# Lake Ice and Conductive Heat Flow

**Levels V-VI**

**Grades 9-12**

## Overview:

Students will use lab data collected in a previous lesson to determine the thermal conductivity of snow and mean conductive heat flow.

## Objectives:

The student will:

- convert, select, and use formulas to compute data; and
- use all the data previously collected and measured to determine mean conductive heat flow of the snow in their area at the time it was collected.

## Materials:

- Calculator
- STUDENT WORKSHEET: "The Science of Snow" completed in an earlier lesson
- STUDENT WORKSHEET: "Lake Ice and Energy Transfer" completed in an earlier lesson
- STUDENT WORKSHEET: "Lake Ice and Conductive Heat Flow"

## GLEs Addressed:

*Science*

- [9] SA1.1 The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, inferring, and communicating.
- [10-11] SA1.1 The student demonstrates an understanding of the processes of science by asking questions, predicting, observing, describing, measuring, classifying, making generalizations, analyzing data, developing models, inferring, and communicating.

*Math*

- [9] MEA-1 The student demonstrates an understanding of measurable attributes by estimating or converting measurements between the English and metric systems in real-world applications, given a conversion factor (e.g., miles/kilmeters) (M2.4.2)

## Activity Procedure:

**Teachers' Note:** The formula for conductive heat flow is:

conductive heat flow = snow temperature gradient x thermal conductivity

Thermal conductivity can be determined from snow density (or r).

1. **REVIEW THE FORMULA FOR SNOW TEMPERATURE GRADIENT:**

$$\textit{Snow Temperature Gradient} = \frac{(\text{surface temperature in °K}) - (\text{bottom temperature in °K})}{\text{snow depth in meters}}$$

If the surface temperature was 252°K and the bottom temperature was 264°K, and snow depth was 0.27 m, what is the snow temperature gradient?

$$\frac{(252°K) - (264°K)}{0.27} = \frac{-12\ °K}{0.27} = -44.44\ °K$$

2. **REVIEW THE FORMULA FOR SNOW DENSITY:**

*Snow density* (or $\rho$) = Mass (g) / Volume ($cm^3$)

$\rho$ = _____ g / _____ $cm^3$ = _____ g / $cm^3$
weight volume

For example, a cylinder that contains 150 $cm^3$ of snow and weighs 3.5 grams:

$\rho$ = 35 g / 150 $cm^3$ = 0.233 $g/cm^3$

3. **EXPLAIN THERMAL CONDUCTIVITY:**

Explain that *thermal conductivity* of snow can be can be predicted by using a formula developed by Matthew Sturm, of the U.S. Army Cold Regions Research and Engineering Laboratory at Ft. Wainwright, in Fairbanks, Alaska. Dr. Sturm has collected and studied hundreds of samples of snow to determine their thermal conductivity. The exact thermal conductivity of a material must be measured. He has developed the following formulas:

If $\rho < 0.156$ $g/cm^3$ then its thermal conductivity is = $0.023 + 0.234 \rho$.

If $0.156 < \rho < 0.6$ $g/cm^3$ then its thermal conductivity is = $0.138 - 1.01 \rho + 3.2332 \rho^2$.

(Note: this formula results in units expressed as watts/meter Kelvin)

For example, if snow density measures 0.233 $g/cm^3$ use the second formula:

Thermal conductivity = $0.138 - 1.01 \rho + 3.2332 \rho^2$ =

$0.138 - 1.01 (.233\ g/cm^3) + 3.2332 (.233\ g/cm^3)^2$ =

$0.138 - .235\ g/cm^3 + 3.2332 (.054\ g/cm^3)$ =

$-0.097\ g/cm^3 + 0.175\ g/cm^3$ = 0.078 watts/meter Kelvin (w/mk)

4. **DEMONSTRATE THE FORMULA FOR CONDUCTIVE HEAT FLOW:**

Based on the above data, show students how to compute *conductive heat flow*:

Conductive heat flow = snow temperature gradient x thermal conductivity

Therefore, using the example above:

-44.44 ˚C/m x 0.079 watts/meter Kelvin = $-3.5$ $watts/m^2$

(Note: the units for conductive heat flow are expressed as $watts/m^2$)

What this indicates is the amount of energy (in watts) released by the above freezing lake water through the ice and snow. The answer is a negative number because it reflects a loss of heat to the air. If the air were warming the lake, the number would be a positive number.

5. Ask students to use data from the STUDENT WORKSHEET: “The Science of Snow” and “Lake Ice and Energy Transfer” to complete the STUDENT WORKSHEET: “Lake Ice and Conductive Heat Flow.”

## Answers:

Answers will vary but should show an understanding of the calculations.

Name:_____

# Lake Ice and Conductive Heat Flow

## Student Worksheet

**Levels V-VI**

1. Record the results from the STUDENT WORKSHEET "Lake Ice and Energy Transfer," question 2.

   _____

2. Convert the recorded temperatures to °K using the following equation: °K = °C+273.

3. Complete the equation:

$$\frac{\text{(surface temperature in }^{\circ}\text{C) - (bottom temperature in }^{\circ}\text{C)}}{\text{snow depth in meters}} = \_\_\_\_\_$$

4. Record the snow density (or p) determined on the STUDENT WORKSHEET: "The Science of Snow."

$$\rho = \frac{\text{\_\_\_\_\_ g}}{\text{average weight}} / \frac{\text{\_\_\_\_\_ cm}^3}{\text{average volume}} = \text{\_\_\_\_\_ g / cm}^3$$

**Compute thermal conductivity based on the snow sampled.**

Thermal conductivity of snow can be determined by using one of the two formulas below, depending on snow density ($\rho$).

If $\rho < 0.156$ g/cm$^3$ then its thermal conductivity is = $0.023 + 0.234\ \rho$.

If $0.156 < \rho < 0.6$ g/cm$^3$ then its thermal conductivity is = $0.138 - 1.01\ \rho + 3.2332\ \rho^2$.

5. Is $\rho < 0.156$ g/cm$^3$ or $0.156 < \rho < 0.6$ g/cm$^3$? _____

6. If $\rho < 0.156$ g/cm$^3$ use this formula: $0.023+ 0.234\ \rho$

   If $0.156 < \rho < 0.6$ g/cm$^3$ use this formula: $0.138 - 1.01\ \rho + 3.2332\ \rho^2$

   Show all work:

   _____

   _____

   _____

   _____

   (Note: the units for thermal conductivity are in watts/meter Kelvin)

**Compute conductive heat flow.**

Conductive heat flow = snow temperature gradient x thermal conductivity

7. _____ x _____ = _____

   (Note: the units for mean conductive heat flow are watts/m$^2$)