By A. H. Drummond, Jr.

Tired of switching from your regular glasses to sunglasses every time you go outdoors? Consider photochromic glasses. When you walk out into bright sunshine, the lenses automatically darken and function as sunglasses. When you enter a building or when the sun sets, the process reverses, and the lenses clear. Just as amazing is that the lenses work by a reversible chemical reaction that is capable of continuing indefinitely, with no loss of activity.

Silver halides

Photochromic glass, glass that darkens in response to light, relies on the light sensitivity of a class of compounds known as silver halides that are dispersed within the glass. (Halides are compounds of fluorine, chlorine, bromine, or iodine). This is the same family of compounds that is used to make photographic film, and the chemical reactions are much the same. However, once photographic film has been darkened by exposure and developing, it can't be reversed (see box "Dark crystals"). The silver halide dispersed in photochromic glass, however, will decompose and reform indefinitely.

Glass is an amorphous substance; that is, it lacks a distinct crystalline structure. It consists of silica (from sand) and a variety of additives. Silica contains subunits of silicon and oxygen that are shaped like a tetrahedron, a pyramid with four equal, triangular faces. Silica, like water, is a powerful solvent. For example, stained glass is made by dissolving metal ions, such as cobalt (blue), chromium (green), or nickel (yellow), in molten glass. Much like sugar dis-

Dark crystals

The basic unit of both sand and glass is a tetrahedron (triangular pyramid, right) that consists of a silicon atom (solid circle) covalently bonded to four oxygen atoms (open circles). Each tetrahedron is joined to others by sharing a common oxygen atom. In sand, the tetrahedrons are arranged in an orderly, crystalline pattern but in glass, an amorphous substance, they are jumbled and disordered.

Photogray glass contains crystals of silver chloride trapped between the silica tetrahedrons.

When the glass is clear, these crystals do not block visible light (top ray in illustration), but they do absorb shorter-wavelength ultraviolet light (not shown). The energy of the ultraviolet light liberates atoms of chlorine and silver.

$$Ag^{+} + Cl^{-} + \text{light} \rightarrow Ag^{0} + Cl^{0}$$

To keep the reaction from immediately going in reverse, a few ions of Cu^{+} are present within the silver chloride crystal to react with the liberated chlorine atoms.

$$Cu^{+} + Cl^{0} \rightarrow Cu^{2+} + Cl^{-}$$

The silver atoms migrate to the surface of the silver chloride crystal and aggregate into small, colloidal crystals of silver metal. Some of the electrons within the metallic silver are mobile (unlike the electrons in silver chloride, which are fixed), and this permits them to interact with

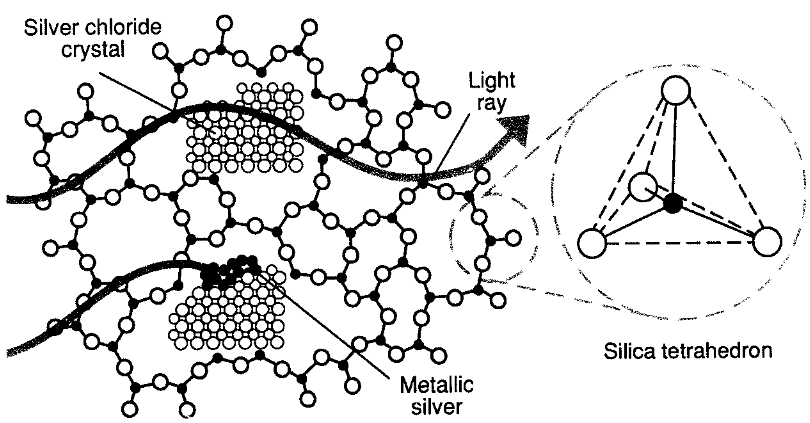
AUTOMATIC SUNGLASSES

the electrical vibrations of light rays. As a result, they absorb visible light (bottom ray in illustration) and make the lens appear dark.

When the sunglasses are brought indoors the Cu^{2-} ions slowly migrate to the surface of the crystal where they accept an electron from the silver.

$$Cu^{2+} + Ag^{0} \longrightarrow Cu^{+} + Ag^{+}$$

The silver ion rejoins the crystal of silver chloride and the darkening fades.



solving in water, the amount of additive that dissolves varies with the temperature. The solubility of silver halide is considerably higher at the melting temperature of glass than it is at room temperature. Consequently, when photochromic glass is cooled, silver halide crystals precipitate out of solution, just as sugar will crystallize as hot, saturated sugar-water cools. When the conditions are controlled properly, the silver halide crystals are too small to absorb rays of visible light, but are large enough to absorb ultraviolet rays.

Darkening and clearing

When a glass containing AgCl is exposed to sunlight containing ultraviolet wavelengths, the ions in the microcrystals of AgCl (actually an ionic lattice consisting of Ag^{+} and Cl^{-} ions) exchange electrons, producing free atoms of silver and chlorine.

$$Cl^{-} + \text{light} \longrightarrow Cl^{0} + e^{-}$$

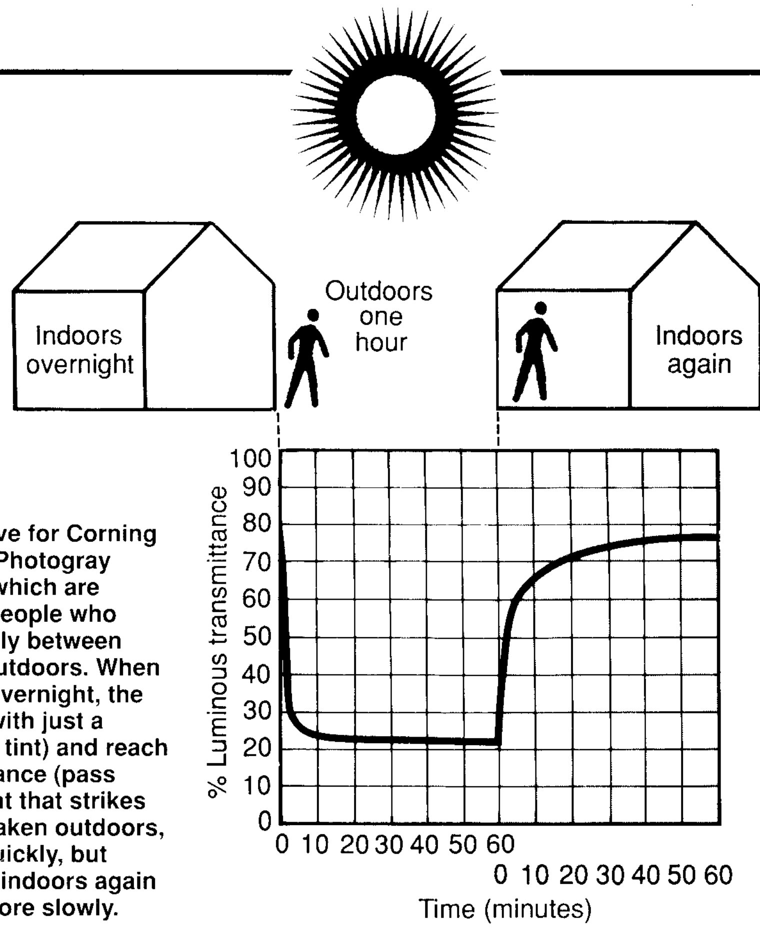
$$Ag^{+} + e^{-} \longrightarrow Ag^{0}$$

The silver atoms then cluster together to form minute particles of silver, and these particles absorb and reflect light and darken the lens. When a person goes indoors and the glass is no longer exposed to the activating ultraviolet light, the silver colloid splits apart into free silver atoms. Then, in an indirect way (see box "Dark crystals"), the silver atoms effectively exchange electrons with chlorine atoms in the reverse of the reaction above, and the original silver chloride microcrystals are reformed.

$$Ag^{0} \longrightarrow Ag^{+} + e^{-}$$

$$Cl^{0} + e^{-} \longrightarrow Cl^{-}$$

It is interesting to compare the

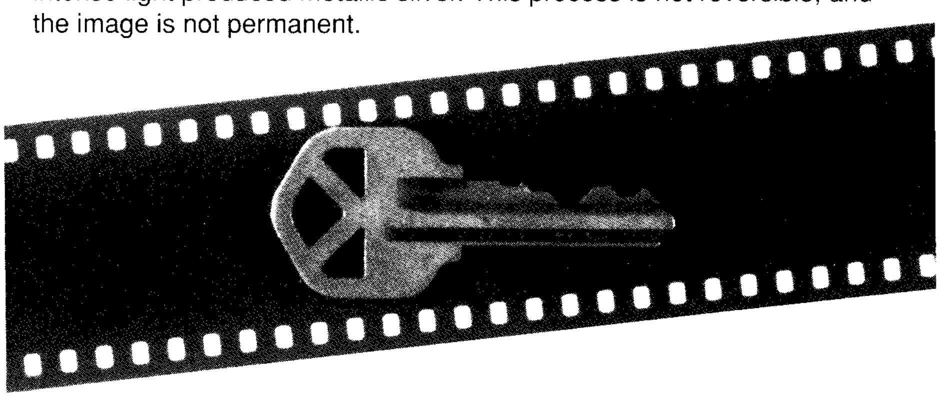


Response curve for Corning Glass Works' Photogray Extra lenses, which are designed for people who move frequently between indoors and outdoors. When kept indoors overnight, the lenses clear (with just a slight residual tint) and reach 85% transmittance (pass 85% of the light that strikes them). When taken outdoors, they darken quickly, but when brought indoors again they lighten more slowly.

Negative image

In photographic film, the silver halide crystals, or "grains" as they are normally called, are invisibly small (diameter less than 10^{-6} m), yet each contains about 10^{12} ions of silver. When a photon of light strikes the crystal, a silver ion is reduced to an atom of silver metal. When enough atoms are produced, they clump together and form a crystal of metallic silver that appears black. This is basically the same as the darkening of photochromic glass but, in film, the process is not reversible. (The chlorine atoms are removed by an irreversible reaction with the gelatin in the film base).

You can demonstrate the darkening process with ordinary black and white film. Working indoors in a dimly lighted room, unroll a strip of film about six inches long and cut it from the roll. Keep the film in your own shadow as you take it outside, place it on the ground, weight down the ends, and place a key (or other small object) on top. Step aside to expose the film to full sunlight for about 15 minutes. Shade the film again, then carry it back inside. You will see a negative image of the key where the intense light produced metallic silver. This process is not reversible, and the image is not permanent.



darkening and clearing behavior of photochromic glass with the way light passes through ordinary clear glass. Ordinary glass has a "transmittance" of about 92%. This means that 92% of the light that strikes the glass passes through it; 8% is reflected or absorbed. Corning Glass Works' Photogray Extra lenses have 85% transmittance when fully cleared. When exposed to sunlight for a few minutes, the lenses darken and pass only 22% of the light. When the lens wearer returns indoors, the transmittance increases to 63% in the first five minutes, after which the lenses clear more gradually.

Future photochromics

Imagine yourself in an airliner flying south early in the morning. You are seated next to a window on the east side of the aircraft. The early morning sun is so bright you must pull the shade down, thus blocking the view you hoped to enjoy. Or perhaps you are in an office that faces west on a sunny afternoon. The glare from the sunlight streaming through the windows is so intense you must drop the shades, plunging the room into a depressing gloom. Or on a beautiful summer day, you have trouble driving your car because of the road glare.

Can such problems be solved with photochromic glass? Yes! This unique glass is now used in sunglasses, but as the cost comes down, you can expect to see it in cars, windows, and dozens of other applications.

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References

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