Chapter 2 Moving heat around

Section 2.1 Heat and temperature

Worked example: Try yourself 2.1.1

ENERGY EFFICIENCY

An electric kettle uses 23.3 kJ of electrical energy as it boils a quantity of water. The efficiency of the kettle is 18%. How much electrical energy is used in actually boiling the water? Give your answer in kJ.	
Thinking	**Working**
Recall the formula for efficiency of energy transfers.	efficiency $(\eta) = \frac{\text{energy output}}{\text{energy input}} \times 100\%$
Substitute the known values into the formula.	input = 23.2 kJ efficiency = 18% $18 = \frac{\text{output}}{23.3 \times 10^3} \times 100$
Solve the equation to find the unknown.	$\text{output} = \frac{18 \times 23.3 \times 10^3}{100}$ $= 4190\,\text{J}$ $= 4.19\,\text{kJ}$

Section 2.1 Review

KEY QUESTIONS SOLUTIONS

1 In coal-fired generators, the *chemical* energy from the coal is used to change water into steam, which possesses *heat* energy. The steam drives a turbine, which produces *kinetic* energy, which drives a generator, which produces *electrical* energy.

2 the mechanical work done on the water

3 $W = Fs$
$= 4.5 \times 9.80 \times 6.0$
$= 265\,\text{J}$

4 $\Delta U = Q + W$
$= 2530 + 240$
$= 2770\,\text{J}$

5 $W = Fs = mg \times s$
$= 980 \times 2.4$
$= 2352\,\text{J}$
$= 2.4\,\text{kJ}$

6 0 J. Since there is no change in position when the mass is being held steady, no work is done.

7 $\eta = \frac{\text{output}}{\text{input}} \times 100\%$
$= \frac{1.2}{4.8} \times 100$
$= 25\%$

8 $\eta = \frac{\text{output}}{\text{input}} \times 100\%$
$70 = \frac{\text{output}}{3.6 \times 10^3} \times 100\%$
$\text{output} = \frac{70}{100} \times 3.6 \times 10^3$
$= 2520\,\text{J}$
$= 2.5\,\text{kJ}$ (to two significant figures)

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9 $U = Q + W$
$= -1239 + 845$
$= -394\text{J}$

10 $\eta = \frac{\text{output}}{\text{input}} \times 100$
$30 = \frac{\text{output}}{2000} \times 100$
$\text{output} = \frac{30}{100} \times 2000$
$= 600\text{J}$

Section 2.2 Conduction

KEY QUESTIONS SOLUTIONS

1 The process is quite slow because the mass of the particles is relatively large and the vibrational velocities are fairly low.

2 Metals conduct heat by free electrons as well as by molecular collisions. Wood does not have any free electrons, so it is a poor conductor of heat.

3 The thickness, surface area, nature of the material and the temperature difference between it and another material.

4 Copper is a better conductor of heat than stainless steel.

5 C. Air is a poor conductor of heat so it limits the transfer of heat.

6 A lot of air is trapped in the down. As air is a poor conductor of heat, the down-filled quilt limits the transfer of heat away from the person.

7 The insulation batts stop the thermal energy from escaping the house. The air trapped in the batts causes the insulation to have low conductivity and so the thermal energy is not able to escape from the house.

8 Plastic and rubber have low conductivity, so they do not allow the transfer of heat from your hand very easily. Metal has high conductivity, so heat transfers from your hand easily and your hand feels cold.

9 Living areas with large windows should be on the northern side of the house and bedrooms with small windows should be on the southern side.

10 The main difference between single-glazed and double-glazed windows is that double-glazed windows have twin panes of glass with a sealed air space between them, which provides additional thermal resistance.

Section 2.3 Convection

KEY QUESTIONS SOLUTIONS

1 liquids and gases

2 upwards

3 Air over certain places, such as roads, heats up and as a result becomes less dense. The less dense air rises, forming a column of rising air called a thermal.

4 Liquids and gases can transfer heat quite quickly through convection, but they are both poor conductors of thermal energy.

5 It is not possible for solids to pass on heat by convection because solids do not contain the free molecules that are required to establish convection currents.

6 The source of heat, the Sun, is at the top of the water. It takes much longer to heat a liquid when the source is at the top as the convection currents will also remain near the top. The warm water is less dense than the cool water and will not allow convection currents to form throughout the water.

7 Near the heat source, gas or liquid expands and hence become less dense.
The less-dense liquid or gas rises, while cooler, more-dense liquid or gas sinks.
This causes convection within the liquid or gas as there is movement of particles within the material.
Hence, heat input into the liquid or gas near the heat source is transferred to other places by the warm, less-dense fluid.

8 The surface area exposed and the temperature difference between the fluid and the second material providing the heat.

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Section 2.4 Radiation

KEY QUESTIONS SOLUTIONS

1 **a** The light can be partially reflected, partially transmitted and partially absorbed.
b Absorption of light is associated with temperature increase.

2 The higher the temperature of the object, the **higher** the frequency and the **shorter** the wavelength of the radiation emitted. For example, if a particular object emits radiation in the visible range, a cooler one could emit light in the **infrared** range of the electromagnetic spectrum.

3 E. The rate of emission or absorption will depend upon:
- the temperature of the object and of the surrounding environment
- the surface area of the object
- the wavelength of the radiation
- the surface characteristics of the object (e.g. its colour, and whether it is shiny or dull).

4 Conduction and convection require the presence of particles to transfer heat. Heat transfer by radiation can occur in a vacuum as the movement of particles is not required.

5 The person will have a higher temperature than their surroundings, and so will emit stronger infrared radiation than their surroundings. The infrared radiation is detected by the thermal imaging technology. The human eye cannot always distinguish a person from their surroundings, especially if they are under cover or if their clothes blend with the background.

6 **a** The matte black beaker cools faster than the others because matte black objects emit radiant energy faster than shiny, white surfaces.
b The gloss white surface will cool the slowest due to its light colour and shiny finish.

7 Heat sinks are made of dark-coloured metals that radiate heat energy strongly and keep the computer cool.

CHAPTER 2 REVIEW

1 **a** $\eta = \frac{\text{output}}{\text{input}} \times 100\%$

Incandescent:

$2 = \frac{\text{output}}{1000} \times 100\%$

$\text{output} = \frac{2}{100} \times 1000$

$\text{output} = 20\,\text{J}$

b LED

$15 = \frac{\text{output}}{1000} \times 100\%$

$\text{output} = \frac{15}{100} \times 1000$

$\text{output} = 150\,\text{J}$

2 Running costs of the incandescent lights are 7.5 times that of the LED lights.

$\text{ratio} = \frac{15\%}{2\%} = 7.5$

3 $U = W + Q$

$= 520 + 1850$

$= 2370\,\text{J}$

4 $Q = mc\ \ T$

$T = \frac{Q}{mc}$

$= \frac{2370}{0.200 \times 4180}$

$= 2.83°\text{C}$

$T_{\text{final}} = T_{\text{initial}} + \ \ T$

$= 20.0 + 2.83$

$= 22.8°\text{C}$

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5 $\Delta Q = mc\Delta T$
$= 0.200 \times 4180 \times (21.50 - 20.0)$
$= 1254\,\text{J}$

6 $\eta = \frac{\text{output}}{\text{input}} \times 100\%$

$= \frac{1254}{2370} \times 100$
$= 52.9\%$

7 C. This will always be from the hottest to the coldest, i.e. from the object with the highest average internal kinetic energy.

8 **a** convection; **b** conduction

9 **a** The end of the poker that is not in the fire is warmed through conduction.
b You will feel the heat primarily through radiation.
c Heat escapes primarily due to conduction.

10 radiation

11 radiation and convection (primarily convection)

12 The Earth radiates an amount of energy into space equal to the amount it receives. This is affected by the composition of the atmosphere and the reflective index of the Earth and the atmosphere. Changes in either would lead to a change in the equilibrium position and a hotter or cooler Earth.

13 The function of the evacuated enclosure between the walls of a vacuum flask is to reduce heat losses due to conduction. (As seen in question 10, the silver coating on the walls reduces losses due to radiation.)

14 Expose both surfaces to a heater under the same temperature and environmental conditions. Measure the time each takes to heat to a particular temperature or measure the temperature of each surface after the same time. Thermal blankets are one real-world example.

15 Premature babies can lose a lot of moisture through their skin by evaporation. For a baby in a very warm environment, like an incubator at 37°C, there will be a large evaporative effect. A significant increase in evaporation occurs at incubator temperatures, and that evaporation of moisture from the baby will cool the baby dramatically. Thus an incubator must have not only a high temperature but also a high humidity. Other factors might include radiative energy loss, blood vessels being close to the skin surface and so there is less insulation than in an older baby.

16 Snow has a low thermal conductivity because it has many tiny air pockets trapped in its structure. Since this air-filled snow has a low thermal conductivity, the snow will not conduct much heat away from an object covered in it.

17 Both will be at the same temperature, matching that of their surroundings.

18 While paper is a better insulator and the can is a better conductor, the can will have a greater mass and hence take longer to heat up.

19 As cold water is denser than hot water, replacement water should enter at the bottom of the tank. Hot water should be drawn off at the top.

20 Air is a poorer conductor of heat than water. Hence, the rate of heat loss in air is less than the rate of heat loss in water. You transfer heat more quickly to the water and thus feel cold. Referring to Chapter 1, the specific heat capacity of water is higher than air so the water in contact with your body will heat up less quickly than the air in contact with your body. This also has the effect of increasing heat transfer away from your body.

 ISBN 978 1 4886 17713