Teaching Chemistry Using *The Girls with Yellow Hands*

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Abstract: Popular media can be used in the classroom to engage students while teaching chemical principles. The PBS series *The Great War and Shaping of the 20th Century* explores problems with handling hazardous materials without proper precautions. An episode of this series, *The Girls with Yellow Hands*, focuses on female munitions workers in Britain during World War I. The obvious danger when working with munitions is the constant threat of explosion; however, a more insidious problem resulted from long term exposure to trinitrotoluene, commonly known as TNT. TNT poisoning causes the skin to become yellow and hair to become discolored. Other indications of TNT poisoning include headache and cold-like symptoms. This paper explores the reasons for these effects and discusses how this event in history can be used to facilitate discussions about chemistry and chemical safety in the classroom.

Introduction

One of the biggest challenges for teachers is keeping students interested and focused. Presenting information in many different ways and from different sources helps to keep students engaged. The use of popular media as an educational tool is a way to present real world examples of science and to provide an opportunity for students to critically evaluate situations where science is used in the media.

One of us (JGG) has published papers that demonstrate how to use the movie *Apollo 13* and the related Home Box Office (HBO) series *From the Earth to the Moon* to teach chemical principles [1–3]. As described in these papers, topics such as the scientific method, accuracy and precision, electrolytes, observation, and properties of chemical reactions can be taught using the movie and the HBO series. The explosion in the oxygen tank on Apollo 13 is the source of discussion on the scientific method and how it is applied to determine the cause of the explosion. Apollo12 landed 535 feet from an unmanned Surveyor probe. This can be used to show the accuracy of the landing. During liftoff of the Apollo 12 lunar mission, the rocket was struck twice by lightning, as highlighted in *From the Earth to the Moon*. The rocket exhaust ionized the surrounding air increasing its electrical conductivity, which resulted in the lightning strikes. The fuels and oxidants used in the rockets stimulate discussions about the chemical reactions involved. More recently, the Discovery Channel's series on the elements explained the use of lanthanum oxide to simulate unfiltered sunlight, a technique used during the filming of *Apollo 13* to recreate lighting conditions found on the moon.

Recent papers by Don Wink [4], and by Mark Griep and Marjorie Milkasen [5] explain how other films can be used to teach additional chemistry related topics. *Legends of the Fall* demonstrates the poisonous properties of chlorine gas and *The Rock* discusses sophisticated nerve gas agents. Acid rain, a common way to discuss the acid–base properties of oxide compounds and the reaction of acids with many metals, can be explored using *Dante's Peak*. The biographical film *Edison, the Man* focuses on the discovery and development of the carbon filament light bulb. *Madame Curie* shows how voltammetry was used to detect and quantify radioactivity in uranium ore. *Silkwood*, a movie about plutonium processing, demonstrates the purification of uranium ore.

The application of chemistry in medicine is another theme explored in popular movies. Medicinal Chemistry is the topic of *The Great Moment* and *The Serpent and the Rainbow*, two movies that illustrate the development of ether and other anesthetics for dental and surgical use. Medical breakthroughs are the subject of three movies: *Lorenzo's Oil, Me and Isaac Newton, and Awakenings*. *Lorenzo's Oil* focuses on a nutritional treatment for adrenoleukodystrophy, a progressive degenerative myelin disorder. The treatment, as recreated in *Lorenzo's Oil*, sets up a discussion of intermediate and long-chained fatty acids as well as enzyme inhibition. *Me and Isaac Newton* teaches viewers about a cure for childhood leukemia, and *Awakenings* explains how L-Dopa temporarily revives patients from long-term comas. The preparation of L-Dopa can be used in advanced chemistry courses to demonstrate the importance of asymmetric catalysis in the first commercial preparation of this important medicinal material [6].

Explosive materials are also prominent in popular media. The movie *1776* includes a song with an exchange between John and Abigail Adams. John inquires about a consignment of saltpeter for gunpowder that he expected from Abigail. Abigail replies that John neglected to inform her about how saltpeter is made to which John retorts "by treating potassium chloride with sodium nitrate." In the episode entitled *Arena* of the original *Star Trek* television series, the preparation of gunpowder is shown. *The Alfred Nobel Story* tells the story of the development of dynamite [5].

With these examples in mind, the PBS series *The Great War and the Shaping of the 20th Century* was examined for its potential use as a teaching tool for chemical education [7, 8]. One episode of the series entitled *The Girls with Yellow Hands* is particularly valuable in this regard. The "Girls" described in the title were munitions workers in Britain during World War I. Their long days in the factories were spent packing shells and making bullets, among other duties, to support the war effort. The workers came from mainly working-class backgrounds and many left other jobs as domestic servants or textile employees to work in munitions factories. Some upper-

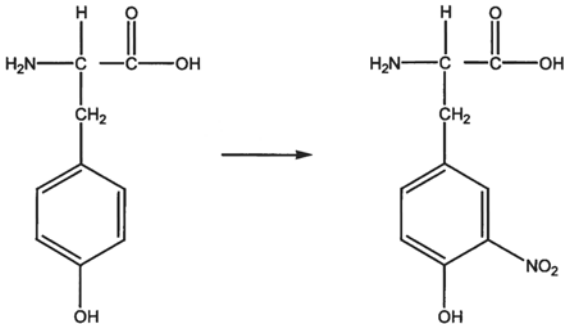

Figure 1. Tyrosine treated with nitric acid produces yellow xanthoproteic acid.

Figure 2. A solution of tyrosine (left) and xanthoproteic acid (right)

class women also joined the workforce as a patriotic contribution to the war effort. In addition to the satisfaction of knowing they were helping their country, munitions work paid much better than other jobs. This allowed many women to earn more money to support their families, while their husbands, fathers, and sons were away fighting on the front lines. The compensation for their work reduced financial stress and improved confidence and independence [7, 9–13].

In addition to these advantages, there were drawbacks to munitions work. Working with explosives was inherently dangerous. During the war, the munitions plants were targets for zeppelin attacks. One unexpected hazard manifested in the discoloration of workers' skin and hair [7, 9, 12, 13]. The yellow skin led to the nickname "Canary Girls." At the time, the condition was referred to as toxic jaundice because of the yellow color of the skin.

Discussion of Chemistry Involved

What causes the yellowing of the skin? Today, the reason for the discoloration is better understood. The protein melanin, containing large amounts of the amino acids tyrosine and tryptophan, is primarily responsible for giving skin its color [14–18]. Compounds such as TNT contain nitro groups (–NO_2) that are known to be part of the nitration of tyrosine and tryptophan causing the melanin to turn yellow [19, 20]. To simulate this result, tyrosine treated with nitric acid produced yellow xanthoproteic acid, as shown in the reaction above (Figure 1). A video clip of the reaction is also available [21].

The image in Figure 2 shows an aqueous solution of tyrosine on the left and the result of the reaction, xanthoproteic acid, on the right. Interestingly, the first published work on the effect of nitric acid upon protein and amino acids was published during World War I by Treat B. Johnson and coworkers [15, 16]. A recent publication described this reaction in more detail [17].

Prolonged exposure to TNT does more than simply cause discoloration in the skin and hair. Additional symptoms of TNT poisoning include headaches, vomiting, and nausea. TNT and similar compounds containing nitro groups and form highly reactive free radicals in the body. Long-term hazards of free radicals are reproductive toxicity, cataracts, mutagenicity, and cancer [19]. The headaches experienced by munitions workers can be attributed to vasodilatation, the expansion of blood vessels, which is another effect of TNT poisoning. Some organonitro compounds cause dilation of blood vessels through the liberation of nitrogen monoxide in the vasculature [19, 20]. Once nitrogen monoxide is present in the vasculature, it signals relaxation and dilation of the arteries allowing for increased blood flow. Nitroglycerin is used to treat heart disease because it is a source of nitrogen monoxide. The mechanism that nitroglycerin, TNT, and other organonitro compound medications are converted to nitrogen monoxide is not well defined and a variety of pathways are possible. One possibility is facilitated by an enzyme, mitochondrial aldehyde dehydrogenase, that plays a role in nitroglycerin's ability to dilate blood vessels. Other possible pathways for utilization of nitroglycerin are currently being investigated [19, 20].

Before the yellowing of the skin and headaches became apparent, the only immediate drawbacks for the munitions workers seemed to be the long work hours and danger of explosion. In retrospect, other more insidious problems were caused by long-term exposure to toxic materials and lack of safety precautions.

Classroom Discussion

The *Girls with Yellow Hands* has been used to address issues of chemical safety in introductory chemistry courses for science and engineering majors, and in introductory chemistry courses for nursing majors. Both introductory courses include students from other disciplines who are taking the course to fulfill a general education science requirement. Students view the *Girls with Yellow Hands* episode either in class or on their own and read information cited in this paper.

Often, students only recognize immediate dangers of a laboratory activity such as strong acids or fire. *The Girls with Yellow Hands* provides a real life example of a safety hazard that did not appear immediately, a slow poisoning. For the women working in the factories, the obvious and immediate danger of explosion was an uncommon occurrence that affected few workers; however, many women became very ill or died as a result of TNT poisoning. Chronic exposure to dangerous materials can easily be overlooked and students need to be educated about the potential consequences of long-term exposure to hazardous materials.

After viewing the episode, students are asked to identify the obvious dangers and hidden hazards in working with munitions. The obvious danger is working with explosive materials, while the hidden danger is TNT poisoning. Related to this theme, students are also asked if they can think of other potentially dangerous careers and work related hazards. The mining industry and working in health care are common responses. In mining, the primary hazard is cave-ins with the hidden danger of developing exposure related conditions such as black lung disease. In health care, the exposure to infected

materials is the obvious hazard, while getting sick from patients is the hidden danger. These discussions focus on the theme of an immediate threat with hidden hazards due to chronic long-term exposure.

Another topic for safety questions is based on what should be done to protect munitions workers, without stopping munitions production. Students glean from the video that better ventilation, personal protection such as gloves, and testing the workers regularly for signs of poisoning are ways to improve safety.

Questions are also asked about the symptoms of TNT poisoning, which include a runny nose, yellowing of the skin, and headaches. This leads to questions of: why the skin turns yellow, what protein in the body and which amino acids are involved, and why this yellowing was called toxic jaundice. The amino acids tryptophan and tyrosine in the protein melanin react with the nitro group from TNT to cause the yellow color (Figure 2). Jaundice is a disease that also causes yellowing of the skin, but not for the same reason as TNT poisoning. Was anything known about the exposure hazard of TNT or similar compounds? The answer is that exposure to similar compounds such as nitroglycerine and dinitrobenzene was known to cause health problems [12, 13].

Finally, one can ask about the reasons that these workers would continue to work in these conditions. Patriotism and the need to, as it was said at the time, "to do their bit" in support of the troops provides the primary answer. The wages were better at munitions factories than in other types of employment available to young women at the time, some of whom needed to support their families. There were also restrictions on the movement of workers to control the labor force [12, 13].

Conclusion

Safety is an important topic to present to students working in a chemistry laboratory environment. Popular media can be used as an aid to teach chemical concepts and safety while keeping students interested and engaged.

The episode *The Girls with Yellow Hands* in the PBS series *The Great War and the Shaping of the 20th Century* provides an historical example of the health hazards experienced by munitions workers during World War I. The munitions workers' hands turned yellow due to exposure to TNT. Additional effects of TNT exposure included cold like symptoms, headaches, sterility, and even death. The clear hazard of working with munitions is the possibility of an explosion, which obscures the hidden danger of long-term exposure. In the classroom, discussion questions based on the episode include what could have been done to improve worker's safety and what was known about the exposure hazard. This paper provides information on what reaction caused the yellowing of skin. The biochemical reactions that yield the cold-like symptoms and headaches are still not fully understood, even though the effects have been observed for over 100 years with a similar compound, nitroglycerine. Critical discussion on this event in history can be broadened and applied to other workplaces.

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