Thermodynamics

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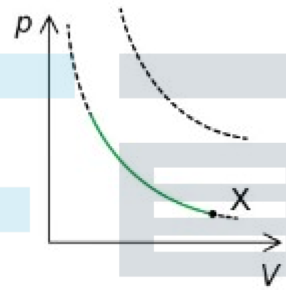
Course	HL IB Physics
Section	The Particulate Nature of Matter
Topic	Thermodynamics
Difficulty	Medium

To be used by all students preparing for HL IB Physics
Students of other boards may also find this useful

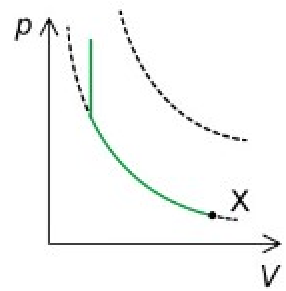
1

The correct answer is **D** because:

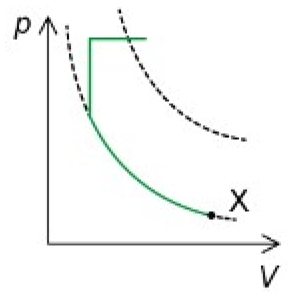
- **Stage 1: Isothermal compression**
  - Isothermal process = constant temperature
  - This is represented by a curve that follows the lower isotherm (dotted line)
  - Compression = decreasing volume, so the arrow must be pointing left



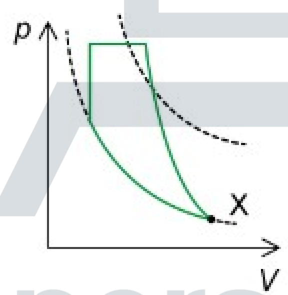
- **Stage 2: Isovolumetric process (ΔU = +Q)**
  - Isovolumetric = constant volume (as no work is done)
  - If thermal energy is gained, the temperature **increases**
  - This is represented by a vertical line with an arrow pointing upwards



- **Stage 3: Isobaric expansion**
  - Isobaric process = constant pressure
  - Since the gas is doing work, the volume must increase, or **expand**
  - This is represented by a horizontal line with an arrow pointing right



- **Stage 4: Adiabatic expansion**
  - Adiabatic = no net energy transfer
  - Expansion = volume increases, so the arrow must be pointing right
  - Additionally, the temperature must **decrease** in adiabatic expansion
  - This is represented by a curved line, steeper than the isotherms, moving to a lower isotherm



2

The correct answer is **B** because:

- The change in entropy, ΔS is calculated using the equation:
  - $\Delta S = k_B \ln\left(\frac{\Omega_f}{\Omega_i}\right)$
  - Here, k_B is the Boltzmann constant, Ω_i is the initial number of microstates and Ω_f is the final number of microstates

- Rearrange the equation to make Ω_f the subject:
  - $\ln\left(\frac{\Omega_f}{\Omega_i}\right) = \frac{\Delta S}{k_B} \Rightarrow \frac{\Omega_f}{\Omega_i} = e^{\frac{\Delta S}{k_B}}$
  - $\Omega_f = e^{\frac{\Delta S}{k_B}} \times \Omega_i$
- The initial number of microstates Ω_i is 1 as all 15 particles are initially in a single section
- Substitute in the known quantities:
  - $\Omega_f = e^{\left(\frac{1.12 \times 10^{-22}}{1.38 \times 10^{-23}}\right)} \times 1$
  - $\Omega_f = 3347$
- This is 3300 to two significant figures

A is incorrect because it is simply the ratio of the change in entropy to Boltzmann's constant

C is incorrect because 3347 rounds to 3300 to two significant figures, not 3400

D is incorrect because it assumes the initial number of microstates is 15, not 1

3

The correct answer is **D** because:

- List the known quantities:
  - Change in mean kinetic energy of a single particle, $\Delta E_{k,\,mean}$ = -3.11×10^{-21} J
  - Number of moles, n = 3
  - Boltzmann's constant, k_B = 1.38×10^{-23} J K^{-1}
  - Work done on the gas, W = –2000 J
  - Gas constant, R = 8.31 J K^{-1} mol^{-1}
- From the data booklet, the change in mean kinetic energy of a single particle, $\Delta E_{k,\,mean}$ is calculated using:
  - $\Delta E_{k,mean} = \frac{3}{2}k_B\Delta T$

- This can be used to calculate the change in temperature:
  - $\Delta T = \frac{2 \times -3.11 \times 10^{-21}}{3 \times 1.38 \times 10^{-23}} = -150.24 \text{ K}$
  - The minus signs are important to show that the temperature has decreased, as mean kinetic energy has decreased

- This change in temperature, along with the number of moles *n*, can then be used to calculate the loss in internal energy ΔU of the gas:
  - $\Delta U = \frac{3}{2}nR\Delta T = \frac{3}{2} \times 3 \times 8.31 \times -150.24$
  - $\Delta U = -5618 \text{ J}$

- Recall the first law of thermodynamics: $Q = \Delta U + W$
- Substitute the change in internal energy and work done to find thermal energy transferred
  - $Q = -5618 + -2000$
  - $Q = -7620 \text{ J}$

A is incorrect, because this is just the work done

B is incorrect, because work is negative when done on the gas, but to obtain this answer, your value of work will have been positive

C is incorrect because this is just the internal energy and work on the gas was not included

4

The correct answer is **B** because:

- The arrangement of the water is becoming more organised as it freezes, so its entropy decreases
  - We can rule out options **A** and **C** based on this first column
- A refrigerator transfers thermal energy to the surroundings, so the temperature of the surroundings increases
- The net entropy must always increase or stay the same
  - If the entropy of the water is decreasing, the entropy of the surroundings must increase to compensate
  - This eliminates option **D**

5

The correct answer is **D** because:

- **Process 1: isovolumetric heating**
    - This rules out option **A** because the gas is not expanding - the phrase 'isovolumetric expansion' is contradictory
    - As there is volume change, no work is done so we cannot rule out **C** here
- **Process 2: isothermal expansion**
    - Adiabatic processes have a steeper gradient than isothermal processes
    - The second process follows an isothermal path between the two grey dashed isotherms
    - This rules out option **B**, which claims this process is adiabatic
- **Process 3: adiabatic cooling / expansion**
    - Both **C** and **D** agree with this - the gas both cools and expands adiabatically in this stage
- **Process 4: isobaric compression**
    - The two final processes involve work being done **on** the gas, the second being isothermal
    - This is because the volume of the gas is reducing
    - This rules out option **C** which states work is done **by** the gas