Past-paper walk-through

Specific Heat and Thermal Conductivity ▪ 9.5

eXercise

Questions in this set

- 2026 Q1
- 2024 Q2
- 2019 Q3

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 1

2026 ▪ Q1

Part A

A sample of n moles of a monatomic, ideal gas is in a large, sealed, thermally conducting container with fixed volume. A small sphere of mass m_S is in the container. The volume of the sphere is much less than the volume of the container.

The gas is initially in State X with pressure P and volume V, as shown in Figure 1.

[Figure 1: A sealed square container labelled "Gas n, P, V" with a small sphere labelled "Sphere m_S" inside near the bottom, connected by an arrow from the "Sphere" label to a dot inside the container. Caption below the figure: "State X". Note: Figure not drawn to scale.]

The sphere is initially in thermal equilibrium with the gas. The gas undergoes a heating process until the gas is in State Y with pressure $3P$ and the sphere is again in

Question 1

thermal equilibrium with the gas. The total energy transferred to the sphere during the heating process is Q_S.

(i) The graph in Figure 2 represents the number of atoms per unit speed as a function of atom speed for the gas when the gas is in State X. On Figure 3, **sketch** a curve that could represent the number of atoms per unit speed as a function of atom speed for the gas when the gas is in State Y.

[Figure 2: Axes labelled "Number of Atoms per Unit Speed" (vertical) vs. "Atom Speed" (horizontal), captioned "State X". A Maxwell-Boltzmann-type curve starts at the origin, rises to a single rounded peak (marked with a dashed horizontal line to the peak height and a dashed vertical line to the corresponding atom speed), then decreases back toward the horizontal axis at higher speeds.]

[Figure 3: Blank axes labelled "Number of Atoms per Unit Speed" (vertical) vs. "Atom Speed" (horizontal), captioned "State Y", with the same dashed reference lines

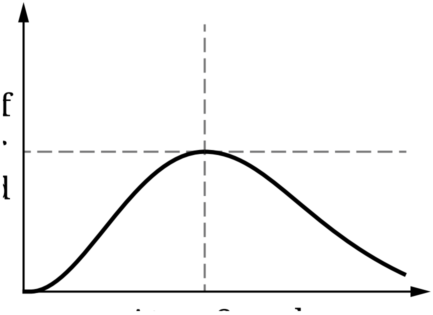
Question 1

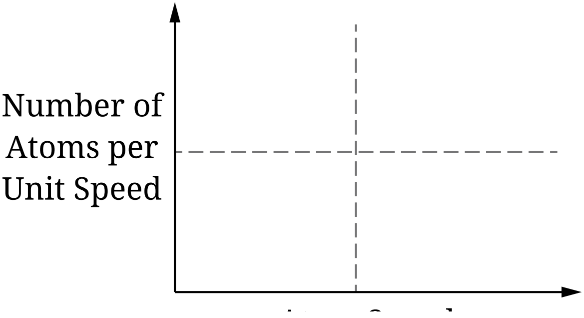
(horizontal at the State X peak height, vertical at the State X peak speed) shown for reference, but no curve drawn — to be sketched by the student.]

(ii) **Derive** an expression for the change ΔT in temperature of the gas for the heating process that the gas undergoes as the gas changes from State X to State Y. Express your answer in terms of n, P, V, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

(iii) **Derive** an expression for the specific heat c_S of the sphere. Express your answer in terms of n, m_S, P, V, Q_S, and physical constants, as appropriate. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

Question 1





Question 1

2026 ▪ Q1

Part A

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The gas is initially in State X with pressure P and volume V, as shown in Figure 1.

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The sphere is initially in thermal equilibrium with the gas. The gas undergoes a heating process until the gas is in State Y with pressure $3P$ and the sphere is again in thermal equilibrium with the gas. The total energy transferred to the sphere during the heating process is Q_S.

(b) Part B

Question 1

An insulated container is filled with a liquid of mass m_{L} and specific heat c_{L}. The original sphere is submerged in the liquid. The sphere has mass m_{S}, where $m_{\mathrm{S}} < m_{\mathrm{L}}$, and specific heat c_{S}, where $c_{\mathrm{S}} < c_{\mathrm{L}}$. The initial temperature of the sphere is greater than the initial temperature of the liquid. Later, the liquid and the sphere reach thermal equilibrium. The absolute values of the changes in the temperatures of the liquid and the sphere are $|\Delta T_{\mathrm{L}}|$ and $|\Delta T_{\mathrm{S}}|$, respectively.
Indicate whether $|\Delta T_{\mathrm{S}}|$ is greater than, less than, or equal to $|\Delta T_{\mathrm{L}}|$. Include one of the following relationships in your response.
- $|\Delta T_{\mathrm{S}}| > |\Delta T_{\mathrm{L}}|$ - $|\Delta T_{\mathrm{S}}| < |\Delta T_{\mathrm{L}}|$ - $|\Delta T_{\mathrm{S}}| = |\Delta T_{\mathrm{L}}|$
Justify your answer. Your justification may include expressions/equations but must include conceptual reasoning beyond algebraic solutions.

Question 2

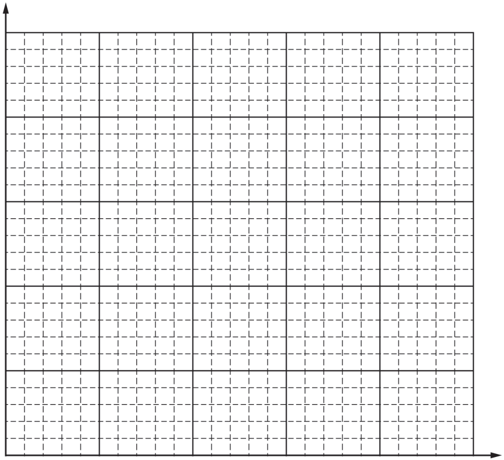
2024 ▪ Q2

[Figure 1: A rectangular sealed chamber labeled "Chamber" with thin, rigid walls. Inside are many small dots labeled "Gas Molecule" scattered throughout the interior. On the left wall is a component labeled "Heater". On the right wall are two circular components labeled "Sensors". Note: Figure not drawn to scale.]

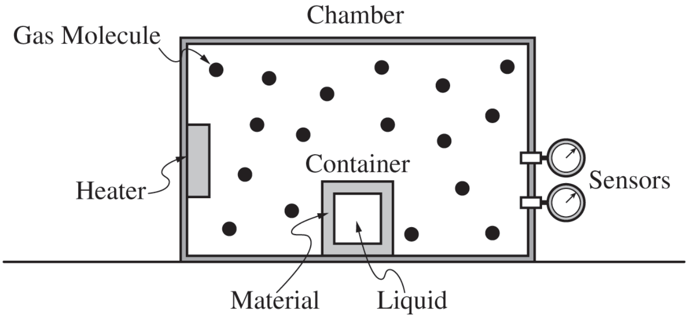
In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(a) Describe a procedure for collecting data that would allow the student to determine an experimental value for N. Provide enough detail so that a student could replicate the experiment, including any steps necessary to reduce experimental uncertainty.

Question 2



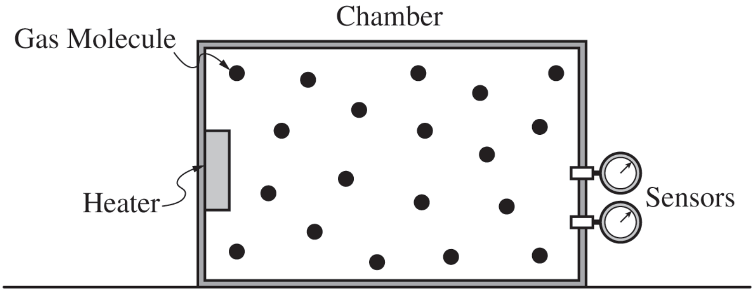
Question 2



<u>Note</u>: Figure not drawn to scale.

Figure 2

Question 2



Note: Figure not drawn to scale.

Figure 1

Question 2

2024 ▪ Q2

[Figure 1: A rectangular sealed chamber labeled “Chamber” with thin, rigid walls. Inside are many small dots labeled “Gas Molecule” scattered throughout the interior. On the left wall is a component labeled “Heater”. On the right wall are two circular components labeled “Sensors”. Note: Figure not drawn to scale.]

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(b)(i) On the following axes, **sketch** a curve or line to represent the expected relationship between the pressure P and volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.

Question 2

[Graph with vertical axis P and horizontal axis V, both starting at origin O; empty dashed gridded axes for the student to sketch on.]

(b)(ii) On the following axes, **sketch** a curve or line to represent the expected relationship between the internal energy U and the volume V of the gas while the heater is on. **Draw** an arrow on the curve or line to represent the direction of the resulting thermal process.

[Graph with vertical axis U and horizontal axis V, both starting at origin O; empty dashed gridded axes for the student to sketch on.]

(b)(iii) Briefly **justify** why the curve or line drawn in part (b)(ii) has the shape that you sketched.

Question 2

2024 ▪ Q2

[Figure 1: A rectangular sealed chamber labeled “Chamber” with thin, rigid walls. Inside are many small dots labeled “Gas Molecule” scattered throughout the interior. On the left wall is a component labeled “Heater”. On the right wall are two circular components labeled “Sensors”. Note: Figure not drawn to scale.]

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(c) [Figure 2: The same rectangular sealed chamber, labeled ”Chamber”, with ”Gas Molecule” dots scattered throughout. On the left wall is ”Heater”. On the right wall are two ”Sensors”. Inside the chamber is a smaller rectangular ”Container” that is

Question 2

completely wrapped, holding a "Material" layer and a "Liquid" layer inside it. Note: Figure not drawn to scale.]

In Experiment 2, shown in Figure 2, a liquid-filled container that is completely wrapped with a material of uniform thickness 0.01 m is inside the sealed chamber that is filled with an ideal gas. The material has a total area of 0.06 m^2 in contact with the gas. The heater is turned on. As the temperature T_G of the gas increases, the following data for the temperature T_L of the liquid and the rate $\dfrac{Q}{\Delta t}$ of energy transfer are collected.

T_G (K)	T_L (K)	$\dfrac{Q}{\Delta t}$ (J/s)
295	295	0.0
371	303	26.3
425	308	43.1
475	313	60.0
528	323	75.0

The student is asked to determine an experimental value of the thermal conductivity k of the material used to wrap the container inside the sealed chamber.

Question 2

(c)(i) Indicate what measured and/or calculated quantities could be graphed to yield a straight line that could be used to calculate an experimental value for the thermal conductivity *k* of the material. Use the blank columns in the table to list any calculated quantities you graph in addition to the data provided.

Vertical Axis: ____________________ Horizontal Axis: ____________________

(c)(ii) Plot the data points for the quantities indicated in part (c)(i) on the graph provided. Clearly scale and **label** all axes, including units, as appropriate.

[Empty gridded graph with axes to be scaled and labeled by the student, with tick marks along both axes for plotting data points.]

(c)(iii) Draw the best-fit line for the data graphed in part (c)(ii).

Question 2

2024 ▪ Q2

[Figure 1: A rectangular sealed chamber labeled "Chamber" with thin, rigid walls. Inside are many small dots labeled "Gas Molecule" scattered throughout the interior. On the left wall is a component labeled "Heater". On the right wall are two circular components labeled "Sensors". Note: Figure not drawn to scale.]

In Experiment 1, shown in Figure 1, a sample of an ideal gas is contained in an insulated, sealed chamber with thin, rigid walls. The chamber contains a heater and sensors that measure the temperature and pressure of the gas. A student is asked to design an experiment to determine the number N of molecules of the gas contained in the chamber.

(d) Using the best-fit line, **calculate** an experimental value for k.

Solution 2

(a) Mark scheme

- Procedure: measure the length, width, and height of the chamber to determine the volume of the gas (measurements of the heater's own dimensions/volume may also earn credit). Activate the heater. Starting at time $t = 0$, use the pressure and temperature sensors to record the pressure and temperature of the gas at multiple times — e.g., every 10 s until $t = 60$ s — so that a temperature/pressure trend over time can be established. Scoring: 1 pt for indicating measurements that could be used to determine the gas volume; 1 pt for indicating the sensors are used to record the gas's temperature and pressure; 1 pt for indicating that multiple different temperature and pressure measurements are recorded (not just one).

Solution 2

(b)(i)

Mark scheme

- Sketch on the P vs. V axes: a vertical line segment (constant V) that never touches either axis, with an arrow pointing upward — pressure increases while volume stays constant as the heater raises the gas's pressure at fixed volume (isochoric heating). Scoring: 1 pt for sketching an upward vertical line/arrow that never touches the horizontal or vertical axes.

Solution 2

(b)(ii)

Mark scheme

- Sketch on the U vs. V axes: a vertical line segment (constant V) that never touches either axis, with an arrow pointing upward — internal energy increases while volume stays constant, consistent with the heater adding thermal energy to the sealed, fixed-volume gas. Scoring: 1 pt for sketching an upward vertical line/arrow that never touches the horizontal or vertical axes.

Solution 2

(b)(iii)

Mark scheme

- Justification (either is acceptable, must be consistent with the part (b)(ii) sketch): 'The heater transfers energy to the gas by heating, so the internal energy of the gas increases.' OR 'The gas has a constant volume [the chamber is sealed/rigid], so all the energy added goes into internal energy, but volume does not change.' Scoring: 1 pt for a justification that correctly relates the (fixed) volume of the chamber to the sketch, or relates the heater's energy transfer to the increase in internal energy shown in the sketch.

Solution 2

(c)

Mark scheme

- This is introductory/stem text (with Figure 2) describing the Experiment 2 setup: a liquid-filled container, completely wrapped in a material of uniform thickness 0.01 m, placed inside the same heated, sensor-equipped chamber. It sets up the thermal-conductivity determination carried out in parts (c)(i)-(c)(iii) and (d). No points are allocated to this stem text itself in the official scoring guidelines; all points for part (c) are attached to leaves 2ci, 2cii, and 2ciii.

Solution 2

(c)(i) Mark scheme

- Vertical axis: $\dfrac{Q}{\Delta t}$ — the rate of heat transfer through the material (heat current). Horizontal axis: $\Delta T = T_G - T_L$ — the temperature difference between the gas side and the liquid side of the material's surfaces. Plotting $Q/\Delta t$ vs. ΔT gives a straight line through the origin whose slope equals kA/L, which can be used to extract the thermal conductivity k. Scoring: 1 pt for correctly indicating the quantities (measured and/or calculated) that, when graphed, yield a straight line usable to find k.

Solution 2

(c)(ii) Mark scheme

- Label the vertical axis $Q/\Delta t$ in J/s and the horizontal axis ΔT in K, each on an evenly spaced linear scale chosen so the plotted data fill roughly half the grid area. Plot each data point at its corresponding $(\Delta T,\ Q/\Delta t)$ value from the experiment's data table (the reference plot shows points increasing roughly linearly from near the origin, e.g. near $(60\,\mathrm{K}, 25\,\mathrm{J/s})$, $(110, 42)$, $(160, 60)$, and $(200, 75)$). Scoring: 1 pt for correctly labeling both axes (including units) on a linear scale sized so the data span about half the graph; 1 pt for plotting the data points correctly at their given values.

Solution 2

(c)(iii)

Mark scheme

- Draw a single straight best-fit line through the plotted points that approximates the overall trend of the data — starting near the origin and increasing with a roughly constant positive slope, with roughly equal numbers of points above and below the line. Scoring: 1 pt for drawing a straight line that reasonably approximates the trend of the plotted data.

Solution 2

(d) Mark scheme

- Relate the graph's slope to the model: since $\frac{Q}{\Delta t} = \frac{kA\Delta T}{L} = \left(\frac{kA}{L}\right)\Delta T$, the slope of the best-fit line equals kA/L. Reading two well-separated points from the best-fit line, e.g. slope $= \frac{(80-44)\ \mathsf{J/s}}{(220-120)\ \mathsf{K}} = 0.36\ \frac{\mathsf{J}}{\mathsf{s\cdot K}}$. Then $k = \frac{L}{A}(\text{slope}) = \frac{0.01\ \mathsf{m}}{0.06\ \mathsf{m}^2}\left(0.36\ \frac{\mathsf{J}}{\mathsf{s\cdot K}}\right) \approx 0.06\ \frac{\mathsf{J}}{\mathsf{s\cdot K\cdot m}}$. Scoring: 1 pt for correctly relating the slope of the line to $Q/\Delta t = kA\Delta T/L$ (i.e., slope $= kA/L$); 1 pt for calculating an experimental value of k approximately equal to $0.06\ \mathsf{J/(s\cdot K\cdot m)}$, using the student's own graph and $A = 0.06\ \mathsf{m}^2$, $L = 0.01\ \mathsf{m}$.

Question 3

2019 ▪ Q3

[Figure: A diagram of an apparatus. From top to bottom: a block labeled "Ice" sits on top of a layer labeled "Slab of Plastic"; below that is a dark rectangle labeled "Hot Plate" on the left with "Container of Boiling Water" labeled to its left; a small container to the right labeled "Water Collected" catches a drip from the slab, shown with a shaded region at the bottom of that container.]

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

Question 3

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)(i) 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.

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

[Figure: A blank grid with axes to be labeled by the student, gridlines shown but no data plotted, no axis labels or scale provided.]

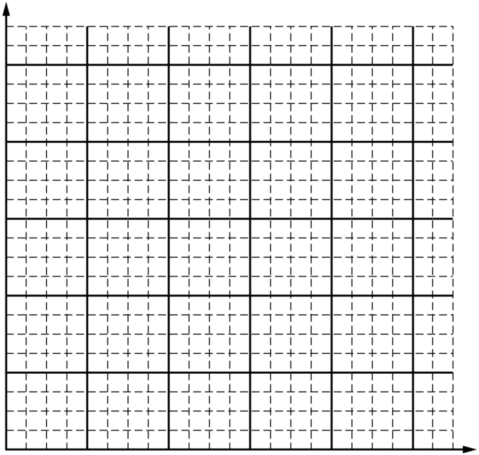
(a)(ii) On the grid on the previous page, create a linear graph using the values for the quantities indicated in part (a)(i). Be sure to do the following.

Question 3

- 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.

(a)(iii) Use the graph to calculate the thermal conductivity of the plastic.

Question 3



Question 3

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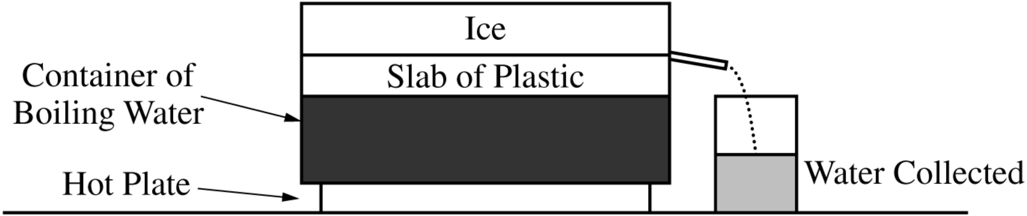
Question 3


Ice
Slab of Plastic
Container of Boiling Water
Hot Plate
Water Collected

Question 3

2019 ▪ Q3

[Figure: A diagram of an apparatus. From top to bottom: a block labeled "Ice" sits on top of a layer labeled "Slab of Plastic"; below that is a dark rectangle labeled "Hot Plate" on the left with "Container of Boiling Water" labeled to its left; a small container to the right labeled "Water Collected" catches a drip from the slab, shown with a shaded region at the bottom of that container.]

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

Question 3

$Q/\Delta t$. 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

(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.

Question 3

2019 ▪ Q3

[Figure: A diagram of an apparatus. From top to bottom: a block labeled "Ice" sits on top of a layer labeled "Slab of Plastic"; below that is a dark rectangle labeled "Hot Plate" on the left with "Container of Boiling Water" labeled to its left; a small container to the right labeled "Water Collected" catches a drip from the slab, shown with a shaded region at the bottom of that container.]

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(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. [Figure: A blank rectangle labeled “Plastic Slab” at the bottom right, representing a side view of the slab, with no arrow drawn.]

Question 3

2019 ▪ Q3

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Total thickness of plastic L (m)	0.010	0.020	0.030	0.040	0.050

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

Question 3

2019 ▪ Q3

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(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.

Solution 3

(a)(i)

Mark scheme

- From $\dfrac{Q}{\Delta t} = \dfrac{kA\Delta T}{L}$, plotting $Q/\Delta t$ (J/s) on the vertical axis against $1/$thickness (units 1/m) on the horizontal axis yields a straight line through the origin with slope $kA\Delta T$. (1 pt for labeling the axes with two quantities that produce a linear graph, including units.)

Solution 3

(a)(ii) Mark scheme

- Complete the table with $1/$thickness values (100, 50, 33.3, 25, 20 m^{-1} for thicknesses 0.01–0.05 m, already shown), then plot $Q/\Delta t$ (97, 53, 31, 27, 18 J/s) against $1/$thickness: points at (100,97), (50,53), (33.3,31), (25,27), (20,18). Scale both axes linearly so the data spans at least half of each axis, plot the points accurately, and draw a best-fit straight line through the data (passing close to the origin, e.g., through approximately (20,20) and (100,100)). Points: 1 pt for scaling the axes linearly so the data extends over at least half of each axis; 1 pt for accurately plotting the data; 1 pt for a best-fit line/curve that fits the trend in the data.

Solution 3

(a)(iii)

Mark scheme

- Using two points on the best-fit line, e.g., (20,20) and (100,100): slope $= \dfrac{(80-20)\ \mathsf{J/s}}{(80-20)\ \mathsf{m}^{-1}} = 1.0\ \mathsf{J \cdot m/s}$ (1 pt for a correct method of calculating the slope using points on the best-fit line). Since slope $= kA\Delta T$, $k = \text{slope}/(A\Delta T) = 1.0\ \mathsf{J \cdot m/s}/\left[(0.025\ \mathsf{m}^2)(100°\mathsf{C})\right] = 0.40\ \mathsf{J/(s \cdot m \cdot °C)}$ (1 pt for determining the thermal conductivity k, with or without units, using the slope found above).

Solution 3

(b) Mark scheme

- Example 1: The setup allows energy to be transferred to the ice from the surrounding air (not solely through the plastic slab from below), so the measured $Q/\Delta t$ includes extra energy that did not pass through the plastic, making the experimental value of k too large. Example 2 (also accepted): The setup allows energy to be lost out the sides of the plastic slab, so the measured $Q/\Delta t$ does not include all the energy that actually passed through the slab, making the experimental value of k too small. Points: 1 pt for any valid indication of an additional thermal interaction with the environment; 1 pt for a reasonable physics explanation of how the added/lost energy changes the experimental conductivity value.

Solution 3

(c)

Mark scheme

- A single arrow drawn pointing toward the top of the page — energy flows by conduction from the hot (100°C) bottom surface, in contact with the boiling water, up through the plastic slab to the cooler (0°C) ice on top. (1 pt for drawing an arrow toward the top of the page.)

Solution 3

(d)

Mark scheme

- At the bottom (hot) surface of the plastic, particles have a higher temperature and thus greater average kinetic energy, so they vibrate faster (1 pt). These faster-vibrating particles collide with neighboring particles above them, transferring kinetic energy from faster to slower particles; this particle-to-particle energy transfer propagates upward through the slab until it reaches the cooler top surface, e.g., "Energy absorbed at the lower surface makes particles jiggle faster; they jiggle particles above them, and so forth until energy reaches the other side" (1 pt).

Solution 3

(e) Mark scheme

- Even though the plastic slab and the wood surface are both at room temperature, they have different thermal conductivities (or: energy is transferred into the plastic and into the wood from the hand at different rates). The plastic (higher thermal conductivity) conducts heat away from the warmer hand faster than the wood (lower thermal conductivity) does, so the plastic feels cooler to the touch even though both objects are actually at the same temperature. (1 pt for indicating the slab and wood have different thermal conductivities or that energy is transferred at different rates, with no incorrect statements.)