1. (a) The equation of state of an ideal gas is

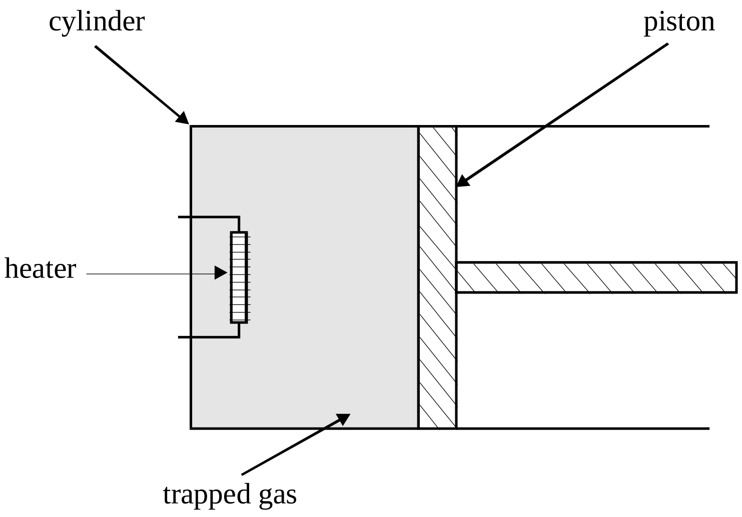
$$pV = nRT$$

For each of these symbols, state the physical quantity and the SI unit.

symbol	physical quantity	unit
p		
V		
n		
R		
T		

(4)

(b) An ideal gas of volume 1.0×10^{-4} m^3 is trapped by a piston in a cylinder as shown in the diagram. There is negligible friction between the piston and the cylinder. Initially, the temperature of the gas is 20 °C and the external atmospheric pressure acting on the piston is 100 kPa.



The gas expands slowly when heat is supplied by an electric heater inside the cylinder.

(i) Calculate the work done by the gas when its volume slowly increases by 5.0×10^{-5} m^3, at a constant pressure, while being heated.

....

....

(ii) What is the temperature of the gas, in °C, following its expansion?

....

....

....

....

....

(iii) Describe **two** changes that occur in the motion of a typical molecule of the gas during the expansion.

....

....

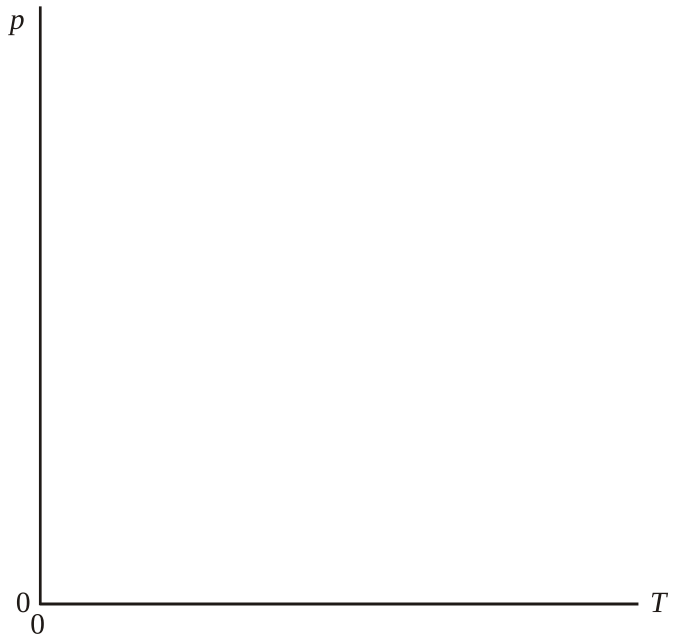
(8)
(Total 12 marks)

2. (a) State the equation of state for an ideal gas.

....

(1)

(b) A fixed mass of an ideal gas is heated while its volume is kept constant. Sketch a graph on the axes below to show how the pressure, *p*, of the gas varies with the absolute temperature, *T*, of the gas.



(2)

(c) Explain in terms of molecular motion, why the pressure of the gas in part (b) varies with the absolute temperature.

You may be awarded marks for the quality of written communication in your answer.

....

....

....

....

....

....

(4)

(d) Calculate the average kinetic energy of the gas molecules at a temperature of 300 K.

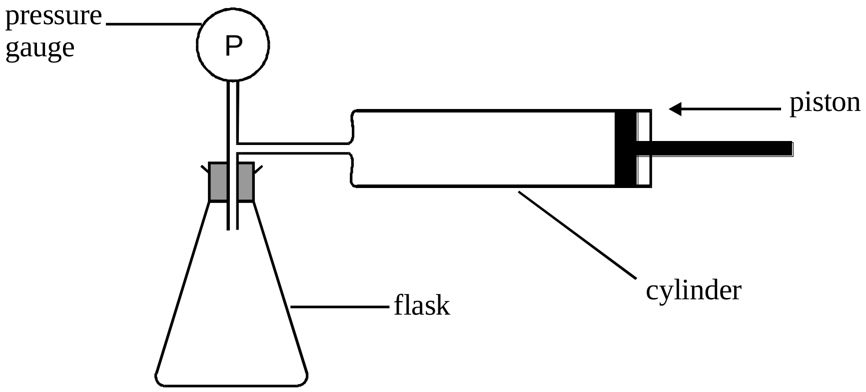
....

....

....

(2)
(Total 9 marks)

3. The diagram shows an arrangement that is used to measure the density of a powder. The air in the cylinder is forced into the flask and the air pressure is measured, by the pressure gauge P, before and after the change. The test is then repeated with the powder present in the flask. In both tests, the initial pressure in the flask is the same.



(a) (i) Explain why, after compression of the air the pressure in the flask is greater when the powder is present than when it is not present.

You may be awarded marks for the quality of written communication in your answer.

....

....

....

....

(ii) Calculate the pressure in the flask, after compression at constant temperature, when no powder was present. Assume that the volume of the tubes and pressure gauge is negligible.

volume of the empty flask = 2.50×10^{-4} m^3
volume of the cylinder = 1.00×10^{-4} m^3
initial pressure of the air in the flask and cylinder = 100 kPa.

....

....

....

....

....

(6)

(b) To test the apparatus, 0.13 kg of powder of density 2700 kg m^{-3} was placed in the flask before compression.

(i) Calculate the volume of this amount of powder.

....

....

....

(ii) The pressure of the air in the flask increased to 150 kPa when the test was carried out with this amount of powder in the flask. By carrying out an appropriate calculation, justify whether or not the test was successful.

....

....

....

....

....

....

....

....

(5)
(Total 11 marks)

4. The number of molecules in one cubic metre of air decreases as altitude increases. The table shows how the pressure and temperature of air compare at sea-level and at an altitude of 10 000 m.

altitude	**pressure/Pa**	**temperature/K**
sea-level	1.0×10^5	300
10 000 m	2.2×10^4	270

(a) Calculate the number of moles of air in a cubic metre of air at

(i) sea-level,

....

....

(ii) 10 000 m.

....

....

(3)

(b) In air, 23% of the molecules are oxygen molecules. Calculate the number of extra oxygen molecules there are per cubic metre at sea-level compared with a cubic metre of air at an altitude of 10 000 m.

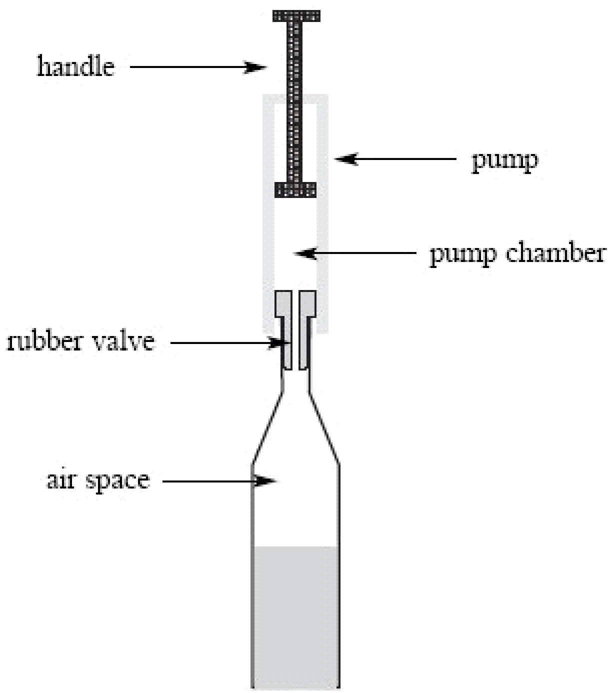
....

....

....

(2)
(Total 5 marks)

5. Some liquids in open bottles deteriorate exposure to air. The diagram below shows one device used to reduce this deterioration. It consists of a rubber valve that is inserted into the neck of the bottle together with a pump that is used to remove some of the air in the bottle through this rubber valve. On an up-stroke of the pump, air enters the pump chamber from the bottle. On the down-stroke, the rubber valve closes and the air in the chamber is expelled to the atmosphere through another valve (not shown) in the handle.



(a) There is 3.5×10^{-4} m^3 of air space in the bottle and the volume of the pump chamber changes from zero at the beginning of the up-stroke to 6.5×10^{-4} m^3 at the end of the up-stroke. The initial pressure of the air in the bottle is that of the atmosphere with a value of 99 kPa.

Assuming the process is at constant temperature, calculate the pressure in the bottle after one up-stroke of the pump.

....

....

....

....

(3)

(b) Calculate the number of molecules of air originally in the air space in the bottle at a temperature of 18 °C.

....

....

....

....

(3)

(c) Explain how the kinetic theory of an ideal gas predicts the existence of a gas pressure inside the bottle. Go on to explain why this pressure decreases when some of the air is removed from the bottle.

....

....

....

....

....

....

....

....

....

(5)
(Total 11 marks)

6. A domestic room heater which uses natural gas as the fuel, produces an output power of 4.5 kW. The energy obtained from a cubic metre of this fuel is 39 MJ. The density of the gas is 0.72 kg m^{-3} at atmospheric pressure.

(a) Show that the volume of gas which must be burnt each minute is $6.9 \leftrightarrow 10^{-3}$ m^3.

....

....

....

(2)

(b) Calculate

(i) the mass of gas which is burnt each minute,

....

....

(ii) the number of molecules of natural gas which pass through the burner each minute if the molar mass of the gas is $1.6 \leftrightarrow 10^{-2}$ kg mo1^{-1}.

....

....

....

(4)

(c) When the heater is first turned on, the temperature of the air entering it is 14°C and the temperature of the air leaving it is 36°C. If the specific heat capacity of air is 990 J kg^{-1} K^{-1}, calculate the mass of air passing through the heater in one minute.

....

....

....

....

(3)

(d) The room could have been heated using a 4.5 kW electric heater. Explain with a suitable calculation why such a heater could **not** be operated from a 13 A, 230 V socket.

....

....

....

....

(2)
(Total 11 marks)

7. In an experiment to measure the temperature of the flame of a Bunsen burner, a lump of copper of mass 0.12 kg is heated in the flame for several minutes. The copper is then transferred quickly to a beaker, of negligible heat capacity, containing 0.45 kg of water, and the temperature rise of the water measured.

Specific heat capacity of water = 4200 J kg^{-1} K^{-1}
Specific heat capacity of copper = 390 J kg^{-1} K^{-1}

(a) (i) The temperature of the water rises from 15ºC to 35ºC. Calculate the thermal energy gained by the water.

thermal energy gained = ...

(ii) Calculate the temperature reached by the copper in the flame. Assume no heat is lost when the copper is transferred.

temperature = ...

(4)

(b) When the lump of copper entered the water, some of the water was turned to steam.

(i) The specific latent heat of vaporisation of steam is 2.25 MJ kg^{-1}. What further measurement would need to be made to calculate the energy used to produce this steam?

....

....

(ii) Without further calculation, describe how this further measurement should be used to obtain a more accurate value of the flame temperature.

....

....

....

....

(3)
(Total 7 marks)

8. (a) The volume of air in a fully expanded pair of human lungs is 5.0×10^{-3} m^3. The pressure of the air in the lungs is 1.0×10^5 Pa and its temperature is 310 K.
Calculate

(i) the number of moles of air in the lungs,

....

....

(ii) the average kinetic energy of an air molecule in the lungs.

....

(4)

(b) Air is a mixture of oxygen and nitrogen molecules. The mass of an oxygen molecule is greater than the mass of a nitrogen molecule. State and explain the effect this has on the mean square speeds of the oxygen and nitrogen molecules in the lungs.

You may be awarded additional marks to those shown in brackets for the quality of written communication in your answer.

....

....

....

....

....

(3)
(Total 7 marks)

9. (a) (i) Write down the equation of state for *n* moles of an ideal gas.

....

(ii) The molecular kinetic theory leads to the derivation of the equation

$$pV = \frac{1}{3} Nm\overline{c^2},$$

where the symbols have their usual meaning.

State **three** assumptions that are made in this derivation.

....

....

....

....

....

(4)

(b) Calculate the average kinetic energy of a gas molecule of an ideal gas at a temperature of 20 °C.

....

....

....

....

(3)

(c) Two different gases at the same temperature have molecules with different mean square speeds.
Explain why this is possible.

....

....

....

....

(2)
(Total 9 marks)

10. (a) (i) State what is meant by *thermal equilibrium***.**

....

....

....

(ii) Explain thermal equilibrium by reference to the behaviour of the molecules when a sample of hot gas is mixed with a sample of cooler gas and thermal equilibrium is reached.

....

....

....

(3)

(b) A sealed container holds a mixture of nitrogen molecules and helium molecules at a temperature of 290 K. The total pressure exerted by the gas on the container is 120 kPa.

molar mass of helium	=	4.00×10^{-3} kg mol^{-1}
molar gas constant R	=	8.31 J K^{-1} mol^{-1}
the Avogadro constant N_A	=	6.02×10^{23} mol^{-1}

(i) Calculate the root mean square speed of the helium molecules.

....

....

....

....

(ii) Calculate the average kinetic energy of a nitrogen molecule.

....

....

....

(iii) If there are twice as many helium molecules as nitrogen molecules in the container, calculate the pressure exerted on the container by the helium molecules.

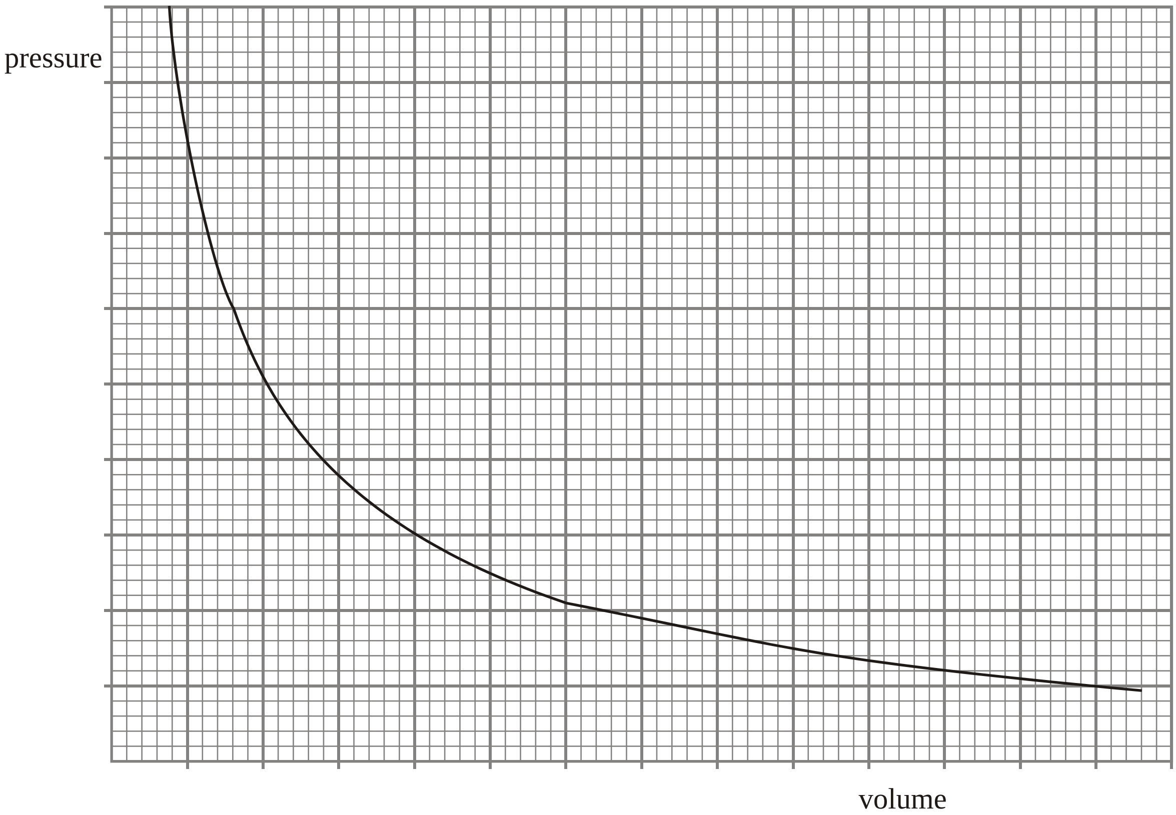
....

....

....

(6)
(Total 9 marks)

11. 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)

12. (a) (i) One of the assumptions of the kinetic theory of gases is that molecules make *elastic collisions.* State what is meant by an elastic collision.

....

....

(ii) State **two** more assumptions that are made in the kinetic theory of gases.

....

....

....

....

(3)

(b) One mole of hydrogen at a temperature of 420 K is mixed with one mole of oxygen at 320 K.
After a short period of time the mixture is in *thermal equilibrium*.

(i) Explain what happens as the two gases approach and then reach thermal equilibrium.

....

....

....

....

(ii) Calculate the average kinetic energy of the hydrogen molecules before they are mixed with the oxygen molecules.

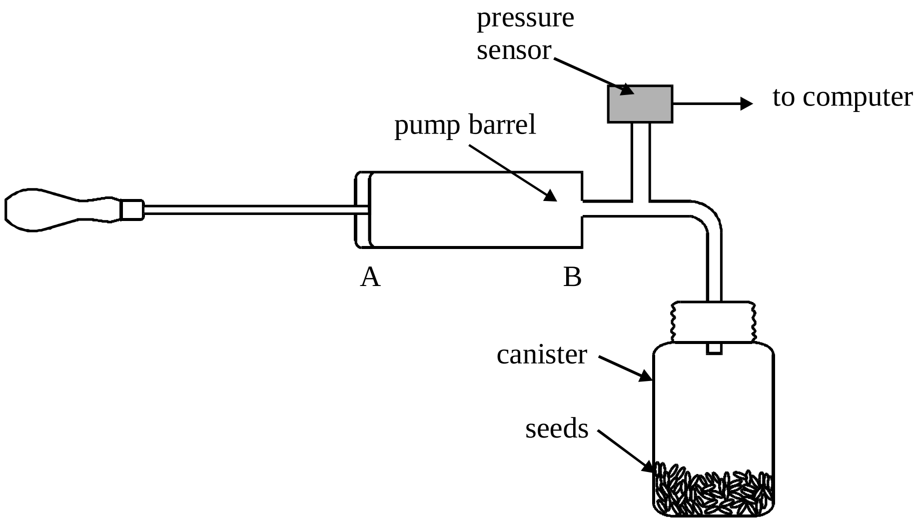
....

....

....

(4)
(Total 7 marks)

13. A biologist investigating the characteristics of stored plant seeds has devised a simple method of measuring the density of the seed material. A large quantity of seeds is weighed accurately to determine their total mass and the seeds are placed in an airtight canister as shown in the diagram. Air is then pumped into the canister using a simple hand pump. The change in pressure is measured by a pressure sensor linked to a computer. This pressure change is used to calculate the total volume of the seeds, and hence the density of the seed material.



The volume of the pump barrel between points A and B the diagram is 30.0 cm^3. With the canister *empty* and the piston at point A, the air pressure is 1.01×10^5 Pa. When the piston is pushed quickly from A to B and held at B, the computer registers a sharp increase in pressure which slowly falls to a steady value of 1.74×10^5 Pa.

(a) By considering the pressure and volume, both initially and after the pressure has settled at a steady value, calculate the volume of air in the empty canister and its connecting pipes.

....

....

....

....

....

....

(b) Explain why the pressure falls to a steady value after initially rising above this value.

....

....

....

....

....

(Total 5 marks)

14. (a) The air in a room of volume 27.0 m^3 is at a temperature of 22 °C and a pressure of 105 kPa.

Calculate

(i) the temperature, in K, of the air,

....

(ii) the number of moles of air in the room,

....

....

....

(iii) the number of gas molecules in the room.

....

....

(5)

(b) The temperature of an ideal gas in a sealed container falls. State, with a reason, what happens to the

(i) mean square speed of the gas molecules,

....

....

....

(ii) pressure of the gas.

....

....

....

....

....

....

(4)
(Total 9 marks)

15. (a) The molecular theory model of an ideal gas leads to the derivation of the equation

$$pV = \frac{1}{3}Nm\overline{c^2}.$$

Explain what each symbol in the equation represents.

p ....

V ....

N ....

....

m ....

$\overline{c^2}$ ....

....

(4)

(b) One assumption used in the derivation of the equation stated in part (a) is that molecules are in state of *random motion.*

(i) Explain what is meant by random motion.

....

....

....

(ii) State **two** more assumptions used in this derivation.

....

....

....

....

(3)

(c) Describe how the motion of gas molecules can be used to explain the pressure exerted by a gas on the walls of its container.

....

....

....

....

....

....

(4)

(Total 11 marks)

16. (a) A cylinder of fixed volume contains 15 mol of an ideal gas at a pressure of 500 kPa and a temperature of 290 K.

(i) Show that the volume of the cylinder is 7.2×10^{-2} m^3.

....

....

(ii) Calculate the average kinetic energy of a gas molecule in the cylinder.

....

....

(4)

(b) A quantity of gas is removed from the cylinder and the pressure of the remaining gas falls to 420 kPa. If the temperature of the gas is unchanged, calculate the amount, in mol, of gas remaining in the cylinder.

....

....

....

(2)

(c) Explain in terms of the kinetic theory why the pressure of the gas in the cylinder falls when gas is removed from the cylinder.

....

....

....

....

....

(4)
(Total 10 marks)

17. (a) Use the kinetic theory of gases to explain why

(i) the pressure exerted by an ideal gas increases when it is heated at constant volume,

....

....

....

....

(ii) the volume occupied by an ideal gas increases when it is heated at constant pressure.

....

....

....

....

(4)

(b) A quantity of 0.25 mol of air enters a diesel engine at a pressure of 1.05×10^5 Pa and a temperature of 27°C. Assume the gas to be ideal.

(i) Calculate the volume occupied by the gas.

....

....

....

....

(ii) When the gas is compressed to one twentieth of its original volume the pressure rises to 7.0×10^6 Pa. Calculate the temperature of the gas immediately after the compression.

....

....

....

....

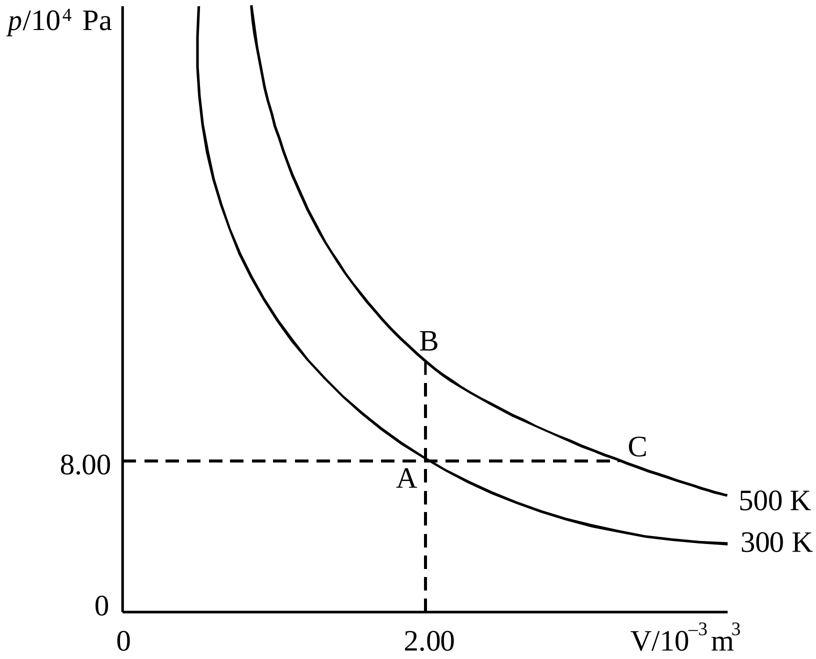
....

....

(4)
(Total 8 marks)

18. (a) The diagram shows curves (not to scale) relating pressure *p*, and volume, *V*, for a fixed mass of an ideal monatomic gas at 300 K and 500 K. The gas is in a container which is closed by a piston which can move with negligible friction.

molar gas constant, *R*, = 8.31 J mol^{-1} K^{-1}



(i) Show that the number of moles of gas in the container is 6.4×10^{-2}

....

....

(ii) Calculate the volume of the gas at point C on the graph.

....

....

(3)

(b) (i) Give an expression for the total kinetic energy of the molecules in one mole of an ideal gas at kelvin temperature *T*.

....

(ii) Calculate the total kinetic energy of the molecules of the gas in the container at point A on the graph.

Explain why this equals the total internal energy for an ideal gas.

....

....

....

....

(4)

(c) Defining the terms used, explain how the first law of thermodynamics, $\Delta Q = \Delta U + \Delta W$, applies to the changes on the graph

(i) at constant volume from A to B,

....

....

....

(ii) at constant pressure from A to C.

....

....

....

(5)

(d) Calculate the heat energy absorbed by the gas in the change

(i) from A to B,

....

....

....

(ii) from A to C

....

....

....

(3)
(Total 15 marks)

19. (a) State **two** quantities which increase when the temperature of a given mass of gas is increased at constant volume.

(i) ....

(ii) ....

(2)

(b) A car tyre of volume 1.0×10^{-2} m^3 contains air at a pressure of 300 kPa and a temperature of 290 K. The mass of one mole of air is 2.9×10^{-2} kg. Assuming that the air behaves as an ideal gas, calculate

(i) *n*, the amount, in mol, of air,

....

....

(ii) the mass of the air,

....

....

(iii) the density of the air.

....

....

(5)

(c) Air contains oxygen and nitrogen molecules. State, with a reason, whether the following are the same for oxygen and nitrogen molecules in air at a given temperature.

(i) The average kinetic energy per molecule

....

....

....

....

(ii) The r.m.s. speed

....

....

....

....

(4)
(Total 11 marks)