3 **(a)** State what is meant by two objects being in thermal equilibrium.

....

....

.... [2]

(b) Fig. 3.1 shows a type of thermometer called a constant volume gas thermometer.

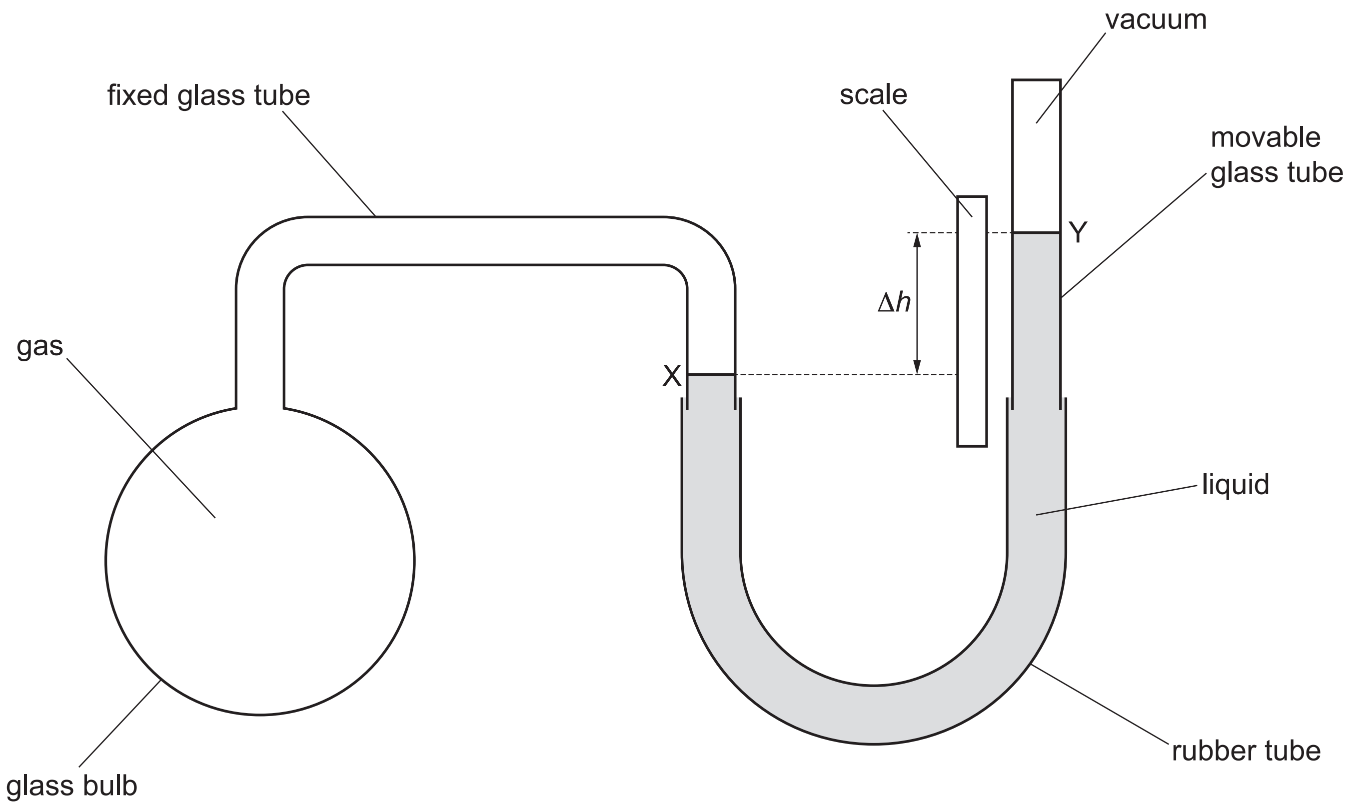

Fig. 3.1 (not to scale)

The thermometer is used to determine the thermodynamic temperature T of the gas in the glass bulb.

The glass bulb is immersed in the environment for which the temperature is to be measured. The height of the movable glass tube is then adjusted so that the level of the liquid on the left-hand side aligns with the reference line X marked on the fixed glass tube. The reference line Y is marked on the side of the movable glass tube. The level of the liquid at Y is higher than at X as a result of the pressure of the gas in the glass bulb.

The difference in height Δh between the liquid levels at X and Y is then measured using the scale. The thermodynamic temperature T of the gas is directly proportional to the pressure of the gas. This pressure is directly proportional to Δh.

(i) The value of Δh can be used to calculate the pressure of the gas. In order to do this, the gravitational field strength is used, along with a property of the liquid.

State the property of the liquid that is used to calculate the pressure.

.... [1]

(ii) Before the measurement of Δh can be made, the glass bulb needs to reach thermal equilibrium with the environment for which the temperature is to be measured.

State **two** disadvantages of using a constant volume gas thermometer to measure temperature.

1 ....

....

2 ....

....
[2]

(iii) Suggest **one** situation in which a constant volume gas thermometer would be an appropriate type of thermometer to choose for measuring temperature.

....

....

.... [1]

(iv) Level X aligns with 2.31 cm on the scale. At 0 °C, level Y aligns with 8.69 cm.

At temperature θ, level Y aligns with 7.83 cm on the scale.

Determine a value for θ in °C.

θ = ... °C [3]

2 **(a)** State **two** ways in which the first law of thermodynamics describes that the internal energy of a system may be changed.

1 ....

....

2 ....

....
[2]

(b) **(i)** Use the first law of thermodynamics to explain why a bicycle pump gets hot when it is used to pump up a tyre quickly.

....

....

....

....

.... [3]

(ii) With reference to molecular energies, explain why the temperature of water remains at 100 °C when it vaporises in a kettle, even though it is being heated.

....

....

....

....

.... [3]

4 **(a)** State the value of absolute zero on:

(i) the Celsius temperature scale

temperature = ... °C [1]

(ii) the thermodynamic temperature scale. Give a unit with your answer.

temperature = ... unit .... [1]

(b) A sample contains a fixed amount of gas. The gas has pressure p, volume V and thermodynamic temperature T.

Fig. 4.1 shows the variation of pV with kT for the sample, where k is the Boltzmann constant.

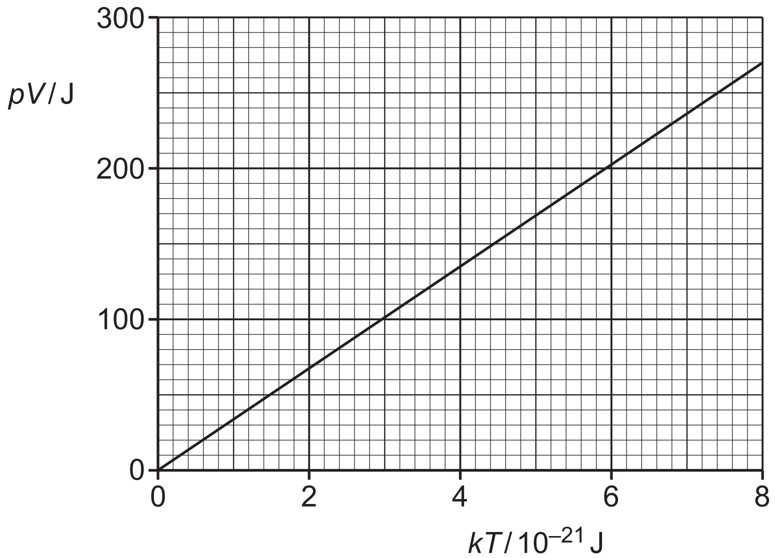

Fig. 4.1

(i) State what is indicated about the nature of the gas from the variation shown in Fig. 4.1.

.... [1]

(ii) Determine the number N of molecules of the gas in the sample.

N = ... [2]

(iii) Use your answer in **(b)(ii)** to determine the amount *n* of gas in the sample.

n = ... mol [1]

(c) The root-mean-square (r.m.s.) speed of the molecules of the gas is 1900 m s^{-1} when pV is equal to 270 J.

Determine the mass, in u, of one molecule of the gas, where u is the unified atomic mass unit.

mass = ... u [4]

2 **(a)** State what is meant by two objects being in thermal equilibrium.

....

....

.... [2]

(b) A mass X of ice at 0 °C is placed in a beaker containing a mass M of water at Celsius temperature t. The beaker is perfectly insulated and has negligible heat capacity. After some time, the ice that was added reaches thermal equilibrium with the original water in the beaker.

The specific latent heat of fusion of water is L. The specific heat capacity of water is c.
The final Celsius temperature of the system is θ.

Give expressions, in terms of some or all of X, M, t, θ, L and c, for the thermal energy:

(i) E_1, gained by the ice as it melts to become water at 0 °C

E_1 = ... [1]

(ii) E_2, lost by the water as its Celsius temperature decreases from t to θ

E_2 = ... [1]

(iii) E_3, gained by the melted ice as its Celsius temperature increases from 0 °C to θ.

E_3 = ... [1]

(c) Use your answers in **(b)** to show that the final Celsius temperature θ of the system is given by

$$\theta = \frac{Mct - XL}{c(M + X)}.$$

[2]

3 **(a)** Define specific heat capacity.

....

....

.... [2]

(b) A block of aluminium has a volume of $3.612 \times 10^{-3}\,m^3$ at a temperature of 0 °C.

Aluminium has a density of $2.700 \times 10^3\,kg\,m^{-3}$ at 0 °C.
It has a density of $2.620 \times 10^3\,kg\,m^{-3}$ at 500 °C.

The block is heated so that its temperature increases from 0 °C to 500 °C at an atmospheric pressure of $1.01 \times 10^5\,Pa$.
The increase in internal energy of the block is 4.38 MJ.

(i) Calculate the mass of the block.

mass = ... kg [2]

(ii) Show that the volume of the block at a temperature of 500 °C is $3.722 \times 10^{-3}\,m^3$.

[1]

(iii) Use the information in **(b)(ii)** to determine the magnitude of the work done on the block when its temperature is raised from 0 °C to 500 °C.

work done = ... J [2]

(iv) Explain whether the work done on the block is positive or negative.

....

....

.... [2]

(v) Use the first law of thermodynamics to determine, to three significant figures, a value for the specific heat capacity of aluminium. Explain your reasoning. Give a unit with your answer.

specific heat capacity = ... unit .... [3]

(c) Without further calculation, suggest with a reason how doubling the pressure in **(b)** is likely to affect the answer in **(b)(v)**.

....

....

.... [1]

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

....

....

.... [2]

(b) Explain why, for a substance, the specific latent heat of vaporisation is usually greater than the specific latent heat of fusion.

....

....

....

....

.... [3]

(c) An ice cube of mass 37.0 g at temperature 0.0 °C is placed in a beaker containing water of mass 208 g at temperature 26.4 °C.

When all the ice has melted, and all the water in the beaker has reached thermal equilibrium, the final temperature of all the water is 10.3 °C.

The specific heat capacity of water is $4.18\,\text{J}\,\text{g}^{-1}\,{}^{\circ}\text{C}^{-1}$.

The beaker has negligible specific heat capacity and is perfectly insulated from the surroundings.

Determine a value, to three significant figures, for the specific latent heat of fusion of water.

specific latent heat of fusion = ... $\text{J}\,\text{g}^{-1}$ [4]

3 **(a)** Two metal cuboids P and Q are in thermal contact with each other.

(i) P and Q are in thermal equilibrium.

State what is meant by the term thermal equilibrium.

....

....

.... [2]

(ii) Data for P and Q are given in Table 3.1.

Table 3.1

	P	Q
specific heat capacity / $J\,kg^{-1}\,K^{-1}$	390	910
mass / kg	0.54	0.37

P and Q are initially both at the same temperature.

P is supplied with 24 kJ of thermal energy. After some time, P and Q are once again both at the same temperature as each other.

P and Q are perfectly insulated from the surroundings.

Determine the change in temperature ΔT of Q.

ΔT = ... K [3]

(b) Nitrogen may be assumed to be an ideal gas. A fixed amount of nitrogen gas is contained at a constant pressure of 1.6×10^5 Pa.

The variation of the volume V of the gas with the temperature θ of the gas is shown in Fig. 3.1.

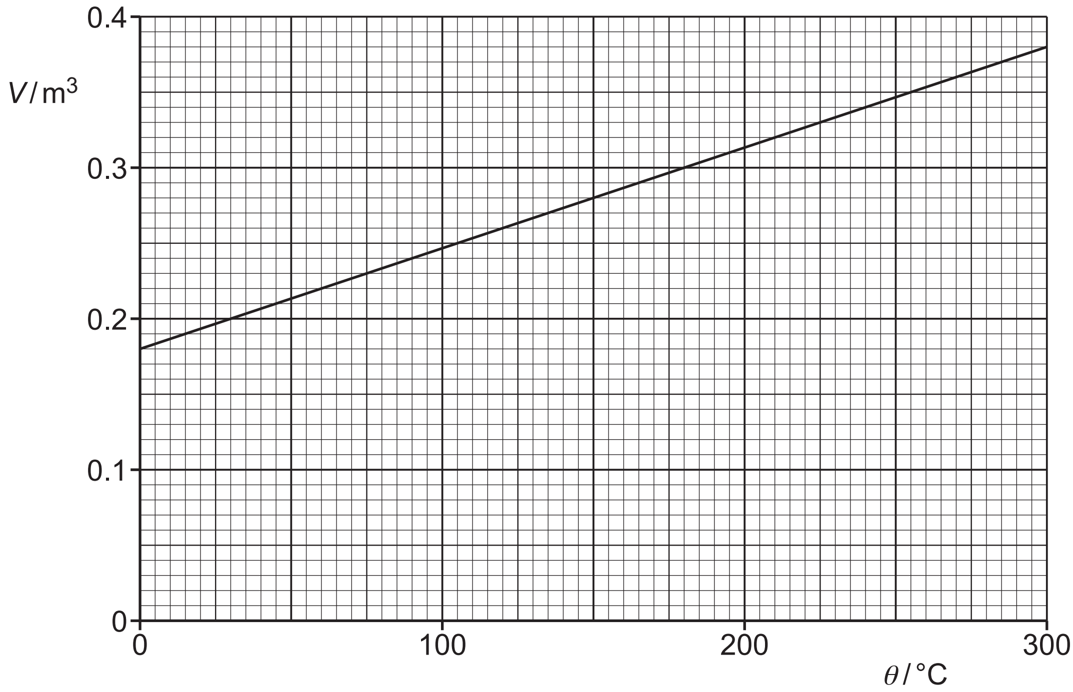

Fig. 3.1

(i) The temperature of the nitrogen gas is increased from 0 °C to 210 °C.
Determine the work done on the gas.

work done = ... J [3]

(ii) Determine the number N of molecules of nitrogen gas.

N = ... [2]

(iii) The mass of a nitrogen molecule is 4.7×10^{-26} kg.

Calculate the root-mean-square (r.m.s.) speed of a nitrogen molecule at 210 °C.

r.m.s. speed = ... $m s^{-1}$ [2]

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

....

....

.... [2]

(b) A dish containing $7.2 \times 10^{-5}\,\text{m}^3$ of a substance rests on a laboratory bench. The substance is initially a liquid of density $710\,\text{kg}\,\text{m}^{-3}$. Atmospheric pressure is $1.0 \times 10^5\,\text{Pa}$.

The liquid is heated at its boiling point so that it completely vaporises. The increase in the internal energy of the substance during this process is 17.6 kJ. The final volume of the vapour is $0.017\,\text{m}^3$.

(i) Show that the magnitude of the work done on the substance when it vaporises is 1.7 kJ.

[2]

(ii) Use the information in **(b)(i)** to calculate the thermal energy Q, in kJ, supplied to the substance to cause it to vaporise.

Q = ... kJ [2]

(iii) Use your answer in **(b)(ii)** to determine a value for the specific latent heat of vaporisation L_V, in $\text{kJ}\,\text{kg}^{-1}$, of the substance.

L_V = ... $\text{kJ}\,\text{kg}^{-1}$ [2]

(c) The substance in **(b)** has a specific latent heat of fusion L_F.

Suggest and explain whether L_F is likely to be less than, the same as, or greater than the answer in **(b)(iii)**.

....

....

....

....

.... [3]

2 **(a)** Define specific heat capacity.

....

....

.... [2]

(b) Two solid blocks X and Y are made from different metals. The blocks have different initial temperatures. Block Y is initially at room temperature.

The blocks are placed in direct thermal contact with each other at time $t = 0$. Fig. 2.1 shows the variation with t of the temperatures of the two blocks.

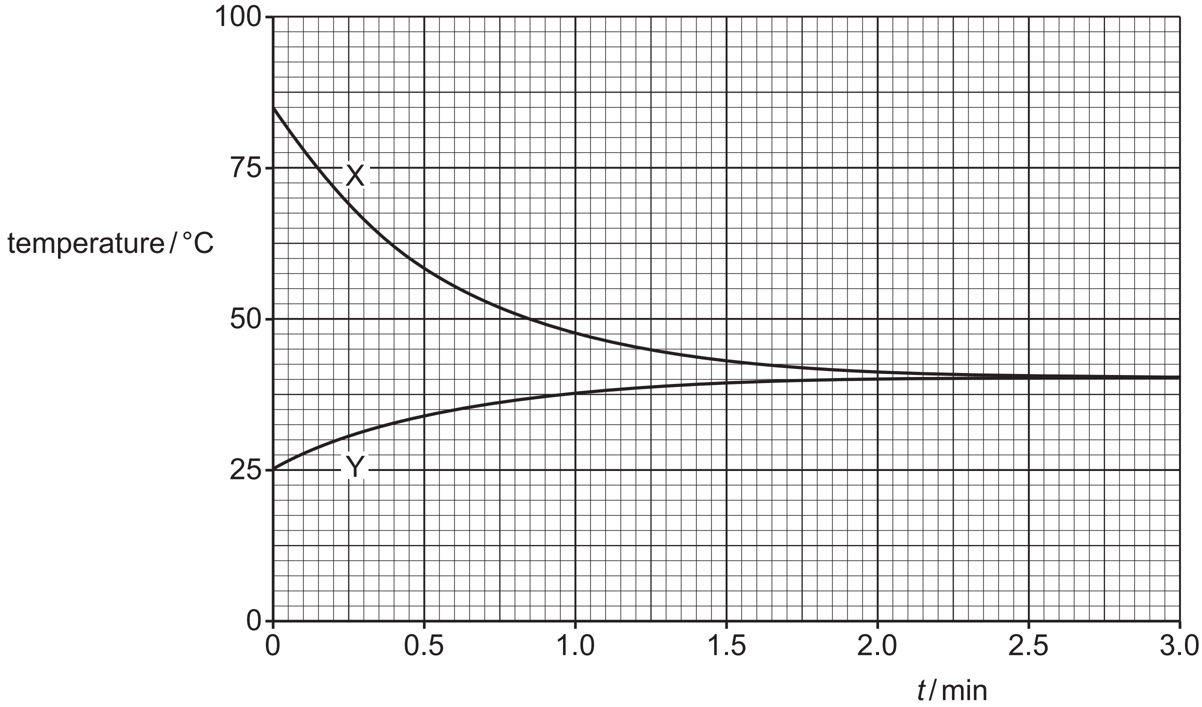

Fig. 2.1

(i) State **three** conclusions that may be drawn from Fig. 2.1. The conclusions may be qualitative or quantitative.

1 ....

....

2 ....

....

3 ....

....
[3]

(ii) The ratio $\frac{\text{mass of block Y}}{\text{mass of block X}}$ is equal to 1.3.

The metal in block Y has a specific heat capacity of $901\,\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$.

Determine the specific heat capacity of the metal in block X.

specific heat capacity = ... $\text{J}\,\text{kg}^{-1}\,\text{K}^{-1}$ [3]

2 **(a)** With reference to thermal energy, state what is meant by two objects being in thermal equilibrium.

....

....

.... [1]

(b) Two cylinders X and Y each contain a sample of an ideal gas. The samples are in thermal equilibrium with each other.

X has a volume of $0.0260\,m^3$ and contains 0.740 mol of gas at a pressure of 1.20×10^5 Pa. Y has a volume of $0.0430\,m^3$ and contains gas at a pressure of 2.90×10^5 Pa. Data for the two cylinders are shown in Fig. 2.1.

X	Y
0.740 mol 1.20×10^5 Pa $0.0260\,m^3$	2.90×10^5 Pa $0.0430\,m^3$

Fig. 2.1

(i) Show that the temperature of the gas in X is 234 °C.

[3]

(ii) Determine the number N of molecules of the gas in Y. Explain your reasoning.

N = ... [3]

(iii) The gas in X consists of molecules that each have a mass that is four times the mass of a molecule of the gas in Y.

Explain how the root-mean-square (r.m.s.) speed of the molecules in X compares with the r.m.s. speed of the molecules in Y.

....

....

....

....

.... [3]

2 **(a)** **(i)** State the magnitude and unit of absolute zero on the thermodynamic temperature scale.

.... [1]

(ii) Explain why temperature measured using a laboratory liquid-in-glass thermometer does **not** give a measurement of thermodynamic temperature.

....

.... [1]

(b) Fig. 2.1 shows a simplified diagram of a type of thermometer called a platinum resistance thermometer.

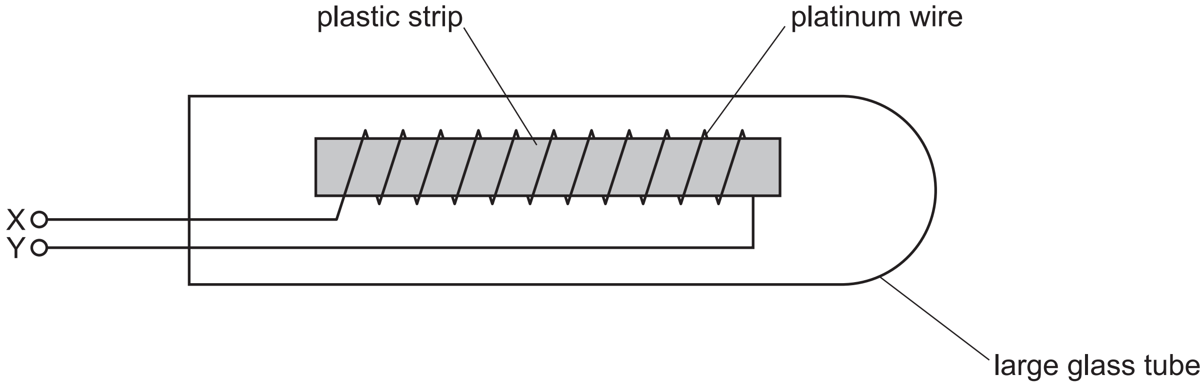

Fig. 2.1

The glass tube is immersed in the environment for which the temperature is to be determined. The resistance between the terminals X and Y is measured.

Fig. 2.2 shows the variation of the resistivity ρ of platinum with thermodynamic temperature T.

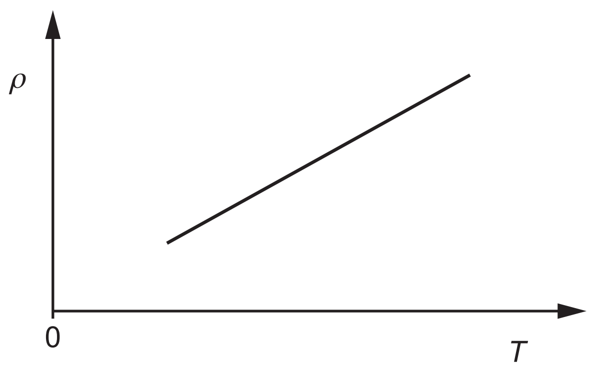

Fig. 2.2

(i) Explain how Fig. 2.2 shows that platinum is a suitable metal for use in a resistance thermometer.

....

....

.... [2]

(ii) Suggest a reason why a platinum resistance thermometer is **not** suitable for measuring a rapidly changing temperature.

....

....

.... [1]

(iii) Suggest a type of thermometer that is suitable for measuring a rapidly changing temperature.

.... [1]

(c) A negative temperature coefficient thermistor may be used as a type of resistance thermometer.

State **one** way in which the variation with temperature of the resistance of a thermistor differs from that of a platinum wire.

....

.... [1]

2 **(a)** By referring to both kinetic energy and potential energy, explain what is meant by the internal energy of an ideal gas.

....

....

....

.... [2]

(b) A fixed mass of an ideal gas at a temperature of 20 °C is sealed in a cylinder by a piston, as shown in Fig. 2.1.

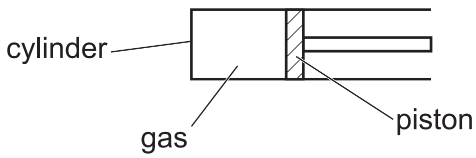

Fig. 2.1

The initial volume of the gas is $1.24 \times 10^{-4}\,m^3$.
Thermal energy is supplied to the gas and its volume increases by $5.20 \times 10^{-5}\,m^3$.

(i) The piston is freely moving so that the gas is always at atmospheric pressure.

Atmospheric pressure is $1.01 \times 10^5\,Pa$.

Calculate the work done by the gas.

work done by gas = ... J [2]

(ii) Calculate the final thermodynamic temperature T of the gas.

T = ... K [2]

(iii) The mass of the gas is 16 g. For this expansion, there is a net transfer of 960 J of thermal energy to the gas.

Calculate the specific heat capacity c of the gas at this pressure.

c = ... $J\,kg^{-1}\,K^{-1}$ [2]

(c) The gas in **(b)** is allowed to return to its starting temperature. The piston is now fixed in position.

Thermal energy is supplied to increase the temperature to the same final temperature as in **(b)**.

Use the first law of thermodynamics to suggest and explain how the specific heat capacity of the gas for this situation compares with the value in **(b)(iii)**.

....

....

....

.... [3]

2 **(a)** Define specific heat capacity.

....

....

.... [2]

(b) An ideal gas of mass 0.35 kg is heated at a constant pressure of 2.0×10^5 Pa so that its internal energy increases by 7600 J. During this process, the volume of the gas increases from 0.038 m^3 to 0.063 m^3 and the temperature increases by 56 °C.

(i) Show that the magnitude of the work done on the gas is 5000 J.

[1]

(ii) Explain whether the work done on the gas is positive or negative.

....

....

.... [2]

(iii) Determine the magnitude of the thermal energy q transferred to the gas.

q = ... J [2]

(iv) Calculate the specific heat capacity of the gas for this process. Give a unit with your answer.

specific heat capacity = ... unit .... [2]

(c) The gas in **(b)** is now heated at constant volume rather than at constant pressure. The increase in internal energy of the gas is the same as in **(b)**.

Use the first law of thermodynamics to explain whether the specific heat capacity of the gas for this process is less than, the same as, or greater than the answer in **(b)(iv)**.

....

....

....

....

.... [3]

3 **(a)** State the reason why two objects that are at the same temperature are described as being in thermal equilibrium.

....

.... [1]

(b) Fig. 3.1 shows the variations with temperature of the densities of mercury and of water between 0 °C and 100 °C.

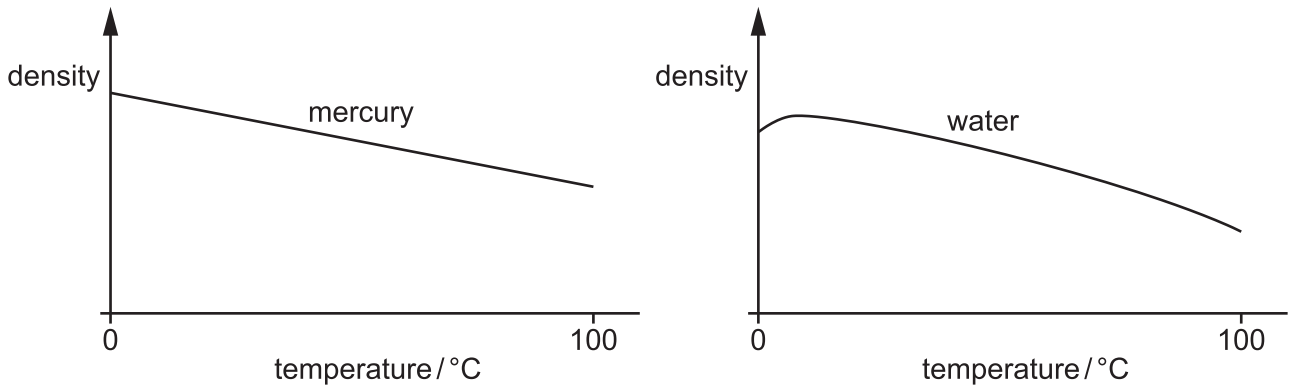

Fig. 3.1

Temperature may be measured using the variation with temperature of the density of a liquid.

Suggest why, for measuring temperature over this temperature range:

(i) mercury is a suitable liquid

....

.... [1]

(ii) water is not a suitable liquid.

....

....

.... [2]

(c) A beaker contains a liquid of mass 120 g. The liquid is supplied with thermal energy at a rate of 810 W. The beaker has a mass of 42 g and a specific heat capacity of 0.84 $J g^{-1} K^{-1}$. The beaker and the liquid are in thermal equilibrium with each other at all times and are insulated from the surroundings.

Fig. 3.2 shows the variation with time *t* of the temperature of the liquid.

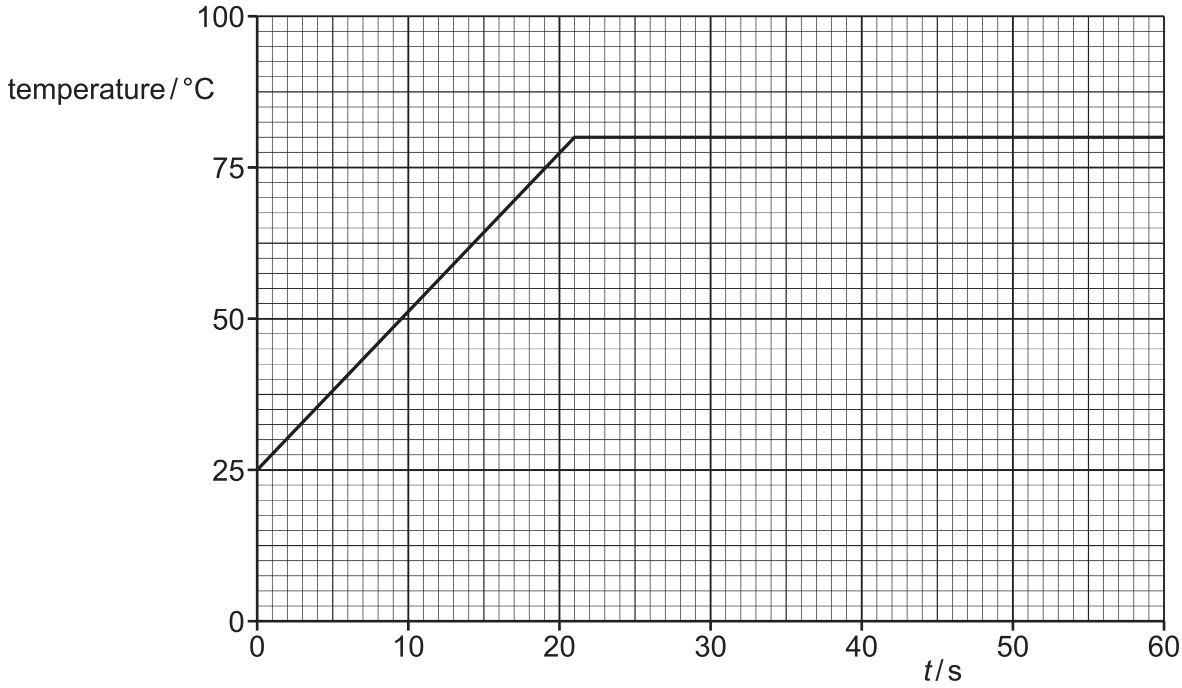

Fig. 3.2

(i) State the boiling temperature, in °C, of the liquid.

temperature = ... °C [1]

(ii) Determine the specific heat capacity, in $J g^{-1} K^{-1}$, of the liquid.

specific heat capacity = ... $J g^{-1} K^{-1}$ [4]

(d) The experiment in **(c)** is repeated using water instead of the liquid in **(c)**. The mass of liquid used, the power supplied, and the initial temperature are all unchanged.
The specific heat capacity of water is approximately twice that of the liquid in **(c)**.
The boiling temperature of water is 100 °C.

On Fig. 3.2, sketch the variation with time t of the temperature of the water between $t = 0$ and $t = 60$ s. Numerical calculations are not required. [2]

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

....

....

.... [2]

(b) A fixed amount of helium gas is sealed in a container. The helium gas has a pressure of 1.10×10^5 Pa, and a volume of $540\,cm^3$ at a temperature of 27 °C.

The volume of the container is rapidly decreased to $30.0\,cm^3$. The pressure of the helium gas increases to 6.70×10^6 Pa and its temperature increases to 742 °C, as illustrated in Fig. 2.1.

initial state	final state
1.10×10^5 Pa	6.70×10^6 Pa
$540\,cm^3$	$30.0\,cm^3$
27 °C	742 °C

Fig. 2.1

No thermal energy enters or leaves the helium gas during this process.

(i) Show that the helium gas behaves as an ideal gas.

[2]

(ii) The first law of thermodynamics may be expressed as

$$\Delta U = q + W.$$

Use the first law of thermodynamics to explain why the temperature of the helium gas increases.

....

....

....

....

.... [2]

(iii) The average translational kinetic energy E_K of a molecule of an ideal gas is given by

$$E_K = \frac{3}{2}kT$$

where k is the Boltzmann constant and T is the thermodynamic temperature.

Calculate the change in the total kinetic energy of the molecules of the helium gas.

change in kinetic energy = ... J [3]

(c) The mass of nitrogen gas in another container is 24.0 g at a temperature of 27 °C. The gas is cooled to its boiling point of –196 °C. Assume all the gas condenses to a liquid.

For this change the specific heat capacity of nitrogen gas is 1.04 kJ kg^{-1} K^{-1}.

The specific latent heat of vaporisation of nitrogen is 199 kJ kg^{-1}.

Determine the thermal energy, in kJ, removed from the nitrogen gas.

energy = ... kJ [3]

2 **(a)** Define specific heat capacity.

....

....

.... [2]

(b) A fixed mass of water in a beaker is at atmospheric pressure.

(i) The initial temperature of the water is 0 °C.

The water is supplied with thermal energy E, so that its temperature increases to 8 °C. There is no net change in the volume of the water.

Use the first law of thermodynamics to complete Table 2.1 for this process.

Table 2.1

work done on water	thermal energy supplied to water	increase in internal energy of water
	+ E	

[2]

(ii) The water is now heated so that its temperature increases by a further 8 °C to a final temperature of 16 °C. This process causes the volume of the water to increase so that work W is done.
Assume that the change in internal energy is the same as in **(b)(i)**.

Use the first law of thermodynamics to complete Table 2.2 for this process.

Table 2.2

work done on water	thermal energy supplied to water	increase in internal energy of water

[2]

(c) Use the information in **(b)** to suggest, with a reason, how the average specific heat capacity of water between 8 °C and 16 °C compares with its average value between 0 °C and 8 °C.

....

.... [1]

2 Fig. 2.1 shows a laboratory thermometer that is calibrated to measure temperature in degrees Celsius.

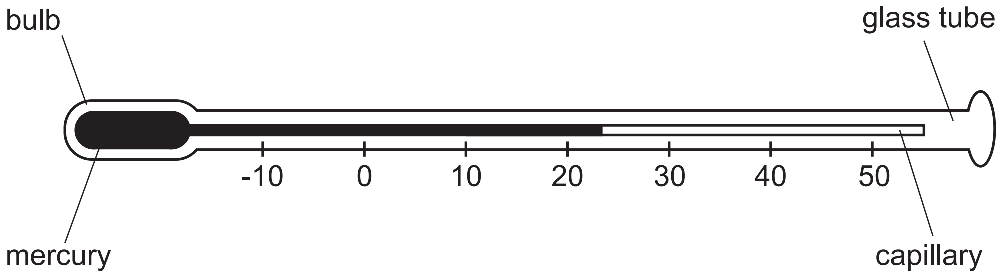

Fig. 2.1

The thermometer makes use of the fact that the density of mercury varies with temperature.

(a) State **two** other physical properties of materials, apart from the density of a liquid, that can be used for measuring temperature.

1 ....

2 ....
[2]

(b) The thermometer is initially at 23.0 °C, as shown in Fig. 2.1. It is used to measure the temperature of an insulated beaker of water that is at 37.4 °C. The bulb of the thermometer is inserted into the water, and the water is stirred until the reading on the thermometer becomes steady.

The mass of water in the beaker is 18.7 g.
The mass of mercury in the thermometer is 6.94 g.
The specific heat capacity of water is 4.18 J g^{-1} K^{-1}.
The specific heat capacity of mercury is 0.140 J g^{-1} K^{-1}.
The glass of the thermometer and the beaker containing the water can be considered to have negligible heat capacity.

(i) Calculate, to three significant figures, the final steady temperature indicated by the thermometer in the water.

temperature = ... °C [4]

(ii) Suggest **one** change that could be made to the design of the thermometer that would enable it to give a more accurate measurement of temperature.

....

.... [1]

(c) **(i)** Explain why the thermometer in Fig. 2.1 does **not** provide a direct measurement of thermodynamic temperature.

....

....

.... [2]

(ii) Thermodynamic temperature T may be determined by the behaviour of a type of substance for which T is proportional to the product of pressure and volume.

State the name of this type of substance.

.... [1]