Teaching Chemistry Using the Movie *Apollo 13*

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For more than 30 years the space program has provided inspiration for scientists and engineers. Recently, the movie *Apollo 13* helped bring the space program back to public attention. Apollo 13, the third lunar landing mission, was launched April 11, 1970, at 13:13 CST. Two days after the launch, an explosion in an oxygen tank turned the mission from one of exploration into one of survival. The movie *Apollo 13* deals with the drama of the return of the damaged spacecraft to Earth. During the past two years, this Academy Award-nominated film has been used as a supplement to lecture material for chemistry classes taught by one of us (JGG). Several textbooks also derive examples and problems based on the space program (*1–4*). In addition, John Wiley Publishing has recently released a CD-ROM called *Liftoff*, a tutorial for chemistry using the space shuttle as a theme (*5*). Two papers from this *Journal* by Kelter, Snyder, and Buchar link chemistry education and the space program (*6*, *7*). The examples presented below are used and are based on the movie and other closely related materials (e.g., the book *Lost Moon* [*8*], upon which the movie is based; the PBS documentary *To the Edge and Back* [*9*], which inspired the movie, and material available on the World Wide Web [*10*]). Recently, a similar paper by Hollis, based on using the movie *Jurassic Park*, was published in this *Journal* (*11*).

This paper will deal with these topics that can be related to the movie: what is of interest to a chemist; the process of observation, explanation, and hypothesis development; the conditions resulting in the rupture of the oxygen tank; the fuels and oxidants used; and the lithium hydroxide–containing carbon dioxide filters.

For the first exercise, the students view the movie and compile a list of as many questions about it as they can. They select the 10 most relevant questions that they judge to be of interest to a chemist. This exercise leads them to think about asking questions, identifying problems to be solved, and then trying to answer them. Examples of the questions asked by the students as well as those developed by one author (JGG), are:

> What were the suspected causes of the accident and how was the final theory determined?
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> What happened in the oxygen tank?
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> What energy sources are involved during the flight?
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> How was the carbon dioxide removed from the spacecraft?

Initial Response

One of the first lessons taught in a science course is on observation, developing hypotheses based on these observations, testing these hypotheses, and developing theories. The movie shows the rupture of the oxygen tank and the subsequent explosion that blew away the side of the spacecraft. The question is raised about why such a depiction is in the movie. How do you know that this is what actually happened?

The discussion begins with the observation of the loss of electrical power. What caused this apparent power loss? Our discussion on observation and explanation can now begin. At Mission Control in Houston, the first hypothesis was instrument failure, since the readings contradicted expectations. Aboard the spacecraft, initial hypotheses were also formed. The mission commander, Jim Lovell (portrayed by Tom Hanks), first suspected a prank by fellow astronaut Fred Haise (portrayed by Bill Paxson). A quick glance at Haise dispelled this possibility. Fred Haise then added his observation of the tunnel connecting the command module and the lunar lander bending, and a new hypothesis was formed: the lunar module may have been hit by a meteor. The attempt to seal the tunnel to prevent the loss of atmosphere was unsuccessful. The continuation of life aboard the spacecraft proved that this explanation was not possible.

The working hypothesis at Mission Control requires additional data to determine whether the measuring device is working properly. If the evidence suggests that it is, then one must come up with a new hypothesis, even though it contradicts the expectations. Soon, Jim Lovell made an observation that would show the accuracy of the data sent to earth. A gas was venting from the ship. This could be correlated with the values going down on the tank and could also explain the buffeting of the spacecraft. At this time, the working hypothesis was that a meteor hit the ship, causing an oxygen tank to leak, which in turn caused the damage to the fuel cells. Near the end of the flight, the service module that contained the oxygen tanks could be seen. The observation indicated more extensive damage, which had to be explained. The cause was revealed at the end of the movie when Tom Hanks, during a voice-over, speaks about a damaged coil as the cause of the explosion.

At this point, a discussion is held on the data necessary to reach this conclusion. This discussion goes beyond the scope of the movie and requires creative thought by the students. The history of the tank was investigated, and it was found that overheating had damaged insulation on an electrical heating coil. The damaged wiring in the oxygen tank set insulation ablaze, which expanded the oxygen and caused the explosion. This theory was then tested on earth to determine if the conditions could be reproduced. The conditions *were* reproduced, and the results are the basis for the explosion scene (*10*).

Chemical Reactions

The next topic for exploration is the condition inside the oxygen tank. Based on the previous discussion, it is known that wires were exposed where insulation had been damaged. The question of why it was necessary to stir the contents of the tanks may be addressed.

The oxygen tank contained its material under supercritical conditions requiring stirring to homogenize the contents so reliable readings on the amount remaining could be obtained. The stirring of the tank provided a spark, which ignited the

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Teflon insulation. Insulation should not be flammable. Teflon-coated frying pans do not burst into flames. Why did the insulation catch fire? This is discussed in terms of concentration of a reactant, oxygen, and its effect on a reaction. The high oxygen concentration allowed a reaction to proceed that normally would not. Once the fire started, the oxygen increased in volume as it was converted to gas. This phenomenon can be used to illustrate the volume occupied by a gas relative to other states of matter. As the amount of gas continued to increase within the volume of the service module, the pressure also increased, as expected from the gas laws, until the oxygen blew the side off the spacecraft.

Energy for the spacecraft is one of the most readily appreciated results of chemical reactions. What reactions provide a spacecraft with power? The oxygen tanks provided a reactant needed to operate fuel cells. The fuel cells converted energy obtained from the reaction between hydrogen and oxygen to generate electrical power. The same reaction is used as fuel for the rocket that propelled the spacecraft from earth's orbit to the moon. The energy of this reaction can be obtained chemically or electrochemically.

$$2\,H_2 + O_2 \rightarrow 2H_2O$$

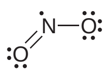
Batteries were also used to supply electrical power. A discussion of the differences between fuel cells using a continuous flow of reactants and batteries with a set amount of reactants can now ensue.

A comparison is made between the nature of the rocket used for lift-off and the small maneuvering thrusters. What fuel and oxidant system is used for each and why? The first stage used a kerosene–liquid oxygen system for maximum thrust. Because the maneuvering thruster did not need great energy output, simplicity of design and operation would be important. The simplest system would have the fuel and oxidant react upon mixing without a requirement for an ignition source. The reactants that satisfy the requirements for this process are a 1:1 mixture of hydrazine and 1,1-dimethylhydrazine and dinitrogen tetroxide. The discussion of this reaction and its materials is used at various times during chemistry courses. First, dinitrogen tetroxide is in equilibrium with nitrogen dioxide. Since nitrogen dioxide is red and dinitrogen tetroxide is colorless, shifting of the equilibrium can readily be observed when the temperature is changed. The Lewis structure of nitrogen dioxide that does not obey the octet rule in this equilibrium can also be correlated with its reactivity.

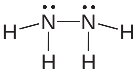
$$N_2O_4 \rightleftharpoons 2NO_2$$

$$2N_2H_4 + N_2O_4 \rightarrow 3N_2 + 4H_2O$$

$$2(CH_3)_2N_2H_2 + 3N_2O_4 \rightarrow 5N_2 + 8H_2O + 2CO_2$$



nitrogen dioxide



hydrazine

This shows a structure–reactivity relationship that is so important. Hydrazine and its structure also provide an example of this relationship. During the discussions of main group chemistry typically found in an inorganic chemistry course, the relative weakness of a nitrogen–nitrogen single bond caused by the lone pairs repulsion on each nitrogen atom is noted. In contrast, the triple bond of dinitrogen is quite stable and provides the driving force for the reaction. The weak nitrogen–nitrogen bond allows for a low activation energy; thus the reaction occurs when the reactants are mixed.

The clearest example of an application of chemistry shown in *Apollo 13* was the use of filters containing lithium hydroxide to remove carbon dioxide. One of the greatest life-threatening problems was the buildup of carbon dioxide in the spacecraft. The problem associated with an increase in carbon dioxide is asphyxiation. Usually, as shown in the news report in the movie, a lack of oxygen was thought to be the problem. In this case, it was not a problem. Plenty of oxygen was available, since stores of oxygen for the planned lunar excursions could be used. Instead, the problem was caused by the buildup of the partial pressure of carbon dioxide. This can lead to a discussion of LeChâtelier's principle and the carbonate buffer found in blood. Fortunately, lithium hydroxide will remove carbon dioxide by nucleophilic attack on the carbon atom. This process is similar to the preparation of acids using carbon dioxide, found in organic chemistry:

$$2LiOH + CO_2 \rightarrow Li_2CO_3 + H_2O$$

This can be related to the common laboratory exercise of storage of sodium hydroxide solutions. Standardized solutions of hydroxide must be kept from the atmosphere for this very same reason. The diffusion of gases is usually thought of as being a fast process. The question is raised of why energy was spent to run a fan to increase the flow of the atmosphere through the filter system. Although gases have relatively large average speeds, the motion is random and is impeded by the other gas atoms. The process would be too slow; thus, the importance of bringing the reactants together is demonstrated.

One goal of this work is to show how applications of chemistry can solve problems involved in activities of space flight. Many other examples can be derived from the movie *Apollo 13.* The movie also illustrates the creative process often lost by students beginning their studies in science. It took time to determine the most likely cause of the explosion. The movie shows that initial hypotheses are not always correct, and highly trained professionals go through several trial hypotheses before a good theory is developed. The movie *Apollo 13* is an excellent teaching tool for chemistry at several levels.

Acknowledgments

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