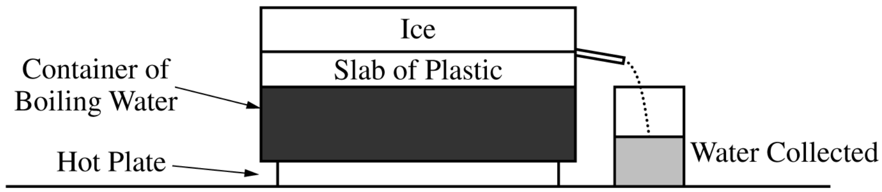


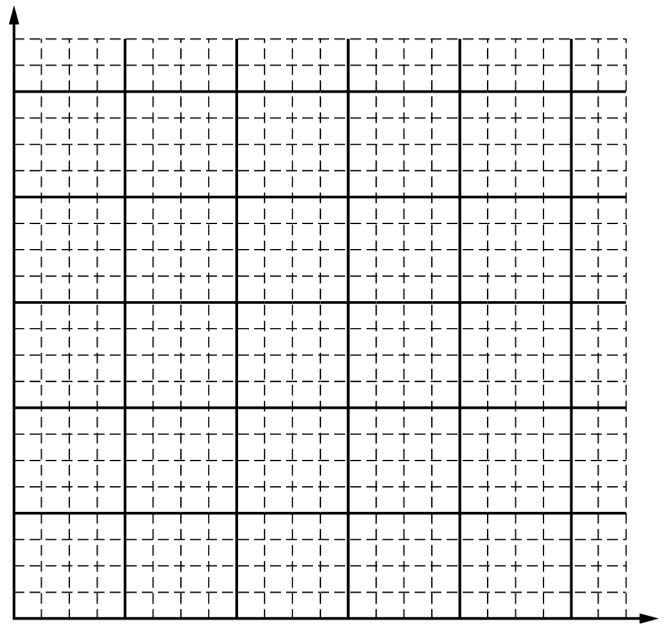
3. (12 points, suggested time 25 minutes)

A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of 100°C. They place a slab of the plastic with area $0.025\ \text{m}^2$ and thickness 0.010 m above the container so that the bottom surface of the slab is at a temperature of 100°C. They put a large block of ice with temperature 0°C on top of the plastic slab. Some of the ice melts, and the students measure the amount of water collected during a time Δt. The students correctly calculate the amount of energy Q delivered to the ice and thus determine $Q/\Delta t$. They repeat this experiment several times, each time adding an identical slab to increase the total thickness L of plastic. Their results are shown in the table below.

Energy flow rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total thickness of plastic L (m)	0.010	0.020	0.030	0.040	0.050

(a) The students want to create a graph to yield a straight line whose slope could be used to calculate the thermal conductivity of the plastic.

i. Label the axes below to indicate a pair of quantities that could be graphed to yield a straight line. Include units for the quantities.

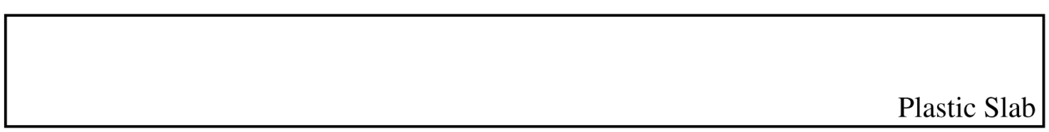


ii. On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following.
- Add to the data table the values of any quantities to be plotted that are not already given.
- Scale the axes.
- Plot the data from the table.
- Draw a line that best represents the data.

iii. Use the graph to calculate the thermal conductivity of the plastic.

(b) Indicate one potential problem with the setup that could lead to an experimental value for the thermal conductivity that is different from the actual value. Use physics principles to explain the effect this problem could have on the experimental value.

(c) The rectangle below represents a side view of the plastic slab. Draw a single arrow on the diagram representing the direction of the net flow of energy through the plastic.



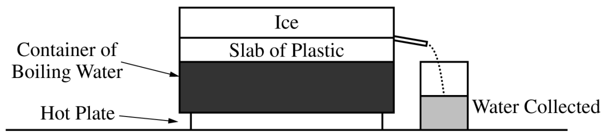
(d) Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).

(e) An extra plastic slab sits on a wood surface, with both the plastic slab and the wood surface at room temperature. A student touches each and finds that the plastic slab feels cooler than the wood surface. Explain what causes this observation.

GO ON TO THE NEXT PAGE.

Question 3

12 points



A group of students use the apparatus shown above to determine the thermal conductivity of a certain type of plastic. A hot plate is used to keep water in a container boiling at a temperature of $100°C$. They place a slab of the plastic with area 0.025 m^2 and thickness 0.010 m above the container so that the bottom surface of the slab is at a temperature of $100°C$. They put a large block of ice with temperature $0°C$ on top of the plastic slab. Some of the ice melts, and the students measure the amount of water collected during a time Δt. The students correctly calculate the amount of energy Q delivered to the ice and thus determine $Q/\Delta t$. They repeat this experiment several times, each time adding an identical slab to increase the total thickness L of plastic. Their results are shown in the table below.

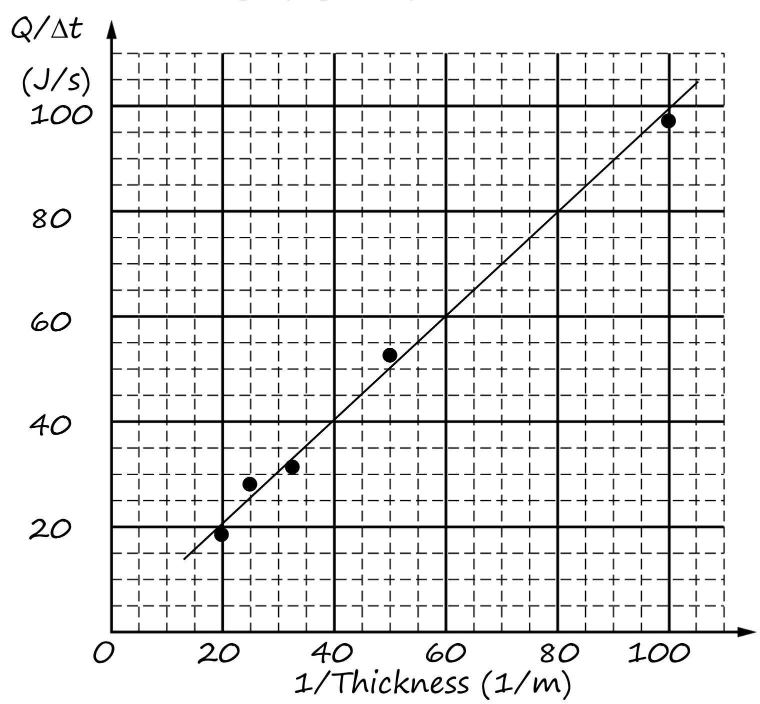
Table with sample entries for part (a)(ii)

Energy Flow Rate $Q/\Delta t$ (J/s)	97	53	31	27	18
Total Thickness of Plastic (m)	0.01	0.02	0.03	0.04	0.05
1/Thickness (1/m)	100	50	33.3	25	20

(a)

The students want to create a graph to yield a straight line whose slope could be used to calculate the thermal conductivity of the plastic.

Sample graph using above data



Question 3 (continued)

(a) (continued)

i. LO 1.E.3.1, SP 4.1, 5.1
1 point

Label the axes below to indicate a pair of quantities that could be graphed to yield a straight line. Include units for the quantities.

$\dfrac{Q}{\Delta t} = \dfrac{kA\,\Delta T}{L}$		
For labeling the axes with two quantities that would produce a linear graph, including units		1 point
Example: $Q/\Delta t$ and $1/\text{thickness}$		

ii. LO 1.E.3.1, SP 4.1, 5.1
3 points

On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following:

- Add to the data table the values of any quantities to be plotted that are not already given.
- Scale the axes.
- Plot the data from the table.
- Draw a line that best represents the data.

For scaling the axes linearly so the data extends over at least half of each axis		1 point
For accurately plotting the data		1 point
For a best-fit curve or line that fits the trend in the data		1 point

iii. LO 1.E.3.1, 5.1
2 points

Use the graph to calculate the thermal conductivity of the plastic.

For a correct method for calculating the slope using points on the best-fit line		1 point
For the graph above, $\text{slope} = \dfrac{(80-20)(\text{J/s})}{(80-20)(1/\text{m})} = 1.0\ \text{J}\bullet\text{m/s}$		
For determining the thermal conductivity k, with or without units using the slope found above		1 point
$\dfrac{Q}{\Delta t} = \dfrac{kA\,\Delta T}{L}$ so $\text{slope} = kA\,\Delta T$		
Using slope above: $k = \text{slope}/A\,\Delta T = 1(\text{J}\bullet\text{m/s})\big/\left(0.025\ \text{m}^2\right)(100°\ \text{C}) = 0.40\ \text{J/s}\bullet\text{m°C}$		

Question 3 (continued)

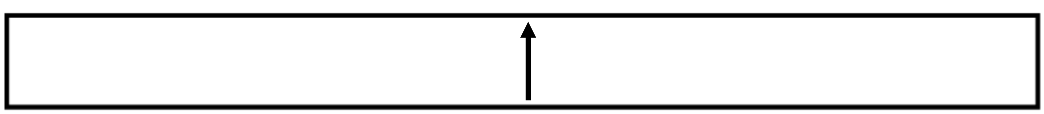
(b) LO 5.B.6.1, SP1.2
2 points

Indicate one potential problem with the setup that could lead to an experimental value for the thermal conductivity that is different from the actual value. Use physics principles to explain the effect this problem could have on the experimental value.

For any valid indication of an additional thermal interaction with the environment		1 point
For a reasonable explanation of how additional energy added or lost could change the experimental value of conductivity		1 point
Example 1: The given setup allows energy to be transferred to the ice from the air around it. This means the values of $Q/\Delta t$ contain energy that did not go through the plastic slab, resulting in a value of k that is too large.		
Example 2: The given setup allows energy to be lost out the sides of the plastic slab. This means the values of $Q/\Delta t$ do not contain all the energy that went through the plastic slab, resulting in a value of k that is too small.		
Claim: The problem leads to a value of k that is too small/large. Evidence: The problem allows energy transfer into/out of the system that is not accounted for. Reasoning: The values of $Q/\Delta t$ contain less/more energy than went through the plastic slab, resulting in a value of k that is too small/large.		

(c) LO 4.C.3.1, SP 6.4
1 point

The rectangle below represents a side view of the plastic slab. Draw a single arrow on the diagram representing the direction of the net flow of energy through the plastic.



For drawing an arrow toward the top of the page		1 point

(d) LO 4.C.3.1, SP 6.4; LO 5.B.6.1, SP 1.2; LO 5.D.1.6, SP 6.4
2 points

Describe what occurs in the plastic at the microscopic level that explains the energy flow you indicated in part (c).

For indicating that particles at the bottom (or a location consistent with part (c)) have a higher temperature or kinetic energy, so they vibrate faster		1 point
For indicating that particles collide with neighboring particles, transferring energy from faster to slower particles in the process		1 point
Example: Energy absorbed at the lower surface makes particles jiggle faster, they jiggle particles above them, and so forth until energy reaches the other side.		

Question 3 (continued)

(e) LO 1.E.3.1, SP 4.1, 4.2
1 point

An extra plastic slab sits on a wood surface, with both the plastic slab and the wood surface at room temperature. A student touches each and finds that the plastic slab feels cooler than the wood surface. Explain what causes this observation.

For indicating that the slab and wood have different thermal conductivities or that energy is transferred into the plastic and wood at different rates, with no incorrect statements		1 point

Learning Objectives

LO 1.E.3.1: The student is able to design an experiment and analyze data from it to examine thermal conductivity. [See Science Practices 4.1, 4.2, 5.1]

LO 4.C.3.1: The student is able to make predictions about the direction of energy transfer due to temperature differences based on interactions at the microscopic level. [See Science Practices 6.4]

LO 5.B.6.1: The student is able to describe the models that represent processes by which energy can be transferred between a system and its environment because of differences in temperature: conduction, convection, and radiation. [See Science Practices 1.2]

LO 5.D.1.6: The student is able to make predictions of the dynamical properties of a system undergoing a collision by application of the principle of linear momentum conservation and the principle of the conservation of energy in situations in which an elastic collision may also be assumed. [See Science Practices 6.4]