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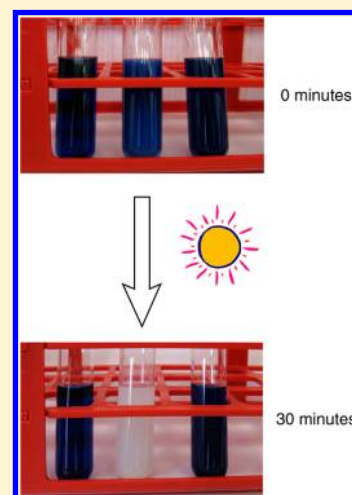
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A Simple Demonstration of Photocatalysis Using Sunlight

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ABSTRACT: A simple demonstration of photocatalysis is presented. The demonstration is visual, simple to perform, and could easily be modified into a laboratory experiment. The mechanism of dye degradation by the photocatalyst is also discussed. In addition to illustrating a photocatalytic reaction, it is also an example of the reduction and oxidation of organic compounds and experimental design that link the catalysis to TiO_2 .



KEYWORDS: Elementary/Middle School Science, First-Year Undergraduate/General, General Public, High School Introductory Chemistry, Demonstrations, Catalysis, Materials Science, Photochemistry

Photocatalysis is the increase in the rate of a light-induced reaction by a catalyst. There are many common examples and applications of this process including self-cleaning glass,¹ water disinfection,² and E Paint, a nontoxic antifoul paint.³ Two applications of photocatalysis that are receiving current attention are the degradation of organic pollutants⁴ and solar-driven splitting of water into oxygen and hydrogen,⁵ which can then be used as a fuel source.⁶ The interest in these two areas of research will become more intense as the world becomes more polluted and the need for noncarbon-based renewable energy sources becomes more pressing. Titanium dioxide (titania or titanium(IV) oxide or TiO_2) is probably the best known photocatalyst, being inexpensive and capable of both splitting water and remediating wastewater.⁷

Demonstrating photocatalysis is difficult to achieve in a classroom or laboratory setting; typically requiring an expensive light source, photoreactor, and either a spectrophotometer to follow the degradation of a colored organic dye⁸ (where the color change might be difficult to distinguish, e.g., methyl orange) or gas chromatograph (GC) instrument to detect H_2 gas evolution⁹ from water splitting. Here we describe a simple demonstration of photocatalysis that has several key advantages for teachers in secondary schools and colleges:

- It can be conducted in a test tube.
- The color change observed in the dye is unambiguous; blue to colorless.
- The reaction is noticeable in five minutes or less and complete color loss occurs in approximately 30 min.

- The light source is natural sunlight (although artificial lighting works as well).

■ DEMONSTRATION

In a typical demonstration using commercially available TiO_2 , it is important to have two controls; one with no photocatalyst to show that sunlight can not degrade the dye on its own and another to have a test tube with a white (the same color as the TiO_2 catalyst) nonphotocatalytically active powder, for example, SiO_2 , to show that the color change comes from the photocatalyst acting on the dye rather than from the powdered sample. A third control can also be included with the photocatalyst added but kept in the dark to confirm that it is the action of sunlight combined with the photocatalyst that causes the color change.

The chemicals used are:

- DCIP (2,6-dichlorophenolindophenol sodium salt hydrate, Fluka/Sigma-Aldrich)
- Glycerol (99+% Alfa Aesar)
- SiO_2 (99.8% Alfa Aesar)
- TiO_2 (~21 nm particle size, Sigma-Aldrich)

DCIP is used as a 0.5 mg/mL of distilled water solution. In a typical demonstration setup, three test tubes are used that contain

- Control 1: 1 mL DCIP, 5 mL water, 0.3 g glycerol, 0 mg of TiO_2

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- Photocatalyst: 1 mL DCIP, 5 mL water, 0.3 g glycerol, 10 mg of TiO_2
- Control 2: 1 mL DCIP, 5 mL water, 0.3 g glycerol, 10 mg of SiO_2

The test tubes are placed in the sun. (Some windows or double glazing systems filter the UV part from the solar spectrum so the samples should be placed in direct sunlight.) The action of sunlight on these samples can be seen in Figure 1, which shows total color loss in the test tube containing the photocatalyst and no color change in the control reactions.

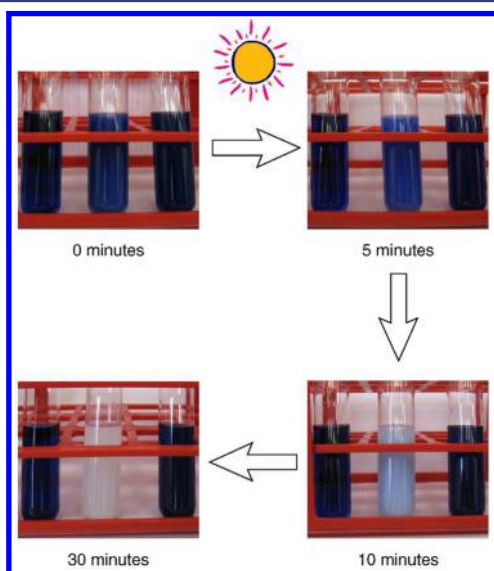


Figure 1. Action of direct sunlight on control 1 (left), control 2 (right), and photocatalyst (middle). Total color loss is observed in 30 min.

The demonstration is simple, inexpensive, unambiguous, and fast. We have also used various artificial light sources and these work well in place of sunlight. However, most artificial light sources do not mimic natural sunlight therefore care should be taken to use a light source with a UV component so as to photoactivate the TiO_2 . Although this is a qualitative demonstration of photocatalysis, it could easily be adapted as a quantitative lab exercise with (or without a spectrophotometer) and nicely complements other photocatalytic practicals, experiments, and demonstrations.^{10–13} The UV–vis spectra of the reaction at $t = 0$ and $t = 30$ min are shown in Figure 2.

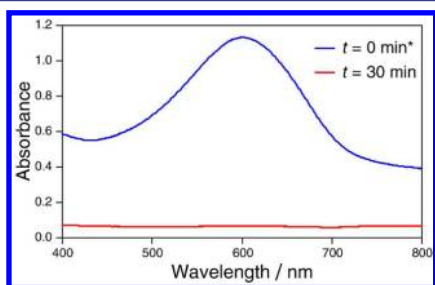


Figure 2. Absorption spectrum of the demonstration at $t = 0$ (*diluted by a factor of 1:5) and $t = 30$ min, in that time the oxidized form of DCIP is reduced.

HAZARDS

DCIP is a dye and will stain skin. Glycerol is irritating to the eyes and SiO_2 is harmful by inhalation and irritating to the respiratory system. Gloves and goggles should be worn and reactions should be prepared in a well ventilated fume hood. If a UV light source is used instead of solar light, appropriate precautions should be taken. UV light can seriously damage the eyes and skin, chronic exposure causing cataracts and skin cancer, respectively.

DISCUSSION

In the photocatalytic reaction, light generates electrons (e^-) and holes (h^+) in the TiO_2 . The electron and holes are prevented from recombining by the presence of a sacrificial electron donor (SED), in this case, glycerol, which is oxidized. This leaves the photogenerated electrons free to reduce the DCIP to its colorless form.¹⁴ A schematic of this process is shown in Figure 3. This is a simplified version of the suggested,

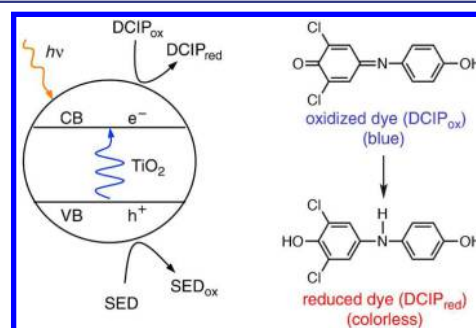
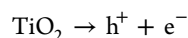


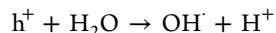
Figure 3. Proposed reaction scheme of the photocatalytic reaction.

complex, full mechanism, in which carbon dioxide and water are the final oxidation products of glycerol via glyceraldehyde, glycolaldehyde, glycolic acid, and formaldehyde.¹⁵

The initial step in this process is the formation of electron–hole pairs in TiO_2 upon irradiation by light of a suitable wavelength.



The holes react with water (from the aqueous solution) to generate hydroxyl groups on the surface of the catalyst.



These then react with glycerol, adsorbed on the surface starting its complicated reaction path.¹⁵ Photogenerated electrons and H^+ are then left to reduce the $\text{C}=\text{O}$ and $=\text{N}-$ groups of DCIP to $\text{C}-\text{OH}$ and $-\text{NH}-$, respectively.

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Notes

The authors declare no competing financial interest.

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