Thermodynamics
May 02

2 Some water in a saucepan is boiling.

(a) Explain why

(i) external work is done by the boiling water,

....

....

....

(ii) there is a change in the internal energy as water changes to steam.

....

....

....
[5]

(b) By reference to the first law of thermodynamics and your answers in **(a)**, show that thermal energy must be supplied to the water during the boiling process.

....

....

....[2]

May 02

3 (a) (i) The kinetic theory of gases leads to the equation

$$\tfrac{1}{2}m\langle c^2\rangle = \tfrac{3}{2}kT.$$

Explain the significance of the quantity $\tfrac{1}{2}m\langle c^2\rangle$.

....

....

(ii) Use the equation to suggest what is meant by the absolute zero of temperature.

....

....

[3]

(b) Two insulated gas cylinders **A** and **B** are connected by a tube of negligible volume, as shown in Fig. 3.1.

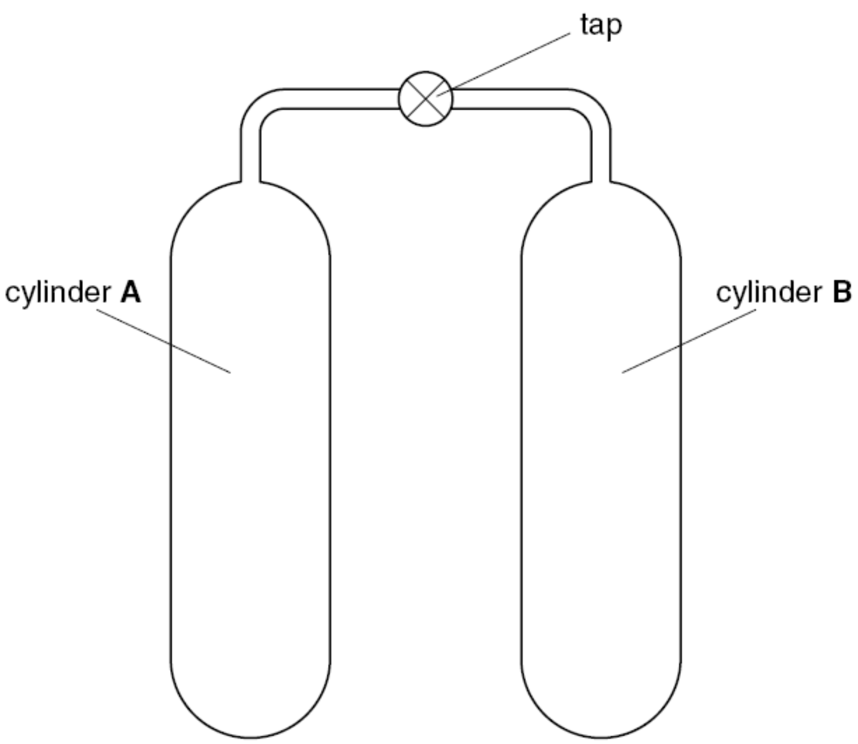

Fig. 3.1

Each cylinder has an internal volume of $2.0 \times 10^{-2}\,m^3$. Initially, the tap is closed and cylinder **A** contains 1.2 mol of an ideal gas at a temperature of 37 °C. Cylinder **B** contains the same ideal gas at pressure 1.2×10^5 Pa and temperature 37 °C.

(i) Calculate the amount, in mol, of the gas in cylinder **B**.

amount = ... mol

(ii) The tap is opened and some gas flows from cylinder **A** to cylinder **B**. Using the fact that the total amount of gas is constant, determine the final pressure of the gas in the cylinders.

pressure = ... Pa

[6]

Nov 02

1 A kettle is rated as 2.3 kW. A mass of 750 g of water at 20 °C is poured into the kettle. When the kettle is switched on, it takes 2.0 minutes for the water to start boiling. In a further 7.0 minutes, one half of the mass of water is boiled away.

(a) Estimate, for this water,

(i) the specific heat capacity,

specific heat capacity = ... $J\,kg^{-1}\,K^{-1}$

(ii) the specific latent heat of vaporisation.

specific latent heat = ... $J\,kg^{-1}$

[5]

(b) State **one** assumption made in your calculations, and explain whether this will lead to an overestimation or an underestimation of the value for the specific latent heat.

....

....

....[2]

May 03

2 **(a)** On Fig. 2.1, place a tick (✓) against those changes where the internal energy of the body is increasing. [2]

water freezing at constant temperature	....
a stone falling under gravity in a vacuum	....
water evaporating at constant temperature	....
stretching a wire at constant temperature	....

Fig. 2.1

(b) A jeweller wishes to harden a sample of pure gold by mixing it with some silver so that the mixture contains 5.0% silver by weight. The jeweller melts some pure gold and then adds the correct weight of silver. The initial temperature of the silver is 27 °C. Use the data of Fig. 2.2 to calculate the initial temperature of the pure gold so that the final mixture is at the melting point of pure gold.

	gold	silver
melting point / K	1340	1240
specific heat capacity (solid or liquid) / $J\,kg^{-1}\,K^{-1}$	129	235
specific latent heat of fusion / $kJ\,kg^{-1}$	628	105

Fig. 2.2

temperature = ... K [5]

(c) Suggest a suitable thermometer for the measurement of the initial temperature of the gold in **(b)**.

.... [1]

Nov 03

3 The volume of some air, assumed to be an ideal gas, in the cylinder of a car engine is 540 cm^3 at a pressure of 1.1×10^5 Pa and a temperature of 27 °C. The air is suddenly compressed, so that no thermal energy enters or leaves the gas, to a volume of 30 cm^3. The pressure rises to 6.5×10^6 Pa.

(a) Determine the temperature of the gas after the compression.

temperature = ... K [3]

(b) (i) State and explain the first law of thermodynamics.

....

....

....

.... [2]

(ii) Use the law to explain why the temperature of the air changed during the compression.

....

....

....

....

.... [4]

May 04

2 The pressure p of an ideal gas is given by the expression

$$p = \frac{1}{3}\frac{Nm}{V}\langle c^2\rangle .$$

(a) Explain the meaning of the symbol $\langle c^2\rangle$.

....

.... [2]

(b) The ideal gas has a density of $2.4\,\mathrm{kg\,m^{-3}}$ at a pressure of $2.0 \times 10^5\,\mathrm{Pa}$ and a temperature of 300 K.

(i) Determine the root-mean-square (r.m.s.) speed of the gas atoms at 300 K.

r.m.s. speed = ... $\mathrm{m\,s^{-1}}$ [3]

(ii) Calculate the temperature of the gas for the atoms to have an r.m.s. speed that is twice that calculated in **(i)**.

temperature = ... K [3]

May 04

6 The first law of thermodynamics may be expressed in the form

$$\Delta U = q + w,$$

where U is the internal energy of the system,
ΔU is the increase in internal energy,
q is the thermal energy supplied to the system,
w is the work done on the system.

Complete Fig. 6.1 for each of the processes shown. Write down the symbol '+' for an increase, the symbol '–' to indicate a decrease and the symbol '0' for no change, as appropriate.

	U	q	w
the compression of an ideal gas at constant temperature			
the heating of a solid with no expansion			
the melting of ice at 0 °C to give water at 0 °C (Note: ice is less dense than water)			

[6]

Fig. 6.1

Nov 04

7 The e.m.f. generated in a thermocouple thermometer may be used for the measurement of temperature.

Fig. 7.1 shows the variation with temperature T of the e.m.f. E.

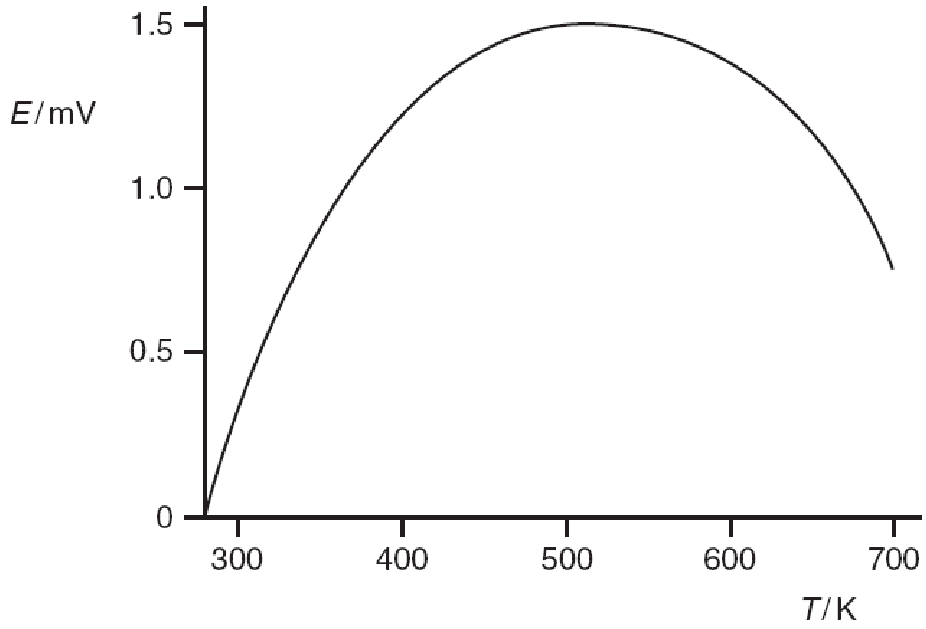

Fig. 7.1

(a) By reference to Fig. 7.1, state two disadvantages of using this thermocouple when the e.m.f. is about 1.0 mV.

1. ....

2. ....[2]

(b) An alternative to the thermocouple thermometer is the resistance thermometer.

State two advantages that a thermocouple thermometer has over a resistance thermometer.

1. ....

....

2. ....

....[2]

May 05

2 **(a)** State what is meant by an *ideal* gas.

....

....

....[2]

(b) The product of pressure p and volume V of an ideal gas of density ρ at temperature T is given by the expressions

$$p = \tfrac{1}{3}\rho\langle c^2\rangle$$

and

$$pV = NkT,$$

where N is the number of molecules and k is the Boltzmann constant.

(i) State the meaning of the symbol $\langle c^2\rangle$.

....[1]

(ii) Deduce that the mean kinetic energy E_K of the molecules of an ideal gas is given by the expression

$$E_K = \tfrac{3}{2}kT.$$

[2]

(c) In order for an atom to escape completely from the Earth's gravitational field, it must have a speed of approximately $1.1 \times 10^4\,\mathrm{m\,s^{-1}}$ at the top of the Earth's atmosphere.

(i) Estimate the temperature at the top of the atmosphere such that helium, assumed to be an ideal gas, could escape from the Earth. The mass of a helium atom is 6.6×10^{-27} kg.

temperature = ... K [2]

(ii) Suggest why some helium atoms will escape at temperatures below that calculated in **(i)**.

....

....[1]

May 05

3 **(a)** Define *specific latent heat of fusion*.

....

....

....[2]

(b) A mass of 24 g of ice at –15 °C is taken from a freezer and placed in a beaker containing 200 g of water at 28 °C. Data for ice and for water are given in Fig. 3.1.

	specific heat capacity / $J\,kg^{-1}\,K^{-1}$	specific latent heat of fusion / $J\,kg^{-1}$
ice	2.1×10^3	3.3×10^5
water	4.2×10^3	–

Fig. 3.1

(i) Calculate the quantity of thermal energy required to convert the ice at –15 °C to water at 0 °C.

energy = ... J [3]

(ii) Assuming that the beaker has negligible mass, calculate the final temperature of the water in the beaker.

temperature = ... °C [3]

Nov 05

2 The air in a car tyre has a constant volume of $3.1 \times 10^{-2}\,m^3$. The pressure of this air is $2.9 \times 10^5\,Pa$ at a temperature of 17 °C. The air may be considered to be an ideal gas.

(a) State what is meant by an *ideal* gas.

....

....

.... [2]

(b) Calculate the amount of air, in mol, in the tyre.

amount = ... mol [2]

(c) The pressure in the tyre is to be increased using a pump. On each stroke of the pump, 0.012 mol of air is forced into the tyre.
Calculate the number of strokes of the pump required to increase the pressure to $3.4 \times 10^5\,Pa$ at a temperature of 27 °C.

number = ... [3]

Nov 05

3 **(a)** State the first law of thermodynamics in terms of the increase in internal energy ΔU, the heating q of the system and the work w done on the system.

....

.... [1]

(b) The volume occupied by 1.00 mol of liquid water at 100 °C is $1.87 \times 10^{-5}\,m^3$. When the water is vaporised at an atmospheric pressure of 1.03×10^5 Pa, the water vapour has a volume of $2.96 \times 10^{-2}\,m^3$.
The latent heat required to vaporise 1.00 mol of water at 100 °C and 1.03×10^5 Pa is 4.05×10^4 J.
Determine, for this change of state,

(i) the work w done on the system,

w = ... J [2]

(ii) the heating q of the system,

q = ... J [1]

(iii) the increase in internal energy ΔU of the system.

ΔU = ... J [1]

(c) Using your answer to **(b)(iii)**, estimate the binding energy per molecule in liquid water.

energy = ... J [2]

May 06

2 **(a)** The equation

$$pV = constant \times T$$

relates the pressure p and volume V of a gas to its kelvin (thermodynamic) temperature T.

State two conditions for the equation to be valid.

1. ....

....

2. ....

.... [2]

(b) A gas cylinder contains $4.00 \times 10^4\,cm^3$ of hydrogen at a pressure of $2.50 \times 10^7\,Pa$ and a temperature of 290 K.

The cylinder is to be used to fill balloons. Each balloon, when filled, contains $7.24 \times 10^3\,cm^3$ of hydrogen at a pressure of $1.85 \times 10^5\,Pa$ and a temperature of 290 K.

Calculate, assuming that the hydrogen obeys the equation in **(a)**,

(i) the total amount of hydrogen in the cylinder,

amount = ……………………….. mol [3]

(ii) the number of balloons that can be filled from the cylinder.

number = ……………………….. [3]

May 06

3 The electrical resistance of a thermistor is to be used to measure temperatures in the range 12 °C to 24 °C. Fig. 3.1 shows the variation with temperature, measured in degrees Celsius, of the resistance of the thermistor.

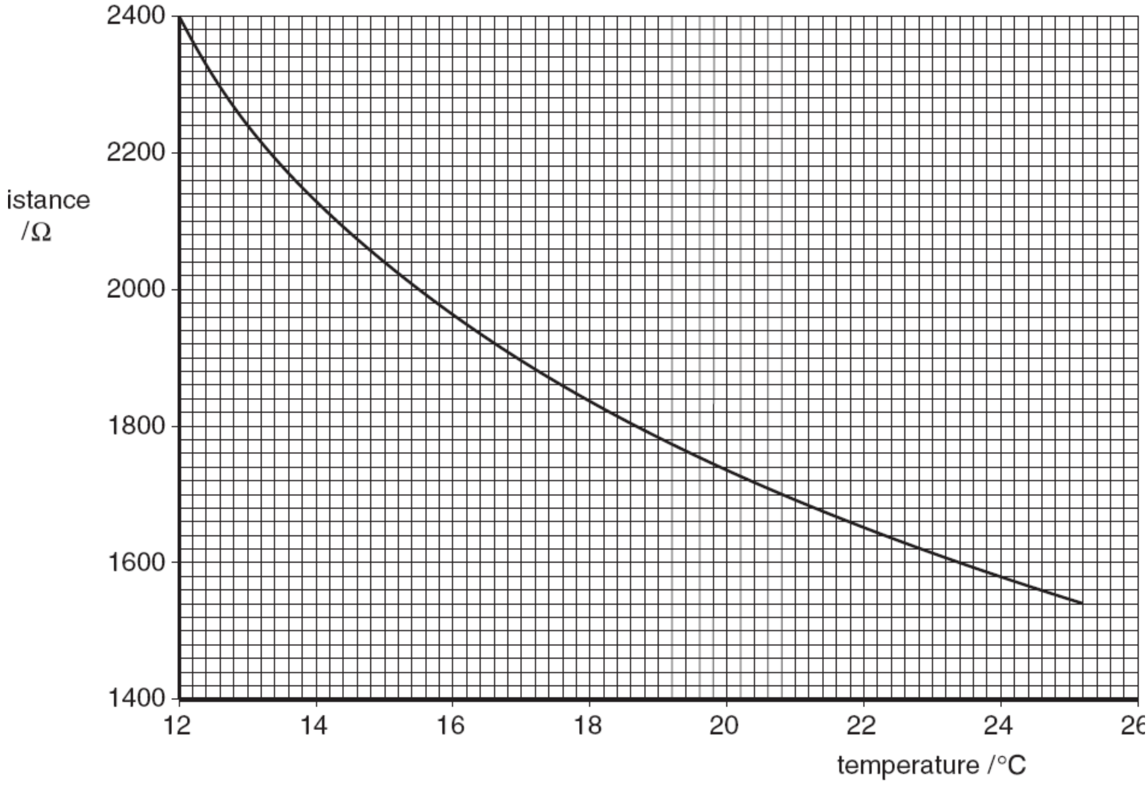

Fig. 3.1

(a) State and explain the feature of Fig. 3.1 which shows that the thermometer has a sensitivity that varies with temperature.

....

....

.... [2]

(b) At one particular temperature, the resistance of the thermistor is 2040 ± 20 Ω.

Determine this temperature, in kelvin, to an appropriate number of decimal places.

temperature = ... K [3]

Nov 06

2 A mercury-in-glass thermometer is to be used to measure the temperature of some oil.

The oil has mass 32.0 g and specific heat capacity 1.40 J g^{-1} K^{-1}. The actual temperature of the oil is 54.0 °C.

The bulb of the thermometer has mass 12.0 g and an average specific heat capacity of 0.180 J g^{-1} K^{-1}. Before immersing the bulb in the oil, the thermometer reads 19.0 °C.

The thermometer bulb is placed in the oil and the steady reading on the thermometer is taken.

(a) Determine

(i) the steady temperature recorded on the thermometer,

temperature = ... °C [3]

(ii) the ratio

$$\frac{\text{change in temperature of oil}}{\text{initial temperature of oil}}.$$

ratio = ... [1]

b) Suggest, with an explanation, a type of thermometer that would be likely to give a smaller value for the ratio calculated in **(a)(ii)**.

....

....

.... [2]

c) The mercury-in-glass thermometer is used to measure the boiling point of a liquid. Suggest why the measured value of the boiling point will **not** be affected by the thermal energy absorbed by the thermometer bulb.

....

....

....

.... [2]

May 07

2 **(a)** Use the kinetic theory of matter to explain why melting requires energy but there is no change in temperature.

....

....

....

.... [3]

(b) Define *specific latent heat of fusion*.

....

....

.... [2]

(c) A block of ice at 0 °C has a hollow in its top surface, as illustrated in Fig. 2.1.

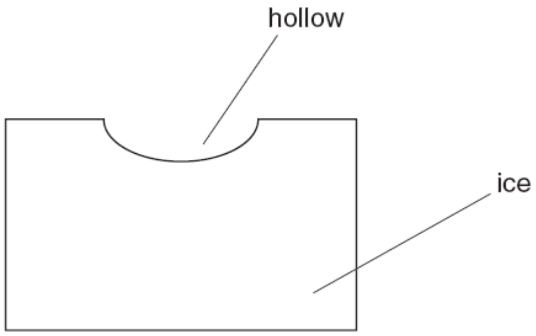

Fig. 2.1

A mass of 160 g of water at 100 °C is poured into the hollow. The water has specific heat capacity 4.20 kJ kg^{-1} K^{-1}. Some of the ice melts and the final mass of water in the hollow is 365 g.

(i) Assuming no heat gain from the atmosphere, calculate a value, in kJ kg^{-1}, for the specific latent heat of fusion of ice.

specific latent heat = ... kJ kg^{-1} [3]

(ii) In practice, heat is gained from the atmosphere during the experiment. This means that your answer to **(i)** is not the correct value for the specific latent heat. State and explain whether your value in **(i)** is greater or smaller than the correct value.

....

....

.... [2]

Nov 07

2 **(a)** An amount of 1.00 mol of Helium-4 gas is contained in a cylinder at a pressure of 1.02×10^5 Pa and a temperature of 27 °C.

(i) Calculate the volume of gas in the cylinder.

volume = ... m^3 [2]

(ii) Hence show that the average separation of gas atoms in the cylinder is approximately 3.4×10^{-9} m.

[2]

(b) Calculate

(i) the gravitational force between two Helium-4 atoms that are separated by a distance of 3.4×10^{-9} m,

force = ... N [3]

(ii) the ratio

$$\frac{\text{weight of a Helium-4 atom}}{\text{gravitational force between two Helium-4 atoms with separation } 3.4 \times 10^{-9}\,\text{m}}.$$

ratio = ...[2]

(c) Comment on your answer to **(b)(ii)** with reference to one of the assumptions of the kinetic theory of gases.

....

....

....[2]

May 08

2 **(a)** Explain qualitatively how molecular movement causes the pressure exerted by a gas.

....

....

....

....[3]

(b) The density of neon gas at a temperature of 273 K and a pressure of 1.02×10^5 Pa is $0.900\,\text{kg}\,\text{m}^{-3}$. Neon may be assumed to be an ideal gas.

Calculate the root-mean-square (r.m.s.) speed of neon atoms at

(i) 273 K,

speed = ... $\text{m}\,\text{s}^{-1}$ [3]

(ii) 546 K.

speed = ... $\text{m}\,\text{s}^{-1}$ [2]

(c) The calculations in **(b)** are based on the density for neon being 0.900 kg m^{-3}.
Suggest the effect, if any, on the root-mean-square speed of changing the density at constant temperature.

....

....

.... [2]

Nov 08

2 **(a)** Define *specific latent heat of fusion.*

....

....

....[2]

(b) Some crushed ice at 0 °C is placed in a funnel together with an electric heater, as shown in Fig. 2.1.

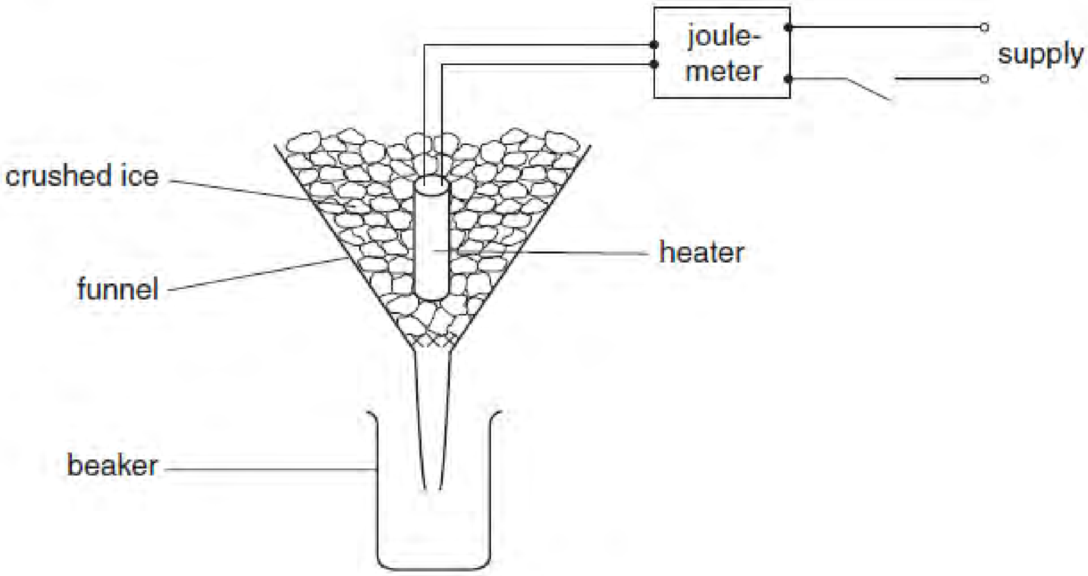

Fig. 2.1

The mass of water collected in the beaker in a measured interval of time is determined with the heater switched off. The mass is then found with the heater switched on. The energy supplied to the heater is also measured.
For both measurements of the mass, water is not collected until melting occurs at a constant rate.
The data shown in Fig. 2.2 are obtained.

	mass of water / g	energy supplied to heater / J	time interval / min
heater switched off heater switched on	16.6 64.7	0 18000	10.0 5.0

Fig. 2.2

(i) State why the mass of water is determined with the heater switched off.

....

....[1]

(ii) Suggest how it can be determined that the ice is melting at a constant rate.

....

....[1]

(iii) Calculate a value for the specific latent heat of fusion of ice.

latent heat = ... kJ kg^{-1} [3]

Nov 08

4 (a) Write down an equation to represent the first law of thermodynamics in terms of the heating q of a system, the work w done on the system and the increase ΔU in the internal energy.

....[1]

(b) The pressure of an ideal gas is decreased at constant temperature.
Explain what change, if any, occurs in the internal energy of the gas.

....

....

....

....[3]

May 09

2 Sources of α-particles are frequently found to contain traces of helium gas.
A radioactive source emits α-particles at a constant rate of $3.5 \times 10^{6}\,s^{-1}$. The α-particles are collected for a period of 40 days. Each α-particle becomes one helium atom.

(a) By reference to the half-life of the source, suggest why it may be assumed that the rate of emission of α-particles is constant.

....

.... [1]

(b) The helium gas may be assumed to be an ideal gas. Calculate the volume of gas that is collected at a pressure of 1.5×10^{5} Pa and at a temperature of 17 °C.

volume = ... m^3 [3]

May 09

3 When a liquid is boiling, thermal energy must be supplied in order to maintain a constant temperature.

(a) State two processes for which thermal energy is required during boiling.

1. ....

....

2. ....

....
[2]

(b) A student carries out an experiment to determine the specific latent heat of vaporisation of a liquid.
Some liquid in a beaker is heated electrically as shown in Fig. 3.1.

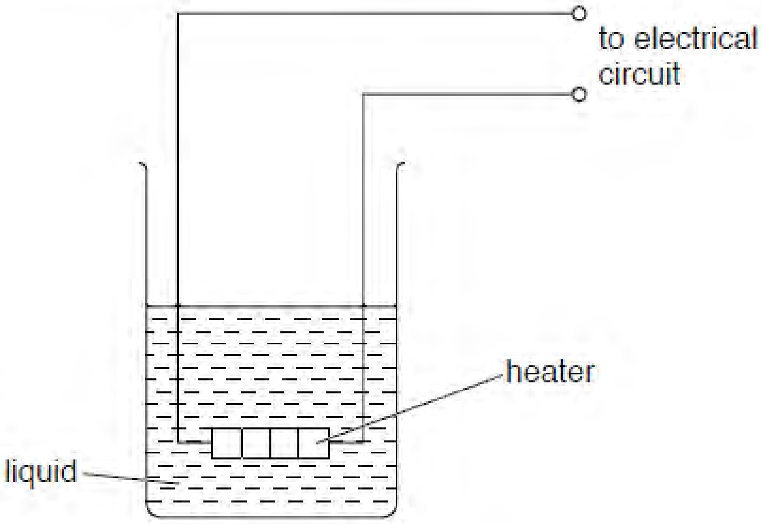

Fig. 3.1

Energy is supplied at a constant rate to the heater. When the liquid is boiling at a constant rate, the mass of liquid evaporated in 5.0 minutes is measured.
The power of the heater is then changed and the procedure is repeated.
Data for the two power ratings are given in Fig. 3.2.

power of heater /W	mass evaporated in 5.0 minutes /g
50.0 70.0	6.5 13.6

Fig. 3.2

(i) Suggest

1. how it may be checked that the liquid is boiling at a constant rate,

....

.... [1]

2. why the rate of evaporation is determined for two different power ratings.

....

.... [1]

(ii) Calculate the specific latent heat of vaporisation of the liquid.

specific latent heat of vaporisation = ... $J\,g^{-1}$ [3]