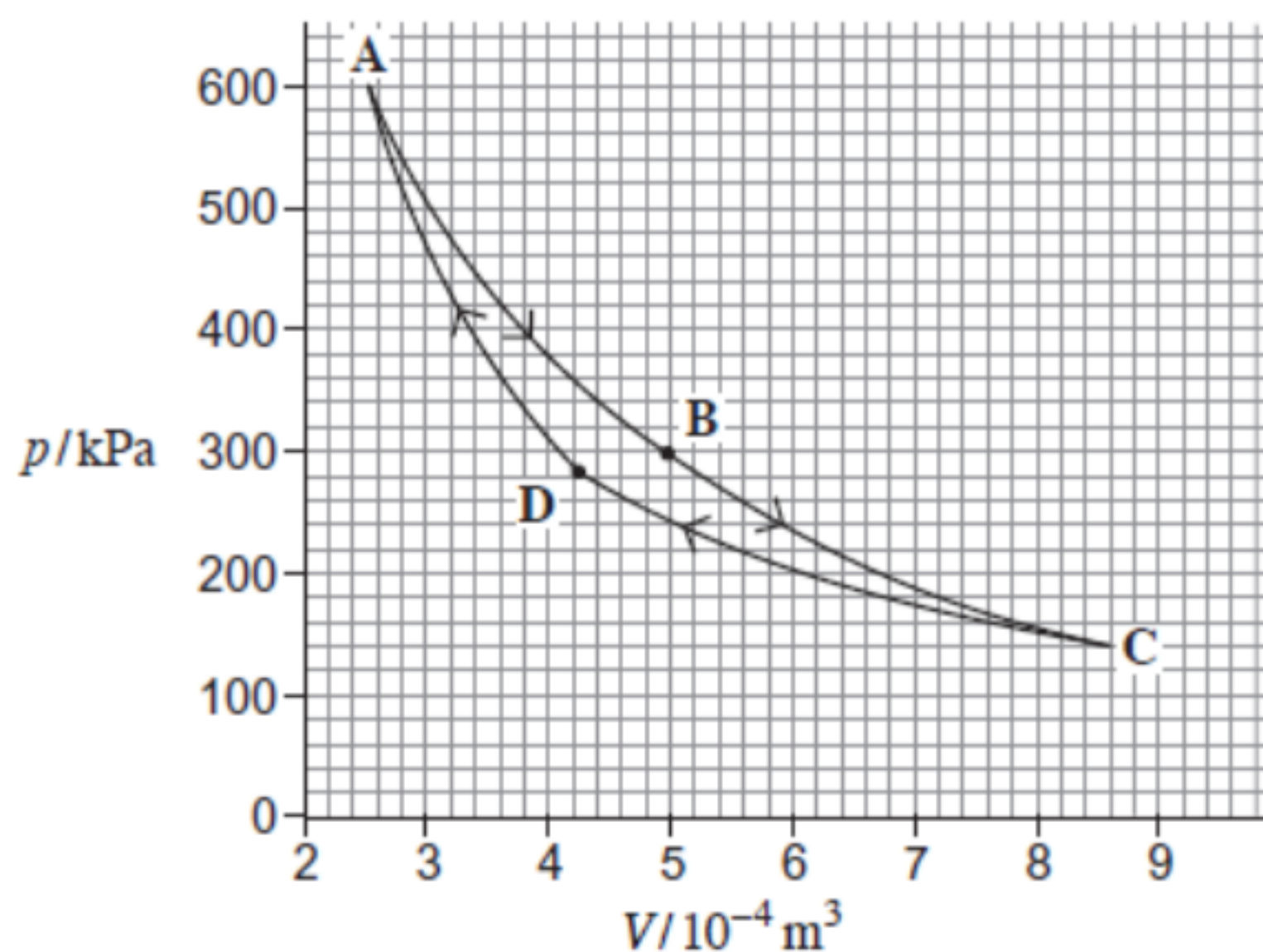


1 The Carnot cycle is the most efficient theoretical cycle of changes for a fixed mass of gas in a heat engine.

The graph below shows the pressure–volume (p – V) diagram for a gas undergoing a Carnot cycle of changes **ABCD**.



(a) (i) Show that during the change **AB** the gas undergoes an isothermal change.

(3)

(ii) Explain how the first law of thermodynamics applies to the gas in the change **BC**.

(3)

(iii) Determine the ratio $\frac{T_A}{T_C}$,

where T_A is the temperature of the gas at **A** and T_C is the temperature of the gas at **C**.

ratio _____

(3)

(b) Show that the work done during the change **AB** is about 110 J.

(2)

- (c) When running at a constant temperature, one practical engine goes through 2400 cycles every minute. In one complete cycle of this engine, 114 J of energy has to be removed by a coolant so that the engine runs at a constant temperature. The temperature of the coolant rises by 18 °C as it passes through the engine.

Calculate the volume of the coolant that flows through the engine in one second.

specific heat capacity of coolant = $3.8 \times 10^3 \text{ J kg}^{-1} \text{ K}^{-1}$

density of coolant = $1.1 \times 10^3 \text{ kg m}^{-3}$

volume flowing in one second _____ m^3

(3)

(Total 14 marks)

2

Figure 1

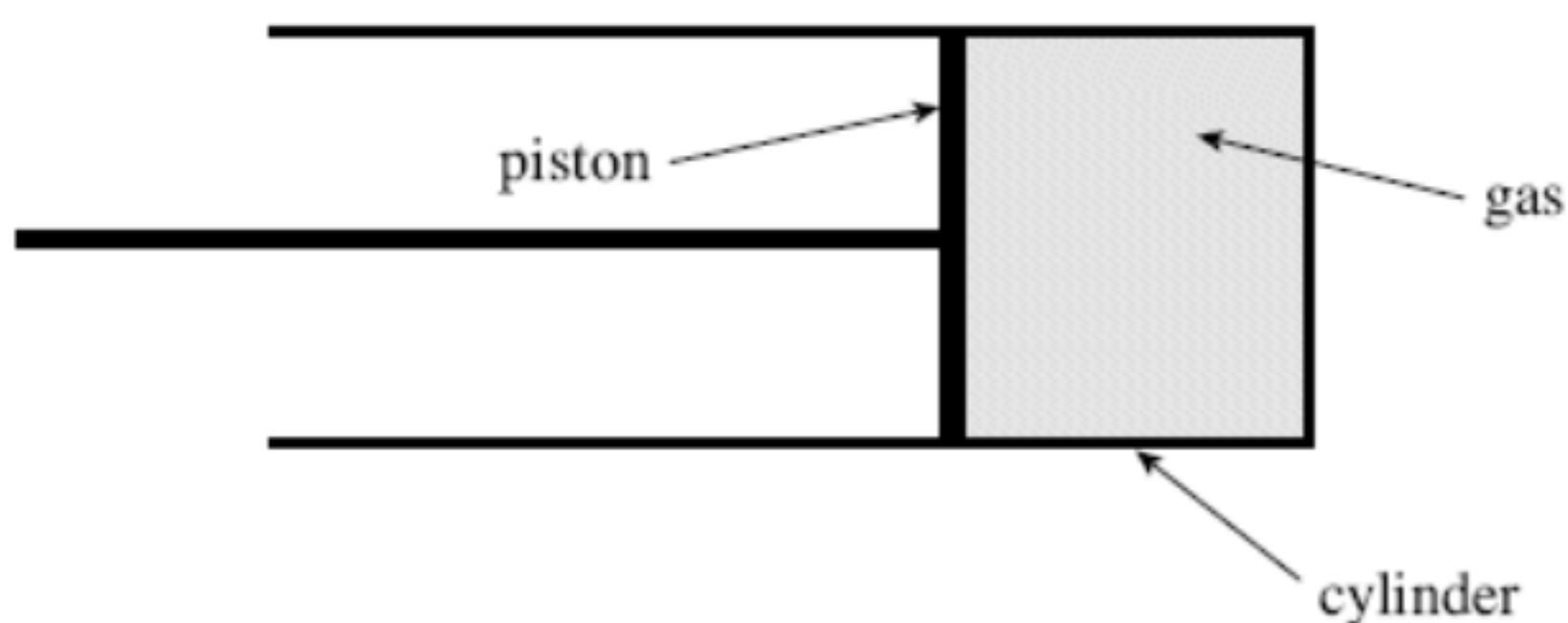
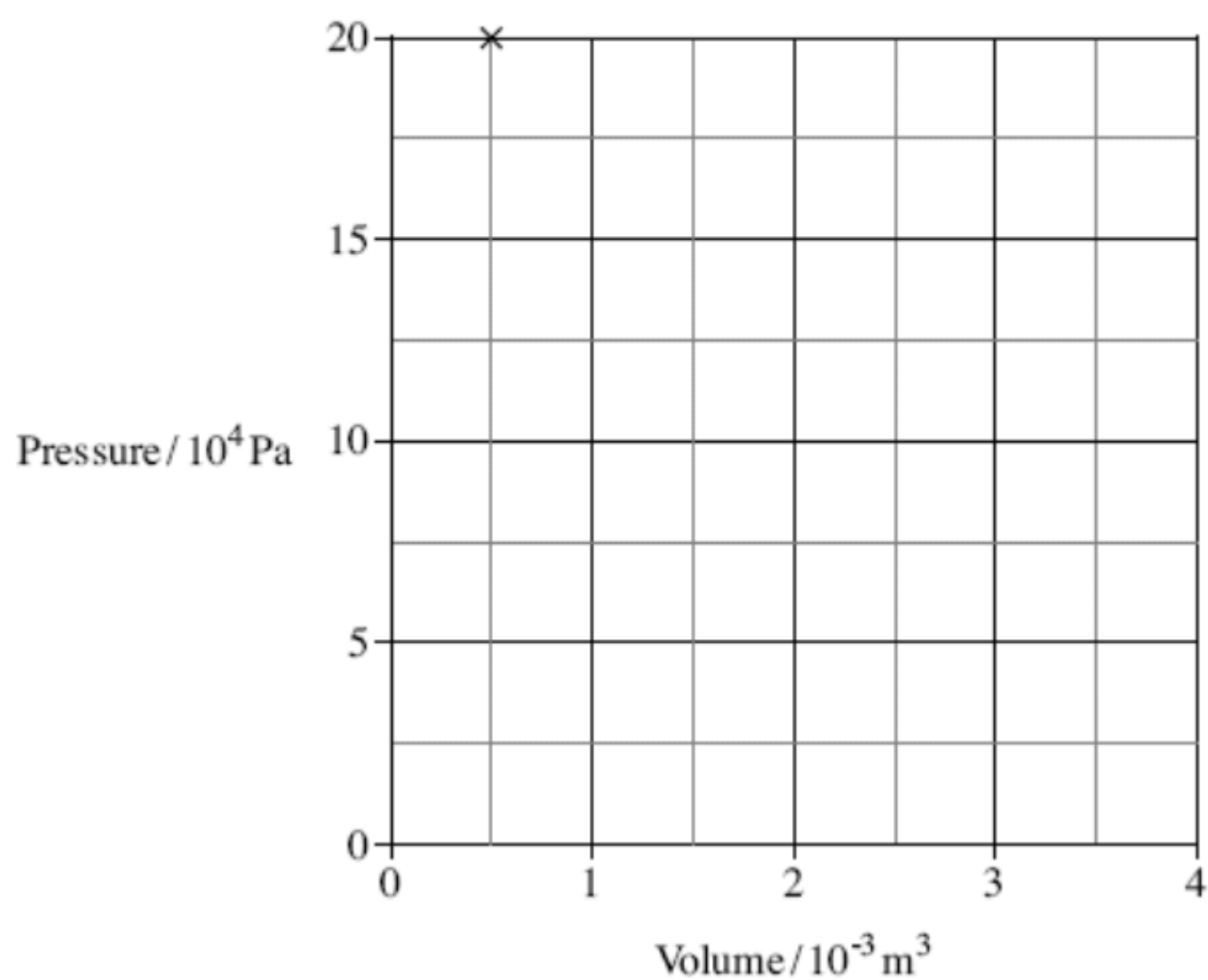


Figure 1 shows a cylinder, fitted with a gas-tight piston, containing an ideal gas at a constant temperature of 290 K. When the pressure, p , in the cylinder is $20 \times 10^4 \text{ Pa}$ the volume, V , is $0.5 \times 10^{-3} \text{ m}^3$.

Figure 2 shows this data plotted.

Figure 2



- (a) By plotting two or three additional points draw a graph, on the axes given in **Figure 2**, to show the relationship between pressure and volume as the piston is slowly pulled out. The temperature of the gas remains constant.

(3)

- (b) (i) Calculate the number of gas molecules in the cylinder.

answer = _____ molecules

(2)

- (ii) Calculate the total kinetic energy of the gas molecules.

answer = _____ J

(3)

- (c) State **four** assumptions made in the molecular kinetic theory model of an ideal gas.

(i) _____

(ii) _____

(iii) _____

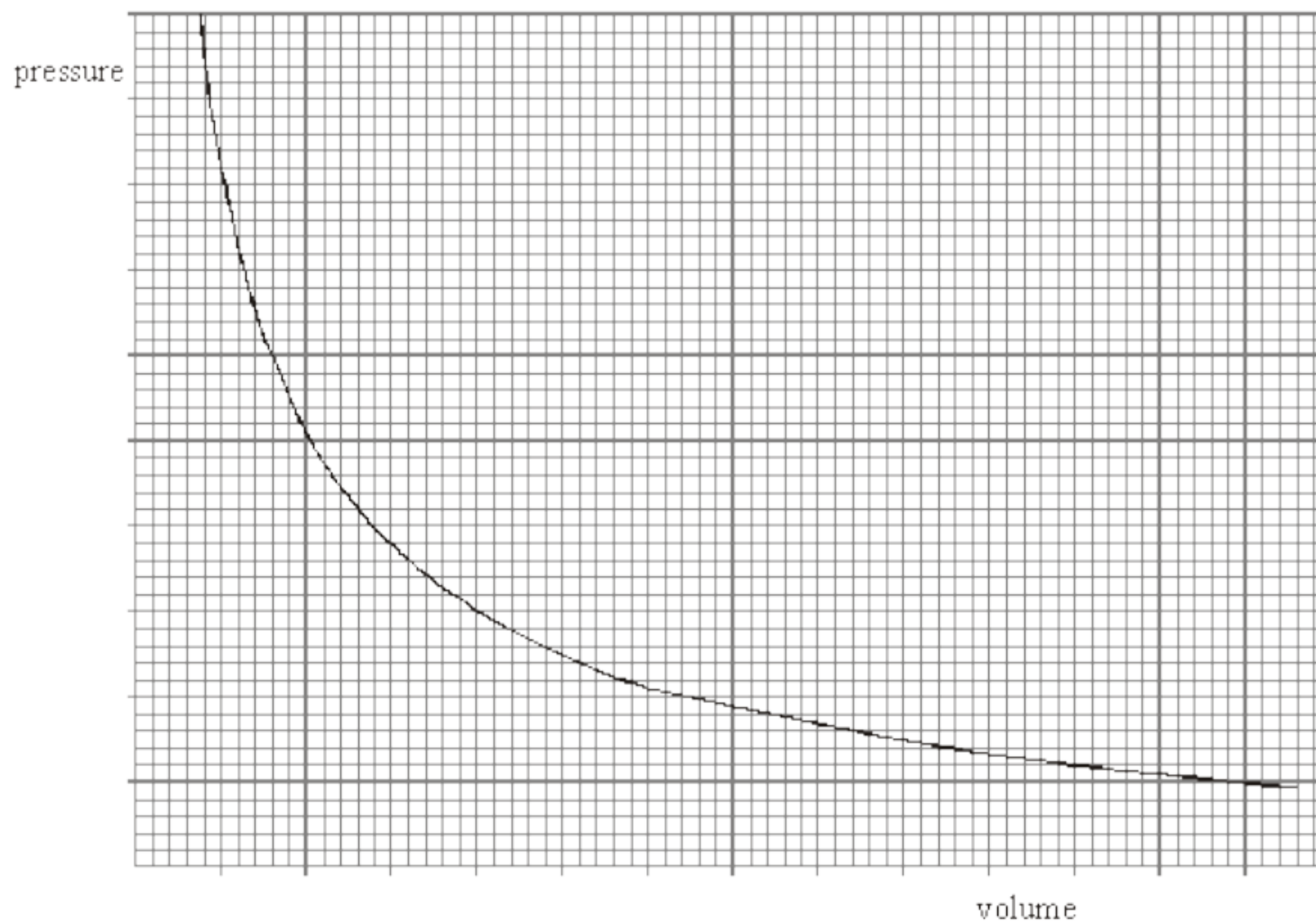
(iv) _____

(4)

(Total 12 marks)

3

The graph shows how the pressure of an ideal gas varies with its volume when the mass and temperature of the gas are constant.



(a) On the same axes, sketch **two** additional curves **A** and **B**, if the following changes are made.

- (i) The same mass of gas at a lower constant temperature (label this **A**).
- (ii) A greater mass of gas at the original constant temperature (label this **B**).

(2)

(b) A cylinder of volume 0.20 m^3 contains an ideal gas at a pressure of 130 kPa and a temperature of 290 K . Calculate

- (i) the amount of gas, in moles, in the cylinder,

- (ii) the average kinetic energy of a molecule of gas in the cylinder,

- (iii) the average kinetic energy of the molecules in the cylinder.

(5)

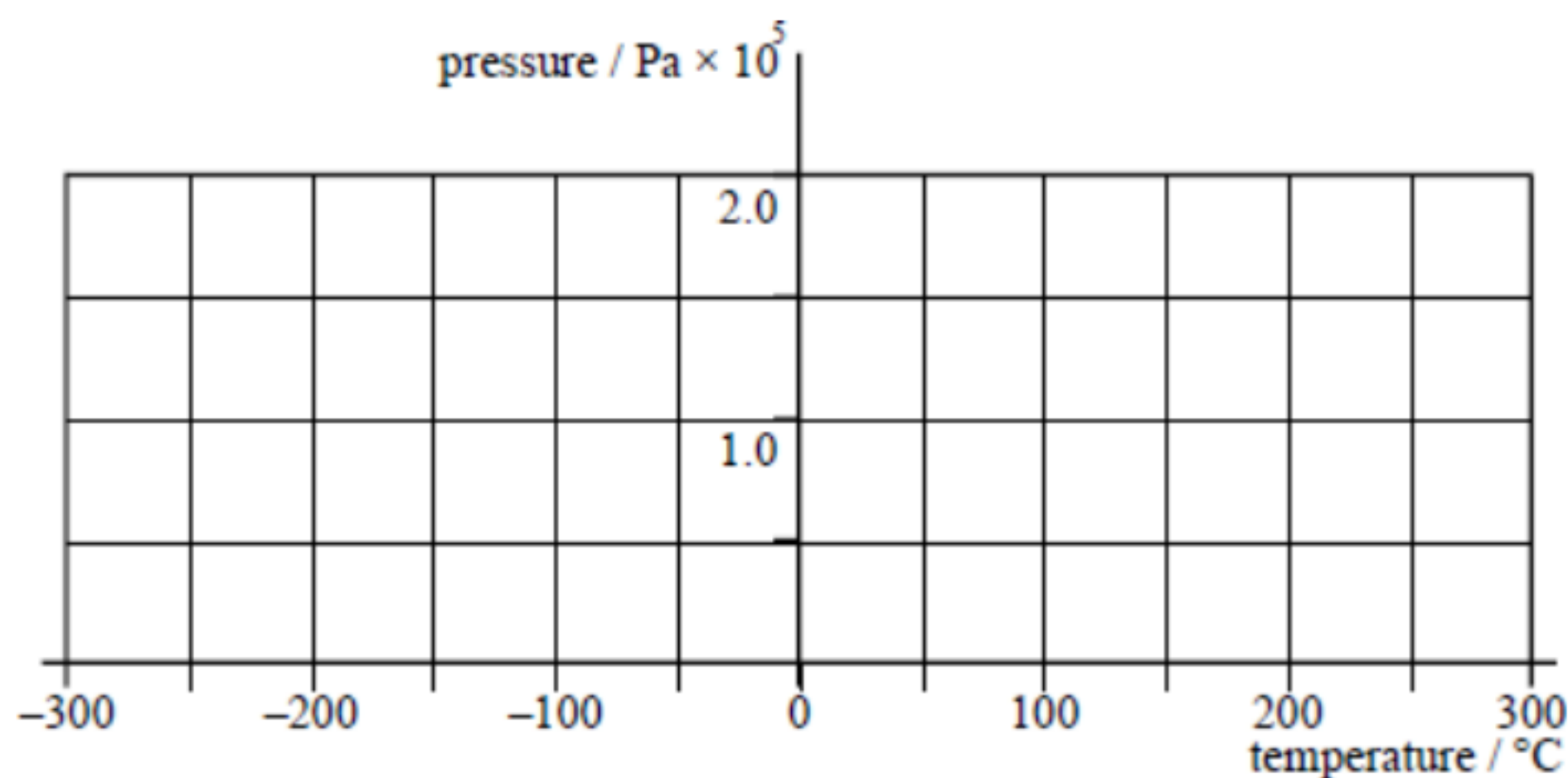
(Total 7 marks)

4 The pressure exerted by an ideal gas in a container of volume $1.2 \times 10^{-5} \text{ m}^3$ is $1.5 \times 10^5 \text{ Pa}$ at a temperature of 50°C .

- (a) Calculate the number of molecules of gas in the container.

(3)

- (b) The pressure of the gas is measured at different temperatures whilst the volume of the container and the mass of the gas remain constant. Draw a graph on the grid to show how the pressure varies with the temperature.



(3)

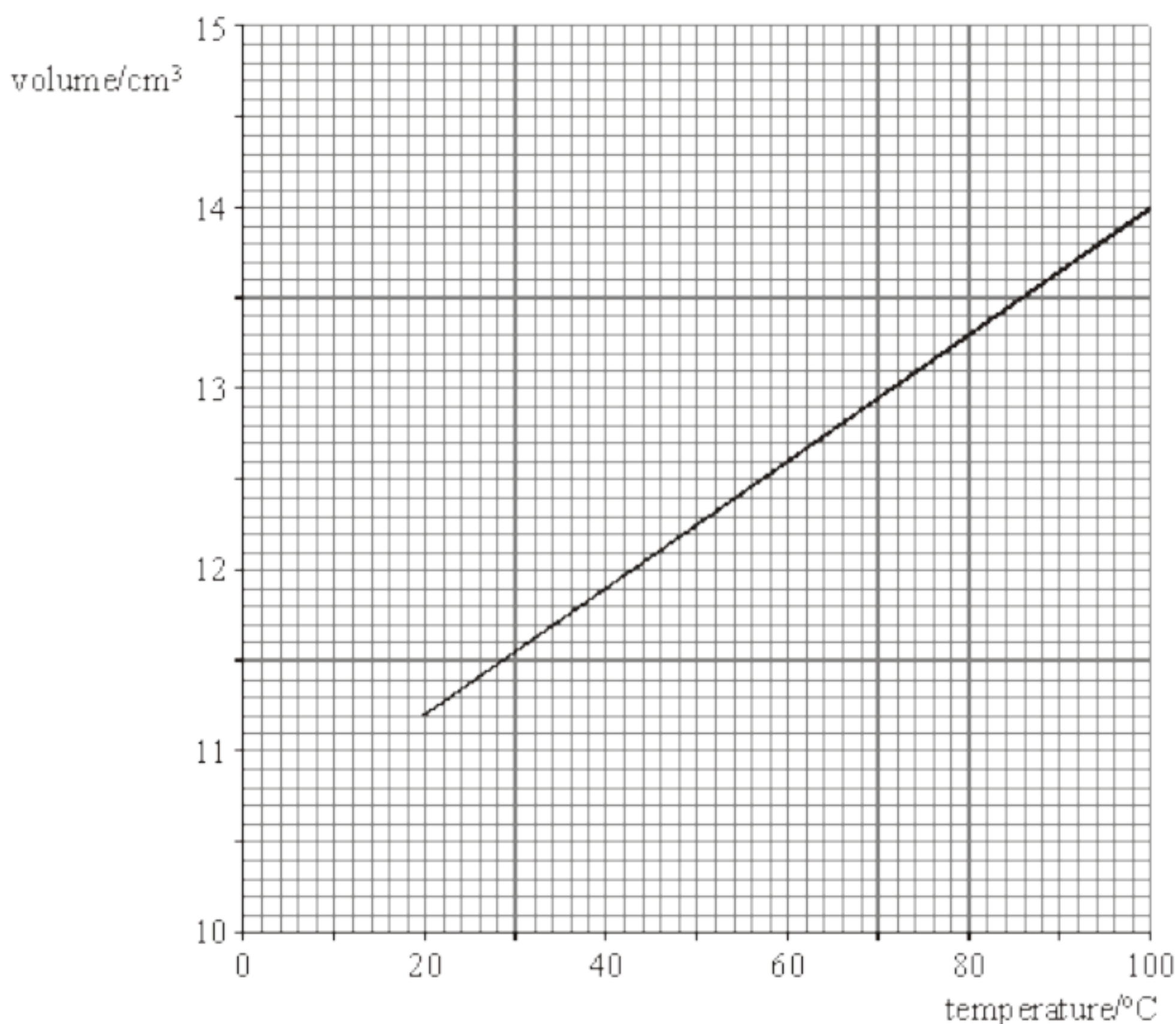
- (c) The container described in part (a) has a release valve that allows gas to escape when the pressure exceeds 2.0×10^5 Pa. Calculate the number of gas molecules that escape when the temperature of the gas is raised to 300°C .

(3)

(Total 9 marks)

5

The graph in the figure below shows the best fit line for the results of an experiment in which the volume of a fixed mass of gas was measured over a temperature range from 20°C to 100°C . The pressure of the gas remained constant throughout the experiment.



- (a) Use the graph in the figure to calculate a value for the absolute zero of temperature in °C.
Show clearly your method of working.

(4)

- (b) Use data from the graph in the figure to calculate the mass of gas used in the experiment.
You may assume that the gas behaved like an ideal gas throughout the experiment.

$$\text{gas pressure throughout the experiment} = 1.0 \times 10^5 \text{ Pa}$$

$$\text{molar gas constant} = 8.3 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$\text{molar mass of the gas used} = 0.044 \text{ kg mol}^{-1}$$

(5)

(Total 9 marks)

6

Figure 1 shows a p – V graph that you are to use to illustrate the process of a gas undergoing two changes.

In its initial state, the gas has a pressure of 50 kPa and a volume of 1.5 m^3 ; this is plotted on the graph.

First, the gas undergoes an isothermal change from an initial volume of 1.5 m^3 to 0.85 m^3 followed by a compression at constant pressure to a volume of 0.35 m^3 .

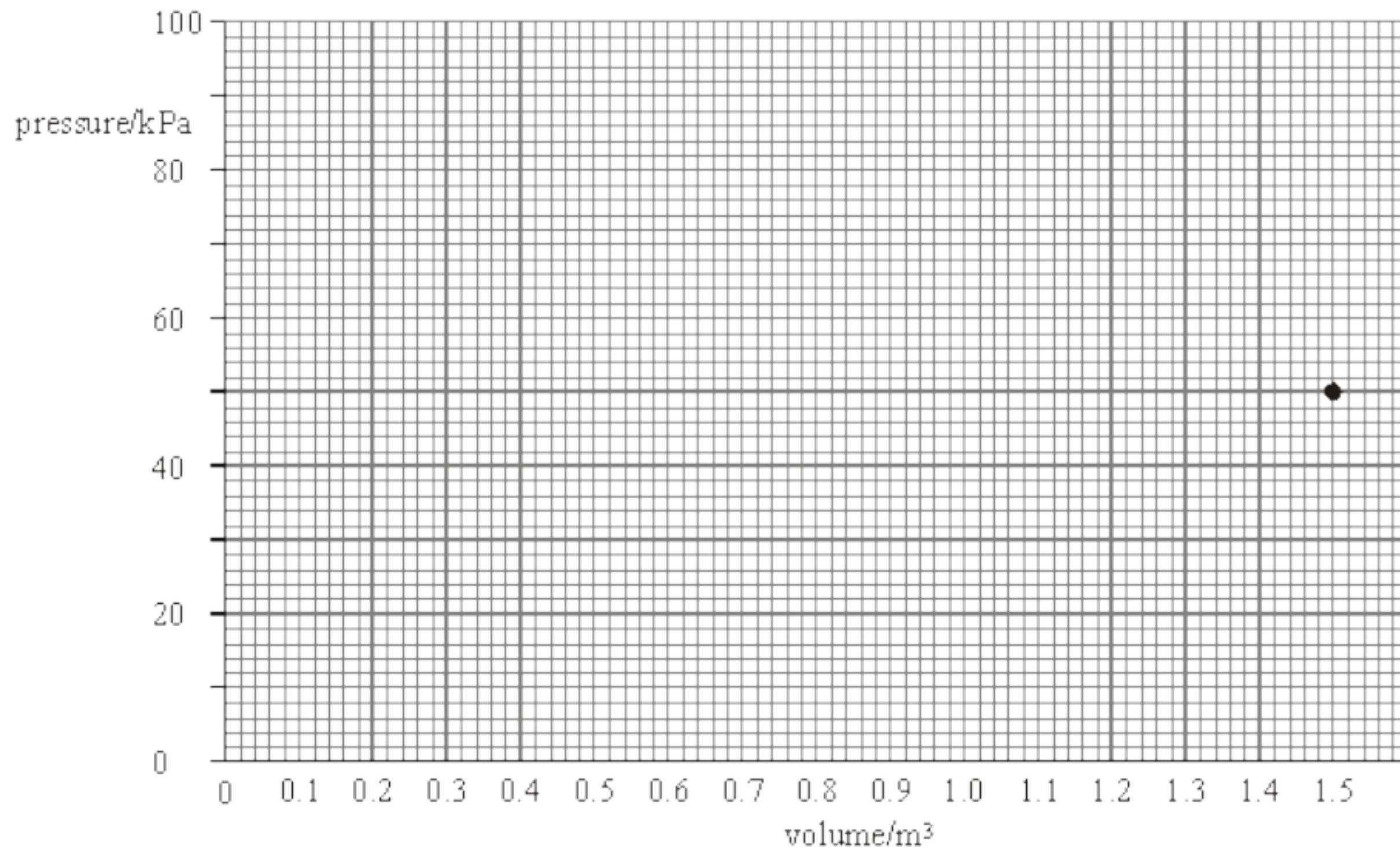


Figure 1

(a) Show that the final pressure of the gas is about 90 kPa.

(2)

(b) Complete the graph in **Figure 1** to show both changes.

(2)

(c) (i) Use your graph to estimate the work done during the whole process.

(3)

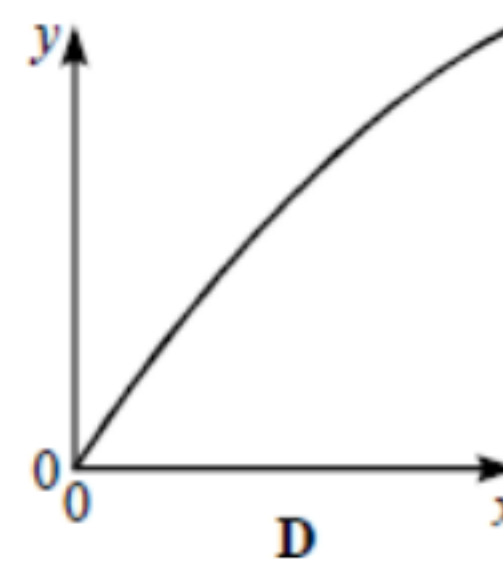
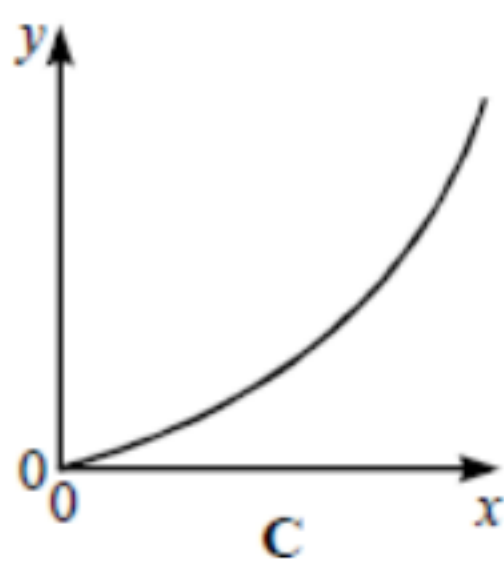
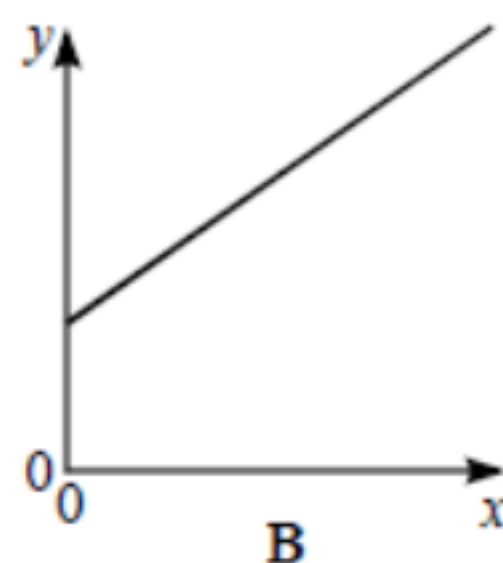
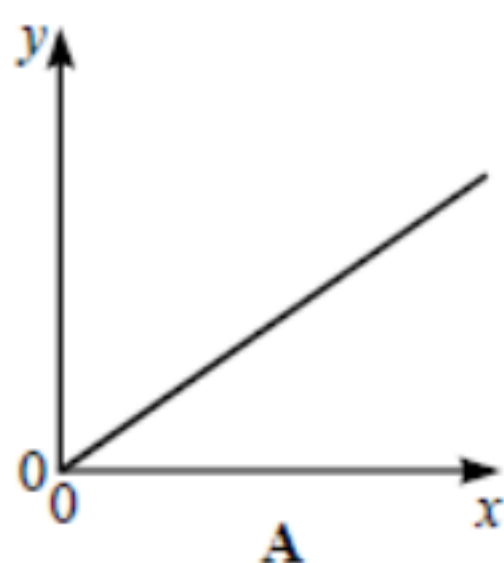
(ii) State and explain whether the work in part (c)(i) is done *on* or *by* the gas.

(1)

(Total 8 marks)

7

Which one of the graphs below shows the relationship between the internal energy of an ideal gas (y -axis) and the absolute temperature of the gas (x -axis)?

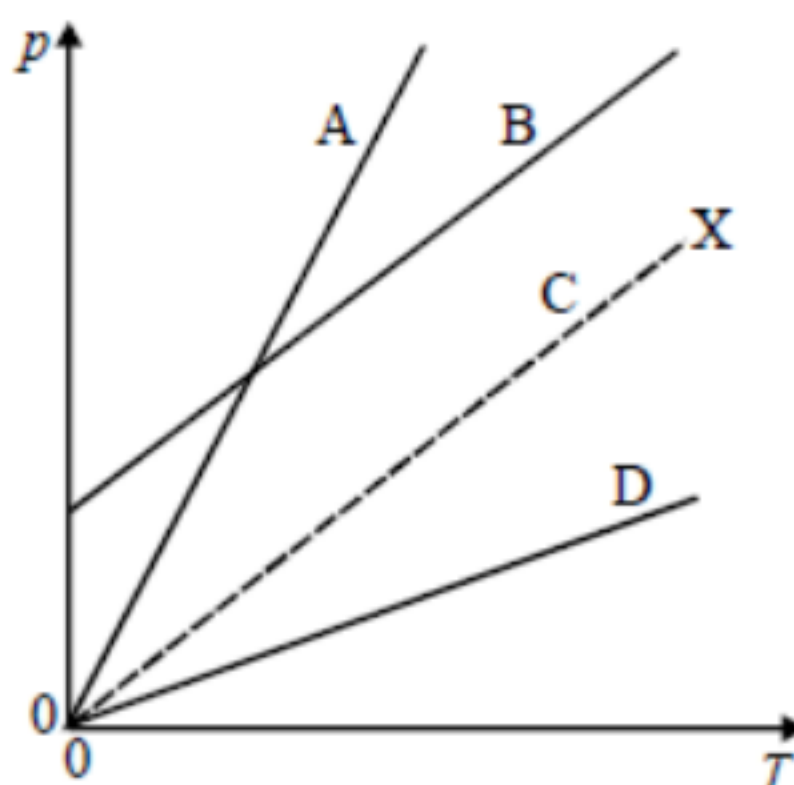


(Total 1 mark)

8

In the diagram the dashed line **X** shows the variation of pressure, p , with absolute temperature, T , for 1 mol of an ideal gas in a container of fixed volume.

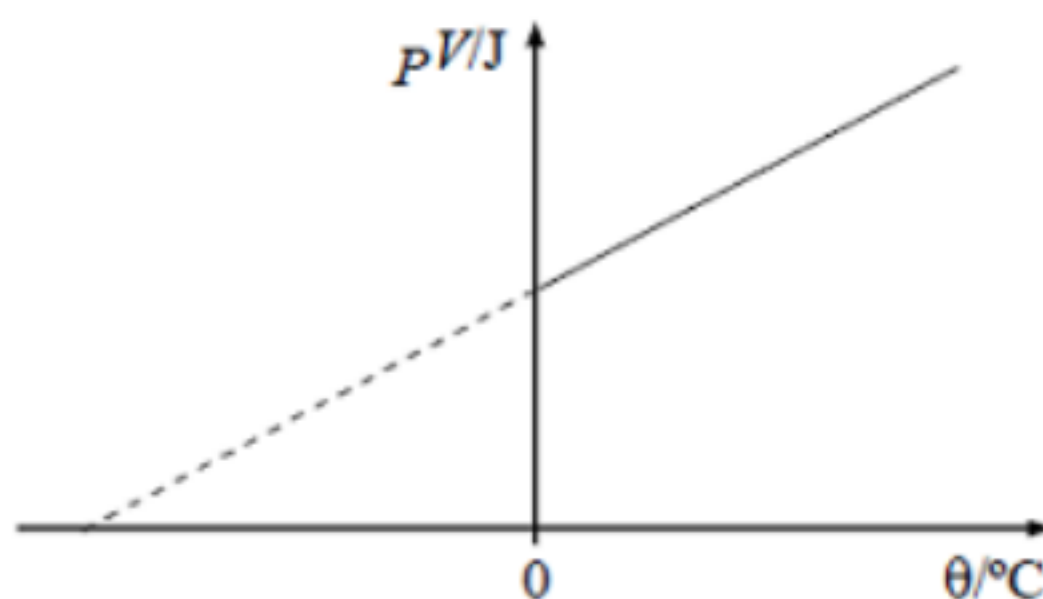
Which line, **A**, **B**, **C** or **D** shows the variation for 2 mol of the gas in the same container?



(Total 1 mark)

9

The graph shows the relation between the product *pressure* $\times$ *volume*, pV , and temperature, θ , in degrees celsius for 1 mol of an ideal gas for which the molar gas constant is R .



Which one of the following expressions gives the gradient of this graph?

- A** $\frac{1}{273}$
- B** $\frac{pV}{\theta}$
- C** $\frac{pV}{(\theta - 273)}$
- D** R

(Total 1 mark)

Mark schemes

1

- (a) (i) Appreciates pV should be constant for isothermal change (by working or statement) $W = p\Delta V$ is TO

Allow only products seen where are approximately 150 for 1 mark

Penalise J as unit here

M1

Demonstrates $pV = \text{constant}$ using 2 points (on the line) set equal to each other or conclusion made or **shows** that for V doubling that p halves (worth 2 marks)

need to see values for p and V

Products should equal 150 to 2 sf

Accept statement that products are slightly different so not quite isothermal

A1

Demonstrates $pV = \text{constant}$ using 3 points (on the line) with conclusion

Need to see values for p and V

Products should equal 150 to 2 sf

Accept statement that products are slightly different so not quite isothermal

A1

3

- (ii) Adiabatic therefore no heat transfer **or**
Adiabatic therefore $Q = 0$

B1

Work is done by gas therefore W is negative **or**

Work is done by gas therefore energy is removed from the system

B1

ΔU is negative therefore internal energy of gas decreases **or**
energy is removed from the system therefore internal energy of gas decreases or work done by the gas so internal energy decreases

Allow

$$-\Delta U = -W \text{ or } \Delta U = -W$$

B1

3

- (iii) Uses $pV / T = \text{constant}$ or uses $pV = nRT$ or uses $pV = NkT$
 e.g. makes T subject or substitutes into an equation with p_A

and V_A or p_C and V_C (condone use of $n = 1$) or their $\frac{(pV)_A}{(pV)_C}$

V_A read off range

$= 2.5 \text{ to } 2.6 (\times 10^{-4})$

$p_A = 600 \times 10^3$

V_C read off range

$= 8.5 \text{ to } 8.6 (\times 10^{-4})$

$p_C = 140 \times 10^3$

C1

Correct substitution of coordinates (inside range) into $\frac{(pV)_A}{(pV)_C}$
 With consistent use of powers of 10

$(pV)_A$ range is 150 to 156 and $(pV)_C$ range is 119 to 120.4

C1

1.2(5) Allow range from 1.2 to 1.3

Accept decimal fraction : 1

A1

- (b) Energy per large square = 10(J) **or** states that work done is equal to area under curve (between A and B)
or energy per small square = 0.4(J)
or square counting seen on correct area

Must be clear that area represents energy either by subject of formula or use of units on 10 or 0.4

Alternative:

*W = area of a trapezium
(with working)*

or $W = P_{mean} \times \Delta V$ **or**

$W = 450 \times 10^3 \times 2.5 \times 10^{-4}$

or *W = area of a rectangle + area of a triangle (with working)*

B1

Number of large squares = 10.5 to 11.5 seen and ($\dot{W}$) = *number of squares $\times$ area of one square (using numbers)*

Range = 105 to 115 (J)

Or

Number of small squares = 263 to 287 seen and ($\dot{W}$) = *number of squares $\times$ area of one square (using numbers)*

Range = 105 to 115 (J)

States that actual work done would be lower because of curvature of line

B1

2

- (c) (Total energy removed per s =) 4560 (J)
or number of cycles per s = 40
or (Mass per second =) $114 \div 68400$ in rearranged form
or their energy $\div$ ($c \Delta T$) **or** their energy $\div$ 68400

C1

0.067 (kg) seen Allow 0.066 (kg) here

or allow $V / t = 1.67 \times 10^{-3} \div 1100$

or $\left(\frac{V}{t}\right) = \frac{E}{\rho c \Delta \theta}$ and correct **substitution** seen

Condone $E = 114$ (J) **or** temperature = 291(K)

C1

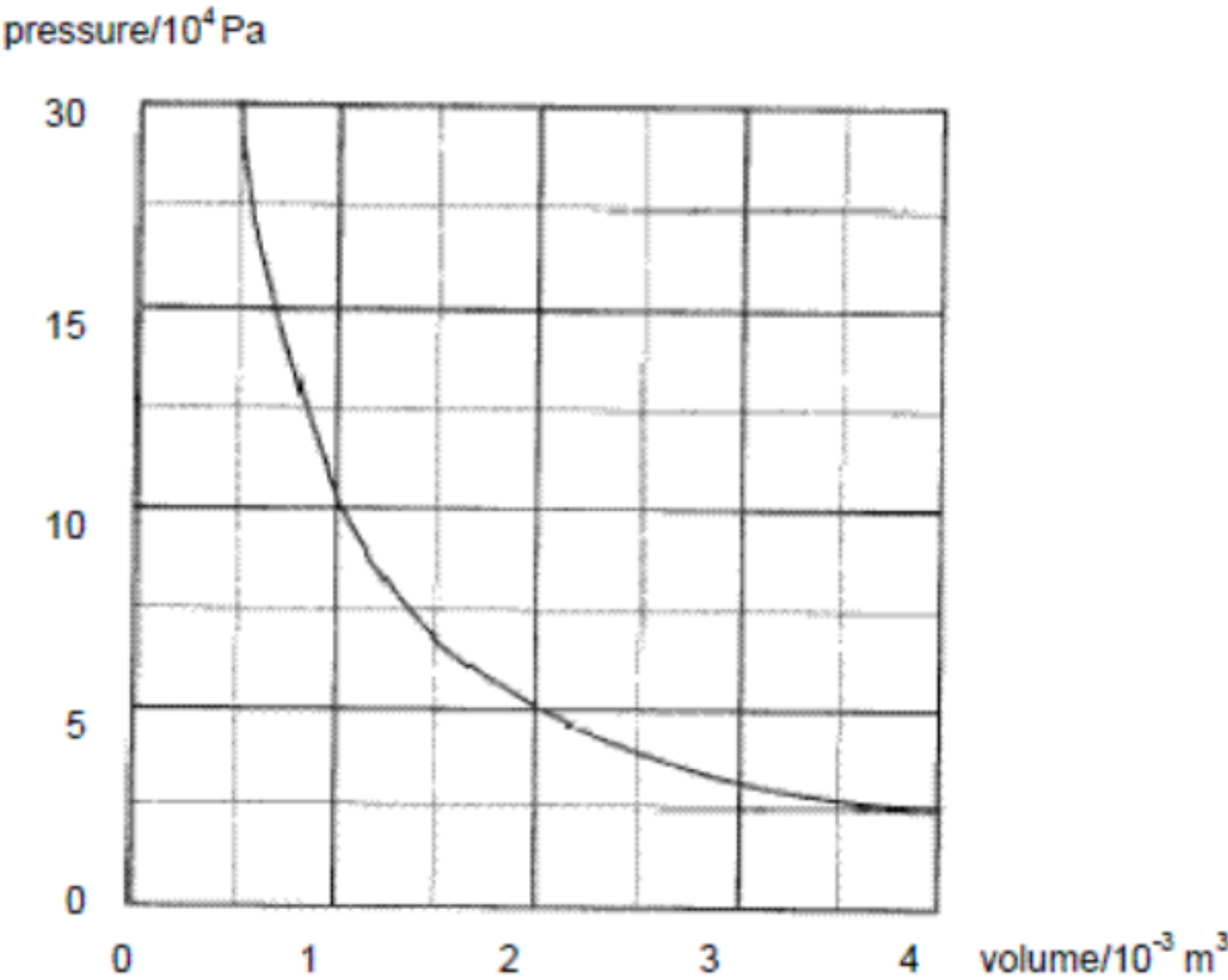
= 0.061×10^{-3} or 6.06×10^{-5} (m^3)

A1

3

2

(a)



3

curve with decreasing negative gradient that passes through the given point which does not touch the x axis **(1)**

designated points	
pressure/ 10^4 Pa	volume/ 10^{-3} m ³
10	1.0
5.0	2.0
4.0	2.5
2.5	4.0

2 of the designated points **(1)(1)** (one mark each)

(b) (i) $N = PV/kT = 5 \times 10^4 \times 2 \times 10^{-3} / 1.38 \times 10^{-23} \times 290$ **(1)**

[or alternative use of $PV = nRT$
 $5 \times 10^4 \times 2.0 \times 10^{-3} / 8.31 \times 290 = 0.0415$ moles]
 $= 2.50 \times 10^{22}$ molecules **(1)**

2

(ii) (mean) kinetic energy of a molecule

$$= \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290 \quad (1) (= 6.00 \times 10^{-21} \text{ J})$$

(total kinetic energy = mean kinetic energy $\times N$)

$$= 6.00 \times 10^{-21} \times 2.50 \times 10^{22} \quad (1)$$

$$= 150 \text{ (J)} \quad (1)$$

3

(c) all molecules/atoms are identical

molecules/atoms are in random motion

Newtonian mechanics apply

gas contains a large number of molecules

the volume of gas molecules is negligible (compared to the volume occupied by the gas) or reference to point masses

no force act between molecules except during collisions or the speed/velocity is constant between collisions or motion is in a straight line between collisions

collisions are elastic or **kinetic** energy is conserved

and of negligible duration

any 4 (1)(1)(1)(1)

max 4

[12]

3

(a) (i) curve A below original, curve B above original (1)

(ii) both curves correct shape (1)

2

(b) (i) (use of $pV = nRT$ gives) $130 \times 10^3 \times 0.20 = n \times 8.31 \times 290 \quad (1)$

$$n = 11 \text{ (mol)} \quad (1) \text{ (10.8 mol)}$$

(ii) (use of $E_k = \frac{3}{2}kT$ gives) $E_k = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290 \quad (1)$

$$= 6.0 \times 10^{-21} \text{ J} \quad (1)$$

(iii) (no. of molecules) $N = 6.02 \times 10^{23} \times 10.8 (= 6.5 \times 10^{24})$

$$\text{total k.e.} = 6.5 \times 10^{24} \times 6.0 \times 10^{-21} = 3.9 \times 10^4 \text{ J} \quad (1)$$

(allow C.E. for value of n and E_k from (i) and (ii))

(use of $n = 11 \text{ (mol)}$ gives total k.e. = $3.9 \text{ (7)} \times 10^4 \text{ J}$)

5

[7]

4

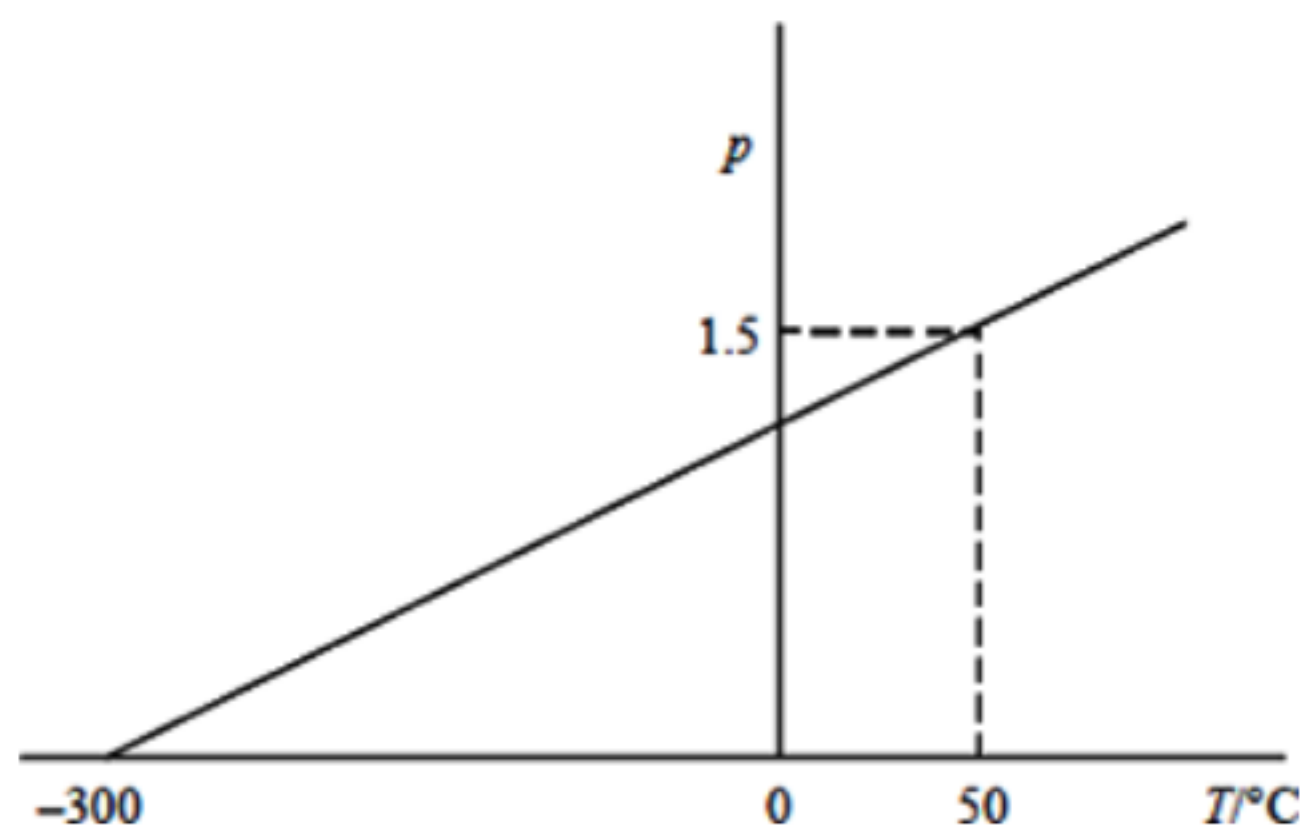
$$(a) \quad n \left(= \frac{pV}{RT} \right) = \frac{1.5 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 323} \quad (1) = (6.71 \times 10^{-4} \text{ mol})$$

$$\begin{aligned} \text{number of molecules} &= nN_A \quad (1) = 6.71 \times 10^{-4} \times 6.02 \times 10^{23} \\ &= 4.04 \times 10^{20} \quad (1) \end{aligned}$$

[or equivalent solution using $pv = NkT$]

(3)

(b)



straight line with positive gradient (1)

through (50, 1.5) (1)

crosses temperature axis between -250 and -300°C (1)

(3)

(c) number of moles left in container after valve opens

$$n \left(= \frac{pV}{RT} \right) = \frac{2.0 \times 10^5 \times 1.2 \times 10^{-5}}{8.31 \times 573} \quad (1) (= 5.04 \times 10^{-4} \text{ mol})$$

$$\begin{aligned} \therefore \text{number of molecules left in container} &= 5.04 \times 10^{-4} \times 6.02 \times 10^{23} \\ &= 3.03 \times 10^{20} \quad (1) \end{aligned}$$

$$\begin{aligned} \therefore \text{number of molecules that escape} &= 4.04 \times 10^{20} - 3.03 \times 10^{20} \\ &= 1.01 \times 10^{20} \quad (1) \end{aligned}$$

[alternative (c)]

$$\begin{aligned} \therefore \text{number of moles that escape} &= (6.71 \times 10^{-4} - 5.04 \times 10^{-4}) \\ &= 1.67 \times 10^{-4} \end{aligned}$$

$$\begin{aligned} \therefore \text{number of molecules that escape} &= 1.67 \times 10^{-4} \times N_A \\ &= 1.01 \times 10^{20} \quad (1) \end{aligned}$$

(3)

[9]

5

(a) $m = \text{gradient} = 0.035 \pm 0.001 \text{ (cm}^2 \text{ }^\circ\text{C}^{-1}\text{)}$

B1

$c = \text{intercept} = 10.5 \pm 0.1 \text{ (cm}^2\text{)}$

B1

$\text{absolute zero} = -c/m$

C1

$= -300 \pm 10 \text{ }^\circ\text{C}$ *some relevant working must be seen*

A1

4

or a meaningful attempt to use similar triangles

M1

an accurate value for the base found

C1

adjustment to the base (if appropriate)

C1

answer = $-300 \pm 10 \text{ }^\circ\text{C}$

A1

4

or *relevant use of* $V_1/T_1 = V_2/T_2$

M1

valid introduction of **unknown** temperature

A1

consistent solution of the equation

C1

answer = $-300 \pm 10 \text{ }^\circ\text{C}$

C1

4

(b) statement of *or use of* $pV = nRT$

C1

accurate reading from the line

C1

Celsius converted to Kelvin (*+273 or + answer to part (a)*)

C1

$n = 4.52 \times 10^{-4}$ **or** 4.11×10^{-4} *or* 4.2×10^{-4} ($\Delta V/\Delta T$) (mol)

A1

$m = n \times 0.044$ ($m = 4.52 \times 0.044 = 2.0 \times 10^{-5}$ kg)

B1

5

[9]

6

(a) $pV = \text{constant}$ seen

C1

$p = 88$ kPa

A1

2

(b) completes correct shape curve to (0.85, 88 000 **or** 90000),

B1

then horizontal to 0.35 m^3

B1

2

(c) attempts to measure area [graph evidence or words]

C1

correct use of graph scale

C1

answer in range (80 – 91) KJ

A1

3

(d) done **on** gas because it is compressed

B1

1

[8]

7

A

[1]

8

A

[1]

9

D

[1]