IB · HL · Physics

2 hours | 13 questions

Structured Questions

Thermodynamics

Thermodynamic Systems (HL) / First Law of Thermodynamics (HL) / Entropy (HL) / Calculating Changes in Entropy (HL) / Second Law of Thermodynamics (HL) / Thermodynamic Processes (HL) / Heat Engines (HL) / The Carnot Cycle (HL)

Easy (5 questions)	/36
Medium (5 questions)	/55
Hard (3 questions)	/37
Total Marks	**/128**

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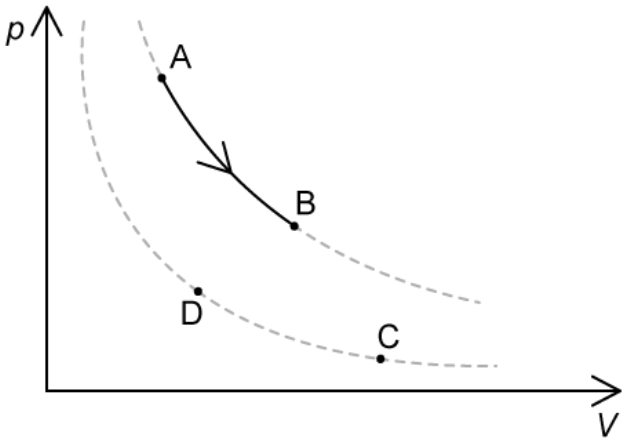
Easy Questions

1 (a) The pV diagram shows an incomplete Carnot cycle, with the starts and ends of each process labelled **A**, **B**, **C** or **D**.

The grey dashed lines represent isotherms.



Complete the Carnot cycle by drawing the other stages on the pV diagram.

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(2 marks)

(b) Complete the following sentences:

From **C** to **D**, work is done ____ the gas.

From **B** to **C**, work is done ____ the gas.

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(2 marks)

(c) There are energy changes throughout the cycle. State the stages of the cycle where:

(i) There is no change in internal energy

(1)

(ii) No thermal energy is transferred

(1)

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(2 marks)

(d) Describe how net work done by the heat engine is represented on a pV diagram.

....

(1 mark)

2 (a) A monatomic gas, contained within a balloon, increases in temperature from 260 K to 300 K.

Calculate the change in its internal energy if the balloon contains 5.2×10^{25} atoms.

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(2 marks)

(b) This process involved 25 kJ of thermal energy being transferred to the gas.

Calculate the work done through this process.

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(2 marks)

(c) State whether the balloon increases or decreases in size.

Explain your answer.

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(3 marks)

(d) The pressure of the gas remains constant at 202 kPa.

Calculate the magnitude of the change in volume of the balloon.

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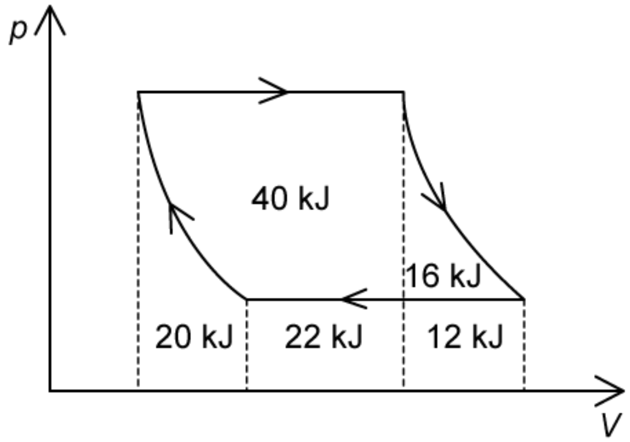
(2 marks)

3 (a) A heat engine cycle is represented on a pV diagram.



Calculate the work done by the gas during isobaric expansion.

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(1 mark)

(b) Calculate the work done during adiabatic compression.

....

(1 mark)

(c) Calculate the total work done on the gas throughout the cycle.

....

(1 mark)

(d) Throughout the cycle, the engine is supplied with 112 kJ of thermal energy from a hot reservoir.

Calculate the efficiency of the heat engine.

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(3 marks)

4 **(a)** State the Clausius form of the second law of thermodynamics.

....

(1 mark)

(b) State the Kelvin–Planck version of the second law of thermodynamics.

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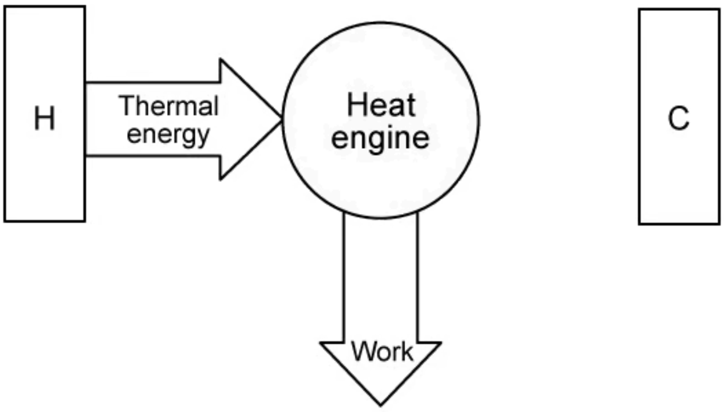
(1 mark)

(c) A student has drawn the diagram below to represent the flow of energy during the operation of a heat engine. **H** represents a hot reservoir, **C** represents a cold reservoir.



The diagram is incorrect. Explain why, referring to one of the statements of the second law of thermodynamics in your answer.

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(2 marks)

(d) Add to the diagram to make it correct.

....

(1 mark)

5 (a) Complete the sentences using words from below:

Of the three main states of matter, the most ordered is ....

Entropy is .... in this state.

Liquid	Increasing	Solid	Highest	Lowest	Gas

(2 marks)

(b) It takes 12.0 kJ to melt a block of iron. The melting point of iron is 1538 °C.

Calculate the entropy change of the melting process.

(2 marks)

(c) In an insulated, sealed chamber, two different gases are mixed.

State how the entropy of the system changes, if at all.

Explain your answer.

(2 marks)

(d) A student is told that the entropy of a glass of water **decreases** when a refrigerator freezes.

The student claims that this cannot be true, as it violates the second law of thermodynamics.

Explain why the student is incorrect.

(3 marks)

Medium Questions

1 (a) A system of particles in a gaseous state in the chamber of a piston has 2400 possible microstates.

Calculate its microscopic entropy in units of $eV\ K^{-1}$.

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....

(2 marks)

(b) The system is reset to another state with a different number of microstates. During a thermodynamic process, the number of microstates increases.

Calculate the factor by which the number of microstates increased if the entropy increased by $1.6 \times 10^{-4}\ eV\ K^{-1}$.

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(2 marks)

(c) The same system then undergoes isothermal expansion.

The gas applies a force of 140 N to a load, lifting it 20 cm vertically.

Calculate the heat transferred to the system.

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(3 marks)

(d) The isothermal process occurs at 300 °C.

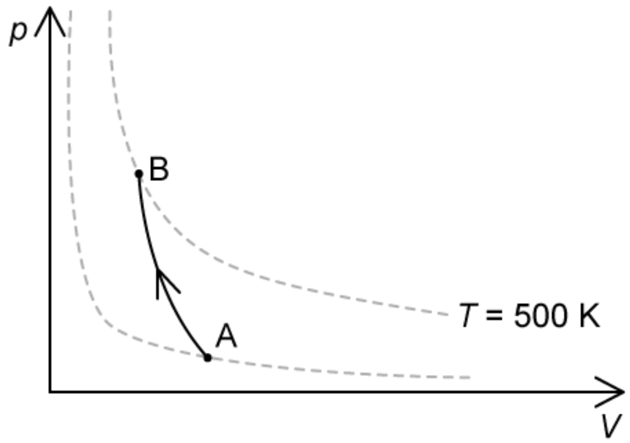
Calculate its entropy change.

(2 marks)

2 (a) An engineer is performing tests on a sample of helium gas (He).

Explain how the pV diagram shows that the internal energy changes during the adiabatic process from **A** to **B**.

The grey dashed lines represent isotherms.



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(3 marks)

(b) In the diagram in part (a), point **B** has coordinates (300 kPa, 0.065 m^3).

Calculate the number of moles of gas in the system.

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(2 marks)

(c) The volume at point **A** in the adiabatic process is 0.083 m^3.

Calculate the pressure at point **A**.

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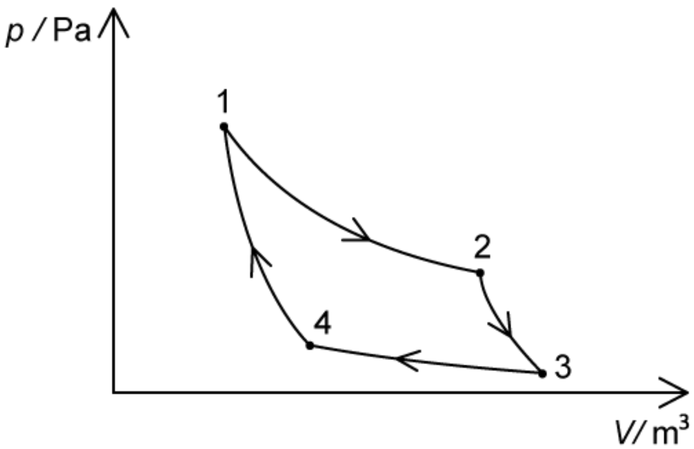
(3 marks)

(d) Explain why the calculation in part (c) would not be valid if the gas was water vapour.

(2 marks)

3 (a) The pV diagram shows a Carnot cycle for 3 moles of a monatomic ideal gas.



Describe the work done, change in internal energy and thermal energy transferred in and out of the system for:

(i) The process from state 1 to state 2

(2)

(ii) The process from state 2 to state 3

(2)

(iii) The process from state 3 to state 4

(2)

(iv) The process from state 4 to state 1

(2)

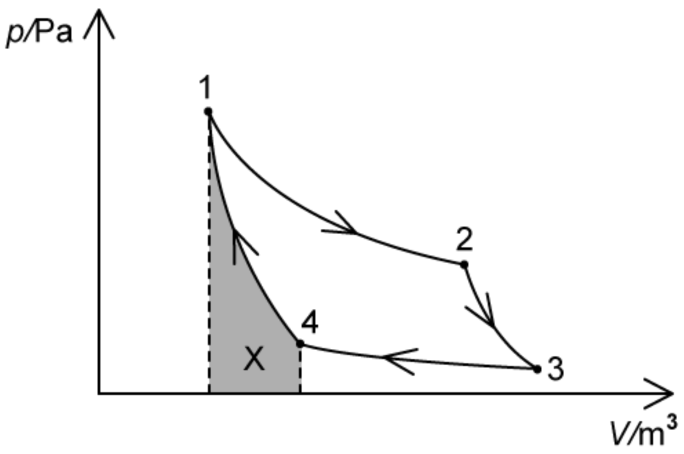
(8 marks)

(b) Give the name of each process throughout this cycle.

(3 marks)

(c) The graph is repeated here for convenience.

The shaded space **X** has an area of 230.



Calculate the change in temperature from stage 4 to stage 1.

(4 marks)

4 **(a)** State the Clausius and Planck-Kelvin statements of the second law of thermodynamics.

Compare these.

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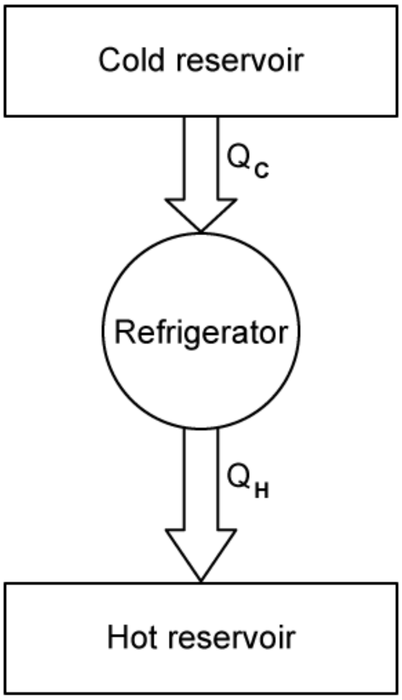
(3 marks)

(b) A student draws an energy flow diagram of a refrigerator operating.



Explain, in terms of entropy, why this diagram disobeys the second law of thermodynamics.

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(3 marks)

(c) Add an arrow to Figure 1, and label the arrow, to correct the diagram.

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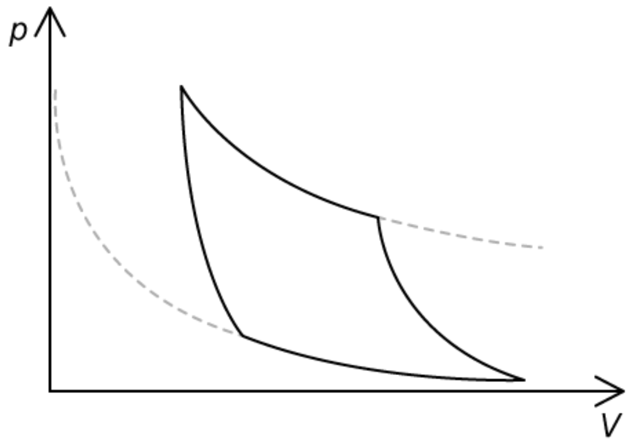
(2 marks)

(d) An idealised refrigerator cycle is shown on the pressure-volume diagram below.



(i) Draw arrows on the diagram to show the direction of the cycle.

[1]

(ii) Explain why this direction of the cycle allows heat to be removed from a cold region.

[2]

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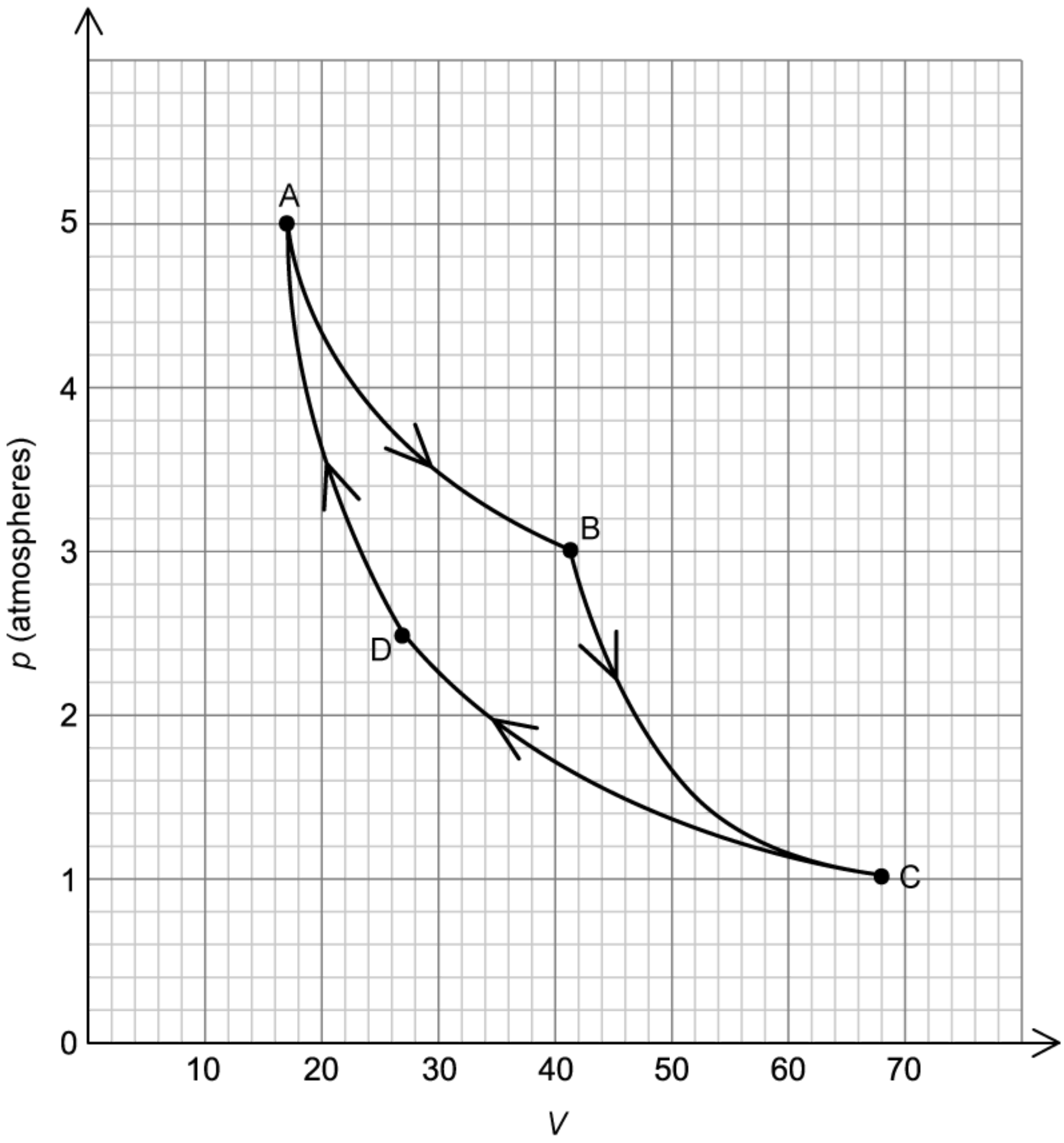
(3 marks)

5 (a) A particular heat engine operates with the following processes:

- Isothermal expansion
- Adiabatic expansion
- Isothermal compression
- Adiabatic compression

This cycle is shown below.



The following unit conversions may be helpful:

$$1 \text{ L} = 0.001 \text{ m}^3$$

1 atm = 101.3 kPa

(i) Calculate the temperature at which isothermal compression occurs, T_C , in terms of the number of moles, n.

(3)

(ii) Calculate the temperature at which isothermal expansion occurs, T_H , in terms of the number of moles, n.

(2)

(4 marks)

(b) State three assumptions made in order to calculate the answers to part (a) of this question.

(3 marks)

(c) Calculate the efficiency of this heat engine to 2 significant figures.

(3 marks)

Hard Questions

1 (a) The coefficient of performance is the ratio of useful energy output to work input.

In one instance, a refrigerator is used to cool food. The same equipment can also be used as a heat pump to warm a room in a cold country.

Suggest why the same equipment has different coefficients of performance in these two scenarios.

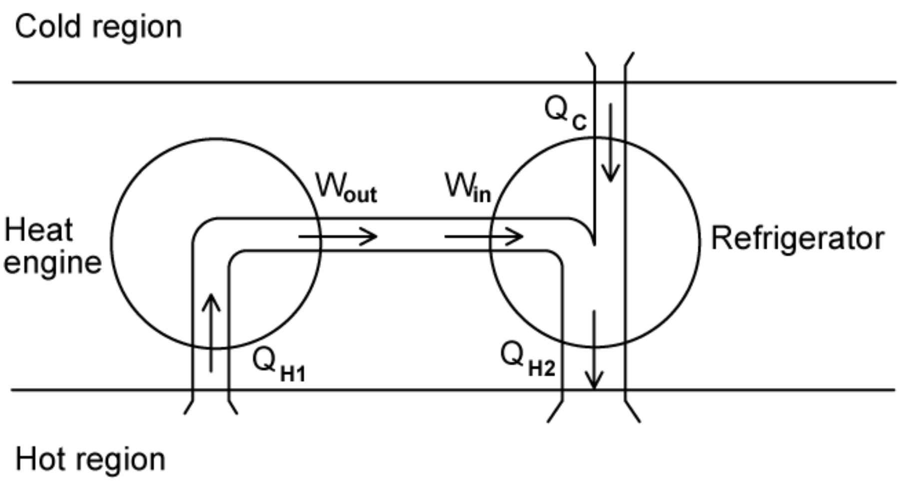
(4 marks)

(b) A refrigerator removes heat from a small space at a rate of 50 W and transfers 1.5 kWh to the room each day.

Calculate its coefficient of performance, *K*.

(4 marks)

(c) The diagram shows a system which is not physically possible.



Explain how the system shown violates the Kelvin and Clausius statements of the second law.

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(4 marks)

2 (a) A newly designed heat engine operates using water vapour, which is triatomic.

The equation used to model adiabatic processes for triatomic gases is:

$$pV^{\frac{4}{3}} = k$$

Here, p represents pressure, V represents volume and k is a constant.

For this form of the adiabatic equation, the work done during an adiabatic process is given by the equation:

$$W = -3k\Delta\left(V^{-\frac{1}{3}}\right)$$

A gas is in an initial state **1**, with a pressure of 301 kPa and volume of 0.0104 m^3. It expands adiabatically to state **2** with a volume of 0.0520 m^3.

Calculate the work done by the gas in this process.

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(3 marks)

(b) Under these conditions, water vapour behaves very closely to an ideal gas.

The process in part (a) forms part of a Carnot cycle.

Show that the efficiency, η, is given by the following equation:

$$\eta = 1 - \frac{p_1 V_1}{p_2 V_2},$$

where p_1 and p_2 are the pressures of states **1** and **2** respectively, and V_1 and V_2 are the volumes of states **1** and **2** respectively.

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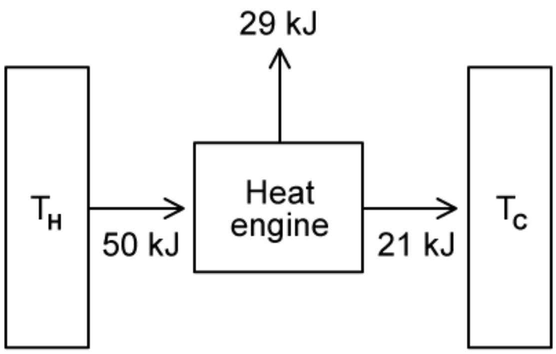
(4 marks)

(c) An engineering company are trying to advertise the heat engine from parts (a) and (b). Their marketing department produce an image for the website as part of the specifications of the heat engine.



Explain why this diagram is incorrect.

(5 marks)

3 (a) Two identical containers, A and B, are filled with the same gas, with the exact same initial conditions.

Both containers are supplied with heat *Q*. In container A, the subsequent process is isobaric. In container B, the subsequent process is isovolumetric.

State the container of the gas with the lowest final temperature.

Explain your answer.

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(4 marks)

(b) The gases in containers A and B are reset to their identical initial states.

This time, the gas in A receives more heat than the gas in B, but both experience the same increase in temperature.

State which gas absorbs heat at constant pressure and which absorbs heat at constant volume.

Explain your answer.

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(4 marks)

(c) Molar specific heat capacity at constant pressure, c_p , is the heat energy required to raise the temperature of one mole of ideal gas by 1 K at constant pressure.

Molar specific heat capacity at constant volume, c_V , is the heat energy required to raise the temperature of one mole of ideal gas by 1 K at constant volume.

Use the first law of thermodynamics to find an expression for the gas constant, R , in terms of c_p and c_V.

For a changing volume and constant pressure, the ideal gas law can be written as the following:

$$p\Delta V = nR\Delta T$$

(5 marks)