# Introduction to the Electromagnetic Spectrum

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GENERAL ATOMICS

# Table of Contents

### *Curriculum Overview:*

# Introduction to the Electromagnetic Spectrum

> In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself often more valuable than 20 formulae extracted from our minds; it is particularly important that a young mind that has yet to find its way about in the world of phenomena should be spared from formulae altogether.
>
> *– Albert Einstein*

## Overview

This section focuses on activities that help students understand the electromagnetic spectrum, one of the six stations on the DIII-D Tokamak Fusion Facility tour at General Atomics in San Diego, California.. The goal is to help teachers teach the often difficult concepts related to the electromagnetic spectrum as well as prepare students for the tour. This section contains a number of more or less informal laboratory units including demonstrations, experiments, and activities that are unlikely to be found in traditional science textbooks or lab manuals. Each unit contains an Instructor's Guide and a master copy of a Student Activity Sheet to be reproduced and distributed to each student participating in the unit.

## Mission Statement

The curriculum contained here was developed by local teachers and scientists working together to improve the state of science education in today's schools. The aim is to increase the understanding and enthusiasm for science in high-schools through the use of more enlightening, empowering, and socially relevant curriculum. We hope to help students understand and master the technological world around them in order to increase their own sense of power and control over their lives. By increasing understanding we seek to reduce the mystification, powerlessness and alienation of people from science, and eliminate the sense of elitism associated with science. These are lofty goals, and we hope to rise to the challenge.

## Contents

The curriculum units have been grouped into six different sections depending on their respective emphasis. These sections are named as follows:

- ***Introduction***
- ***Visible Light***
- ***Sunlight***
- ***Infrared Radiation***
- ***Ultraviolet Light***
- ***Radio and Microwaves***

A complete listing of the units in each section is given in the Table of Contents that follows.

## Format

From collective meetings and discussions with teachers at various levels, an optimized format for presenting each curriculum unit was devised. Each unit includes a master copy of a single double-sided Student Activity Sheet, organized according to the table below. It was decided early on to restrain each Activity Sheet to a single double sided page since many teachers feel that anymore overwhelms the student or tends to get lost in the hustle, bustle, and shuffle of a typical school day.

Each Student Activity Sheet is accompanied with an Instructor's Guide. The Instructor's Guide contains stated goals and objectives along with background information, helpful hints and available resources, and ideas for further investigation. In most cases a complete description of each unit is contained in the Student Activity Sheet, while the Instructors Guide is intended to serve as an aid for the instructor organizing the activity at hand. In the case of laboratory demonstrations, however, the bulk of the material is contained in the Instructor's Guide.

A master copy for reproduction of each Student Activity Sheet directly follows each Instructor's Guide unit. A second set of Student Activity Sheets are also grouped together in a separately organized Student Activity Handbook. Teachers may wish to have the handbook duplicated as a whole.

***continued***

***Table 1*** Organizational format of each curriculum unit

| ***Instructor's Guide:*** | ***Student Activity Sheet:*** |
|---|---|
| Goals | Purpose |
| Objectives | Required Equipment |
| Background Information | Discussion |
| Helpful Hints | Review Questions |
| Extensions | Procedure |
| References | Analysis Questions |

## Resource Box

A *Resource Box* containing the more unusual, expensive, or hard-to-obtain items involved in each of the Activity Units has been developed and assembled by the DIII–D Tokamak Fusion group to be distributed with this Curriculum. The more common classroom items such as an overhead projector, paper, tape, etc. are assumed to be available and will not be included in the Resource Box. Since the availability of many materials varies with each school, please evaluate the *Required Equipment and Supplies* list in each activity and note what is and is not available at your school.

Four Resource Boxes have been assembled and placed at different San Diego county schools to facilitate distribution to local teachers. Each of these participating schools is charges with loaning and maintaining an individual Resource Box. A Resource Box may be obtained by contacting one of the following teachers:

**Rick Halsey** Scripps Ranch High School (621-9020)

**Lori Pena** Roosevelt Junior High School (293-8675)

**Steve Rodecker** Chula Vista High School (691-5439)

**Billy Simms** La Jolla Country Day School (453-3440 x169)

This curriculum is an evolving work and needs your input. Evaluations and comments can be submitted to the Fusion Education Curriculum Web page or to Dr. Daniel Finkenthal at (619) 455-4135, E-mail to *finkenthl@gak.gat.com.* Periodic updates will also be made available at the Web site:

**http://FusionEd.gat.com/**

### *Instructor's Guide to Lab No. 1:*

# The Visible Electromagnetic Spectrum

## Goal

The goal is to introduce the visible electromagnetic spectrum to students through use of materials readily available to most high school science classes.

## Objectives

After observing these demonstrations, students should be able to:

- Use a diffraction grating to separate a visible light source into its component parts.
- Explain what a continuous emission spectrum is and give several examples.
- Explain what a bright line emission spectrum is and give several examples.
- Explain what an absorption spectrum is and give several examples.
- Relate the color of viewed objects to both the wavelengths of light incident upon it and the wavelength of light it absorbs/reflects.

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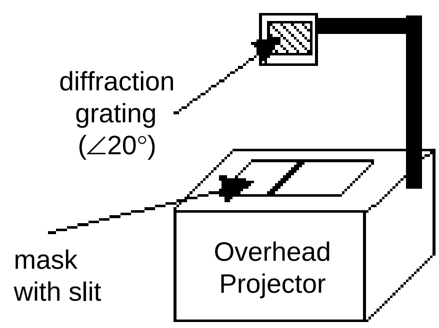
## Background Information

The phrase "electromagnetic spectrum" is frequently referred to in the study of science. In biology it is often a part of the discussion of photosynthesis, the physiology of the eye, and mutagenic sources. In earth and space science electromagnetic radiation is often a part of a discussion of radioactive minerals, cosmic rays being deflected by the earth's magnetic field, and analyzing incoming radiation from stars by optical and radio telescopes or other means. In chemistry the spectrum is often discussed when talking about evidence for different electron energy levels and characteristic properties of elements. In physics it is a part of the study of waves, electricity and magnetism, and modern physics. The table on the following page divides the electromagnetic spectrum into eight bands by common names although the differences between types are gradual rather than discrete.

## Helpful Hints




1. **Timeline**

   One to two class periods depending on which spectra sources are chosen.

2. **Overhead Projector Setup**

   A. A mask, made from two pieces of cardboard, for example, can be used to block out all but a narrow (2 to 4 cm) slit of light coming from the projector. Tape the large ***holographic diffraction grating*** (see description below) to a frame of cardboard and tape this frame to the focusing lens of the overhead. The grating should be mounted at an angle of about 20° from the head. Darkening the room will increase contrast; decreasing the slit width dims the intensity but increases the dispersion (color separation). The brighter the overhead, the brighter the spectrum will be. Overheads used to project LCD panels, typically 4000 lumens or more, are especially good. Use of a movie screen rather than a white board (marker/dry erase board) is preferable.

| NAME | λ RANGE (m) | f RANGE (Hz) | ORIGIN/ CAUSE | INTERESTING FACTS | USES / RELATED CAREERS |
|---|---|---|---|---|---|
| Electric Power | $>10^5$ | $<10^2$ | vibrating atoms or molecules over macroscopic distances | 60 Hz hum heard near electric trans-formers | transmits electric energy to homes from power stations; electrician; electrical engineer |
| Radio/TV | $10^{-1}$-$10^4$ | $10^9$ - $10^4$ | vibrating atoms or molecules over macroscopic distances | low frequencies are reflected by earth's atmosphere | Radio and TV; electrical engineer; communications industry, medicine, magnetic resonance imaging |
| microwave | $10^{-3}$ - $10^{-1}$ | $10^{11}$ - $10^9$ | vibrating atoms or molecules | these waves are blocked by "dots" on μλ oven doors | cooking; long distance TV and phone; radar; terrain mapping |
| infrared (IR) | $10^{-7}$ - $10^{-3}$ | $10^{14}$ -$10^9$ | vibrating atoms or electron transitions | passes through haze in the atmosphere | heating & drying; "night vision" cameras; TV & garage door remotes; satellite remote sensing |
| visible | 4-7 x $10^{-7}$ | 7.5x$10^{14}$- 4.3x$10^{14}$ | vibrating atoms or electron transitions | about 1/40 of total EMR spectrum | what the eye and typical film can "see"; optometrist |
| ultraviolet (UV) | $10^{-8}$- 7x$10^{-7}$ | $10^{16}$ -$10^{14}$ | vibrating atoms or electron transitions | "burning" rays of sun; | germicidal, photo-chemical, photo-electric effects; hardening casts in medicine |
| X-ray | $10^{-11}$- $10^{-8}$ | $10^{19}$ - $10^{16}$ | electron transitions and braking | λ is size of atom | medicine; crystallography; astrophysicist; remote sensing |
| gamma | $<10^{-11}$ | $>10^{19}$ | nuclear transition | can cause tissue damage and ionization | research into structure of nucleus; geophysics; mineral exploration |

B. A ***holographic diffraction grating*** is a transmission phase delay grating which produces a very bright first order image (energy transmitted to the zero order is minimized by maximizing interference at the center of visible spectrum at about 550 nm). The cost[4] is about $6 each. *Forty of these are included in each RB, one per student*. Most inexpensive student hand-held spectroscopes are less dispersive and produce a less intense first order image.

C. A grating produces a number of repeating spectra on either side of the central image (also called the zero order, which is an image of the source), and they are called first order, second order, etc. The zero order and one or more orders can be shown at the same time, or by adjusting the angle that the overhead projector has with respect to the screen, and by adjusting the projector to screen distance, one can show just one bright first order spectrum. If a meter stick is taped to the screen and the correct projector to screen distance is chosen, the 40 to 70 cm range on the meter stick can represent the 400 to 700 nm visible spectrum for rough estimates of wavelength. Or, a long sheet of paper may be taped to the screen, and the appropriate intervals marked off. The brightness of the projected spectrum can be maximized by rotating (in a vertical plane) one edge of the grating away from the lens to about 20°.

## 3. Spectra Sources

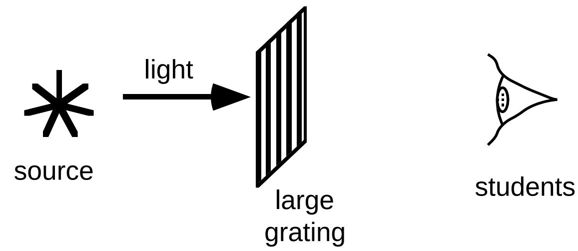
A. Emission Spectrum - Continuous

*Use the overhead projector as described above.*

- ***Complete spectrum*** - You should be able to obtain a single bright spectrum if you have aimed the projector off-center and rotated the grating at about 20°. The width of the opening on the overhead projector platen has some effect on intensity.

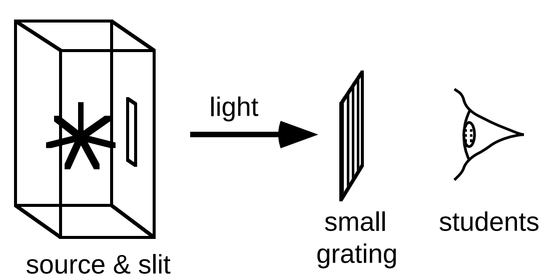
B. Emission Spectrum - Bright Line

*Remove the large grating from the overhead. An entire class can view the spectrum from the following two sources if light from the source is passed through the large grating.*




- ***Flame Test*** – Spectra are produced by heating salt solutions in a clean burning Bunsen flame. A wire loop is cleaned by inserting it into hydrochloric acid and then heated to incandescence in the flame until no color shows in the flame. Then it is placed into the test salt and held in the burner flame. The salts typically burn quickly so students must be alert to pick out the lines. You can expect the following lines to be observed: Calcium chloride (orange-yellow), potassium chloride (violet), sodium chloride (yellow), and strontium chloride (red).
- ***Gas Discharge Tube*** – A hot gas under low pressure will emit certain bright lines that can be distinguished with the grating. The gas tubes are placed across high voltage which ionizes the gas. Commonly available gases include hydrogen, helium and neon. Neon is particularly good because of its brightness. This is a very good way to illustrate the differences in electron energies. However neither the spectrum tubes ($20 and up) nor the power supplies ($125 and up) are common outside the physics classroom. You can expect hydrogen to produce at least one violet, one blue-green, and one red band that can be seen. Neon has over a dozen bands, mostly in the yellow to red end of the spectrum. Helium has bands in the violet, blue, blue green, yellow, and red.
- ***Mercury Discharge Lamp*** – A hot mercury gas under low pressure emits distinct bright lines of several wavelenghts that can be distinguished with the grating. You can expect to see violet, blue, blue- green, green, yellow, and orange.

*The following sources are generally too weak to be projected for an entire class, but are visible if each student has their own small grating*[5] *and views the source in a darkened room. Each emits one or more bands of light. One possible method of demonstrating these spectra is to have stations set up around the room and to have students visit each station and record their observations.*




- ***Cyalume Sticks*** (available in several colors in diving shops and some toy stores for $1-$2 each) Expected Outcomes: The green emits strongly in the green but also has some yellow and blue; the red produces most strongly in the red, orange, and yellow, with some green.
- ***Neon bulbs*** ($10-$20, available in specialty lighting stores) and **GrowLux**© fluorescent lamps ($2-$4, available in gardening supply stores) – Neon has over a

dozen bands, mostly in the yellow to red end of the spectrum. GrowLux© has many bands, especially red, and blue/violet.

- ***LEDs of various colors*** (available from electronics supply shops such as Radio Shack for $1-$2; they are current limited so must be wired in series with a resistor when attached to a battery or power supply) - red, yellow, and green emitters are available. Expected Outcome: some narrow band red, yellow, and green emitters are available that emit only those colors but common LEDs usually emit strongly in one region and weakly in others.
- ***Blacklight fluorescent lamps*** - violet, green, and yellow lines can be expected.
- ***Fluorescent Crayons*** - Illuminate with the UV sources. Each color will produce a variety of lines.

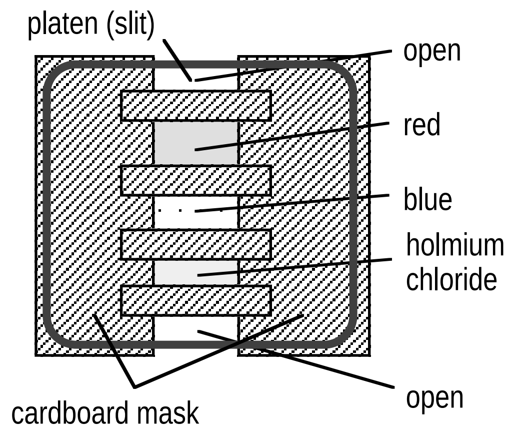
C. Absorption Spectra

*Set up the overhead projector with the grating mask as in the first demonstration. Maximize separation. Use mirrors to mix colors; show the effect of absorption by blocking one or more colors.*

1. Hold a chlorophyll solution in portions of the projected spectrum and note that bands of the spectrum are absorbed. This solution can be made by placing a handful or two of fresh green plant matter, such as grass clippings, in a blender. Add alcohol, blend, and filter. You will have to play around with the concen–tration to obtain the desired effect. Several wavelengths in both the red and blue end of the spectrum are absorbed so the resulting spectrum will appear dimmed in these regions compared to white light.
2. Hold glassblower glasses (neodymium and praseodymium, sometimes called didymium) in portions of the projected spectrum and note that a band in the yellow is strongly absorbed; bands in the violet, blue, green, orange, and red are absorbed to a lesser extent. Neodymium salts will also produce this effect.
3. Cobalt glass, used for welders glasses and in various physics experiments strongly absorbs yellow and orange, plus some red and green).
4. Hold a beaker of Vanish© Toilet Bowl Cleaner in portions of the projected spectrum and note that it strongly absorbs in the mid red range. The crystal product is not the same as the liquid, so be sure to buy liquid Vanish. If the solution is held in a white light source, the projected light appears blue and only slightly dimmed because the red absorption band is narrow. However, if a helium-neon laser is pointed at the solution, the absorption is almost complete as the emitted wavelength of a He-Ne laser is near the middle of the range of frequencies absorbed by Vanish.
5. Hold colored plastic sheets, especially theatrical lighting gels, in portions of the projected spectrum and note absorption bands. Or place the gels directly on the platen. Depending on the quality of the gel, absorption can be narrow or broad. A good quality red filter will pass only red and orange and possibly a faint bit of yellow. Poor filters may strongly pass the red end but weakly transmit the rest.
6. Take a fluorescent (glow-in-the-dark) marking pen and remove the cap; soak the tip in about 50 ml of alcohol overnight. This solution absorbs in the green and red. Dilute solutions of water-soluble fluorescent paints also work. In either case, be sure to read the label carefully before buying as some pens and paints are called fluorescent when in fact they are bright colors. True fluorescent materials must be subjected to either long or short wave UV (from the sun or UV lamps) before they work. *Note: The "Invisible Ink" included in the activity kit can be used here.*

D. Combined Spectra

An especially effective display can be made by comparing the spectra formed by several of the above demonstrations at the same time. For example, place a red gel, a green gel, the cobalt glass, and the fluorescent dye one below the other on the platen of the overhead with a narrow strip of cardboard between each (to set off the spectra when projected). If space for white light is made available at the top and bottom of this sequence, a comparison can be made to a full spectrum.




## 4. Color Theory

*Note: The following two activities require a bright projector and a dark room to be effective.*

A. Reflection Characteristics

Have students view different colored objects, such as sheets of colored paper, in white light; then have them observe the same objects in portions of the spectrum produced by the overhead projector and grating. Note the color that the object appears to be depends on both the color of the incident light as well as the “color” of object itself. Have students predict the color of test objects.

B. Color Mixing

Mirrors placed in the path of the projected spectrum and aimed so that light of different colors falls on the same spot allow students to experiment with the effects of color mixing. Students are sometimes surprised that certain colors such as yellow can be produced without any yellow at all by mixing green and red!

## 5. Polarization of Light

A. Use the OHP to show the polarization of light.|

Place a single sheet of polarizing film (Polaroid) on the projector and have students note the decreased transmission. Place a second sheet on top of the first and rotate to show transmission and absorbtion. Next place a third sheet diagonally in between two crossed polarizers. Several polarizing filters are included in the resource box.

B. Colors from Cellophane

Place some crumpled cellophane over one of the polaroids on the OHP (also try strips of cellophane tape overlapped at different angles, and experiment with different brands of transparent tape). Project the image onto a screen and rotate a second, slightly large Polaroid in front of the OHP lens. Do this in rhythm with some “hip” music and you’ll have a spectacular light show.

C. Colors from Karo Syrup

Place a bottle of Karo (corn syrup) between two sheets of polaroid, and place a white light source behind the seemingly-clear syrup. Have students view through the Polaroids and syrup and view the spectacular colors as you rotate one of the polarizers. This can also be projected onto a screen using OHP with a flat container of Karo, such as a petri dish.

D. Calcite crystal

A calcite crystal can be used as above to demonstrate another more complicated polarization effect resulting from a combination of double refraction and bifringence.

E. Liquid Crystal Displays

The common LCDs used all over the place in calculators, watches, clocks, etc., make use of the polarization of light using a liquid crystal that changes polarization with an applied voltage. Have students examine a typical display through a Polaroid. Have them rotate the Polaroid to ensure they get the full effect.

F. Polarized Light Microscope

Students can view spectacular interference colors with this setup. Any microscope, including an inexpensive toy microscope, can be converted into a polarized-light microscope by fitting a piece of Polaroid inside the eyepiece and taping another onto the stage of the microscope. Mix drops of naphthalene and benzene on a slide and watch the growth of crystals. Rotate the eyepiece and change the colors. Or simply observe the interference colors of pieces of cellophane or transparent tape.

**6. Blue Skies and Red Sunsets**

This activity is presented in Laboratory 6. It is worth doing as a quick demo using if you do not have the time for the formal lab activity. Use a slide projector for best results. It also makes a good home project, since it only needs a flashlight and a large glass bowl.

**7. Interference by Thin Films**

You can do this one as a demo or assign it as a home project in the kitchen sink. Dip a dark-colored coffee cup (dark colors make the best background for viewing interference colors) in dish washing detergent, and then hold it sideways and look at the reflected light from the soap film that covers its mouth. Swirling colors appear as the soap runs down to form a wedge that grows thicker at the bottom with time. The top becomes thinner, so thin that it appears black. This tell us that its thickness is less than one-fourth the thickness of the shortest waves of visible light. Whatever its wavelength, light reflecting from the outer surface reverses phase, rejoins light reflecting from the inner surface which doesn't reverses phase and cancels. The film soon becomes so thin it pops.

## References


 This apple means that a particular item is included in the **Resource Box**.

1. Philip Sadler, "Projecting Spectra for Classroom Investigations," *Physics Teacher* **29**, 423 (1991).
2. George A. Burman, "Overhead Spectroscopy," *Physics Teacher* **29**, 470 (1991).
3. Kenneth Brecher, "Do Atoms Really 'Emit' Absorption Lines? ," *Physics Teacher* **29**, 454 (1991).
4. Learning Technologies Inc., 59 Walden St., Cambridge, MA 02140 (617) 547-7724. One 4.5" x 5" sheet with four color filters costs $6 plus shipping and handling. *Included in Resource Box*.
5. Holographic diffraction gratings enclosed in 35 mm glass slide mounts are available for $3 each from Arbor Scientific, P.O. Box 2750, Ann Arbor, MI 48106-2750, (800) 367-6695. *These have been included in the Resource Box, enough for an entire classroom.*

### *Laboratory No.1:*

# The Visible Electromagnetic Spectrum

## Purpose

The purpose is to investigate the visible electromagnetic spectrum using a diffraction grating to observe different light sources.

## Required Equipment and Supplies

Diffraction gratings or hand-held spectroscopes; overhead projector with mounted large holographic diffraction grating; various light sources.

## Discussion

Energy emitted from vibrating electric charges produces electromagnetic waves. Our eyes are sensitive to just a small portion of the electromagnetic spectrum. The sun, normal incandescent bulbs, and most fluorescent bulbs produce nearly white light by mixing all the frequencies (colors) together. White light can be separated into its component colors, called a spectrum, by passing the light through a prism or a diffraction grating. If a light source produces all the visible frequencies (such as the sun), the spectrum is called a continuous emission spectrum. If the source produces only certain frequencies (such as a gas at low pressure, a neon sign for example), the resulting spectrum is called a bright line emission spectrum. If a transparent substance (such as stained glass) absorbs or removes certain frequencies from white light, the spectrum produced is called an absorption spectrum.

## Review Questions

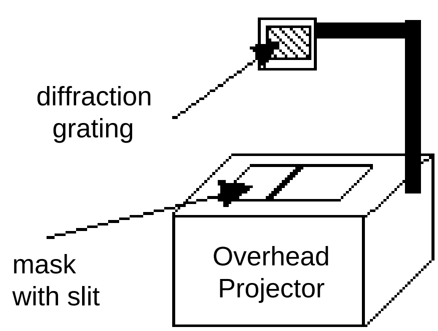
1. What causes electromagnetic waves?
2. What event causes visible light to be produced?
3. What are the three types of spectra?
4. Do atoms emit absorption lines?
5. Does the color of a banana change if the color of light hitting it changes?

## Procedure

The instructor will set up a number of different sources of light, producing a variety of spectra. Observe each of these sources through a diffraction grating, and record the source name and observations for each of the spectra types.

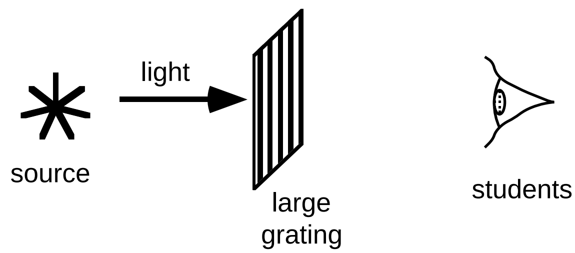
**Describe your findings for the following demonstrations:**

1. ***Continuous emission spectrum* –**
   This is produced using the “white hot” incandenscent light bulb inside an overhead projector, which is masked to allow only a narrow slit of light which is then passed through a a large diffraction grating after being focused by the projector lens.




***Overhead Projector Setup***

**2.** ***Bright line emission spectrum –***
A number of different emissison spectra will be produced, including:
a. flame tests
b. gas discharge tubes
c. Cyalume sticks
d. LEDs
e. blacklight
f. neon bulb
g. GrowLux
h. fluorescent Crayons




***Observation of Light Source through Grating (Lab Station)***

**3.** ***Absorption spectrum –***
Several different absorption spectra are to be demonstrated, including:
a. chlorophyll
b. didymium glass
c. colbalt glass
d. holmium chloride
e. Vanish
f. lighting gels
g. fluorescent dye

## Analysis of Experiment

1. What physical event produces the different frequencies that make up a continuous spectrum? What evidence do you have from this investigation that your answer is correct?
2. If white light is passed through a cloud of sodium gas and then dispersed by a grating, certain frequencies at about 590 nm are removed. What frequencies do you think would be emitted by sodium if it were heated to high temperature? Why?
3. Is the color of an object always the same? What evidence do you have from this investigation? What color would a red dress appear if viewed under blue light?
4. Do filters (gels) turn one color of light into another color of light? For example would green light turn into blue if passed through a blue filter? What evidence do you have from this investigation?
5. Can you produce yellow light without using any yellow? Explain.
6. Could spectral analysis (such as the flame test or placing the chlorophyll in the light path) help you identify an unknown object? Explain. Could this be used in forensics?

### *Instructor's Guide to Lab No. 2:*

# Demonstrating the Invisible Regions of the Electromagnetic Spectrum

## Goal

The goal is to outline techniques for demonstrating the invisible regions of the electromagnetic spectrum using materials commonly available to high school physics courses.

## Objectives

After observing these demonstrations, students should be able to:

- Explain that visible light is only a small portion of the electromagnetic spectrum;
- Recognize that the spectrum produced by a blackbody radiator is related to the temperature of the radiator;
- Use an ultraviolet viewer or UV sensitive liquid crystal to detect the presence of UV rays in common electromagnetic radiation sources;
- Recognize that infrared waves transfer energy by waves which have properties similar to light waves such as reflection, refraction, and diffraction;
- Explain that radio and TV signals are waves which can be shielded;
- Demonstrate that microwaves are larger than the interhole distance on a microwave oven door and explain that microwave heating is due to two radiation effects;

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## Background Information

See background information on visible electromagnetic radiation. The phrase "electromagnetic spectrum" is frequently referred to in the study of science. In biology it is often a part of the discussion of photosynthesis, the physiology of the eye, and mutatgenic sources. In earth and space science electromagnetic radiation is often a part of a discussion of radioactive minerals, cosmic rays being deflected by the earth's magnetic field: analyzing incoming radiation from stars by optical and radio telescopes or other means. In chemistry the spectrum is often discussed when talking about evidence for different electron energy levels and characteristic properties of elements. In physics it is a part of the study of waves, electricity and magnetism, and modern physics. The table on the following page divides the electromagnetic spectrum into eight bands by common names although the differences between types are gradual rather than precipitous.

## Helpful Hints

1. **Blackbody Radiation:**

   The variation of the spectrum produced by a heated object, called blackbody radiation, can be demonstrated with a variac (a variable ac power supply), a 100-200 W clear glass bulb ($3–$4), and a porcelain socket ($2). As an alternative to the variac, an in-circuit dimmer extension cord ($15–$20), or a light switch dimmer ($5–$6 if you can do some wiring) can be used. The dimmer can be obtained from a hardware or specialty lighting store. Produce a narrow band of light from your source to reduce stray reflections by placing it inside a large can, such as a 48 oz juice can, with a narrow slit cut in one side. Allow for ventilation. Be careful as the can will get hot! Pass the light through a large diffraction grating[1] (as discussed in the activity *Demonstrating the Visible Electromagnetic Spectrum*) and project the resulting spectrum upon a screen. Vary the temperature of the filament by varying the voltage; note the change in the spectrum. Turn up the voltage until the filament just starts to glow red, and then back it off to the point where the filament no longer glows red. Have students view the spectrum as the voltage is changed. They should note that as the voltage (and therefore temperature) increases, so does the intensity of the blue end of the spectrum, indicating more energy being radiated.

*Note: A triac-type ac dimmer is included in the Resource Box for this demonstration. It is wired into a three-prong socket and cord. It is to be used with the High-Power Light Source (Frey Scientific) also included in the RB, which consists of a socket, clamp, chord, and cardboard shroud. Fashion a slit out of cardboard to place in front of the hole in the shroud, held together with elastic bands. Even better is to mount the slit in the end of a cardboard tube, the other of which is mounted to the shroud of the light source.*

**2. Ultra-Violet Radiation:**

Both infrared and ultraviolet light can be detected by UV or IR sensitive digital cameras, but they cost tens of thousands of dollars. UV, IR, and x–rays can be detected by films obtained from photography supply stores, but there is the cost and delay of development. Ultraviolet can however, be detected with a simple filter[2] costing about \$30–\$40. A credit card-sized UV detector[3] is also available for about \$5 which reacts in seconds to UV and indicates a relative intensity level on a liquid crystal strip. Students can use either of these to detect variations in UV production from the blackbody radiator (*Demonstration No. 1*) and from many other sources such as the sun, TVs, computer monitors, burner flames, and stoves. Show off the fluorescent mineral set, crayons, and black light poster included in the resource box using the long-wave UV lamp also included.

*Note: Both the UV bandpass filter and several card-size detectors have been included in the Resource Box. The filter is to be assembled with the enclosed PVC tubes to form the UV detector. Details are in the Resource Box.*

**3. Infrared Radiation**

The best method we have found for demonstrating IR is using an ordinary CCD or viticon-based TV camera. The semiconductor detector chips in some of these are very sensitive to IR. We have obtained a number of surplus security cameras, and included one in each Resource Box. Point any type of IR-based remote control unit at the camera and it appears as a bright source on the monitor. Also use the included "IR Flashlight" (an infra-red LED wired into an ordinary flashlight in place of the normal bulb) with the included prism and/or diffraction grating to show diffraction. Use developed color film as an IR bandpass filter to filter out excess visible light. The lights can be turned out and the IR flashlight can be used to illuminate students. Watch out, you can be observed in the darkest of nights! A lot can be done with this set up. Be imaginative, and let us know what you come up with!

The TV camera can be used with the optical bench (meterstick type) and diffraction grating included in the resource box to demonstrate Laboratory No. 4 on the TV monitor. First use the mercury lamp to demonstrate and measure the various visible lines, then replace the mercury source with the infra-red LED light source that has been put together for this purpose. The "invisible" lines can be clearly seen on the monitor. Again, the developed color film can be used to screen out most of the unwanted visible wavelengths.

The wave properties of IR can be demonstrated using toy ray guns.[4] The Photon© ray gun, made by Entertech, or the Bravestarr Evil Laser-Fire Backpack© by Mattel can be used. A homemade version[5] can be made for about $5 using a TV remote control as the signal, and an infrared photo transistor, resistor, LED, and battery as the detector. The details of the detector are given in the appendix. The simplest demonstration involves aiming the IR beam into a mirror and having it reflect onto the target sensor. In the case of the Photon gun, the target has a light which changes from green to red when hit with IR. Other demonstrations illustrating wave properties such as the focusing effect of parabolic mirrors, refraction through plastic prisms, total internal reflection in thick Lucite bars, and diffraction around sharp objects can be demonstrated. *Note: The "Light Listener" described below can be used for these demos.*

A "Light Listener" that responds to IR can be built, and plans are included in *The Instructor's Guide to Lab No. 6* (p. 46). It is the receiving end of a simple amplitude-modulated light wave communications system. It can be used to "listen" to the signals produced by light sources such as an IR remote control. Students can use it to hear what their TV remote control is saying (a series of tones.) An incandescent lamp will produce a hum, a flourescent lamp a buzz, and an electronic camera flash will produce a large pop. A flashlight beam can be swept slowly across the light listener's detector to produce a soft swishing sound, while a fast sweep will produce pops. Tap the flashlight with a pencil and a ringing sound will be heard as the filament vibrates. Interesting!

Yet another approach is to use an infrared heat lamp, an IR filter,[6] and a radiometer. The heat lamp will cause the radiometer to rotate; placing the IR filter between the lamp and the radiometer significantly reduces the IR flow and causes the radiometer to slow or stop. Some slide projectors have these glass IR filters between the lamp and the slide to reduce heat transfer to the slide. IR bandpass filters[6] which allow only a narrow band of IR to pass through the filter are also available. This filter can be placed in front of light from an incandescent lamp or the sun, blocking the visible light and allowing only the IR. This filter can be used, for example, by placing the radiometer in a box with a hole cut in it the size of the filter. A heat lamp or other bright incandescent source can be placed in front of the filter causing the radiometer to rotate. Viewed from overhead, the box remains relatively dark, yet the radiometer vanes rotate. *Again, depending on the setup, developed color film may work here.*

**4. Radio and TV Waves**

*Many of these demonstrations are included as individual student activities in the "Radio Waves and Microwaves (Labs 18–23)." You may wish to demo some here and save some for the students to do themselves*.

The wave properties commonly associated with light can also be illustrated with radio and TV signals. AM waves are reflected by the ionosphere and therefore can travel 1000s of kilometers. Demonstrate this by tuning in a station from a distant city on an AM radio (this can be a somewhat unreliable demonstration as the heights of the various ion layers vary with weather, time of day, and particle production by the sun). The shielding of radio waves can be demonstrated by placing a playing radio or TV inside a wire mesh cage made from window screen or a metal box. Note that the signal dies away.

**5. Radiation**

Some wave properties can be even more easily illustrated with microwaves than with light waves but microwave generators and detectors are expensive. However, the ubiquitous microwave oven can be used to illustrate some wave properties. An often asked question is, "Why can we see through a microwave oven door but the microwaves don't come out?” The explanation is the same one that explains why a sieve allows the sand in a sand and rock mix to pass through but not the rocks. The rocks are too big. Microwaves have a wavelength of about 12 cm, much larger than the inter hole distance in the screen of the door that is but a few mm. The oven can be used to investigate various calorimetric variables[7] such as efficiency of the magnetron power tube, specific heat of different liquids, oven parameters etc.

The heating effect of microwave ovens is due primarily to its ability to cause water molecules to vibrate (dipole rotation). There is a secondary absorption method called ionic conduction[8]. This effect can be demonstrated by comparing the times to boiling of equal masses of pure water and salted water. The salted water will heat much faster in the microwave even though its boiling point is higher due to the increased energy absorption by the ions. Heated on the stove, the salted water takes more time than the pure water to reach boiling!

## References:


1. Learning Technologies Inc., 59 Walden St., Cambridge, MA 02140, (617) 547-7724. One 4.5" x 5" sheet with 4 color filters costs $6 plus shipping and handling.
2. Tom Donohue and Howard Wallace, "Ultraviolet Viewer," *Physics Teacher* **31**, 41 (1993).
3. Science Kit, P.O. Box 5059, San Luis Obispo, CA 93403, (800) 828-9572.
4. R. S. Halada, "Demonstrations of Infrared Ray Optics Using Ray Guns," *Physics Teacher* **29**, 370 (1991).
5. John W. Jewett, Jr., "*Physics Begins With An M,”* p 311, Allyn and Bacon (1994).
6. The IR absorbing filter $22.50 and the IR bandpass filter $52.80 are available from CENCO Scientific, 3300 CENCO Pkwy, Franklin Park, IL 60131, (800) 262-3626. The radiometer is a common device available from most science supply houses (including the Reuben H. Fleet Space Museum) for about $5–$10.
7. Ron Fritz, "Calibration and Efficiency of Microwave Ovens,",*Physics Teacher*r **28**, 564 (1990).
8. John W. Jewett, Jr., "*Physics Begins With An M,”* p 323, Allyn and Bacon (1994).

### *Laboratory No. 2:*

# Demonstrating the Invisible Regions of the Electromagnetic Spectrum

## Purpose

The purpose of this demonstration is to investigate the invisible electromagnetic spectrum by employing various detectors to indicate the presence of waves.

## Required Equipment and Supplies

Diffraction grating; variable voltage supply; 100–200 W clear lamp and socket; sensitive temperature sensor; UV source and detector; IR source and detector; small portable radio or TV; Faraday cage, metal box, or wire mesh box; microwave oven; distilled water; NaCl; two 250 ml beakers; stopwatch; leaf electroscope; Crookes tube and induction coil; electrical wire; gamma source; aluminum sheet; lead sheet.

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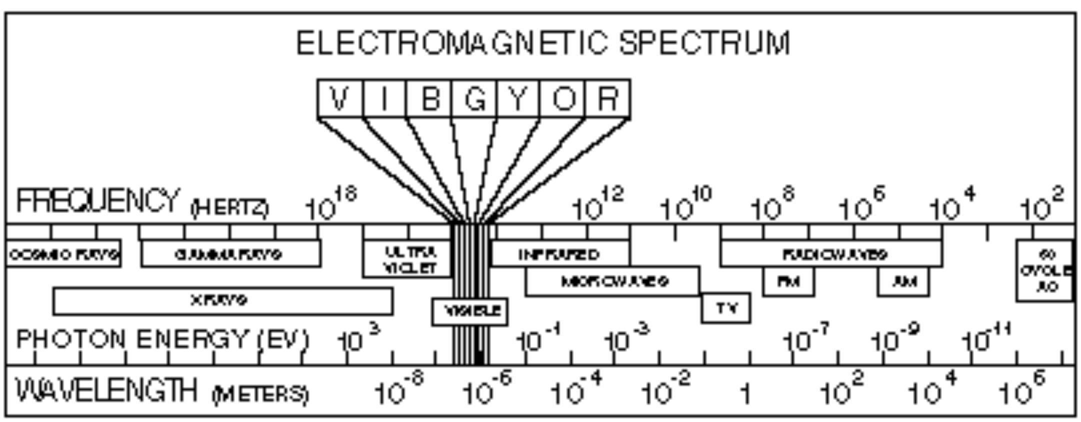
## Discussion

Energy that is emitted from vibrating electric charges produces electromagnetic waves. Power waves, radio/TV waves, and microwaves are produced by atoms or molecules vibrating slowly over macroscopic distances. Infrared waves are produced by more rapidly vibrating atoms or molecules or by slowly vibrating electrons. Electrons vibrating at a faster rate produce visible light. Even more rapidly vibrating electrons produce ultraviolet and X-rays. Gamma rays are produced by nuclear transitions (changes of the nucleus from one energy level to another). It can generally be stated that the more massive the particle, the more slowly it vibrates. Therefore only tiny masses, such as electrons, can vibrate fast enough to produce high frequencies, whereas large masses, such as atoms and molecules, vibrate slowly enough to produce low frequencies. The faster an object vibrates, the more energy it can release.



## Review Questions

1. Make a statement that relates the mass of a particle to the kind of wave it produces.
2. What causes an electromagnetic wave?
3. What is a heat wave? Can you see a heat wave?
4. Why can't you see UV or IR?
5. What is a nuclear transition?

## Procedure

Record your observations for each of the types of invisible radiation that your teacher demonstrates.

## Analysis of Experiment

Answer the following question based on your observations in class:

1. ***Blackbody Radiator***
   (a) What do you notice about the spectrum as the brightness (temperature) of the light bulb increases?
   (b) What proof do you have from the demonstration that electromagnetic waves are produced by a heated but not glowing bulb?
2. ***Ultraviolet***
   (a) Describe the UV detector.
   (b) What sources of UV did you detect?
3. ***Infrared***
   (a) Describe the IR detector.
   (b) How did this investigation demonstrate the presence of IR waves?
4. ***Radio/TV***
   (a) How does the shielding experiment demonstrate that radio signals are waves?
5. ***Microwaves***
   (a) Why don't microwaves pass through the screening on the oven door?
   (b) Why does salted water heat faster than pure water in the microwave oven?

### *Instructor's Guide to Lab No. 3 (a & b):*

# Why Are There Colors in a Compact Disk?

## Goal

The goal is to introduce the phenomena of interference and diffraction using a common everyday items such as a audio compact disk (CD). Identify natural examples of iridescence found in nature.

## Objectives

After performing this exercise students will be able to:

- Understand the phenomena of wave diffraction
- Understand the phenomena of wave interference
- Use a diffraction grating to separate a visible light source into its component parts.
- Calculate the wavelength of different colors of light using an ordinary CD

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## Background Information

We have divided this lab into two sections: the first just examines the cause of the colors in the CD and the general property of iridescence and interference patterns. The second part actually uses the CD as a diffraction grating; students start with the known value of the wavelength of violet light (450 nm) and then determine the spacing between tracks on the CD.

This lab offers a fascinating look at the CD as a diffraction grating. An excellent description of the phenomena is presented in the student labs. Because of their wide use and desirability, students find it quite compelling to learn about the CDs. This might be a good opportunity to introduce some of physics that goes on in the standard operation of a CD player. The article by T.D. Rossing is a fitting reference here.

It is interesting to note that there are no continuous grooves or even tracks present as a mechanical structure on a CD. The occurrence of closely spaced pits, however, is sufficient to give the strong visual interference effects. This shows that an ideal grating is not required; a sufficiently periodic structure also does the job!

A similar phenomena is *thin film interference*. See the demo described in the extension below. The bright colors in a peacock's feathers, as well as the similarly bright colors on the throat of a hummingbird, are due to *interference*, not to absorption and reflection as with "normal" colored objects. Structures in the feathers act as multilayer interference films that exhibit constructive interference for the colors that you see from the feathers, for example, blue and green from the peacock feather. Look at the peacock feather from different angles and notice how the color changes. Other creatures exhibit similar interference effects, such as the *Morpho* butterfly from South America and the beetle *Chrysochroa fulminans*, for which the interference combines with a highly glossy surface to give colors which range from metallic gold to green (Jewitt, 1994).

## Helpful Hints

- Use a peacock feather for students to examine natural examples of iridescence. Have students look at the peacock feather from different angles and notice how the color changes. Introduce them to abalone shells and have them identify the multiple thin layers that cause the beautiful colors.
- Set up various light sources for the students to study with the CD as a diffraction grating. Use the mercury and neon lamps included in the resource box.
- Sample data for the track spacing measurements in Lab No. 3b is: $s$ = 20 cm, $r$ = 6.0 cm, which results in a track spacing of $d$ = 1566 nm, very close to 1600 nm!

## Extensions

- Another way to do this experiment would be to start the students with the known track spacing for the CD (1600 nm from manufacturers data) and have them determine the approximate wavelength of violet light (450 nm).
- After measuring the track spacing, you may want to have you students approximate the total *track length* on the CD. A good way to do this would be measure the width of the CD surface ($r_{outer} - r_{inner}$) and divide by the track spacing (1600 nm) to determine the total number of tracks. Then multiply this by the average radius $\frac{1}{2}(r_{outer} + r_{inner})$. This should come out to be several miles!
- Do your students believe that light can never pass through a metal, no matter however thin it is? Make them look through a CD. They have to believe you, though, that the material inside is a metal.
- ***Interference by Thin Films -*** Dip a dark-colored coffee cup (dark colors make the best background for viewing interference colors) in dish washing detergent, and then hold it sideways and look at the reflected light from the soap film that covers its mouth. Swirling colors appear as the soap runs down to form a wedge that grows thicker at the bottom with time. The top becomes thinner, so thin that it appears black. This tell us that its thickness is less than one-fourth the thickness of the shortest waves of visible light. Whatever its wavelength, light reflecting from the inner surface reverses phase, rejoins light reflecting from the inner surface reverses phase, rejoins light reflecting from the outer surface, and cancels. The film soon becomes so thin it pops.

## References

J.W. Jewitt, *Physics Begins With an M* (Allyn and Baker, Needahm Heights, MA, 1994).

T.D. Rossing, "The Compact Disc Digital Audio System," *The Physics Teacher* **25**, 556 (1987).

C. Noldeke "Compact Disk Diffraction," *The Physics Teacher* **28**, 484 (1990).

G. Ramme, "Colors on Soap Films – An Interference Phenomenon," *The Physics Teacher* **28**, 479 (1990).

## *Laboratory No. 3a*

# Why Are There Colors in a Compact Disk?

### Purpose

To investigate the diffraction and interference of light reflected from a normal audio compact disk.

### Required Equipment and Supplies

Compact disk (CD), ordinary incandescent light source, miscellaneous light sources.

### Discussion

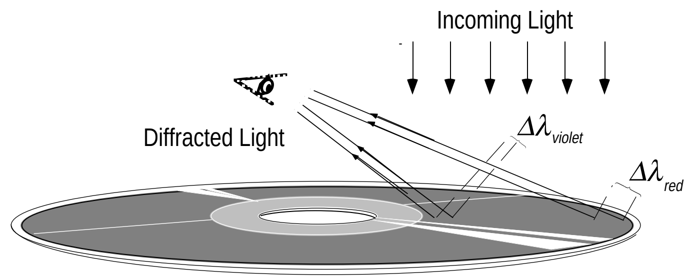

**Figure 1**

The rainbow of colors reflected from the surface of a compact audio disk is a familiar sight. This is the same display of colors that is produced by a diffraction grating such as the one used in the previous labs to investigate visible spectra. This means that a CD essentially behaves as a diffraction grating. In order to understand how a diffraction grating works to separate colors of light, we need to examine some of the special wave properties of light. The wave properties of light create some of nature's most beautiful spectacles, including the colors in a peacocks tail, abalone shells, rainbows, and soap films.

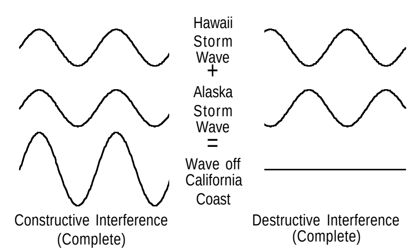

**Figure 2**

One of the most interesting properties of waves is called *interference*, which is caused by the overlapping of waves sharing the same space at the same time. When waves overlap they combine to form a new wave which is the sum of the effects of each wave. Interference can be either *constructive* or *destructive*. Figure 2 shows a hypothetical situation in which waves from a storm off the Alaska coast might interfere with waves from Hawaii near a California beach. When the waves from each storm arrive crest-to-crest ("in-phase") they interfere constructively and combine to form a stronger wave. When the waves arrive crest-to-trough ("out of phase") they interfere destructively and cancel one another out. Interference effects can be either partial or complete.

When light is reflected from a regular pattern of tiny objects, interference causes colors to appear. Figure 1 shows how light striking the reflective surface of a CD composed of regularly spaced tracks can interfere constructively, causing intense reflection of particular wavelength at certain angles. If the viewer changes angles with respect to the CD, some other wavelength interferes constructively – the color seen depends on the angle of observation, just as with a rainbow.

Such colors from interference are called iridescence (iris: Latin for rainbow). The shells and wings of some wasps and beetles have parallel grooves that produce iridescence. Iridescent butterflies have scales that act as reflective gratings. Iridescence can also come from constructive reflections of thin films such as soap films or gasoline on a wet street. The brilliant iridescent blues and greens from some types of seaweed and from abalone shells come from constructive reflections from multiple thin layers. The bright colors in a peacock's feathers and the throat of a hummingbird are also due to iridescence. Structures in the feathers act as multilayer interference films that exhibit constructive interference for the colors that you see from the feathers.

As well as being beautiful, interference patterns are extremely useful, and provided the first convincing demonstration of the wave nature of light. We can use a reflective surface with regularly spaced grooves in it, called a diffraction grating, to measure and study light. In the previous labs you used another type of grating called a transmission diffraction grating to disperse light into its constituent colors and to determine the colors of light that are emitted by different light sources.

Both transmission and reflection-type diffraction gratings are extensively used in the sciences to study light; the use and function of each is essentially the same. Both types are manufactured very carefully, and typically contain six-hundred or so grooves or lines per millimeter!

It turns out that the regular pattern of pits contained on the reflective surface of a CD causes the CD to behave much like a grating. As with a manufactured grating, different angles of viewing cause constructive interference to occur for different wavelengths (colors) of light. Thus, reflection of white light off the surface gives a spectrum of colors across the surface of the CD. At small viewing angles, the shorter wavelengths constructively interfere (violet, blue, and indigo) while the longer wavelengths will constructively interfere at larger viewing angles (red, orange, and yellow). Interestingly enough, diffraction gratings might be more reasonably called interference gratings!

### Review Questions

1. What is interference?
2. What is iridescence?
3. How is a CD similar to a diffraction grating?
4 In what way would a diffraction grating be better called an interference grating.

### Activities

1. Take a normal audio CD to a incandescent source of light and examine the interference pattern that results from reflected light. What colors do you see? What order are they in? Which end of the spectrum is closest to you, violet or red? What does this say about the wavelengths of each color in the spectrum?

2. Examine the CD in front of the mercury light source. What colors do you see? What does this say about the wavelengths of light emitted by excited mercury gas. Use the CD to examine the light emission of other light sources setup by your instructor, such as a neon glow lamp, Gro-Lux lamp, and Cyalume light sticks.

3. Are the brilliant feathers of a peacock really blue and green? Look at a peacock feather at different angles and notice how the color changes. What is going on here? What is the source of the brilliant blues and greens we see? Pigmentation or interference effects?

4. You can do this one as a home project in the kitchen sink. Dip a dark-colored coffee cup (dark colors make the best background for viewing interference colors) in dish washing detergent, and then hold it sideways and look at the reflected light from the soap film that covers its mouth. Swirling colors appear as the soap runs down to form a wedge that grows thicker at the bottom with time. This is called thin-film interference. Ask your instructor for a detailed description. Interference phenomena is all around us! Can you spot more?

## *Laboratory No. 3b*

# The Compact Disk as Diffraction Grating

### Purpose

To use an audio compact disk (CD) as a diffraction grating and the known wavelength of violet light to measure the spacing between tracks.

### Required Equipment and Supplies

Compact disk, ordinary incandescent light source (40 W bulb will do), and a ruler.

### Discussion

When light is reflected from a regular pattern of tiny objects, interference causes colors to appear. In the previous lab we saw how light striking the reflective surface of a CD composed of regularly spaced tracks can interfere constructively, causing intense reflection of particular wavelength at certain angles. The pattern of colors generated by both reflection and transmission diffraction gratings is called an *interference pattern.* These patterns can be both strikingly beautiful and extremely useful, and provided the first convincing demonstration of the wave nature of light.

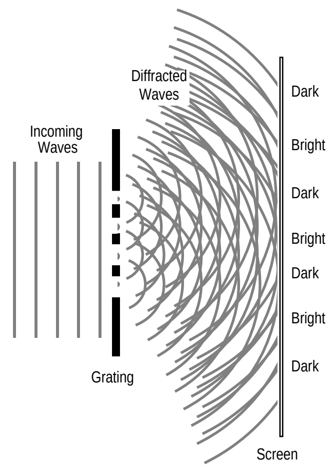


**Figure 1**

Both transmission and reflection-type diffraction gratings are extensively used in the sciences to study light; the use and function of each is essentially the same. Although the interference patterns produced by gratings are generated by the interference properties of light, there is another important wave phenomena going on here called *diffraction*. This is one of the more obvious properties of waves and refers to the spreading and bending of waves around objects. This is why sound can bend around corners, allowing you to hear a stereo play from another room before you actually enter the room and see the stereo. You might wonder, though, why light does not bend in the same manner, if it is truly a wave. If light and sound are both waves, why don't they act the same? The reason turns out to be one of size. In fact, light does bend, but on a much smaller scale because of its much smaller wavelength. In order for diffraction to be noticeable, the object causing the bending or spreading must be about the same size as the wave. This is only several hundred nanometers ($10^{-9}$ m) for visible light! This is why typical diffraction gratings used for visible contain thousands of closely spaces lines (called *rules* or *slits*), about 600 *per* millimeter.

When light from a light source passes through a *transmission* diffraction grating, each slit in the grating diffracts or spreads the light as if it were originating from a point source. In effect, a diffraction grating produces thousands of closely-spaced mini-light sources. Furthermore, since the light originated from the same source behind the grating, the light from each slit is coherent (synchronized) with one another. A compact disk, with its closely spaced grooves and reflective aluminum plating, essentially provides thousands of tiny, closely spaced mirrors capable of diffracting light by *reflection*. It is these closely spaced coherent light "sources" created by diffraction that interact to produce the interference patterns that we use to detect, study, and measure light. For example, if we know the distance *d* between slits or rules on the grating, then we can use the grating to measure the wavelengths of light emitted by any source using the grating. Conversely, we can use a known wavelength of a particular color of light, such as violet ($\lambda$ = 450 nm), to measure the tiny distance between tracks on a CD! In a sense, we're using the wavelength of light itself as a sort of super-fine meterstick to measure distances smaller the width of a human hair!

Now that we understand the concepts involved, let's take a closer look at how we can use a CD as diffraction grating to measure the tiny spacing between tracks. Although interference patterns might seem complicated, it's really just a matter of geometry and the simple fact that constructive interference occurs at places that are multiple wavelengths from each source. The details of the calculation will become clearer as you follow the procedure below.

## Review Questions

1. How is a CD similar to a diffraction grating?
2. What is diffraction?
3. What is interference?

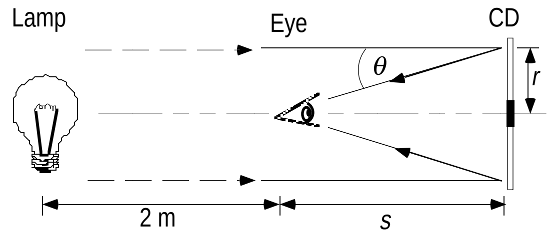

**Figure 2**

## Procedure

1. Working with a partner, take a CD and a ruler and stand about 2 m from the light source, which should be placed at eye level behind you. Hold the CD at various positions in the light and examine the brilliant colors that are reflected from the surface.
2. Hold the CD in front of you so that the reflection of the bulb disappears in the center hole. Hold the CD about 10 cm from your eye so that circular spectrum can be observed on the disk. Increase the distance until a violet pat of the spectrum appears on the edge of the CD. Measure the distance between your eye and the disk: this is the distance *s* in Figure 2. With the help of the visual structures on the edge of the CD, take notice of the radial position of the violet ring appearing on the disk. Measure the radius of the disk from the center to outside edge where the violet ring was observed; this is the distance *r* in Figure 2.

## Analysis

A typical drawing detailing the geometry for constructive interference from a diffraction grating is shown in Figure 3. The grating constant *d* is effectively the track spacing of the CD. Using the accepted value of $\lambda$ = 450 nm for violet light, use this drawing together with your measured values of *r* and *s* to determine the approximate track spacing *d*. The procedure is outlined below.

For a typical diffraction grating, light rays that are reflected straight back without deviation interfere constructively to produce the brightest image at the center of the screen (or the observer's eye). This image is useful for alignment of the diffracted spectra, and was conveniently passed through the hole of CD in this experiment. Constructive interference also occurs for any angle $\theta$ such that the rays from adjacent tracks each travel an extra distance of $\Delta l = n\lambda$, where is *n* is an integer that denotes the order of the image. Using trigonometry, we see that constructive interference occurs when the angle $\theta_n$ is such that

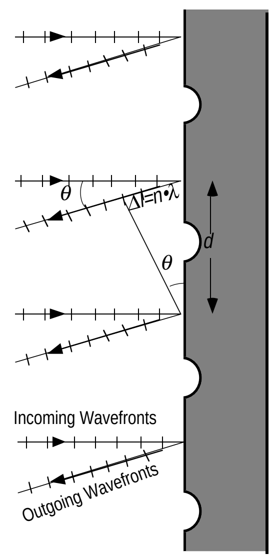

**Figure 3**

$$\Delta l = d\sin\theta_n = n\lambda \quad n = 1, 2, 3, \ldots$$

The ring you measured on the CD is the first in a series of spectral images, and is called the *first order (n* = 1). The angle $\theta$ in Figure 3 is the same as the angle shown in Figure 2. By varying the distance s you effectively changed the angle $\theta$, which causes different wavelengths (colors) of light to constructively interfere. We can use the Pythagorean theorem for right triangles to calculate the sine of the angle $\theta$:

$$\sin\theta_n = \frac{\text{opposite}}{\text{hypotenuse}} = \frac{r}{\sqrt{s^2 + r^2}}$$

The track spacing *d* can be found by combining these two the equations and rearranging a little:

$$d = n\lambda\frac{1}{\sin\theta_n} = n\lambda\cdot\frac{\sqrt{s^2+r^2}}{r} = (1)(450\text{ nm})\cdot\frac{\sqrt{(\quad\text{cm})^2 + (\quad\text{cm})^2}}{(\quad\text{cm})} = \qquad \text{nm}$$

The international manufacturing standard for the track spacing of a CD is 1600 nm. How does your measured value compare with this standard?

## *Instructor's Guide to Laboratory No. 4:*
# Measuring Wavelengths of Light

### Goal
The goal is to learn how to measure the wavelengths of various colors of light and line spectra using an optical slit with a diffraction grating and simple optical bench.

### Objectives
After performing this exercise students will be able to:

- Understand the phenomena of wave diffraction
- Understand the phenomena of wave interference
- Use a diffraction grating to separate a visible light source into its component parts.
- Calculate the wavelength of different colors of light using an ordinary CD

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### Background Information
An excellent description of the phenomena is presented in the student lab. Everything required to do this experiment except a meterstick is included in the Resource Box.

This experiment can also be done as a demonstration using the TV camera as the observer. Clear line spectra can be seen on the screen. This setup can then be used with an IR source to view IR spectra.

### Helpful Hints
- You may want to introduce the interference patterns here with the Moiré-pattern slides included in the Resource Box. Use an OHP and overlay the two slides on one another. Move the slides around to demonstrate various configurations of interference. You may want to save this demo for the next lab, Young's Experiment.
- An excellent way to conduct this lab is to assign the measurement of different line spectra to different groups of students.
- The mercury source included in the Box has several filters to isolate several different mercury lines.
- An incandescent-type neon bulb has some rich lines that can be observed.
- You may want to do the Young's Experiment lab before this one.

### Extensions
- This setup can then be used with an IR source to view IR spectra.
- This experiment can also be done as a demonstration using the TV camera as the observer. Clear line spectra can be seen on the screen. This setup can then be used with an IR source to view IR spectra.

### References
J.D. Wilson, *Physics Laboratory Experiments 3e* (D.C. Heath and Company, Lexington, MA, 1990), Chap 50.

Name: Class: Date:



### *Laboratory No. 4*

# Measuring Wavelengths of Light

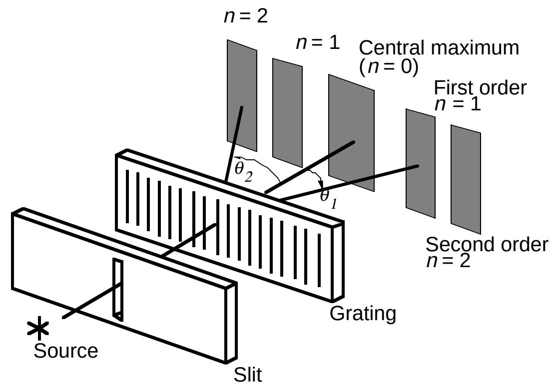
## Purpose

To measure the wavelengths of light using a diffraction grating.

## Required Equipment and Supplies

Optical bench (meterstick with supports), optical slit with scale and holder, diffraction grating with holder, mercury light source, incandescent light source.

## Discussion




A diffraction grating consists of a piece of metal or glass with a very large number of evenly spaced parallel lines or grooves. Common laboratory gratings have 200 or 600 groves per mm. There are two types of gratings: reflection gratings and transmission gratings. Reflection gratings are ruled on polished metal surfaces and light is reflected from the unruled areas which act as a row of "slits." Transmission gratings are ruled on glass and the unruled slit areas transmit incident light. The transmission type diffraction grating is used in this experiment.

Diffraction refers to the "bending" of waves around sharp edges or corners. The slits of a grating cause light to be diffracted, and the diffracted light interferes with itself so as to set up interference patterns, which produces a series of images of the source slit (Figure 1). The brightest image is the undeviated and undiffracted central maximum, which appears directly in front of the slit as expected. Complete constructive interference of the waves occurs where the phase or path difference is equal to one wavelength, which occurs symmetrically on both sides of the central maximum at locations corresponding to

$$d \sin\theta_n = n\lambda \qquad n = 1, 2, 3, \ldots$$

where $\lambda$ is the wavelength of light being diffracted, $n$ is the order of the image being formed (first, second, etc.), $d$ is the grating constant or the distance between the grating lines, $\theta_n$ is the angle the rays are diffracted from the incident direction, and $d \sin\theta_n$ is the path difference between adjacent rays. The grating constant is given by

$$d = 1/N$$

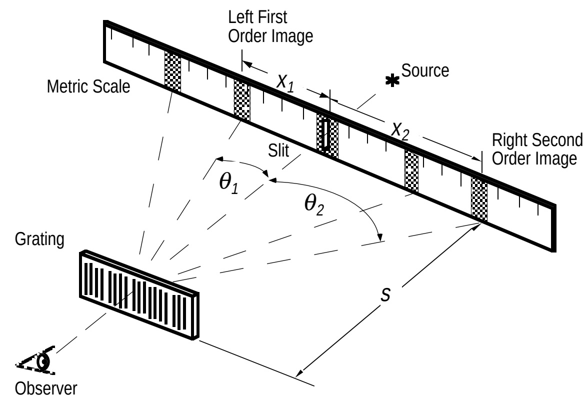
where $N$ is the number of lines or grooves per mm of the grating.

These devices, like prisms, disperse white light into colors. Whereas a prism separates the colors of light by refraction, a diffraction grating separates colors by interference. Usually only the first few orders are easily observed, with the total number of orders depending on the grating constant. If the incident light is monochromatic (composed of a single wavelength), the grating will spread the light into a series of well-determined lines. The wavelength of these lines can be determined with a simple optical bench.

## Review Questions

1. What is a diffraction grating?
2. What is diffraction?
3. How is a diffraction grating similar to a refraction prism?

## Procedure




1. Record the number of lines per mm of your grating in part in the data table below. Mount the grating and the slit scale on the meterstick-type optical bench as shown in Figure 2. The planes of the grating and the slit scale should be parallel.
2. Position an incandescent light source behind the slit and observe the diffraction orders of the continuous spectrum superimposed on the scale with distance *s* between the slit and the grating at 60, 80 and 100 cm. Looking through the grating, note the difference in the pattern positions $x_1$ and $x_2$ for the first two orders in each case. The images of the slit for a given order should appear at equal distances from the center line. If they do not, rotate the grating slightly until they do.
3. Replace the incandescent light with the mercury vapor lamp fitted with one of the color filters. Record the color of the filter in the data table below.
4. Looking through the grating, measure the apparent displacements of the brightest line in the first or second order spectrum, for both the left and right sides. Record your measurements for $s$ = 60, 80, and 100 cm in the data table, and the order *n* you chose to measure.
5. From Figure 2 it can be seen that $\sin\theta_n$ for a given order can be determined using trigonometry, that is

$$\sin\theta = \frac{\text{side opposite } \theta}{\text{hypotenuse}} = \frac{x}{\sqrt{s^2 + x^2}}$$

   Compute sin for the measured first and second order for each distance $s$ and find the average value of $\sin\theta_n$ for each order.

6. Compute the grating constant *d*. Convert this number to nanometers by multiplying by $10^6 (1 \text{ mm} = 10^6 \text{ nm})$ and record in the table below. Calculate the average wavelength of the measured mercury line using the equation $d\sin\theta_n = n\lambda$. Be sure to include the correct order $n$ you chose to measure.

**Data Table**

| Grating lines per mm: $N$ = ________ | | Image order: $n$ = ___________ | | Color |
|---|---|---|---|---|
| Distance $s$ (cm) | $x_n$ left (cm) | $x_n$ right (cm) | Avg. $x_n$ (cm) | $\sin\theta_n$ |
| | | | | |
| | | | | |
| | | | | |
| | | | Average $\sin\theta_n$ | |
| | | | Grating constant $d = (\frac{1}{N} \text{ mm}) \times (10^6 \text{ nm/mm})$ | nm |
| | | | Wavelength $\lambda_{\exp} = \frac{d}{n}\sin\theta_n = \frac{(\quad \text{nm})}{(\quad)}(\qquad)$ | nm |

### Analysis of Experiment

Fill out the data table and calculate the wavelength of the measured line. Find out from your teacher what the accepted value is. Can you identify any sources of error in your measurements?

## *Instructor's Guide to Laboratory No. 5:*

# Young's Experiment

### Goal

The goal is to reproduce Young's famous double-slit experiment, verify the wave nature of light, and measure the wavelength of red light.

### Objectives

After performing this exercise students will be able to:

- Understand the phenomena of wave diffraction.
- Understand the phenomena of wave interference.
- Understand the method and phenomena of double-slit interference.
- Reproduce Young's classic experiment and verify the wave nature of light

### Background Information

An excellent description of the method and history of this experiment is presented in the student lab. Everything required to do this experiment except a meterstick is included in the Resource Box.

This experiment is even more dramatic when done with a laser. The pattern may be projected on a screen.

### Helpful Hints

- Introduce the interference patterns here with the Moiré-pattern slides included in the Resource Box. Use an OHP and overlay the two slides on one another. Move the slides around to demonstrate various configurations of interference. You may want to save this demo for the next lab, Young's Experiment.
- This experiment is even more dramatic when done with a laser. The pattern may be projected on a screen.

### Extensions

- You may want to duplicate Young's original method of manufacturing a double slit: hold a microscope slide inverted over a candle and carefully coat the surface evenly with lampblack. Scratch two slits as per the student lab.
- Thomas Young made many contribution to various fields. He makes a good biographical subject.

### References

Consult any good Physics text for a detailed history and explanation of this experiment.

Name: Class: Date:

## The Electromagnetic Spectrum

**Visible Light**

**Experiment**

### Laboratory No. 5

# Young's Experiment

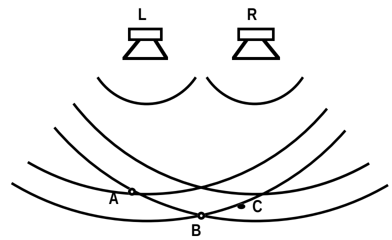
### Purpose

To reproduce Young's double-slit experiment and measure the wavelength of red light.

### Required Equipment and Supplies

Optical slits kit, ruler, masking tape, micrometer (optional).

### Discussion




In 1801 the wave nature of light was convincingly demonstrated when the British physicist and physician Thomas Young performed his now-famous interference experiment. Young found that light directed through two closely spaced pinholes recombined to produce fringes of brightness and darkness on a screen behind. The bright fringes resulted from light waves of the two holes arriving crest to crest, while the dark areas resulted from light waves arriving trough to crest. This pattern of interference fringes is called an *interference pattern*, and is a general wave phenomena that arises whenever a series of waves arrive at the same place from two synchronized sources, or from the same source by traversing two different paths.

The easiest way to demonstrate an interference pattern is with sound waves from two synchronized speakers, each sounding the same signal. Because of the wave nature of sound some surprising effects occur: the total loudness is not simply double that which would occur from a single speaker! Looking at the figure above, we see that at the speakers, both sound waves are perfectly in step. But most places in the room in front of them are closer to one speaker than to the other, so the waves don't arrive perfectly synchronized since they have traveled different distances to reach their common destination. Point A in the figure is exactly one wavelength farther from the right speaker than from the left one, and so arrive exactly one wavelength out of step. The interference between the waves here is constructive, meaning the waves reinforce each other and produce an extra strong tone. The same condition applies at point B, which is equally as far from the left speaker as from the right one.

Point C, however, is one-half wavelength closer to its nearest speaker, and here the waves arrive exactly out of step. The maximum air pressure for one wave coincides exactly with minimum air pressure for the other. In this case we get destructive interference, meaning the waves cancel each other and little or no sound is heard!

The key to understanding an interference pattern is straightforward: take the difference between the distances from the two sources and divide by the wavelength. The resulting number will tell you what kind of interference will take place. If it is an integer (i.e., 0, 1, 2, 3, ...), the interference is *constructive*. If it lies halfway between two integers (i.e., $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, ...), the interference is *destructive.* Intermediate values will give intermediate results, including not-quite-perfect reinforcement and not-quite-perfect cancellation; within an interference pattern, wave effects may be increased, decreased, or neutralized.

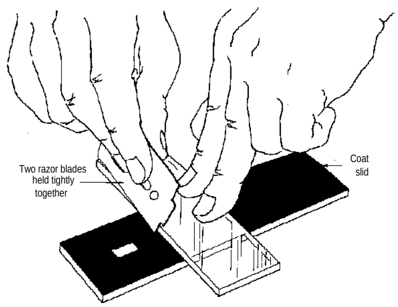
It is hard to synchronize two light sources, so interference patterns with light are usually produced by splitting a light beam into two or more parts and recombining them on a screen. This was originally done by Thomas Young using two closely spaced pinholes; each tiny pinhole behaved as a synchronized source because of another wave phenomena known as *diffraction*. Diffraction is the bending of waves around sharp objects, which causes waves to spread out as if originating from a point source.

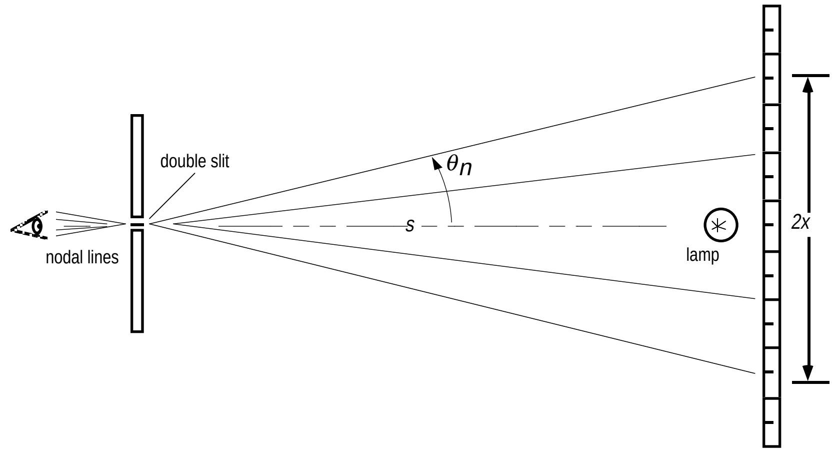
Young's experiment is now done with two closely spaced slits instead of pinholes, so that the fringe patterns are straight lines. You can observe the interference of a single-slit diffraction pattern by holding up your hand to a light source with two fingers closely spaced together. The light passing through the "slit" between your fingers is seen as a series of lines! Interference of light waves does not, by the way, create or destroy light energy; it merely redistributes it.

Interference patterns are not limited to single and double slits. A multitude of closely spaces slits make up a diffraction grating. These devices, like prisms, disperse white light into colors. Whereas a prism separates the colors of light by refraction, a diffraction grating separates colors by interference.

### Review Questions

1. How was the wave nature of light demonstrated?
2. What is diffraction?
3. What is interference?




## Procedure

1. Coat a glass slide with a colloidal suspension of graphite and let it dry. Be sure the coating is uniform. Scratch a pair of slits as shown in the sketch. Hold the two razor blades tightly together and use little pressure. Make several pairs of slits. Select for use those which show at least three clear white lines when you look a the line filament lamp. Scratch a window across each pair of slits as shown.
2. Tape a clear slide over the graphite surface to protect the surface. The width between the slits is equal to the thickness of one razor blade. If available, use a micrometer to determine the thickness of a single blade, or else use an ordinary ruler to measure the thickness of a stack of blades and divide by the number of blades. Record the thickness *d* in the data table below.
3. Connect the lamp to 115V. Use a ringstand to mount a ruler slightly above the lamp. Look through the slits toward the filament of the light bulb from a distance of about 2 meters (Figure 2). Note what you see.
4. Tape two paper markers at positions on the ruler about where the farthest dark fringes (nodal lines) can be seen. Since the nodal lines come in symmetric pairs (one on each side of the center), you will use these markers to measure the distance between the farthest pair of nodal lines you can observe.
5. Cover part of the bulb with red cellophane (using an elastic band) and note the effect on the pattern. The interference pattern and the paper markers on the ruler can be seen simultaneously by looking through the slits and the "window" scratched in the slide at the same time.
6. Now cover the whole bulb with red cellophane. Looking through the slide, move toward or away from the ruler until you can align the furthest visible pair of fringe lines with the paper markers on the ruler. Determine which number nodal line you are aligning to by counting the total fringes between the markers and dividing by two. Also record the distance from the double-slit to the ruler.
7. Now cover part of the bulb and part with blue. Note from your observations which color you think has the shortest wavelength, and estimate the ratio of the wavelength of red light to the wavelength of blue light.

## Analysis of Experiment

Young determined the double-slit interference pattern obeys the mathematical relationship

$$d\sin\theta_n = \left(n - \tfrac{1}{2}\right)\lambda \qquad n = 1, 2, 3, \ldots$$

You can use this with your experimental measurements to calculate the wavelength of light! To a good approximation $\sin\theta_n \approx x_n / s$.

Using the data table to the right, calculate

$$\lambda = \frac{d\sin\theta_n}{\left(n - \frac{1}{2}\right)} =$$

**Data Table**

| | |
|---|---|
| Distance between slits $d$ | mm |
| Convert to nm ($d \cdot 10^6$) | nm |
| Nodal line measured: | $n =$ |
| Distance between nodes | cm |
| Half of distance ($x_n$) | cm |
| Distance from ruler $s$ | cm |
| $\sin\theta_n \approx x_n / s$ | |
| Est. Ratio: $\lambda_{red} / \lambda_{blue}$ | cm |

### *Instructor's Guide to Laboratory No. 6:*

# Blue Skies and Red Sunsets

## Goal

The goal here is to investigate the processes of scattering and absorption which give rise to the different colors of the sky, sunsets, clouds, and oceans.

## Objectives

After performing this activity students will be able to:

- Understand the process of light scattering by small particles and molecules.
- Duplicate the effect using a flashlight and bowl of water.
- Apply their new knowledge of color theory
- Understand why the sky appears blue.
- Understand why the sun appears to become increasingly redder as it sets.
- Describe the different scattering effects that make clouds appear blue.
- Explain why oceans appear blue.

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## Background Information

This activity is fully described in the student handout. You may wish to have students do this one at home.

It is interesting to note that the blue of the sky varies in different places under different conditions. A principal factor is the water vapor content of the atmosphere. On clear dry days the sky is a much deeper blue than on clear days with high humidity. Places where the upper air is exceptionally dry, such as Italy and Greece, have beautifully blue skies that have inspired painters for centuries. Where there are a lot of particles of dust and other particles larger than oxygen and nitrogen molecules, the lower frequencies of light are scattered more. This makes the sky less blue, and it takes on a whitish appearance. After a heavy rainstorm when the particles have been washed away, the sky becomes a deeper blue.

## Helpful Hints

- You may want to do this one as a demo using a bright light source such as a slide projector.
- This lab makes a good home project, since it only needs a flashlight and a large glass bowl.

## Extensions

- Have students investigate the polarization of the scattered light using Polaroid filters included in the Resource Box. Have them compare this to their findings for the real sky (the one outdoors!)

## References

Consult any good Physics or Physical Sciences text for a detailed description of this and related phenomena.

### *Laboratory No. 6*

# Blue Skies and Red Sunsets

## Purpose

To investigate how the scattering of sunlight by the Earth's atmosphere produces blue skies and orange sunsets.

## Required Equipment and Supplies

Flashlight or slide projector, large glass bowl or pitcher filled with water, a few drops of milk or a pinch of coffee creamer, and a polarizing filter (optional).

## Discussion

When light interacts with objects that are much smaller than the wavelength of the light, the light is said to be scattered rather than reflected. The electrons of such a small object are all shaken up and down at the same time by the electric field of the light wave, and they radiate that frequency of light in all directions. It turns out that the higher the frequency of the light, the more the light is scattered.

The diameter of most molecules is much smaller than the wavelengths of visible light. Most of the ultraviolet light from the sun is absorbed by a thin protective layer of ozone gas in the upper atmosphere, and the remaining ultraviolet sunlight that passes through the atmosphere is scattered by atmospheric particles and molecules. Of the visible frequencies of light, the high-frequency violet is scattered the most, followed by blue, green, yellow, orange, and red, in the order of decreasing frequency. Red is scattered less than a tenth as much as violet. Although violet light is scattered more than blue, our eyes are not very sensitive to violet and there tends to be more blue light in sunlight than violet. The blue predominates in our vision, so we see a blue sky!

The grayish haze in the skies of large cities is a result of particles emitted by internal combustion engines (cars, trucks, industrial plants). Even when idling, a typical automobile engine emits more than 100 billion particles per second. Most are invisible and provide a framework to which other particle adhere. These are the primary scatterers of lower frequency light. For the larger of these particles, absorption rather than scattering takes place and brownish haze we call smog is produced. Yuk!

Since the lower frequencies of light are scattered the least by nitrogen and oxygen molecules (the primary components of our atmosphere), red, orange, green, and yellow light are transmitted through the atmosphere much more than violet and blue. Red, which is scattered the least, passes through more atmosphere than any other color. Therefore, when white light passes through a thick atmosphere, the higher frequency blue and violet is scattered the most while the lower frequencies such as red are transmitted with minimal scattering. Such a thicker atmosphere is presented to sunlight at sunset, since the path through the atmosphere is longer as the sun is lower on the horizon. This means that the sun becomes progressively redder as the sun goes down, going from yellow to orange.

Clusters of water molecules in variety of sizes make up clouds. The different size clusters result in a variety of scattered frequencies: the tiniest, blue; slightly large clusters, green; and still larger clusters, red. The overall result is a white cloud! For even larger droplets, absorption occurs and the scattered intensity is less. The clouds are darker. What about even bigger drops? Well, their increased size causes them to fall to earth, and we have rain!

Since we're on the subject of colors, let's discuss water. The color of water is not the beautiful deep blue that you often see on a surface of a lake or the ocean. That blue is the reflected color of the sky. The color of water itself, as you can see by looking at a piece of white material under water, is a pale greenish blue.

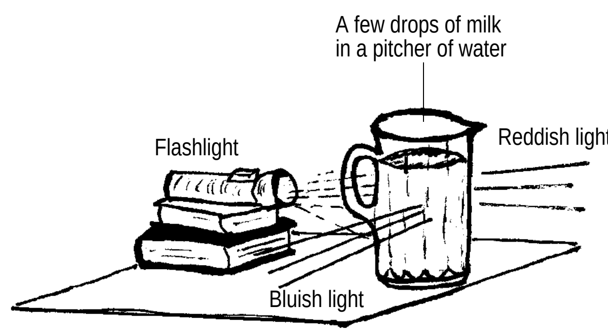
Although water is transparent to nearly all the visible frequencies of light, water molecules very weakly absorb visible red light, and strongly absorb infrared waves. The energy of infrared waves is transformed into internal energy in the water, which is why sunlight warms water. Weakly-absorbed visible red light is reduced to a quarter of its initial brightness by 15 meters of water, and there is very little red light in the sunlight that penetrates below 30 meters of water. When red is taken away from white light, what color remains? This question can be asked another way: What is the complementary color of red? The complementary color of red is cyan – a bluish green color. In sea water, the color of everything at these depths looks greenish.

So while the sky is blue because blue is strongly scattered by molecules in the atmosphere, water is bluish green because red is absorbed by molecules in the water. We see that the colors of things depend on which colors are scattered or reflected by molecules and also on which colors are absorbed by molecules.

## Review Questions

1. What happens when light interacts with objects that are much smaller than the wavelength of the light?
2. Why does the sky appear blue?
3. Why are sunsets red?
4. What causes oceans to appear blue?

## Activity




1. Here's a way to make your own blue skies and reddish sunsets. When a flashlight beam penetrates a pitcher of clear water, there's little change in the color of the beam. Add a few drops of milk to the water, however, and you'll see the beam of light turn a reddish orange (Figure 1). The milk's molecules scatter the blue light (and some green and yellow, too) in all directions before it can reach your eyes, just as the air's molecules do for the rays of sunlight at sunset. Now look through the side of the pitcher, perpendicular to the beam. Wow! There's the blue light scattered to the sides (and in all directions), just as the air scatters blue light from sunlight to give us blue skies.
2. Look at the scattered light through a polarizer. Rotate the polarizer and explain what you see. Does this mean that the scattered blue light of the sky is polarized? After you answer this question, take the polarizer outside or to a window and check your answer. Notice the the polarization of different parts of the sky by rotating the polarizer.

## *Instructor's Guide to Lab No. 7:*

# Living on Borrowed Sunshine

### Goal

The goal of this particular lesson is to allow students to use their own creativity in order to better understand and remember the complex pathways of photosynthesis.

### Objectives

After the explorations the students should be able to:

1. The student will understand the basic operation of photosynthesis by using creative writing techniques to form a story that involves fundamental aspects of the process.
2. The student will appreciate the interrelatedness of light energy and energy transfers with life on earth.
3. By using the story approach, the student will gain an appreciation for the complexity of life processes such as photosynthesis.

---

### Background Information

The suggested lesson here is to have the students learn the process of photosynthesis by writing a creative story. In this regard, the traditional, cool detachment of science is disregarded and a more humanistic approach is used. By identifying photons, for example, with human names, a student has an easier time remembering the complexities.

Photosynthesis can be broken down into two basic steps:

1. **Light dependent reaction:**
   a. water molecule breakdown
   b. photon capture
   c. coenzyme interaction
   d. photon capture
   e. coenzyme interaction
   f. NADPH+ reaction
2. **Light independent reaction:**
   a. carbon dioxide capture
   b. carbon fixing reaction
   c. introduction of hydrogens
   d. PGAL production
   e. cycle continuation

It would be helpful to set up stories or other activities so that they are limited to one of the two major steps. This way other groups can interact with each other and exchange information.

### Additional Activities

1. Using a traditional text as a source, create a comic or some other graphic outline to "draw" out the story so it be used as an aid in understanding the plot. See attached.

2. Students often enjoy acting out the parts they discover in their story. A skit, allowing students to use their full range of talents, gives another avenue by which understanding can be achieved. For example, students could be various co-enzymes, tennis balls could be used for photons, etc. An active process allows the students to grasp the meaning of an otherwise abstract concept. Besides, it's fun. It is recommended that a group of at least five students be used per skit. This allows the various portions of photosynthesis to be displayed without one student doing too many parts.

## Helpful Hints

- **Note:** *This is a sample story to help the teacher better understand the potential of this kind of assignment. It is suggested that it not be read or distributed to the students since they will have a tendency to use it instead of their own imagination. This particular story focuses on photons, but any angle is appropriate as long as it pulls in the major portions of photosynthesis. It is assumed that the reader has some familiarity with the process.*

### Living on Borrowed Sunshine

It was a typical beach party. Blankets on the sand, a roaring fire and marshmallows roasting over the coals. It was here that I came upon a realization, an epiphany beyond my wildest dreams. In fact it took a dream to come full circle to help me understand what it all meant. It has to do with the fire that resides within us all. The borrowed sunshine that powers all life on earth.

But first, the beach party.

"Your marshmallow is on fire," a friend warned.

Pulling the burning puff of sugar from the flames, I wondered out loud why it was burning at all.

"Sugar," my friend said.

"Sugar?"

"Yes. All sugar will burn if you give it enough heat. Just like the wood in the fire."

It was then I began to wonder. Burning sugar. Burning wood. Where did all this potential fire come from? Then it hit me. The sun! Both the sugar and the wood had been produced by plants. The plants had taken energy from the sun and stored it within their roots, stems and leaves. The fire I was watching was actually borrowed sunshine being released into the air, warming everything around it.

"Fire. Sunshine. Photosynthesis. It all makes sense now," I mumbled to myself.

"What?"

I turned to my friend and tried to explain. It wasn't long however, before his eyes began to glaze over and roll like the cherries in a slot machine. I took this as a hint of inappropriate party conversion and excused myself.

I left the party and walked alone down the beach, finding a soft spot to rest to further ponder my thoughts. It was late and the day's activities had left me spent. Therefore, it wasn't long before I succumbed to my own heavy eyelids and wandering neurons. A pre-snoozing body jerk eventually left me falling into a deep sleep. Thoughts of sunshine danced in my head. The answers to my questions were to come to me in my dreams . . .

Polly the photon was wiggling her way to earth through the void of space. As a packet of light energy generated by the vibrating electrons on the sun, she represented a distinct quantity of light. And as such, she could cause only certain kinds of reactions when she hit the surface of some distant molecule. Like many of her other visible light friends, she might very well end up traveling through the windshield of some parked car, hitting the plastic seats and be converted into basic heat energy by the molecules she bumped into. Unable to escape the car's interior due the new, lower energy level, and hence larger wavelength, her spent energy would help turn the passenger compartment into a solar powered oven.

She would never have the opportunity to contribute to greater things.

However, this was not to be Polly's fate. Her destiny would be much more productive by her chance encounter with a leaf. For leaves need photons like Polly. Her wavelength and therefore, her color, were just right for the energy requirements of photosynthesis, the powerhouse of life on earth. Instead of being wasted on a hot steering wheel, Polly would end up helping to build the foundation of all living things.

Meanwhile, the leaves down on earth were waving in the wind, hoping for a few million photons to come their way. Not just any photon, but specific ones. The violet-blues and the orange-reds are desired most. These are what power the photosynthetic machine within the leaf. The greens, however, are shunned and reflected. Thus, the leaves appear green. They show off the colors rejected, not absorbed. The colors we see are in fact the unwanted hues. In this sense then, the green leaf is every color but green. A confusing state indeed.

Polly had a wavelength that appeared red. 680 nanometers to be exact. A nanometer is pretty small. A million of them span the tiny distance of a millimeter. So Polly's wavelength was tiny, but compared to things like X-rays which can be a million times smaller and thus more dangerous for their ability to penetrate into things, her waves were still quite respectable. Not too small, not too large. This was exactly what the leaves were looking for.

Upon reaching the earth after leaving the sun little more than eight minutes before, at her standard speed of 186,000 miles per second, Polly slammed into an apple tree leaf.

"Come on in," the chlorophyll molecule said with a snicker. "Welcome aboard."

Along with another one of her friends, who was Polly's exact twin, the two photons entered the photo system II station house. This was a magical place where the chlorophyll lived and completely absorbed the energy of the appropriate incoming photons. Sadly, Polly and her friend were no more, but their energy lived on. It was used to kick Mr. Z into action and to push two tiny electrons through a series of molecules. Where, one may ask, do these little electrons come from? Surprisingly, the answer is water . Now the need for sprinklers can be finally understood. Plants need water molecules to steal their electrons. Two electrons per molecule to be exact. This is accomplished within a little fellow called the Z particle. Mr. Z for short. Mr. Z beats up the water with energy from the photons, throws its two protons into the lumen, coughs out its oxygen and frees two new electrons to be energized by photons like Polly and her friend. Once the electrons have ripped from their mother water, they travel through several stationary molecules. During the first part of their journey, their energy is used to pump protons into the lumen for the production of a special transfer molecule called ATP.

The lumen? This is a fluid filled space within a round, little structure called a thylakoid. Hundreds of these thylakoids lay in stacks, pancake stacks, within the chloroplast, a larger round object found by the thousands inside all green leaves. Little things within bigger things. Such is the nature of nature. The leaf is no exception. And the $H^+$ protons? These are atomic particles with a positive charge floating freely outside the lumen and becoming attracted to the moving, positively charged electrons.

I partially awaken myself with a snore as I snort in a lung full of air. "Ah, this is where my oxygen comes from", I thought to myself. "Coughing Z's, Mr. Z, Mr. Z, Mr. Z . . ." I drift back to sleep and into my dreams.

But alas, energy cannot last forever. The energy given to them by Polly and friend is shortly exhausted. Time for more. At this point the two electrons hang out at the photo system I station until two more photons appear. These are a bit less what energetic than Polly was, by 20 nanometers to be exact, but they get the job done.

Yipes!" cried the abused electrons as they receive their new burst of borrowed sunshine.

Through the maze of additional molecules they travel until they are picked up by a roving marauder, $NADP^+$. Capturing the two unsuspecting electrons and two $H^+$ protons that happen to be floating along, $NADP^+$ changes his name to $NADPH+H^+$.

Rushing away from the scene of the crime, the marauder looses one of his $H^+$ protons and gets lost in the Stroma, the Land of Darkness. It is here where the work really begins.

The rising tide tickles my feet with a lapping wave. I awaken with a face full of wet sand.

"Argghh"

As I slowly make my way back to the fire, I find only smoldering embers and a quiet beach. I reached down and grab an apple from the supplies I had brought earlier. An apple made of the same building blocks as the wood that had burned several hours earlier.

"Crunch." The apple is fresh and filled with natural sugar. How did it get there?

Once the marauding NADPH reaches the Land of Darkness within the chloroplast, he delivers his booty of $H^+$ protons to the sugar cycle. These protons are added to a mix of carbon dioxide and other carbon molecules to produce PGAL. This in turn is sent to the glucose factory to produce glucose, the basic building block of all plant life.

As I finish my apple and find my way to the car, my mind drifts through the confines of my car's engine. Might the gasoline, made from oil, formed in the ground by partially decayed plant material, also be borrowed sunshine? I feel my forehead and ask myself, "do I too owe this heat to the power of the sun?"

Polly has long since vanished.

## References

1. Robert Wallace/Jack King/Gerald Sanders, *Biology, the Science of Life*, 2nd edition, Scott, Foresman and Company, 1986. This is one of the better descriptions of photosynthesis, although there are some confusing points.

### *Laboratory No. 7*

# Living on Borrowed Sunshine

## Purpose

The purpose of this particular lesson to gain a better understanding of the complex pathways of photosynthesis through creative writing.

## Required Equipment and Supplies

Paper, pen, and a creative spirit.

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## Activity

Your mission is to simplify the complexities of photosynthesis. Select one of the two major parts of the process, either the light dependent or light independent reaction, and write a creative story or plan a skit with a group of five to seven other students. Give names to your characters such as Mr. Z for the *z* particle that breaks up the water molecule or distinct personalities to major players like the photons.

## Review Questions

1. What is the purpose of photosynthesis?
2. What role does water play in the light dependent reaction?
3. Are photons "used," "transformed," or "burned" during photosynthesis? Explain.
4. What does the energy obtained from photons actually do?
5. Can the light independent process, often called the dark cycle, occur during both the day and night? Explain.

***Instructor's Guide to Labs No. 8 & 9:***

# Infrared Radiation and the Inverse-Square Rule

***and***

# Detecting Infrared Radiation Using a Prism

## Goal

The goal of these two lab exercises is to introduce the infrared region of the electromagnetic spectrum to students through three different explorations.

## Objectives

After the explorations the students will be able to:

- Understand which regions of the electromagnetic spectrum penetrate the earth's atmosphere.
- Identify similarities in  magnetic waves.
- Explain three ways infrared radiation can be detected.
- Explain the relationship between the number of rotations and the distance from the source when using the radiometer.
- Predict the results of this relationship using a mathematical model (inverse-square law).
- Determine the temperature beyond the red region.
- Understand the transmissive and reflective properties of infrared radiation by using a photodetector setup.

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## Background Information

There are three forms of radiation: electromagnetic (EM), mechanical, and particle. These three experiments will be focusing on electromagnetic radiation. Electromagnetic radiation is sometimes referred to as light or radiant energy. Electromagnetic radiation travels outward from its source as waves (pulses) or photons (packets) of energy. The speed of a photon or EM wave in a vacuum is the same no matter how much energy it carries. This speed is referred to as the speed of light which is equal to 299,792,456 m/sec and represented by the letter *c*.

This section deals with the infrared region of the spectrum. Vibrations and rotations of atoms and molecules and the motions of their electrons produce this region of the spectrum. The nature of infrared (IR) has been given in the student exploration. It is important that the students understand the properties of IR. It can be  transmitted, absorbed or  reflected. These properties are also characteristics of the other regions of the EM spectrum.

## Helpful Hints

- **Resources:**

  Everything needed to conduct this experiment is included in the Resource Box. *Descriptions below of materials other than what is in the Box is for informational use.*

- **Student Handouts:**

  This unit is comprised of two separate laboratory exercises, and includes separate student handouts for each. Refer to each handout for details about materials and procedures. Note that the discussion and review questions are duplicated in each lab so that they may be used as individual units if time dictates.

- **Lab No. 1:**

  The first lab uses a hotplate. The one I use is approximately 11 x 11 cm. (corning). I use the high setting. You may want to try the experiment using the hotplates available at your site. You may have to vary the temperature setting, etc. I also use any metal baking pan available to raise the hotplate up to the radiometer's level.

  The mathematical relationship the students should be able to see is that one physical quantity (number of rotations) varies as the inverse square of the distance from its source. This is referred to as the inverse-square law. Depending on the data collection skills used by the students, this law can be seen in the individual experiments. It can readily be seen when the students data are pooled together and averaged for each distance-time interval.

- **Lab No. 2:**

  I strongly suggest that you test this setup in advance. It works well with correct size box and light source. The students will be able to record a noticeable difference in the temperature increase of the IR region just beyond the visible red region.

  This experiment also can be done using the large diffraction grating to disperse the spectra.

## *Laboratory No. 8:*

# Infrared Radiation and the Inverse-Square Law

### Purpose

The purpose of these labs are to investigate the infrared (IR) region of the electromagnetic spectrum using devices that detect IR sources.

### Required Equipment and Supplies

Hot plate, radiometer, pan, or other item to raise hot plate, metric ruler, graph paper, and stopwatch.

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### Discussion

One form of radiation is electromagnetic or radiant energy. Sunlight is a familiar form of electromagnetic radiation. Only the visible radiation and parts of the infrared and radio regions penetrate the atmosphere completely. Due to absorption by atmospheric nitrogen and oxygen none of the short-wavelength, high-energy gamma rays, x–rays, and short-wavelength (up to 210 nm) ultraviolet radiation make it through. Stratospheric ozone ($O_3$) eliminates another section of the UV band, between 210 and 310 nm.

The various parts of the electromagnetic spectrum produce very different effects when they interact with matter but they all travel at the same speed in a vacuum 299,792,456 m/sec (speed of light). The wavelength range between about 750 nm to 1,000,000 nm (or 1 mm) is called the infrared region. William Herschel discovered this part of the electromagnetic spectrum when he placed a thermometer just outside the red end of the color spectrum. It registered a large temperature increase. Hence, infrared radiation may be detected as heat. The heat you feel from a fireplace, campfire, sunlight, or the ground are all sources of infrared radiation.

Many living things emit infrared radiation. Rattlesnakes (pit-vipers) have a special pit organ that is sensitive to infrared radiation and allows them to see minute temperature variations in their environment. Detecting small temperature variations allows the snake to detect its prey even in the "darkest of burrows." The radiometer is a device that was invented by Sir William Crookes in 1875 to demonstrate the mechanical effect of light radiation. Later it was used to detect and measure the intensity of infrared radiation. The radiometer is a partially-evacuated tube which contains a structure with four vanes. Each vane has a dark (black) and a light (silver) side. The dark side absorbs much of the infrared radiation and the light side reflects more than it absorbs. The free molecules present in the tube gain energy and react more with the dark side and push the dark side away from the radiation source. The speed of rotation indicates the amount of radiation. Radiometers have been replaced by solid-state electronic devices that measure radiant energy more accurately.

## Review Questions

1. Which regions of the electromagnetic spectrum penetrate the earth’s atmosphere completely?
2. Which waves do not penetrate the earths atmosphere?
3. What do all electromagnetic waves have in common?
4. What are three ways you can detect infrared radiation?
5. How can a pit viper tell that a mouse is hiding in a very dark place?
6. Can you see infrared waves? Explain.

## Procedure

1. Place hot plate on its side and plug it in. The hot plate must be at approximately the same level as the vanes of the radiometer (place on block or pan).
2. Turn on the hot plate and give it two minutes to warm up.
3. After the hot plate warms up you will be setting the radiometer in front of it about 24 cm away. You are to observe the number of rotations the vanes on the radiometer make in a two-minute period.
4. Move the radiometer to 22 cm observing the number of rotations for another 2 minutes. Continue to move the radiometer in at 2 cm intervals and record for two minutes at each interval. Record the number of rotations on your data table. Repeat this step until you reach 6 cm.
6. Record data in table below.

| *TRIAL* | *DISTANCE FROM SOURCE* | *TIME* | *NUMBER OF ROTATIONS* |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |
| 6 | | | |
| 7 | | | |
| 8 | | | |
| 9 | | | |
| 10 | | | |
| 11 | | | |
| 12 | | | |
| 13 | | | |
| 14 | | | |
| 15 | | | |

## Analysis of Experiment

1. Graph the number of rotations and the distance.
2. Did distance affect the radiometer's rotation?
3. What mathematical model can you use to predict the results?
4. Explain the journey of the infrared radiation from the moment it leaves the hot plate to the point at which the radiometer begins to rotate.

### *Laboratory No. 9:*

# Detecting Infrared Radiation Using a Prism

## Purpose

The purpose of these labs are to investigate the infrared (IR) region of the electromagnetic spectrum using devices that detect IR sources.

## Required Equipment and Supplies

Box (24 in. long and ~8–12 in. high), quartz bulb with socket, prism, thermometer, 8 x 12 in. backboard (to display spectra), and black sheet of paper. Optional: diffraction grating

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## Discussion

One form of radiation is electromagnetic or radiant energy. Sunlight is a familiar form of electromagnetic radiation. Only the visible radiation and parts of the infrared and radio regions penetrate the atmosphere completely. Due to absorption by atmospheric nitrogen and oxygen none of the short-wavelength, high-energy gamma rays, x–rays, and short-wavelength (up to 210 nm) ultraviolet radiation make it through. Stratospheric ozone ($O_3$) elim–inates another section of the UV band, between 210 and 310 nm.

The various parts of the electromagnetic spectrum produce very different effects when they interact with matter but they all travel at the same speed in a vacuum 299,792,456 m/sec (speed of light). The wavelength range between about 750 to 1,000,000 nm (or 1 mm) is called the infrared region. William Herschel discovered this part of the electromagnetic spectrum when he placed a thermometer just outside the red end of the color spectrum. It registered a large temperature increase. Hence, infrared radiation may be detected as heat. The heat you feel from a fireplace, campfire, sunlight, or the ground are all sources of infrared radiation.

Many living things emit infrared radiation. Rattlesnakes (pit-vipers) have a special pit organ that is sensitive to infrared radiation and allows them to see minute temperature variations in their environment. Detecting small temperature variations allows the snake to detect its prey even in the "darkest of burrows." The radiometer is a device that was invented by Sir William Crookes in 1875 to demonstrate the mechanical effect of light radiation. It was later used to detect and measure the intensity of infrared radiation. The radiometer is a partially evacuated tube which contains a structure with four vanes. Each vane has a dark (black) and a light (silver) side. The dark side absorbs much of the infrared radiation and the light side reflects more than it absorbs. The free molecules present in the tube gain energy and react more with the dark side and push the dark side away from the radiation source. The speed of rotation indicates the amount of radiation. Radiometers have been replaced by solid-state electronic devices that measure radiant energy more accurately.

## Review Questions

1. Which regions of the electromagnetic spectrum penetrate the earth's atmosphere completely?
2. Which waves do not penetrate the earths atmosphere?
3. What do all electromagnetic waves have in common?
4. What are three ways you can detect infrared radiation?
5. How can a pit viper tell that a mouse is hiding in a very dark place?
6. Can you see infrared waves? Explain.

## Procedure

1. Place quartz bulb in box at one end.
2. Cut a slit approximately 5 mm x 15 mm in the opposite end of the box.
3. Place the black piece of paper 3–5 cm inches from bulb (this paper acts as a partition between the bulb and the other end of the box and helps to focus the light rays). Punch a hole at about the same level as the slit.
4. Place a parallel white piece of paper approximately 20 cm away from slit. Place prism in front of the slit. Turn on light and move prism until a visible spectrum comes into focus.
5. Record the temperature of the following areas:
    (a) Room (away from spectrum area)
    (b) Visible area of spectrum (red, orange, yellow, green, blue, and violet)
    (c) The dark region just past the red.

## Analysis of Experiment

1. Is the region beyond the red hotter or cooler than the visible area?
2. Why would the region beyond the red be hotter than other areas of the visible region?
3. What generalization(s) can you make about the region beyond the red and what evidence can you state to support your generalization(s)?

### *Instructor's Guide to Lab Nos. 10a–b:*

# Investigation of IR Light Using an IR Transmitter and Receiver *and* Investigation of IR Light Using a Close-Circuit TV Camera

## Goal

The goal of this lab to investigate the transmission and propagation of infrared (IR) light and to introduce the concept of lightwave communications using an IR transmitter and receiver.

## Objectives

After performing this exercise students will be able to:

- Have a feeling for the existence and use of "invisible" light.
- Understand how a typical TV remote control works.
- Understand the concept of light-wave communications.
- Understand the phenomena of light-wave reflection, refraction, and absorption.
- Use a prism and diffraction grating to disperse IR light in the same manner as visible light.

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## Background Information

Infrared waves are electromagnetic waves with frequencies lower than visible light. The lowest frequencies of visible light are red, so we call the lower frequencies *infrared*, meaning *beyond red*. This type of electromagnetic radiation is widely used for local communications, in which the sender and receiver are very close together, such as a VCR remote control (transmitter) with the VCR receiver. Infrared light is sent by the VCR remote using a special electronic device called an *emitting diode*, which emits light when an electric current is passed through it. Behind a window in the VCR is a matched diode which passes current when it absorbs infrared light. The transmitter uses infrared light to carry information by modulating the signal, usually using a series of short on/off pulses similar to Morse code, which are received and decoded by the receiver and circuitry in the VCR.

This lab is separated into two versions, A and B. Version A lab calls for a matched IR transmitter/Receiver pair. This setup can be built for less than $20 using parts available from RadioShack in the circuit shown below.[1] It is a simple amplitude-modulated light wave communications system. Alternatively, just the receiving end can be built and used to "listen" to the signals produced by light sources such as an IR remote control. Allowing for interchangeable photodiodes (to switch between visible and infrared) in the circuit makes it even more versatile. Students can use it to hear what their TV remote control is saying (a series of tones.) An incandescent lamp will produce a hum, a fluorescent lamp a buzz, and an electronic camera flash will produce a large pop. A flashlight beam can be swept slowly across the light listener's detector to produce a soft swishing sound, while a fast sweep will produce pops. Tap the flashlight with a pencil and a ringing sound will be heard as the filament vibrates. Interesting!

Version B of this lab calls for an ordinary CCD or viticon-based TV camera. The semiconductor detector chips in some of these are very sensitive to IR. This setup is used in place of the IR Transmitter/Receiver in the B version of this experiment. We have obtained a number of surplus security cameras, and included one in each Resource Box. Point any type of IR-based remote control unit at the camera and it appears as a bright source on the monitor. Also use the included "IR Flashlight" (an infrared LED wired into an ordinary flashlight in place of the normal bulb) with the included prism and/or diffraction grating to show diffraction. Use developed color film as an IR bandpass filter to filter out excess visible. The lights can be turned out and the IR flashlight can be used to illuminate students. Watch out, you can be observed in the darkest of nights! A lot can be done with this set up. Be imaginative, and let us know what you come up with!

### Helpful Hints

- A simpler circuit[2] is shown in Figure 2. The source can be modulated by turning on/off, or a typical TV remote control can be used.
- This lab can be done using toy ray guns[3]. The Photon© ray gun, made by Entertech, or the Bravestarr Evil Laser-Fire Backpack© by Mattel can be used.

### References

1. Forest M. Mimms, *Engineers Mini-Notebook: Communications Projects*, pg. 28-29 (1994). Available at RadioShack stores.
2. Forest M. Mimms, *Engineers Mini-Notebook: Communications Projects*, pg. 24-25, (1994). Available at RadioShack stores.
3. R. S. Halada, "Demonstrations of Infrared Ray Optics Using Ray Guns," *Physics Teacher* **29**, 370 (1991).

### *Laboratory No. 10a:*

# Investigation of the Properties of Light Using an IR Transmitter and Receiver

## Purpose

The purpose of this lab is to investigate the transmission and propagation of light using an infrared transmitter and receiver.

## Required Equipment and Supplies

IR transmitter, IR receiver, focusing tube with lens, glass plate, clear, tinted and opaque plastic plates, IR prism, pocket mirror, white card, and black card.

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## Discussion

Infrared waves are electromagnetic waves with frequencies lower than visible light. The lowest frequencies of visible light are red, so we call the lower frequencies *infrared*, meaning *beyond red*. This type of electromagnetic radiation is widely used for local communications, in which the sender and receiver are very close together, such as a VCR remote control (transmitter) with the VCR receiver. Infrared light is sent by the VCR remote using a special electronic device called an *emitting diode*, which emits light when an electric current is passed through it. Behind a window in the VCR is a matched diode which passes current when it absorbs infrared light. The transmitter uses infrared light to carry information by modulating the signal, usually using a series of short on/off pulses similar to Morse code, which are received and decoded by the receiver and circuitry in the VCR.

## Review Questions

1. Can you see infrared waves? Explain.
2. What is a common use for Infrared waves? Can you think of another?

## Procedure A: *The Transmission and Reception of IR Light*

1. Assemble the transmitter and receiver by hooking up the speaker to the receiver and the radio to the transmitter.
2. Turn on the transmitter and receiver and place in front of one another so that the diodes are in close proximity and facing each other.
3. Turn on the radio and align the diodes until you can hear the radio playing. Tune the radio to find a strong signal from a nearby radio station.
4. Move the receiver away from the transmitter slowly and carefully. Try to keep the diodes aligned so that the radio continues to play through the speaker.
5. Determine the maximum range of the transmitter/receiver pair by slowly moving the receiver away until the signal breaks-up into random noise.
6. Now place the receiver at a distance from the transmitter of about one-half of the maximum range. Carefully align the receiver to pick up the best signal.
7. Now place the glass plate between the receiver and the transmitter and note what happens to the signal.

8. Repeat (7) with the clear, tinted, and then opaque plastic sheets, noting what happens to the signal in each case.

### Procedure B: *The Reflective, Refractive, and Transmissive Properties of Light.*

1. Bring the receiver and transmitter together so that the diodes are directly facing each other, with the transmitter in front of you and facing away. Make sure a clear signal is being picked up by the receiver.
2. Now place the receiver at a 45° angle to the transmitter.
3. Place the prism directly in front of the transmitter diode and rotate it until the radio is heard through the speaker, indicating a signal is being received. Note the position and orientation of the prism.
4. Replace the prism with the pocket mirror, orienting it until a signal is picked up. Note the position and orientation of the mirror.
5. Repeat (4) using the white card and then the black card. Note whether or not the signal is being received, and the position and orientation of the cards.

### Analysis of Experiment

1. Explain how the music is traveling from the transmitter to the receiver.
2. Explain the effect the prism had on the signal while in front of the transmitter. What properties of light are being exhibited: refraction, reflection, absorption, and/or transmission?
3. Explain the effect the mirror had on the signal while in front of the transmitter. What properties of light are being exhibited?
4. Explain the effect the white card had on the signal while in front of the transmitter. What properties of light are being exhibited?
5. Explain the effect the black card had on the signal while in front of the transmitter. What properties of light are being exhibited? Where did the energy of the signal go?

## *Laboratory No. 10b:*

# Investigation of IR Light Using a Close-Circuit TV Camera

### Purpose

The purpose of this lab is to investigate the transmission and propagation of light using an infrared transmitter and receiver.

### Required Equipment and Supplies

Closed-circuit Black and White TV camera and monitor, Source of IR light (TV remote control transmitter and/or IR light emitting diodes (LEDs) and power supply), pieces of developed color film.

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### Discussion

Infrared waves are electromagnetic waves with frequencies lower than visible light. The lowest frequencies of visible light are red, so we call the lower frequencies *infrared*, meaning *beyond red*. This type of electromagnetic radiation is widely used for local communications, in which the sender and receiver are very close together, such as a VCR remote control (transmitter) with the VCR receiver. Infrared light is sent by the VCR remote using a special electronic device called an *emitting diode*, which emits light when an electric current is passed through it. Behind a window in the VCR is a matched diode which passes current when it absorbs infrared light. The transmitter uses infrared light to carry information by modulating the signal, usually using a series of short on/off pulses similar to Morse code, which are received and decoded by the receiver and circuitry in the VCR.

The rods and cones in our eyes don't respond to IR light, so we say that it is invisible. However, the semiconductor detector chips in some types of black and white TV cameras are sensitive to IR and so can "see" it. The black and white picture on the TV tube the camera shows us, then, will show IR light. Hence, we can use the camera to image IR light from a remote control or other device. In fact, a high-power IR lamp can be used to illuminate a large area at a distance, without us humans even knowing it. The TV camera, though, and the person viewing through it, can see us. Watch out, you can be observed in the darkest of nights by invisible IR light beams!

### Review Questions

1. Can you see infrared waves? Explain.
2. What is a common use for Infrared waves? Can you think of another?
3. Why does IR light show up on the monitor of a black and white TV camera?

### Procedure A: *The Transmission and Reception of IR Light*

1. Connect the TV camera and monitor together, and focus the camera on an object several meters away or so.
2. Standing several meters away, aim and "shoot" the remote control at the TV camera and observe what happens on the monitor.

3. Have a partner hold some developed color film in front of the camera while you shoot the remote. Observe changes in the background light and that from the remote.
4. Have a partner hold a piece of developed color film in front of the camera while you shoot the remote. Observe changes in the background light and that from the remote.
5. Turn out the lights and watch the TV monitor while you shoot the remote. Observe changes in the background light and that from the remote.

### Procedure B: *The Reflective, Refractive, and Transmissive Properties of Light.*

1. Bring the camera and IR light source (either an IR LED or a TV remote control) together so that the diode is directly shining into the camera. Make sure a clear image is being picked up by the camera and displayed on the monitor.
2. Now place the transmitter at a 45° angle to the camera
3. Place the prism directly in front of the transmitter diode and rotate it until the image of the diode is seen on monitor. Note the position and orientation of the prism.
4. Replace the prism with the pocket mirror, orienting it until a signal is picked up. Note the position and orientation of the mirror.
5. Repeat (4) using the white card and then the black card. Note whether or not the signal is being received, and the position and orientation of the cards.
6. Align the transmitter diode and camera so a clear image of the diode is seen. Place a diffraction grating in front of the camera lens. Note any changes in the image – this is the first-order image of the diode. Now move the transmitter along a line perpendicular to the camera, keeping the diode pointed at the camera lens/grating. Stop when you see the first-order image.
7. Your teacher may want you to measure the wavelength of the IR light emitted by the diode. This can be done by measuring the distances involved. Can you figure out how? Recall earlier labs in which you measured the wavelengths of various colors of visible light using a diffraction grating.

### Analysis of Experiment

1. How is the image of the IR LED being generated on the TV monitor?
2. Explain the effect the prism had on the signal while in front of the IR diode (transmitter). What properties of light are being exhibited: refraction, reflection, absorption, and/or transmission?
3. Explain the effect the mirror had on the signal while in front of the IR transmitter. What properties of light are being exhibited?
4. Explain the effect the white card had on the signal while in front of the IR transmitter. What properties of light are being exhibited?
5. Explain the effect the black card had on the signal while in front of the IR transmitter. What properties of light are being exhibited? Where did the energy of the signal go?
6. *Optional:* Determine the wavelength of the IR light from the source you used.

## *Instructor's Guide to Lab No. 11:*

# Fluorescence

### Goal

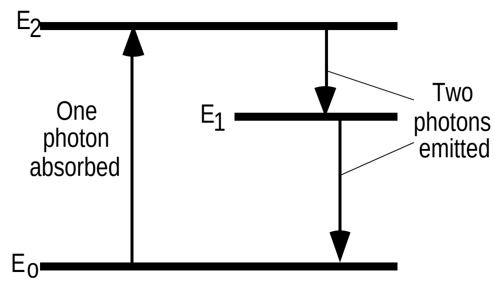
To investigate the phenomena known as fluorescence and phosphorescence.

### Objectives

After doing this lab or observing this demonstration students will be able to:

- Understand what causes fluorescence.
- Understand how fluorescence can be used.
- Understand what causes phosphorescence .
- How to detect ultraviolet light using fluorescent material

### Background Information




When an atom is excited from one energy state to a higher stage by the absorption of a photon, it may return to the lower level in a series of two (or more) jumps if there is an energy level in between. The photons emitted will consequently have lower energy and frequency than the absorbed photon. This phenomenon is called **fluorescence**; common fluorescent rocks and paints can emit visible light after absorbing UV light.

Fluoresence is responsible for the appearance of objects under the so-called "black light," which is a source of ultraviolet radiation. Photons in the ultraviolet region, invisible to the human eye, have higher energies than those in the visible region, and hence if an ultraviolet photon is absorbed by an atom, the outer electron (which is responsible for the visible transitions) can be excited to high levels. These electrons make transitions back to their ground state, accompanied by the emission of photons in the visible region.

Objects seen in ultraviolet light often show colors in the blue or violet end of the spectrum which are not present when the objects are viewed in sunlight; common fluorescent rocks and paints can emit visible light after absorbing invisible UV light. We can understand this effect by considering the composition of sunlight and the optical excited states of a typical atom. The intensity of sunlight is concentrated in the center of the visible spectrum in the yellow region; very little intensity is present in the red or blue ends of the visible spectrum. The "yellow" photons have enough energy to excite an atom up to its lower levels, but not enough to reach the higher levels. However, the higher-energy UV photons *do* have sufficient energy to reach the higher level, so the light emitted by the atom has a stronger blue component when that atom is excited by ultraviolet light than when excited by sunlight.

The wavelength for which fluorescence will occur depends on the energy levels of the particular atoms. Because the frequencies are different for different substances, and because many substances fluoresce readily, fluorescence is a powerful tool for identification of compounds. It is also used for assaying – determining how much of a substance is present–and for following substances along a natural pathway as in plants and animals. For detection of a given compound, the stimulation light must be monochromatic, and solvents or other materials present must not fluoresce in the same region of the spectrum. Often the observation of fluorescent light being emitted is sufficient; in other cases, spectrometers are used to measure the wavelengths and intensities of the light.

Fluorescent light bulbs work in a two-step process. The applied voltage accelerates electrons that strike atoms of the gas in the tube and cause them to be excited. When the excited atoms jump down to their normal levels, they emit UV photons which strike a fluorescent coating (called a phosphor) on the inside of the tube. The light we see is a result of this material fluorescing in response to the UV light striking it.

Materials such as those used for luminous watch dials are said to be phosphorescent. In a phosphorescent substance, atoms can be excited by absorption of a photon to an energy level said to be metastable. When an atom is raised to a normal excited state, it drops back down within about $10^{-8}$ sec. Metastable states can be much longer – even a few seconds or longer. In a collection of such atoms, many of the atoms will descend to the lower state fairly soon, but many will remain in the excited state for over an hour. Hence, light will be emitted even after long periods. When you put a watch dial close to a bright lamp, it excites many atoms to metastable states, and you can see the glow a long time after.

### Helpful Hints

- The optional UV viewer described in the lab requires a UV bandpass filter. We have built one of these for each Resource Box using a PVC pipe fitting. Use the “invisible ink” to make the detector screen.

### References

Tom Donohue and Howard Wallace, "Ultraviolet Viewer," *Physics Teacher* **31**, 41 (1993).

## *Laboratory No. 11:*
# Fluorescence

### Purpose

To investigate the properties of UV light using the process of fluorescence.

### Required Equipment and Supplies

Long-wave ultraviolet lamp (black light), short-wave UV lamp, fluorescent mineral set, invisible ink, fluorescent crayons, UV detector cards, (*optional:* UV bandpass filter, tube to make UV viewer.)

### Discussion

We have learned that atoms can become excited by *absorbing* light, and also de-excited by *emitting* light. The atoms of each element have a unique set of wavelengths for the absorption and emission of light, depending on the different possible energy states the atom possess. Many atoms can absorb invisible light such as ultraviolet and then *spontaneously* emit less energetic visible light. This way of giving off light is called **fluorescence**, and is responsible for the appearance of objects under so-called “black light,” which is a source of ultraviolet radiation. Objects seen in ultraviolet light often show colors in the blue or violet end of the spectrum that are not present when the objects are viewed in sunlight. Common fluorescent rocks and paints can emit visible light after absorbing invisible UV light.

We can use fluorescent materials to test for the presence of invisible ultraviolet radiation by putting an object under a special light filter that blocks out all light except UV. If the material fluoresces, then there is UV present. If it is dark, then there is no UV.

A familiar example of fluorescence is the common fluorescent lamp you might be sitting under right now. In a fluorescent lamp, oscillating electrons excite atoms of mercury gas, which then give off photons of intense and invisible ultraviolet light. The inside surface of the lamp is covered with a powdery fluorescent material called a phosphor, and this material first absorbs the ultraviolet photons and then emits photons of visible light. The excited atoms in the phosphor take several steps, or transitions, to return to their original energy (ground) state. Each step results in the emission of less energetic photons that have frequencies in the range of visible light, which combine to produce white-looking light. Different phosphors can be used to produce different colors of light.

Because the fluorescence frequencies are different for different substances, fluorescence is a powerful tool for identification of rocks, minerals, and other compounds. It is also used for assaying – determining how much of a substance is present – and for following substances along a natural pathway as in plants and animals.

Some materials have excited states which are **metastable**, where the transition to a lower energy state is not spontaneous and takes more time. Materials that exhibit this peculiar property are said to have phosphorescence. The element phosphorus, which is used in luminous clock dials and in other objects that are made to glow in the dark, is a good example. Atoms or molecules in these materials are excited by incident visible light. Rather than de-exciting immediately, as fluorescent materials do, many of the atoms remain in a state of excitement, sometimes for as long as several hours – although most undergo de-excitation rather quickly. If the source of excitation is removed – for example if the lights are put out – an afterglow occurs while millions of atoms spontaneously undergo gradual de-excitation.

A TV screen is slightly phosphorescent, the glow decays rather quickly, but just slowly enough so that successive scans of the picture blend into one another. The afterglow of some phosphorescent light switches in the home may last more than an hour. The same is true for luminous clock dials, excited by visible light. Some older clock dials glow indefinitely in the dark, not because of a long time delay between excitation and de-excitation, but because they contain radium or some other radioactive material which continuously supplies energy to keep the excitation process going. Such dials are no longer common because of the potential harm of the radioactive material to the user.

Examples of phosphorescence are found in living creatures – from bacteria to fireflies and large animals like jellyfish. These creatures chemically excite molecules in their bodies that give off light, a process we call bioluminescence. The firefly uses a chemical reaction to emit light so it can be seen. However, certain squid emit visible light to become invisible! To fool predators below, these squid use light as camouflage by carefully regulating their brightness to match the intensity of the sunlight at their depth. Under some circumstances certain fish become luminescent when they swim, but remain dark when still. Schools of these fish hang motionless and are not seen, but when alarmed they streak away with a sudden burst of light, creating a sort of deep sea fireworks. The mechanism of bioluminescence is not yet well understood and needs to be carefully investigated, perhaps by future scientists such as yourselves.

### Review Questions

1. What kind of light is sometimes called “black light”?
2. What causes materials to be fluorescent?
3. What is a common example of fluorescence?
4. What is the main difference between fluorescence and phosphorescence?
5. What is an example of bioluminescence?

### Procedure

1. Draw a picture using the special fluorescent crayons provided in the kit. Take some time to draw a decent picture.
1. Set up the black light contained in the kit. Also set up the UV lamp, BUT DO NOT TURN IT ON.
3. Using the invisible ink, write something witty on the cardboard screen that will be inserted into the detector. Place the screen into the detector.
4 Try and detect the presence of UV light at different places in the classroom. If you can, take the detector outside into sunlight and record any changes in the image. Try and detect UV with the UV detector card. Record your observations.
5. Turn on the black light lamp. Use the UV detector to try and detect the presence of ultraviolet light. Try and detect UV with the UV detector card. Record your observations.
6. Place each of the various minerals contained in the kit under the black-light lamp. Record what you see. Note which minerals respond, and with what colors.
7. Place your picture under the lamp and observe the changes in the colors.
8. Put on your UV-goggles, and turn on the UV lamp. Leave the black light turned on. Use the UV detector and record any differences you can observe.
9. Record any changes you can observe in the minerals and your artwork. Note which minerals respond, and with what colors.
10. Now turn off the black light and observe and record any changes in the fluorescence of the minerals, your artwork, and the UV detector.
11. Turn off the UV lamp. Remove goggles.

### *Instructor's Guide to Labs No. 12 & 13*

# UV Light Detection
### *and*
# Absorption of UV Light by Oxygen

## Goal

To test various types of plastic and glass for UV transmittance, and to investigate the absorption of UV light by oxygen.

## Objectives

After completing these two labs students will be able to:

- Determine which brand of sunglasses block UV light most effectively.
- Determine which types of plastic and glass allow UV transmittance.
- Discuss the formation and destruction of ozone.
- Be able to work with UV light safely.
- Determine what happens to the transmittance of UV as the concentration of oxygen increases.

---

## Background Information

For certain applications it is necessary to know how well various materials transmit or block UV light. Sunglasses are a good example. *See the discussion section in the student handouts for more information.*

## Cautions

- Students working with the UVA and UVB lamps must wear goggles at all times since UV light can damage the retina.
- The resin must be poured and kept in a well-ventilated area during the entire experiment.

## Helpful Hints – *Gas absorption apparatus*

- Make sure the hose and stopper fit gas tight.
- Make sure the flask is cleaned out well in between uses.
- The UV light should be 10 cm above the gas testing device. It can be hooked to a ring-stand for convenience.

## Extensions

Other gases besides oxygen can be tested with the gas absorption apparatus.

## *Laboratory No. 12:*

# UV Light Detection

### Purpose

To test various types of plastic and glass for UV transmittance.

### Required Equipment and Supplies

Some type of UV light detector, UV filter, UV light, five types of clear plastic, five types of clear glass, one pair of sunglasses brought by each student, five clear plastic or glass items from the classroom, ring stand, two clamps, goggles.

*Caution: Always wear plastic goggles when working with UV light since UV cannot pass through plastic.*

### Discussion

Some types of glass and plastic will stop ultraviolet (UV) light while others are transparent to it. This lab will explore the degree to which types of glass, plastic, and sunglasses are opaque or transparent to UV light.

### Procedure

1. Hang the UV light on the ring stand so that it is 15 cm above the surface of the table.
2. Place the clamp to hold the material samples 3 cm below the UV light source.
3. Place the first type of plastic into the clamp.
4. Place the UV light detector directly underneath the sample to be tested.
5. Put on goggles and then turn on the UV light source.
6. Record the type of plastic and the transmittance in a table.
7. Repeat for the four remaining types of plastic, five types of glass, each type of sunglasses, the UV filter, and the five assorted lab items.

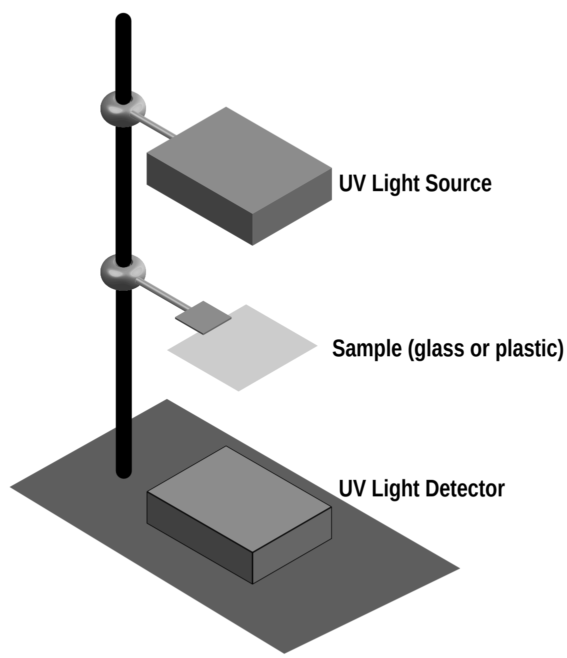



**Figure 1** The UV light testing apparatus.

### Analysis of Experiment

1. Make a bar graph showing the type of material versus the transmittance.
2. Which type of plastic was best? Worst?
3. Which type of glass was best? Worst?
4. Rank order the sunglasses by brand from best to worst for UV protection.
5. Can you say how the absorption characteristics of each material are related to the transmittance values recorded?

### *Laboratory No. 13:*

# Investigating the Absorption of UV Light by Oxygen

## Purpose

To investigate the absorption of UV light by Oxygen.

## Required Equipment and Supplies

Gas testing apparatus, Liquid Crystal UV light detector, UV light, rubber tubing, rubber stopper, 250 ml Erlenmeyer flask, manganese dioxide, hydrogen peroxide (3%), mass balance, goggles.

*Caution: Always wear plastic goggles when working with UV light since UV cannot pass through plastic.*

---

## Discussion

The earth is surrounded by a thin layer of ozone gas present in the stratosphere which absorbs almost all of the incoming UV light from the sun. Without this shield, life on this planet would have evolved very differently.

Ozone ($O_3$) is produced when atmospheric oxygen ($O_2$) is dissociated by UV radiation into two individual oxygen atoms, and one of these atoms combines with $O_2$, forming $O_3$.

$$O_2 + \text{UV Radiation} \rightarrow O + O$$

$$O + O_2 + \text{Mediator} \rightarrow O_3 + \text{Mediator}$$

Ozone itself can then be dissociated by UV light into $O_2$ and O. The amount of ozone in the earth's atmosphere is about 3 billion tons. Despite this high number, if this amount of ozone were moved to the earth's surface, it would form a layer only 3 mm thick. It exists in the atmosphere in a concentration of only about twenty to thirty parts per million.

The destruction of the earth's ozone layer is a major environmental concern. Many chemicals used by industries and consumers actively destroy ozone. These chemicals include chloro-fluorocarbons used to produce some types of styrofoam, freon used in refrigeration and air-conditioning units, and spray cans that contain fluorocarbons. A large effort is being undertaken by environmentalists and chemists together to find and use alternatives to these destructive products.

Ironically, ozone itself is produced artificially at the earth's surface by industrial processes and the combustion of fossil fuels, and is a serious pollution problem for major cities like Los Angeles. Ozone is a noxious pollutant which can hurt eyes, plants, and destroy rubber products.

## Review Questions

1. Where is most of the earth's ozone concentrated?
2. What is the chemical formula of ozone gas?
3. Write the chemical equations which describe how ozone is produced, then destroyed.
4. How much ozone is there in the atmosphere?
5. What is the concentration of ozone in the atmosphere?
6. How can ozone also be a pollutant?

## Procedure

1. Set up the gas testing apparatus and ring stand assembly as shown in Figure 1. Place the liquid crystal UV detector directly underneath the gas testing device. *Do not leave any air space between the detector and the gas testing device: the figure shown is an exploded view for clarity*
2. Put the rubber hosing onto the device and the stopper into the flask
3. Place the UV light 3 cm above the gas testing device.
4. Put on the goggles and turn on the UV light.
5. Record the transmittance on the UV detector for the atmosphere, then turn out the UV light.

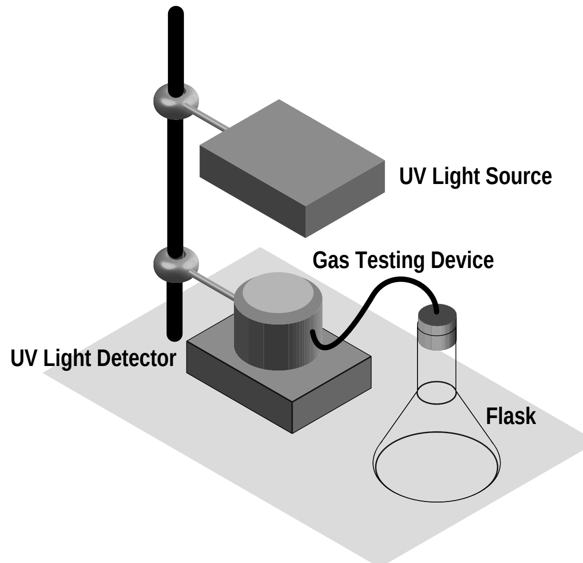



**Figure 1**

6. Remove the stopper from the flask.
7. Measure out 0.1 g of manganese dioxide and place it in the flask.
8. Add 20 ml of hydrogen peroxide and quickly stopper the flask.
9. Wait until the reaction in the flask has stopped.
10. Turn on the UV light, record the transmittance, then turn out the UV light.
11. Clean out the flask and the gas testing device, and then repeat steps 5 through 9 with 30 ml and 50 ml of hydrogen peroxide mixed with 0.1 g of manganese dioxide each time.
12. Record the UV transmittance after each trial.

## Analysis of Experiment

1. Make a graph indicating the amount of manganese dioxide used (an indication of the amount of oxygen produced) versus UV transmittance.
2. What happened to the UV transmittance as the amount of oxygen increased? Why?

### *Instructor's Guide to Lab No. 14:*

# The Effect of UV Light on Yeast

## Goal

The goal of this lab is to introduce students to the effects of UV light on a test organism (the yeast.)

## Objectives

After completing this lab, students will be able to:

- Explain the effect of UV light on yeast growth.
- Analyze colony growth on agar plates.
- Describe where UV light fits into the overall Electromagnetic Spectrum.
- Explain why UV light has a deleterious effect on yeast growth.
- Demonstrate sterile technique for growing yeasts.
- Calculate dilutions for yeast growth.
- Accurately graph yeast growth versus exposure time.

---

## Background Information

Found in student handout.

## Helpful Hints

- UV light sensitive yeast can be purchased from large scientific supply houses.
- Use a germicidal UV lamp if possible. (This is supplied in the Resource Box.)
- Make sure students swirl or vortex mix the yeast suspensions and dilution tubes thoroughly each time.
- ***Making the nutrient agar plates:***
  (a) Make 10 nutrient agar plates per group.
  (b) Mix nutrient agar with deionized water according to directions on the label of the nutrient agar jar.
  (c) Sterilize at 20 lbs of pressure for 20 minutes.
- ***Starting the yeast culture:*** Each group will need one experimental and one control sample of yeast.
  (a) Make 0.1 molar sucrose and pour 15 ml into two test tubes *for each group*.
  (b) On the day before the lab, sterilly add the UV sensitive yeast to the test tubes. Let them grow overnight.
  (c) On the day of the lab, sterilly pour the yeast suspension into two sterile petri dishes, one marked "Experimental" and the other "Control."
- ***"Plating" the yeast cells:***
  (a) Students dip glass spreader into alcohol and immediately place it into the Bunsen burner flame. Let the flame go out.
  (b) Open the lid of the agar plate slightly and gently rub it across the agar 3-4 times to cool it down. *Be careful, the agar can tear!!*

(c) Remove 100 µl (0.1 ml) from the yeast tube, carefully lift the cover of the agar plate just a crack, and inject the yeast onto the agar.

(d) Immediately turn the spreading dish wheel and move the glass spreader back and forth 5–6 times along it to spread the yeast evenly onto the nutrient agar.

(e) Close the plate cover.

- Store the completed plates up side down at 37° C for 1–2 days in an incubator.
- Make sure students do not open the petri dishes when counting the colonies.
- ***Analyzing the results:*** Theoretically, students will see a dose response to increasing time exposure to UV light. As the length of UV exposure time increases, fewer and fewer yeast cells will be observed.

## Extensions

- Mix so called antioxidant compounds in with the yeast to see if survivability is increased over a control.
- Place UV filters (even sunglasses) above the yeast to test for the protective effects.

## *Laboratory No. 14:*

# The Effect of UV Light on Yeast

### Purpose

To determine the effects of UV light on yeast growth.

### Required Equipment and Supplies

Two yeast cultures in petri dishes, UV lamp, petri dish, incubator; Per group: goggles, 10 nutrient agar petri dishes, glass spreader, plating wheel, Bunsen burner, striker, pipetter (or plastic pipette), sterile cover dish. *Optional:* vortex mixer, plating wheel.

*Caution: Always wear plastic goggles when working with UV light since UV cannot pass through plastic. Sterile technique must be used throughout the lab to ensure proper results.*

### Discussion

Ultraviolet (UV) light has a wavelength range of 5 to 400 nanometers (1 nm = $10^{-9}$ m) placing it between visible light and x–rays on the electromagnetic spectrum (Figure 1). It has a shorter wavelength and therefore more energy than visible light.

UV at a wavelength between 29 and 31 nm causes melanin production in skin cells of human beings, which causes fairskinned persons to tan. This same wavelength is necessary for vitamin D production in human beings. Since UV is a type of ionizing radiation it can damage cells. Overexposure to UV in sunlight can cause sunburns which could lead to skin cancer. Only about 1% of the UV from the sun is able to penetrate the earth's atmosphere. Directly looking at UV light can damage the retina of the eye.

Certain insects have eyes which see in UV light. Since some flowers show very distinctive and different coloration in UV light compared to visible light, this allows insects such as bees to distinguish easily among flowers which look very similar in visible light.

Some wavelengths of UV light kill cells and are used to sterilize medical instruments.

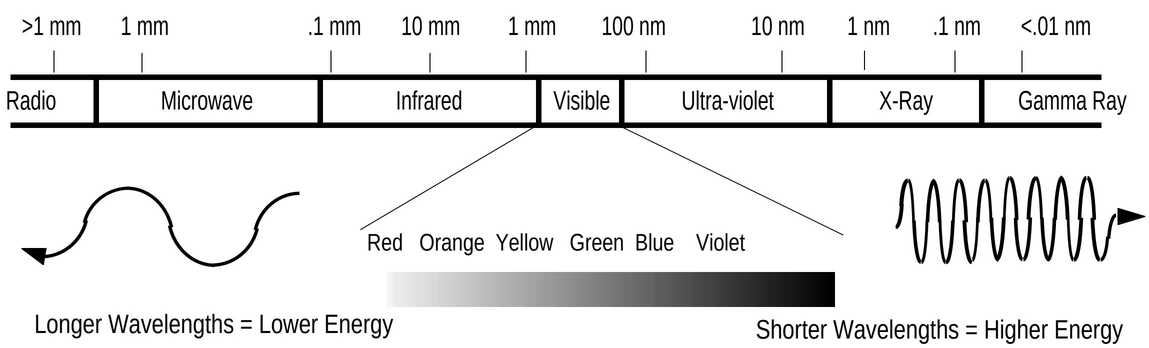



**Figure 1**

### Review Questions

1. Where is UV light found in the Electromagnetic Spectrum?
2. What is its wavelength range?
3. Is UV more or less energetic than visible light? Why?
4. Which wavelength causes suntans and sunburns?
5. What can these lead to?
6. How much of the UV from the sun penetrates the Earth's atmosphere?
7. Which kind of animal can 'see' in UV light?
8. Why can UV light be used to sterilize medical instruments?

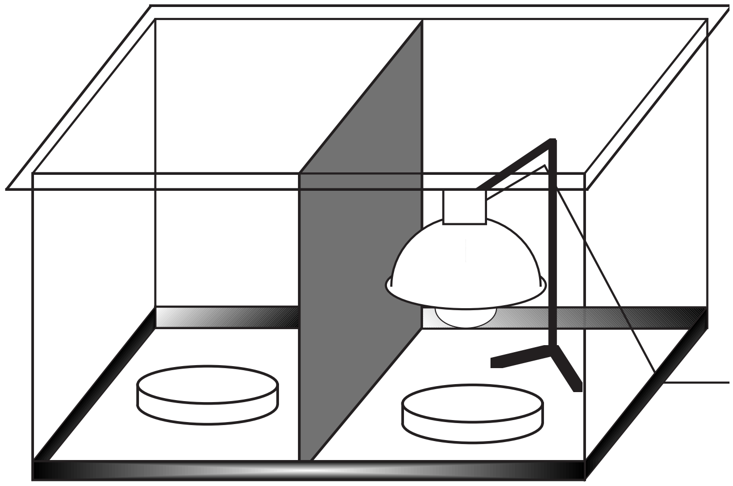



**Figure 2**

## Procedure– *Day 1*

1. Raise the sterile cover and remove 0.1 ml of yeast from the experimental culture and 0.1 ml from the control culture in separate pipetters.
2. Plate six nutrient agar petri dishes with the experimental culture and six nutrient agar petri dishes with the control culture. Label each experimental petri dish as E1 through E4, and the control dish as “Control.”
3. Setup the UV light at a distance of 8 cm above where the petri dish will be placed (see Figure 2).
4. Place the control dish in the compartment seperated from the UV lamp.
5. Tun on the UV lamp.
6. Place the first experimental petri dish (E1) under the UV lamp for **15 seconds** and then quickly remove. Be sure to time the exposure accurately.
7. Repeat step 5 using dishes E2 through E4 for **30**, **45**, and **60 seconds**, respectively.
8. Cover the petri dishes and set aside in a place where they won’t be disturbed for two days.

## *Day 3*

9. After waiting two days, count the number of yeast colonies on each. *Note: do not open the petri dishes.*
10. Make a graph of Exposure Time versus Yeast Colonies. Plot the control and experimental numbers on the same graph.

## Analysis of Experiment

1. What is the fraction of yeast in the final nutrient agar petri dish?
2. What was the reason for the control?
3. What was the effect of UV light on the yeast? Why?

## *Instructor's Guide to Lab No. 15:*
# Effect of UV Light on DNA

### Goal
To determine the effects of UV light on DNA.

### Objectives
After doing this lab or observing this demonstration students will be able to:
- Discuss the three forms of DNA which result from UV damage.
- Make, load, and run a gel with DNA.
- Calculate the quantitative degree of DNA damage which results from exposure to UV light.

---

### Background Information
Being able to accurately quantify DNA strand breaks in an isolated system is a fairly new technique. The quantification of these breaks can be achieved by using plasmid DNA, electrophoresis, and measuring the square area of the bands produced.

When a DNA system is exposed to ionizing radiation, there are two potentially damaging forces, one direct and the other indirect. The direct source of damage is due to physical deposition of energy that disrupts atomic structure, actually ionizing the DNA. The indirect means of radiation damage is due to free radical formation. The indirect means of radiation damage is due to free radical formation. It is this indirect means of damage (i.e., radical formation) that will be measured in this system.

Electrons located in shells surrounding the nuclei can absorb radiation and move to shells of higher energy levels. If the energy absorbed is great enough, the electron will escape its atom or molecule, resulting in a free electron and an atom or molecule which is missing an electron. These electron-deficient species, also called free radicals, are highly unstable and will rapidly react with the surrounding environment.

One of the most important radicals is the hydroxyl radical ($OH^-$) not only because it is one of the most reactive species, but also due to its relative abundance. The hydroxyl radical is generated with radiation by the hydrolysis of water. The $OH^-$ is a common radical linked with genetic mutation, aging, and DNA strand breakage.

When a hydroxyl radical reacts with DNA, a strand break can occur. This happens because a hydrogen atom is ripped off of the deoxyribose sugar of the DNA, thereby quenching the $OH^-$ into $H_20$. However, the resulting free electron, through an unknown mechanism, will break the strand. If only one strand break occurs on the supercoiled DNA, an open circular form will be assumed. Similarly, if two strand breaks occur in close enough proximity, the DNA will assume a linear form.

### Cautions
- Students working with the UVA and UVB lamps must wear goggles at all times since UV light can damage the retina.

## Helpful Hints

- ***Agarose Gels:*** **(**1) Make 1% agarose gels by mixing 1 part agarose to 99 parts 1X-TBE solution. (2) Make enough to cast the appropriate number of gels for your class.
- ***TBE running buffer:*** (1) can be purchased commercially in 50X or 20X stock solutions. (2) Be sure to dilute to appropriate strength before using.
- ***Plasmid DNA:*** pUC plasmid can be purchased from commercial scientific supply houses. Make sure it is as near to 100% supercoiled as possible!! This will greatly enhance results!!!
- ***Loading Dye:*** Can be purchased from scientific supply houses.
- Make sure the DNA is kept on ice at all times. Ice under the UV lamp will melt and will need constant re-supply.

## Analysis of Results

- The gels can be stained with ethidium bromide and visualized with UV light or methylene blue and visualized with white light.
- The band migrating the furthest will be supercoiled followed by a middle band of open circles, and if enough UV is given, a third band of linear.

## Extensions

Substances known to be free radical scavengers (i.e., vitamins) can be tested in this system. A free radical scavenger is a molecular species which reacts with free radicals to transform them into either a non-radical species, or a more stable radical. The scavengers usually do this by donating an electron to the free radical, thus stabilizing it.

### *Laboratory No. 15:*

# The Effect of UV Light on DNA

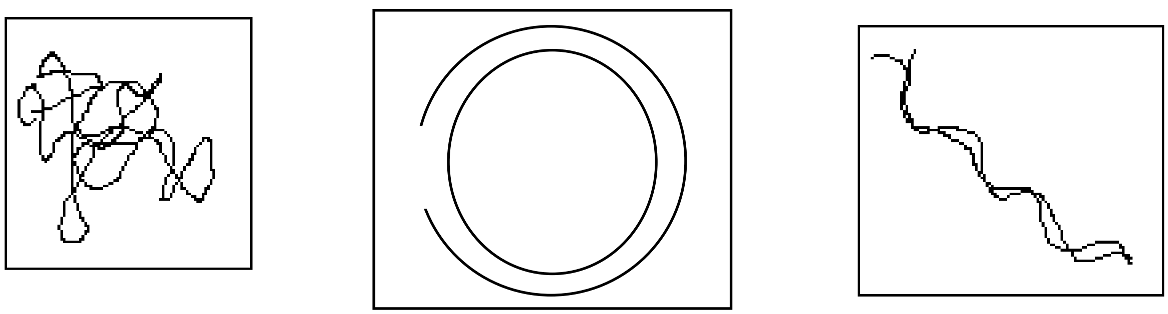
## Purpose

To determine the effects of UV light on DNA.

## Required Equipment and Supplies

TBE (Tris-borate-EDTA) running buffer, gel box, agarose, power supply, plasmid DNA (pUC18 or BR322), pipette, loading dye (BTB and xylene cyanol), stain (methylene blue, ethidium bromide, or a proprietary DNA stain), UV light, 1.5 ml microfuge tubes, ruler, poloroid camera, goggles, light box**.**

*Caution: Always wear plastic goggles when working with UV light since UV cannot pass through plastic. Sterile technique must be used throughout the lab to ensure proper results.*



Supercoiled DNA Single Strand Break- Open Circle Double Strand Break - Linear/Twisted

**Figure 1** Illustrations of uncut and cut DNA.

## Discussion

Ultraviolet (UV) light is a type of ionizing radiation which can damage DNA. When UV light strikes DNA, it can cut one or two strands, leaving two types of breaks in the DNA. This breakage is particularly apparent when using plasmid DNA, since it is in the form of a circle. If one strand of the plasmid DNA is struck by UV light, an open circle results. If both strands of the DNA are cut, a linear form of DNA results. The uncut DNA remains in the supercoiled form, as illustrated in Figure 1 above. When run on a gel, the results look like Figure 2 at right.

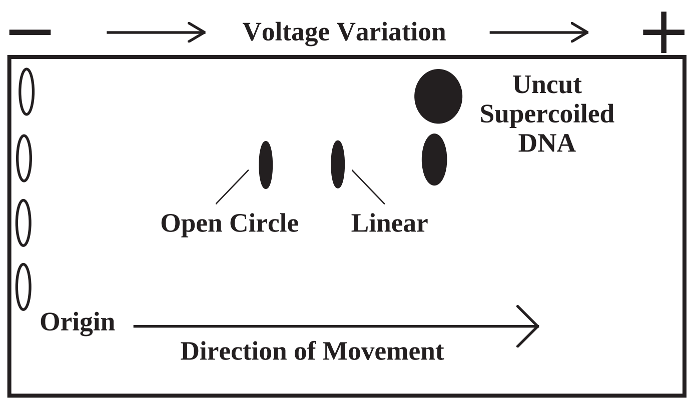



**Figure 2** The uncut DNA moves most quickly through the DNA, followed by the linear circle and linear species.

## Review Questions

1. What kind of radiation is UV light?
2. Why is plasmid DNA used to study the effects of UV light on DNA?
3. If DNA remains uncut, what form results?
4. If one strand of DNA is cut, which form results?
5. If two strands of DNA are cut, which form results?
6. Draw a gel and place the 3 forms in order on the gel.

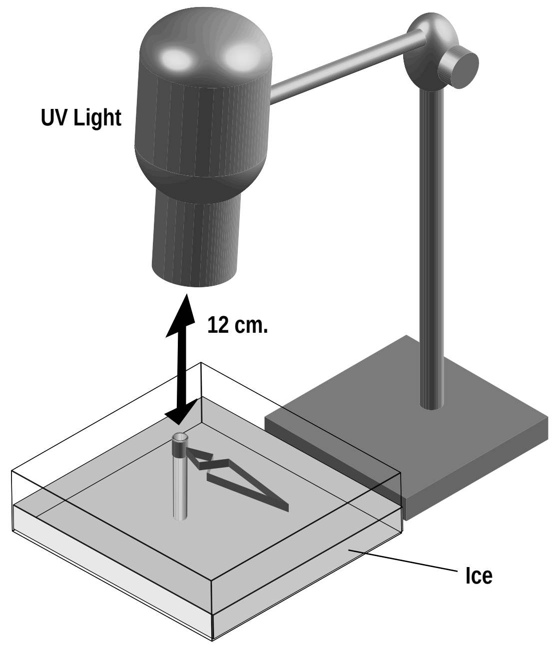



Figure 3

## Procedure - *Day 1*

1. Cast 1% agarose gels and place them in the gel boxes.
2. Pour TBE buffer until the level just immerses the gels.
3. Remove 5μl from the UV tube , add 1 μl of loading dye, and place the sample in well 1 on the gel for UV light. Repeat this procedure for the control group.
4. Place the open 1.5 ml tube 8 cm below the UV light and position it. Put on goggles and then turn the lamp on.
5. After 10 minutes, remove another 5 μl sample, add 1 μl of loading dye, and place it in well 2 on the gel. Repeat this procedure for the control group.
6. Continue taking 5 μl samples, adding loading dye, at 10 minute intervals up to 50 minutes for both the UV experimental sample and the control sample.
7. After the last sample has been taken, seal the gel boxes, and turn the power supply to 22 volts.
8. Let the gels run for 12–13 hours.

## Procedure – *Day 2*

9. Stain the gels with either ethidium bromide or methylene blue, or other DNA stain.
10. Take a picture of the gel.
11. Enlarge the picture on a copy machine 200%.
12. Measure the square area of each band and record it.

## Analysis of Experiment

1. Find the square area of linear, open circle, and supercoiled (uncut) DNA in each band.
2. What happens to the percentage of supercoiled DNA as the time of UV irradiation increases?
3. What happens to the percentage of linear and open circle DNA as the time of UV irradiation increases? Why?

### *Instructor's Guide to Lab No. 16:*

# Which Wavelength Causes Photogray Lenses to Change Color?

## Goal

To determine which wavelength (color) of light causes photogray lenses to change color.

## Objectives

After doing this lab or observing this demonstration students will be able to:

- Explain which wavelength causes Photogray glasses to turn dark.

---

## Background Information

Photogray lenses absorb UV light which causes them to change to a darker color, providing an automatic sunglass effect.

## Helpful Hints

- This activity can be done as either a demonstration in front of class or as one lab station among several.
- Make sure the lenses have been kept in the dark before the lab/demonstration to ensure that they are clear.
- The darkening reaction in the lenses should begin quickly after exposure to UV light.

## Extensions

Using a Photodetector measure the light absorbed by the photogray lenses when clear and when dark. Determine absorbtion characteristics of the lenses.

### Laboratrory No. 16:

# Which Wavelength Causes Photogray Lenses to Change Color?

## Purpose

To determine which wavelength (color) of light causes photogray lenses to change color.

## Required Equipment and Supplies

2 photogray lenses; UVA, UVB lamps; IR lamp; red, orange, yellow, green, blue, violet filters; lamps for the filters; clay or other stand for the lenses, opaque box with side cut out to hold lens.

*Caution: Always wear plastic goggles when working with UV light since UV cannot pass through plastic.*

## Discussion

Photogray lenses contain a substance which causes them to turn darker when exposed to sunlight, and clear again when the sunlight is gone. Sunlight consists of many different wavelengths of light (color), one or several of which could cause the photogray lenses to turn dark.

## Hypothesis

1. Which wavelength of of light do you suspect will have the greatest effect on the photogray lenses? Why?

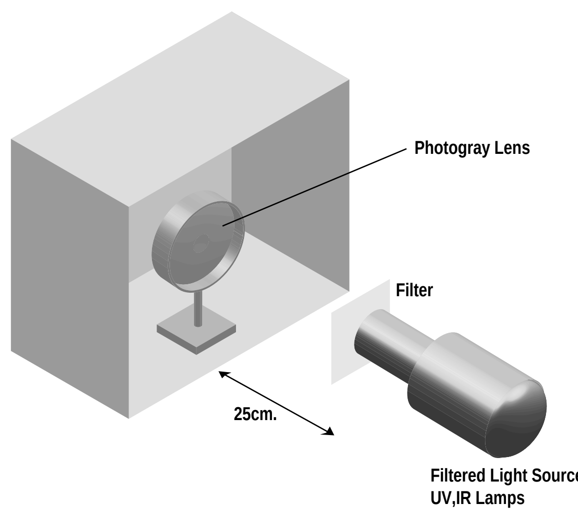



**Figure 1**

## Procedure

1. Set up the photogray lenses on its stand and place it in a box with the open side pointed in (see Figure 1).
2. Place the filtered lamp in between the lenses pointed away from each other.
3. Position the lamp 25 cm from the lens and turn it on.
4. Wait 30 seconds to see if there is a reaction.
5. Continue using all of the lamps until a reaction is seen.

## Analysis of Experiment

1. Which wavelength of light turned the lenses gray?
2. What kind of chemical reaction is occuring in the glass?

### *Instructor's Guide to Lab No. 17:*

# Which Wavelength Causes Sunrez® to Solidify?

## Goal

To introduce students to a light-dependent chemical reaction.

## Objectives

After doing this lab or observing this demonstration students will be able to:

- Determine which frequency in the electromagnetic spectrum causes Sunrez to solidify.
- Graph the results accurately.
- Explain why goggles must be worn around UV light.
- Distinguish between the wavelengths associated with UV, IR, and visible light.

## Background Information

Sunrez® is an unsaturated polysester resin with a boiling point of 294°F and a flashpoint of 70-80°F. It is a photocuring resin which will only soldify with exposure to a photo initiator such as UVA. It reacts just beyond the visible range at 380–410 nanometers. This resin may absorb other frequencies but primarily cures best in the UVA range.

## Cautions

- Students working with the UVA and UVB lamps must wear goggles at all times since UV light can damage the retina.
- The resin must be poured and kept in a well-ventilated area during the entire experiment.

## Helpful Hints

- Sunrez® or a similar photo-curing adhesive resin can be obtained at auto windshield repair shops.

## Analysis of Results

Students should find that only in UVA and somewhat in UVB will the resin harden. It will become viscous in the other frequencies, and even in the dark, but only in UVA/B will it solidify. If direct sunlight is used as a positive control, it will of course harden. This should become apparent to the students as the force to pull the popsicle stick increases in UVA/B and remains low and constant in the other wavelengths.

## *Laboratory No. 17:*

# Which Wavelength Causes Sunrez® to Solidify?

### Purpose

The purpose of this lab is to determine which wavelength of light causes Sunrez to turn from a liquid to a solid.

### Required Equipment and Supplies

Sunrez® or similar photo-curing adhesive resin, UVA lamp, UVB lamp, infrared lamp; red, orange, yellow, green,blue, violet filters; dark area, lamps for each color, goggles, 10 small plastic drinking cups, spring scales, popsicle stick. Direct sunlight can be used as a positive control if it is sunny on the day of the experiment. Simply add one more group and one more small plastic drinking cup/ popsicle.

*Caution: Always wear plastic goggles when working with UV light. Sunrez is caustic; avoid contact with skin and eyes.*

### Discussion

Certain types of adhesives and resins such as Sunrez® turn from liquid to solid in the presence of certain wavelengths of light. This process is called *photocuring* and is typically used to join optical components. As such, it is considered a photocuring resin. Sunrez® is used to repair car windshields.

The sun emits energy at many different wavelengths, including infrared, visible, and ultraviolet.

### Review Questions

1. What kind of resin is Sunrez®?

### Procedure

1. The class will be divided into 10 groups, one for each wavelength of light and one control group (dark).
2. Coat the inside of the cup with vaseline.
3. Pour 2 cm of resin into your group's cup and place a popsicle stick into the middle.
4. Attach a spring scale sideways to the popsicle stick and pull. Record the grams of resistance for your color.

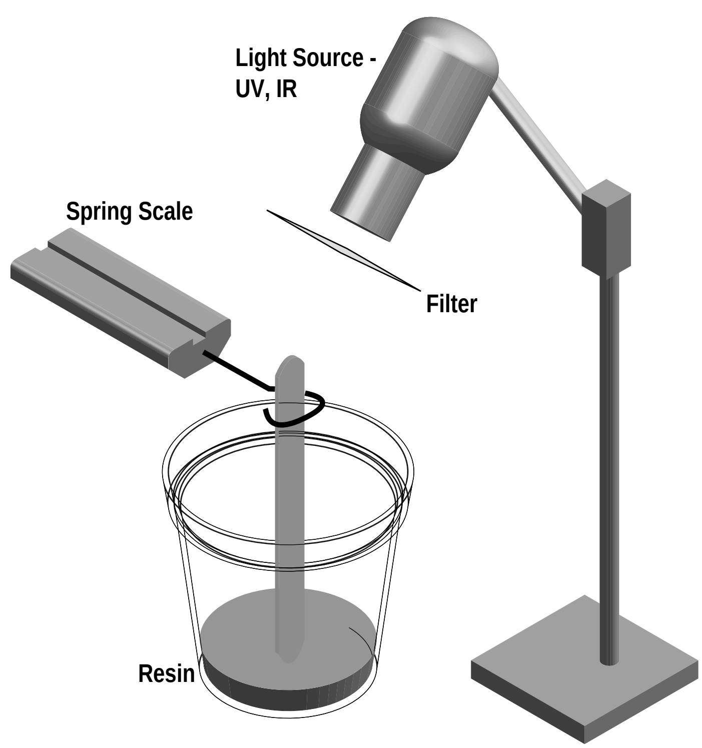



**Figure 1**

## Procedure (*continued*)

5. Place your sample under your lamp so the surface of the resin is 15 cm away from the lamp. Turn the lamp on.
6. Every 2 minutes reattach the spring scale and pull to determine the grams of resistance.
7. Continue taking readings every 2 minutes for 30 minutes.
8. Record your data on the board, and copy the entire data table.
9. Graph the change in viscosity (grams of resistance) for each wavelength (color) vs. time on a graph.

## Analysis

1. Which wavelength(s) worked best to solidify Sunrez?
2. How do you know?

### *Instructor's Guide to Lab Nos. 18-23:*

# Radio and Microwave Experiments

## Goal

To familiarize students with radio-frequency electromagnetic waves.

## Objectives

After doing these radio/microwave activities the student should:

- Understand the fact that light, radio, television, and other forms of electromagnetic waves are really only one phenomenon.
- Be able to calculate the wavelength of electromagnetic waves given the frequency or calculate the frequency given the wavelength.
- Better understand how a diffraction grating works by adding waves that are in phase and producing strong signals in certain directions.
- Be able to estimate the wavelength of electromagnetic waves being used in a certain application just by looking at the sizes of the structures involved.
- Have an idea that generation of electromagnetic waves by acceleration of charged particles, usually electrons, and detection of these waves by their effect on free electrons as the wave passes are just reciprocal processes. Appreciate that an electric field, whether produced by a battery connected to a wire or a traveling electromagnetic wave, will accelerate charges such as electrons.

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## Background Information

A full description of each Radio Science lab is presented in the Student Activity sheets. Many of these lab activities are intended as home projects, such as Lab No. 20 which requires that the student tune in an AM radio signal at night in order to detect changes in the Earth's ionosphere between day and night.

## Helpful Hints

- The Resource Box contains four crystal-radio kits for students to build for Lab No. 19. The crystal radio consists of a simple resonant circuit that can be tuned to AM radio-frequencies to detect radio waves with an antenna consisting of a long wire.
- You may want to get a cheap amplified-speaker setup that can used to amplify a crystal radio for the entire class to hear. These can be obtained for about $10 at computer stores.
- Crystal radio kits can be obtained through science education suppliers such as Frey or Cenco. A crystal-type radio can be built from common electronic components by wrapping your own tuning coils using copper wire around an ordinary 35 mm film canister. See Figure 1 below for details.
- An inexpensive AM/FM radio is included in the Resource Box. This radio can be used as the signal detector in the radio-wave diffraction experiment (Lab No. 22). It is important that the radio detector does not have Automatic Gain Control (AGC). This is a special circuit that even many inexpensive radios have to compensate for varying receiving signal strengths. Since the experiment requires that students detect differences in signal intensity (strength), the AGC circuit will offset this effect and ruin the experiment. We have found RadioShack #12-734 to work well for this.

- Some wire-mesh screening is included in the RB to make a Farady-cage. Form this into box-like cage and place the radio in it to demonstrate the shielding of electromagnetic waves.
- We have put together ONE Microwave Transmitter/Receiver apparatus so far. This apparatus will be loaned out to one Resource Box unit at a time until we can build more.

## References

1. Forest M. Mimms, *Engineers Mini-Notebook: Communications Projects*, pg. 34-35, (1994.) Available at RadioShack stores.

### *Laboratory No. 18:*

# Measuring the Length of Radio Waves

## Purpose

To investigate the relative wavelengths of electromagnetic waves.

## Required Equipment and Supplies

Car with an AM/FM radio, someone to drive it, and a tunnel.

## Discussion

All electromagnetic waves travel at the speed of light $c$ which is equal to the product of the length of the wave (wavelength) $\lambda$ times its frequency $f$, written as

$$c = \lambda \cdot f$$

If we measure frequency in cycles per second (hertz, or Hz), and wavelength in meters (m), then the speed of light will be measured in meters per second. Its measured value is very close to

$$c = 3\times10^{8}\ \text{m/s}$$

which is scientific notation for *three* with *eight* zeros after it, or 300,000,000 m/sec. This is about 186,000 miles per second! All electromagnetic waves travel at the same velocity in vacuum, the speed of light. If the waves are traveling through some material like air or glass, they may travel at some other slower speed. In this case the frequency stays the same as it was in vacuum, but the wavelength decreases.

The relationship $c = \lambda \cdot f$ says something very interesting. It says that if the frequency of the wave $f$ gets higher, the wavelength $\lambda$ must get shorter, since $\lambda = c/f$. This means that the waves used for the FM band are about a hundred times smaller in wavelength than the waves used for the AM band. When you listen to KFMB AM 760, the 760 means that the frequency of the electromagnetic waves being broadcast by the station is 760 kilohertz, or 760 thousand cycles per second. For this frequency the wavelength is:

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\ \text{m/s}}{760\times10^{3}\ \text{cycles/s}} = 395\ \text{m}$$

When you listen to KPBS, the frequency is 89.5 MHz, or 89.5 million cycles per second. For KPBS the wavelength is:

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\ \text{m/s}}{89.5\times10^{6}\ \text{cycles/s}} = 3.35\ \text{m}$$

Your microwave oven operates at a frequency of 2.45 GHz (*giga*hertz), which is 2.45 *thousand* million cycles per second. For your microwave oven, then, the wavelength is:

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\ \text{m/s}}{2.45\times10^{9}\ \text{cycles/s}} = 0.122\ \text{m}$$

So we have familiar electromagnetic waves, which we use every day, with wavelengths ranging from the length of four football fields to about the size of a dollar bill. What about light waves for comparison? The red light from a He-Ne laser has a frequency of 474 *million-*million cycles per second, so its wavelength is:

$$\lambda = \frac{c}{f} = \frac{3\times10^{8}\ \text{m/s}}{474\times10^{12}\ \text{cycles/s}} = 0.0000006328\ \text{m}$$

This wavelength is very small, so small that we typically measure light in *nano*meters (nm), which is $10^9$ meters. But you can see light and you have probably done some experiments with light like dispersing it with diffraction gratings. Now we'll try some experiments with radio waves that show that they behave just like light but with much bigger sizes of experimental objects to handle the much longer wavelengths

It should be clear to us by now that the main difference in the types of electromagnetic waves we have investigated, including visible light, microwaves, ultraviolet, and infrared, is the wavelength (or frequency) of the waves. After all, radio waves can be thought of as just being long-wavelength light waves (or light can be thought of as being super-short radio waves!). Because of their different wavelengths, radio waves interact with matter somewhat differently than light waves, although both certainly display the same type of electromagnetic wave behavior – like interference, diffraction, and reflection – but on a different size scale. Similarly, because of their size difference, carrier waves used by the AM band interact with matter slightly differently than FM carrier waves because of their great size difference.

Although electromagnetic waves travel freely through space, they can get balky when we try to confine them. They can pass through a tube if the diameter of the tube is several wavelengths or more, but they cannot pass if the diameter gets comparable to a wavelength or smaller. This fact permits us to find out what the wavelengths of electromagnetic waves are just by looking for them in confined areas. For example, since the wavelength of the waves used in microwave ovens are about 12 centimeters long, the small holes in the door of your microwave prevent the passage of the high power microwaves you use to cook and yet pass the shorter wavelength visible light.

## Review Questions

1. What is the speed of all electromagnetic waves traveling in a vacuum?
2. How is this speed related to the frequency and wavelength of an electromagnetic wave?
3. Which waves are longer, visible light or the waves used in a microwave oven?

## Procedure

1. There are lots of tunnels around on our freeway system, one good one goes under I-5 near the airport, but you can get the effect even if you only go under the freeway at an overpass. Drive into the tunnel with your radio at 760 AM and then do it again using the fm band. The AM signal will get weak or fade out altogether in the tunnel, but the fm signal should stay strong with almost no fade. What is the difference between the two signals in terms of their wavelengths? (See the calculation done in the discussion section.) Can you see through the tunnel? (Note: All good car radios have a circuit called Automatic Gain Control, which tries to compensate for changes in received signal strength by boosting the gain when the signal goes down. This circuit competes with the effects this experiment is trying to demonstrate, so do not be discouraged if you have to look for just the right tunnel. It will be better to use a relatively weak radio station, so 760 works well in north county, but you might have better luck with a Los Angeles station like 1070 in areas closer to downtown San Diego. If necessary, get a cheap AM/FM radio which doesn't have this AGC circuit.) What is the wavelength of light compared to the tunnel diameter?

2. Measure the size of the holes in the door of your microwave oven and tell what you can conclude from your measurements about the wavelength of light and the wavelength of the microwaves you use to cook.

## *Laboratory No. 19:*
# Tuning Into Radio Waves

### Purpose

To understand the principles of radio communication.

### Required Equipment and Supplies

Crystal radio kit.

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### Discussion

Radio and television sets operate with electromagnetic waves generated by commercial and public stations. Here's a brief explanation of how a radio wave is broadcast at one location and received at another.

If you stand at the edge of a pond of still water and shake the end of a stick back and forth in the water, you'll produce waves on the water surface. These waves will spread outward as they travel away from you, weakening as they spread. If your friend is standing not to far away at the other edge of the pond, she will see the waves you created at the other side. She might watch a small piece of wood floating on the surface bob up in down in the waves. Using these waves you can actually send messages to your friend by slightly modifying, or modulating, the way you shake the stick. One way would be to shake harder or softer, causing your waves to be bigger or smaller. Your friend will see corresponding increases and decreases in the amplitude of the bobbing wood. This method of sending a message is called amplitude-modulation, or AM. Another way to send information would be to slightly change the rate at which you shake the stick, which would slightly change the frequency of your waves and the oscillation rate of the floating wood.

This is the principle behind radio and lightwave communication. Of course we don't use water waves to broadcast our favorite music and important information; we use electromagnetic waves. It works in a similar way, though. If you shake an electrically-charged rod to and fro in empty space, you'll produce electromagnetic waves in space. This is because the moving charge is actually an electric current. What surrounds an electric current? The answer is a magnetic field. What surrounds a changing electric current? The answer is a changing magnetic field! In this way the vibrating electric and magnetic fields regenerate each other to make an electromagnetic wave, which moves outward from the vibrating charge at the speed of light.

This is essentially how a radio transmitting antenna sends out a wave. Rather than shake a large charged antenna, however, we shake the electrons inside the metal of the antenna using oscillating electric currents. These electric currents are generated by a transmitter, and the oscillation rate determines the frequency of the electromagnetic waves that are sent out. Every radio station has an assigned frequency at which it broadcasts; the electromagnetic wave transmitted at this frequency is called the carrier wave. This carrier wave is either amplitude or frequency modulated, depending on the type of radio station broadcasting. AM stations broadcast in the range of 535 to 1605 kilohertz (thousands of waves per second), while FM stations broadcast in the higher frequency range of 88 to 108 megahertz (millions of waves per second). Both of these electromagnetic frequency ranges are like very low-frequency light waves. Amplitude modulation can be thought of as changing the brightness of a constant color light bulb. Frequency modulation is like changing the color of a constant-intensity light bulb.

With both AM and FM the carrier wave is modulated by electrical currents we call the signal. The signal is produced by converting sound vibrations from a voice or musical instrument into electrical vibrations (currents) using a microphone at the radio station.

As a radio wave leaves the transmitting antenna, it spreads out in all directions. The oscillating electric field of the wave causes the movable electrons in a distant radio's metal antenna to oscillate. These electrons dance a jig that is a miniature version of the electron motion in the transmitting antenna. Although the signal weakens as the energy of the wave is spread out over a larger and larger distance, radios that aren't too far away can pick up the signal. This signal is very weak and is usually amplified and then sent through an electrical circuit that reconstructs the original sound from the radio station and plays it through a speaker or headphone. It turns out that just about any piece of metal can be used as a receiving antenna. In fact, each metal pot and pan in our kitchens is receiving radio signals, causing the electrons within them to oscillate with the incoming radio waves. Of course our pots and pans don't usually have the circuits, amplifiers, and speakers required to process these electrical signals and replay the sound being broadcast, though.

Since radio waves are generally coming in from many nearby stations at the same time, a radio must be able to be adjusted, or tuned, to pick out only one carrier signal at a time from the many being received by the antenna. This is done by an electrical circuit called a tuner using a process called resonance. A resonant circuit is easy to build using common electrical components. We can build a simple AM radio using a capacitor, an inductor, and a one-way crystal to detect and tune into some of the many radio waves surrounding us.

## Review Questions

1. Are sound waves part of the electromagnetic spectrum?
2. What is meant by modulation?
3. What is the difference between AM and FM?

## Procedure

1. Assemble the crystal radio included in the supply kit.
2. Examine the device closely and try to understand how it operates. Look for an external source of power, such as a battery or power chord.
4. Attach the antenna leads to a large metal object.
3. Connect your earphone to the radio and try to tune in a local AM station. If no signal is obtained, try stringing several meters of electrical wire around the room as an antenna.
4. Listen to the broadcast until the station is identified (this is done regularly throughout the day). Place a piece of masking tape along the length of the coil and note the position of the tap on the tape. Write the stations call number at this point.
5. Reconnect the antenna leads to a larger piece of metal. Note whether there is a change in the strength of the sound.

## Analysis of Experiment

1. The crystal radio has no battery! Where does the power come from?
2. What role does the tap position play in the circuit?
3. What is the frequency of the station you detected and tuned into? Remember, AM frequencies are given in kHz.
4. Electromagnetic waves travel at the speed of light $c$ which is equal to the product of the length of the wave $\lambda$ times its frequency $f$, written as $c = \lambda \cdot f$. What is the length of the wave you tuned into?
5. What is the wavelength of the carrier wave used by your favorite FM station? Remember, FM frequencies are given in MHz, so KPBS at 89.5 uses 89.5 million cycles per second wave to broadcast its signal.

### *Laboratory No. 20:*

# The Shielding of Radio Waves by Metal

## Purpose

To understand the principles of radio communication.

## Required Equipment and Supplies

Portable AM radio, aluminum foil, small cardboard box.

## Discussion

Radio waves (as well as many other electromagnetic waves) move electrons only at the surface of metal; electric fields can't penetrate metal because the mobile electrons at the surface will quickly move around in such a way as to cancel out the electric field at the surface. Instead, the oscillating electrons at the surface absorb a wave and then, because of their own accelerations, re-emit it in the action called *reflection*. Metals reflect radio waves just as a mirror reflects light. A radio won't play inside a closed metal box. Lightning can't penetrate to the inside of a metal car.

Surprisingly, radio waves pass right through our bodies all day, every day. It's easy to prove by putting a small portable radio on the ground, and laying over it, the radio still plays! Radio waves don't greatly disturb the electrons in any non-conducting matter because the waves carry very little energy and the electrons aren't free to move around in a nonconductor. Compared to metals, humans are very poor conductors of electricity. We don't disturb the incoming waves much. Although nonconductors can shield electromagnetic waves by absorbing them, the material must be at least several times thicker than the wavelength of the wave for total absorption. Since our bodies and many of the nonconduction objects around us are thin compared to the wavelength of radios waves, radio waves can pass through a roof, a wall, or a person without much absorption.

For radio communication, radio-frequency interference can be a big problem. Just about every electronic circuit that has changing or oscillating currents in it will radiate electromagnetic radiation, a lot of it in the range of frequencies that includes radio and TV. Most electronics products have to be shielded so that they don't interfere with other devices or disrupt radio and TV communications. This is why so many electronic products carry a label that shows that the device is approved for home use by the Federal Communications Commission (FCC). Computers especially produce a lot of electromagnetic radiation because there are so many electrons being accelerated in the circuits as the computers do calculations. If you take a radio which is not tuned to any station and hold it near to a computer, you will be amazed at how strong the signal is. You can actually hear it work, just like the CIA tries to hear the computers working in foreign embassies. You have to try to put a metal shield box around all the radiating circuits to keep the electromagnetic radiation inside the computer if possible and if you look inside the computer, you will see that the designers did just that. Nevertheless, your computer is a rather good radio transmitter. Embassies often put their sensitive computers in rooms with metal walls so the eavesdroppers are stymied. In this case it is necessary to use old fashioned spies like James Bond and Matta Hari!

## Review Questions

1. Can radio waves pass through metal?
2. Can radio waves pass through people?
3. Explain why your answers to questions one and two may be different.

## Activities

1. Find a small cardboard box that the portable radio will fit inside. While the radio is playing and tuned into a strong station, put the radio inside the box and close the box. Can you still hear the radio playing? Of course the sound coming from the radio is muffled, but is it still receiving the station? Now completely cover the box with aluminum foil, or place the radio in a cage made from wire mesh. Is the radio still playing? Poke some large holes in the box. Is it still playing now? What does this tell you about the shielding of radio waves by cardboard versus the foil? Why are they different? The free electrons in the metal oscillate with the incoming wave and cancel its electric field inside the metal. If you ship an audio tape across country to a friend, you might wrap it in aluminum foil to keep any stray electric fields from damaging the tape in transit.

2. Use a portable AM radio to detect the radio-frequency emissions of a computer. Try using an AM radio tuned to about 550 kHz, since there is usually no radio station transmitting at this frequency. Have the computer do something like read a file into memory. Notice what you hear. Take the radio to other nearby electronic devices and circuits that you suspect might be emitting radio waves. Make a note those that generate radio-frequency “noise” (at 550 kilohertz or so).

3. When electromagnetic waves penetrate into some material which absorbs them strongly, they can be detected about one wavelength into the material almost no matter how strong the absorption. Sea water strongly absorbs electromagnetic waves. If you wanted to communicate with a submarine which was submerged, would use short or long radio waves? It turns out that the wavelength of electromagnetic waves in water is shorter than it is in air, so you will need even lower frequencies than you might think for this job. In fact, you will need frequencies of only a few hertz, or a few cycles per second. Because you need quite a few wavelengths of the wave to pass before you can tell that you are receiving an electromagnetic wave and interpret either the AM or FM signal which is superimposed on the wave, this means that the amount of information you can transmit is quite limited ...t hings like “launch,” “don’t launch,” or “good-bye” are about it.

### *Laboratory No. 21:*

# Using the Earth's Ionosphere to Reflect Radio Waves

## Purpose

To investigate the long distance transmission of AM and short-wave radio waves via reflection waves by the earth's ionosphere.

## Required Equipment and Supplies

Portable AM radio or AM car radio.

## Discussion

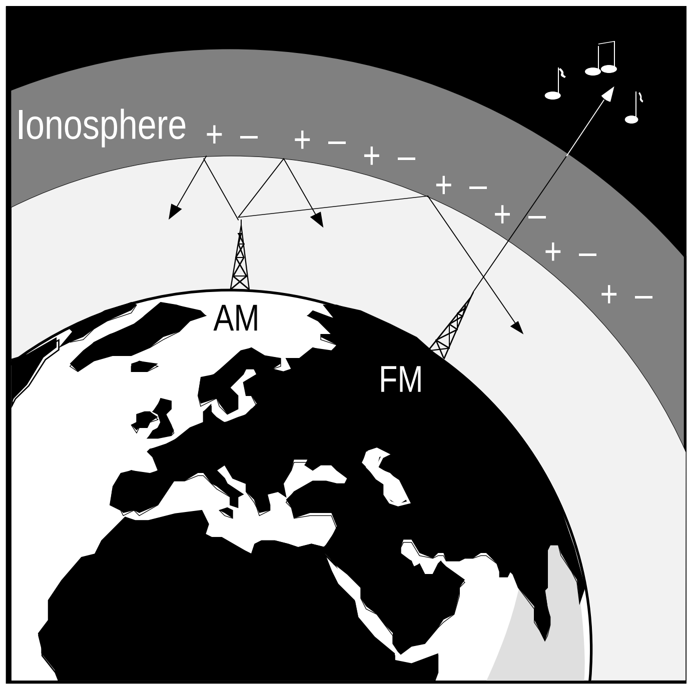



**Figure 1**

In the thin gas of the earth's atmosphere, above the ozone layer, strong ultraviolet radiation from the sun ionizes (breaks apart into charged particles) some atoms and molecules, creating what is called the ionosphere (Figure 1). These ions (charged particles) respond to the oscillating fields of AM radio waves rising from the earth's surface, causing them to be reflected back to earth. This is allows short-wave radio transmissions and some AM radio stations to be received over great distances without a straight line of sight to the transmitters. The ionosphere does not reflect FM radio and TV signals, however. Their frequencies are so high that the ionosphere's electrons can't respond fast enough to the changes in the electric field of those waves to reflect them back to earth.

## Review Questions

1. What produces the Earth's ionosphere?
2. Why are AM radio waves reflected off the ionosphere while FM are not?
3. Why can short-wave radio operators communicate with one another half way across the world?

## Activities

1. Some night when you are in a car, tune the AM radio to the farthest station you can find on the AM band. Listen for the call sign of the station and what city it is broadcasting from (note that you will never find an FM signal transmitted from so far away, since they are not reflected off the ionosphere like the longer AM waves). Then leave the dial untouched and return to the car the next morning. You won't be able to receive the station. What you are indirectly demonstrating is the daytime/nighttime change in height and ion concentration of the ionosphere. The solar UV radiation that forms the ions in the daytime is absent at night, allowing many of the ions to begin to recombine into neutral atoms. This recombination into atoms happens fastest where the ions are closer together, at the lower (and hence more dense) edge of the ionosphere. As night falls, it is as if the lower boundary of the ionosphere rises, and the reflected AM radio waves can go farther since they are reflected at greater heights, as shown in Figure 2.

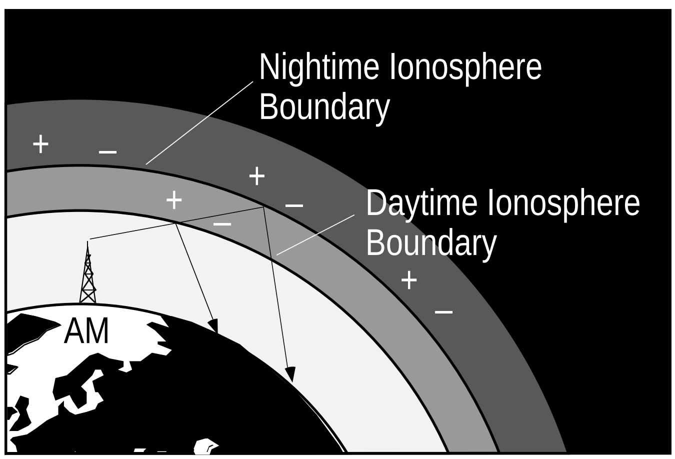



**Figure 2**

## *Laboratory No. 22:*

# A Diffraction Grating for Radio Waves

### Purpose

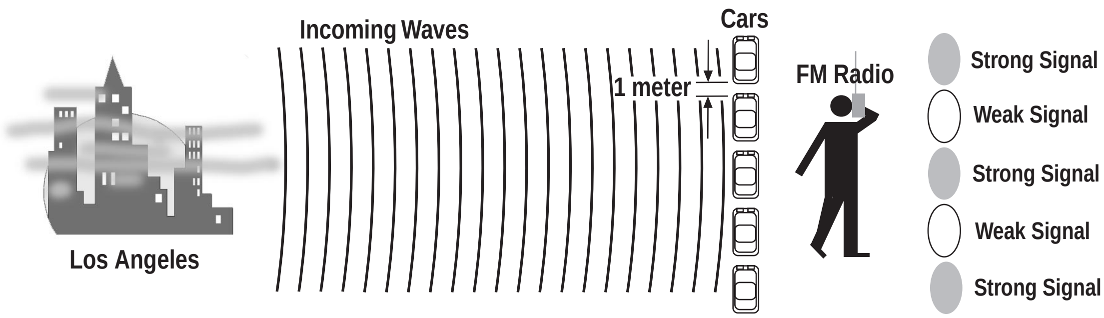
To understand the principles of wave diffraction using radio waves.

### Required Equipment and Supplies

Five or four cars. Portable FM radio (cheap, without automatic gain control (AGC) circuitry); Permission for field trip!

### Discussion

In earlier lab activities you used a diffraction grating to disperse visible light by creating an interference pattern. Recall that the interference pattern was formed because of the effects of diffraction and interference of light as it passed through a series of closely spaced slits. The slits were spaced about one wavelength of the light apart. Both diffraction and interference effects are general properties exhibited by all electromagnetic waves, including radio waves. In theory, then, we should be able to make a diffraction grating that works for radio waves! Since the wavelength of radio waves is much longer than light, though, the dimensions of the radio grating have to be HUGE. So how exactly can we make a diffraction grating that works for radio waves? Well, we need something that screens out the radio waves (metal) and which can have gaps in it about a wavelength apart. The wavelength of FM radio waves is about a meter. So what can we use as a diffraction grating? Cars!! Check out the diagram below to see how it might be done.




### Review Questions

1. What type of device is used to form an interference pattern?
2. What two wave properties cause electromagnetic waves to form an interference pattern?
2. Which electromagnetic wave has a longer wavelength – radio waves or visible light?
3. Why is it so difficult to make a diffraction grating for radio waves?

## Procedure

1. For this activity we have to choose the location carefully, since radio waves bounce off metal objects just the way light bounces off a silvered mirror. A path over water is good to avoid this, so try parking three cars at the Moonlight Beach parking lot.
2. Park the cars nose to tail with about 1 meter gap between them. Try to orient the cars so the direction to Los Angeles is perpendicular to their line.
3. Tune the small portable radio to a Los Angeles FM station.
4. Move away from the cars so they are between you and Los Angeles. Go about 6 meters away, as shown in the diagram above.
5. Now walk parallel to the line of cars and note what happens to the signal strength. There should be positions of strong signal and positions of weak signal. You have constructed a diffraction grating for radio waves which works just like the one for light, but in the case of radio, the dimensions have to be HUGE.

### *Laboratory No. 23*

# A Diffraction Grating for Microwaves

## Purpose

To understand the principles of wave diffraction using microwaves.

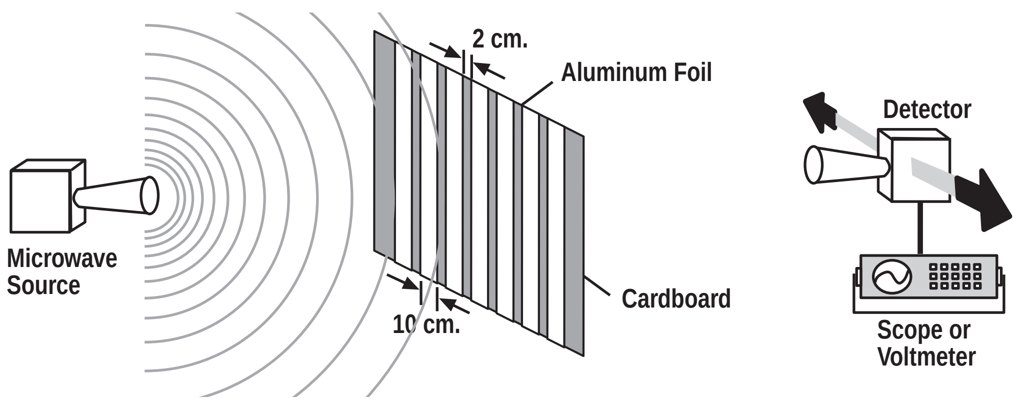
## Required Equipment and Supplies

Microwave transmitter and receiver, oscilloscope or voltmeter, aluminum foil, cardboard screen, tape.

## Discussion

We have examined the phenomena of diffraction and interference in great detail in previous labs. Why do it with microwaves? Well, first of all we may be interested in seeing how microwaves are and are not like electromagnetic waves in other regions of the spectrum. Second of all, the wavelength of microwaves turns out to be an excellent size for interference and diffraction experiments. Recall that the spacing in a diffraction grating must be on the order of the same length of the waves to be diffracted. For light, this is tiny, so small that the wavelengths are measured in nanometers ($10^{-9}$ m). Great care must be taken in order to make a diffraction grating with any kind of precision. On the other hand, we have seen that radio waves can be several meters long or so. This size is also hard to make a diffraction grating for. Microwaves, however, have wavelengths measured in centimeters, which make them easy to experiment with. In fact, we can make a precision diffraction grating out of aluminum foil and cardboard using scissors!

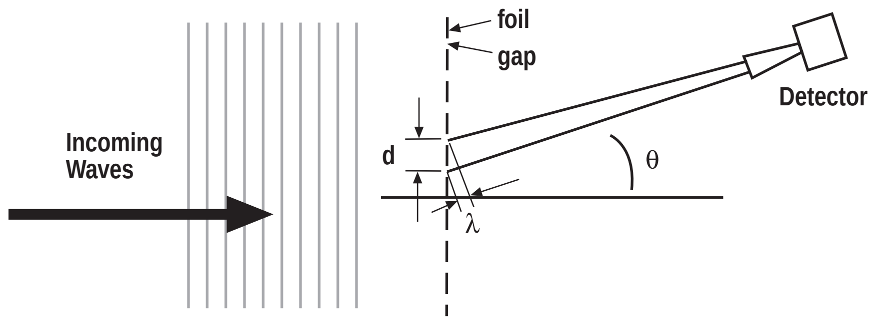
It is also easy to make totally and even partially reflecting “mirrors” out of wire mesh. This makes microwaves an especially well-suited for demonstrating interference using what is known as the Michelson-Morely method. This name is given to a special interference arrangement that helped lead to the development of the Theory of Relativity! Your instructor can give you the details – let’s get down to our microwave experiment!




It would be fun to do this experiment using the high power microwaves in your microwave oven. You could cook stripes into a piece of pizza dough, for example. But, unfortunately, no mother wants her kid to come home with stripes, so we have to do this experiment with a small microwave source. These are rather expensive, but some sources and detectors which are low power and are safe to use have been made available. These transmitters and receivers are surplus units from microwave systems and use a Gunn diode both as the transmitter and as the local oscillator for the receiver. The power is only about 30 mW.

## Review Questions

1. Why are microwaves useful for interference and diffraction experiments?
2. Which is longest and which is shortest, microwaves, radio waves, or visible light?
3. About how long is a microwave?




## Procedure

1. Make a transmission diffraction grating using a piece of cardboard and aluminum foil. Space strips of foil so that there is about a 2 cm gap between them. and put about 5 or 10 strips on the cardboard. Each strip should be about a wavelength wide (about 10 cm at 2.5 GHz) and all strips and all gaps should be the same width.
2. Illuminate the grating with the microwave source and move the detector back and forth on the other side of the grating looking for maxima and minima in signal strength. There should be periodic maxima and minima. If you can still detect the signal, go far away from the grating and measure the angle to the first maximum off from perpendicular. This can be done using trigonometry. Measure the perpendicular distance of the detector from the centerline ($x$) and the length along the centerline ($s$). It can be seen that

$$\sin\theta = \frac{\text{side opposite } \theta}{\text{hypotenuse}} = \frac{x}{\sqrt{s^2 + x^2}}$$

3. This angle is the one where the waves from one slit have to go just one wavelength farther on their way to the detector than the waves from the neighboring slit, so they all arrive at the detector “in phase” or such that they all add up, creating a strong microwave signal.

## Analysis of Experiment

Calculate the wavelength at which your microwave source is operating from the following equation, which works for optical diffraction gratings and for your microwave one made from foil:

$$\lambda = d\sin\theta$$

where $d$ is the width of your foil strips (actually the distance between the centers of the areas between the foil strips) and $\theta$ is the angle off-perpendicular to where the detector sees its first maximum.

# The Curriculum Resource Box

Below is a list of the items included in the Resource Box developed for use with *The Electromagnetic Spectrum* curriculum. Each item is packaged with a label for identification and repacking. Operating instructions and specifications of the individual equipment is reproduced in the section following. When you are finished with the Resource Box (RB) and are ready to pass it on, please repack it carefully. Feel free to contact Dr. Daniel Finkenthal at (619) 455-4664 or finkenthl@gak.gat.com for assistance. *Good luck and enjoy!*

## *List of Contents:*

| ResourceBox # | Item Description | Q | Source |
|---|---|---|---|
| RB-01 | UV Lamp (Mineralight UVG-11) | 1 | Frey #F14062 |
| RB-02 | Mercury Vapor Light Source | 1 | Frey #F23384 |
| RB-03 | Intense Light Source | 1 | Frey #F01910 |
| RB-04 | Video Monitor | 1 | Gateway |
| RB-05 | Video Camera | 1 | Gateway |
| RB-06 | Clamp Type Lamp | 1 | Frey #F00223 |
| RB-07 | Economy Hot Plate | 1 | Frey #F01953 |
| RB-08 | Variable AC Dimmer (Triac) | 1 | Finkenthal |
| RB-09 | UV Goggles | 4 | Frey #F14583 |
| RB-10 | Electroscope | 1 | Frey #F02678 |
| RB-11 | Fluorescent Mineral Collection | | Frey #F08934 |
| RB-12 | Flame Test Salts (set) | 1 | Frey #F02685 |
| RB-13 | Optical Slits Kit | 1 | Frey #F01920 |
| **RB-14** | Scale and Slit | 1 | Cenco 86260-01 |
| " | Metal Suports Set (for ob) | 1 | Cenco 85850-01 |
| " | Screen Support | 1 | Cenco 85970-01 |
| " | Mercury Thermometer<br>(10 to 110 x 1°C) | 1 | Frey #F12885 |
| " | X-Acto Knife | 1 | GA |
| RB-15a | Crystal Radio Kits (Small Parts) | 4 | Frey #F991138 |
| RB-15b | Crystal Radio Kits (Bases) | 4 | " |
| **RB-16** | Curriculum Manual | 1 | GA |
| " | Holographic Diffraction Grating (large) | 2 | Learning Technologies |
| " | Latex Gloves | 5 pr | GA |
| " | Color Filters (Red, Blue, Green) | 2 | Edmund C35,135 |
| RB-17 | Portable AM/FM Radio | 1 | Radio Shack 12-734 |
| RB-18 | Wire Mesh for Faraday Cage | 1d | Finkenthal |
| RB-19 | Compact Disks (gratings) | 30 | GA |
| RB-20 | Wheeled Tote Locker | 1 | HomeBase |

| | | | |
|---|---|---|---|
| RB-21 | Radiometer | 1 | Frey #F990224 |
| " | Holographic Diffraction Dratings | 30 | Arbor Scientific |
| " | Glass Prism | 1 | Frey #F990924 |
| " | Polarizers -2.5 in diameter | 8 | Edmund C38,396 |
| " | Calcite Crystal | 1 | Edmund C39,946 |
| " | Black Light Incandescent | 1 | Frey #F05285 |
| " | Clear/ Yellow/ Halogen/ Showcase Bulbs | 1 ea | GTE Sylvania |
| " | Flourescent Crayons Set | 5 | Frey #F00231 |
| " | Invisible (fluoresent) Ink, Fluor. Markers | 1 | Frey #F02101 |
| " | Cobalt Blue Glass (4” sq.) | 2 | Frey #F07137 |
| " | UV Detector-Viewer/ UV Bandpass Filter | 1 | Finkenthal/ Oriel |
| " | UV Detector Card | 4 | Science Kit |
| " | IR LED Light Source | 1 | Finkenthal |
| " | Lantern Mantel (Thorium Radiation Srce) | 1 | Sportsmart |
| " | Microscope Slides | 40 | Frey #F14680 |
| " | Colloidal Graphite | 1 | Frey #F02641 |
| " | Cyalume Sticks -Assorted Colors | 5 | Edmund C37,218 |

## Sources

Frey Scientific
905 Hickory Lane, PO Box 8101
Mansfield, OH 44901-8101
Toll Free: 800-225-FREY
(419) 589-1900 FAX: (419) 589-1522

CENCO (Central Scientific Company)
3300 CENCO Parkway
Franklin Park, Illinois 60131-1364
800-262-3626 FAX: (708) 451-0231

Edmund Scientific Company
101 E. Gloucester Pike
Barrington, NJ 08007-1380
(609) 573-6295 FAX: (609) 573-6295

Sargent-Welch
P.O. Box 5229, Buffalo Grove, IL 60089-5229
800 727 4368 FAX 800 676 2540
E-Mail sarwel@sargentwelch.com

Learning Technologies Inc
59 Walden St.
Cambridge, MA 02140
(617) 547-7724

Gateway Electronics, Inc of California
9222 Chesapeake Drive
San Diego, CA 92123
(619) 279-6802 FAX: (619) 279-7294

ORIEL Corp.
250 Long Beach Blvd., PO Box 872
Stratford, CT 06497-0872
(203)377-7877

Science Kit
PO Box 5059
San Luis Obispoo, CA 93403
(800) 828-9572

Arbor Scientific
PO Box 2750
Ann Arbor, MI 48106-2750
(800) 367-6695

RadioShack (local outlets available)

HomeBase (local building supply retail outlet)