Teaching Chemistry Using *From the Earth to the Moon*

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The space program and media based on it have provided examples that can be used to teach chemistry *(1–5)*. Recently, a paper was published in this *Journal* entitled "Teaching Chemistry Using the Movie *Apollo 13*" *(4)*. The movie *Apollo 13* was followed by an Home Box Office (HBO) original movie series *From the Earth to the Moon (6)*. This latter series, along with the documentary *Moonshot*, provide examples from the other missions in the Apollo program that can be used to teach chemistry *(7)*. Viewing segments of these videos during class has been used to facilitate discussion of chemical topics.

Experimental Conditions

Most reactions conducted in undergraduate chemistry laboratories take place under normal atmospheric conditions. *Apollo 1,* the first major tragedy of the American space program, never got off the ground. During one of the final ground tests, a spark in the spacecraft started a fire that killed astronauts Gus Grissom, Ed White, and Roger Chaffee. The atmosphere inside the spacecraft was comprised of oxygen at a pressure of about 850 torr *(8)*. The increased oxygen concentration led to the rapid rate of the combustion reaction. The spacecraft interior had Velcro on the inside walls that was used to keep items from floating freely in the microgravity environment in space *(6, 7)*. In air, Velcro does not burn easily. In the oxygen rich environment of the spacecraft, Velcro burned very rapidly, almost explosively. In *From the Earth to the Moon*, the effect of oxygen concentration on the rate of Velcro combustion is dramatically demonstrated *(6, 9)*. This is a harsh but effective lesson on conditions causing changes in reactivity. It also serves as a reminder that safety is based on what might happen, and that failure to anticipate problems can lead to disaster.

Electrolytes

A topic in the first semester of most general chemistry courses is the classification of compounds as strong electrolytes, weak electrolytes, or nonelectrolytes as determined by their effect on the electrical conductivity of aqueous solutions. *Apollo 12,* the second mission to the moon, provides an instructive example of the effect of putting electrolytes in solution. In this case, the solution is air. It was raining on the day of the launch, but there had not been any lightning in the area *(8)*. Thirty-seven seconds after liftoff, the rocket was struck by lightning *(6, 8, 10)*. What would cause the rocket to be struck by lightning? The rocket, as it ascended, left a trail of gaseous ions created by the high temperature combustion of the kerosene rocket fuel. These gaseous ions left behind in the contrail made a good conductive pathway for the lightning to travel from the rocket to the ground.

Accuracy and Relative Error

The Apollo 12 mission provides a good example of how what appears to be a large error is actually quite small. *Apollo 11,* the first mission to land on the moon, missed its landing site by about four miles *(8)*. Accurate landings would be required if the moon was to be explored relatively safely and systematically. *Apollo 12* had a landing site near an unmanned lunar lander, *Surveyor 3.* An objective of the mission was to retrieve parts from *Surveyor 3* to determine the condition of the spacecraft. The lunar lander needed to be within walking distance of *Surveyor 3* for the mission to be totally successful. The *Apollo 12* lunar lander touched down 535 feet or approximately one-tenth of a mile from *Surveyor 3 (11, 12)*! The question posed to students is, how accurate is the landing? An absolute error of this magnitude may seem quite large to many students. However, when this error is put in relative terms, it becomes much smaller. The landing site on the moon is approximately 1.25 billion feet away from the Earth *(13)*. Calculation of the percent error yields a result of 0.0000428%:

$$\frac{535\ \text{feet}}{1.25 \times 10^{9}\ \text{feet}} \times 100 = 0.0000428\%$$

The astronauts traveled about a quarter of a million miles and missed their intended target by less than two football fields. When viewed in this perspective, it is easy to see that the landing was extremely accurate.

The accuracy of the landing can be examined in a different manner. An ellipse approximately 11-miles long by 3-miles wide defined the landing zone *(8)*. Assume the *Surveyor* probe was at the center of this area. Dividing the area of a circle with a radius defined as the distance from the lunar lander to the *Surveyor 3* by the area of the landing zone results in a percent error of 0.031%:

$$\frac{\pi \times (535\ \text{feet})^2}{\pi \times (15840\ \text{feet}) \times (58080\ \text{feet})} \times 100 = 0.0311\%$$

The landing can be seen as accurate in this context as well.

Requirements for a Reaction

Apollo 14 was the next mission to go to the moon following the near disaster of *Apollo 13.* A key function of any lunar mission required an astronaut to dock the command module with the lunar module, then the combined spacecraft and crew would travel to the moon. The docking procedure can be related to the factors required for a chemical reaction. First, molecules of the reacting species need to come into contact in much the same manner that the command module had to contact the lunar module. Second, molecules of the two reacting species must collide in the correct orientation, as was required for the command and lunar modules to successfully dock. The docking probe had to contact the lunar lander in the docking collar. Improper orientation during docking of a spacecraft with the Russian space station *Mir* almost led to disaster. Third, the reactants need to collide with enough energy to overcome the activation barrier as did the command and lunar modules. On *Apollo 14,* the command module contacted the lunar module in the proper orientation, but it did not have sufficient energy to dock. Docking was finally achieved when the energy barrier was overcome *(7, 14).* For chemical species to react with each other, all three of these conditions must be met.

The Educated Observer

To this day, NASA wrestles with justifying the cost of sending humans into space. Why send humans when robots may be able to do what astronauts were doing at less cost and without the risk to life? The answer to this question lies in the goals of the Apollo lunar missions, which included geological surveying and sampling. Few astronauts had any significant scientific background, since most of them were selected based on their ability as test pilots. Would a random sampling of rocks and dust from the lunar surface done by robots be better than relying on untrained observations of astronauts? The decision was made to educate the astronauts to become scientific observers. *From the Earth to the Moon* shows details of how the astronauts were educated to be observers. They would learn to seek out unusual lunar samples that could provide clues to the history of the moon and the solar system.

NASA realized that they had a group of highly motivated people who were ready to do whatever was necessary to make their mission be the most successful. The astronauts' instructors successfully prepared well-educated scientists ready for lunar exploration. This serves to show that when intellectually stimulating teachers can get their students motivated, instruction becomes more effective. The flight of *Apollo 15* resulted in the discovery of a sample of crystalline rock that was 4.5 billion years old *(1, 15, 16).* This sample is part of the primordial lunar crust. As mission commander Dave Scott said, “We went to the moon as trained observers not just to gather data with our instruments onboard, but also with our minds” *(15, 17).*

Apollo 17, the last mission to the moon, had a geologist on the crew. Harrison “Jack” Schmitt was not only an astronaut but was also a scientist. He had been instrumental in the preparation of the astronauts for the previous missions and selection of the landing sites. Astronaut Schmitt and mission commander Gene Cernan were the team on the moon collecting samples. As they were collecting samples, Jack Schmitt noticed an unusual color on the lunar surface. Was this unusual color due to light reflection of the lunar surface itself? He had seen reflections earlier that resulted in unusual colors. As he examined the new location, he made careful observations, eliminated the possibility of light reflection, and concluded that it was the lunar dust itself that was orange *(6, 18).* A photograph of the orange dust is available at the Web site in ref *19.*

It is important to note that Jack Schmitt did not simply assume that the color was due to a reflection; he investigated it further. During any type of scientific experimentation and exploration, it is extremely important to note all observations.

The moon is often viewed as a vast wasteland, void of color. Astronaut James Lovell first described the moon as gray with no other color during the flight of *Apollo 8.* Many of the lunar samples collected by Apollo missions contained silicates and transition metal oxides. The latter imparts the distinctive color to some samples such as the one found by Astronauts Schmitt and Cernan. In fact, some samples that appear gray on the macroscopic level have other colors such as green when viewed on the microscopic level *(1, 19).*

Concluding Remarks

The Apollo missions provide many analogies to chemistry and applications of chemistry. *Moonshot, Apollo 13,* and *From the Earth to the Moon* give visual instructional aids for these analogies and applications. Many students find video segments from these media to be helpful in learning chemical concepts.

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