A-Level Physics

Ideal Gases

Question Paper

Time available: 75 minutes
Marks available: 49 marks

1. (a) In the kinetic theory model, it is assumed that there are many identical particles moving at random.

State **two** other assumptions made in deriving the equation $pV = \frac{1}{3}Nm\,(c_{rms})^2$.

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2 ____

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(2)

(b) Explain why molecules of a gas exert a force on the walls of a container.
Refer to Newton's laws of motion in your answer.

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(3)

(c) A sealed flask of volume $0.35\ \text{m}^3$ contains an ideal gas at a pressure of $220\ \text{kPa}$.
The mean kinetic energy of the gas molecules is $6.7 \times 10^{-21}\ \text{J}$.

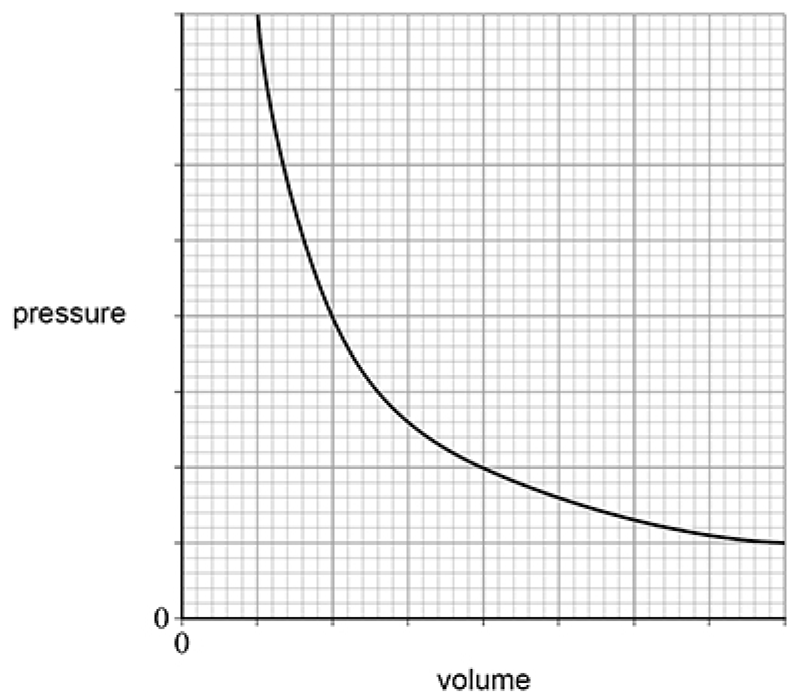
Calculate the amount of gas in the container.

amount of gas = _______________ mol

(3)

(d) The figure below shows the variation of pressure with volume for a fixed mass of an ideal gas at constant absolute temperature T.

Draw, on the figure below, the graph for the same gas at temperature $2T$.



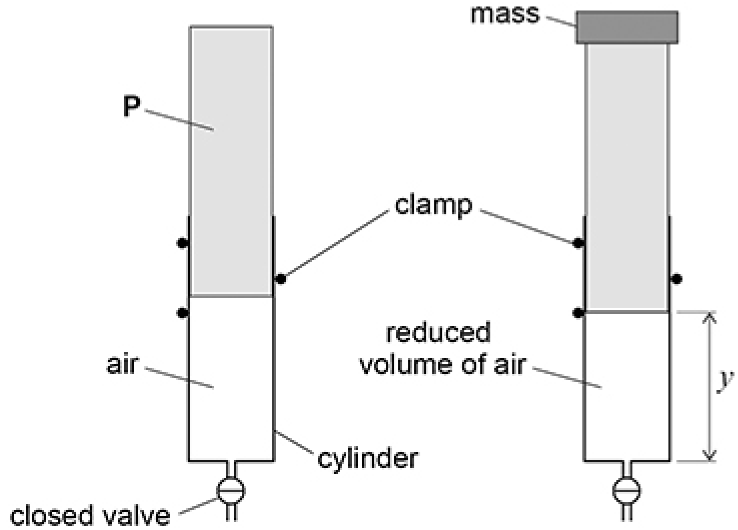
(2)

(Total 10 marks)

2. **Figure 1** shows air trapped in a vertical cylinder by a valve and a piston **P**.
The valve remains closed throughout the experiment.

A mass is placed on top of **P**.
P moves downwards and the volume of the trapped air decreases.
There are no air leaks and there is no friction between the cylinder and **P**.

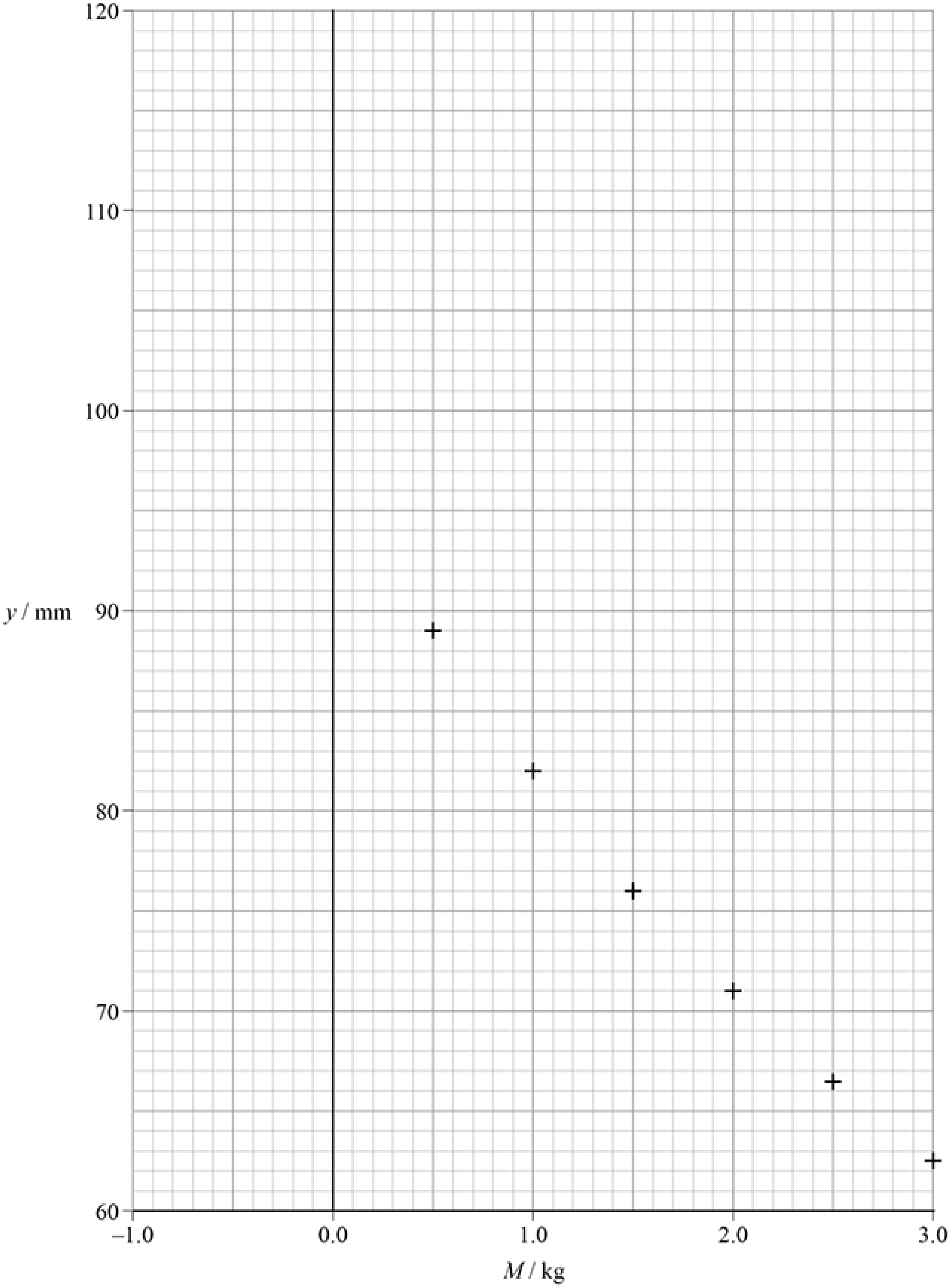
Figure 1



The vertical distance y between the end of **P** and the closed end of the cylinder is measured.
Additional masses are used to find out how y depends on the total mass M placed on top of **P**.

Figure 2 shows a graph of these data.

Figure 2

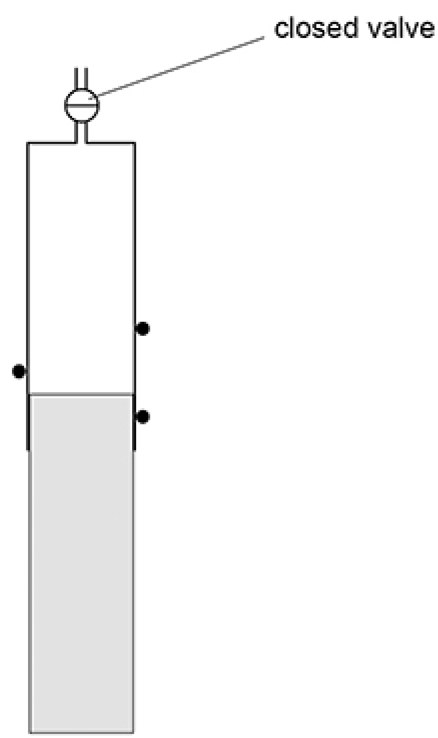


(a) Show that y is **not** inversely proportional to M.
Use data points from **Figure 2**.

(2)

(b) The masses are removed and the cylinder is inverted.
P moves downwards without friction before coming to rest, as shown in **Figure 3**.

Figure 3



Explain why **P** does not fall out of the cylinder unless the valve is opened.

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(3)

(c) The mass of **P** is 0.350 kg.

Deduce y when the cylinder is in the inverted position shown in **Figure 3**.

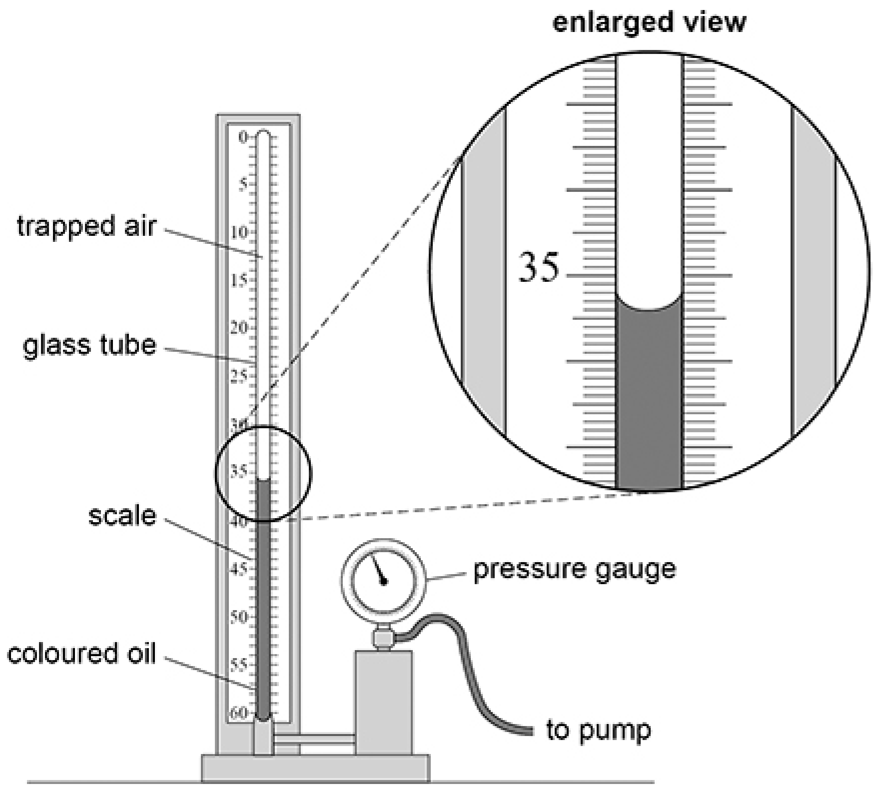
Draw a line of best fit on **Figure 2** to arrive at your answer.

y = ____________________ mm

(4)

Figure 4 shows apparatus used in schools to investigate Boyle's law.

Figure 4



A fixed mass of air is trapped above some coloured oil inside a glass tube, closed at the top.
A pump applies pressure to the oil and the air.

The trapped air is compressed and its pressure p is read from the pressure gauge.

(d) A scale, marked in $0.2\ \text{cm}^3$ intervals, is used to measure the volume V of the air.
A student says that the reading for V shown in **Figure 4** is $35.4\ \text{cm}^3$.

State:

- the error the student has made
- the correct reading, in cm^3, of the volume.

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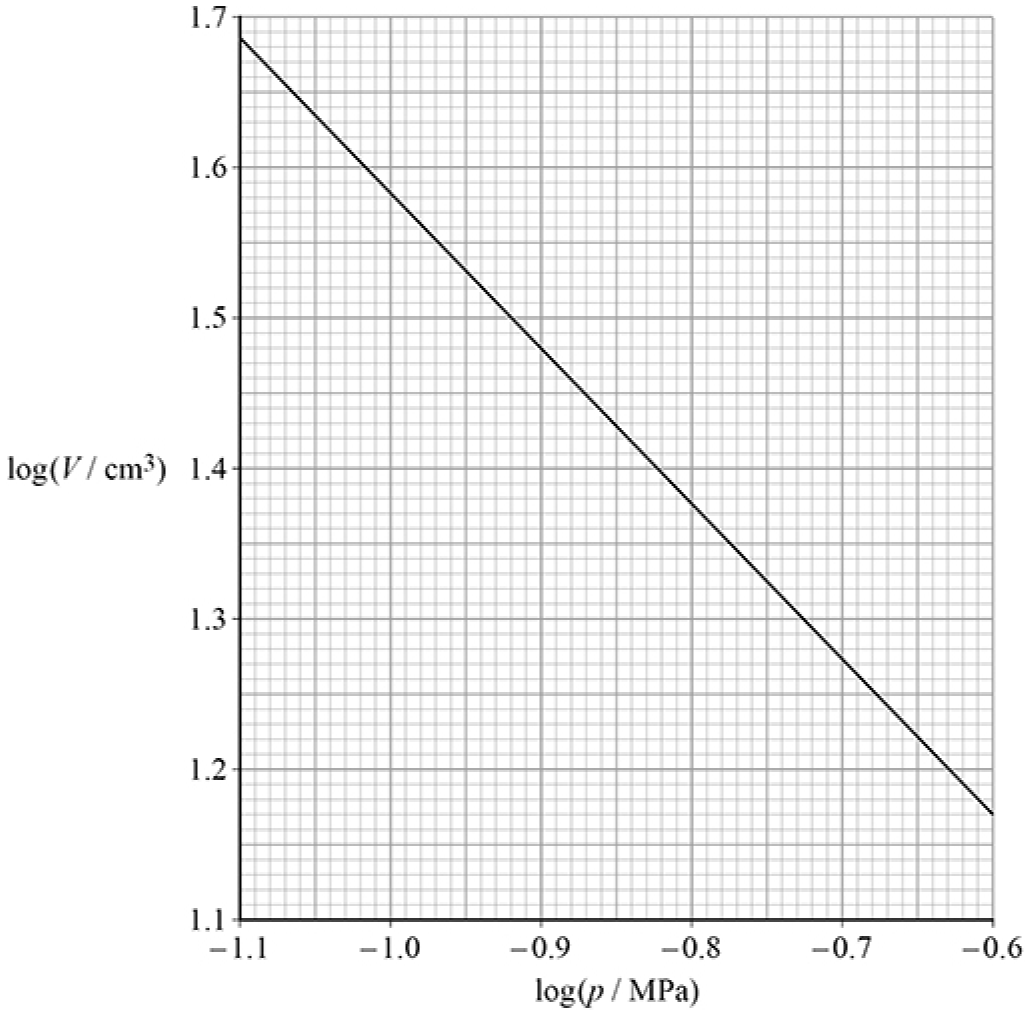
volume = _______________ cm^3

(2)

(e) **Figure 5** shows data obtained using the apparatus in **Figure 4**.

Figure 5



Explain why the gradient of the graph in **Figure 5** confirms that the air obeys Boyle's law.

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(3)

(f) The largest pressure that can be read from the pressure gauge is 3.4×10^5 Pa.

Determine, using **Figure 5**, the volume *V* corresponding to this pressure.

V = _______________ cm^3

(3)

(g) State **one** property of the air that must not change during the experiment.
Go on to suggest how this can be achieved.

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(2)

(Total 19 marks)

3. **Figure 1** and **Figure 2** show apparatus used in an experiment to confirm the distribution of atom speeds in a gas at a particular temperature.

Figure 1

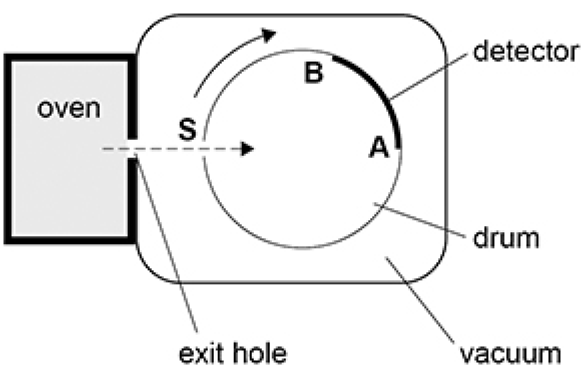
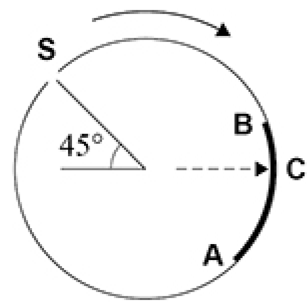


Figure 2



The oven contains an ideal gas kept at a constant temperature. Atoms of the gas emerge from the oven and some pass through the narrow slit **S** in a rapidly rotating drum. The drum is in a vacuum.

(a) Explain why the drum must be in a vacuum.

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(1)

One atom leaves the oven, enters the drum through **S** and travels in a straight line across the drum.
In the time taken for the atom to move from **S** to the detector **AB**, the drum rotates through 45°.
The atom hits the detector at point **C**, as shown in **Figure 2**.

drum diameter = distance from **S** to **A** = 0.500 m
drum rotational speed = 120 revolutions per second

(b) Show that the atom is moving at a speed of about 500 m s^{-1}.

(2)

(c) The speed of the atom in part (b) is equal to c_{rms}, the root mean square speed of the atoms of the gas in the oven.
The molar mass of the gas is 0.209 kg mol^{-1}.

Calculate the temperature of the gas in the oven.

temperature = _______________ K

(3)

(d) The oven temperature is kept constant during the experiment but the pressure in the oven decreases as atoms leave through the exit hole.

Explain, using the kinetic theory, why the pressure decreases.

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(2)

(e) The pressure of gas in the oven is initially 5.0×10^4 Pa.
The volume of the oven is 2.7×10^{-2} m^3.
During the experiment the pressure in the oven decreases to 4.5×10^4 Pa.

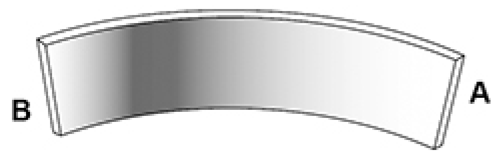
Calculate, in mol, the amount of gas that has emerged from the oven.

amount of gas = _______________ mol

(1)

(f) Atoms enter the drum every time **S** passes the exit hole. The detector darkens at the point where an atom strikes it.
After a time, the detector is removed from the drum.
Figure 3 shows the appearance of the detector.

Figure 3



A new detector is placed in the drum and the experiment is repeated with a new sample of the same gas at a higher temperature.

Describe and explain the appearance of this detector when the experiment is repeated.

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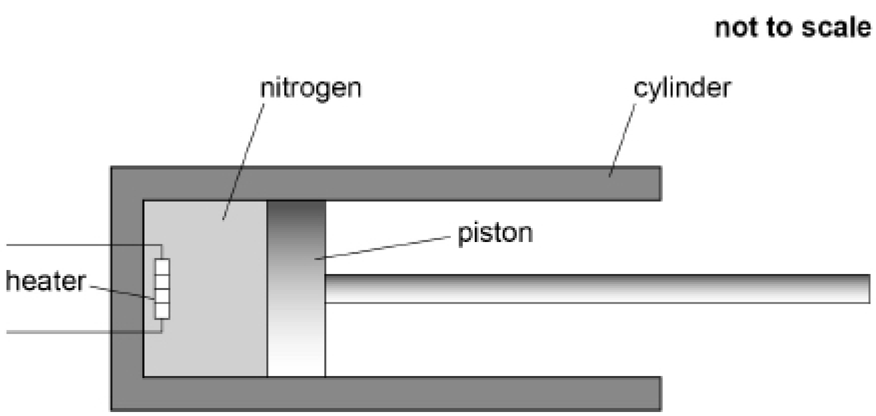
(2)
(Total 11 marks)

4. The diagram shows a perfectly insulated cylinder containing 0.050 kg of liquid nitrogen at a temperature of 70 K.
A heater transfers energy at a constant rate of 12 W to the nitrogen.
A piston maintains the pressure at 1.0×10^5 Pa during the heating process.



(a) The nitrogen is heated from 70 K and is completely turned into a gas after 890 s.

Calculate the specific heat capacity of liquid nitrogen.
Give an appropriate unit for your answer.

specific latent heat of vaporisation of nitrogen = 2.0×10^5 J kg^{-1}

boiling point of nitrogen = 77 K

specific heat capacity = ____________________ unit = ___________

(5)

(b) The work done by the nitrogen in the cylinder when expanding due to a change of state is **X**.
The energy required to change the state of the nitrogen from a liquid to a gas is **Y**.

Deduce which is greater, **X** or **Y**.

density of liquid nitrogen at its boiling temperature = 810 kg m^{-3}

density of nitrogen gas at its boiling temperature = 3.8 kg m^{-3}

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(4)
(Total 9 marks)