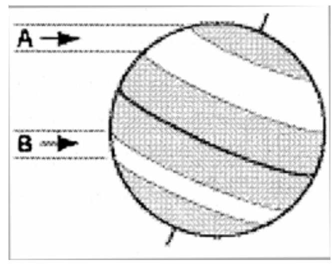
LAB 5-1
SOLAR INSOLATION
AND HEAT TRANSFER IN THE EARTH
"It's A Small World After All"

PURPOSE AND BACKGROUND

This lab will help you understand and also addresses some of the misconceptions about seasons, and climate. The fallacy held by many graduates and faculty from Harvard University is seen during the first 3:15 minutes of the video "A private Universe". These highly educated individuals' misconception about seasons is that summer occurs when the Earth is closer to the Sun, and vice versa for winter.

The seasons occur because of differences in the intensity of sunlight on various places due to the earth's 23.5^{o} tilt. As seen in the figure to the right, the sun's rays are nearly parallel as they reach the Earth. The same amount of energy is found in each of the groups A and B, as Each pair of lines are the same distance apart. Both groups start at the same latitude above and below the equator. Due to the tilt of the Earth, the are covered by group A is greater than B. Therefore, the amount of energy per unit area is smaller for group A. The northern hemisphere is therefore cooler and experiencing winter.



A location's climate is affected not only by its distance from the equator, but also by its relationship of bodies of water. London, England and the southern tip of Hudson Bay are both at approximately 51^{o} north. However, London has a much milder climate as England is surrounded by the Atlantic Ocean and the North Sea while Hudson Bay is landlocked in the middle of Canada. Due to a higher specific heat capacity the oceans do not change temperature as fast giving England a milder climate. However, simply being near a body of water does not guarantee a mild climate. San Diego, California and Savannah, Georgia are both situated on a cost both at about 31^{o} North. San Diego's climate is dry while Savannah's is humid die to the temperature of their ocean currents. The currents off southern California are cold while the Gulf Stream off Georgia is one of the warmest. The temperature of the current affects the level of evaporation, leading to the differences in humidity.

The purpose of this lab is to investigate how heat transfer and insolation of the Earth affects temperature ranges in a particular area and around the globe. The objective is also to understand how the angle of incident light on the surface of the Earth and the specific heat capacity of an abiotic material affects the heating and cooling of the surrounding ecosystem.

This lab has been divided into two parts. The first part will focus on the affects of the angle of incidence on the intensity or energy of the light on a surface. The second part will extend this concept while investigating how different materials absorb and emit energy.

MATERIALS (For a group of 4.)

Electronic balance
15-cm rulers
Masking tape
6 straws
Protractor
Flashlight (2-D batteries)
2 sheets of paper
Scissors
Aluminum foil
3 x 250-mL beakers
ring stands
ring-stand clamps
stopwatch
1-m of string
5 x 6" (short) thermometer
moist soil (200-mL)
sand (200-mL)
water
heat lamp with clamps

OPTIONAL EQUIPMENT

LabQuest (temperature probe, light sensor, and data logger software)

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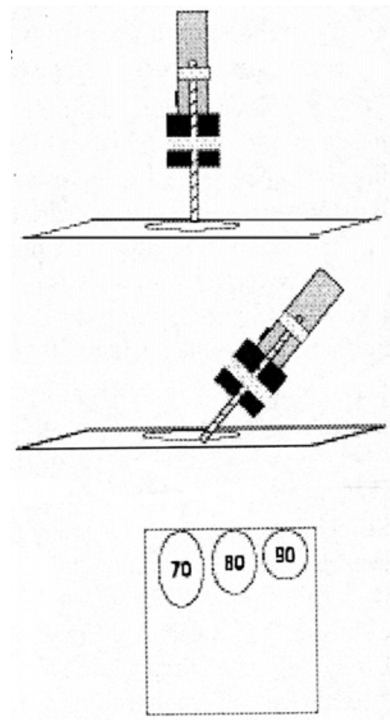
PROCEDURE

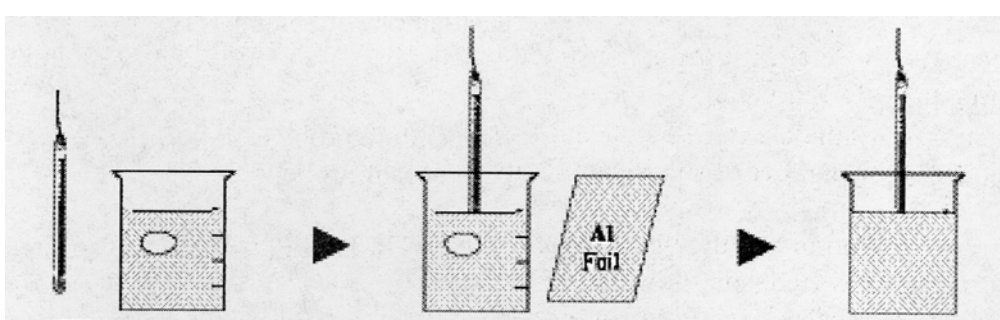
Part A – Insolation



1. Cut out and find the mass of a 10-cm x 10-cm piece of paper. This mass will be used to calculate the areas of the "ellipses" of light. Put this answer on line #1 under Evaluation.
2. Tape a straw to a flashlight such that 8 cm extends beyond the end of the flashlight.
3. Place another sheet of paper on the lab bench.
4. Turn on the flashlight and then shut off all the lights in the room.
5. Position the flashlight so that the straw touches the upper right hand corner of the paper at a 90^{o} angle to the paper. Use a protractor to measure the angle.
6. Use a pencil to trace the circumference of the brightness portion of the circle or ellipse. Label this ellipse as 90. Optional- Place the LabQuest Light Sensor from in the center of the ellipse of light to determine light intensity or illuminance (lux) for each angle.
7. Repeat at eight more locations on the paper using the angles listed in Table 1. Properly title the table.
8. Measure the long axis (L) and average short axis (S) of each ellipse and convert answer to meters. Put the data in column C and D, respectively, in Table 1.
9. Cut out each ellipse and determine the mass of each. Put answer in column A of Table 1.

Part B – Insolation and Specific Heat Capacity

1. Fill each of the 250-mL beakers to the 200-mL mark with water, sand, or soil. Optional- Use LabQuest temperature probe instead of thermometers.
2. Insert a thermometer into the soil and one into the sand such that each bulb is just below the surface – approximately 1-cm.
3. For the water thermometer, tie a string to the upper end of the thermometer. Attach the string to the end of a clamp. Cover the string with aluminum foil so it will not burn when the heat lamp is turned on.
4. Attach the clamp to the ring stand. Lower the clamp so the thermometer is just below the surface of the water – approximately 1-cm.



5. Use a sheet of aluminum foil to cover each of the beakers to just below the 200-mL line.
6. Clamp the heat lamp to the ring stand, but do not turn it on yet.
7. Move each beaker and/or heat lamp so that each beaker's 200-mL mark is 20 cm below the heat lamp.

8. Record the initial temperature of each substance in Table 2 under Time = 0.
9. Turn on the heat lamp and record the temperature in Table 2 for each of beaker every minute until 10 minutes has elapsed.
10. Turn off the heat lamp and record the temperature in Table 3 for each beaker every minute until another 10 minutes has elapsed (minutes 11 – 20).
11. Dump the sand and soil on the "used" trays and the water down the drain.
12. Repeat steps 1, 2, 3, and 4.
13. Repeat steps 7 – 10 at an angle such that the heat lamp is still 20 cm from the 200 mL level of each beaker. Your will be assigned the angles needed.
14. Place your results in Tables 4 and 5.

EVALUATION

Part A

1. Mass of the 10-cm x 10-cm piece of paper = ___________________ g.
2. The 10-cm x 10-cm paper is equal to how many m^2 of paper? _________________m^2.
   Note: $m^2 = (100\text{-cm})^2$
3. Determine the mass per m^2 for the paper = ________________ g/m^2
4. Find the area of each ellipse by dividing the mass by the answer in #3 above. Do two of the conversions below making sure to show units to verify that this will give an answer in m^2. Put your answers in Column B of Table 1.

   <u>90^o</u>   <u>80^o</u>

5. Mathematically determine the area using the formula Area = (π x L x S)/4. Put your answers in Table 1, column E.
6. Compare the Math determined area and Mass determined area. Which is more accurate? Think about the number of significant digits from your measurements.

   ____
7. Make an assumption that the light emitted from the heat lamp has a power of 100-Watts at the surface of the sand, soil, or water. Find the Energy per Area by dividing the 100 Watts by the area of each ellipse. Put your answers in Table 1, column F.
8. Fill in the illuminance in lux in the column G if using LabQuest light sensor.

Table 1. ____

Angle	A	B	C	D	E	F	G
	Mass (g)	Mass Determined Area (m^2)	Long Axis (L)	Short Axis (S)	Math Determined Area (m^2)	Energy Area (Watts/m^2)	Illuminance (lux)

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9. Graph the Angle (x-axis) vs. the Energy / Area (y-axis) including a title, labels, and legend.
10. Which value is the independent value and is the dependent value? Explain.
11. Optional – Put light intensity or illuminance (lux) as a second y-axis on the right side of the chart and graph the data. How do the two lines compare?

12. Describe what happens to the light intensity as the angle increases.
13. What effect does this have on the heating at different latitudes of the Earth?
14. Describe how this affects the temperature going from the equator to the poles.
15. Why would this lead to the flow of air (or winds)?

Part B

Light Source Directly Above Surface

Table 2 – Heating: Record Temperature in Degrees Celsius

	Time (minutes)										
Beaker	0	1	2	3	4	5	6	7	8	9	10
Sand											
Water											
Soil											

Table 3 – Cooling: Record Temperature in Degrees Celsius

	Time (minutes)										
Beaker	11	12	13	14	15	16	17	18	19	20	
Sand											
Water											
Soil											

1. If the tips of the thermometers are inserted too deep into the soil, sand, or water, the temperature changes will not be noticed immediately. Why?
2. Why was the aluminum foil used to cover the sides of the beakers?
3. Which substance heated up fastest? Which heated up the slowest?

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4. In Table 2 and 3, is temperature or time the independent variable? Explain.
5. Remembering that the independent variable goes on the x-axis, graph the results from Table 2 and 3 on Graph 2 making sure to include a title, labels, and legend (Hint: Use different colors for sand, water, and soil).

Graph 2 ____

6. Calculate the average slope ($\Delta y/\Delta x$) for heating of each substance in ^{o}C per minute (minutes 0 – 10).

Sand	Soil	Water

7. Calculate the average slope ($\Delta y/\Delta x$) for cooling of each substance in ^{o}C per minute (minutes 11 – 20).

Sand	Soil	Water

8. Which substance cooled off the fastest? Which cooled off the slowest?

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9. Calculate the energy required to heat a substance: The specific heat capacity of a material is the amount of heat (in Joules) required to raise the temperature of a one-gram mass by 1°C. The formula is:

Heat Energy (q) = Mass (m) x Specific Heat (c_s) x Change in Temperature (ΔT)

Or

$$q = mc_s\Delta T$$

Calculate the amount of energy (in Joules) needed to heat 1 gram of each of the following substances by 10°C.

Sand (SiO_2)
C_s = 0.739J/(g°C)

Water (H_2O)
c_s = 4.186J/(g°C)

10. Which substance requires more energy to heat to the same temperature? Why?
11. What affect does specific heat capacity have on cooling? Explain.
12. Does the specific heat capacity agree with your data? Explain.
13. If typical room air has a specific heat capacity of 1.012J/(g°C), predict where its line would be on the graph.
14. From what you have learned, explain why is it generally cooler near the ocean during the day?
15. Why is it generally warmer inland during the day?
16. What direction would the winds blow during the day? Why?
17. Would coastal areas stay warmer or colder than deserts at night? Why?
18. What direction would winds blow at night? Why?
19. What would happen to the temperature of the sand if it were black?
20. How would the surface temperature be influenced if there were cloud cover during the day? Or the night?

Light Source at Angle to Surface

Table 4 – Heating: Record Temperature in Degrees Celsius

	Time (minutes)										
Beaker	0	1	2	3	4	5	6	7	8	9	10
Sand											
Water											
Soil											

Table 5 – Cooling: Record Temperature in Degrees Celsius

	Time (minutes)										
Beaker	0	1	2	3	4	5	6	7	8	9	10
Sand											
Water											
Soil											

21. Go back to Graph 2 and include the data from Table 4 and 5 making the lines the same color but dashed instead of solid.
22. How did the temperature change for each material compared to the previous data on the graph?
23. What does being at an angle differ from the vertical have on the heating of the Earth?
24. Would the time of day have an affect on the heating of the Earth?
25. London, England and the southern tip of Hudson Bay are both at approximately 51° north. Why does London have a much milder climate than the Hudson Bay, Canada?
26. Climate is even more complicated. San Diego, California and Savannah, Georgia are both situated on a cost at approximately 31° north. Why is San Diego dry while Savannah humid?

27. What additional fact(s) are needed to fully explain the seasons? Draw a picture to help explain your answer
28. In what manner is the data collected in this lab represent an inaccurate model of the Earth? What are some modifications to the lab that would make it a better model?
29. How would you modify the lab to increase the accuracy?
30. Discuss some of the errors of the lab.