

**Active Astronomy:
Classroom Activities for Learning About Infrared Light**

Teacher's Guide Table of Contents

Acknowledgements	<i>i</i>
Overview and Assessment	
1.1 For the Teacher	1
1.2 Learning About Infrared Light Student Test	7
1.3 Learning About Infrared Student Answer Sheet	9
1.4 Learning About Infrared Light Teacher Answer Key	11
1.5 Materials and Preparation	13
What's Getting Through To You?	
2.1 Teacher Notes	21
2.2 Student Activity Sheet	27
2.3 Teacher Answer Key	33
Sensing the Invisible	
3.1 Teacher Notes	41
3.2 Student Activity Sheet	51
3.3 Teacher Answer Key	57

Reflection

4.1 Teacher Notes	63
4.2 Student Activity Sheet	67
4.3 Teacher Answer Key	69

Listening to Light

5.1 Teacher Notes	71
5.2 Student Activity Sheet	81
5.3 Teacher Answer Key	85



STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY
DEVELOPED AND OPERATED FOR NASA BY USRA

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We would like to thank the following pilot test teachers and their students, informal educators, education facilitators, and astronomers who reviewed or tested *Active Astronomy: Classroom Activities for Learning About Infrared Light*. Their critical comments and recommendations based on nationwide classroom use of these activities contributed to this teacher's guide. Their participation in the pilot does not necessarily imply endorsement of the guide. Their recommendations were invaluable and have been recorded and integrated into the activities. We especially appreciate the students' input. Thank You!

The Montana State University Conceptual Astronomy and Physics Education Research (CAPER) Activities Development Team worked in partnership with Stratospheric Observatory For Infrared Astronomy (SOFIA) Education and Public Outreach staff developing this teacher's guide. The evaluation team at the Space Telescope Science Institute provided the helpful preliminary review, prior to field testing in school classrooms. We would also like to thank Sven Kohle and Till Credner at the Astronomical Institutes of the University of Bonn, for the use of the Crab Nebula image. Thanks everyone.

SOFIA is being developed and operated for NASA by the Universities Space Research Association (USRA). The SETI Institute and the Astronomical Society of the Pacific lead the Education and Outreach Program for SOFIA.

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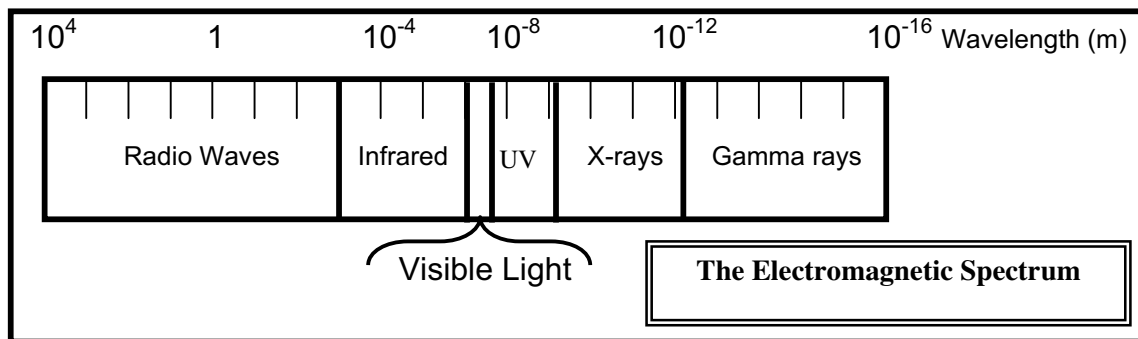
Active Astronomy Classroom Activities for Learning about Infrared Light

1.1 For the Teacher

Most students are familiar with the rainbow of colors that make up visible light. They're often less comfortable dealing with light from the other portions of the electromagnetic spectrum — gamma rays, x-rays, ultraviolet light, visible light, infrared light, microwaves, and radio waves. Students may not realize the important role played by non-visible light in their everyday lives. For example, TV remote controls, car-locking systems, and some grocery store check-out scanners use infrared light to signal between devices or read bar-codes. Computers use infrared light to read CD-ROMs. Night-vision goggles register infrared light (also known as heat radiation), as do search-and-rescue monitors that look for the heat given off by someone lost in the wilderness at night.

The activities in "Active Astronomy: Classroom Activities for Learning about Infrared Light" focus on improving student understanding of infrared light, which occupies the portion of the electromagnetic spectrum between visible light and microwaves, the shortest of the radio waves.

It is appropriate to refer to each portion of the electromagnetic spectrum as "light." All forms of light—from the lowest energy radio waves to the highest energy gamma rays—can be described as waves. The major difference distinguishing one from the other is wavelength; the shortest wavelength gamma rays have a wavelength about the size of the atomic nucleus, whereas the wavelength of radio waves from FM 101 is about 3 meters. Visible light is only a small part of the electromagnetic spectrum with wavelengths ranging from 0.4 to 0.7 microns (a micron is a millionth of a meter). The wavelengths of light in the infrared region vary from about 1 to 350 microns.



1.1 Active Astronomy: Classroom Activities for Learning about Infrared Light

To understand the universe, astronomers must observe at all wavelength regions, including the infrared. However, water vapor in the Earth's atmosphere absorbs infrared light, keeping it from reaching telescopes on the ground (some narrow bands of infrared light do reach the ground and can be observed from the tops of high mountains). To study infrared emissions from space, astronomers have put telescopes in airplanes, which can fly high above most of the water vapor in the atmosphere, or in space.

The Stratospheric Observatory for Infrared Astronomy (SOFIA), developed by NASA and the German Aerospace Center, DLR, is the latest in a series of “flying telescopes.” For SOFIA, technicians modified a Boeing 747SP aircraft to carry a 2.5-meter (8.2-foot) infrared telescope that observes the sky through a hole in the side of the airplane. When fully operational, SOFIA will be the largest airborne telescope in the world, and will make observations that are impossible for even the largest and highest of ground-based telescopes. SOFIA will observe the universe from visible (0.3 microns), through infrared (1 to 350 microns), and microwave (1600 microns) wavelengths.



Every object that has a temperature above absolute zero (0 K) emits energy in the infrared region of the spectrum. Infrared astronomy covers nearly everything in the universe. Objects too cool or too faint to be seen in visible light, such as dim, cool stars and interstellar dust particles, can be studied in the infrared. Infrared light can penetrate deep into interstellar clouds of dust and gas that block visible light, revealing astronomical phenomena that would otherwise be obscured from view. Because of this, astronomers interested in exploring the interstellar clouds that serve as the birthplaces of stars observe them in infrared light.

Previous ground-based, satellite and airborne infrared observatories have explored the infrared region of the spectrum. SOFIA will exploit and extend this scientific legacy with instruments that reveal even greater details in spectra and photographs taken in the infrared. Topics to be addressed by SOFIA scientists include:

- how stars form and evolve over time;
- how planets form around stars;
- the conditions in space between stars;
- the origin and evolution of the complex atoms and molecules important to life;
- the study of comets, planetary atmospheres and rings in the Solar System;
- how other galaxies compare to our own Milky Way Galaxy;
- the dynamic activity surrounding the super massive black hole in the center of the Milky Way Galaxy.

SOFIA is a mission in NASA's Origins Program (<http://origins.jpl.nasa.gov>). The Origins Program asks questions humans have pondered for centuries: Where do we come from? Are we alone? Additional information about SOFIA and its astronomical research can be found at the SOFIA web site: <http://www.sofia.arc.nasa.gov>.

1.1 Active Astronomy: Classroom Activities for Learning about Infrared Light

The Activities

These activities are designed to *supplement* classroom instruction about the electromagnetic spectrum, and are not intended as a complete curriculum. The activities in this packet have been designed for use with middle school and high school physical science, astronomy and space science courses. Each activity has been designed to take 1-2 class periods (see the individual activities for more details about activity length). The activities are:

What's Getting Through to You?

Students are introduced to light and colored filters(gels), and learn about the usefulness of filters to astronomers.

Sensing the Invisible

Just as our ears cannot hear all wavelengths of sound, our eyes cannot see all wavelengths of light. Students learn that "invisible light" exists and that we can detect this light with instruments other than our eyes.

Reflection

Students learn that infrared light is reflected in the same manner as visible light. Students deduce that infrared light is another form of light and is a part of the electromagnetic spectrum.

Listening to Light

Students learn that light carries information and that infrared radiation is a form of light that in some cases behaves like visible light and other cases behaves very differently.

Student Prerequisites and Common Misconceptions

- Students are assumed to be familiar with the visible spectrum before beginning these activities, and to have some knowledge of the electromagnetic spectrum and how it relates to the visible spectrum.
- Students are assumed to have some familiarity with the idea of reflected, absorbed, and transmitted light, and to understand the terms “opaque” and “transparent.”
- Students may not realize that light travels from one object to another. This may create problems for students in understanding the material in these activities. Teachers may want to address this misconception in their teaching.

"Many elementary- and middle-school students do not believe that their eyes receive light when they look at an object. Students' conceptions of vision vary from the notion that light fills space ('the room is full of light') and the eye 'sees' without anything linking it to the object to the idea that light illuminates surfaces that we can see by the action of our eyes on them... The conception that the eye sees without anything linking it to the object persists after traditional instruction in optics; however, some 5th graders can understand

1.1 Active Astronomy: Classroom Activities for Learning about Infrared Light

seeing as ‘detecting’ reflected light after specially designed instruction." *Benchmarks for Science Literacy*: p. 339.

- Students are assumed to have some familiarity assembling and working with electronic circuits.
-

Science Standards

These activities support the following standards and benchmarks:

National Science Education Standards — Grades 5-8

Content Standard A: Abilities necessary to do scientific inquiry (NSES, page 145)

- Use appropriate tools and techniques to gather, analyze, and interpret data
- Develop descriptions, explanations, predictions, and models using evidence

Content Standard B: Physical Science, Transfer of Energy (NSES, page 155)

- Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection). To see an object, light from that object—emitted by or scattered from it—must enter the eye.
- The sun is a major source of energy for changes on the earth's surface. The sun loses energy by emitting light. A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun's energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.

Content Standard E: Science and Technology (NSES, page 166)

- Science and technology are reciprocal. Science helps drive technology as it addresses questions that demand more sophisticated instruments and provides principles for better instrumentation and techniques. Technology is essential to science, because it provides instruments and techniques that enable observations of objects and phenomena that are otherwise unobservable due to factors such as quantity, distance, location, size and speed. Technology also provides tools for investigations, inquiry and analysis.

National Science Education Standards — Grades 9-12

Content Standard A: Abilities necessary to do scientific inquiry (NSES, page 175)

- Formulate and revise scientific explanations and models using logic and evidence

Content Standard B: Physical Science (NSES, page 180)

- Electromagnetic waves result when a charged object is accelerated or decelerated. Electromagnetic waves include radio waves (the longest wavelength), microwaves, infrared radiation (radiant heat), visible light, ultraviolet radiation, x-rays, and gamma rays. The energy of electromagnetic waves is carried in packets whose magnitude is inversely proportional to the wavelength.

Benchmarks for Science Literacy — Grades 6-8

The Physical Setting, 4f: Motion (pages 90-92)

- Light from the sun is made up of a mixture of many different colors of light, seen though to the eye the light looks almost white. Other things that give off or reflect light have a different mix of colors.
- Human eyes respond to only a narrow range of wavelengths of electromagnetic radiation—visible light. Differences of wavelength within that range are perceived as differences in color.

Benchmarks for Science Literacy — Grades 9-12

The Physical Setting, 4f: Motion (page 92)

- Waves can superimpose on one another, bend around corners, reflect off of surfaces, be absorbed by materials they enter, and change direction when entering a new material. All these effects vary with wavelength. The energy of waves (like any form of energy) can be changed into other forms of energy.

Hardware and Materials Needed

These activities are designed to use easy-to-obtain materials. Information on where to obtain materials and components is listed in section 1.5.

For demonstrations (one set of materials & hardware required):

- Photocell Detector
 - Photocell (solar cell)—NOTE: Photocells may not be in stock at local electronic parts stores. But they can be special ordered, or ordered directly online or by phone (see section 1.5 for more information). *Allow at least a week for delivery.*
 - Amplifier/Speaker
 - 9-Volt battery for amplifier/speaker
 - Audio Cable with 1/8" mini-plug on one end
 - Two Jumper Cables with alligator clips on both ends
- Transmitter Circuit
 - Infrared Light-Emitting Diode (LED)
 - 0.22 μ F (microfarad) Capacitor
 - Audio Cable with 1/8" mini-plug on one end
 - 5 Jumper Cables with alligator clips on both ends
 - AA Battery
 - AA Battery Holder
- Large magnifying glass, with focal length around 15 cm (fairly standard)
- Flashlight
- Laser pointer (or other laser device)
- Collection of remote control devices (TV, VCR) from several different manufacturers
- Sony Walkman, transistor radio or other music source
- Clear plastic bag
- Colored plastic bag

1.1 Active Astronomy: Classroom Activities for Learning about Infrared Light

- Tissue
- Piece of paper
- Piece of cardboard
- Phillips screw driver

The materials needed for *each group of students* to complete all four activities are:

- White paper
 - Black and red construction paper
 - Red and blue crayons
 - Red and blue gels
 - Internet access or downloaded versions of images mentioned (Crab Nebula, visible bag, IR bag, multiband logo)
 - Slide projector or overhead projector
 - Diffraction grating (handle with gloves) or prism
 - Fan
 - Masking Tape
 - Slide Mount
 - Undeveloped exposed photographic film
 - Red and green gels
 - TV or VCR remote controls (with working batteries) from different manufacturers
 - 1-4 mirrors (the larger the better) A way to mount the mirrors so they stay in place (e.g., tape to boxes, tape to wall, lumps of clay, etc.)
-

CREDITS

These activities were developed in partnership with the Montana State University Conceptual Astronomy and Physics Education Research (CAPER) Team.

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Directions: Write all of your answers on the answer sheet. Do NOT Write on the test.

Matching: On your answer sheet, you will find diagrams. Match the diagrams to the following terms. Mark your answer on the answer sheet, not on the test.

1. Reflection
2. Transmission
3. Absorption
4. Emission

Multiple Choice: Select the one best answer for each question. Mark your answer on the answer sheet.

5. Which of the following best describes why infrared telescopes enable observations that are not possible with visible light telescopes?
 - A. Infrared light is less harmful than visible light.
 - B. Visible light travels slower than infrared light.
 - C. Infrared light will pass through the stellar dust clouds.
 - D. All of the above
6. What colors of light make up the light from the sun?
 - A. Red, Yellow, Blue, White, and Black
 - B. White and Yellow
 - C. Red, Orange, Yellow, Green, Blue, Indigo, and Violet
 - D. White and Black
7. Which of the following best describes the speed of infrared light?
 - A. Faster than the speed of visible light
 - B. Same as the speed of visible light
 - C. Slower than the speed of visible light
 - D. None of the above
8. Which of the following describes electromagnetic energy interacting with matter?
 - A. Interrupted infrared red light on a solar cell connected to an amplifier
 - B. White light passing through a green filter
 - C. Microwaves hitting a telescope
 - D. All of the above
9. Which of the following is a common use of infrared light?
 - A. Tanning lamp
 - B. Remote control
 - C. Street light
 - D. Microwave oven

1.2 Student Pretest—Learning about Infrared Light

Directions: Write all of your answers on the answer sheet. Do NOT Write on the test.

10. A blue object viewed in red light appears

- A. Blue
- B. Red
- C. Purple
- D. Black

Short Answer: Answer all parts of the questions in the spaces provided on the answer sheet. You do not have to answer in complete sentences.

11. On the answer sheet, fill in the blanks with the names of the different kinds of electromagnetic waves, in order of increasing wavelength.

12. On the answer sheet, complete the diagram to explain what color the viewer observes. Please write a few sentences to explain the diagram.

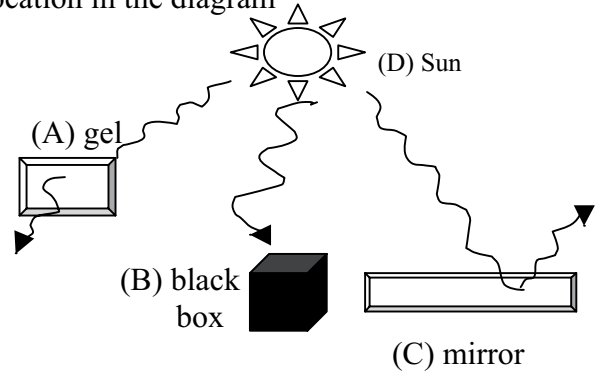
Name: _____

1.3 Student Answer Sheet—Learning about Infrared Light

Directions: Write all of your answers on this answer sheet. Do NOT Write on the test.

Matching: Below is a diagram. Mark your answer on the answer sheet, not on the test. Circle the letter that corresponds to the question items location in the diagram

- | | | | | |
|-------------------------|---|---|---|---|
| 1. Reflection | A | B | C | D |
| 2. Partial Transmission | A | B | C | D |
| 3. Absorption | A | B | C | D |
| 4. Emission | A | B | C | D |



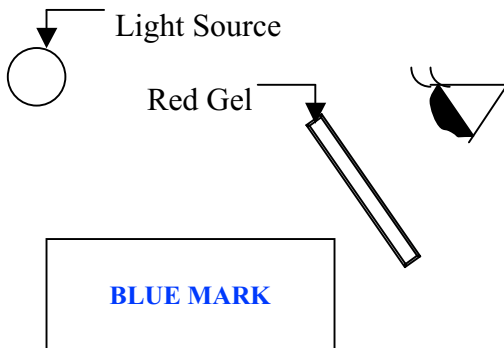
Multiple Choice: Circle the letter of the one best answer for each question.

- | | | | | |
|-----|---|---|---|---|
| 5. | A | B | C | D |
| 6. | A | B | C | D |
| 7. | A | B | C | D |
| 8. | A | B | C | D |
| 9. | A | B | C | D |
| 10. | A | B | C | D |

Short Answer: Answer all parts of the questions in the spaces provided on the answer sheet. You do not have to answer in complete sentences.

11. _____, _____, _____, _____, _____
_____, _____

12. Explain what color the viewer observes. You may also use a few sentences to clarify your answer.



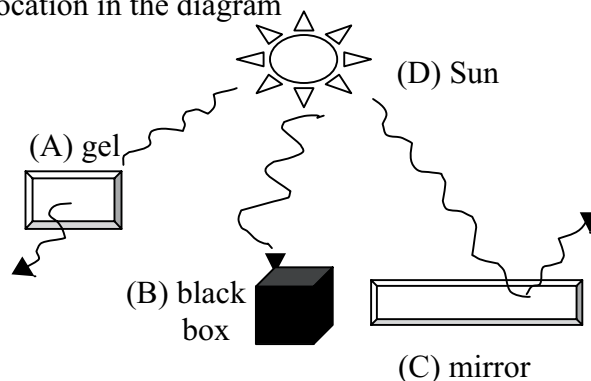
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1.4 Teacher Answer Key—Learning about Infrared Light

Directions: Write all of your answers on this answer sheet. Do NOT Write on the test.

Matching: Below is a diagram. Mark your answer on the answer sheet, not on the test. Circle the letter that corresponds to the question items location in the diagram

- | | | | | |
|-------------------------|----------|----------|----------|----------|
| 1. Reflection | A | B | <u>C</u> | D |
| 2. Partial Transmission | <u>A</u> | B | C | D |
| 3. Absorption | A | <u>B</u> | C | D |
| 4. Emission | A | B | C | <u>D</u> |



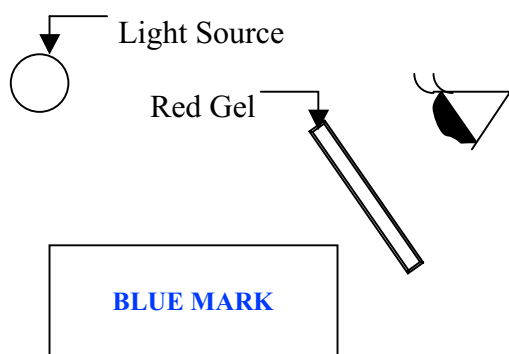
Multiple Choice: Circle the letter of the one best answer for each question.

- | | | | | |
|----|---|----------|----------|----------|
| 5. | A | B | <u>C</u> | D |
| 6. | A | B | <u>C</u> | D |
| 7. | A | <u>B</u> | C | D |
| 8. | A | B | C | <u>D</u> |
| 9. | A | <u>B</u> | C | D |
| 10 | A | B | C | <u>D</u> |

Short Answer: Answer all parts of the questions in the spaces provided on the answer sheet. You do not have to answer in complete sentences.

11. gamma, x-ray, ultra-violet light, visible light, infrared light, microwave, radio

12. Explain what color the viewer observes. You may also use a few sentences to clarify your answer.



Through the red gel, the student will only be able to see the blue mark. The red filter absorbs the blue light that is reflected by the blue mark. Therefore, no light reaches the eye from the mark, the blue will appear black.

1.4 Teacher Answer Key—Learning about Infrared Light

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MATERIALS AND PREPARATION

CLASSROOM MATERIALS

CRAYONS

Suggested colors for the red and blue crayons, respectively, are: Crayola orange-red, violet red, blizzard blue, and aquamarine.

MAGNIFYING GLASS

Magnifying lens may be purchased in a set or individually, from:

Sargent Welch**

P.O. Box 5229

Buffalo Grove, IL 60089-5229

Phone: (800) 727-4368

<http://www.sargentwelch.com>

5 cm diameter bifocal, plastic (Item # WLS 44501) Cost: \$3.95

5 cm diameter economy, plastic (Item # WL 8068) Cost: \$1.60

Lens set: A set of 20 lenses 50 mm in diameter (10 each of 285 mm focal length, and 10 each of 96 mm focal length) This set is also used in the “More than Magnifiers” GEMS activity.

(Item # WL53200-38L) Cost: \$19.99

Flinn Scientific Inc

P.O. Box 219

Batavia, IL 60510

Phone: (800) 452 -261

<http://www.flinnsci.com/>

Plastic Magnifier Dual Lens (Item # AB1134) Cost: \$1.75

SPECIAL MATERIALS

DIFFRACTION GRATING

Holographic diffraction gratings can be purchased as a roll (6 feet x 5 inches) for \$38 or in 5 x 5 inch sheets (2 sheets for \$9) from:

Learning Technologies, Inc.**

40 Cameron Avenue

Somerville, MA 02144

Phone: (800) 537-8703 or (617) 628-1459

Fax: (617) 628-8606 fax

<http://www.starlab.com>

1.5 Materials and Preparation

Or in a 12cm square, mounted between glass plates (Item #WL3820) for \$46.76 from:

Sargent Welch
P.O. Box 5229
Buffalo Grove, IL 60089-5229
Phone: (800) 727-4368
<http://www.sargentwelch.com>

ELECTRONIC ITEMS

The following items can be found at your local electronic parts store.

AA BATTERY HOLDER

This battery holder should have wire connectors

AMPLIFIER/SPEAKER

200 mWatt speaker (Input sensitivity 1mV, Input impedance 5k, distortion (1kHz) < 2% THD @ 200mW, Frequency Response 100 Hz – 10 kHz)
This is the most expensive part for the detector, typically costing \$11.99.

AUDIO CABLE

Audio cables must have a 1/8" mini-plug on at least one end. We prefer audio cable that has a mini-plug on one end, and exposed wires on the other (easier to connect with the jumper cables), but mini-plugs on both ends will work too. Note that a Y-Adapter Audio Cable will not work in this activity. Audio Cables typically cost around \$3 - \$4.

CAPACITOR

Sub mini PC mount with radial leads, 0.22 μ F, 50 WVDC max.

JUMPER CABLES

Be sure to get cables with mini-alligator clips on both ends.

LED

This Infrared Light Emitting Diode (LED) emits IR with a peak wavelength of 940 nm (0.94 μ m).

The vendors and Item # for these electronic parts are:

Radio Shack**

at local Radio Shack stores

Phone: (800) the-shack

<http://www.radioshack.com>

AA battery holder (Item #270-401) Cost ~ \$0.89

Amplifier/Speaker (Item #277-1008C) Cost: \$11.99

Audio cable (Item #42-2434 or 42-2378) Cost: \$3-\$4

Capacitor (0.22 μ F) (Item #272-1070) Cost ~ \$0.89

1.5 Materials and Preparation

Jumper cables (Item #278-1157) Cost for a bag of eight: \$3.99
LED (Item #276-143 or #276-142) Cost ~ \$1.79

Philmore-DATAK
3660 Publishers Drive
Rockford, IL 61109
Phone: (800) 645-2262
<http://www.philmore-datak.com>

Call for pricing

Infrared LED (Item #11-681)
Audio cable 1/8" mini to tinned leads (Item #CA48)
Jumper lead set (Item #SA22)

Mouser Electronics
1000 North Main St.
Mansfield, TX 76063
Phone: (800) 346-6873
<http://www.mouser.com>

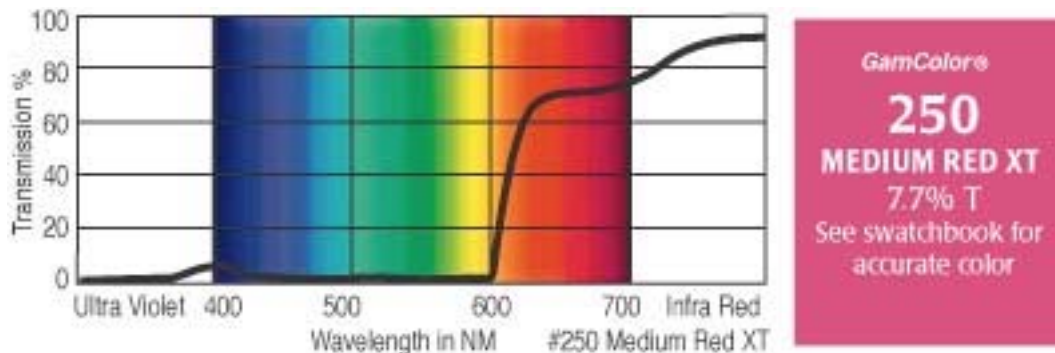
AA Battery Holder (Item #534-2465) Cost: \$0.58
Capacitor (Item #140-PM2A224K) Cost: \$0.36
Amplifier/Speaker: For those electronically inclined, speaker parts may be purchased and assembled into a mini amp/speaker.

GELS

Theatrical gels (filters) are normally used to change the colors of lights in the theater, film, and television work. Because of the need for reliable color, these gels are made to exacting specifications with regard to which wavelengths of light they transmit and which ones they absorb. You can buy gels at a local theatrical supply store, or directly from the companies listed below.

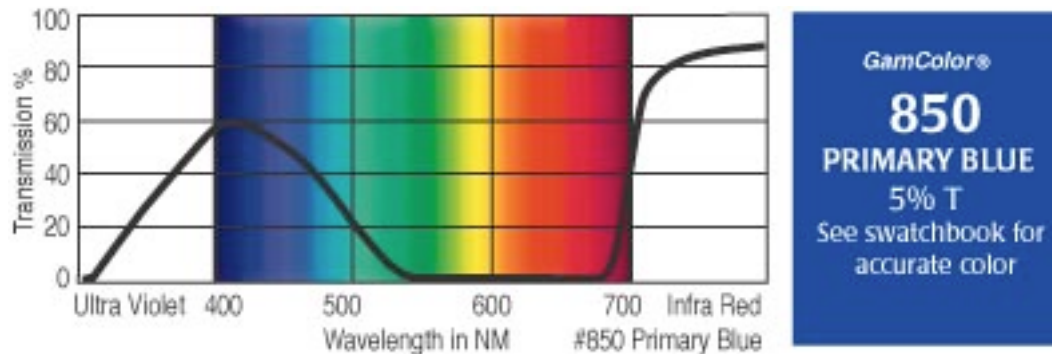
We recommend the following gels (filters), shown with the light transmission curve (percent of light transmitted at each wavelength) for each:

GamColor #250 Medium Red XT

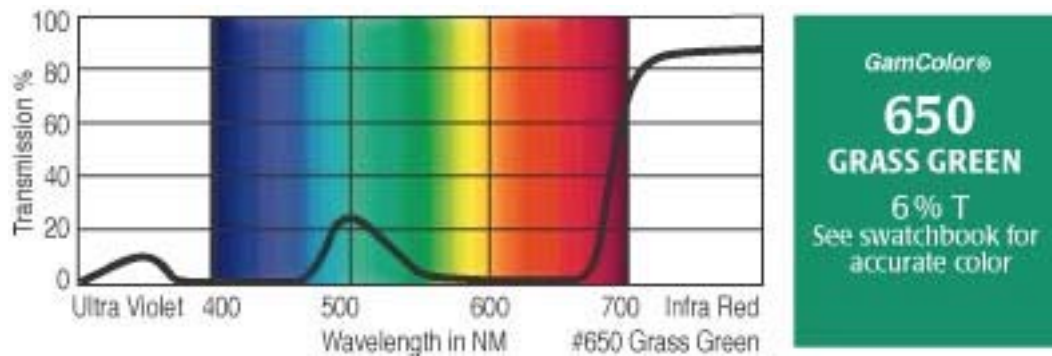


1.5 Materials and Preparation

GamColor #850 Primary Blue



GamColor #650 Grass Green



These gels can be obtained from:

Great American Market (GamProducts, Inc.)**

826 N. Cole Avenue

Hollywood, CA 90038

Toll-free phone:(888)GAMCOLOR

Phone: (323)461-0200

Fax: (323)461-4308

<http://www.gamonline.com/catalog/gamcolor/index.shtml>

The web site lists local dealers of their products. Filters cost \$6.25 for a 20-inch by 24-inch sheet, the smallest size available. You can also get a “junior roll” that corresponds to nearly 10 sheets (24 inches by 198 inches) for \$49.95.

Mainstage Theatrical Supply, Inc distributes GAM Color Gels.

Two locations:

Milwaukee, WI

Phone: (800) 236 0878

Pensacola, FL

Phone: (800) 851 3618

Online: <http://www.mainstage.com/Catalogs.html>

If your local supplier does not carry GamColor filters, you can find acceptable substitutes from among the following products (with recommended filter numbers for each):

Roscolux Filters

Rosco USA

52 Harbor View

Stamford, CT 06902

Toll-Free Phone: (800)767-2669

Phone: (203)708-8900

Fax: (203)708-8919

#80 Primary Blue

#27 Medium Red

#389 Chroma Green

For information on filters:

<http://www.rosco-ca.com/products/filters/index.cfm?fuseaction=Roscolux#Color>

To find local dealers of Roscolux filters:

http://www.rosco-ca.com/intl/top_offices.html

Note that Cinegel filters are also made by Roscolux

Or

LEE Filters

2237 N. Hollywood Way

Burbank, CA 91505

Phone: (800)576-5055

Fax: (818)238-1228

<http://www.leefilters.com/home.asp>

#106 Primary Red

#079 Just Blue

#139 Primary Green

Note that you can compare the light transmission curves for these alternative filters (many available online) with those of the recommended GamColor gels. If you use an alternative filter, try to match the transmission curves as closely as possible. You want filters that transmit as much blue or red light as possible, with as little light with other wavelengths transmitted as you can get.

1.5 Materials and Preparation

SOLAR CELLS

The solar cell in this application is an encapsulated mini solar panel. The vendors and part numbers are:

Solar World**

2807 North Prospect

Colorado Springs, CO 80907

<http://www.solarworld.com>

Phone: (719) 635-5125

Fax: (719) 635-5398

Solar Cell 0.5A at 0.5V, 3" x 1 3/4" (Item #3-300) Cost: \$6.00

Silicon Solar

LLC 16 Winkler Rd.

PO Box 225

Sidney, NY 13838

http://www.siliconsolar.com/solar_cells.htm

Solar Cell .42 A at .58 V 25mm x 62.5mm (Item #SS SC 400)

Cost: \$2.25

Ward's Natural Science

<http://www.wardsci.com/>

Phone: (800) 962-2660

Solar Cell 0.2 A at 0.45 V 2" x 4" (Item #16 V 0508) Cost: \$8.75

****vendor products pilot tested**

PREPARATION

Detailed preparation instructions are in each teacher note section. The information below is supplemental.

2.1 "What's Getting Through to You"

Slide sized sections of the gels can be mounted into a piece of cardboard for each student. The images can be downloaded and printed as overhead slides, in lieu of internet access during class.

4.1 "Reflection"

The reflection activities are more successful with stable mounted mirrors. Wood blocks with grooves or kerfs, or modeling clay are recommended.

3.1 "Sensing the Invisible" and 5.1 "Listening to Light"

This material package contains materials for one each photocell detector receiver and transmitter circuits, for demonstration. For student teams, additional materials may be purchased as indicated above. The Teacher Notes in Sections 3.1, and 5.1 contain detailed assembly instructions for the photocell detector receiver and transmitter circuits. Hard metal to metal connections to complete the circuits, and very fresh batteries are key to the success of the activities.

As stated in the teacher notes, the audio cable leads can be connected directly to solar cell leads. If soldering materials or wire nuts are not available, hook and twist the leads together and insulate with electrical tape. Similarly, the jumper leads can be cut in half, wire stripped and connected to the battery holder, and to the second audio cable (for the sound source). The alligator clip to alligator clip connections must be head on and insulated as shown below.



OVERVIEW

Table of Vendors

Item:	Vendor:	Alternate vendor(s):
diffraction grating	Learning Technologies	Sargent Welch
electronic items	Radio Shack	Philmore-DATAK, Mouser Electronics
gels	GAM Products, Inc.	Roscolux Filters, LEE Filters
magnifying glass	Sargent Welch	Flinn Scientific Inc.
solar cells	Solar World	Silicon Solar, Ward's Natural Science

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WHAT'S GETTING THROUGH TO YOU? TEACHER NOTES

2.1 What's This About?

Students are introduced to light and colored gels (filters). Students make and test predictions about light and color using gels, by looking at messages written with differently colored crayons on differently colored paper with differently colored gels. Students then learn about the importance of gels (filters) to astronomers by looking at an astronomical image through red and blue gels and comparing the parts of the image that are enhanced by the gels. Then, they analyze images taken with regular and infrared cameras to see that objects opaque to light at one wavelength may be transparent to light of a different wavelength.

Suggested Grade Levels

7-12

Suggested Time Required

100 minutes

Suggested Learning Outcomes

After completing this activity, students will be able to:

- Predict the color of light that is transmitted through a gel.
- Describe why astronomers use gels to observe and interpret light emitted by objects in space.
- Compare the transmission qualities of visible and infrared light.

Student Prerequisites

- Students are assumed to be familiar with the visible spectrum and to have some knowledge of the electromagnetic spectrum, and how it relates to the visible spectrum.
- Students are assumed to have some familiarity with the idea of reflected, absorbed and transmitted light, and to understand the terms “opaque” and “transparent.”

Common Misconceptions

Students may have the following misconceptions, which should be addressed in the activity.

- Students may not realize that light travels from one object to another, and that they “see” an object because of the light reflected off of it.
- Students may think that black represents all colors mixed together.

The Activity

PART I — HIDDEN MESSAGES

The students will make and test predictions about light and color using filters.

This activity familiarizes students with the behavior of filters or gels. The student begins by predicting what blank white, red, and black paper will look like through the red and blue gels, then testing their predictions. This gives students a better understanding of the function of gels (filters). The student is then asked to predict what they will see when they look through red and blue gels at two superimposed messages, one written in red, the other in blue, on white and black construction paper, before testing their prediction by looking at the messages through the gels.

Messages written with red and blue crayon work well in this activity, while those made using felt markers of any kind do not. Encourage students to use a heavy hand when writing their messages, that is, to write thick letters, to make the messages easier to see and read through the gels. The gels used should be theatrical gels because they are made in ways that ensure they transmit only certain wavelengths of light (see the Materials section below for more on the gels). Colored cellophane will not work properly. The darker the black construction paper, the better the results students will get.

When looking at the messages on the white construction paper, students should find that they need to look through the blue gel to read the red message, and vice versa. Conversely, when looking at the messages on the black construction paper, they need to look through the red gel to read the red message, and the blue gel to see the blue message.

Note that reading the messages on the black construction paper is more difficult than on the white paper and may cause problems for students. The point to stress is that students cannot see the same-colored message when looking through a gel at the white paper, but can see the same-colored message when looking at the black paper. This is easier to see when using the red gel, which does not allow any blue light to pass through it. Because of the way they are made, blue gels do allow some red light to pass through them. This can allow students to see both messages when looking through the blue gel at the black paper, which they may find confusing.

If this happens, encourage students to focus on the red gel. Ask students to note whether they can see the red message when looking through the red gel at the white paper. They should not be able to see it, or see it only faintly. The blue message, however, should be very noticeable (appearing black). Then ask students if they can see the red message when looking through the red gel at the black paper. The red message will appear bright against the black background, although they may not be able to read it clearly. Similarly, students should see the red message quite clearly when looking through the blue gel at the white paper, while having trouble seeing the blue message. And the blue message will appear brighter than the black background when viewed through the blue gel at the black paper. However, students may still be able to see the opposite-colored message through the gels when looking at the black paper, especially when using the blue gel; the messages will appear “blacker than black.”

2.1 Teacher Notes—What's Getting Through to You?

In the last activity of this section, students look at an image of the Crab Nebula (<http://www.physics.montana.edu/classes/101/adams/sofia/crabnebula.html>) through red and blue gels. You should download this image in advance and have it ready on a computer monitor that students can see. This relates what students have been doing with gels to the practical application of ways that astronomers use them. It shows how astronomers use filters to help them more easily observe particular aspects of astronomical objects. It also shows the effect that the background has on filter selection. On a white background, a red gel was chosen to see a blue message whereas on a black background, a red gel is chosen to see a red message. Be aware that your students may have improperly generalized the knowledge they gained and feel that to view a red object, you must use the blue colored gel, regardless of the background.

A more extensive treatment of light and color, intended for grades 5 - 8, can be found at <http://www.lhs.berkeley.edu/GEMS/GEM225&226.html>

PART II — HIDDEN STARS

The student will recognize that objects opaque to light of one wavelength may be transparent to light of a different wavelength.

The purpose of this section is to introduce students to the idea that different wavelengths of light can pass through some everyday objects but not through others. Students look at two images of a plastic bag over a toaster. One image was taken in visible light “Visible Light View of a Hot Toaster,” the other with a camera that registers infrared light “IR Light View of a Hot Toaster.” You should download all these images in advance from the *Section 2 Images File* on the CD and have them available on a computer monitor for students to see.

Students should notice that the infrared camera can “see” the toaster, even if something (like a plastic bag) blocks visible light reflected from it from reaching a camera. This reinforces the idea that not all wavelengths of light are visible to the human eye. Students may hold the belief that if an object is opaque to visible light, no other wavelengths of light will pass through it. Conversely, students may hold the belief that if an object is transparent to visible light, it will be transparent to all wavelengths of light. If your students seem to be having trouble with these ideas, show them that an opaque plastic bag does not block the IR signal from a remote control from turning on a television. Make sure they understand that the remote control emits infrared light (that’s how it signals the television), and that the infrared light passes through the plastic bag in the same way that heat from the toaster passed through the plastic bag and was recorded by the camera.

Students may not realize that the toaster behind the bag emits infrared light, or heat. They may think they see it because of reflected infrared light, as the visible light reflected off the bag. This provides an opportunity to stress that infrared wavelengths corresponds to radiant heat.

Finally, students look at two images of logos covered by a piece of fabric (<http://www.physics.montana.edu/classes/101/adams/sofia/multiband-logo.html>) the “Multi-Band Logo” images are also included in the *Section 2 Images File* on the CD. One image shows the scene in visible light; students see only the fabric cover which hides the logos. The second image is taken in the infrared; students will see the logos through the fabric which is transparent

2.1 Teacher Notes—What's Getting Through to You?

to IR. Not all fabric is transparent to IR, only some synthetics. The papers on which the logos are printed are at room temperature, heated by the Sun and the bricks beneath them. As a result, they emit infrared radiation, the amount of which depends on the color of print on the paper (dark areas of the paper are cooler than light-colored areas). As a result, the logos (written with black ink on white paper) show up against the rest of the paper's background. The fabric is not a good emitter of infrared light, and so does not appear in the infrared photograph.

BACKGROUND SCIENCE

Astronomers often use different “filters” to make images with telescopes, but this name can be a little misleading. A *red filter* is designed to block out all colors *except* red; any green or blue light, for example, will not get through this substance. Often this is confusing because we think of filters being designed to keep a particular substance out. In an attempt to avoid this confusion, we have used the term *gel* (rather than filter) here to refer to the theatrical acetate sheets used in this activity. *Note: as you read the following description, it is helpful to do the activity at the same time.*

When you look through a red gel at a white sheet of paper, the paper appears red. White light – a combination of all colors – is reflecting off of the paper in all directions. However, only the red light is allowed to pass through the gel and go into your eyes. Thus, the paper looks red. If you switch to a blue gel, mostly blue light will pass through the gel and the paper will appear blue.

SOFIA SCIENCE

At the infrared wavelengths that SOFIA observes, interstellar dust does not interfere with the infrared light traveling through space. SOFIA is able to make observations of previously unstudied objects.

What happens when you look at something red through the red gel? Look at the red and white construction paper at the same time. The red paper appears red to our eyes because it reflects the red light that hits it and absorbs all other colors. When you look through the red gel, since red is reflecting from both the red and white papers, both sheets will appear the same color: red. Now look at these with the blue gel. No blue is reflecting from the red paper, but blue will be reflected off the white paper. The white paper appears blue, but the red paper should look black, indicating an absence of light passing through the gel. In reality the sheet may not appear true black because of scattering, color variations in the paper, and gel density – but it should be a noticeable difference.

When you look through a red gel at a message written with a blue crayon on a white piece of paper, the blue light reflected from the blue crayon is absorbed by the red gel, and the writing looks black. On the other hand, red light reflected from the red crayon mixes with the red light reflected from the white paper, making it hard to distinguish the red message from the background paper. Similarly, the red light reflected from a red crayon message is absorbed by the blue gel, and the writing looks black. The blue light reflected from the blue crayon mixes with blue light reflected from the white paper, making it hard to see the blue message through the blue gel. Thus, a red gel makes it easier to see blue messages on white paper, and vice versa.

2.1 Teacher Notes—What's Getting Through to You?

When you look through a red gel at a message written in blue crayon on a black piece of paper, however, the blue light reflected from the blue crayon is absorbed by the red gel, and the writing looks black. This writing mixes with the black background, making it hard to see the message. On the other hand, red light reflected from the red crayon, passes through the red gel, making the red message stand out against the black background. In the same way, the red light reflected from a red crayon message is absorbed by a blue gel, making the red writing look black and blend in with the black background. The blue light reflected from the blue crayon passes through the blue gel, making the blue message stand out against the black background. Thus, a red gel makes it easier to see a red message on black paper, and a blue gel makes it easier to see a blue message on the same paper.

Astronomers collect light of many different wavelengths emitted by objects in space. Each part of the spectrum emitted by an object contains specific information about that object, so different detectors can be used to learn about different things. For example, an infrared telescope can be used to view objects whose visible light images are obscured by interstellar dust. For some color pictures of this effect see SIRTf's web site at <http://www.ipac.caltech.edu/Outreach/Edu/importance.html>. The “IR Telescope Images” are also included in the *Section 2 Images File* on the CD. That’s because the wavelengths of infrared light are too large to be scattered effectively by the tiny grains of interstellar dust. Visible light, however, with its smaller wavelengths closer in size to the dust grains, is effectively scattered by the dust. In a similar way, scattering also explains why sunsets are red and the sky is blue. Molecules in the Earth’s atmosphere scatter blue light more effectively than red light, because blue wavelengths are closer in size to that of the molecules, hence, the sky is blue. When the Sun is near the horizon, its light must pass through a large amount of air, and, as a result, nearly all the blue light is scattered out of the line of sight (to be seen overhead as a blue sky), making the Sun look red.

The image used in this activity, the Crab Nebula, is a supernova remnant. In 1054 AD, Chinese astronomers recorded the sudden appearance of a star where they had never seen one before. It shone brightly in the night sky for several months, before fading from view. When modern astronomers look in the position in the sky where the Chinese recorded the “guest star,” they see this nebula, a huge cloud of glowing gas and dust. A massive star, much more massive than our Sun, had ended its life in a super-explosion. Having used up all the nuclear fuel at its center, the star’s core collapsed catastrophically, then rebounded in a powerful explosion that tore the star to pieces. What we see in the Crab Nebula now is the material that once made up the star expanding outward at speeds of several thousand kilometers per second.

Another example of how astronomers use other regions of the electromagnetic spectrum to observe the universe, an astronomer could detect x-rays from extremely hot matter, such as the material in the center of a supernova, even though visible light is blocked by surrounding dust (for more information about x-ray astronomy, see the web site for the Chandra x-ray satellite at <http://xrtpub.harvard.edu/edu/chandra1018.html>).

Infrared detectors used in astronomy are made out of materials sensitive to infrared light, such as lead sulfide, germanium, and indium-antimony alloys. Similarly, the cameras used to make the infrared photographs shown in this activity have detectors sensitive to infrared light. Many use

2.1 Teacher Notes—What's Getting Through to You?

Charge-Coupled Devices, or CCDs, as detectors. CCDs are electronic chips made out of a grid-like array of squares, or picture elements (pixels for short). When a light photon strikes a pixel, it generates an electric charge. The more photons that strike the pixel, the higher its charge. At the end of an exposure, a computer monitors the total electrical charge in each pixel, resulting in a picture that shows how many photons are coming from where. More information about CCDs and how they work can be found at:

<http://www.sciencenet.org.uk/database/Technology/9810/t00246d.html>

In the photographs studied by students in this activity, areas with high numbers of infrared photons (that is, areas that are warmer) appear bright, while areas emitting low numbers of infrared photons (colder) appear dark.

Materials Needed

- white paper
- black and red construction paper
- red and blue crayons*
- red and blue gels*
- Internet access or downloaded versions of the images mentioned (Crab Nebula, Visible Light View of a Hot Toaster, IR Light View of a Hot Toaster and the Multi-band logo)

*see section 1.5 for more details

2.2 PART I — HIDDEN MESSAGES

Name _____ Date _____ Period _____

White light, like the light from the Sun or a light bulb, is made up of many different colors. In this activity, you will explore light and color.

MATERIALS: Red and blue crayons, sheets of white, red, and black construction paper, and red and blue “gels” (a gel is simply a sheet of transparent colored plastic).

A. Predict what color, if any, you will see when you look at a blank white, red, and black sheet through the red gel and through the blue gel.

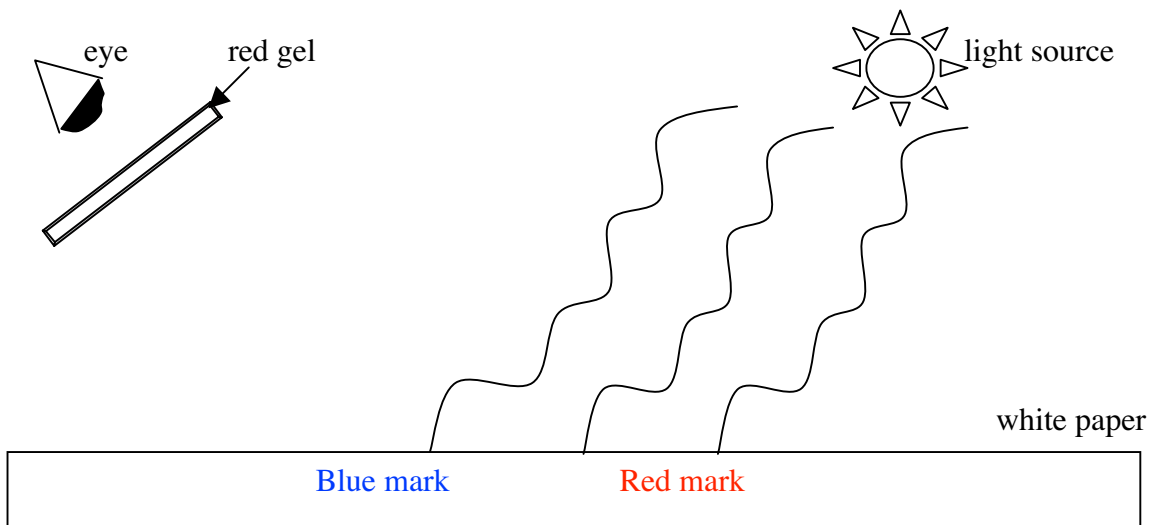
		blank white sheet	blank red sheet	blank black sheet
red gel	Predicted			
	Observed			
blue gel	Predicted			
	Observed			

Explain your reasoning for the predictions you just made.

B. Isaac Newton, a 17th century scientist, discovered that white light is comprised of all colors. You might have seen this if you’ve ever directed white light (such as a flashlight, a slide projector beam, or sunlight) through a prism. Another example is a rainbow in the sky, which is created when water droplets in the atmosphere act like a prism and separate sunlight into its colors.

1. According to Newton’s theory, what colors of light are bouncing off the white sheet and entering your eye (when no gel is present)?
2. Now, look at the blank sheet of white paper through the red gel. Write the color you see, if any, in the appropriate column of the table above. Did this match your earlier prediction?

C. Use the red and blue crayons to complete the diagram below, showing the path that each color of light travels after it is reflected from the blue and red mark on the white paper through the red gel to your eye.



D. Predict what you will see if you look at a blank sheet of RED paper through the BLUE gel. (Hold the construction paper overhead, with room lights behind, to avoid a glare) Explain your reasoning using a sketch if necessary. Then test your prediction and write what you see in the table in Part A.

E. Look at a blank sheet of black paper through the red gel.

1. Write down what you see in the table in Part A. Did this match your prediction? Repeat with the blue gel.
2. Consider the following statements from two students:

Student #1: I've heard that black is a combination of all colors. So, when we look at something that appears black, we're seeing all the colors mixed together.

Student #2: I've heard that black is the absence of all colors. So, when we look at something that appears black, we're not seeing any reflected light.

State whether you agree or disagree with EACH student and use your observations in explaining your choices.

- With one crayon, write the same message on both the white and the black blank sheets of paper. With the other crayon, on each sheet, write a second message directly on top of the first, so that the first message is partly covered by the second. It is okay if, when you are done, you are not able to clearly read the two messages.

Predict which message you will be able to read, if any, when you look at the white sheet and the black sheet through the red gel, and then through the blue gel.

		which message you will see on white paper	which message you will see on black paper
red gel	Predicted		
	Observed		
blue gel	Predicted		
	Observed		

- Test your predictions by looking at the messages with each of the gels. Explain why the red gel reveals the message that it does for each sheet of paper.
- When you looked at the messages on the white and black paper through a gel, you could read one of the two messages, without it being obscured by the other message. Astronomers use gels, which they call "filters", in a similar manner when they look at the sky. Sometimes when an astronomer wants to look at a particular star or nebula, he or she will use a filter to select part of the light from that star or nebula to study to highlight specific features of visible in that one color.

Go to the following web site:

<http://www.physics.montana.edu/classes/101/adams/sofia/crabnebula.html>

(This image is also included in the “Images File” on the CD-ROM)



Image copyright ©1995 by Sven Kohle and Till Credner.

1. If you only wanted to look at the center of the nebula, and didn't want to be distracted by the light coming from the outer edges of the nebula, which gel do you think you should use, red or blue? Explain your reasoning.

2. Look at the picture on the computer screen through the gel. Was your prediction correct?

PART II — HIDDEN STARS

Name _____ Date _____ Period _____

In PART I — HIDDEN MESSAGES, you placed gels between your eyes and the objects at which you were looking. This blocked some of the colors of visible light from reaching your eyes. Sometimes, however, things exist between us and the objects we wish to observe that block all the visible light from reaching our eyes.

- A. Look at the picture entitled "Visible Light View of a Hot Toaster." It shows a toaster covered in a plastic bag. As you can see, the plastic bag blocks all the visible light bouncing off the toaster. Does this mean that the plastic bag will block all wavelengths of the electromagnetic spectrum?
- B. Now look at the picture entitled "Infrared Light View of a Hot Toaster." It shows the same toaster, but this picture was taken with a camera that detects infrared light.
1. Draw a sketch of the toaster with the bag in front of it, showing what is happening in both the visible light and infrared light ranges of the electromagnetic spectrum.
 2. With your group, think of any differences or similarities between what happened when you looked through the gels in Part I of this activity and what happened with the plastic bag in these pictures. Draw a Venn diagram for the gels and the plastic bag using your red and blue crayons and a black pen or pencil.

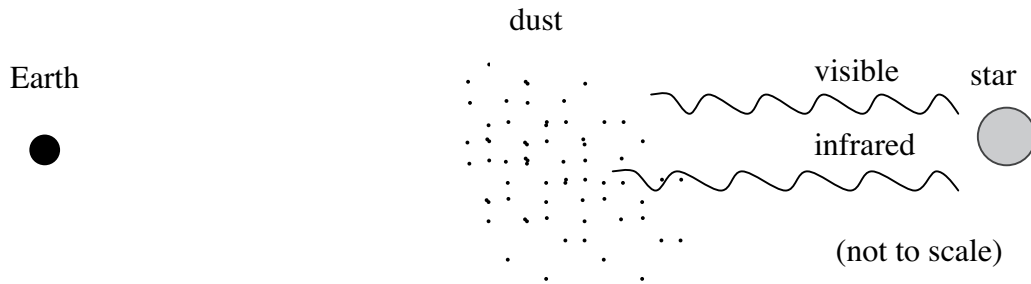
- C. Plastic bags aren't the only things that are opaque to visible light, but allow infrared light to pass through. The URL: <http://www.physics.montana.edu/classes/101/adams/sofia/multiband-logo.html> (this image is also included in the CD-ROM) shows two pictures of the same thing, one taken with a standard video camera and one with a camera that detects infrared light.

Explain why can't you see the SOFIA logo in the photo taken with visible light.

- D. Recall that infrared light is not visible to the naked eye, and that it corresponds to the energy given off by thermal radiation or heat. Write down as many actual uses of infrared light and cameras that register infrared light that you can think of.

- E. In space, there are small particles of dust called interstellar dust, because the dust particles float in the nearly empty spaces between the stars. This dust behaves like the plastic bag and the striped cloth in the pictures. It is opaque to visible light, but allows other parts of the electromagnetic spectrum to pass through, most notably infrared light.

- Complete the sketch below showing the effect of interstellar dust on the light from a star. Show the path that visible light takes once it leaves the star, and the path that infrared light takes.



- Explain why an astronomer would use an infrared telescope to look at the star.

2.3 Teacher Answer Key—What's Getting Through to You?

2.3 PART I — HIDDEN MESSAGES

Name _____ Date _____ Period _____

White light, like the light from the Sun or a light bulb, is made up of many different colors. In this activity, you will explore light and color.

MATERIALS: Red and blue crayons, sheets of white, red, and black construction paper, and red and blue “gels” (a gel is simply a sheet of transparent colored plastic).

A. Predict what color, if any, you will see when you look at a blank white, red, and black sheet through the red gel and through the blue gel.

		blank white sheet	blank red sheet	blank black sheet
red gel	Predicted	<i>Answers will vary</i>	<i>Answers will vary</i>	<i>Answers will vary</i>
	Observed	<i>red</i>	<i>red</i>	<i>black</i>
blue gel	Predicted	<i>Answers will vary</i>	<i>Answers will vary</i>	<i>Answers will vary</i>
	Observed	<i>blue</i>	<i>black</i>	<i>black</i>

Explain your reasoning for the predictions you just made.

Answers will vary.

B. Isaac Newton, a seventeenth century scientist, discovered that white light contains all colors. You might have seen this if you've ever directed white light (such as a flashlight, a slide projector beam, or sunlight) through a prism. Another example is a rainbow in the sky, which is created when water droplets in the atmosphere act like a prism and separate sunlight into its colors.

1. According to Newton's theory, what colors of light are bouncing off the white sheet and entering your eye (when no gel is present)?

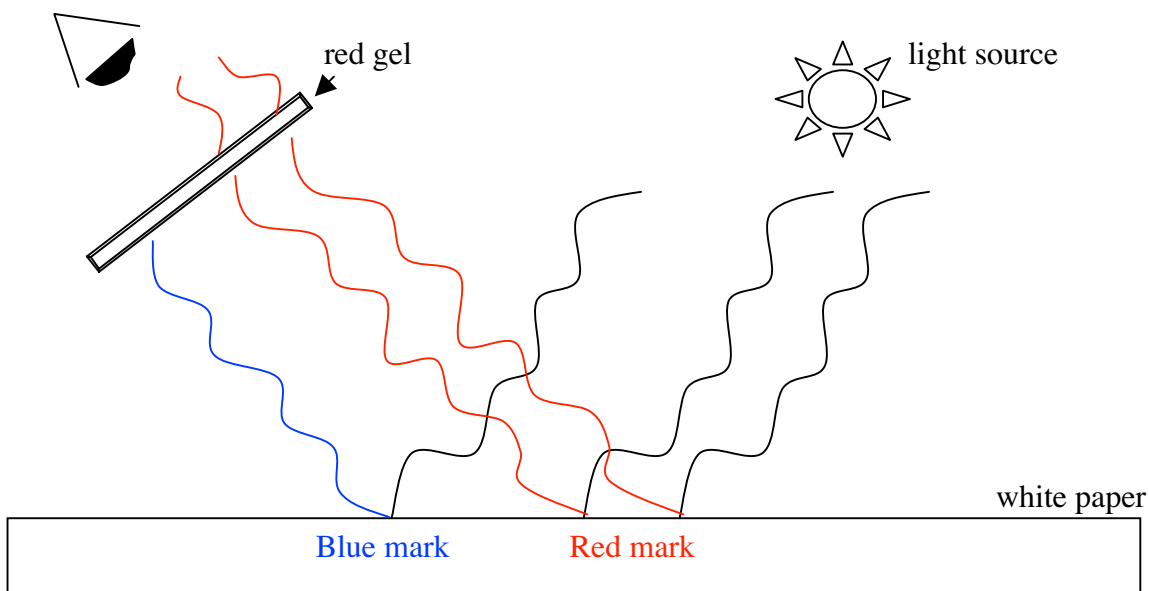
All colors of light are bouncing off the sheet and entering your eye when no gel is present.

2. Now, look at the blank sheet of white paper through the red gel. Write the color you see, if any, in the appropriate column of the table above. Did this match your earlier prediction?

2.3 Teacher Answer Key—What's Getting Through to You?

White paper viewed through the red gel looks red because the red gel absorbs (or blocks) all the other colors reflecting off the white paper, keeping them from reaching your eye. Only the red light can pass through the gel, so the paper looks red.

- C. Use the red and blue crayons to complete the diagram below, showing the path that each color of light travels after it is reflected from the white paper through the red gel to your eye.



The diagram should show red light bouncing off the paper, passing through the gel and entering the eye. Blue light bounces off the paper, but is absorbed or stopped by the gel and does not enter the eye.

- D. Predict what you will see if you look at a blank sheet of RED paper through the BLUE gel and write your prediction in the table. Explain your reasoning using a sketch if necessary. Then test your prediction and write what you see in the table.

The red paper reflects only red light. The blue gel absorbs or blocks the red light (only blue light can pass through the gel). Thus no light gets through the gel, and the red paper looks black when viewed through the blue gel.

- E. Look at a blank sheet of black paper through the red gel. Write down what you see in the table. Did this match your prediction? Repeat with the blue gel.

2.3 Teacher Answer Key—What's Getting Through to You?

The black paper should look black through the red gel and through the blue gel. No light reflects off the black paper, so there is no light to pass through the gels. Note that the black paper may not look perfectly black because of scattering, color variations in the paper, and gel density.

F. Consider the following statements from two students:

Student #1: I've heard that black is a combination of all colors. So, when we look at something that appears black, we're seeing all the colors mixed together.

Student #2: I've heard that black is the absence of all colors. So, when we look at something that appears black, we're not seeing any reflected light.

State whether you agree or disagree with EACH student and use your observations in explaining your choices.

Disagree with Student #1. White is made up of all colors mixed together, as we saw when we looked at the same white paper with the red and blue gels. Both red and blue light were reflected from the white paper.

Agree with Student #2. Black is the absence of all colors, as we saw when we looked at the same piece of black paper with the red and blue gels. Neither red nor blue light was reflected from the black paper. No color is reflected from the black paper.

G. With one crayon, write the same message on both the white and the black blank sheets of paper. With the other crayon, on each sheet, write a second message directly on top of the first, so that the first message is partly covered by the second. It is okay if, when you are done, you are not able to clearly read the two messages.

Predict which message you will be able to read, if any, when you look at the white sheet and the black sheet through the red gel, and then through the blue gel.

		which message you will see on white paper	which message you will see on black paper
red gel	Predicted	<i>Answers will vary</i>	<i>Answers will vary</i>
	Observed	<i>blue</i>	<i>red</i>
blue gel	Predicted	<i>Answers will vary</i>	<i>Answers will vary</i>
	Observed	<i>red</i>	<i>blue</i>

H. Test your predictions by looking at the messages with each of the gels. Explain why the red gel reveals the message that it does for each sheet of paper.

2.3 Teacher Answer Key—What's Getting Through to You?

When you look through a red gel at a message written with a blue crayon on white paper, the blue light reflected off the crayon is absorbed by the red gel, and the writing looks black against the background. On the other hand, red light reflected off the red crayon message mixes with the red light reflected from the white paper, making it hard to distinguish the red message from the background paper. Thus, it is easier to see the blue message (which appears black) on the white paper through the red gel.

When you look through a red gel at a message written with a blue crayon on black paper, the writing still looks black, but it is now seen against a black background (since the black paper doesn't reflect any light it appears black, no matter what gel is used). On the other hand, the red light reflected off the red crayon message passes through the gel and appears as a brighter red against a black background. So, you should more easily see the red message (which appears red) on the black paper through the red gel.

- I. When you looked at the messages on the white and black paper through a gel, you could read one of the two messages, without it being obscured by the other message. Astronomers use gels, which they call "filters", in a similar manner when they look at the sky. Sometimes when an astronomer wants to look at a particular star or nebula, he or she will use a filter to select part of the light from that star or nebula to study to highlight specific features of visible in that one color.

Go to the following web site:

<http://www.physics.montana.edu/classes/101/adams/sofia/crabnebula.html>

(This image is also included in the "Images File" on the CD-ROM)



Image copyright ©1995 by Sven Kohle and Till Credner.

2.3 Teacher Answer Key—What's Getting Through to You?

1. If you only wanted to look at the center of the nebula, and didn't want to be distracted by the light coming from the outer edges of the nebula, which gel do you think you should use, red or blue? Explain your reasoning.

Blue. The outer parts of the nebula are red, while the inner parts are blue. Because the background of the picture is black, you would use a blue gel to see the blue inner parts.

2. Look at the picture on the computer screen through the gel. Was your prediction correct?

Answers will vary.

2.3 Teacher Answer Key—What's Getting Through to You?

PART II — HIDDEN STARS

Name _____ Date _____ Period _____

In Part I of this activity, you placed gels between your eyes and the objects at which you were looking. This blocked some of the colors of visible light from reaching your eyes. Sometimes, however, things exist between us and the objects we wish to observe that block all the visible light from reaching our eyes.

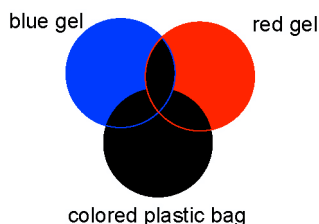
- A. Look at the picture entitled "Visible Light View of a Hot Toaster." It shows a toaster covered with a plastic bag. As you can see, the plastic bag blocks all the visible light bouncing off the toaster. Does this mean that the plastic bag will block all wavelengths of the electromagnetic spectrum?

No. Just because the plastic bag blocks visible light does not mean it will block all other wavelengths of the electromagnetic spectrum.

- B. Now look at the picture entitled "Infrared Light View of a Hot Toaster." It shows the same toaster, but this picture was taken with a camera that detects infrared light.
1. Draw a sketch of the toaster with the bag in front of it, showing what is happening in both the visible light and infrared light ranges of the electromagnetic spectrum.

The sketch should show the toaster, the plastic bag and a camera. Visible light coming from the toaster is absorbed by the plastic bag and doesn't pass through it to the camera. Infrared light, on the other hand, passes through the plastic bag and enters the camera.

2. With your group, think of any differences or similarities between what happened when you looked through the gels in Part I of this activity and what happened with the plastic bag in these pictures. Draw a Venn diagram for the gels and the plastic bag.



2.3 Teacher Answer Key—What's Getting Through to You?

- D. Plastic bags aren't the only things that are opaque to visible light, but allow infrared light to pass through. The URL: <http://www.physics.montana.edu/classes/101/adams/sofia/multiband-logo.html> (this image is also included in the CD-ROM) shows two pictures of the same thing, one taken with a standard video camera and one with a camera that detects infrared light. Explain why can't you see the SOFIA logo in the photo taken with visible light.

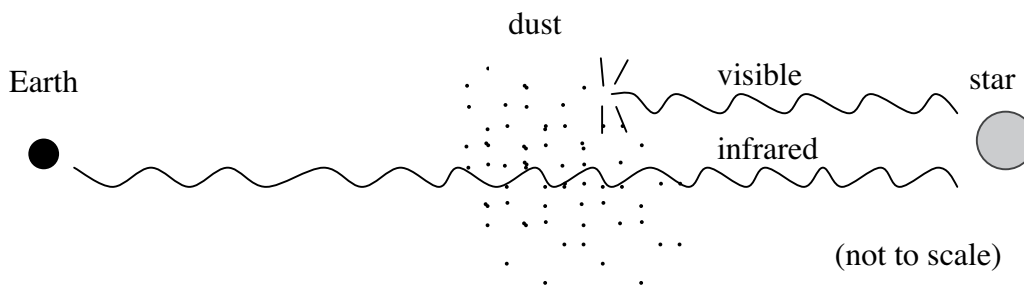
The logo is covered by the fabric, which is opaque to visible light coming from behind it. However, it is not opaque to infrared light emitted by the paper, which can be detected by an infrared-sensitive camera.

- D. Recall that infrared light is not visible to the naked eye, and that it corresponds to the energy given off by thermal radiation or heat. Write down as many actual uses of infrared light and cameras that register infrared light that you can think of.

Among the uses listed may be: TV remote, car-locking system, grocery store check-out scanners, computers (to read CD-ROMs), night vision goggles, search and rescue monitors, weather satellites, fire-fighting (to see where fires are), keep food warm at restaurants, astronomical observations, environmental monitoring, medical scanning, looking for places where heat is lost from buildings

- E. In space, there are small particles of dust called interstellar dust, because the dust particles float in the nearly empty spaces between the stars. This dust behaves like the plastic bag and the striped cloth in the pictures. It is opaque to visible light, but allows other parts of the electromagnetic spectrum to pass through, most notably infrared light.

1. Complete the sketch below showing the effect of interstellar dust on the light from a star. Show the path that visible light takes once it leaves the star, and the path that infrared light takes.



The diagram should show visible light coming from the star, and being scattered out of the line of sight from the star to the Earth by the dust. Infrared light, however, will leave the star, pass through the dust cloud and come straight to Earth.

2. Explain why an astronomer would use an infrared telescope to look at the star.

2.3 Teacher Answer Key—What's Getting Through to You?

Since infrared light can pass through the dust cloud without being scattered, astronomers will be able to study infrared light from the star to learn about the star. Looking at the star with a visible-light telescope will reveal only the dust cloud, and no information about the star behind it.

Sensing the Invisible — Teacher Notes

3.1 What's This About?

Just as our ears cannot hear all wavelengths of sound, our eyes cannot see all wavelengths of light. Students build a photocell detector, and use it to detect different colors of light in a spectrum. Then they place the detector just outside the red region of the spectrum and see that the detector detects the presence of light there, even though there is no color visible. Students learn that "invisible light" exists and that we can detect this light with instruments other than our eyes. In a final part of the activity, students investigate the IR signals emitted by TV and VCR remote controls.

Suggested Grade Levels

7-12

Suggested Time Required

50 minutes

Suggested Learning Outcomes

After completing this activity, students will be able to:

- Describe a method for observing light using a photocell detector.
- Predict the color of light transmitted through a gel.
- Identify the infrared as a form of invisible light that is located next to the color red in the visible spectrum.

Student Prerequisites

- Students are assumed to be familiar with the visible spectrum and to have some knowledge of the electromagnetic spectrum, and how it relates to the visible spectrum.
- This activity assumes some familiarity assembling and working with electronic circuits.

The Activity

This activity assumes that students work with the materials in small groups. This requires the purchase of enough materials for each group to make their own photocell detector, in addition to each group needing its own overhead or slide projector. This activity can also be done as a teacher-led demonstration, with the teacher manipulating only one photocell detector and using only one overhead projector, or set up as an experimental station in the classroom.

SOFIA SCIENCE

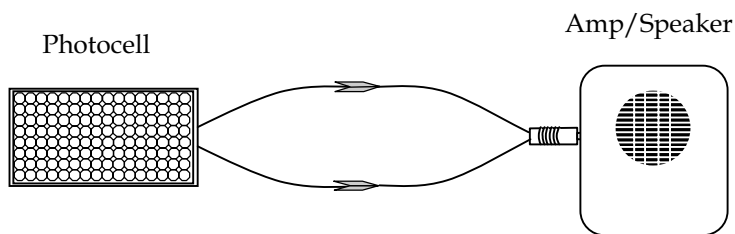
Flying at 41,000 feet, SOFIA will be above 99% of our atmosphere's obscuring water vapor that absorbs infrared radiation from the universe. The crew works in a commercial airliner environment for 8 or 9 hours at a time.

3.1 Teacher Notes—Sensing the Invisible

Part I - Hearing Light: *Students will use a detector to hear the presence of light.*

Since we cannot see infrared light, we must detect it with another of our senses. This activity leads students to "hear" infrared radiation via a photocell and speaker.. Students first consider how to tell, while blindfolded, if a cow is standing in a gym. Instead of the cow analogy, the instructor could also bring objects that have distinctive sounds and smells into the classroom and ask the students to close their eyes and identify them. Students then build a simple photocell detector, and see what happens when they move their hand back and forth in front of it. This same photocell detector is also used in the “Listening to Light” activity.

The photocell (or solar cell), connected as shown below, produces an electric current when exposed to light. Because of the way speakers are constructed, a changing current is needed to produce a sound in the speaker; a constant current will not produce a sound. When a constant light source illuminates the photocell, it produces a constant current and no sound is produced. Students should hear static, if anything, when a constant light source illuminates the photocell. When the light is continuously interrupted, or “chopped”, the current produced will continuously change and the speaker will produce a series of “pops” each time the light is chopped back on. NOTE: For best results, turn off any overhead fluorescent lights in the classroom. Fluorescent lights will generate a constant hum , which may interfere with students’ hearing sound from the visible spectrum.



To make the photocell detector, use jumper cables to connect the photocell with the amplifier/speaker (requires a 9 volt battery). Clip one alligator clip from a jumper cable to one of the leads from the photocell, and clip the alligator clip at the other end of the jumper cable to one of the leads of the audio cable (which has its 1/8" mini-plug plugged into the "input" of the amp/speaker). Use a second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.

This works best if you use an audio cable with a mini-plug on one end, and two exposed wire leads on the other. You can also use an audio cable with a mini-plug on both ends. In this case, connect the alligator clip from one jumper cable near the end of the mini-plug, and connect the alligator clip from the other jumper cable near the base of the mini-plug (next to the plastic piece that protects the rest of the audio cable). Be sure both alligator clips are in contact with metal parts of the mini-plug, and that they do not touch one another. Note that a Y-Adaptor Audio Cable will not work in this activity.

The chopper can be as simple as someone moving their hand back and forth in the beam of light, or as complicated as a fan placed in the light beam either before or after the diffraction grating. Since the chopper is required for so much of this activity, a fan is recommended. Be sure the fan used has spaces between the blades, to allow light to shine periodically through the fan.

Part II - The Visible Spectrum: *Students predict what portions of the spectrum are blocked by colored filters and then test their predictions. They recognize that some colors are not primary, but are the addition of several primary colors.*

We recommend using a holographic diffraction grating to produce a visible spectrum using light from a slide projector or overhead projector. A holographic diffraction grating will produce a brighter, more spread out, color spectrum that students will find easier to use. A prism placed in a light beam will also produce a visible spectrum, but it will tend to be fainter, with the colors less dispersed, which makes it harder for students to make their measurements.

There are two ways you can generate a spectrum with a diffraction grating: with an overhead projector or a slide projector. If you use an overhead projector, place two pieces of 8" x 10" construction paper on the overhead, instead of a transparency, so that there is a slit about 1" wide on the base plate of the projector. Turn on the projector lamp and focus the projector on a white wall or screen. Place the diffraction grating (about 4 or 5 inches square) in front of the upper lens of the overhead, and rotate the grating until the spectrum appears on either side of the projected slit on the wall or screen. Note that this works best in a very dark room. You can place a fan in front of the diffraction grating to act as a chopper, or wave your hand back and forth.

3.1 Teacher Notes—Sensing the Invisible



Overhead projector set up for EM spectrum projection using black construction paper. Slit width can be adjusted for best projection of visible and IR radiation. Recommended width is approximately 2.5cm.

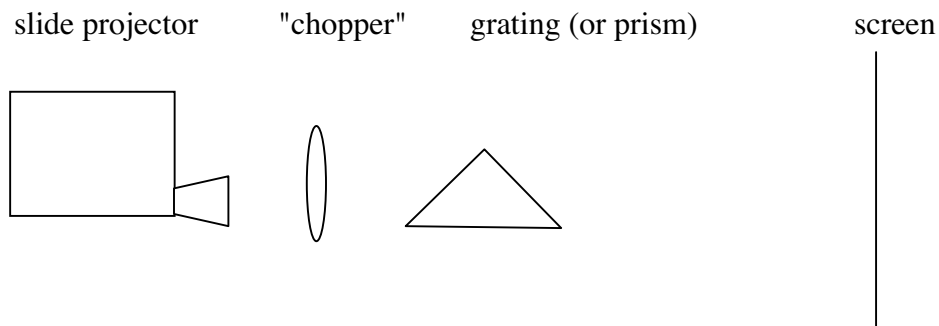
Overhead Projector Head with Holographic Grating attached



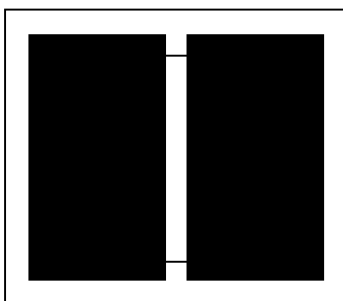
Note: The holographic grating is available pre-mounted between glass panes. This may reduce IR transmission.

3.1 Teacher Notes—Sensing the Invisible

Alternative method: *NOTE: Using a prism produces much narrower dispersion than using the holographic spectrum grating, and makes the experiments harder to conduct. It is included in the event that you do not have access to a holographic grating. A slide projector can also be used to generate the spectrum as shown in the figure below.*



The regular beam from a slide projector is too broad to generate a good spectrum. To limit the beam, you can make a slide using common undeveloped photographic film or pieces of black electrical tape. Mount two pieces of undeveloped film in a slide mount with a space between them, as shown in the figure below, to produce a line of light.



Place the slide with the mounted film in it in the projector, and turn on the projector's lamp. The slide should make a white vertical line on the screen or wall. Focus the projector. Place the diffraction grating in front of the projector lens. Rotate the grating until the spectrum appears on either side of the white line on the screen or wall. *Note that this works best in a very dark room.*

Once the spectrum is visible on a screen or wall where you want it, tell students not to move the projector and diffraction grating (or prism). When placing a gel into the beam of light, have students hold the gel between the diffraction grating and the screen or wall where the spectrum is displayed. It works best if they hold the gel close to the grating, so all of the light from the projector passes through the gel.

Theatrical gels are readily available from any theater supply store or can be ordered directly from the manufacturer (for more information, see the Materials Needed section below). We use the word "gel" instead of "filter" because filter can cause confusion. Some students may think that a red filter takes out the red, while others may feel that a red filter would allow only red to go

3.1 Teacher Notes—Sensing the Invisible

through. It is clear from this activity that a red gel allows red to pass through while absorbing the other colors of the visible spectrum. Students will also see that a green gel allows some blue and yellow light to pass through it, in addition to the green. This is proof that green is not a primary color, like red, blue and yellow. *Note that theatrical gels are required for this activity; colored cellophane works poorly or not at all.*

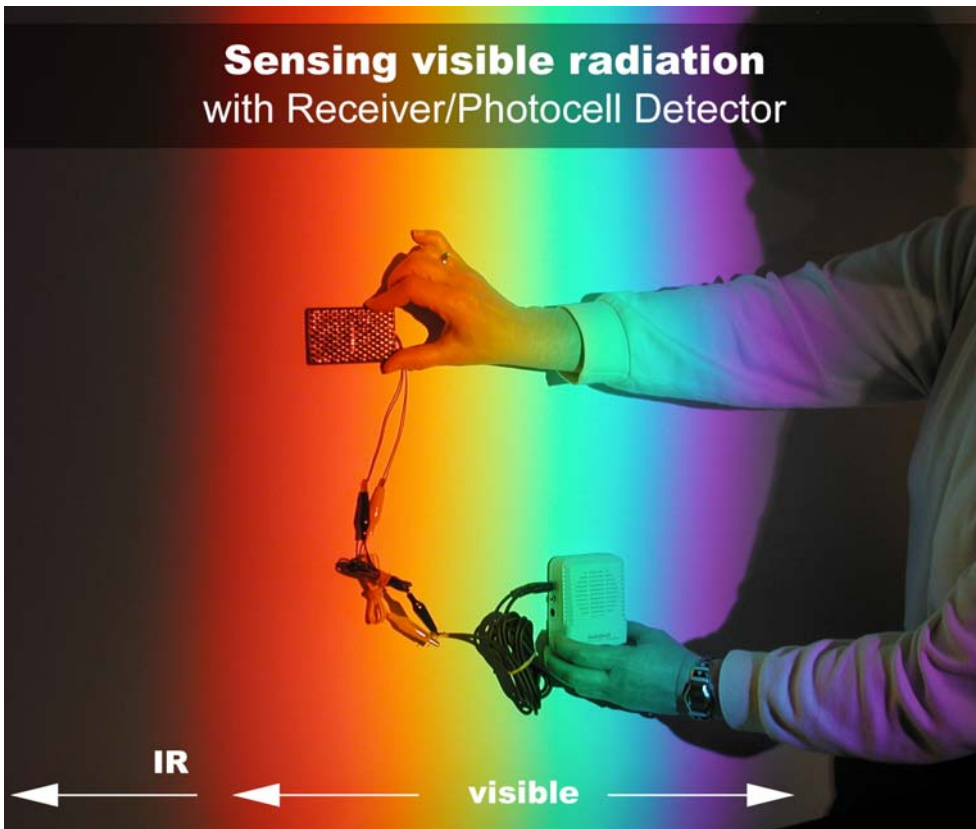
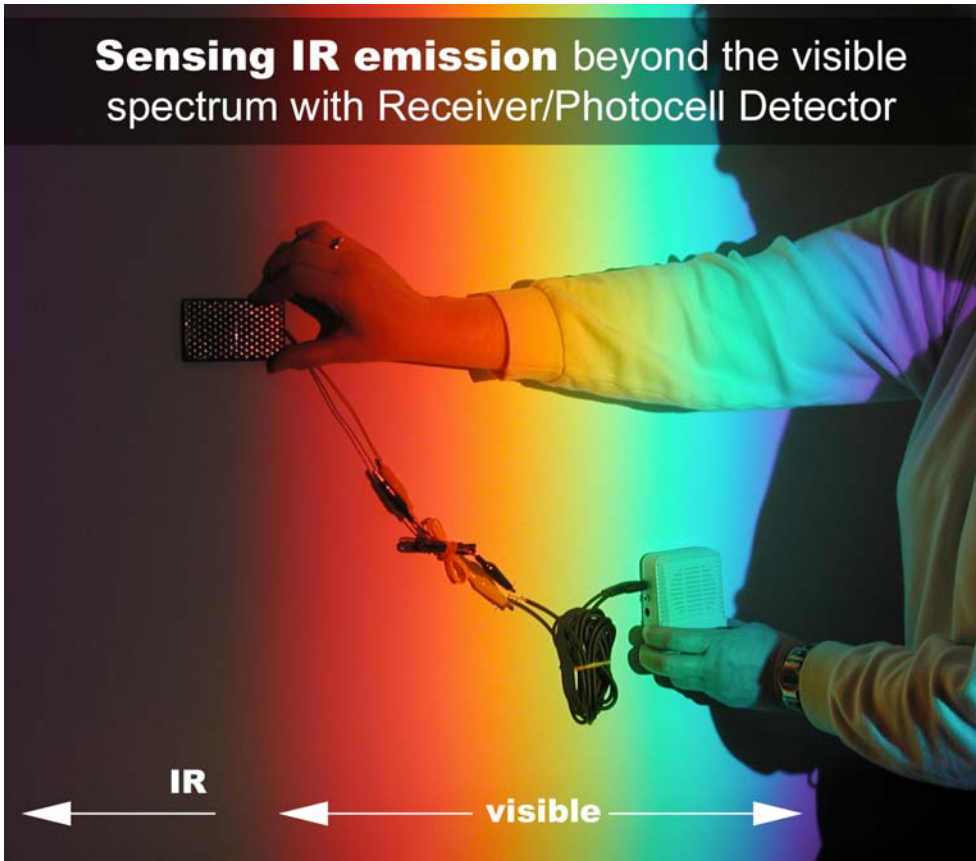
Part III - Where is the End of the Rainbow? *Students find that radiation exists beyond the red portion of the spectrum.*

This activity emphasizes the use of gels. In the visible spectrum, a red gel allows only red light to pass through (transmit). The green gel allows green—plus some blue—light to go through. Both gels, however, should allow infrared light to pass through them to the photocell detector. If you look at the transmitted light curves for the two gels (given in the Materials Needed section below), you can see that both gels transmit more than 80% of light at infrared wavelengths.

The bulb in a slide projector or overhead projector generates infrared light as well as visible light. When the light passes through a diffraction grating (or prism), the infrared light is spread out, as are all of the constituent colors of the visible light. The sound generated by the photocell just beyond the red part of the spectrum is evidence of infrared light. Many slide projectors contain infrared-absorbing glass inside them, to absorb heat from the lamp and keep it from melting the slides. This may reduce the amount of infrared light available for students to detect. Even with the reduced infrared output, students should be able to “hear” infrared light with their photocell detector when no gels are used. However, they may have trouble detecting infrared light with the photocell when the gels are used, since the gels do reduce even further the amount of infrared light transmitted. The gels (especially the red and green gels together) may, therefore, cut the intensity of infrared light enough to drop it below the threshold for detection of the photocell. If this happens, explain to the students that if the detector was more sensitive, they would have detected an infrared signal even with both the red and green gel in the beam of light.

To ensure that students place the photocell in such a way as to detect the infrared, suggest students start by placing the photocell in the red. Then suggest they move it just outside the red and see if they still detect anything. Students can then move the detector slightly farther away from the red, continuing until they no longer detect any signal from the photocell. This helps students see that the infrared is a continuation of the visible spectrum.

This activity emphasizes that infrared is the same as visible light except that our eyes are not able to detect it. Stars, planets, comets, galaxies, interstellar dust and molecules all emit at many wavelengths. Some only emit radiation in the infrared and radio. Viewing objects in different regions of the electromagnetic spectrum through the use of filters and different kinds of telescopes gives astronomers more information about the universe.



3.1 Teacher Notes—Sensing the Invisible

Part IV - The remote control: *Students investigate the IR signals used by TV remote control devices.*

This activity demonstrates one way in which students use infrared light in their everyday lives. They will hear different pitches and sounds when they aim remote controls from different manufacturers at the photocell. They may even hear different pitches and sounds when they press different buttons on a single remote control. For example, a remote control that controls both a VCR and a TV will produce different sounds from the photocell when you press the buttons that relate to the TV versus the buttons that relate to the VCR. These different pitches and sounds illustrate why a Sony remote control won't work on an RCA TV.

If printing costs are an issue, the instructions for this part of the lesson can be given verbally by the teacher or written on the board. Without the instructions for Part IV, the student handout is only four pages (two pages back-to-back). Students can then be instructed to write the results of their experiments with the remote controls on a separate piece of paper.

If you would like students to read more about infrared light, the following web sites contain appropriate material:

For the story of how Sir William Herschel discovered infrared light in 1800:

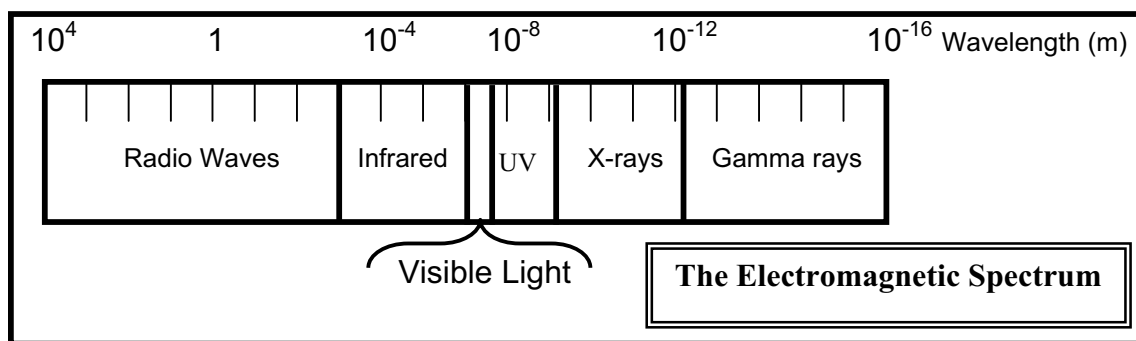
http://sirtf.caltech.edu/Education/Herschel/herschel_bio.html

For more information on how infrared light is used in our everyday world:

<http://sirtf.caltech.edu/Education/IRapp/benefits.html>

Background Science

Visible light and infrared light are simply two different parts of the electromagnetic spectrum. The spectrum is composed of electromagnetic waves. Different parts of the spectrum correspond to different ranges of wavelengths. Radiation or light with wavelengths between $0.4\mu\text{m}$ ($1\mu\text{m} = 10^{-6}\text{m}$) and $0.7\mu\text{m}$ are visible to the human eye. Radiation or light with wavelengths between $0.7\mu\text{m}$ and 1.6 mm is called infrared light. Infrared waves are not visible to the human eye, but since they are the same type of waves as visible light, they exhibit the same properties. For example, like visible light, infrared light can reflect off a mirror.



Because of its longer wavelengths, infrared light is not absorbed by the gels students use in this activity (the gels are maximized to absorb certain visible wavelengths). As a result, it passes through the red and green gels and is detected by the photocell. The longer wavelengths also enable infrared light to pass through huge clouds of gas and dust between stars, which efficiently scatter and absorb visible light that tries to pass through them. Thus, astronomers can learn about what is happening in the centers of these clouds by observing in the infrared. Because of this, infrared astronomy has helped astronomers learn about the life cycles of very young stars, born in the centers of these huge clouds of gas and dust; the young stars cannot be seen in visible light.

The wavelengths of infrared light correspond to those of thermal radiation, or heat. Students sense infrared light every time they sit next to a campfire, hold their hand over the hot burners of a stove, or sit outside on a nice sunny day. Your skin is a good IR detector. Generally speaking, the warmer an object, the more infrared light it emits. For more information on infrared light, and its uses, see:

<http://www.ipac.caltech.edu/Outreach/Edu/infrared.html>

This web site includes background information on infrared light, as well as examples of ways in which people use infrared light, e.g., in meteorology, search and rescue, and environmental monitoring. For more classroom activities involving infrared light, including the same experiment done by Sir William Herschel in 1800 in which he discovered the existence of light outside the visible spectrum, see: http://sirtf.caltech.edu/SSC_EPO.html

Solar Photo Cells: The solar cell used in this activity is known as a photovoltaic cell because it converts light (photo) into electricity (voltaic). When visible or infrared light strikes the solar cell, some of it is absorbed by the special material (usually silicon), called a semiconductor, out of which it is made. The energy of the absorbed light is transferred to the semiconductor material, knocking electrons in it loose. These loose electrons can then move freely throughout the material, resulting in an electric current. Most solar cells also have one or more electric fields in them which force the moving electrons to flow in one direction. By placing metal contacts at the top and bottom of the solar cell, the current flowing within it can be drawn off for use externally. In the case of this activity, the current generated by the light is sent to the amplifier/speaker, where it is converted into sound waves, which we can hear. For more detailed information about how a solar cell works, see: <http://www.howstuffworks.com/solar-cell.htm>

3.1 Teacher Notes—Sensing the Invisible

Speakers: Inside a speaker, a flexible cone (usually made of paper, plastic, or metal) vibrates rapidly in response to a changing electrical current. As it moves, it pushes the air molecules around it. Those air molecules, in turn, push the air molecules near them, and the vibration is transmitted through the air as a sound wave. Our ears detect the vibration of air molecules and convert them into an electrical signal that our brain interprets as music. Within the speaker, the flexible cone needs a changing current to vibrate. If the current is constant, the cone will not vibrate. For more information on how speakers work, see:

<http://www.howstuffworks.com/speaker.htm>

Remote Controls: When you press the button of a remote control, an electrical connection is made that tells a computer chip inside the remote which button was pressed. The chip then produces a morse-code-like electrical signal that is different and distinct for each button. Transistors inside the remote control amplify the signal and send it to a Light-Emitting Diode, or LED, a kind of small light bulb. The LED converts the electrical signal into infrared light. Because the LED emits infrared light, which our eyes cannot detect, we do not see any light passing between the remote control and the TV (or VCR). But, the TV (or VCR) has a detector which can see infrared light. Depending on the exact nature of the signal (its wavelength, frequency, or intensity), the TV (or VCR) carries out the desired command. Note that many camcorders can also detect infrared light. If you aim a remote control at a camcorder and push a button, you should see infrared light flashing in the viewfinder. For more information about how remote controls work, see: <http://www.howthingswork.com/inside-rc.htm>

MATERIALS NEEDED

- Slide Projector or Overhead Projector
- Holographic diffraction grating or prism*
- Fan (optional)
- Masking tape
- 2 pieces of 8" x 10" construction paper
- Slide mount (if using slide projector)
- Undeveloped photographic film, or black electrical tape (if using slide projector)
- Photocell Detector (This device is also used in "Listening to Light.")
 - Solar cell*
 - Amplifier/Speaker*
 - Audio Cable with 1/8" mini-plug on one end*
 - 2 Jumper Cables with alligator clips on both ends*
 - 9 Volt Battery for Amplifier/Speaker
- red and green gels*
- Remote control devices (for TV, VCR, etc.) from several different manufacturers
- Philips screw driver

*see section 1.5 for details

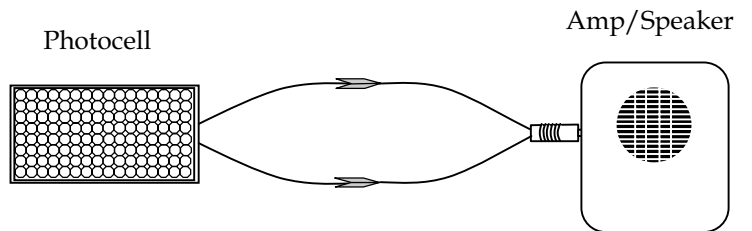
3.2 PART I — HEARING LIGHT

Name _____ Date _____ Period _____

- A. How can we tell that something is there if you can't see it? Let's pretend that there is a cow standing in the middle of the school gym. You are blindfolded and put into the gym as well.

List several different ways that you could tell if the cow was also in the gym without taking off your blindfold.

- B. A photocell uses light to generate an electric current. When transmitted through the wires to the speaker, this current can generate a sound. Make sure the photocell is connected to the speaker. Conduct the following experiments and record what you hear.



Experiment	What do you hear?
Shine a flashlight directly on the photocell	
Move your hand back and forth so that you interrupt or "chop" the light	
Place an electric fan in the beam of light so that the blades of the fan chop the light	

Describe what must happen to “hear” light with a photocell.

PART II — THE VISIBLE SPECTRUM

As you know, white light can be split up into a spectrum of colors. Your teacher has set up a diffraction grating (or prism) in the beam of a projector to produce the visible spectrum on the wall. Place a strip of masking tape along the top or bottom of the spectrum, and mark the location of the red, yellow and green bands of light on the masking tape. Once the locations are marked, be careful not to move the equipment (projector, grating, chopper).

In the rest of this activity, we will be using "gels." A gel is a sheet of colored plastic, which your teacher will provide.

- A. Predict what the spectrum will look like if a red or green gel is placed in the beam of the projector (either before or after the beam passes through the grating) and fill in the first line of the table below. Explain your reasoning. Then test your prediction by placing the gel in the beam. Fill in the rest of the table based on your observations.

Experiment	Red Gel	Green Gel
Predict what the spectrum will look like when you place a gel in the beam of the projector. Explain your reasoning.		
What color(s) of the spectrum does the gel allow to pass through?		
What color(s) of the spectrum does the gel block or absorb?		
What do you see at the location of yellow light in the spectrum?		
Predict what color(s) will appear on the wall when both a red and green gel are placed in the beam. Explain your reasoning and your results.	Put your prediction here	Record your observation here

PART III — WHERE IS THE END OF THE RAINBOW?

In Part I we found that we could hear light with a photocell, provided we "chop the light" to create a changing voltage in the photocell. You'll need to use a "chopper" between the light source and the wall for the remainder of this experiment, either an electric fan or a student moving their hand rapidly back and forth in the beam of light.

- A. Leave the projector, grating, and chopper set up as in Part II. Hold the photocell in the red region of the spectrum on the wall. If the chopper is in place, you should "hear" the red light at this location. Predict what you will hear when you make the following changes to the beam, while holding the photocell in the same location on the wall. Then record your actual observations, and, in the column labeled "Conclusion," explain why you think your observed results happened.

Experiment	Prediction	Observation	Conclusion
Place a red gel in the beam			
Place a green gel in the beam			
Place both a red and green gel in the beam			

- B. Move the photocell to the dark region right next to the red part of the spectrum. Predict what you will hear when you make the following changes to the beam, while holding the photocell in the same location on the wall. Then record your actual observations, and, in the column labeled “Conclusion,” explain why you think your observed results happened.

Experiment	Prediction	Observation	Conclusion
Hold the photocell in the dark region right next to the red part of the spectrum.			
Place a red gel in the beam.			
Place a red and green gel in the beam.			

The grating spreads white light out into a spectrum of colors. What do you think is interacting with the photocell to produce the sound in the dark region next to the red part of the spectrum? Explain your answer.

Astronomy is often like detecting the cow when you are blindfolded. Much like the red and green gels combined, interstellar dust can absorb all visible light sent in our direction by stars and other sources. Astronomers must then "look" for light from these sources in the invisible part of the spectrum to observe the obscured stars and other objects.

PART IV — THE REMOTE CONTROL

The invisible light near the red part of the spectrum is called infrared light (IR). Remote controls like those used with TVs and VCRs use IR signals to send commands to televisions, VCRs, etc.. Your instructor will provide several remote controls with which to experiment. Point a remote control at the photocell and push a button. Describe what you hear in the table below. Try different buttons on the same remote and different brands of remote controls, and describe what you hear in each case.

Indicate which button is pushed and which brand of remote control is used	Describe what you hear.

Explain why a Sony remote will not operate an RCA television.

3.3 PART I – HEARING LIGHT

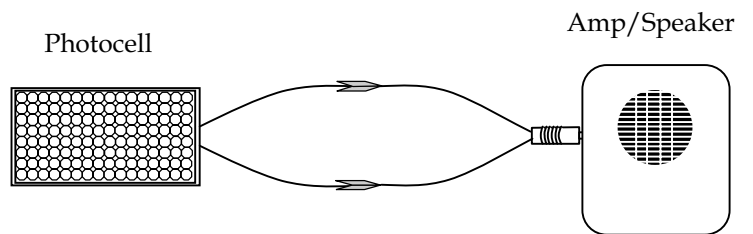
Name _____ Date _____ Period _____

- A. How can we tell that something is there if you can't see it? Let's pretend that there is a cow standing in the middle of the school gym. You are blindfolded and put into the gym as well.

List several different ways that you could tell if the cow was also in the gym without taking off your blindfold.

You would have to use your other senses. Listen for sounds (moo), smell the cow, walk around and touch it, although I doubt you'd want to taste it, you could.

- B. A photocell uses light to generate an electric current. When transmitted through the wires to the speaker, this current can generate a sound. Make sure the photocell is connected to the speaker. Conduct the following experiments and record what you hear.



3.3 Teacher Answer Key—Sensing the Invisible

Experiment	What do you hear?
Shine a flashlight directly on the photocell	<i>Nothing. Static.</i>
Move your hand back and forth so that you interrupt or "chop" the light	<i>A popping sound each time the light is chopped on.</i>
Place an electric fan in the beam of light so that the blades of the fan chop the light	<i>A more constant popping sound.</i>

Describe what must happen to “hear” light with a photocell.

Light cannot be constant. It has to continuously be turned on and off, or chopped, to hear it.

PART II – THE VISIBLE SPECTRUM

As you know, white light can be split up into a spectrum of colors. Your teacher has set up a diffraction grating (or prism) in the beam of a projector to produce the visible spectrum on the wall. Place a strip of masking tape along the top or bottom of the spectrum, and mark the location of the red, yellow and green bands of light on the masking tape. Once the locations are marked, be careful not to move the equipment (projector, grating, chopper).

In the rest of this activity, we will be using "gels." A gel is a sheet of colored plastic, which your teacher will provide.

- A. Predict what the spectrum will look like if a red or green gel is placed in the beam of the projector and record your predictions in the first line of the table below. Explain your reasoning. Then test your prediction by placing the gel in the beam. Fill in the rest of the table based on your observations.

Experiment	Red Gel	Green Gel
Predict what the spectrum will look like when you place a gel in the beam of the projector. Explain your reasoning.	<i>Answers will vary.</i>	<i>Answers will vary.</i>
What color(s) of the spectrum does the gel allow to pass through?	<i>Red</i>	<i>Green and some blue</i>
What color(s) of the spectrum does the gel block or absorb?	<i>Everything except red</i>	<i>Everything except green, some blue, and maybe some yellow (depends on the gel)</i>
What do you see at the location of yellow light in the spectrum?	<i>Nothing</i>	Depending on the gel, there may be either some yellow or nothing
Predict what color(s) will appear on the wall when both a red and green gel are placed in the beam. Explain your reasoning and your results.	Put your prediction here <i>Answers will vary</i>	Record your observation here <i>No color should appear on the wall. The red gel only transmits red light, and the green gel absorbs red, (or vice versa) so no light gets through both</i>

PART III — WHERE IS THE END OF THE RAINBOW?

In Part I we found that we could hear light with a photocell, provided we "chop the light" to create a changing voltage in the photocell. You'll need to use a "chopper" between the light source and the wall for the remainder of this experiment, either an electric fan or a student moving their hand rapidly back and forth in the beam of light.

- A. Leave the projector, grating, and chopper set up as in Part II. Hold the photocell in the red region of the spectrum on the wall. If the chopper is in place, you should "hear" the red light at this location. Predict what you will hear when you make the following changes to the beam, while holding the photocell in the same location on the wall. Then record your actual observations, and, in the column labeled "Conclusion," explain why you think your observed results happened.

3.3 Teacher Answer Key—Sensing the Invisible

Experiment	Prediction	Observation	Conclusion
Place a red gel in the beam	<i>Answers will vary</i>	<i>Hear a popping sound as the light beam is chopped</i>	<i>Red light is being transmitted by the red gel and is being detected by the photocell</i>
Place a green gel in the beam	<i>Answers will vary</i>	<i>Should not hear anything</i>	<i>The green gel does not transmit any red light, so there is no light coming through to the red part of the spectrum for the photocell to detect.</i>
Place both a red and green gel in the beam	<i>Answers will vary</i>	<i>Should not hear anything</i>	<i>The red gel transmits only red light, while the green gel absorbs any red light transmitted (or vice versa), so no light gets through for the photocell to detect</i>

- B. Move the photocell to the dark region right next to the red part of the spectrum. Predict what you will hear when you make the following changes to the beam, while holding the photocell in the same location on the wall. Then record your actual observations, and, in the column labeled “Conclusion,” explain why you think your observed results happened.

C.

Experiment	Prediction	Observation	Conclusion
Hold the photocell in the dark region right next to the red part of the spectrum.	<i>Answers will vary</i>	<i>Hear popping sounds as the light beam is chopped</i>	<i>Some kind of light that we cannot see is still getting through</i>
Place a red gel in the beam.	<i>Answers will vary</i>	<i>Hear popping sounds as the light beam is chopped, although the sound may be fainter</i>	<i>Some kind of light that we cannot see is still getting through. Since the red gel transmits only red light, students may assume the invisible light is related to red light.</i>
Place a red and green gel in the beam.	<i>Answers will vary</i>	<i>Hear popping sounds as the light beam is chopped, although the sound is probably much fainter than when there was no gel in light beam</i>	<i>“Invisible” light being detected can pass through some things that visible light cannot.</i>

The grating spreads white light out into a spectrum of colors. What do you think is interacting with the photocell to produce the sound in the dark region next to the red part of the spectrum? Explain your answer.

An “invisible” kind of light (that can pass through a combination of gels that stops visible light) is also spread out by the grating and is being detected by the photocell. OR “Colors” exist in the rainbow that we cannot see with our eyes.

Astronomy is often like detecting the cow with a blindfold on. Much like the red and green gels combined, interstellar dust can absorb or scatter all visible light sent in our direction by stars and other sources. Astronomers must then "look" for light from these sources in the invisible part of

3.3 Teacher Answer Key—Sensing the Invisible

the spectrum to observe the obscured stars and other objects.

PART IV — THE REMOTE CONTROL

The invisible light near the red part of the spectrum is called infrared light (IR). Remote controls like those used with TVs and VCRs use IR signals to send commands to televisions, VCRs, etc.. Your instructor will provide several remote controls with which to experiment. Point a remote control at the photocell and push a button. Describe what you hear in the table below. Try different buttons on the same remote and different brands of remote controls, and describe what you hear in each case.

Indicate which button is pushed and which brand of remote control is used	Describe what you hear.
<i>Answers will vary</i>	<i>Students should describe different pitches of sound coming from the detector, with the sound “flickering” on and off at different rates</i>

Explain why a Sony remote will not operate an RCA television.

The Sony remote emits infrared light at a different pitch or rate than the RCA TV is looking for. Therefore, the RCA TV doesn't “see” the signal sent by the Sony remote.

Reflection — Teacher Notes

4.1 What's This About?

Students learn that infrared light is reflected in the same manner as visible light. Students align a series of mirrors so that they can turn on a TV with a remote control when the remote is not in a direct line with the TV. As a result of their experiment with reflection, students deduce that infrared light is another form of light and is a part of the electromagnetic spectrum

Suggested Grade Levels

7-12

Suggested Time Required

50 minutes

Suggested Learning Outcomes

After completing this activity, students will be able to:

- Explain that infrared light can be reflected by a mirror in the same way as visible light is reflected.
- Deduce that, since infrared and visible light behave in similar ways, both are part of a larger collection of light known as the electromagnetic spectrum.

Student Prerequisites

- Students are assumed to be familiar with the visible spectrum and to have some knowledge of the electromagnetic spectrum, and how it relates to the visible spectrum.
- Students are assumed to be familiar with the concept of reflection of visible light and mirrors.

Common Misconceptions

- Students may not realize that the infrared light beam emitted by the remote control spreads out over distance. As a result, if the light path followed by the infrared signal is too long, the remote may not be able to start the TV. Students may think the failure to turn on the TV is because the light signal “wears out” as it travels, or that it only travels a certain distance and then quits, not that the light beam spreads out with distance. This should be explained, if the situation arises.

The Activity

For this activity, challenge each student group to turn on a TV set when it is not in a direct line with a remote control. Utilize the barriers and space that you have in your classroom to create an obstacle course for your students. Each group will have different setups and answers, based on the space and materials provided. Have students try to turn on the TV with the remote

4.1 Teacher Notes—Reflection

before reflecting the signal off any mirrors, to confirm that the remote does work initially. Some remotes will still work if pointed slightly away from the TV. If the TV does turn on initially, have students turn or move somewhere else so that the remote will not work without being reflected. Be sure to point out to students where the infrared light detector on the TV is, so they can try to aim the remote control at it.

Students will likely want to visually sight along the mirrors until they can see the sensor on the television. This helps reinforce the idea that infrared and visible light behave in the same way when reflected. Encourage students to be creative, but be aware of distance – the remote control’s signal is not a focused beam, but spreads out as it travels (thus the signal from a distant remote may be too weak to trigger the sensor on a television set). Be careful when explaining this concept to students, who may think that the light signal “wears out” as it travels, or that it only travels so far.

SOFIA SCIENCE

SOFIA carries a 2.5-m primary mirror that weighs 1936 pounds or 880 kilograms. This mirror is used to collect and focus infrared light in the same way that visible light reflects off the mirror in a regular telescope.

Suggested TV/Student Group Setups

- TV or group in hallway, working around door
- Group behind TV
- Lab tables or other barriers between TV and group

Extension

Have students replace one or more mirrors with another object. When we look at a textbook, for example, we see it because light reflects off the book and comes to our eyes. Such objects will often reflect infrared light as well. Replace one of the mirrors, for example, with a book or use a dry-wipe board for a reflecting surface.

As a follow-up homework assignment, have students duplicate this activity with their home TV sets and remote controls. Students should draw the path(s) from the remote control to the TV that worked

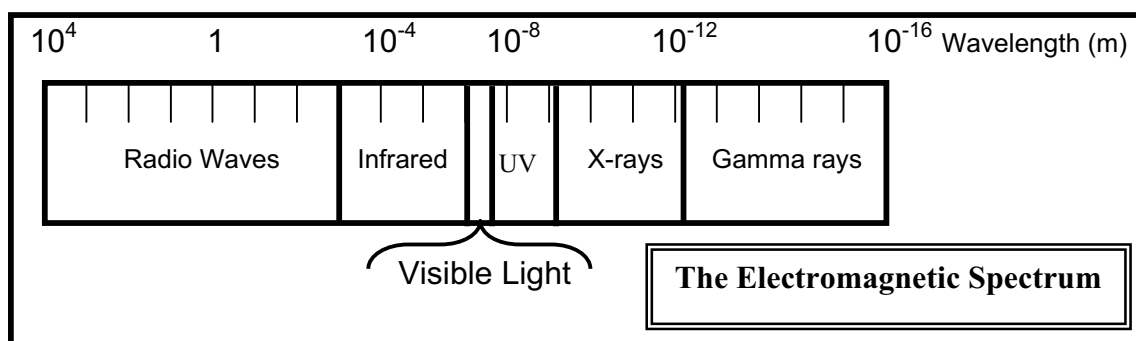
VCR Olympics:

Materials required: 2 VCR’s with remotes, aluminum foil

Divide class into two teams. Each team must locate the IR receiver by moving a sheet of aluminum foil with a cutout the size of a postage stamp around in front of the VCR while attempting to power the unit on and off. Each team then turns on the VCR using one, two and three mirrors as reflectors. Once the teams are satisfied with their practice, time all three trials to determine a winning team.

Background Science

All types of light are characterized by wave properties that can be measured or observed. Visible light is only a small part of the electromagnetic spectrum. Infrared light, x-rays, radio waves, ultraviolet light, and gamma rays are often overlooked by students, but are also parts of this spectrum. Of course, this means that infrared light shares the same wave-like properties as visible light. For example, you know from looking in a mirror that visible light is reflected off the surface of a mirror. All waves undergo reflection at a barrier, or at the boundary when they move from one kind of medium (e.g., air) to another (the mirror). During reflection, the wave always bounces off the barrier at the same angle as it approaches the barrier. For example, if the wave heads straight for the barrier, it reflects straight back. If it moves toward the barrier from the left, it will reflect off to the right at the same angle. For more detailed information on reflection and mirrors, see: <http://www.physicsclassroom.com/Class/refln/refIntoc.html> The fact that infrared light, which is used by the remote control in this activity, is also reflected off the mirrors provides evidence in support of the idea that infrared light behaves like visible light.



The infrared light (IR) beam emitted by the remote control, spreads out as it moves away from the remote control. As it gets farther away, the same overall intensity of IR is spread out over a larger area. As a result, the IR will appear fainter the farther away from the source a detector is. In fact, the apparent brightness is inversely proportional to the square of the distance (the same inverse square law that applies to all electromagnetic radiation). For example, when viewed two times farther away, the light will appear four times fainter. Because of this, if the path the infrared light beam has to travel is too long, the signal that reaches the detector on the TV may not be strong enough to turn on the TV.

When you press the button of a remote control, an electrical connection is made that tells a computer chip inside the remote which button was pressed. The chip then produces a morse-code-like electrical signal that is different and distinct for each button. Transistors inside the remote control amplify the signal and send it to a Light-Emitting Diode, or LED, a kind of small light bulb. The LED converts the electrical signal into infrared light. Because the LED emits infrared light, which our eyes cannot detect, we do not see any light passing between the remote control and the TV (or VCR). But, the TV (or VCR) has a detector which can see infrared light. Depending on the exact nature of the signal (its wavelength, frequency, or intensity), the TV (or VCR) carries out the desired command. Note that many camcorders can also detect infrared light. If you aim a remote control at a camcorder and push a button, you should see infrared light flashing in the viewfinder. For more information about how remote controls work, see:

4.1 Teacher Notes—Reflection

<http://www.howthingswork.com/inside-rc.htm>

MATERIALS AND EQUIPMENT

- TV and remote control (with working batteries!) for each student group
- 1-4 mirrors for each student group – mirrors can vary in size (no smaller than 4x4 inches; the larger the mirror, the better)
- HELPFUL, BUT NOT NECESSARY: A way to mount the mirrors so that they stay in the same places (not dependent on being held by students who move slightly without realizing it). Holders, taping to boxes, taping to a wall, lumps of clay, etc. will all work as holders.

4.2 REFLECTION

Name_____ Date_____ Period_____

Your challenge:

Using a remote control, turn on a TV when you are not in a direct line with it.

Rules:

1. You have only ONE SHOT to successfully turn on the TV – no practice shots!
2. You must use all the mirrors provided to your group.

Questions:

1. Before trying to use the remote, draw a diagram showing where the TV and remote control are, where you need to place the mirrors so the remote control can turn on the TV, and where any barriers (such as walls, lab benches, or doors) are located.

2. With the mirrors arranged as in the drawing above, press the On button on the remote. Were you able to turn on the TV the first time? If not, why do you think you did not turn on the TV?

3. How did you know when you had the mirrors set up the right way before you tried it?

4. What does this experiment tell you about the similarities between visible and infrared light?

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4.3 REFLECTION

Name _____ Date _____ Period _____

Your challenge:

Using a remote control, turn on a TV when you are not in a direct line with it.

Rules:

1. You have only ONE SHOT to successfully turn on the TV – no practice shots!
2. You must use all the mirrors provided to your group.

Questions:

1. Before trying to use the remote, draw a diagram showing where the TV and remote control are, where you need to place the mirrors so the remote control can turn on the TV, and where any barriers (such as walls, lab benches, or doors) are located. Include the path the infrared light beam follows from the remote control to the TV.

Drawings will vary, but should show the mirrors placed in such a way that the incoming IR beam at each mirror reflects off at the same angle as it approached the mirror (the angle of incidence should equal the angle of reflection).

2. With the mirrors arranged as in the drawing above, press the On button on the remote. Were you able to turn on the TV the first time? If not, why do you think you did not turn on the TV?

Answers will vary, but may include that the mirrors were not aligned properly, or that the path the infrared light beam had to travel was too far and the infrared light beam was too faint to turn on the TV by the time it got to the TV.

3. How did you know when you had the mirrors set up the right way before you tried it?

Make sure you could see with your eyes that all the mirrors were lined up in such a way that you could see the infrared detector on the TV when you look at the first mirror the remote control's light will hit. Then aim the remote control at that spot on the first mirror.

4. What does this experiment tell you about the similarities between visible and infrared light?

Both visible and infrared light reflect off of mirrors in the same way. Both behave the same way, and must, therefore, be similar kinds of light. In fact, both act like waves, and both are part of the electromagnetic spectrum.

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Listening to Light — Teacher Notes

5.1 WHAT'S THIS ABOUT?

Students learn that light carries information and that infrared (IR) radiation is a form of light that in some cases behaves like visible light and other cases behaves very differently. Students first see how a photocell (solar cell) can be used to detect the presence of light. They then learn how the photocell reacts to light from a laser pointer (or other laser) and a remote control, and see that information, for example a message, can be transmitted by visible and infrared light. They listen as an infrared-emitting diode is used to transmit music from an audio source (like a CD player) to the photocell with a speaker connected to it. Finally, students test the effects on the transmission of music when various objects are placed in between the infrared-emitting diode and the photocell. They learn that some objects that block visible light allow infrared light to pass through.

Grade Levels

7-12

Time Required

50-100 minutes, 1 to 2 class periods

Learning Objectives

After completing this activity, students will be able to:

- Describe different characteristics of visible and infrared light observed using a photocell as a detector.
- Explain how information can be carried by visible and infrared light.
- Predict whether visible or infrared light will be transmitted through various objects.

Student Prerequisites and Misconceptions

- Students are assumed to be familiar with visible light and infrared light, and that both are part of the electromagnetic spectrum. For an introduction to the electromagnetic spectrum, see: <http://imagers.gsfc.nasa.gov/ems/ems.html>
- This activity assumes some familiarity assembling and working with electronic circuits, magnifying glass lenses, laser light, and remote controls.
- Common misconceptions are described in the overview for these activities, "Active Astronomy : Classroom Activities for Learning about Infrared Light," page 3.

5.1 Teacher Notes-Listening to Light

BACKGROUND INFORMATION ON THE SCIENCE & TECHNOLOGY

In this lecture demonstration, an infrared light-emitting diode (LED) is used to transmit music across open space to a speaker. The music can come from a Walkman, stereo, CD player, computer, amplified microphone, or any similar device. The transmitter circuit contains an infrared Light Emitting Diode (LED) whose brightness varies in response to changes in input current. The receiver circuit uses a photocell to detect the IR signal and convert it back to an electrical signal for the speaker. The student activity sheets call the receiver circuit the “photocell detector.”

After showing the basic operation of this demonstration, the equipment can be used to investigate some basic properties of the infrared light coming from the diode. First, and most obvious, is that the IR light is invisible. Second, a magnifying glass can be used to show that infrared signal is focused the same as visible light. (Note: Glass is not transparent to all infrared light. It is transparent to near-infrared light—wavelengths close to visible light. The LED used in this activity emits near-infrared light. Glass is opaque, however, to infrared light with longer wavelengths.) Finally, different materials are placed between the diode and the photocell to show that the IR light can pass through many materials that visible light cannot.

SOFIA SCIENCE

Long light waves ranging from 03 to 1600 micrometers are normally invisible to human eyes. SOFIA's electronic detectors and computers will covert light gathered by the telescope into signals that humans can understand.

Light-Emitting Diodes (LEDs) can be thought of as tiny light bulbs. (Note: A diode is a silicon crystal (semiconductor) that allows current to flow in one direction only, kind of like a one-way turnstile for electrons.) When a current is applied to an LED, electrons in the semiconductor material emit light. Because of the composition of the material in the LED used in this activity (usually a silicon compound), it emits infrared light, not visible light. The higher the incoming current, the more light the LED will emit. If the electrical signal coming into the LED is not strong enough, however, it will not emit any light. The battery and capacitor in the transmitter circuit provide a constant source of current that keeps the LED above this threshold, so it emits at least a constant amount of light, regardless of the incoming audio signal. Since the receiver circuit does not produce any sound when exposed to a constant light source, the constant light from the LED caused by the battery and capacitor is not detected. Instead, the receiver circuit detects changes in the brightness of light emitted by the LED, changes that are caused by fluctuations in the incoming current from the audio source that are added on top of the battery's constant one.

Solar/Photo Cells: The solar cell used in this activity is known as a photovoltaic cell because it converts light (photo) into electricity (voltaic). When visible or infrared light strikes the solar cell, some of it is absorbed by the special material (usually silicon), called a semiconductor, out of which it is made. The energy of the absorbed light is transferred to the semiconductor material, knocking electrons in it loose. These loose electrons can then move freely throughout the material, resulting in an electric current. Most solar cells also have one or more electric fields in them which force the moving electrons to flow in one direction. By placing metal contacts at the top and bottom of the solar cell, the current flowing within it can be drawn off for use

externally. In the case of this activity, the current generated by the light is sent to the amplifier/speaker, where it is converted into sound waves, which we can hear. For more detailed information about how a solar cell works, see: <http://www.howstuffworks.com/solar-cell.htm>

Audio Speakers: Inside a speaker, a flexible cone (usually made of paper, plastic, or metal) vibrates rapidly in response to a changing electrical current. As it moves, it pushes the air molecules around it. Those air molecules, in turn, push the air molecules near them, and the vibration is transmitted through the air as a sound wave. Our ears detect the vibration of air molecules and convert them into an electrical signal that our brain interprets as music. Within the speaker, the flexible cone needs a changing current to vibrate. If the current is constant, the cone will not vibrate. For more information on how speakers work, see: <http://www.howstuffworks.com/speaker.htm>

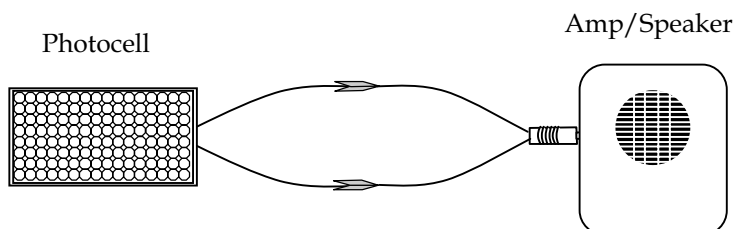
Remote Controls: When you press the button of a remote control, an electrical connection is made that tells a computer chip inside the remote which button was pressed. The chip then produces a morse-code-like electrical signal that is different and distinct for each button. Transistors inside the remote control amplify the signal and send it to a Light-Emitting Diode, or LED, a kind of small light bulb. The LED converts the electrical signal into infrared light. Because the LED emits infrared light, which our eyes cannot detect, we do not see any light passing between the remote control and the TV (or VCR). But, the TV (or VCR) has a detector which can see infrared light. Depending on the exact nature of the signal (its wavelength, frequency, or intensity), the TV (or VCR) carries out the desired command. *Note that many camcorders can also detect infrared light. If you aim a remote control at a camcorder and push a button, you should see infrared light flashing in the viewfinder.* For more information about how remote controls work, see: <http://www.howthingswork.com/inside-rc.htm>

BUILDING THE DEMONSTRATION APARATUS

This lesson is described in the demonstration format based on the assumption that you will have only one apparatus available. Students in small groups can also build this apparatus if sufficient hardware is purchased.

The Receiver Circuit: How It Works

In this circuit, the photocell receives the IR signal from the LED and converts it to an electrical signal that is sent to the amplifier-speaker. This circuit is also used in another activity, "Sensing the Invisible."



5.1 Teacher Notes-Listening to Light

Receiver: Photocell Detector



Note: Audiocable can be connected to photocell directly with small wire nuts, or soldered. Wrap with electrical tape, or use shrink tubing to insulate.

The photocell (or solar cell), connected as shown above, produces an electric current when exposed to light. Because of the way speakers are constructed, a changing current is needed to produce a sound in the speaker; a constant current will not produce a sound. When a constant light source illuminates the photocell, it produces a constant current and no sound is produced. Students should hear static, if anything, when a constant light source illuminates the photocell. When the light changes in brightness, the current produced by the photocell also changes accordingly, and the speaker will produce a sound. If the light is turned on and off (as happens if you move your hand back and forth in the beam of light), you will hear series of “pops” each time the light is turned back on. If the light varies because of a changing electrical current from an audio source, you will hear music from the speaker.

NOTE: For best results, turn off any overhead fluorescent lights in the classroom. When the photocell is exposed to the fluorescent overhead lights, the speaker will emit a constant buzzing sound or hum. This buzzing occurs because the intensity of the classroom light fluctuates due to the 60 Hz AC current it receives. Thus, fluorescent lights will generate a constant hum, which may interfere with students’ hearing sound produced from the flashlight and the infrared diode in the transmitter circuit.

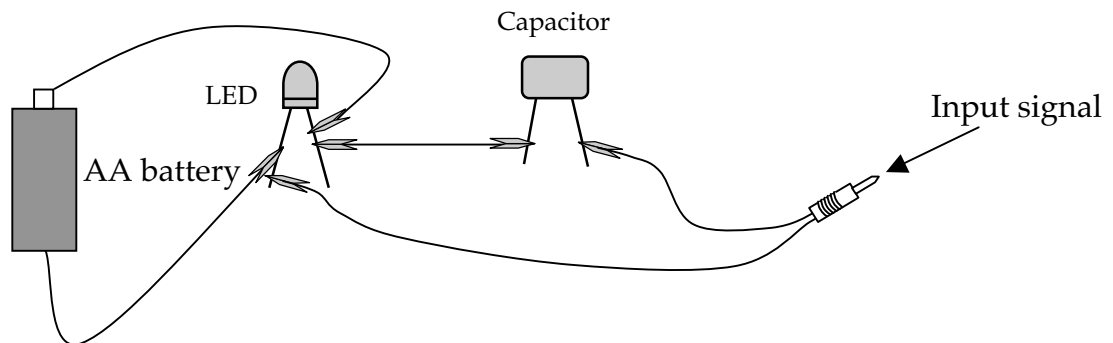
How to Build the Receiver Circuit:

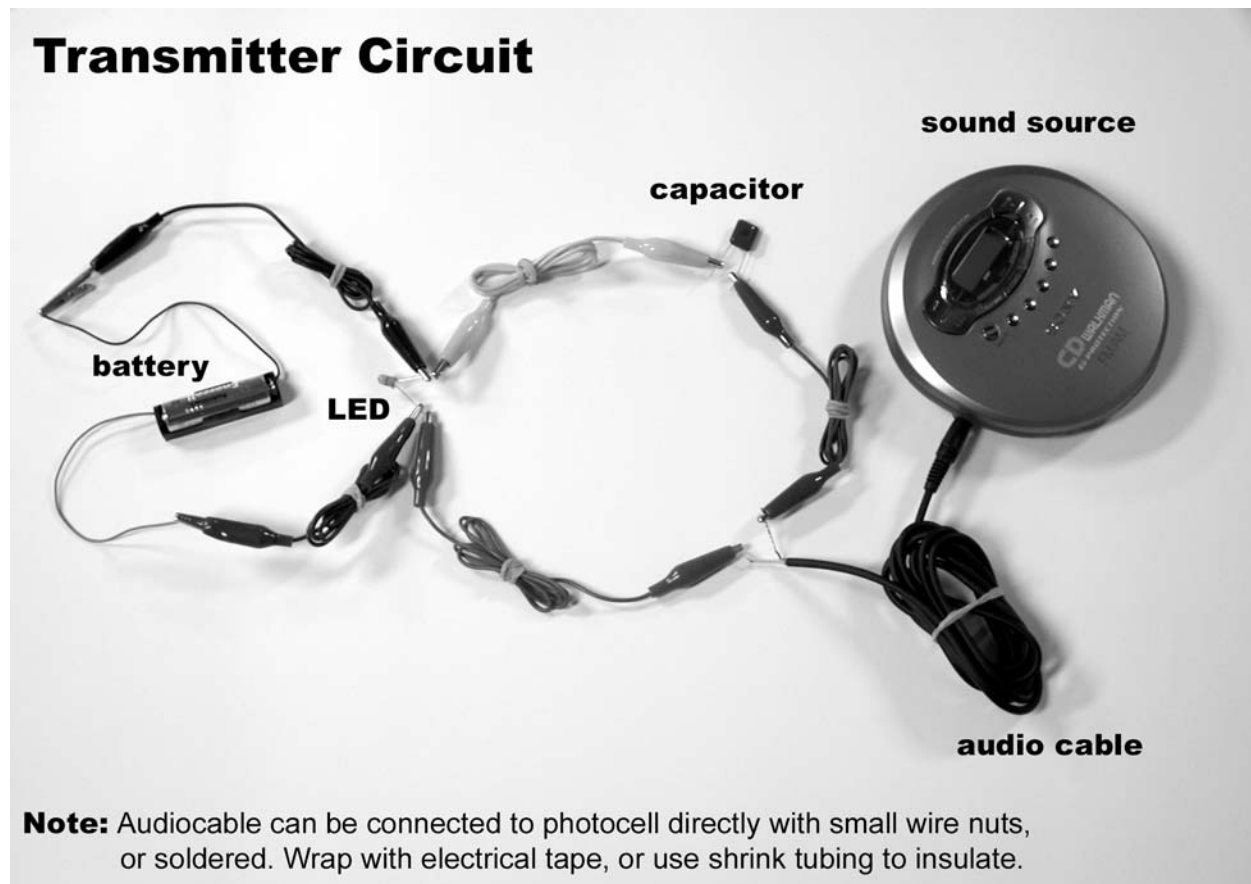
To make the photocell detector, use jumper cables to connect the photocell with the amplifier/speaker (amplifier/speaker requires a 9V battery). Clip one alligator clip from a jumper cable to one of the leads from the photocell, and clip the alligator clip at the other end of the jumper cable to one of the leads of the audio cable (which has its 1/8" mini-plug plugged into the "input" of the amp/speaker). Use a second jumper cable to connect the other lead from the photocell to the other lead of the audio cable.

This works best if you use an audio cable with a mini-plug on one end, and two exposed wire leads on the other. You can also use an audio cable with a mini-plug on both ends. In this case, connect the alligator clip from one jumper cable near the end of the mini-plug, and connect the alligator clip from the other jumper cable near the base of the mini-plug (next to the plastic piece that protects the rest of the audio cable). Be sure both alligator clips are in contact with metal parts of the mini-plug, and that they do not touch one another. Note that a Y-Adaptor Audio Cable will not work in this activity.

How to Build the The Transmitter Circuit

This circuit takes the output audio signal from an audio source (CD player, transistor radio, stereo, etc.), in the form of a changing electrical current, and sends it to the infrared light-emitting diode (LED). The LED converts the current into infrared light, in much the same way a regular light bulb "shines" when the light switch is turned on.





To make the transmitter circuit, use jumper cables to connect the LED to the battery, capacitor, and to the audio cable coming out of the audio source (CD player, transistor radio, etc.), as shown in the diagram above. Be sure to connect the audio cable to the Line Out jack of the audio source (like a Walkman), (or the Headphone jack if the Line Out is not effective). Comments about connecting the jumper cables to the audio cable made in the section on the Receiver Circuit, also apply here.

NOTE: YOU WILL NOT BE ABLE TO “SEE” WITH YOUR EYES IF THE LED IS EMITTING INFRARED LIGHT. Test the LED with the receiver circuit. If the LED does not work (you get no sound from the speaker when the LED is placed just above the photocell), switch the polarity of the battery (i. e. take the jumper cable connected to the positive terminal and connect it to the negative terminal, and vice versa).

TEACHING NOTES ON "LISTENING TO LIGHT"

Part I - The Photocell: *Students will use a detector to hear the presence of light.*

These demonstrations show students how the photocell detector can be used to “listen” to light. For the first demonstration, turn off the overhead fluorescent lights. Use a DC battery powered flashlight to shine on the surface of the photocell. Because the flashlight operates on DC current,

there will be no fluctuations in the brightness of the light emitted and the speaker will be silent. The speaker only responds to *changes* in the voltage it receives, and a constant light source will cause the photocell to produce a constant voltage. However, if the teacher moves her or his hand back and forth to block the beam reaching the photocell, the speaker will emit a sound. The students should answer questions A-D while the teacher demonstrates the effects of the flashlight on the photocell detector. Question E should be answered before the teacher tests the students' predictions. Questions D and F allow the students to demonstrate an understanding that the photocell detector enables them to listen to *changes* in the brightness of light, not how bright the light is.

Part II - Your Own Music Station: *Students discover that information can be carried by visible and infrared light.*

These demonstrations show how information can be carried by both visible and infrared light. The first demonstration involves a laser beam aimed at the photocell surface from across the room.

SAFETY PRECAUTION: Be sure to caution students not to look into the laser beam.

Visible Light Demonstration

The laser should be aimed at the photocell surface before students answer Question A. Because the brightness of the laser light does not fluctuate, the speaker will emit no sound (although it may make a popping sound when the laser pointer is initially turned on, followed by no sound, or static, as the laser pointer continues to shine on it). It is up to the students to suggest that interrupting the light signal will produce a sound, and that this method might be used to send information along the laser beam (perhaps using Morse code). After the students have provided a method of communicating with their friend, the teacher can test their suggestions using the equipment.

Infrared Light Demonstration

When the teacher hits the photocell detector with the infrared signal from a remote control, the speaker makes a sound like a blaster gun from a science fiction movie. Different buttons on the remote produce signals with different fluctuations, but these changes are difficult to hear with the simple circuit used in the demonstration. If different brands of remote controls or different remote control devices are used, the sounds are easier to distinguish. Question B should be answered after the teacher demonstrates the response of the receiver to the remote control signal.

Before students answer Questions C, the teacher should demonstrate how the two circuits shown above are used to transmit and receive music via an IR signal. For best results, aim the top (not the side) of the LED directly at the photocell (so that the prongs on the LED point directly away from the photocell). To begin, hold the LED close to the photocell (within an inch or two). This ensures that students hear the music as loudly as possible at the beginning of the demonstration. Note that the music coming from the speaker will probably be rather quiet, even at its loudest. But it should still be easily heard, even if not loud.

5.1 Teacher Notes-Listening to Light

The volume of the music will go down if the LED is moved farther away from the photocell surface. A simplified but appropriate explanation for this is that the light from the LED spreads out as it moves farther away. As a result of this spreading out, it appears “dimmer” the farther away it is. However, this is not the whole story. The sound produced in the speaker does not depend directly on the brightness of the light detected by the photocell, but rather on the changes in the brightness. As the LED moves farther away, and its light gets dimmer, the size of the brightness fluctuations detected by the photocell necessarily decreases. The smaller fluctuations in the light detected by the photocell result in smaller changes in the current sent to the speaker, and the resulting volume of the speaker is quieter.

Part III - What Gets Through? *Students investigate the infrared transmission properties of various everyday objects.*

The first demonstration uses a magnifying glass to focus the infrared light from the transmitter on the distant photocell. The LED and photocell should be placed about 1 meter apart with the LED still aimed toward the photocell. The signal will be so weak that no sound is heard. However, when a magnifying glass is placed between the LED and the photocell the sound becomes audible. The magnifying glass needs to be about 15 cm from the diode and should be moved back and forth to find the optimal location.

If students are not familiar with how a magnifying glass focuses visible light, this can be demonstrated using the flashlight. The fact that both visible light and infrared light are focused by the magnifying glass provides evidence that IR light does, in this instance, behave very much like visible light. *Note: Test the magnifying glass used prior to class. Different types of plastic and glass absorb IR emission, and you may find that your magnifying glass absorbs most of the IR from the LED.*

The activities associated with Question C & D demonstrate that many materials that are opaque to visible light are either totally or partially transparent to IR light.

Question E uses the observations from part III to help understand why astronomers are interested in using telescopes that view infrared light. Infrared light can indeed carry information in much the way that visible light can, but it can pass through interstellar dust, which is opaque to visible light. If you would like to show students images of astronomical objects taken in different wavelength ranges, see: <http://www.ipac.caltech.edu/Outreach/Multiwave> (“Objects at Multiple Wavelengths” are also included in section 5 of the “Image File” on the CD-ROM).

Note that objects at different temperatures emit light in different wavelength regions, with x-rays and gamma rays emitted by the hottest objects (millions and billions of degrees), and radio waves emitted by the coolest (tens of degrees above absolute zero). For example, an x-ray image of the Sun reveals gas in the outermost layers of the Sun at temperatures of millions of degrees, while a visible light image shows gas at much cooler temperatures (thousands of degrees) located deeper in the Sun.

MATERIALS NEEDED

NOTE: One set of these materials is required to teach this activity as a demonstration. Or, if sufficient materials are available, student can conduct the activities as a laboratory experiment in which case each group of students would require a set of materials.

Transmitter Circuit

- Infrared Light Emitting Diode (LED)*
- 0.22 μ F (microfarad) Capacitor*
- Audio Cable with 1/8" mini-plug on one end*
- 5 Jumper Cables with alligator clips on both ends *
- AA Battery
- AA battery holder*

Receiver Circuit (Also used in "Sensing the Invisible")

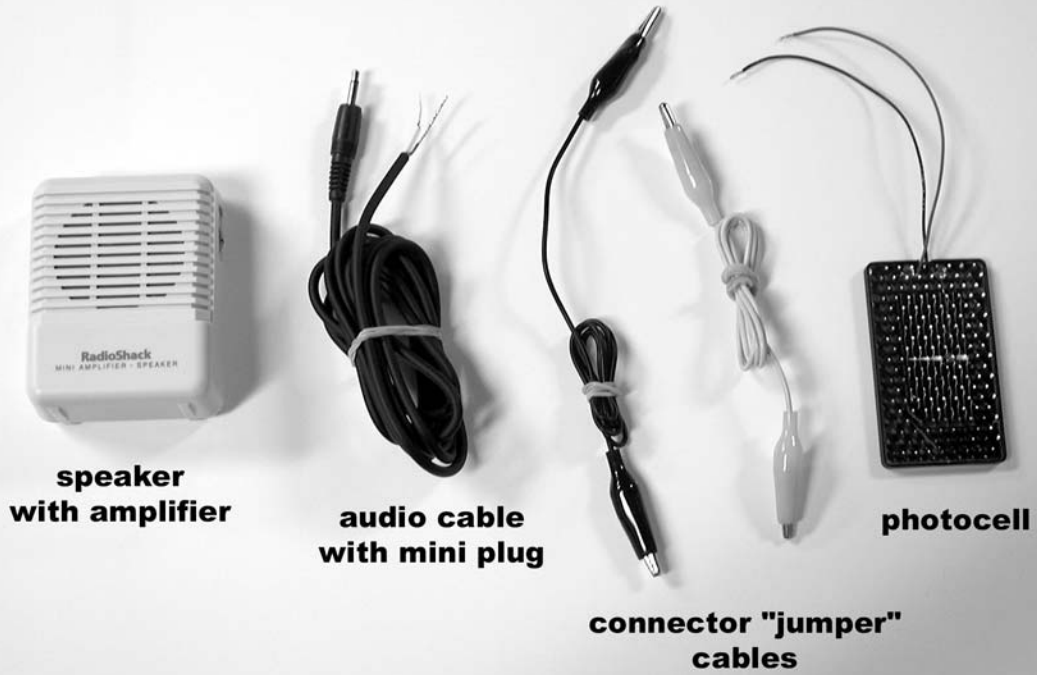
- Solar cell*
- Amplifier/Speaker*
- Audio Cable with 1/8" mini-plug on one end*
- 2 Jumper Cables with alligator clips on both ends*
- 9 Volt Battery for Amplifier/Speaker

Other Materials Required

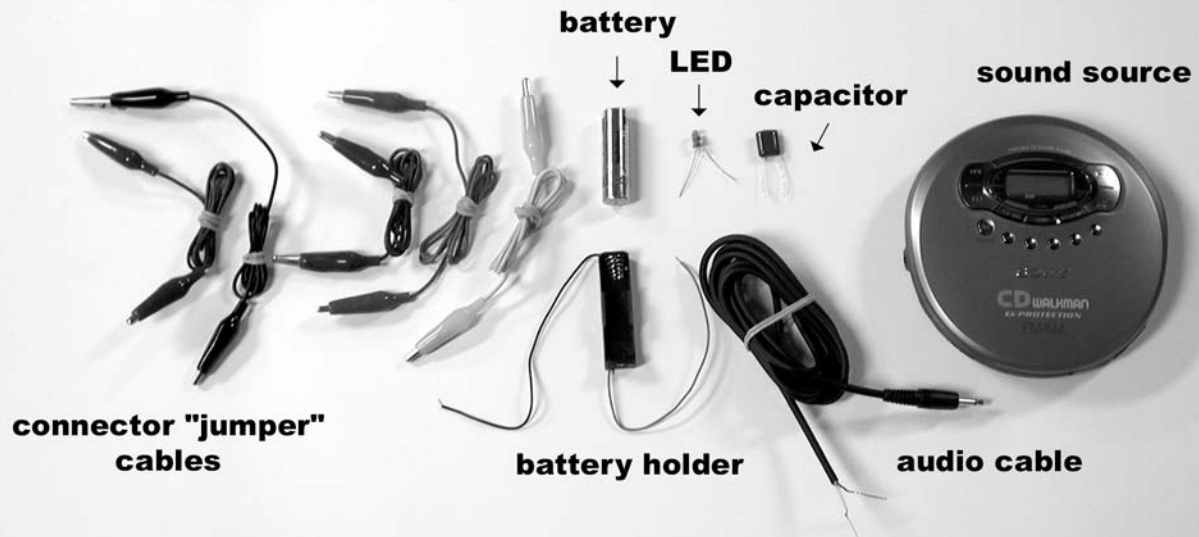
- Audio source (CD Player, Walkman, or Transistor radio)
- Large magnifying glass of focal length around 15cm *(fairly standard)
- Flashlight
- Laser pointer (or other laser device)
- Collection of remote control devices from several different manufacturers
- Clear plastic bag
- Colored plastic bag
- Tissue
- Piece of paper
- Piece of cardboard
- Phillips screw driver

*see section 1.5 for details

Receiver: Photocell Detector Parts



Transmitter Parts



5.2 PART I — THE PHOTOCELL

Name _____ Date _____ Period _____

In this activity we use a detector (a photocell connected to a speaker) to “listen” to light. Our detector is capable of detecting light in both the visible and infrared parts of the electromagnetic spectrum.

Experiment	Results
A. Describe what you hear from the speaker when your teacher shines a flashlight on the photocell detector.	
B. Do you hear any difference as your teacher moves the flashlight closer and farther away from the photocell to make the light dimmer and brighter?	
C. Describe what you hear when your teacher moves her or his hand back and forth between the flashlight and the photocell.	

D. Does the sound from the photocell detector result from the brightness of the light or from changes in the brightness of the light? What is your evidence?

	Prediction	Observation
E. What will you hear when the photocell detector is exposed to light from the fluorescent overhead lights?		

F. Is the light from a fluorescent bulb constant or does it change? Explain how you know.

PART II — YOUR OWN MUSIC STATION

Now we will explore how information can be carried by both visible and infrared light.

Experiment	Results
A. What happens when a laser beam shines on the photocell from across the room.	
Imagine that you had a similar apparatus set up between your house and your friend's house at the end of the block. How could you use this arrangement to send information to your friend?	

B. Describe what you hear when your teacher hits the photocell with the signal from a remote control.	
Is this information being transmitted using visible or invisible light?	
The small device in the end of the remote control that produces the infrared light is called an infrared diode. Is the "brightness" of the light from the infrared diode constant or does it flicker? How do you know?	

When the brightness of an infrared diode is changed using the output from an audio source, such as a CD player, the information in the music can be transmitted to a photocell and on to a speaker.

- C. Explain carefully, possibly with a picture, why the volume of the music goes down as the infrared diode is moved farther away from the photocell.

PART III — WHAT GETS THROUGH?

In this part we will look at how infrared light is similar to visible light and how it is different.

Experiment	Result
A. What happens when the transmitter (infrared diode) is placed about 1 meter from the receiver?	
B. What happens when your teacher uses a magnifying glass to focus the IR light from the transmitter?	

C. Predict (circle) what will happen to the volume of the music when each of the objects listed is placed between the diode and the photocell. Then record your observations after your teacher performs each experiment.

1. A hand:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

2. A clear plastic bag:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

3. A colored plastic bag:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

4. A tissue:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

5. A piece of paper:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

6. A piece of cardboard:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

D. When your teacher performed each of the experiments, were any of the results surprising? Which ones?

E. Space is not as empty as we often think it is. Much of space is filled with gas and dust that astronomers call the interstellar medium. This dust can block visible light from distant objects making them impossible to see. Why did the development of infrared telescopes allow astronomers to “see” these previously unseen objects?

5.3 PART I — THE PHOTOCELL

Name _____ Date _____ Period _____

In this activity we use a detector (a photocell connected to a speaker) to “listen” to light. Our detector is capable of detecting light in both the visible and infrared parts of the electromagnetic spectrum.

Experiment	Results
A. Describe what you hear from the speaker when your teacher shines a flashlight on the photocell detector.	<i>Initial “pop” when light from the flashlight hits, then nothing (but static) while the light continues to shine on the photocell.</i>
B. Do you hear any difference as your teacher moves the flashlight closer and farther away from the photocell to make the light dimmer and brighter?	<i>No. There may be an increase in static as the flashlight is moved farther away.</i>
C. Describe what you hear when your teacher moves her or his hand back and forth between the flashlight and the photocell.	<i>Popping sound every time the light hits the photocell.</i>

D. Does the sound from the photocell detector result from the brightness of the light or from changes in the brightness of the light? What is your evidence?

The photocell detects changes in the brightness of the light. There was no sound when the flashlight was close to the photocell (bright), and still no sound when it was farther away (dim). So the brightness of the light can't be what's detected. When the light is interrupted or changed rapidly (when the hand was moved back and forth between the flashlight and the photocell), there was a popping sound. This change in brightness was what was detected by the photocell and sent to the speaker.

	Prediction	Observation
E. What you will hear when the photocell detector is exposed to light from the fluorescent overhead lights?	<i>Answers will vary.</i>	<i>Fluorescent lights cause a constant hum at a specific pitch.</i>

F. Is the light from a fluorescent bulb constant or does it change? Explain how you know.

The light from a fluorescent bulb changes. Because the photocell only detects light that's changing, the constant hum produced in the speaker by the photocell proves the light is constantly changing.

5.3 Teacher Answer Key—Listening to Light

PART II — YOUR OWN MUSIC STATION

Now we will explore how information can be carried by both visible and infrared light.

Experiment	Results
A. What happens when a laser beam shines on the photocell from across the room.	<i>Not much. There may be an initial pop when the laser first hits the photocell, but then nothing (but static) while the laser continues to shine on the photocell.</i>
Imagine that you had a similar apparatus set up between your house and your friend's house at the end of the block. How could you use this arrangement to send information to your friend?	<i>You would have to have some way to interrupt or rapidly change the brightness of the laser beam, so that it flashed in something like Morse Code.</i>

B. Describe what you hear when your teacher hits the photocell with the signal from a remote control.	<i>Sound like a blaster gun from a science fiction movie; the sound continues to fluctuate rapidly as long as the button is pressed.</i>
Is this information being transmitted using visible or invisible light?	<i>Infrared light.</i>
The small device in the end of the remote control that produces the infrared light is called an infrared diode. Is the "brightness" of the light from the infrared diode constant or does it flicker? How do you know?	<i>The brightness of light from the infrared diode must flicker because sound was heard from the speaker and that only happens when the brightness of light that strikes the photocell is changing.</i>

When the brightness of an infrared diode is changed using the output from an audio source, such as a CD player, the information (music) can be transmitted to a photocell and on to a speaker.

C. Explain carefully, possibly with a picture, why the volume of the music goes down as the infrared diode is moved farther away from the photocell.

As the infrared diode is moved farther away, the light it emits gets spread out over a larger area and, therefore, appears dimmer. Thus the changes in the light that the photocell detects are smaller and the signal sent to the speaker is smaller and the volume goes down.

PART III – WHAT GETS THROUGH?

In this part we will look at how infrared light is similar to visible light and how it is different.

Experiment	Result
A. What happens when the transmitter (infrared diode) is placed about 1 meter from the receiver?	<i>The music should not be able to be heard because the signal from the distant infrared diode is too weak to be detected by the photocell.</i>
B. What happens when your teacher uses a magnifying glass to focus the IR light from the transmitter?	<i>You can hear the music again, although it may be faint. The magnifying glass focused the infrared light, just like it does visible light, increasing the brightness of the infrared signal enough to be detected again.</i>

C. Predict (circle) what will happen to the volume of the music when each of the objects listed is placed between the diode and the photocell. Then record your observations after your teacher performs each experiment.

1. A hand:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

2. A clear plastic bag:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

3. A colored plastic bag:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

4. A tissue:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent

5. A piece of paper:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent
 Which result you get depends on the thickness of the paper.

6. A piece of cardboard:

Prediction: stay the same get slightly quieter get a lot quieter become silent
Observation: stay the same get slightly quieter get a lot quieter become silent
 Which result you get depends on the thickness of the cardboard.

5.3 Teacher Answer Key—Listening to Light

- D. When your teacher performed each of the experiments, were any of the results surprising? Which ones?

Answers will vary, but students may express surprise that objects that block visible light let some or all of the infrared light pass through them, e.g., the colored plastic bag, the paper, and the cardboard.

- E. Space is not as empty as we often think it is. Much of space is filled with gas and dust astronomers call the interstellar medium. This dust can block visible light from distant objects making them impossible to see. Why did the development of infrared telescopes allow astronomers to “see” these previously unseen objects?

Like the colored plastic bag, the paper, or the cardboard, interstellar dust blocks visible light but lets infrared light pass through it. Any objects located behind the dust and emitting visible light cannot be seen. Astronomers using telescopes that can detect infrared light can “see” through the dust to the objects emitting the infrared light, just as the photocell could “see” the brightness changes from the infrared diode (produced by the music) through the colored plastic bag, paper and cardboard.