Educational Materials

Green Light for Chemistry

Royal Society Summer Science Exhibition

Summer 2019

www.nottingham.ac.uk/go/photo-electro

Colour Changing Photo-Chemical Reaction

Teacher's Resource

Topic: Photochemical Reaction, chemistry demonstration/ video

Age range: 14-16

Prep time: 10-20 min

Activity time: 15 – 30 min

Description: The following activity is a demonstration for teachers to use to reinforce concepts of chemical reactions and introduce the topic of photochemistry. The demonstration involves a colour changing redox reaction wherein a purple/blue solution turns colourless after exposure to light. The activity includes a student resource (worksheet). Please note if preferred, a link to a video describing the demonstration is provided. (On our YouTube channel "Green Light For Chemistry" or by following this link https://www.youtube.com/channel/UCR5exvJpTNMAeJN494RmaIw/videos).

Aims:

- Demonstrate a reversible oxidation-reduction reaction.
- Introduce light as an energy source for chemical reactions - photochemistry.
- Relate the use of light as an energy source to sustainable chemistry practices.

Link to curriculum:

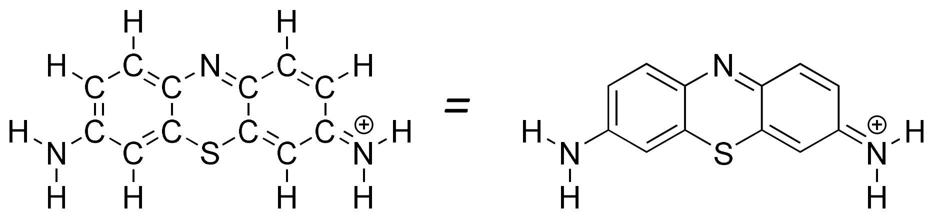
- Chemistry: Chemical Changes – Reactivity of metals
- Chemistry: The rate and extend of chemical change - reversible reactions and dynamic equilibrium
- Chemistry: Using Resources

Extension of curriculum: The idea of light as an energy source for chemical reactions is presented introducing the field of photochemistry. This is reinforced with examples of chemicals that can be made photochemically.

Link to Exhibit at RS Summer Science Exhibition: The "Green Light for Chemistry" exhibit focuses on explaining how light and electricity can be used to make chemical processes cleaner and more sustainable. This is part of a collaborative project called Photo-Electro involving the Universities of Nottingham, Bristol and Southampton. A demonstration on the exhibit will be a colour changing reaction in a reactor called the PhotoVap.

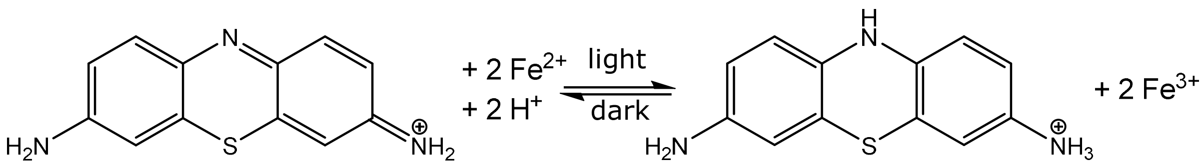
Background:

Thionine can be used as a dye. The chemical structure of thionine is shown below:



On irradiation thionine is reduced by Fe(II) which is simultaneously oxidized to Fe(III). This causes the reaction solution to change from blue/purple to colourless. In the dark the reduced form of thionine is oxidized by Fe (III) back to the blue/purple form so the reaction is reversible. Without the addition of an energy source, light, this reaction would not proceed.

$$\textbf{[Thionine]} + 2Fe^{2+} + 2H^{+} \underset{\text{dark}}{\overset{\text{light}}{\rightleftharpoons}} \textbf{[Thionine-2H]} + 2Fe^{3+}$$



As well as this reaction, many other reactions can proceed using photochemistry. Some examples are the production of the medicines Artemisinin (an anti-malarial) and Ascaridole (a deworming agent). Also photochemistry is used in the production of rose oxide (a perfume) and in the synthesis of other useful chemicals such as caprolactam (used in the manufacture of nylon).

Safety:

Please review the MSDS for all chemicals and complete CLEAPSS assessments, where relevant, prior to beginning any preparation/demonstration.

Apparatus and equipment:

- Beakers (1 L and 600 mL)
- Graduated cylinders (10 mL and 500 mL)
- Light source (i.e. projector light, also a LED from a bright torch works well)
- Aluminium foil

Chemicals:

- Thionin acetate or Lauth's Violet (CAS: 78338-22-4)
- Iron (II) sulphate hydrate crystals (CAS: 13463-43-9)
- Sulfuric Acid, 2 M
- Deionised Water

Preparation:

Prepare a thionine stock solution by dissolving 0.23 g thionin acetate in 1 L deionised water. Stir to dissolve.

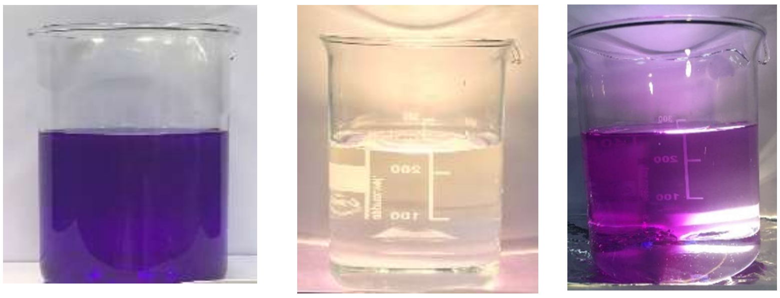
Demonstration Solution – Prepare the demonstration solution in the 600 mL beaker by adding 10 mL thionine stock solution, 1 mL sulfuric acid (2M) and 2 g iron (II) sulphate crystals to 500 mL deionised water. Stir vigorously to combine and dissolve the iron (II) sulphate.

Irradiation of the blue/purple demonstration solution should result in a change to colourless.

Demonstration Procedure:

Place beaker of the demonstration solution above the surface of a light source (i.e. overhead projector, bright LED). Switch on the light until the solution is decolourised. Switch off the light until the blue/purple colour returns. This process can be repeated several times.

It is possible to create a two-toned solution to enhance the visualisation of the reaction. To achieve this, cover half of the beaker with aluminium foil prior to light exposure. Expose the solution to the light until the exposed half decolourises. Switch the light off, and take off the aluminium foil. This should create a two-toned solution where the half with light exposure is colourless while the covered half remains blue/purple. Over time, the colourless half will return to blue/purple.



Photos showing the thionine solution before (*left*) and after (*middle*) irradiation. Two toned solution produced when half of lamp is covered (*right*).

Teaching Tips:

The thionine stock solution may naturally bleach over time. The stock solution can be used for demonstration until the colour change cannot be clearly visualised. The 'demonstration solution' made from the stock should be made fresh for each demonstration. It is advised to make up the demonstration solution several hours before needed and to put the solution through several cycles for reproducible results.

Video: On our YouTube channel "Green Light For Chemistry" or by following this link
https://www.youtube.com/channel/UCR5exvJpTNMAeJN494RmaIw/videos

Answers to student Questions:

1. *Activation Energy* is the energy required to start a chemical reaction.
2. What form of energy is used to change the colour of the solution? *light*
3. What type of resource is this? *Renewable (discussion point)*
4. What type of reaction is occurring? *Photochemical and Redox*
5. What metal is used in this reaction? *Iron*
6. What colour is the solution before light is shown on it? *Blue/purple*
7. What colour is the solution after light is put on it? *Colourless*
8. Is the reaction reversible? If it is, what happens? *Yes, goes blue/purple.*

Bonus:

1. How could we increase the rate of formation of the colourless product?
   Brighter light, Additional acid, increase [Fe^{2+}] present.
2. What is oxidised/reduced at both sides of the reaction?
   In forward reaction, thionine is reduced, Fe is oxidised. Opposite in reverse

References: adapted from H. W Roesky, K. Mockel, 1996. *Chemical Curiosities*. Wiley-VCH.

Colour changing Photo-Chemical Reaction

Student Resource

Background:

As well as using heat to promote chemicals reactions, light can also be used. These type of reactions are called photochemical reactions. An example of a colour changing reaction is the reduction of thionine:

$$\textbf{[Thionine]} + 2Fe^{2+} + 2H^{+} \underset{\text{dark}}{\overset{\text{light}}{\rightleftharpoons}} \textbf{[Thionine-2H]} + 2Fe^{3+}$$

After observing the reaction, try and answer the questions below.

1. ____________ ____________ is the energy required to start a chemical reaction.

2. What form of energy is used to change the colour of the solution?

3. What type of resource is this? (circle correct answer)

   Renewable   Finite

4. What type of reaction is occurring?

5. What metal is used in this reaction?

6. What colour is the solution before irradiated with light?

7. What colour is the solution after irradiated with light?

8. Is the reaction reversible? If it is, what happens?

Bonus:

1. How could we increase the rate of formation of the colourless product?

2. What is oxidised/reduced at both sides of the reaction?

Green Chemistry Videos

Teachers Resource

Topic: Periodic Table of Videos/Periodic Table of Lessons– video and questions

Age Range: 12-16

Timing: 20-30 min (dependent on length of video and time to do questions)

Description: We have put together a playlist of some videos which highlight topics of green chemistry (e.g. biofuels, making chemicals from renewable feedstocks, etc).

More broadly, teachers may be interested by Nottingham's collaboration with the TED-Ed website to produce a Periodic Table of Lessons, https://www.youtube.com/watch?v=9xZU5lJFbos and http://ed.ted.com/periodic-videos.

This website has a series of 118 lessons, each based on one of our videos about a particular element. It can be used as a classroom resource by educators who can edit the questions to suit their own teaching; registration on the site is free. The site is in the process of being updated and questions will be available in the autumn for our most recent videos.

Playlist URL: http://bit.ly/GreenChemPlaylist

Links to: sustainability, periodic table, elements

Link to Curriculum: Using resources

Link to Exhibit at RS Summer Science Exhibition 2019: The "Green Light for Chemistry" exhibit focuses on explaining how light and electricity can be used to make chemical processes cleaner and more sustainable. This is part of a collaborative project called Photo-Electro involving the Universities of Nottingham, Bristol and Southampton. The University of Nottingham has produced a large number of chemistry-related videos, www.periodicvideos.com (also on YouTube), some of which aim to shed light on sustainability issues in chemistry.

List of Videos:

1. **Green Chemistry:** What does the term green chemistry mean to Professor Martyn Poliakoff? Green chemistry is a set of principles to apply to chemical synthesis to make it as efficient as possible while reducing its carbon footprint. One green chemistry principle is in the elimination of waste. The professor gives real life examples of waste elimination and is excited green chemistry is an area of chemistry that the public finds important.

2. **Water bottles and Green Chemistry:** Martyn Poliakoff presents his water bottle collection containing bottles from across the globe. But why does he have so many? He explains that he would like to replace traditional petroleum derived solvents with water. Specifically, he is researching water under high temperature and pressure which will permit organic solvents and water to mix. This is a way towards greener chemistry practices as it eliminates the need for solvents. Teraphalic acid, a component of water bottles, is one product Martyn is researching in High Temperature Water.

3. **Plants & Chemistry:** Travel to a rapeseed field and explore how plants use sunlight to react carbon dioxide and water to produce sugar and oxygen. The professor explains that he is interested in learning about the processes in plants so that he can exploit them in the lab to produce useful chemicals more sustainably. He explains that he is working with many scientists to learn how to use biomass for chemical synthesis.

4. **Bioethanol:** Travel to Brazil and explore bioethanol, car fuel made from the fermentation of sugar. Sugar cane makes sugar by using carbon dioxide and sunlight. When this biofuel is burned in cars, carbon dioxide is released into the atmosphere completing the carbon dioxide cycle; however, the amount of carbon dioxide added to the atmosphere is not increased as it would be with gasoline. Bioethanol is not as efficient as gasoline yet it is just as expensive. Therefore, biofuels are not used as frequently as expected. Could we use a difference source for ethanol production? This video could be the platform for debates about lifecycle analysis and the need for greener chemical processes in your classroom.

5. **Automatic Chemistry:** Learn how chemical reactors are being used for greener chemical synthesis processes. The professor details a recent publication where in line analytics help optimise productivity in an example chemical reaction. He explains how this research helped reduce optimisation time from 84 days to 36 hours! Saving time and reactants is the way of the future to help support our global needs. You're able to see a reactor in action in the Nottingham lab!

6. **Fighting Malaria with Green Chemistry (Artemisinin):** Malaria is a devastating disease. The professor explains how scientists at the University of Nottingham are researching ways of synthesising Artemisinin, an anti-malarial drug, through more efficient and greener processes. Two ways of the greener synthesis of Artemisinin are described.

7. **Wooden Laboratory:** Take a tour of the GSK Carbon Neutral Laboratory at the University of Nottingham. This building was built using sustainable, natural materials, which were purposefully chosen to reduce the environmental impact of the building's construction. Learn unique features that were added to the building's design to help the building run more efficiently.

8. **Carbon Dioxide (Part 1):** The molecular structure of carbon dioxide is explained as well as its properties as a gas, liquid and solid. Experiments are conducted with all three forms of carbon dioxide showing its capabilities in each phase of matter.

9. **Whitening the Taj Mahal:** The Taj Mahal's marble is constantly becoming dirty due to smoke and traffic pollution. There are great efforts to clean the marble; however, in order to best clean the marble you need to understand the composition of the 'dirt'. Therefore, scientists have used a method of patch testing to understand what is causing the Taj Mahal to become dirty. Through their experiments, the components of the dirt were determined and the best way to clean the marble was found to be the way wool is cleaned – with Fuller's Earth (a clay material). The professor goes onto explain the science behind Fuller's Earth's ability to clean both wool and marble.

10. **The Professor is Knighted at Buckingham Palace:** Watch Sir Martyn Poliakoff become a knight and discuss Green Chemistry and its application to an anti-malarial drug with HRH Prince Charles.

11. **Red Sludge:** The professor describes a disaster that occurred in Hungary in 2010 where the red sludge waste from the processing of aluminium escaped from its holding pond. Characteristics of the sludge including its composition, colour and acidity are explained. The professor goes on to describe the danger of the sludge to the water systems. However, he reveals the damage can be reversed, even though it is not an easy task. The video ends with a take home message that large scale processing of minerals needs proper risk management prior to beginning processing. This can be expanded to any project large or small.

12. **Supercritical Fluids:** The professor explains that a supercritical fluid is a highly compressed gas and goes through a demonstration used often in his laboratory for teaching purposes. He goes on to explain that the use of supercritical fluids, particularly carbon dioxide, are important because they are non-toxic. The demonstration shows a video of a cell containing both liquid and gas. As the liquid is heated, it boils causing materials to go from the liquid to the gaseous phase. This causes the density of the gas to increase. At the same time the heated liquid becomes less dense. This occurs until the two phases, liquid and gas, are at the same density leaving you with a gas that has the density which is around half of the density of the liquid. This is called a super critical fluid. The demonstration goes on to show what happens when this heated super critical fluid is cooled.

13. **The Professor on Viagra:** Despite the title, this video is completely innocuous and suitable for children. The professor obtained a pure sample of Sildenafil citrate, the white salt of citric acid also known to many as Viagra, and discusses a few properties of this "blockbuster" drug. The structure and function of Viagra are explained through the use of a molecular structure. Viagra fits in the active site of an enzyme called phosodiesterase (PDE5), an enzyme whose function is to cause contraction of blood vessels. When Viagra is in the active site, it blocks the enzyme’s function allowing blood vessels to stay dilated. Furthering the information on the drug, the use of Green Chemistry is highlighted as Green Chemistry applications were able to reduce the amount of solvent needed to synthesise the drug from 13.5L to 60mL. In addition, the solvents used in the reduced solvent synthesis were more environmentally friendly, showing how there are ways to make the chemicals we need in a more sustainable way.