FUN WITH TRANSPARENCY FILMS: THE RUTHERFORD GOLD FOIL EXPERIMENTS AND BEYOND

Robert Gregory, PhD
Department of Chemistry
Indiana University Purdue University Fort Wayne
2101 East Coliseum Blvd.
Fort Wayne, Indiana 46805
gregoryr@ipfw.edu
(260) 481-6298

CHEMICAL CONCEPTS

Atomic Structure

- An analogy to the Rutherford gold-foil experiments

Scientific Process

- An opportunity to demonstrate an example of discrepant events that change scientific thought
- The example highlights the fluid nature of scientific knowledge, which is, in and of itself, a topic of misconception for many students

Optics

- Scattering phenomena
- Diffraction

HOW DEMONSTRATION ADDRESSES THE CONCEPTS

In the Rutherford-Geiger-Marsden experiments, alpha particles were streamed into a thin gold foil in an attempt to prove the plum pudding model of the atom. The results were one of the most striking examples of a discrepant event in scientific history. This demonstration provides the student with a visual sense of what Rutherford and his researchers expected to find, and then what they actually did find.

This demonstration uses little in the way of materials. The alpha particle beam is represented by a laser pointer, while the gold foil is represented by a picture frame containing some transparency material. In fact, two frames are used, the first of which is empty, the second of which contains the film. These two frames set up the discrepant event.

The choice of transparency film is important here. The films used to demonstrate the scattering of the alpha particles must be of the ink-jet variety, because it is the coating that is embossed on the plastic that creates the scatter. But even within that category, the choice of brand is very important, for several other optical effects come along with that patterning of the surface. Notable, Airy rings are an almost ubiquitous diffraction feature of all of the films commercially available. This is an obviously good way to demonstrate point diffraction to students. In the films where the airy rings are not present, no real scatter occurs, but in most of those, linear diffraction is very noticeable present. These represent some convenient ways to demonstrate these diffraction effects to more advanced classes, such as those in analytical instrumentation.

PREPARING AND PERFORMING THE DEMONSTRATION

Safety

- Laser pointers are potential eye hazards. While there is conflicting evidence for any long lasting adverse outcomes from exposure to the light from these devices in the medical documentation, it is important to protect the students from any potential adverse hazard. This demonstration results in both scattered and reflected laser light. The instructor MUST take care to perform the demonstration so that none of these stray light paths impinge on students.

Equipment and Materials (for one presentation)

- Laser Pointer. Red laser pointers will work, but green gives a much more striking image of the scattered photons. Additionally, the secondary diffraction effects are most easily seen using the green laser, as the diffraction is farther away from the incident beam. The primary attribute of the laser that is of prime importance is that the beam be as round as possible. Many of the less expensive red pointers have very diffracted beams, which are not suitable for the effect we are trying to see.
- Ink-jet transparency film. 3M Multi Purpose Transparency Film CG6000 gives the best balance of scatter to diffraction. Office Depot Universal Ink-Jet Printer Film (catalog number 753-641) produces a scatter pattern that is similar but slightly geometric looking.
- To demonstrate the Airy ring effect, 3M CG 3480 ink jet transparency film or 3M Highland 707 film give very good results, the latter providing a broader scatter and diffraction pattern, which is easier to see in small rooms.
- For the linear diffraction patterns, the Office Max Inkjet Transparency Film for Canon and Epson printers are the best choice. They create a linearly diffracted beam oriented in the vertical direction when looking at the film in the ‘portrait’ orientation.
- Picture frames (without the glass), or matte board, or some other method of fixing the films, as well as provide the illusion of a film for the ‘expected’ portion of the Rutherford demonstration.
- Ring stands and clamps to hold the frames in a fixed position to minimize shaking, and maximize shaking (which makes the scatter nearly impossible to see).

Advance Preparation:

- In my original demonstration, I used empty 5”x7” picture frames, with the glass and backing removed. Subsequently, gluing the film to a 5”x7” matte board with a 4”x6” cutout has proved to be more useful. I will refer to any means of fixing the films as a frame.
- One of the frames is left empty. This frame is the analogy to what Rutherford expected to find.
- The scattering frame represents what was actually found in the experiment. It consists of the same type of frame, this time holding a plastic sheet which has a surface that is rough on the scale of the laser beam. In the final form of the demonstration, an ink-jet printer film was used as the scattering medium.
- Fixing the plastic sheet in a frame so that it is stationary and flat, as opposed to simply holding the film, is important. If the plastic sheet is handheld, the projected image moves and blurs considerably, making the effect very hard to see. It also reduces the amount of manual dexterity required of the lecturer, which is crucial, at least for some of me.
- Just as importantly, handholding the film makes it quite difficult to control the retro-reflection, which is still a beam of laser light. Laser pointers are typically designed as Class II devices (<1 mW), however, Class IIIa devices (1-5 mW) are available (in fact, the laser pointer used today for this demonstration is such a device). It has been noted in the literature that both classes are considered dangerous for direct viewing, and even Class II lasers have been reported to temporarily damage eyesight on viewing of errant reflections. No matter what the power of the laser, it is not good safety practice to allow the possibility of a student being struck by an errant beam. Likewise, if picture frames are used, the glass should not be included. The glass is sufficiently smooth that the retro-reflection produces a strong, single beam, and at the least will be 4% of the incoming power.

Performing the Demonstration

The Gold Foil Experiments:

- This exercise first demonstrates an analogy to what Rutherford expected Geiger and Marsden to find, and then demonstrates another analogy to what they actually found. The demo consists of two picture frames and a laser pointer. The instructor places two ring stands on the lecture table. One holds the laser pointer fixed in a three-fingered clamp, while the other holds a picture frame. The lecturer prefaces the demo with a description of the plum pudding model and what was to be an elegant confirmation of the structure of the atom: they expected very little scattering. When the laser pointer is turned on, the beam shines through the frame containing no transparency film and strikes a screen or an unpopulated side wall, showing a single beam of light, unimpeded by any intervening object.

- The lecturer continues, announcing that the only problem is that it isn't the way the experiment turned out. The picture frame is replaced with the frame that contains the film. When the laser hits that frame, the wall is again illuminated with a similar strong beam of light, but it is surrounded by scattered smaller points of light that indicate that some of the light has been deflected out of the beam as it struck the target. The rest of the lecture topic follows naturally from that point.

Diffraction effects:

- In a discussion of diffraction, using a film that emphasizes the Airy pattern is a simple enough task. Relating that pattern to the fact that the surface of the film is intentionally roughened is a very good lead into discussions of scattering media, such as clouds in atmospheric and fiberoptic laser transmission, polarization randomization, etc.
- In demonstrating linear diffraction, the laser diffraction from the linear diffractors is quite pronounced, resulting in a strong central beam from the laser, with peaks of light of decreasing intensity as one moves from the center of the pattern. One very interesting (and visually impressive) demonstration is to use two collinear diffractors, showing the linear diffraction, then rotating one of the films to show two-dimensional diffraction.
- One can also utilize two colors of lasers to show the dependence of diffraction on wavelength. Using a green laser pointer and a red one provides a nice visual demonstration of the effect.

PEDAGOGICAL STRATEGIES FOR FOSTERING LEARNING AND UNDERSTANDING OF THE CONCEPTS

- In my view, the chief benefit to discussing the Rutherford-Geiger-Marsden experiments is to discuss the fluid nature of science. Many of my students, especially those not entering science as their main field of study, expect science to be static. They take what they read as a finished and final answer to the questions we pose about nature. They often express their frustration that current knowledge seems to be contradicted by new studies constantly. This violates their expectations that the facts they know about science will always be true. These experiments offer an opportunity to address those concerns.
- I attempt to set up the historical context first. I try to paint a picture that logically leads to the plum-pudding model of the atom. In advanced classes, this is more difficult, since most of the students already know the outcome of the experiment. The context points up several issues: What they didn't know about atomic structure (mass of the electron, electron as particle or wave, etc); That based on what they knew, the plum pudding model was the simplest and most logical model they could have produced; That the model actually was more intuitively sensible than the one that replaced it.

- I then explain that what Rutherford's lab set out to do was to prove that model was true.
- It is a wonderful example of the scientific method, and why the scientific method is important. They started with a hypothesis. They designed the test, postulated what they expected the results to be, and then tested the hypothesis. When they didn't get the results they expected, they refined their experiments to find out why the result was discrepant.
- It is important to note here that this is a marvelous discrepant event. Relating Rutherford's results to discrepant events that the students have encountered in class to this point is a great tie-in.
- This is also a good time to discuss serendipity in science. Rutherford, Geiger, and Marsden were very lucky to have seen the effect at all. They only had radium, an emitter of only modest kinetic energy particles, as an alpha source, and they picked heavy elements to look at. If the experiment were done today, we might pick an easily obtained foil, such as aluminum, for instance, and the effect would not have been seen. The original theory would have been supported by the experiment.
- In the end, I explain, they revised their theory to the only possible explanation for what they had found. Their explanation, two years in the making, revolutionized thinking into atomic structure, and paved the way for more discoveries that brought us into the modern era of atomic physics and chemistry.
- I then use this to lead the students into the concept that, not only is science not static, be that we really *want* it to be fluid. That no theory is the complete, indelible picture, but merely the best one we know how to draw at any given point in time. The joy of getting to add color to the charcoal drawing is why we are scientists, and the change that brings is how we all learn more about the universe.

REFERENCES

Tipler, P.A., Llewellyn, R.A. *Modern Physics*, 4th edition; W.H. Freeman and Company: New York, New York, 2003; pp. 165-168
Duggan, J.L.; Yegge, J.F. *J. Chem. Educ.* **1968**, *45*, 85
Garbarino, J.R.; Wartell, M.A. *J. Chem. Educ.* **1973**, *50*, 792
Silversmith, E.F. *J. Chem. Educ.* **1971**, *48*, A499
Hau, Kit-Tai. *J. Chem Educ.* **1982**, 59, 973
Vitz, E. J. Chem. Educ. **2003**, 80,30
Ibanez, J.G. *J. Chem. Educ.* **2003**, 80, 30