

# Teaching about the Electromagnetic Spectrum Using the Herschel Experiment

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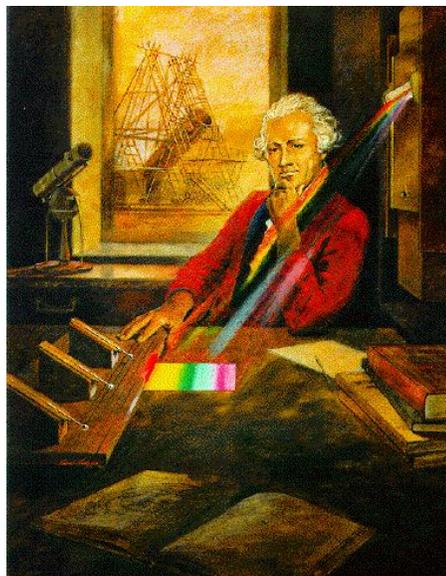
## ABSTRACT

A discussion of the parts of the electromagnetic spectrum, along with wave and particle models of light, are often taken as starting points in introductory physics and optics courses. Creating a spectrum and recreating Herschel's experiment verifying the presence of infrared energy is an effective demonstration for students at all levels. However, such a supposedly simple experiment has a number of potential pitfalls, which will be examined in this paper. Methods of doing the experiment both indoors and outside with simple experimental materials will be described and recommendations on best ways to link this experiment to further studies about the spectrum will be given. The use of digital cameras for near infrared imaging in a classroom setting will also be discussed briefly. Having students perform the Herschel experiment provides an excellent introduction to the history of optics and gives them experience in the scientific process. Such a guided inquiry approach can be used successfully to increase student learning and achievement in optics.

**Keywords:** optics education, infrared, inquiry, electromagnetic spectrum, Herschel

## 1. INTRODUCTION

Much can be learned by an examination of the classic science experiments and key discoveries. The work of William Herschel and the discovery of the invisible "calorific rays" is no exception. Using a few simple and easily obtained pieces of equipment, Herschel devised an experiment that demonstrated unequivocally that the visible spectrum did not represent the complete range of energy in sunlight. Using a light source, thermometers, and a prism, students can conduct an experiment similar to Herschel's. Our original motivation for a deeper understanding of the Herschel experiment was the process of creating a teacher's guide on the electromagnetic spectrum for the Great Explorations in Math and Science (GEMS) program at the Lawrence Hall of Science. As part of this teacher's guide, we felt that an indoor version of the experiment would be more widely used than the traditional version, which takes place outdoors. An outdoor experiment requires a sunny day, and equally importantly, the ability to take the class outdoors. These requirements are difficult for many schools in the United States to fulfill. For many parts of the country, a sunny day is a rarity in the winter and many schools have placed severe restrictions on the abilities of teachers to take their students outdoors. An indoor experiment similar to Herschel's would be extremely convenient for teachers and would add to its educational utility.



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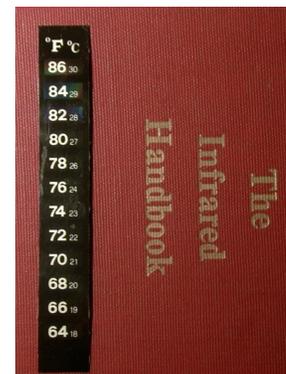
## 2. INDOOR EXPERIMENTS

Our indoor experiment was to be done in an ordinary classroom. The source of light would be an overhead projector. Ordinary alcohol thermometers with their bulbs blackened would be the detector. On the overhead projector was a sheet of transmissive diffraction grating material. A slit was created by using two pieces of opaque cardboard placed on the horizontal surface of the projector itself. Such a setup for demonstrating a spectrum using a sheet of grating material was described by Sadler<sup>1</sup> (1991). When oriented properly, this setup projects a brilliant spectrum to the left and right of the center of the projected light.



The spectrum was projected onto a large sheet of white paper that was taped to the wall of the classroom. The paper made it easy to note the position of the different colors in the spectrum, and to identify a position beyond the red to place the infrared-sensing thermometer. The thermometers are placed at the positions of different colors along the spectrum, and then the overhead projector was turned off. Other thermometers were placed above and below the spectrum and off to the side, and acted as controls.

When we conducted the experiment, the temperature of the thermometers in the positions of the various colors went up over a period of 5 minutes when the overhead projector was switched on. The infrared thermometer also registered a rise in temperature. However the infrared thermometer temperature reading was not significantly different than the readings for the other colors. These results are approximately what might be expected. When the experiment is done outside, the infrared thermometer temperature reading usually exceeds the temperature reading for the other parts of the spectrum. The thermometers used as controls should not register an increase in temperature when the light source is turned on, as they are not illuminated.



Unfortunately, some of the control thermometers, which were not illuminated by the spectrum, also registered a temperature rise, though not as significant a rise as the other thermometers. Clearly something was wrong. After repeated experiments under controlled conditions, we concluded that there was not enough energy from the overhead projector to do the Herschel experiment with ordinary thermometers. First, the surface area of the thermometer bulb is probably too small to intercept much of the energy from the projector. Secondly, the energy density of the spectrum is low as two rather large spectrums are created. Moving the projector closer to the screen was tried, but did not appreciably affect the outcome.

We believe that the heat dissipated by the projector was responsible for most of the change in thermometer values. The heat was being vented towards the thermometers. In an attempt to be more precise, we used digital readout thermometers with the tips painted black and sheets of liquid crystal, sensitive to a small range of temperatures around room temperature. Neither worked significantly better than the apparatus we began with that used simple thermometers.

The importance of using extra thermometers as controls was perhaps the primary lesson learned and communicated to the students. Liquid crystal thermometers used in aquarium temperature regulation (illustrated above) are more sensitive and may work adequately for an indoor demonstration of the Herschel experiment.

### 3. OUTDOOR EXPERIMENTS

Doing the experiment outside requires sunlight, thermometers, and a prism. Dr. Michelle Thaller at NASA's Jet Propulsion Lab has created web pages that describe in detail how to set up the Herschel Experiment outdoors.<sup>2</sup> These photographs are from the SIRTF web site. Troy Cline and Sallie Smith of Goddard Space Flight Center also have worked on versions of the experiment.<sup>3</sup> Generally, the Sun is positioned so that the light through the prism is projected onto the bottom of a cardboard box, upon which the blackened thermometers have been placed. The control thermometer is positioned so that it measures air temperature and is not exposed to sunlight.



When the experiment is done this way, the thermometer capturing the infrared portion of the spectrum gets the warmest. However, there is a puzzle here since sunlight is brightest in the middle of the visible spectrum. Solar output is not maximized in the infrared, so how can this be? Chester gives an excellent explanation of how this can happen.<sup>4</sup> He explains that the index of refraction of the glass in the prism varies non-linearly with wavelength. Because of this, the wavelengths will not be uniformly spaced along the detecting area. In particular, the infrared portion of the spectrum is more compressed in comparison to the other wavelengths. Because of this, the measurement of a change in the infrared region thermometer under exposure to sunlight becomes more apparent.

### 4. CONCLUSION

The Herschel experiment is an excellent way to introduce students to the infrared. It provides a tangible demonstration of one part of the electromagnetic spectrum that cannot be seen. When the experiment is done, particular attention must be paid to the use of control thermometers to verify that the temperature increase in the infrared is not an artifact. With a more extensive use of technology, there are probably other ways to do the Herschel experiment. For example, non-contact thermometers can be used. A simpler, low-tech way to get a better measurement is to use liquid crystal thermometers such as those used for aquaria or reptile terrariums instead of alcohol thermometers. These liquid crystal thermometers have more sensitivity to temperature changes than the blackened alcohol thermometers. We are still working on ways to do the experiment indoors, with an overhead projector. Some types of overhead projector have heat-absorbing glass that absorbs much of the infrared. A successful exhibit on the Herschel experiment was done several years ago at the Flandrau Science Center in Tucson, designed by Dr. Stephen Jacobs of the Optical Sciences Center at the University of Arizona. It used a quartz iodide light source, glass prism, collimating lens, slit, and liquid crystal on a rotating drum. In another approach, the infrared portion of the spectrum ought to be able to be photographed by a CCD camera with a visible blocking filter. These cameras can detect the spectral region between the red portion of the spectrum and about 1 micron. We are still searching for the optimal ways to do the experiment indoors with simple equipment easily available to teachers.

### 5. ACKNOWLEDGEMENTS

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### 6. REFERENCES

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- <sup>2</sup> Michelle Thaller, NASA SIRTF Project Educational Web pages at <http://sirtf.caltech.edu/Education/Herschel/herschel.html>
- <sup>3</sup> Troy Cline and Sallie M. Smith, NASA Goddard Space Flight Center, Greenbelt MD Educational material found at [http://istp.gsfc.nasa.gov/istp/outreach/solar\\_observation.pdf](http://istp.gsfc.nasa.gov/istp/outreach/solar_observation.pdf)  
[http://istp.gsfc.nasa.gov/istp/outreach/student\\_booklet.pdf](http://istp.gsfc.nasa.gov/istp/outreach/student_booklet.pdf)
- <sup>4</sup> See T. Chester's web pages Reconciling the Herschel Experiment at <http://sd.znet.com/~schester/calculations/herschel/index.html>