue

With the discovery of the noble gas argon in 1894, it became possible to lengthen the life of a lightbulb by filling it with this very unreactive gas. Not only did argon offer an oxygen-free filler, it also controlled the sublimation rate of the filament by transferring some of the excess heat away from the glowing metal.

The transfer process is called convection. As atoms of argon bump into the hot filament, some of the kinetic energy of the tungsten atoms is transferred to the argon atoms. This transfer cools the filament and heats the argon. The argon atoms then speed off to collide with the inner wall of the glass bulb. Upon impact, the argon atoms transfer some of their kinetic energy to the glass, raising its temperature.

In the process, glowing incandescent light bulbs become blistering hot. In fact, about 90% of the electrical energy consumed by an incandescent lightbulb is dissipated as heat.

Krypton would be a better noble gas to use in a lightbulb than argon, since it is a poorer conductor of heat. But krypton is very expensive. The only place to get krypton is from the atmosphere, where its concentration is only about 1 part per million (ppm). By contrast, argon comprises nearly 1% of the atmosphere, making it 10,000 times more abundant than krypton.

Krypton is usually used to fill small flashlight bulbs. Because argon-filled bulbs readily transfer energy away from the glowing filament to the glass, batteries drain rapidly in the process. But when poorer-heat-conducting krypton fills the space, the bulb feels cool to the touch even after extended use, and batteries last longer.

Extended-life bulb

An extended-life lightbulb contains a much longer filament. As a result, there is more surface area to dissipate the heat. The filament does not get as hot and does not sublimate as quickly.

The drawback is that the light produced by the extended-life bulb is dimmer and redder. It takes a higher wattage to produce the same amount of light as a typical incandescent bulb. Wattage refers to how much energy is used per second. So, even though they last longer, extended-life bulbs may not really be a bargain. They actually cost more money due to the greater wattage required to operate them.

Heat lamp bulb

A heat lamp is essentially an incandescent bulb with a very long filament. The filament has a long life and glows a dull red color. The cooler filament emits most of its energy as longer-wavelength infrared light, which cannot be seen but will still heat up objects on which it falls. The globe of the bulb is very large; this increased surface area allows it to radiate more heat. This design makes the heat lamp very practical, since its intended purpose is to give off heat, not light.

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Fluorescent lamps

Since all incandescent bulbs give off a great deal of heat, cool fluorescent lamps offer a much more efficient alternative. Introduced in the 1950s, they soon became widely accepted for nearly all schools, offices, and commercial buildings.

Fluorescent lamps consist of a sealed glass tube containing a mixture of noble gases and a few drops of mercury that vaporize within the tube. When an electric current passes through the gas in the tube, some of the electrons of mercury become excited. Excitation occurs when electrons absorb energy and temporarily achieve a higher energy level. As they return to ground state, the energy previously absorbed by the electrons is primarily released as ultraviolet (UV) light, a light with shorter wavelength and greater energy per photon than visible light.

Because UV light is invisible to humans, the fluorescent lamp must convert it into visible light. This is accomplished by the white phosphor coating on the inside of the bulb. When UV light strikes this phosphor coating, it is converted into visible light. Thus, unlike incandescent bulbs, fluorescent lamps do not give off light by heating any of their components. That makes them much more energy-efficient.

If you have a UV-sanitizing cabinet for goggles in your classroom, examine the bulb inside. It will resemble a typical fluorescent bulb, but with one big difference. It's transparent. The lack of a phosphor coating means that the bulb emits UV light, with very little visible light. It is this UV light that kills microorganisms and sterilizes your goggles.

Halogen bulb

Halogen bulbs, another type of incandescent bulb, produce intense white light. They are commonly used in car headlights, floodlights, and other applications where very bright light is needed. Halogen bulbs, as their name implies, contain the vapor of a halogen (group 17 on the periodic table), usually bromine or iodine. The halogen molecules act as chemical scavengers, picking up stray tungsten atoms that have sublimed and depositing them back on the filament. The unique ability of the halogen atoms to combine with tungsten atoms means you're not likely to find black spots on the inside of the bulb. However, the filament of the bulb eventually breaks due to uneven deposition of tungsten atoms on the filament.

Since the filament lasts much longer, halogen bulbs are designed to glow several hundred degrees hotter than a typical incandescent lightbulb. Generating intense heat, halogen lamps have been known to cause fires. Homeowners must take care to keep the lamps away from draperies and other combustibles. Furthermore, since halogen bulbs give off so much heat, their energy efficiency gets low marks.

Neon lights

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Neon signs are similar to fluorescent lamps, except that they contain no mercury or phosphor coatings. A mixture of neon and other gases within the tube gives off colored light when the electrons are excited by an electric current.

Light-emitting diodes

Eventually, both incandescent and fluorescent bulbs may give way to light-emitting diodes (LEDs). The indicator lights on computers and the numbers on digital alarm clocks utilize LEDs—light sources based on the properties of semiconductors such as silicon. For an explanation of how these durable devices operate, see "Light-Emitting Diodes—Tune in to the Blues" in the April 2001 issue of *ChemMatters*.

TRY THIS!

Can you assemble these three familiar items correctly so that the light bulb lights? You'll need a 12-inch piece of insulated wire with exposed metal at each end, a C or D-cell power source, and a flashlight bulb.

If you succeed on the first try, you are a shining example to us all! A well-known video distributed to educators by the Private Universe Project in 1989 shows recent Harvard and Massachusetts Institute of Technology (MIT) grads struggling with the challenge. In the video, one frustrated individual exclaims, "I'm a mechanical engineer, not an electrical engineer!" (Private Universe Project, *A Private Universe* [Videotape], Harvard-Smithsonian Center for Astrophysics: Cambridge, MA, 1989)

The answer appears on page 20.

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Brian Rohrig teaches chemistry at the Eastmoor Academy in Columbus, OH. His most recent article for *ChemMatters*, "Matches—Striking Chemistry at Your Fingertips", appeared in the December 2002 issue.

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