A2 Level Physics

Chapter 9 – Thermal Physics

9.3.2 Thermal Properties of Materials

Worked Examples

www.tutorpacks.co.uk

@tutorpacks

Thermal Properties of Materials

Exam Style Question 1

(a) State the terms used to describe the thermal energy required to change

(i) a solid into a liquid at a constant temperature.

(ii) a liquid into a gas at a constant temperature.

(b) Most households waste energy by overfilling electric kettles. Assume that, on average, 0.80 kg of water per household per day is unnecessarily boiled.

(i) Estimate the energy required when $0.80\ kg$ of water, initially at $18\ °C$, is heated in an electric kettle. The kettle switches off automatically when the water is boiling steadily at $100\ °C$. The specific heat capacity of water is $4200\ J\ kg^{-1}\ K^{-1}$.

(ii) State and explain two different reasons why the actual quantity of energy required to warm the water to $100\ °C$ is greater than the estimate in **(i)**.

(iii) Calculate, in $kW\ h$, the average annual energy wasted per household by boiling too much water.

Thermal Properties of Materials

Exam Style Question 1

(a)State the terms used to describe the thermal energy required to change

(i) a solid into a liquid at a constant temperature.

Latent heat of fusion.

(ii) a liquid into a gas at a constant temperature.

Latent heat of vaporisation.

(b) (i) Estimate the energy required when $0.80\ kg$ of water, initially at $18\ °C$, is heated in an electric kettle. The kettle switches off automatically when the water is boiling steadily at $100\ °C$. The specific heat capacity of water is $4200\ J\ kg^{-1}\ K^{-1}$.

$$E = mc\Delta\theta$$

$$E = (0.8\ kg)(4200\ J\ kg^{-1}\ K^{-1})(100℃ - 18℃)$$

$$E = 275520\ J = 2.8 \times 10^{5}\ J$$

(b) (ii) State and explain two different reasons why the actual quantity of energy required to warm the water to $100\ °C$ is greater than the estimate in (i).

Some heat used to heat the kettle.

Some heat lost to surroundings.

(b) (iii) Calculate, in $kW\ h$, the average annual energy wasted per household by boiling too much water.

$$1\ kWh = 1000\ W \times 3600\ s = 3.6 \times 10^{6}\ J$$

$$Waste\ per\ year = \frac{(2.8 \times 10^{5}\ J)(365\ days)}{3.6 \times 10^{6}\ J}$$

$$Waste\ per\ year = 28\ kWh$$

Thermal Properties of Materials

Exam Style Question 2

A room measures $4.5\ m \times 4.0\ m \times 2.4\ m$. The air in the room is heated by a gas-powered heater from $12\ °C$ to $21\ °C$. The density of the air, assumed to remain constant, is $1.3\ kg\ m^{-3}$.

(a) Calculate the thermal energy required to raise the temperature of the air in the room. The specific heat capacity of air is $990\ J\ kg^{-1}\ K^{-1}$.

(b) The heater has an output power of $2.3\ kW$. The heating gas has a density $0.72\ kg\ m^{-3}$. Each cubic metre of heating gas provides $39\ MJ$ of thermal energy. Use your answer to (a) to calculate

(i) the time required to raise the temperature of the air from $12\ °C$ to $21\ °C$.

(ii) the mass of heating gas used in this time.

(c) Suggest two reasons why the time required and the mass of heating gas will in practice be greater than the values calculated in (b).

Thermal Properties of Materials

Exam Style Question 2

(a) Calculate the thermal energy required to raise the temperature of the air in the room. The specific heat capacity of air is $990\ J\ kg^{-1}\ K^{-1}$.

Use $Q = mc\Delta\theta$

Step 1: calculate the mass of air:

$$m_{air} = V\rho_{air} = (4.5\ m \times 4\ m \times 2.4\ m)(1.3\ kg\ m^{-3})$$
$$m_{air} = 56.16\ kg$$

Step 2: Substitute it back into $Q = mc\Delta\theta$

$$Q = (56.16\ kg)(990\ J\ kg^{-1}\ K^{-1})(21℃ - 12℃)$$
$$Q = 500385.6\ J \approx 5.0 \times 10^5\ J$$

(b) The heater has an output power of $2.3\ kW$. The heating gas has a density $0.72\ kg\ m^{-3}$. Each cubic metre of heating gas provides $39\ MJ$ of thermal energy. Use your answer to (a) to calculate

(i) the time required to raise the temperature of the air from $12\ °C$ to $21\ °C$.

Use $P = \frac{E}{t}$ and rearrange for t:

$$t = \frac{E}{P} = \frac{5.00385 \times 10^5\ J}{2300\ W} = 218\ s$$

(ii) the mass of heating gas used in this time.

Step 1: calculate the volume of the heating gas supplied by the heater.

$$V_{gas} = \frac{5.0 \times 10^5\ J}{39 \times 10^6\ J} = 0.128\ m^3$$

Step 2: Calculate the mass of heating gas using

$$m_{heating\ gas} = V_{heating\ gas}\rho_{heating\ gas}$$
$$m = (0.0128\ m^3)(0.72\ kg\ m^{-3})$$
$$m = 9.2 \times 10^{-3}\ kg$$

(c) Suggest two reasons why the time required and the mass of heating gas will in practice be greater than the values calculated in (b).

Thermal energy (or heat) will be lost through the walls, windows, etc..

Warm air might escape the room or some cold air might enter the room.

Thermal Properties of Materials

Exam Style Question 3

(a) (i) Define specific heat capacity.

(ii) Describe the difference between the latent heat of fusion and the latent heat of vaporisation.

(b) The graph in Fig. 4.1 shows the variation of temperature with time for a fixed mass of substance when heated by a constant power source. At **A** the substance is a solid; at **E** the substance is a vapour.

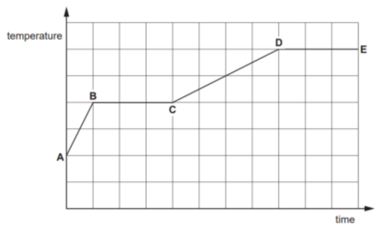

Fig. 4.1

(i) Describe the changes taking place in the kinetic energy and potential energy of the molecules for the following sections:

- A to B
- B to C

(ii) State and explain what you can conclude from Fig. 4.1 about the specific heat capacity of the substance in the solid state compared with the specific heat capacity of the substance in the liquid state.

(c) The electric heating element of a bathroom shower has a power rating of $5.0\ kW$. An attempt is made to test the accuracy of this value by measuring the rate of flow of the water and the temperature of the water before and after passing the element.

The results of the test and other required data are as follows:
temperature of water supply to the shower = $17.4\ °C$
temperature of water after being heated by the element = $36.7\ °C$
rate of flow of water = $3.60 \times 10^{-3}\ m^3\ min^{-1}$
density of water = $1000\ kg\ m^{-3}$
specific heat capacity of water = $4200\ J\ kg^{-1}\ K^{-1}$

(i) Show that the power of the heating element is approximately $5\ kW$.

(ii) State and explain a possible source of uncertainty that might affect the reliability of the test.

Thermal Properties of Materials

Exam Style Question 3

(a)(i) Define specific heat capacity.

Energy required to raise the temperature of a unit mass of a substance by unit temperature rise.

(a) (ii) Describe the difference between the latent heat of fusion and the latent heat of vaporisation.

LH of fusion is energy needed to change a substance from solid to liquid.
LH of vaporisation is energy needed to change a substance from liquid to gas/vapour.

(b) (i) Describe the changes taking place in the kinetic energy and potential energy of the molecules for the following sections:

- A to B

KE of molecules increases and PE of molecules small increase.

- B to C

KE of molecules remain constant and PE of molecules increases.

(b) (ii) State and explain what you can conclude from Fig. 4.1 about the specific heat capacity of the substance in the solid state compared with the specific heat capacity of the substance in the liquid state.

c_{solid} is less than c_{liquid}.
Gradient for solid is greater than gradient for liquid and the gradient is inversely proportional to specific heat capacity.

Exam Style Question 3

(a) (i) Define specific heat capacity.

(ii) Describe the difference between the latent heat of fusion and the latent heat of vaporisation.

(b) The graph in Fig. 4.1 shows the variation of temperature with time for a fixed mass of substance when heated by a constant power source. At **A** the substance is a solid; at **E** the substance is a vapour.

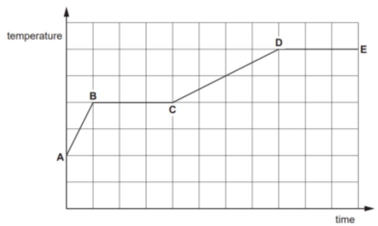

Fig. 4.1

(i) Describe the changes taking place in the kinetic energy and potential energy of the molecules for the following sections:

- A to B
- B to C

(ii) State and explain what you can conclude from Fig. 4.1 about the specific heat capacity of the substance in the solid state compared with the specific heat capacity of the substance in the liquid state.

(c) The electric heating element of a bathroom shower has a power rating of $5.0\ kW$. An attempt is made to test the accuracy of this value by measuring the rate of flow of the water and the temperature of the water before and after passing the element.

The results of the test and other required data are as follows:
temperature of water supply to the shower = $17.4\ °C$
temperature of water after being heated by the element = $36.7\ °C$
rate of flow of water = $3.60 \times 10^{-3}\ m^3\ min^{-1}$
density of water = $1000\ kg\ m^{-3}$
specific heat capacity of water = $4200\ J\ kg^{-1}\ K^{-1}$

(i) Show that the power of the heating element is approximately $5\ kW$.

(ii) State and explain a possible source of uncertainty that might affect the reliability of the test.

Thermal Properties of Materials

Exam Style Question 3

(c) (i) Show that the power of the heating element is approximately $5\ kW$.

In one second:

Volume flowing through = $\frac{3{,}6\times10^{-3}\ m^3\ min^{-1}}{60} = 6.0\times10^{-5}\ m^3\ s^{-1}$

Mass flowing through = $V\rho = (6.0\times10^{-5}\ m^3\ s^{-1})(1000\ kg\ m^{-3})$

Mass flowing through = $0.06\ kg\ s^{-1}$

Energy gained by water $E = mc\Delta\theta$

$$E = (0.060)(4200)(36.7 - 17.4)$$

$$E = 4863.6$$

Therefore $Power = \frac{E}{t} = \frac{4863.6}{1} = 4.9\times10^3 \approx 5\ kW$

(c) (ii) State and explain a possible source of uncertainty that might affect the reliability of the test.

Rate of flow of water changes because water pressure changes.
Inlet temperature changes because ambient temperature changes.

Thermal Properties of Materials

Exam Style Question 4

(a) State the term used for the energy required to change a solid into a liquid.

(b) (i) Define the internal energy of a system.

(ii) There is a change in internal energy when a mass of water at $100°C$ becomes an equal mass of vapour at $100°C$. Explain why.

(c) (i) The air in a greenhouse has a volume of $15\ m^3$, a density of $1.2\ kg\ m^{-3}$ and a specific heat capacity of $990\ J\ kg^{-1}\ K^{-1}$. Immediately after sunset, the soil is transferring thermal energy to the air at an average rate of $12W$. Estimate the increase in temperature of the air in the greenhouse one hour after sunset as a result of this energy transfer from the soil.

(ii) Suggest two possible reasons why the actual increase in temperature of the air is likely to be much lower than this estimate.

tutorpacks.co.uk

Thermal Properties of Materials

Exam Style Question 4

(a)State the term used for the energy required to change a solid into a liquid.
Latent heat of fusion.

(b) (i) Define the internal energy of a system.
Sum of randomly distributed KE and PE of molecules/atoms.

(ii) There is a change in internal energy when a mass of water at $100°C$ becomes an equal mass of vapour at $100°C$. Explain why.
PE of the molecules increases.
KE of the molecules is constant for water and steam since the temperature is the same. Work is done in moving molecules apart.

(c) (i) Estimate the increase in temperature of the air in the greenhouse one hour after sunset as a result of this energy transfer from the soil.

$$m_{air} = V\rho = (15\ m^3)(1.2\ kg\ m^{-3}) = 18\ kg$$

Heat energy transferred to air in one hour:

$$P = \frac{E}{t}$$

$$\therefore E = Pt = (12\ W)(3600\ seconds) = 43200\ J$$

Use $Q = mc\Delta\theta$ and rearrange for $\Delta\theta$

$$\Delta\theta = \frac{Q}{mc} = \frac{43200\ J}{(18\ kg)(990\ J\ kg^{-1}K^{-1})}$$

Therefore temperature rise in one hour $= 2.4\ K$

(ii) Suggest two possible reasons why the actual increase in temperature of the air is likely to be much lower than this estimate.

- Heat lost to the structure of the greenhouse.
- Heat lost through the glass.
- Average rate of loss of heat reduces as temperature falls.

tutorpacks.co.uk

Thermal Properties of Materials

Exam Style Question 5

Next to the 3000-year-old Drombeg circle in Ireland is a stone-lined pit known as a Fulacht Fiadh. It is believed that this was used as a cooking place for meat caught by hunters. The pit was filled with water. Large stones were heated in a fire and then placed in the water to bring it to the boil and cook the meat.

In experiments to test this idea it was found that the water in the pit started to boil after twenty-two heated stones had been added. The total mass of the added stones was 198 kg and the mass of water was 513 kg.

(a) Show that this gives a minimum temperature for the fire of about 900 $°C$.

Specific heat capacity of water = $4200\ J\ kg^{-1}\ °C^{-1}$

Average specific heat capacity of stone = $1100\ J\ kg^{-1}\ °C^{-1}$

Initial temperature of water = $18\ °C$

Temperature of boiling water = $100\ °C$

Thermal Properties of Materials

Exam Style Question 5

(a) Show that this gives a minimum temperature for the fire of about $\mathbf{900\ °C}$.

Heat lost by stone = heat gained by water

$$(mc\Delta\theta)_{stone} = (mc\Delta\theta)_{water}$$

$$(198\ kg)(1100\ J\ kg^{-1}\ ℃^{-1})\Delta\theta$$
$$= (513\ kg)(4200\ J\ kg^{-1}\ ℃^{-1})(100\ ℃ - 18\ ℃)$$
$$(217800)\Delta\theta = 176677200$$
$$\Delta\theta = \frac{176677200}{217800} = 811℃$$
$$\theta = 811℃ + 100℃ = 911℃$$

Please see ‘9.3.1 Thermal Properties of Materials notes’ pack for revision notes.

For more revision notes, tutorials and worked examples please visit www.tutorpacks.co.uk.