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Educational Product	
Teachers	Grades 9–12

Discover Earth

National Aeronautics and Space Administration
Earth Science Enterprise

Earth's Energy Budget
classroom materials for precollege teachers

Discover Earth

Classroom Materials*

1 Discover Earth is a NASA-sponsored project for teachers of grades 5-12, designed to:

- enhance understanding of the Earth as an integrated system
- enhance the interdisciplinary approach to science instruction, and
- provide classroom materials that focus on those goals.

2 Discover Earth is conducted by the Institute for Global Environmental Strategies in collaboration with Dr. Eric Barron, Director, Earth System Science Center, The Pennsylvania State University; and Dr. Robert Hudson, Chair, the Department of Meteorology, University of Maryland at College Park.

3 The enclosed materials:

- represent only part of the Discover Earth materials,
- were developed by classroom teachers who are participating in the Discover Earth project,
- utilize an investigative approach and on-line data, and
- can be effectively adjusted to classrooms with greater/without technology access.

4 The Discover Earth classroom materials focus on the Earth system and key issues of global climate change including topics such as the greenhouse effect, clouds and Earth's radiation balance, surface hydrology and land cover, and volcanoes and climate change. All the materials developed to date are available on line at < http://www.strategies.org >

5 You are encouraged to submit comments and recommendations about these materials to the Discover Earth project manager, contact information is listed below. You are welcome to duplicate all these materials.

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Discover Earth — Earth's Energy Budget or Can You Spare a Sun?

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Grade Level: 9-12

Objectives: Students will:

- develop a concept map reflecting an understanding of the Earth's energy budget;
- demonstrate an understanding of albedo, solar luminosity, and selective absorption;
- derive the equation for the Earth's energy budget;
- develop an appreciation for the delicate nature of the interactions existing between various components of the Earth system.

Disciplines Encompassed: Earth science
environmental science
mathematics

Key Concepts:

energy budget	Equilibrium between the radiation received by, and the radiation emitted by Earth.
concept mapping	Visual representation of information that includes concepts and the relationship between concepts -- it can encourage overview or systemic thinking.

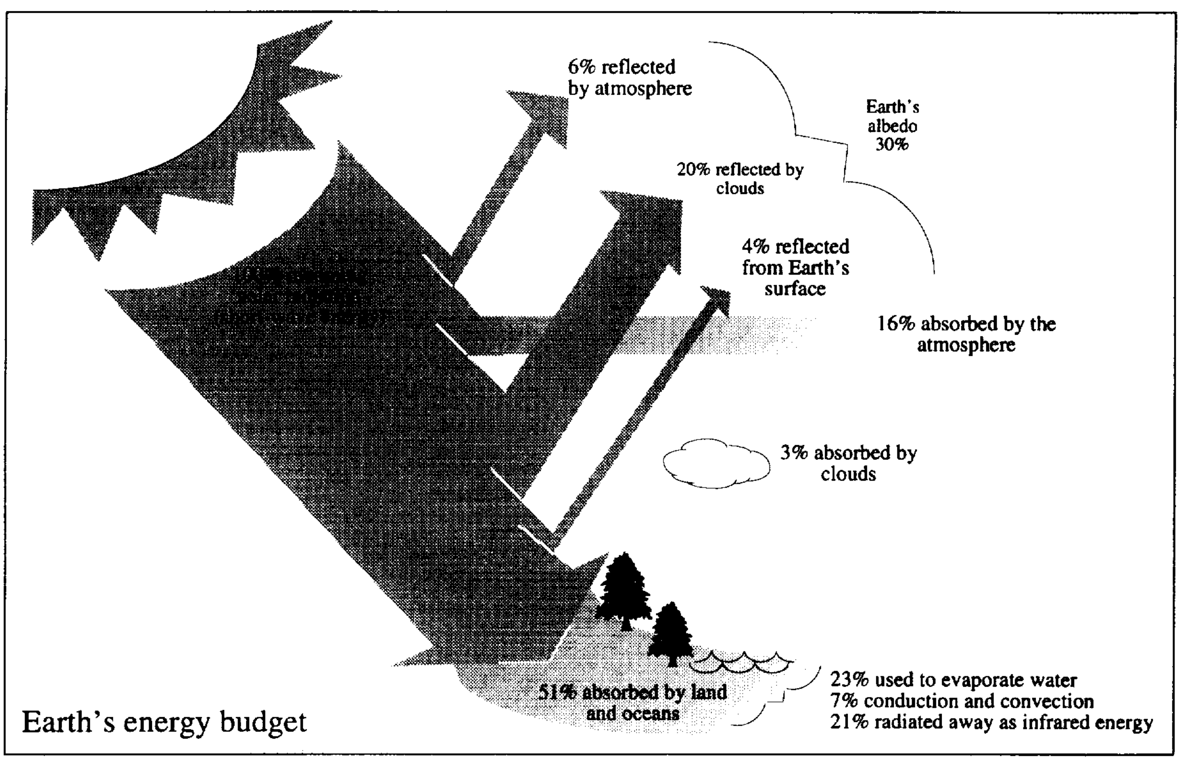
Cognitive Tasks: analyzing
graphing
measuring

Time Requirements: Three to six class periods for a 45 minute class.

Prerequisite Skills: ability to generate concept maps
ability to use Netscape or other image viewer
ability to create and interpret graphs

Data Sources:

NASA's Mission to Planet Earth	http://www.hq.nasa.gov/office/mtpe
NASA site, *color diagram, Earth's energy budget*	http://asd-www.larc.nasa.gov/erbe/components2.gif
NASA's Observatorium *Earth and space data*	http://observe.IVV.nasa.gov
NASA Goddard Space Flight Center	http://pao.gsfc.nasa.gov/gsfc/service/gallery
NASA - National Space Science Data Ctr.	http://nssdc.gsfc.nasa.gov/earth/rb.html
NOAA - Solar and Upper Atmospheric Data Services	http://www.ngdc.noaa.gov/stp/SOLAR/ IRRADIANCE/irrad.html
Dept. of Meteorology, U Maryland CP *diagram, effect low clouds on energy balance*	http://www.meto.umd.edu/~loftus/IMAGES2/ stratus.html
USA Today *how greenhouse effect works*	http://www.usatoday.com/weather/wgrnhse.html
U Florida *Earth's radiation budget*	http://ess.geology.ufl.edu/HTMLpages/ESS/ GLY1033_Notes/lecture2.html
U Florida, *color illustration, Earth's energy budget*	http://ess.geology.ufl.edu/HTMLpages/ESS/ GLY1033_Notes/Radiation_Budget.gif



Earth's energy budget

Key Terms:

albedo — The ratio of the outgoing solar radiation reflected by an object to the incoming solar radiation incident upon it. A measurement of reflectivity. Albedo is measured from 0-1. The more reflective a surface, the higher the albedo.

blackbody — Any object with a temperature above absolute zero (0 Kelvin) emits some radiation. An object that is a perfect thermal radiator--that absorbs and reradiates all incident radiation with complete (perfect) efficiency--is called a blackbody.

greenhouse effect — Process by which changes in the chemistry of Earth's atmosphere may enhance the natural process that warms our planet. If the Earth's average temperatures change, some plant and animal species could be threatened with extinction.

inverse square law — Explains why distant lights appear fainter than lights nearby--when both are the same brightness. Brightness is proportional (α) to the area over which the light is spread. Brightness $\alpha\ 1/R^2$

Brightness of bulb A at one meter: brightness $\alpha\ \frac{1}{1^2} = 1$

Brightness of bulb A at five meters: brightness $\alpha\ \frac{1}{5^2} = \frac{1}{25}$

This can also be calculated as the surface of a sphere, with the light being diluted as it covers a greater area. Area = $4\pi R^2$

Kelvin — Absolute zero is 0 on the Kelvin scale. On the centigrade scale absolute zero is -273.16 degrees. To convert centigrade to Kelvin, K = C + 273 or more accurately, K = C + 273.16

selective absorption — Specific substances impact the retention of radiant energy. The absorbing medium may emit radiation, but only after an energy conversion has occurred.

solar constant — The constant expressing the amount of solar radiation that reaches the top of the atmosphere when Earth is at its average distance from the Sun. The constant - 1370 W/m^2 - is actually variable.

solar luminosity — Energy coming from the Sun as visible light, radio waves, heat, ultraviolet waves, and x-rays. These forms of energy make up the electromagnetic spectrum.

Stefan-Boltzmann constant — relates the power emitted by a blackbody--per unit surface area of the blackbody--to the fourth power of its temperature. The constant is:

5.67×10^{-8} Watts per meter squared in Kelvin or

$5.67 \times 10^{-8}\ W/m^2\ K^4$

Stefan-Boltzmann law

The total energy emitted by each m2 of the surface of a blackbody depends only on the temperature.

$$E = \sigma T^4$$

E is the power radiated per unit area (watts/m^2) - is a constant
T is the temperature of the blackbody in Kelvin
σ is the Stefan-Boltzmann constant - 5.67 x 10^{-8} W/m^2 K

Background:

Concept maps are used to represent information visually. They can enable students to "see" the relationships that exist among specific information and encourage the understanding of complex information quickly. The use of concept maps should help students develop their powers of critical thinking. To develop their own maps, students will have to identify and rank concepts and select cross links, as well as possibly adding specific examples to their hierarchy, flowchart, and systems. <http://w3.aces.uicu.edu/AIM>.

Life on this planet is supported by energy from the Sun. The Earth's energy budget is a balance between energy inputs and outputs. Earth's climatic system has an important role in maintaining the balance between the energy that reaches the Earth from the Sun and the energy going back into space from the Earth. Radiation received from the Sun is absorbed and scattered by molecules of gases, liquids, and solids in the atmosphere, by clouds, by the Earth's surface. Radiation that is absorbed causes the planet to heat up. Earth retransmits as much energy as it absorbs from the Sun via reflection and emission. However, the heat emitted by Earth is in the form of long wave radiation, rather than in the shorter wavelengths that it received. The air will absorb some of the radiation emitted by Earth, some of the energy is radiated back to Earth and some radiated into space. See figure titled Earth's Energy Budget from <http://ess.geology.ufl.edu/HTMLpages/ESS/GLY1033_Notes/ Radiation_Budget.gifess.geology.ufl.edu>.

The amount of solar energy that is reflected back to space is called the albedo. Earth's average albedo is .3, meaning about 30% of incoming solar energy is reflected back to space.

A potentially important effect in climate change is a variation in the solar irradiance reaching Earth. Scientists monitor solar variability and use models--mathematical representations--of the Earth system to understand how changes could affect climate. For example, an increase or decrease in global cloud cover could increase or decrease Earth's albedo, which would increase or decrease the amount of solar radiation reaching Earth.

Earth's energy balance is described by the following equation:

$$\frac{S}{4}(1 - A) = j\sigma T^4$$

s = solar "constant", 1370 W/m^2 (equivalent of 256,000 cal/cm^2/year)
A = albedo
σ = 5.67 x 10^{-8} W/m^2/K^4
T = Earth's temperature in Kelvins
j = atmospheric constant

Activity 1: Brainstorming

Objective: This is the opening session for the lesson, "Earth's Energy Budget", and is designed to get students thinking about the "Energy Balance Equation" by finding suggestions for answers to a key question.

Materials: The question: "What factors affect climate?"

Procedure:

1. Students can arrive at answers through teams, or by a teacher-guided-session where the teacher can focus student suggestions by asking questions.

2. The ideas which the students generate are to be used as the central starting point for generating a concept map(s), which in turn leads to establishing the energy balance equation--an equation which scientists use to understand climate.

3. Discussion: to represent our climate, the energy equation must balance. We can better understand Earth's climate from this model which represents global warming and the temperature variability of Earth.

Activity 2: Albedo

Objective: Students will demonstrate an understanding of the effects of albedo on Earth's energy budget.

Background:

The amount of solar energy that is reflected from Earth back to space is called the albedo.

albedoes are a ratio with a value between 0 and 1	$\dfrac{\text{outgoing solar radiation reflected}}{\text{incoming incident solar radiation}}$

Oceans and forests reflect only small amounts of solar radiation, and thus have low albedoes. Deserts and clouds have high albedoes because they reflect large portions of the Sun's energy. Clouds reflect large portions of the Sun's energy before it can reach and heat the Earth's surface, thus causing the Earth to be cooler. Clouds also trap some of the long wave radiation emitted by Earth and radiate it back to Earth's surface, causing the Earth to be warmer. Generally, low, thick clouds tend to reflect radiation--meaning less radiation reaches Earth's surface, resulting in cooler temperatures. High, thin clouds will reflect less radiation and allow more to reach the surface, warming Earth. Cloud surfaces can reflect up to 50 W/m^2 of solar radiation.

The temperature, thickness, and types of particles making up a cloud will impact the cloud's albedo and its transmission of long wave radiation. The position of the continents, biological innovation (vegetation type and density), mountains, deforestation, and the rise and fall of sea levels also impact the albedo of Earth. If the albedo goes down, more energy is added to the system.

Albedo is influenced by dust and water in the atmosphere, and snow and ice. Albedo is also a function of the angle of incident. The larger the angle of incident the smaller the fraction of reflection.

note: The balance between the cooling and warming actions of global cloud cover is very close, but overall, cloud cover produces cooling on a global basis..

Materials for albedo studies:

- aluminum foil
- cheesecloth
- colored paper
- computer, with interface
- light source
- metric rulers
- ring stands
- scissors
- stopwatch or clock
- 3-4 temperature probes/group

Procedure for albedo studies: Notes for the teacher

1. In order to help students understand the role of heat absorption in the Earth's energy balance, this exercise requires students to evaluate the absorptive abilities of different colored materials--which are used to simulate varying heat absorbencies of differing Earth surfaces. Student instructions for this study are on page 8-10.

2. This exercise uses a constructivist approach. Following the brainstorming (engagement), you can either give the students the suggested materials for the lab, or let them generate a list of materials that will accomplish the required task. This will be the exploration phase, to be followed by explanation, elaboration, and evaluation.

3. The lab procedure for this study includes approaches for three levels of technology. The first uses computers with an interface box and temperature probes, the second uses TI-82 graphing calculators with CBL (calculator-based laboratory) temperature probes, the third uses laboratory thermometers. All three levels respond to the same goals--listed under (4.) Part A and Part B.

4. **Part A:**
Students design a lab simulation--based upon their understanding of albedo and its affect on the Earth's energy balance--that shows the varied heating that might take place on Earth due to color variances of the Earth's surfaces. These color variances would result in different albedoes which would impact global climate conditions. The simulation will utilize technology available to your classroom. Students will obtain your approval of their proposed procedure before running a simulation and producing graphs of the results.

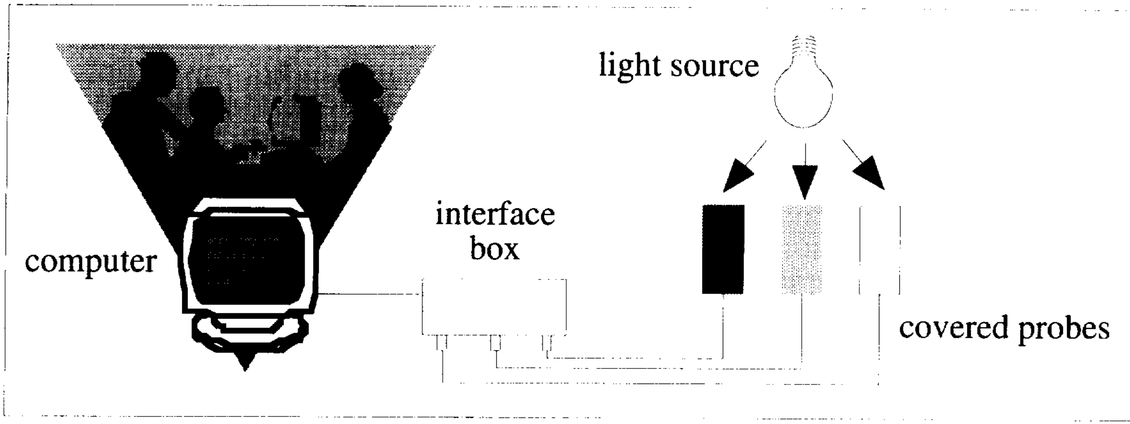
Possible student-designed response to (4.) Part A:
a. Students use 2-3 pieces of different colored papers and one piece of aluminum foil (to enhance reflectivity) to test varied heating of Earth's surfaces.
b. Place a light source above probes covered with the colored papers and foil.
c. Run the exercise for five minutes or other time agreed upon by the lab group.
d. Produce a graph of the data.

Part B:
a. Simulate a cloud covering that cuts reflectivity approximately in half.
b. Run the experiment as before.
c. Have the students generate a paragraph that compares and discusses how the simulated albedoes would impact the energy balance of the Earth. Students should use their Part A & Part B graphs to illustrate their comments.

Possible student-designed response for (4.) Part B:
a. Run the experiment again, this time incorporating partial cloud cover into your lab set-up. Decide as a group how to best accomplish this.
b. After running this second set-up, produce a graph of your data.
c. Compare and interpret the graphs from Part A & B--how do they illustrate possible albedoes of the Earth's surface?

5. **Procedure using computers with an interface box and temperature probes for Part A:**
a. Connect 3-4 temperature probes to an interface box which has been connected to a computer. The temperature probes should be lying horizontally on a counter top.
b. Cut pieces of colored construction paper to cover the temperature probes. Students should have 2-3 different colored pieces of paper and one aluminum foil cover (to enhance reflectivity).
c. Place a light source above the covered probes.
d. Run the exercise for five minutes or other time agreed upon by the lab group.
e. Produce a graph of the captured data using the computer program.

for Part B:
a. Simulate a cloud by suspending cheesecloth between two ring stands over part (approximately 50%) of the covered temperature probes
b. Run the experiment as before.
c. Have the students generate a paragraph that compares and discusses how the simulated albedoes would impact the energy balance of the Earth. Students should use their Part A & Part B graphs to illustrate their comments.



5. using computers with an interface box and probes

6. **Procedure using TI-82 graphing calculators**
TI-82 graphing calculators with Calculator Based Lab (CBL) temperature probes can be used instead of computer-based equipment. Print the TI-82 graph on a computer if possible. If not, have students manually generate graphs on graph paper.

7. **Procedure using laboratory thermometers.**
Use laboratory thermometers and graph paper.

8. Conduct a class discussion about the results of the lab exercise. Have students answer the following questions individually. Use the rubric on page 8 - 9 if desired.

   (a.) From Part A, which color of paper absorbed heat faster? Why?

   (b.) From Part A, did the colored paper absorb heat faster than the aluminum foil? Why/why not?

   (c.) From Part B, what effect did the "cloud" of cheesecloth have upon the colored paper surfaces and the aluminum foil? Relate this to the Earth's cloud cover and albedo.

   (d.) What do you think would have happened if the colored papers and aluminum foil had be crumpled? Explain your answer relative to Earth colors and surfaces.

9. Instead of or in addition to the above questions, a collective question might be asked, again using the rubric if desired.

Extension of this exercise:

To observe the differences in temperature resulting from albedo, students with access to weather satellite imagery can:

1. capture infrared weather images, and take temperature readings of different colored surfaces, and

   note: In infrared images, cloud surfaces will be much colder than land surfaces; light surfaces on both land and water will be colder than dark surfaces.

2. map temperature for the area in which they live and compare their findings to infrared satellite images.

Informative Rubric

	Proficient		Non-proficient	
	4	3	2	1
Development	Accurate, specific, and purposeful information is extended and expanded to fully explain the topic.	Accurate, specific, and purposeful information explains the topic with some extension of ideas.	Information is somewhat accurate but may be general or extraneous in the attempt to explain the topic.	Information is inadequate to explain the topic and is often inaccurate, general, or irrelevant.
Organization	The plan is logical, purposefully ordered, and uniquely enhances the understanding of the information.	The plan is usually logical, purposefully ordered, and facilitates the understanding of the information.	The plan is somewhat logical, but the order sometimes interferes with the understanding of the information.	The plan is illogical and confusing.
Audience:	The intended audience is consistently addressed.	The intended audience is usually addressed.	The intended audience is sometimes addressed.	The intended audience is not addressed.
Language	Word choice is appropriate, extensive, and creative.	Word choice is appropriate and varied. Minor errors in usage, grammar, and mechanics may be present but do not interfere with meaning. Spelling follows known patterns.	Word choice is adequate but errors in usage, grammar, mechanics, and spelling interfere with meaning.	Word choice is limited. Many errors in usage, grammar, mechanics, and spelling are present and interfere with meaning.
Oral Presentation	There are very few, if any, errors in usage, grammar, spelling, and mechanics.	Presentation skills are usually applied to adequately convey content.	The partial application of presentation skills may detract from the content.	The lack of presentation skills thoroughly detract from the content.

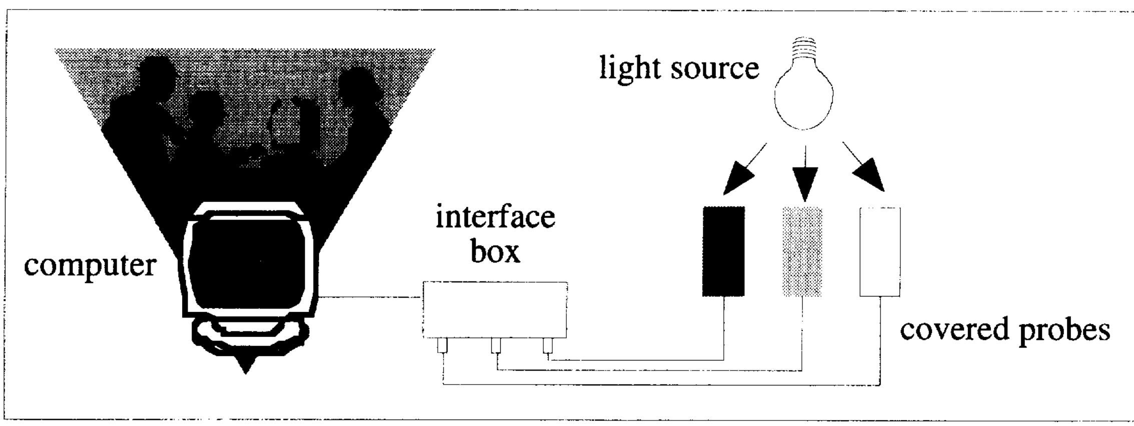
Procedure for albedo studies

Student Instructions

Part A: Based upon your understanding of albedo and its affect on the Earth's energy balance, design a lab simulation that will show the varied heating that might take place on Earth due to color variances of the Earth's surfaces. These color variances would result in differing albedoes, which would impact global climate conditions. Your simulation should utilize a computer, interface box, and associated temperature probes or alternate equipment. When your procedure is approved by your teacher, run the simulation and produce a graph of your data.

Part B: Run the experiment again, this time incorporating partial cloud cover into your lab set-up. Decide as a group how to best accomplish this. After running this second set-up, produce a graph of your data.

Compare and interpret the graphs from Part A & B--how do they illustrate possible albedoes of the Earth's surface?



using a computer with an interface box and probes

Questions:

Answer the following questions by yourself, following a group discussion about the results of the lab exercise.

1. From Part A, which color of paper absorbed heat faster? Why?

2. From Part A, did the colored paper absorb heat faster than the aluminum foil? Why/why not?

3. From Part B, what effect did the "cloud" of cheesecloth have upon the colored paper surfaces and the aluminum foil? Relate this to the Earth's cloud cover and albedo.

4. What do you think would have happened if the colored papers and aluminum foil had been crumpled? Explain your answer relative to Earth colors and surfaces.

Objective: Students will be able to determine the spectra of light sources with different intensities, and relate the spectra to the energies of each.

Background: One aspect of the energy balance--solar luminosity--is a function of the energy given off by the Sun and the Earth-Sun distance. To calculate the energy given off by the Sun, we must look at the electromagnetic spectrum. Waves which have a shorter wavelength, such as x-rays, give off higher amounts of energy. Waves which have a longer wavelength, such as infrared rays, give off lower amounts of energy.

The Sun is a black body--meaning it gives off energy at all wavelengths all the time. Using the Stefan-Boltzmann law, we can determine how much energy is given off by the Sun. The formula for this is:

$$E = \sigma T^4$$

E is the amount of energy released in W/m^2

T is the temperature of the Sun in Kelvins

σ is the Stefan-Boltzmann constant of $5.67 \times 10^{-8}\ W/m^2/K^4$.

Assuming that only a disc of the Sun is reaching the Earth's surface at one time, we can use the proportion $(r_o/r)2$ by the inverse square law. In this exercise, you will attempt to demonstrate the inverse square law and discover how the wavelength is a function of the energy released by an emitter.

Materials:
- compact fluorescent light source
- flashlight
- graph paper - 2 sheets (1 cm x 1 cm grid)
- incandescent light source
- meter stick
- pen or pencil
- spectroscope

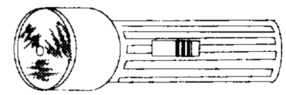
Procedure:

1. Turn on the incandescent light source. View the light source through the spectroscope. Record your observations of the wavelengths of this light source and the relative heat given off by the light bulb.

2. Turn off the incandescent light source, and turn on the compact fluorescent light source. Record your observations of the wavelengths of this light source and the relative heat given off of the light bulb. Turn off the compact fluorescent light source.

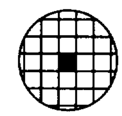
3. Answer conclusion questions 1-3.

4. Cut a circle from graph paper that will cover the surface of the flashlight. Cut out only one (1 cm x 1 cm) square closest to the center of the circle. Attach the circle to the flashlight.

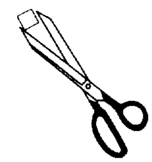


5. Attach an uncut piece of graph paper to the black construction paper.

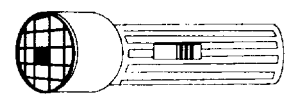
6. Position the paper at one end of the meter stick and the flashlight rim at a distance of 5 centimeters from the edge of the ruler. Turn the flashlight on and count the number of squares illuminated on the graph paper. Record your results.



7. Now move the rim of the flashlight to a distance of 10 centimeters from the edge of the meter stick. Count and record the number of grid squares illuminated.

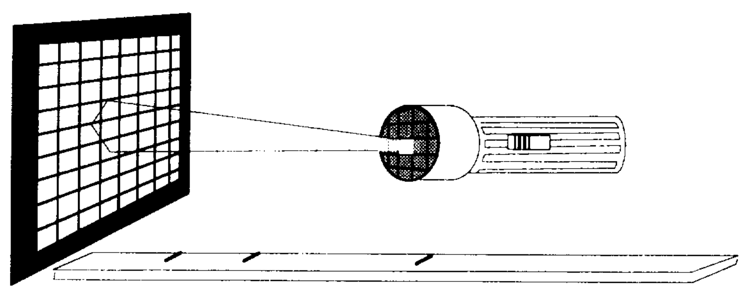


8. Finally, move the rim of the flashlight 20 centimeters away from the edge of the meter stick. Count and record the number of grid squares illuminated.



9. Graph the results as a function of distance between the flashlight and the graph paper, and the number of squares illuminated.

10. Answer conclusion questions 4-7.



Conclusion Questions:

1. What wavelengths of light did the incandescent light source give off? What wavelengths did the compact fluorescent light give off?

2. Which was hotter, the incandescent light or the compact fluorescent light?

3. What conclusion can you make between the amount of energy (heat) given off and the wavelength of the light?

4. How many squares on the graph were illuminated when the distance was 5 centimeters? 10 centimeters? 20 centimeters?

5. Refer to the graph of distance and illuminated squares. How many squares would be lit if the distance was 15 centimeters? 30 centimeters?

6. Extrapolate the graph to determine the number of lit squares if the distance were increased to 40 centimeters. Is this what you expected?

7. Based on your data, formulate a relationship between the distance of the objects and the amount of light received.

Activity 4: UV Absorption

Objective: To understand the effect of ultraviolet absorption.

Discussion: Various materials in the Earth's atmosphere and on the Earth's surface selectively absorb electromagnetic energy from the Sun. We can see this with visible wavelengths of light, but with non-visible wavelengths--such as ultraviolet--we need to "see" this indirectly.

Materials:
emery paper, fine grade - needed if glass sheets are used
glass or Plexiglas sheets, several small sheets (4" x 5")
minerals which will respond to ultraviolet light by fluorescing in various colors (available at science supply houses).
sunblock lotions of various ratings, commonly used for the beach.
ultraviolet lamp - can be obtained from science supply houses or use standard fluorescent fixtures (for 15" bulbs are good size) and black light bulbs (available at lighting or speciality party supply stores).

Procedure:

1. If glass sheets are used, use the emery paper to smooth edges.
2. Place a mineral that fluoresces on a table or stage.
3. Either have a student hold the UV lamp or construct a jig that will hold the lamp about a foot above the table or stage.
4. Coat a sheet of glass (or Plexiglas) with the sunblock lotion.
5. Turn on the UV lamp in a semi-darkened room so that the response of the mineral can be seen.
6. Place the sheet with the sunblock between the UV lamp and the mineral. Notice any changes in the response of the mineral. Sunblocks of various ratings can be tried. Discuss the selective absorption of the sunblocks.

Assessment:

1. What causes the fluorescent response of the mineral?
2. What happens to the response when the sheet with sunblock is placed in the light path?
3. What happens to the response when no sunblock is used?
4. What happens to human skin when it selectively absorbs ultraviolet radiation over time?

Activity 5: Colors

Objective: To understand that various surfaces reflect back specific energies (wavelengths) and absorb others. This is known as selective absorption.

Discussion: The various energies (wavelengths) of the electromagnetic spectrum have different responses (absorption or reflection) to different surfaces. This can be seen in the visible part of the spectrum but also takes place in the non-visible portion. This affects the temperature of the Earth and can be understood through the Energy Balance Equation.

Materials:

- colored shirts (the shirts students are wearing will work nicely)
- construction paper in each of the colors of the rainbow plus black and white
- pieces of colored, translucent plastic (the type used to make clipboards which have fluorescent pigment impregnated work well; fluorescent yellow, magenta, and light green all work very well). Be sure to use colors which when viewed from the side, appear intensely brighter--as if there were a light within the plastic.
- images of the Earth from space, available via the Internet or without charge from NASA

Procedure:

1. Place the sheets of colored construction paper side by side. Ask students why each looks a different color. Work to an understanding of the selective absorption of all the colors except the color being perceived.
2. Develop the same understanding of the pigment in the dyes used in clothing (refer to the shirts students are wearing as examples).
3. Continue with the sheets of colored plastic. Again ask questions which lead to understanding the selective absorption of the pigment in the plastic.
4. View the images of the Earth from space. Discuss why, due to selective absorption, the different surfaces on Earth appear the way they do.

Assessment:

1. From your observations, explain what is happening in the visible part of the spectrum to the sheets of paper, clothing, colored plastic, and surfaces of Earth seen in the images from space.
2. What do you think happens to the colors (energies or wavelengths) not seen on the various papers, clothing, plastic, and surfaces of the Earth?

Teacher Note: In the case of the transparent/translucent plastic - certain energies are allowed to pass through rather than be absorbed, except the color being reradiated, as happens with Earth's atmosphere.

3. Discuss the nature of the energies arising from the surfaces of Earth which are selectively absorbed.

Going Further:

See the activity on pages 8-23 and 8-24 for a demonstration of the emissive properties of certain materials in the visible spectrum when illuminated with ultraviolet light.

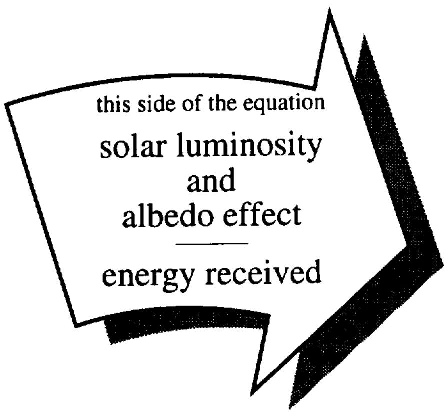
Activity 6: Energy Balance Equation

Objective: To use knowledge of Stefan-Boltzmann Law and constant, and the Inverse Square Law to manipulate the energy balance equation.

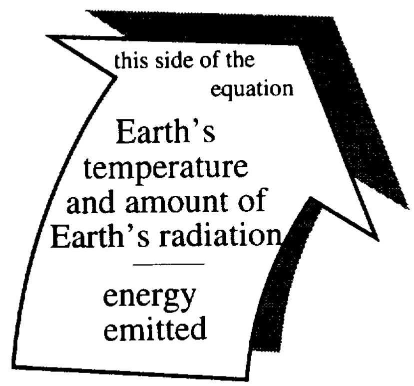
Prerequisite Skills: Knowledge of Stefan-Boltzmann Law, Stefan-Boltzmann constant, the Inverse Square Law, and the energy balance equation.

Background: We know that the Earth constantly receives tremendous amounts of solar energy. In spite of that fact, the Earth maintains a fairly consistent average temperature. To achieve this equilibrium, the Earth must be emitting as much energy as it receives from the Sun. This heat balance can be described by the

primitive energy balance equation:



$$\frac{S}{4}(1-A) = \sigma T_e^4$$



T_e^4	is the temperature of Earth in Kelvins
S	is solar luminosity = 1370 Watts per m^2
σ	is the Stefan-Boltzmann constant (5.67×10^{-8} $W/m^2/K^4$)
A	is the average albedo for Earth (0.3)

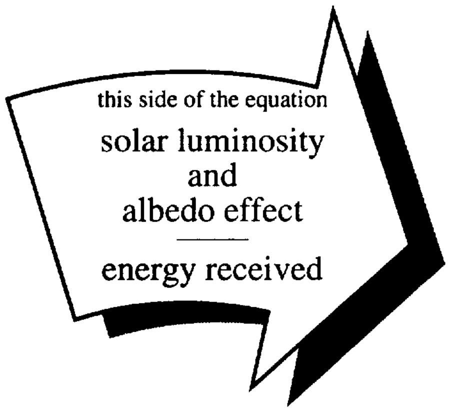
Materials: scientific calculator
answers for exercises 1 through 4 on page 8-17 and 8-18.

Exercise 1: A key factor in the energy balance equation is missing. Prove that something is missing and how you know your proof is correct. (hint - the average temperature of Earth is 288K.)

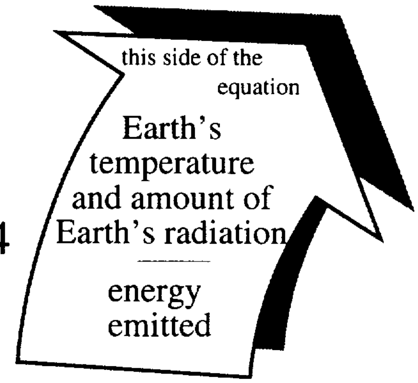
We know that the primitive energy balance equation does have something missing. This *something* is the greenhouse effect. The greenhouse effect is included in the improved energy balance equation and is represented by the letter *j*.

Exercise 2: Calculate the value for *j* using the primitive energy balance equation. Show ALL work.

The improved energy balance equation can now be written as:



$$\frac{S}{4}(1-A) = j\sigma Te^4$$



T_e^4	is the temperature of Earth in Kelvins
S	is solar luminosity = 1370 Watts per m^2
σ	is the Stefan-Boltzmann constant (5.67 X 10^{-8} $W/m^2/K^4$)
A	is the average albedo for Earth (0.3)
j	is the greenhouse effect

Exercise 3: Use the improved energy balance equation to make a list of factors which might influence climate change. Don't forget factors that will produce colder--as well as warmer--climates. Describe how each of these factors would influence climate change.

Exercise 4: Use the improved energy balance equation to calculate the temperature of our planet if the following occurred:

a. the Earth-Sun distance doubled (remember the inverse square law)
b. the Earth-Sun distance halved (remember the inverse square law)
c. solar luminosity decreased by 1 %
d. solar luminosity increased by 1 %
e. the greenhouse effect was doubled (be careful with the number you choose)

Be sure to show ALL work for each of the problems

Exercise 5: Summarize in your own words, exactly what the greenhouse effect is and how it affects the temperature of the Earth.

Answers for the exercises on page 8-15 and 8-16

Exercise 1

$$\frac{S}{4}(1-A) = \sigma Te^4$$

Figure out both sides of the equation

$$\frac{1370}{4}(1 - 0.3) = (5.67 \times 10^{-8})(288^4)$$

$$342.5\,(0.7) = (5.67 \times 10^{-8})(6.879 \times 10^9)$$

Because the sides of the equation are not equal, something must be missing

$$239.75 \neq 390.04$$

Exercise 2

$$\frac{S}{4}(1-A) = j\sigma\, Te^4$$

solve for j

$$\frac{1370}{4}(1 - 0.3) = j\,(5.67 \times 10^{-8})(288^4)$$

$$342.5\,(0.7) = j\,(5.67 \times 10^{-8})(6.879 \times 10^9)$$

$$\frac{239.75}{390.04} = j\,\frac{390.04}{390.04}$$

$$j = 0.615$$

Exercise 3

Some answers may include:

- changes in Earth - Sun distance
- solar luminosity changes
- albedo changes
- changes in amounts of greenhouse gases

Exercise 4 - a

If the Earth - Sun distance doubled, the "s" term would be 1/4 the amount

$$\frac{1370/4}{4}(1 - 0.3) = 0.615\,(5.67 \times 10^{-8})(Te^4)$$

$$85.63\,(0.7) = 3.487 \times 10^{-8}\,(Te^4)$$

$$Te^4 = 1.719 \times 10^9$$

$$Te = 203.62\ K$$

Exercise 4 - b

If the Earth - Sun distance were halved, the "s" term would be increased by 4 times

$$\frac{1370\ (4)}{4}\ (1 - 0.3) = 0.615\ (5.67 \times 10^{-8})\ (Te^4)$$

$$1370\ (0.7) = 3.487 \times 10^{-8}\ (Te^4)$$

$$Te^4 = 2.750 \times 10^{10}$$

$$Te = 407.23\ K$$

Exercise 4 - c

If solar luminosity decreased by 1%, the "s" term would become 1356.3

$$\frac{1356.3}{4}\ (1 - 0.3) = 0.615\ (5.67 \times 10^{-8})\ (Te^4)$$

$$339.08\ (0.7) = 3.487 \times 10^{-8}\ (Te^4)$$

$$Te^4 = 6.807 \times 10^9$$

$$Te = 287.23\ K$$

Exercise 4 - d

If solar luminosity increased by 1%, the "s" term would become 1383.7

$$\frac{1383.7}{4}\ (1 - 0.3) = 0.615\ (5.67 \times 10^{-8})\ (Te^4)$$

$$345.9\ (0.7) = 3.487 \times 10^{-8}\ (Te^4)$$

$$Te^4 = 6.944 \times 10^9$$

$$Te = 288.67\ K$$

Exercise 4 - e

If the greenhouse effect was doubled, the "j" term would be halved.*

$$\frac{1370}{4}\ (1 - 0.3) = 0.3075\ (5.67 \times 10^{-8})\ (Te^4)$$

$$342.5\ (0.7) = 1.744 \times 10^{-8}\ (Te^4)$$

$$Te^4 = 1.375 \times 10^{10}$$

$$Te = 342.4\ K$$

* Because the "j" term is on the side of the equation which represents energy emitted, the stronger the greenhouse effect, the less energy is emitted.

Activity 7: Filters

Objective: To understand the effect that filtering materials have upon the transmission of electromagnetic radiation.

Discussion: As electromagnetic radiation passes through the atmosphere and strikes the Earth's surface, it encounters materials which selectively absorb various energies (wavelengths). Scientists can model the energy balance equation with reasonable accuracy because of this understanding.

Materials:

black construction paper

colored gels (5 cm by 15 cm), a red gel and either or both green and blue gels, obtain from stationery or art supply store

large (4" x 4") holographic diffraction grating mounted in a clear plastic photo display unit with a foot (curved to form a base for the display unit to rest upon). A standard transmission grating will not work as well.

overhead projector

Sources for holographic diffraction gratings:

Arbor Scientific
P.O. Box 2750
Ann Arbor, MI 48106-2750
Phone: 1-800-367-6695

Flinn Scientific
P.O. Box 219
131 Flinn Street
Batavia, IL 60510
Phone: 1-800-452-1261

Learning Technologies, Inc.
59 Walden Street
Cambridge, MA 02140
Phone: 1-800-537-8703

Procedure:

1. Cut the black construction paper into two pieces and use it to cover all of the stage on the overhead projector except for a narrow slot of light about 1 cm wide. Larger overhead projectors may require additional paper. Locate the projector quite close to the screen to accommodate the spectra in step 3.

2. Place the diffraction grating in the plastic photo display unit upside down and hang it from the top of the lens housing for the overhead projector. This allows you to walk around while keeping the diffraction grating in place.

   NOTE: you may simply tape the diffraction grating to the top of the lens housing instead of using the photo holder.

3. With the spectra on the screen, alternately place the red, blue and/or green gels across the bottom half of the narrow slot. The non-filtered spectra should be visible above as a reference with the filtered spectra below. Discuss the selective absorption of the gels on the spectra.

Assessment:

1. What colors are absorbed by the red filter? How much of each of the colors of the continuous spectrum are absorbed?

2. What colors are absorbed by the blue filter? How much of each of the colors of the continuous spectrum are absorbed?

3. What colors are absorbed by the green filter? How much of each of the colors of the continuous spectrum are absorbed?

4. Compare the absorption of the red with the green and blue. How is the red different?

5. How does this comparison of the different filters relate to different surfaces and materials found on the Earth?

Going Further:

See the activity book "Color Analyzer" available from:

GEMS
Lawrence Hall of Science
University of California
Berkeley, California 94720
Phone: 510-642-7771

Objective: To graph and analyze raw data for concentrations of four greenhouse gases in our atmosphere.

Materials: graph paper
pen/pencil or graphing program on a computer
data on page 8-22

Procedure:

1. Plot the data set for each of the greenhouse gases as a function of time versus concentration. Time should be on the horizontal (x) axis. Concentration should be on the vertical (y) axis.

2. Answer the conclusion questions.

Conclusion Questions:

1. In what year did the CFCs reach their maximum concentration? Why do you think that it occurred in this year?

2. What is the difference in parts per billion by volume (ppbv) between the concentrations of nitrous oxide in the years 1960-1970? For 1980-1990?

3. What is the slope of the line of carbon dioxide concentrations? What does this slope represent?

4. What is the difference in concentrations of methane between 1850-1990?

5. Explain the importance of ozone in our atmosphere.

6. What types of chemicals destroy the ozone layer?

7. What is the greenhouse effect? How does it work?

8. Where are the two largest holes (depleted areas) located in the ozone layer? What negative effects will this have on Earth's organisms, present day sea level, and weather patterns?

9. What, in your opinion, do you think will happen to the *j* factor in the improved energy balance equation? What ultimate effect will this have on the energy balance of the Earth?

Carbon Dioxide Concentrations
Mauna Loa, Hawaii

Year	ppmv	Year	ppmv
1958	314.8	1974	330.4
1959	316.1	1975	331.0
1960	317.0	1976	332.1
1961	317.7	1977	333.6
1962	318.6	1978	335.2
1963	319.1	1979	336.5
1964	319.4	1980	338.4
1965	320.4	1981	339.5
1966	321.1	1982	340.8
1967	322.0	1983	342.8
1968	322.8	1984	344.3
1969	324.2	1985	345.7
1970	325.5	1986	346.9
1971	326.5	1987	348.6
1972	327.6	1988	351.2
1973	329.8		

Methane Gas Concentration

Year	ppm	Year	ppm
1850	0.09	1975	1.45
1879	0.93	1976	1.47
1880	0.90	1977	1.50
1892	0.88	1978	1.52
1908	1.00	1979	1.55
1917	1.00	1980	1.56
1918	1.02	1981	1.58
1927	1.03	1982	1.60
1929	1.13	1983	1.60
1940	1.12	1984	1.61
1949	1.18	1985	1.62
1950	1.20	1986	1.63
1955	1.26	1987	1.65
1956	1.30	1988	1.67
1957	1.34	1989	1.69
1958	1.35	1990	1.72

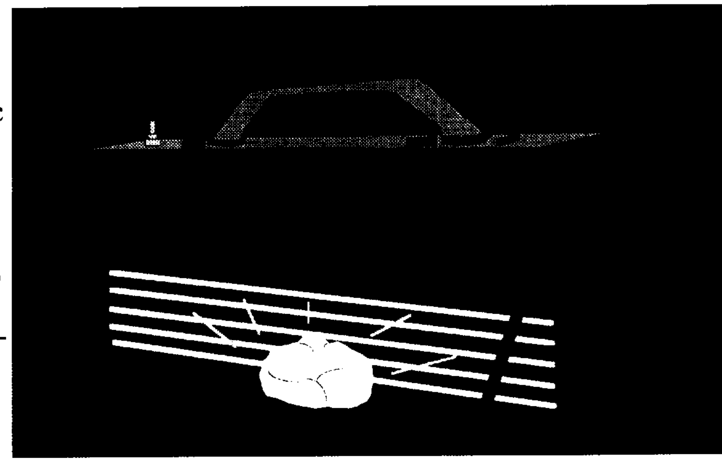
Chlorofluorocarbon (CFC) Production
in kilotons per year

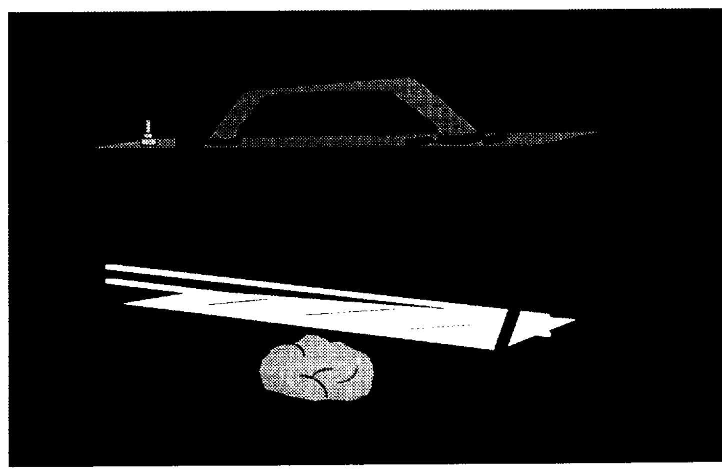
Year	Amount	Year	Amount
1955	100	1975	350
1957	120	1977	360
1959	140	1979	330
1961	150	1981	325
1963	150	1983	320
1965	200	1985	340
1967	225	1987	300
1969	290	1989	305
1971	320	1991	310
1973	375		

Nitrous Oxide Concentration

Year	ppbv	Year	ppbv
1750	283.0	1880	289.5
1760	283.5	1890	290.0
1770	284.0	1900	291.0
1780	284.5	1910	292.0
1790	285.0	1920	292.5
1800	285.5	1930	293.0
1810	286.0	1940	294.0
1820	286.5	1950	295.0
1830	287.0	1960	297.0
1840	287.5	1970	299.0
1850	288.0	1980	305.0
1860	288.5	1990	310.0
1870	289.0		

Ultraviolet Absorption





Description: A piece of glass or clear plastic blocks shortwave ultraviolet light.

Objective: To show that the atmosphere is transparent to low-energy ultraviolet light but not to high-energy ultraviolet light.

Materials: Ultraviolet light (black light) - broad spectrum (may be available from high school science laboratory or rock and mineral collector)

Fluorescent mineral (see note in the discussion section.)

Window glass or clear plastic

Dark room

Procedure:

1. Darken the room and turn on the ultraviolet (UV) light. (See **Caution** at the end of discussion section.) Direct the UV light's beam onto the fluorescent minerals. Observe the color of the emitted light.
2. Place glass between the light and the mineral and again observe the emitted light.

Discussion:

Certain minerals and a variety of other substances fluoresce or emit visible light when illuminated by ultraviolet light. Fluorescence is a process that exchanges ultraviolet-light energy for visible-light energy. Photons of ultraviolet light are captured by electrons orbiting the nuclei of atoms within those materials. The electrons, gaining energy, are boosted to excited energy states. The electrons eventually release this captured energy as visible light as they return to lower energy states.

Low-energy ultraviolet light -- sometimes called long-wave UV -- penetrates to Earth's surface. This low-energy ultraviolet light cause Day-Glo paints to give off spectacular colors and white clothing to glow brightly when washed in detergents that contain fluorescent dyes (advertised as making clothes "whiter than white"). Most of the high-energy ultraviolet light -- sometimes called short-wave UV -- is blocked by the ozone layer in Earth's upper atmosphere. High energy ultraviolet light causes skin tanning. Extended exposure can lead to eye damage and skin cancer in light-skinned people. Skin cancer is rare in dark-skinned people.

Although transparent to lower-energy ultraviolet light, glass blocks higher-energy ultraviolet light. Lotions that are advertised as Sun blockers also block higher energy ultraviolet light. When the glass is inserted between the lamp and the fluorescing material in this demonstration, the fluorescence diminishes or stops. Some materials fluoresce with lower energy ultraviolet waves as well as the higher energy waves, and any continued fluorescence is the result of lower energy waves.

Ultraviolet light tells astronomers several things. For example, the local neighborhood of our Sun -- within 50 light years -- contains many thousands of low-mass stars that glow in the ultraviolet. When low-mass stars use up all their fuel, they begin to cool. Over billions of years, the internal heat left over from stellar fusion reactions radiates into space. This leftover heat contains a great deal of energy. These stars, called *white dwarfs*, radiate mostly ultraviolet light. Until astronomers could make observations with ultraviolet telescopes in space, they had very little information about this phase of a star's evolution.

Caution: Do not look into the light emitted by the broad spectrum ultraviolet lamp.

Avoid directing the light to reflective surfaces. Everyone should wear eye protection such as laboratory safety glasses or ordinary eye glasses.

Where to Obtain Ultraviolet Lights and Minerals:

Many science-supply catalogs sell ultraviolet lights and fluorescent minerals. If you purchase a light, be sure to obtain a broad spectrum light because it will emit both long and short wave ultraviolet light. Order minerals, such as calcite, fluorite, and franklinite, that fluoresce at short wavelengths, long wavelengths, and both long and short wavelengths. If you do not wish to purchase a lamp and minerals, check with other schools to see if they have equipment you can borrow. Also check with local rock and mineral clubs. Many collectors have lights and fluorescent minerals and may be willing to come to your school to give a demonstration. If ultraviolet minerals are not available, experiment with ultraviolet-sensitive paints or paper.

For Further Research:

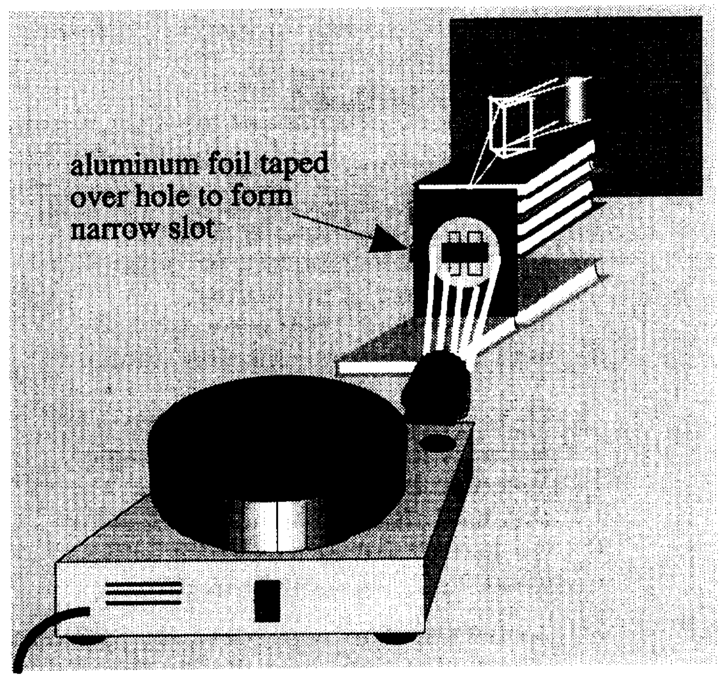
- Check recent magazine articles about problems with Earth's ozone layer and ultraviolet radiation at Earth's surface. Learn what can be done to help protect Earth's ozone layer.

- Take a field trip to a science museum that has displays of fluorescent minerals or arrange for a rock and mineral collector to bring a fluorescent mineral display to your school.

This activity (pages 8-23 and 8-24) is reprinted from the NASA publication, Space Based Astronomy, which is available on line at:

<http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Materials/Sciences/Astronomy/Space.Astronomy.Teachers.Guide.5-8/Space.Astronomy.Teacher.Guide. Part.2.pdf>

Projecting Spectra



Description: Two methods for projecting the visible spectrum are explained.

Objective: To study the range of colors in the visible spectrum.

Materials:

Method 1-
- slide projector
- opaque screen (See instructions)
- glass prism
- several books
- projection screen

Method 2-
- overhead projector
- holographic diffraction grating (sources on page 8-27)
- opaque screen (see instructions)
- several books
- tape
- projection screen

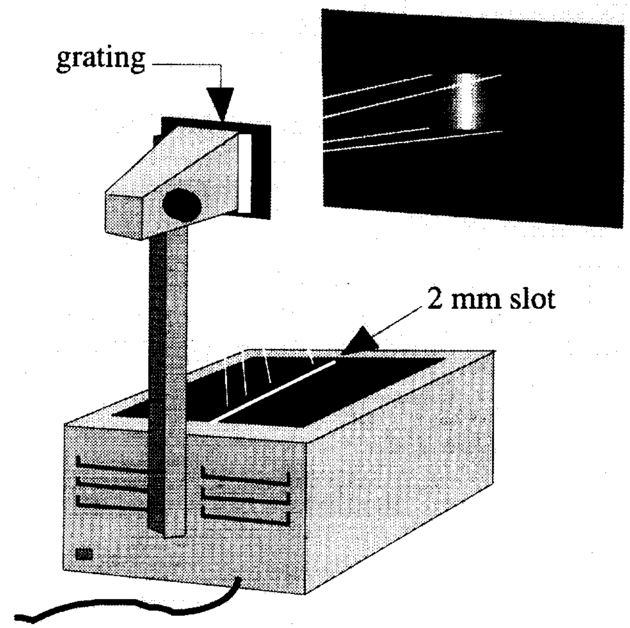
Procedure: Method 1

1. Make an opaque screen approximately 25 cm square from a piece of cardboard, poster board, or wood. Cut a 5 cm-diameter hole out of the middle. Tape two pieces of opaque paper or aluminum foil over the hole so that there is a vertical gap between them no wider than 1 mm. Stand the screen upright between two books.

2. Arrange the slide projector, opaque screen, prism, and projection screen as shown in the diagram. Darken the room. Aim the projector's beam at the slot in the opaque screen and adjust the projector so that the light does not extend around the edges of the opaque screen.

3. Slowly rotate the prism until the narrow slot of light disperses the visible spectrum. Depending upon the exact alignment, the spectrum may fall on a wall rather than a screen. Adjust the setup so that the spectrum is displayed on the projection screen.

Procedure: Method 2



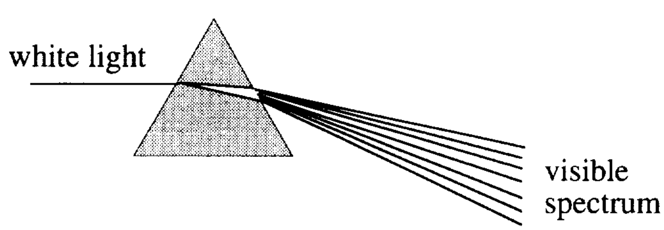
1. For this method, you must obtain a piece of holographic diffraction grating -- a grating produced by accurate holographic techniques. See page 8-27 for the source of the grating.
   Note: Method 2 will not work well with a standard transmission grating.

2. Make an opaque screen from two pieces of dark paper or other opaque material. Place the pieces on the overhead projector stage so that there is a narrow slot no wider than 2 mm where light can come through.

3. Darken the room and turn on the projector. Using tape, hang a piece of holographic diffraction grating over the upper lens of the projector. Before taping, rotate the grating until the best spectra is displayed. Two brilliant visible spectra appear on opposite sides of a line running from the projector perpendicular to the screen. The size of the display can be changed by moving the projector closer or farther away from the screen. Refer to the Analytical Spectroscope activity for more information on how the diffraction grating works.

Discussion:

Visible light, passing through a prism at a suitable angle, is dispersed into its component colors. This happens because of *refraction*. When visible light waves cross an interface between two media of different densities (such as from air into glass) at an angle other than 90 degrees, the light waves are bent (refracted). Different wavelengths of visible light are bent different amounts and this causes them to be dispersed into a continuum of colors. (See diagram)



Diffraction gratings also disperse light. There are two main kinds of gratings. One transmits light directly. The other is a mirror-like reflection grating. In either case, diffraction gratings have thousands of tiny lines cut into their surfaces. In both kinds of gratings, the visible colors are created by constructive and deconstructive interference. Additional information on how diffraction gratings work is found in the Analytical Spectroscope activity and in many physics and physical science textbooks.

For Further Research:

- Use crayons or colored pencils to sketch the spectra displayed by either projection method. What colors are visible?

- Who discovered the visible spectrum? How many colors did the scientist see?

- A compact audio disk acts like a reflection diffraction grating. Darken the room and shine a strong beam of white light from a flashlight on the disk. The beam will be dispersed by the grating and be visible on the wall.

Sources:

Holographic diffraction gratings are available from:

Arbor Scientific
PO Box 2750
Ann Arbor, MI 48106-2750
Phone: 1-800-367-6695

Flinn Scientific
PO box 219
131 Flinn Street
Batavia, IL 60510
Phone: 1-800-452-1261

Learning Technologies, Inc.
59 Walden Street
Cambridge, MA 02140
Phone: 1-800-537-8703

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<http://spacelink.nasa.gov/Instructional.Materials/Curriculum.Materials/Sciences/Astronomy/Space.Astronomy.Teachers.Guide.5-8/Space.Astronomy.Teacher.Guide. Part.2.pdf>