Report

Chemical Interactions in a Reduced Gravity Environment W

by Paul Focke,* Maria Spector,* Bob Holicek, and Jeff Spector

The NASA Reduced Gravity Program is operated by the NASA Lyndon B. Johnson Space Center (JSC) in Houston, Texas, and provides the unique "weightless" environment of space flight for test and training purposes. Started in 1959, the Reduced Gravity Program is used to investigate human and hardware reactions to a weightless environment. The reduced gravity environment is obtained with a specially modified KC-135A turbojet (Fig. 1) that flies parabolic arcs to produce weightless periods of 20–25 seconds. A typical mission is 2–3 hours long and consists of 30–40 parabolas.

Twice a year, college students from around the country are allowed to submit proposals for experiments to be conducted through the Reduced Gravity Student Flight Opportunities Program (*1*). Information about the specifics of this program including how to get involved can be obtained at *http://www.tsgc.utexas.edu/tsgc/floatn/*. Our team consisted of Maria Spector, Paul Focke, Bob Holicek, and Jeff Spector (Fig. 2). Maria and Paul are seniors majoring in molecular biology, Bob is a junior majoring in chemical engineering and Jeff is a freshman and undecided. Together we wrote one of the 40 proposals that was accepted. To get accepted our proposal needed to include where our funding would come from, which was generously provided by the Department of Chemistry and the Engineering Mechanics Program in the Department of Engineering Physics. Our idea was to study general chemistry concepts on the KC-135A. This research was unique because it was one of the few that did not study engineering-based concepts. Our goal was to design experiments that would examine general chemistry concepts that could be videotaped with the purpose of educating students and teachers about how chemistry can be drastically different when the force of gravity is removed. We needed to choose experiments that would be visually stimulating, while at the same time taking into account the fact that we would only be in a reduced gravity environment for 20–25 seconds at a time. With this in mind, we designed experiments to study liquid immiscibility, crystal formation, polymer formation, magnetism, and three-dimensional molecular modeling.

Liquid immiscibility was examined with a 1-L plastic soda bottle filled with 1/3 vegetable oil and 2/3 water. This bottle was shaken during the microgravity time period. (The environment inside the plane is termed microgravity because it is not perfect 0-g.) On Earth, it is obvious that liquids will separate with the more dense liquid forming the bottom layer.

Figure 1. The KC-135 during its climb to 35,000 feet. It then drops to 25,000 feet, creating a microgravity environment inside the plane for 20–25 seconds.

Figure 2. The authors onboard the KC-135, loading the test bed onto the plane the day before the flight. From left are Paul Focke, Bob Holicek, Jeff Spector, and Maria Spector.

We suspected that in a reduced gravity environment the liquids would have no reason to separate based on their density, which was exactly what was observed. The two liquids remained immiscible, yet did not separate.

The second experiment that we performed was crystal formation. Crystals of hydrated forms of $CoCl_2$, $CuCl_2$, and $NiCl_2$ were grown in a commercial sodium silicate solution. Since we did not expect to observe complete crystal formation in 25 seconds, we looked at this experiment in a different light. While the plane is climbing, the force of gravity inside the plane doubles to 2-g. We chose to examine the effects of subjecting crystal growth to the periodic swing of microgravity to 2-g. What we observed was interesting; crystal growth initially appeared normal, but upon closer inspection we noticed that the growth was stunted during the 2-g climb. What actually happened was that the crystals grew normally during the 0-g intervals, but tended to grow to the side during the 2-g intervals, forming an overall zigzag pattern towards the top of the container. We hypothesize that the crystals were trying to grow vertically, but the force of 2-g was too much, causing them to grow to the side. When the images caught on videotape are compared with crystals grown entirely under normal, 1-g conditions, the difference is obvious (Fig. 3).

Our third experiment examined the formation of polyurethane foam (*2*) during microgravity. This was done by combining two liquids in a small container, mixing, and watching the differences in polymer foam formation resulting from differences in gravitational pull. In a 1-g environment the foam rises out of the container in a uniform fashion, forming a cupcake-like shape around whatever container it is in. This formation was not observed in a reduced gravity environment. The foam did indeed rise out of the container, but continued to climb without falling or being pulled in any direction (Fig. 4). The energy provided by the reaction provided the only directional push applied to the system.

Our fourth experiment looked at ferrofluid properties in reduced gravity. Ferrofluid is a liquid that contains suspended nano-sized magnetic particles. When a magnet is held up to the liquid, the particles align themselves with the magnetic field, creating spike-like formations in the liquid (Fig. 5). The spike formations are easy to observe, yet harder to videotape clearly; thus we had to design an experiment that would be visually easy to see. We decided to observe what would occur if we allowed ferrofluid to float freely toward a magnet. What happened was the elongation and apparent increase in velocity of the liquid as it approached the magnets.

Our final experiment consisted of an attempt at molecular modeling. We chose to use two colors of plastic balls with cylindrical magnets protruding from the spheres in tetrahedral and octahedral arrangements. Balls of one color had magnets oriented with one polarity, while balls of the other color had magnets of the opposite polarity. We were hoping to achieve patterned self-assembly, mimicking common mineral structures with this experiment. Our expectation was that energy for the system would be provided by the magnetic repulsion of similarly colored balls. This did not occur as expected. In fact, placement of the magnets led to similarly colored balls having attractive interactions. The effect was not strong enough to be observed in a 1-g environment, but when the gravity was reduced, similarly colored balls were observed to bind. Unfortunately, this did not allow a definitive pattern to be observed (Fig. 6).

These experiments aboard the KC-135A that were captured on video were put together to produce a comprehensive video of images. It was not an easy task to capture good images while in microgravity. Everything happened so fast that it took a lot of planning and preparation to get the timing right. Fortunately our planning paid off, and good images were obtained. Our comprehensive video was recently displayed at the 1999 Engineering Expo at the University of Wisconsin–Madison. We set up a booth that allowed people of all ages to examine how things they take for granted prove to be different in the absence of gravity. The combination of the video displaying what happens in reduced gravity in addition to the hands-on experiments that were provided on the table proved to be an excellent educational tool. In the upcoming months, our goal is to produce a Web page that will allow the public to view these experiments both in microgravity and in 1-g. Descriptions of the projects will also be provided. A link to our Web site can be found at *http://jchemed.chem.wisc.edu/Journal/Issues/1999/Jul/abs880.html.*

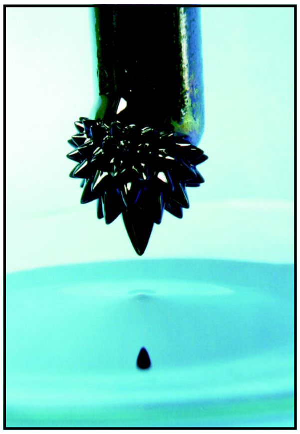

photo by George Lisensky

Figure 5. This photograph of ferrofluid was not taken on board the KC-135, but illustrates its properties. The ferrofluid forms spikes when it comes in contact with a magnet; if it isn't touching the magnet, it will be pulled toward it.

Many of the photographs in this article were obtained from a video that was taken in a microgravity environment during the KC-135 flight. Two video cameras were strategically placed in the test bed and were left running for the entire flight so the experiments were continuously being taped.

Figure 4. The formation pattern of the polyurethane foam. This formation is very different from what is observed in a 1-g environment where the foam would have fallen to make a nonuniform structure. In the photograph the foam is still soft and so this formation will fall during the 2-g before it has time to harden.

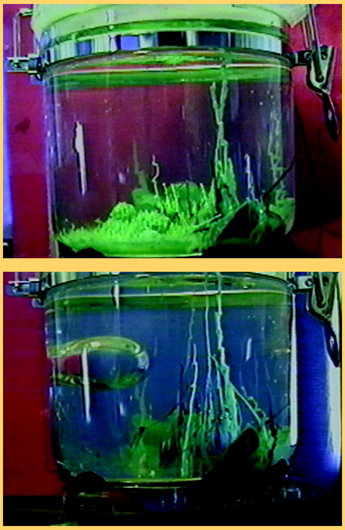

Figure 3. Crystals after a number of parabolas of 0-g to 2-g. The main difference observed in this experiment is in the shape of the crystals—it is clear that they have formed in a zigzag pattern. This is very different from what we observe in a 1-g environment where the crystals mainly grow straight.

Figure 6. An example of the 3-dimensional molecular modeling that was attempted. These magnetic balls were released during the 0-g interval and allowed to come into contact with each other. This experiment didn't come out as expected, as is described in the paper. Nevertheless some interesting still shots of the magnets were obtained.

Overall, this was a very rewarding experience, both the chance to experience reduced gravity as well as the opportunity to explain and educate people about the importance of space-related research. With the coming of age of the International Space Station and other space-related projects, education about the challenges and opportunities associated with environments differing from that of our own is necessary. Our team is very grateful to have been a part of this project.

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Note

[W]Supplementary materials for this article are available on *JCE Online* at *http://jchemed.chem.wisc.edu/Journal/issues/1999/Jul/abs880.html.*

Literature Cited

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