2019

AP CollegeBoard

# AP® Physics 2: Algebra-Based

## Sample Student Responses and Scoring Commentary

### Inside:

Free Response Question 3

- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

## General Notes About 2019 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

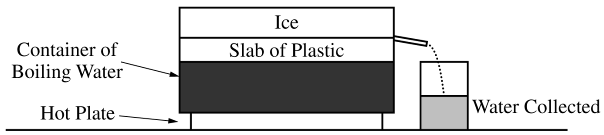
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of $10 \text{ m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

## 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 $\Delta t$. 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.

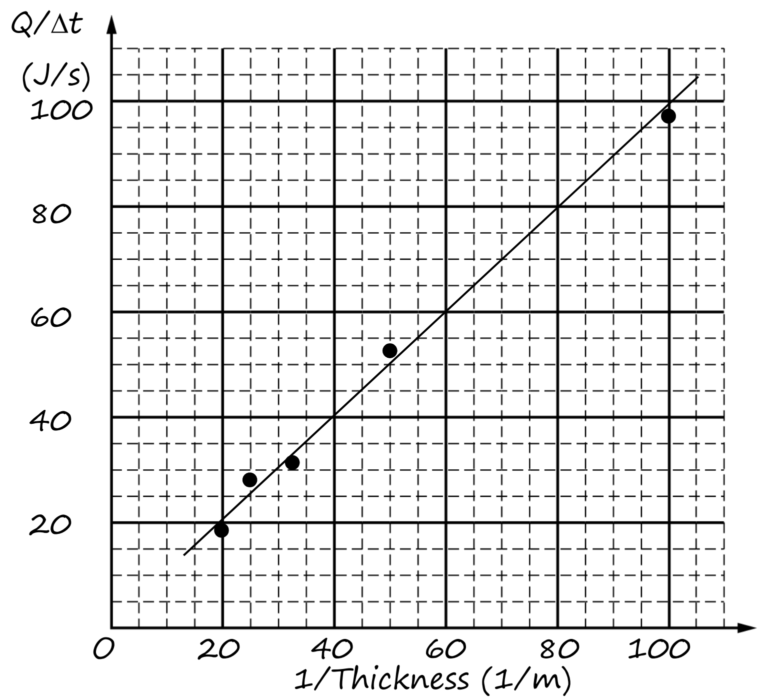
Table with sample entries for part (a)(ii)

| 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, $\text{slope} = \dfrac{(80-20)(\text{J/s})}{(80-20)(1/\text{m})} = 1.0\ \text{J•m/s}$ | | |
| 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: $k = \text{slope}/A\,\Delta T = 1(\text{J•m/s})/\left(0.025\ \text{m}^2\right)(100°\ \text{C}) = 0.40\ \text{J/s•m°C}$ | | |

## Question 3 (continued)

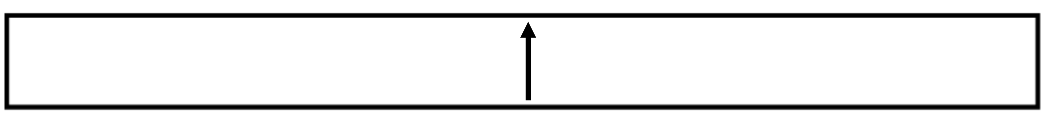
(b) LO 5.B.6.1, SP1.2
2 points

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.<br>Evidence: The problem allows energy transfer into/out of the system that is not accounted for.<br>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 |

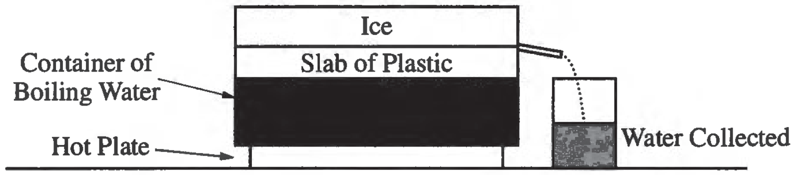
**Learning Objectives**

**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]



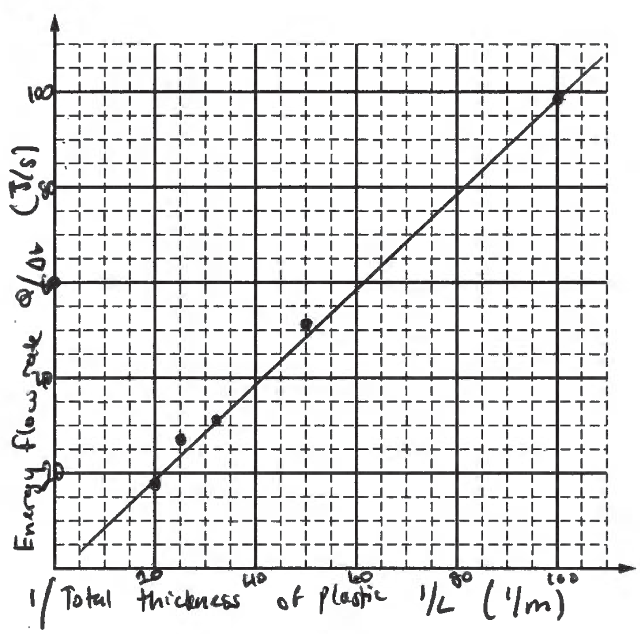

3. (12 points, suggested time 25 minutes)

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 $0.025\ m^2$ 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 $\Delta t$. 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 |
| 1/Total thickness of plastic 1/L (1/m) | 100 | 50 | 33 | 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.

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.






GO ON TO THE NEXT PAGE.

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.

slope = ~~60~~ ~~Q/t~~ $\frac{QL}{\Delta t} = kA\Delta T$

$k = \frac{1\ J/s \cdot m}{(0.025 m^2)(100°C)} = \frac{1\ J/s \cdot m}{2.5 m^2 °C}$

Slope $= \frac{79-59}{80-60} = 1 = \frac{QL}{\Delta t}$

$\therefore 1 = kA\Delta T$

$k = 1/A\Delta T$

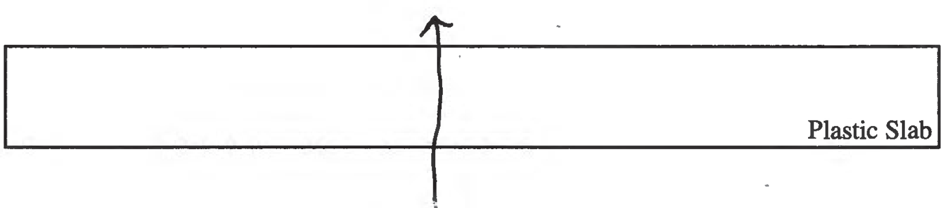
~~k = 0.4/m² °C~~

$k = 0.4\ J/ms\ °C$

(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.

The system is not isolated or sealed. When thermal energy is given off by the hot plate, some of the energy is lost to the surroundings instead of transferring to the slab of plastic. This decreases the change in temperature of the plastic and in turn the ~~change~~ ~~in temperature of the~~ amount of ice that melted, giving a smaller thermal conductivity in the experiment. ~~than it should~~

(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.




Question 3 continues on the next page.



GO ON TO THE NEXT PAGE.

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

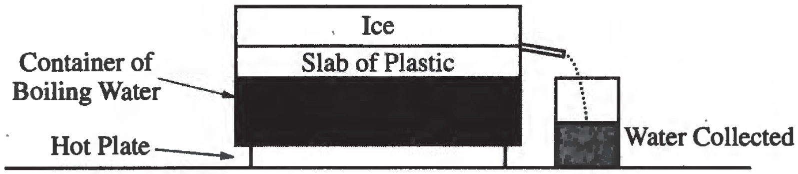
Thermal energy is given off by the hot plate, which this energy is transferred into the plastic as thermal energy. The particles become excited and gain energy. ~~extra~~ ~~more~~ This energy is then transferred to the ice above it ~~to~~ in thermal energy, thus heating the plastic.

(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.

Plastic is a good thermal conductor while wood is not. Thus plastic is more prone to temperature changes than wood is. This is why the plastic feels colder, because thermal energy is easier to flow in and out of the plastic. In this case, the thermal energy left.



GO ON TO THE NEXT PAGE.



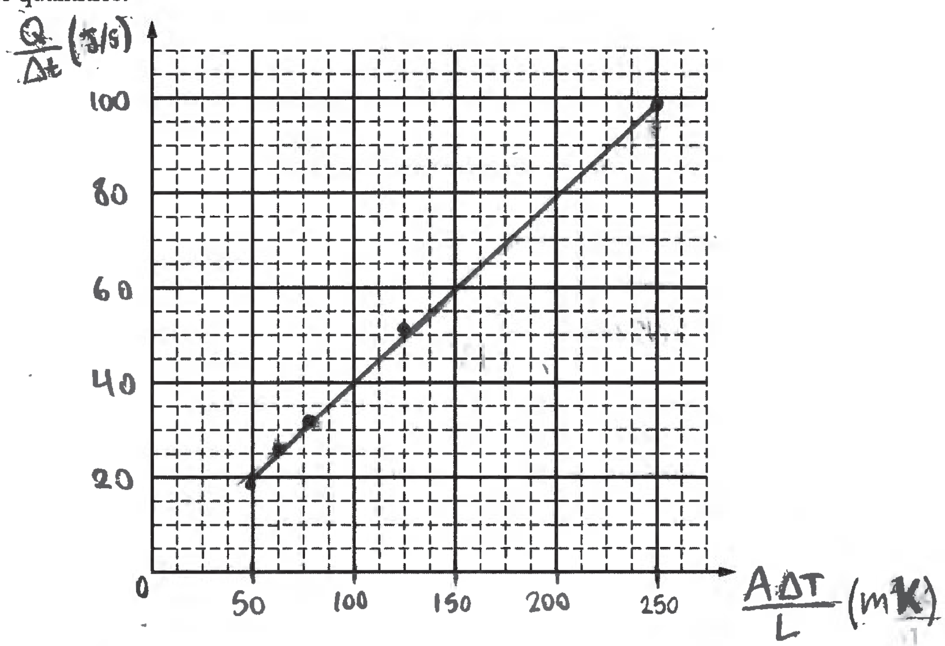

3. (12 points, suggested time 25 minutes)

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 $0.025\ m^2$ 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 $\Delta t$. 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 |
| $A\Delta T/L$ (mK) | 250 | 125 | 83,33 | 62.5 | 50 |
| | | | | | |

(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.




$$\frac{Q}{\Delta t} = \frac{kA\Delta T}{L}$$



GO ON TO THE NEXT PAGE.

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.

97/250 = .388
53/125 = .424
31/83.33 = .372
27/62.5 = .432
18/50 = .36

table
$\frac{1.976}{5} = .3952$

graph
20/50 = .4

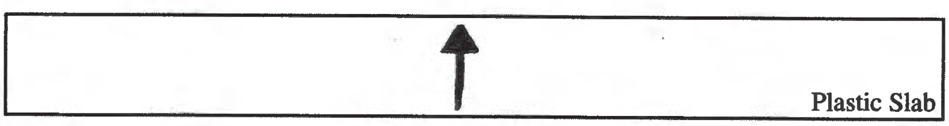
thermal conductivity ≈ .4

(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.

Room temperature can easily vary and skew the data if it isn't constant. The ice may melt faster or slower.

The Hot plate heats the air too and the air could heat up the outside of the container. Thus, causing the ice to melt faster

(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.




Question 3 continues on the next page.



GO ON TO THE NEXT PAGE.

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

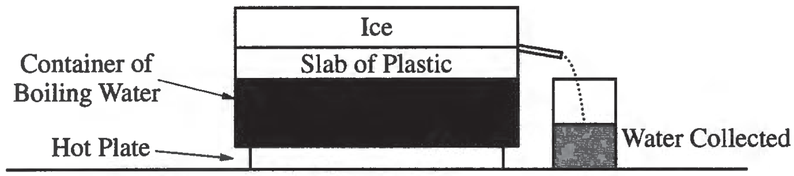
Heat is atoms vibrating, the hotter they are, the more they vibrate (more energy). The ice is melting, so the heat is rising up through the plastic. Thus, the energy flow is upwards.

(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.

The greater the thermal conductivity of a material, the cooler they will feel in comparison to a lower thermally conductive material at the same temperature.



GO ON TO THE NEXT PAGE.




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 $0.025\ m^2$ 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 $\Delta t$. 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.

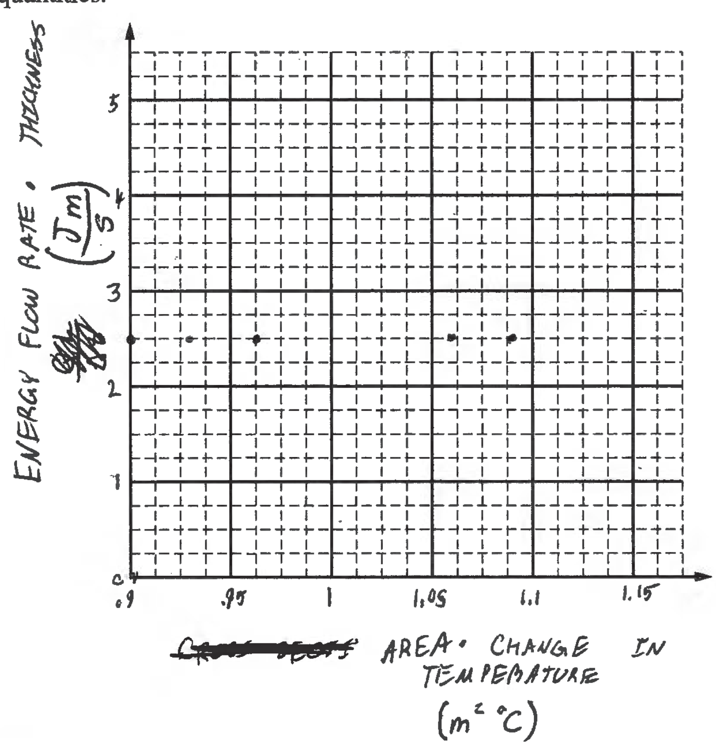
| Energy flow rate $Q/\Delta t$ (J/s) | 97 | 53 | 31 | 27 | 18 |
|---|---|---|---|---|---|
| Total thickness of plastic $L$ (m) | 0.010 | 0.020 | 0.030 | 0.040 | 0.050 |
| $QL/\Delta t$ (J m/s) | .97 | 1.06 | .93 | 1.08 | .9 |
| $A\Delta T$ (m² °C) | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |

(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.

$$\frac{Q}{\Delta t} = \frac{k A \Delta T}{L}$$

$$\frac{QL}{A \Delta T \Delta t} = k$$






GO ON TO THE NEXT PAGE.

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.

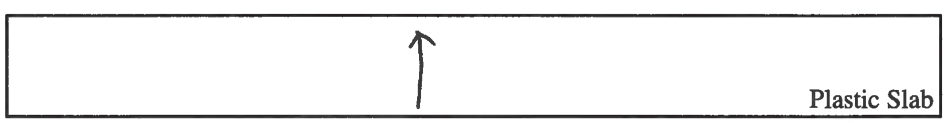
iii. Use the graph to calculate the thermal conductivity of the plastic.

k=.388

(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.

ONE POTENTIAL PROBLEM IS THAT

(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.




Question 3 continues on the next page.



GO ON TO THE NEXT PAGE.

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

AS THE WATER BELOW THE PLASTIC GETS HOTTER, ENERGY IS TRANSFERED INTO THE PLASTIC MOLECULES CAUSING THEM TO GAIN MORE KINETIC ENERGY AND ~~this~~ BECAUSE KINETIC ENERGY AND TEMPERATURE ARE DIRECTLY RELATED, TEMPERATURE INCREASES.

(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.

THIS HAPPENS BECAUSE THE PLASTIC HAS A HIGHER THERMAL CONDUCTIVITY THAN THE WOOD BECAUSE THE PLASTIC IS MORE EASILY ABLE TO CONDUCT THERMAL ENERGY OUT OF THE HAND AND INTO ITSELF THAN THE WOOD.



GO ON TO THE NEXT PAGE.

## Question 3

**Note:** Student samples are quoted verbatim and may contain spelling and grammatical errors.

**Overview**

Parts (a) and (b) of this question assessed students' laboratory and graphing skills. In part (a) students were expected to determine which quantities to graph to linearize the data, graph the data, and extract experimental results from the slope. Part (b) assessed student understanding of experimental error. Parts (c), (d), and (e) assessed student understanding of energy transfer via thermal processes, specifically that energy flows from hot to cold objects (through increased kinetic energy and collisions) and that thermal conductivity is a property of a material that determines energy flow.

**Sample: P2 Q3 A**
**Score: 10**

Full credit was earned in part (a). The graph has correct labels, scaling, plotted points, and best-fit line. The slope of the best-fit line of the graph is used to determine the value of $k$ by substituting constants into the equation. Full credit was earned for part (b) for indicating that energy lost to the surroundings as a source of error would yield a lower experimental value for $k$. Part (c) earned 1 point for an arrow pointing up. No credit was earned for part (d) because energy transferred by collisions between neighboring molecules is not addressed. Part (e) earned full credit because plastic is identified as the better thermal conductor.

**Sample: P2 Q3 B**
**Score: 8**

Full credit was earned in parts (a)(i) and (a)(ii) for correct labels, scaling, plotted points, and best-fit line. There was no penalty for labeling the horizontal axis with K when the values are expressed in $^\circ\mathrm{C}$. No credit was earned for (a)(iii) because the first data point values are averaged, and then one point on the graph is used to determine $k$. In part (b) 1 of 2 points was earned for recognizing that the surrounding air was a possible source of error in this experiment. In part (c) full credit was earned for an arrow pointing up. In part (d) 1 of 2 points was earned for indicating that higher-temperature particles move faster. Full credit was earned for part (e) for stating that materials with greater thermal conductivity feel cooler.

**Sample: P2 Q3 C**
**Score: 4**

Part (a)(i) earned 1 point for axis labels with units that would produce a linear graph. Part (a)(ii) earned no points because the data points do not extend over at least half of the vertical axis, the data is not correctly plotted, and a best-fit line is not drawn. Part (a)(iii) earned no points because a method for determining $k$ using a best-fit line is not provided. Part (b) earned no points because no problem is indicated. Part (c) earned 1 point for an arrow pointing up. Part (d) earned 1 point for indicating that higher-temperature particles move faster. Part (e) earned 1 point for indicating that plastic is a better thermal conductor.