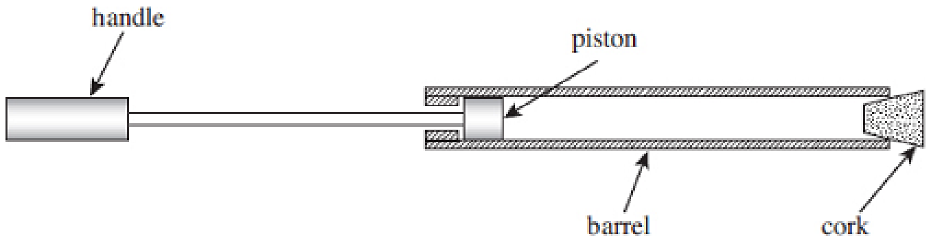
Q1. The figure below shows a child's 'pop' gun in which a piston is pushed quickly along the barrel, compressing the air in the barrel. When the pressure is high enough, the cork is expelled at high speed from the end of the barrel.



The figure above shows the gun before it is 'fired'. The air in the barrel is at a pressure of 1.0×10^5 Pa, a temperature of 290 K and the volume is 2.1×10^{-5} m^3.

(a) (i) The volume of air in the barrel at the instant the cork is expelled is 1.2×10^{-5} m^3. Calculate the pressure of the air in the barrel at the instant the cork is expelled. Assume that the air is compressed adiabatically.

adiabatic index, γ, for air = 1.4

answer = ... Pa

(2)

(ii) Calculate the maximum temperature reached by the air in the gun. Give your answer to an appropriate number of significant figures.

answer = ... K

(3)

(b) The work needed to compress the air adiabatically from 2.1×10^{-5} m^3 to 1.2×10^{-5} m^3 is 1.4 J. Use the first law of thermodynamics to determine the change in internal energy of the air during the compression. Explain how you arrived at your answer.

answer = ... J

(2)

(c) Explain, giving your reasons, whether the volume of air in the barrel at the point when the cork leaves the gun would be less than, equal to, or greater than 1.2×10^{-5} m^3 if the handle of the gun had been pushed in slowly. Assume there is no leakage of air past the cork or piston. You may find it helpful to sketch a *p* - *V* diagram of the compression.

....

....

....

....

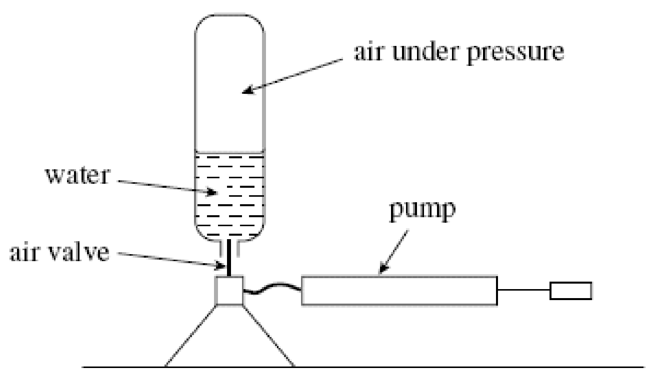
....

....

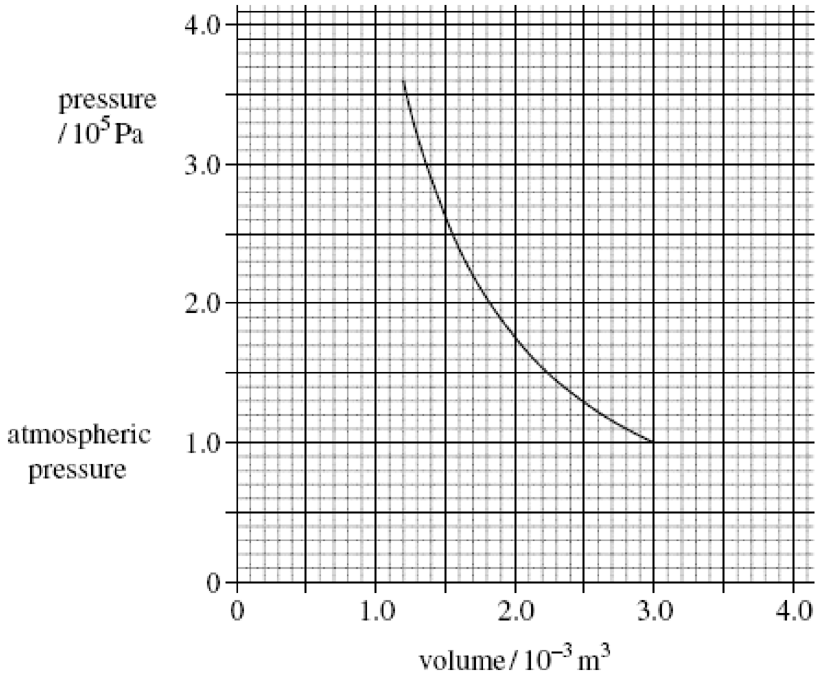
(3)
(Total 10 marks)

Q2. The figure below shows a model rocket for demonstrating the principle of rocket propulsion. Air is pumped into an upside-down plastic bottle that has been partly filled with water.

When the pressure reaches 3.6×10^5 Pa, (i.e. 2.6×10^5 Pa above atmospheric pressure) the air valve is forced out by the water pressure and the air in the bottle expands. The expanding air forces the water out of the neck of the bottle at high speed; this provides the thrust that lifts the bottle high into the air.



The graph shows the variation of pressure with volume for the air initially in the bottle as it expands from 3.6×10^5 Pa to atmospheric pressure, assuming the expansion is adiabatic.



(a) Use the graph to estimate the work done by the air as it expands from a pressure of 3.6×10^5 Pa to atmospheric pressure.

answer = ... J

(3)

(b) With reference to the graph above, state and explain whether the rocket would have reached the same height if the air had expanded isothermally.

....

....

....

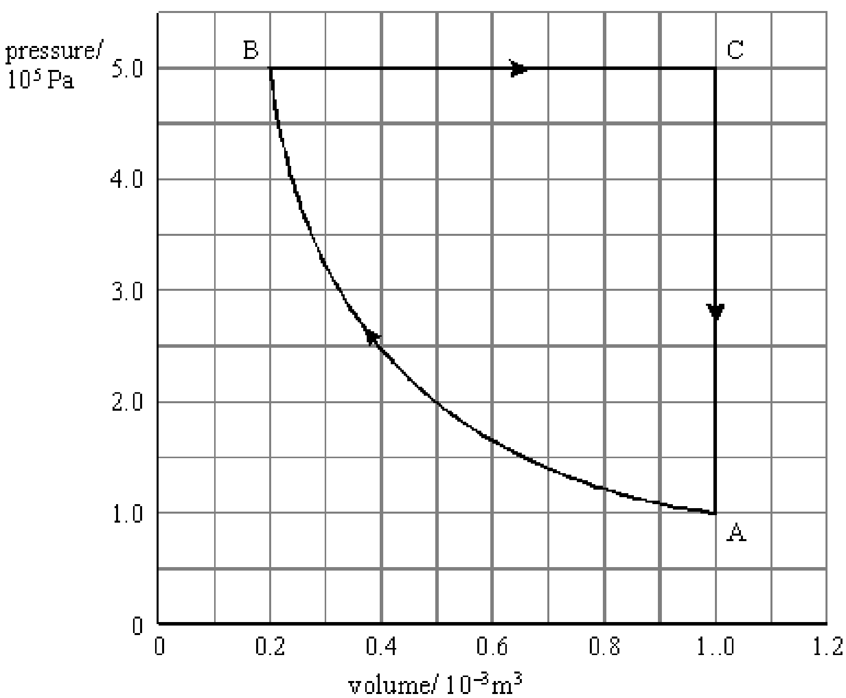
....

....

....

(3)
(Total 6 marks)

Q3. The *p V* diagram shows a cycle in which a fixed mass of an ideal gas is taken through the following processes: A → B isothermal compression, B → C expansion at constant pressure, C → A reduction in pressure at constant volume.



(a) Show that the compression in process A → B is isothermal.

....

....

....

(2)

(b) In which **two** of the three processes must heat be removed from the gas?

....

(1)

(c) Calculate the work done by the gas during process B → C.

....

....

....

(2)

(d) The cycle shown in the diagram involves 6.9×10^{-2} mol of gas.

(i) At which point in the cycle is the temperature of the gas greatest?

....

(ii) Calculate the temperature of the gas at this point.

....

....

....

....

(4)
(Total 9 marks)

M1. (a) (i) $p_2 = p_1 (V_2/V_1)^{1.4} = 1.0 \times 10^5 (2.1/1.2)^{1.4}$ ✓

OR $1.0 \times 10^5 \times (2.1 \times 10^{-5})^{1.4} = p_2 \times ((1.2 \times 10^{-5})1.4$ ✓

$p_2 = 2.2 \times 10^5$ Pa ✓

2

(ii) $T_2 = \frac{p_2 V_2 T_1}{p_1 V_1} = \frac{2.2 \times 10^5 \times (1.2 \times 10^{-5}) \times 290}{1.0 \times 10^5 \times 2.1 \times 10^{-5}}$ ✓

OR use of $p_1V_1 = nRT_1$ to find n or nR and substitute in

$p_2V_2 = nRT_2$ to find T_2 ✓

$T_2 = 360$ K ✓ 2 sig fig ✓

3

(b) ($Q = W + \Delta U$)

$Q = 0$ (and W negative) ✓

So ΔU (= - W) = 1.4 J ✓

2

(c) (slow) compression is (nearly) isothermal / at constant temperature ✓

greater change in volume needed to rise to same final pressure ✓

(OR correct *p*-*V* sketches showing adiabatic and isothermal processes ✓)

hence less / piston pushed in further ✓

3

[10]

M2. (a) work done = area under line **(1)**

appropriate method for finding area eg counting squares **(1)**

correct scaling factor used (to give answer of 150 J ± 10 J) **(1)**

if candidate correctly calculates area under curve to a pressure of zero Pa, (330 J ± 20 J) award 2 marks

3

(b) if isothermal line would have been less steep **(1)**

(so greater area under line and) more work done **(1)**

so rocket would rise higher **(1)**

3

[6]

M3. (a) pV = constant for any two points online AB **(1)**
two points chosen and constant calculated **(1)**
(e.g. at A, $pV = 1.0 \times 10^{5} \times 1.0 \times 10^{-3} = 100$ (J)
at B, $pV = 5.0 \times 10^{5} \times 0.2 \times 10^{-3} = 100$ (J))

2

(b) A → B and C → A **(1)**

1

(c) $W = p\Delta V$
$= 5.0 \times 10^{5} \times (1.0 - 0.2) \times 10^{-3} = 400$ (J) **(1)**

1

(d) (i) C **(1)**

1

(ii) $pV = nRT$ **(1)**

$5.0 \times 10^{5} \times 1.0 \times 10^{-3} = 6.9 \times 10^{-2} \times 8.3 \times T$ **(1)**

T=870K (872K) **(1)**

(allow C.E. if wrong point in (i))

4

[9]