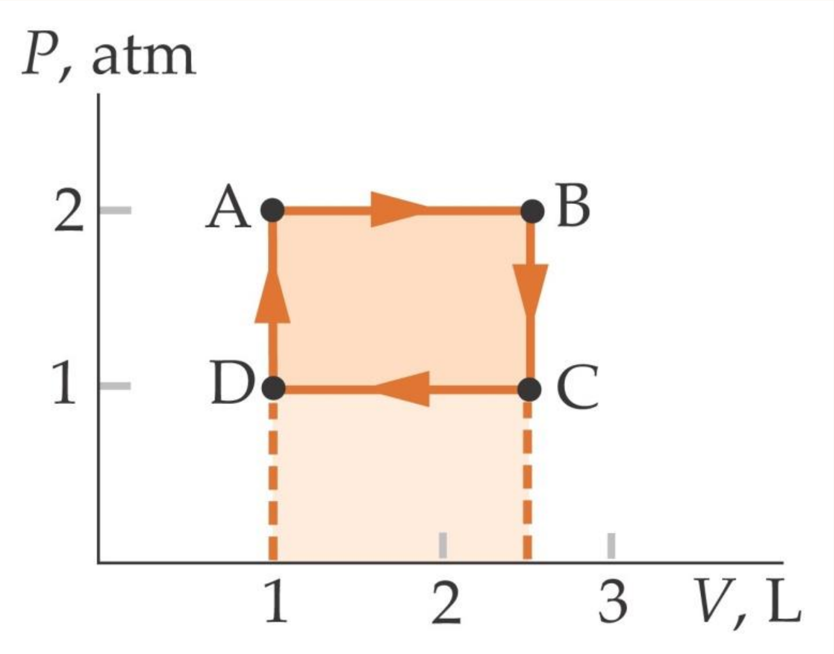
PHAS1000 – THERMAL PHYSICS

Lecture 12

Thermodynamic Processes



Overview

This lecture covers:

- State variables
- Isobaric process
- Isochoric process
- Isothermal process

Reminder of equations:

Always true:

$$Q_{in} = \Delta U + W_{by} \qquad W_{by} = \int_{V_i}^{V_f} PdV$$

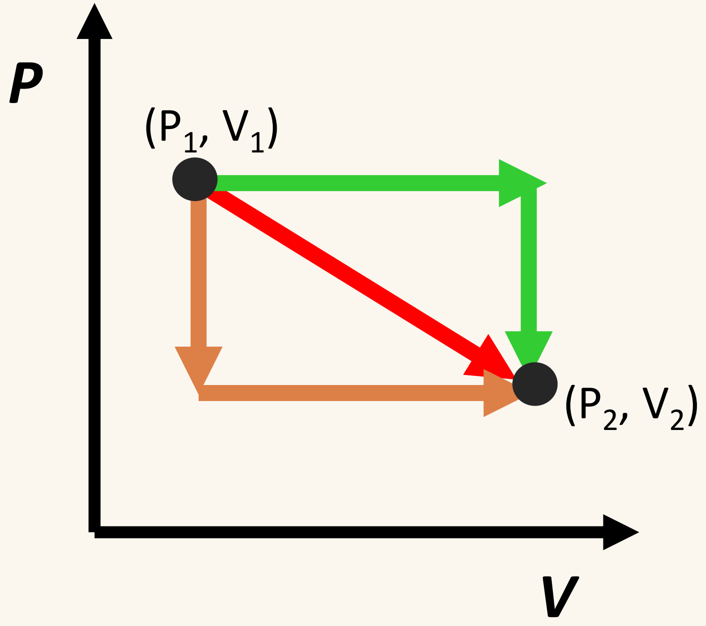
For ideal gas:

$$\Delta U = \mathrm{n}c_v' \Delta T$$

$$U = nf\frac{1}{2}RT \qquad c_p' - c_v' = R$$

$$PV = nRT$$

State Variables



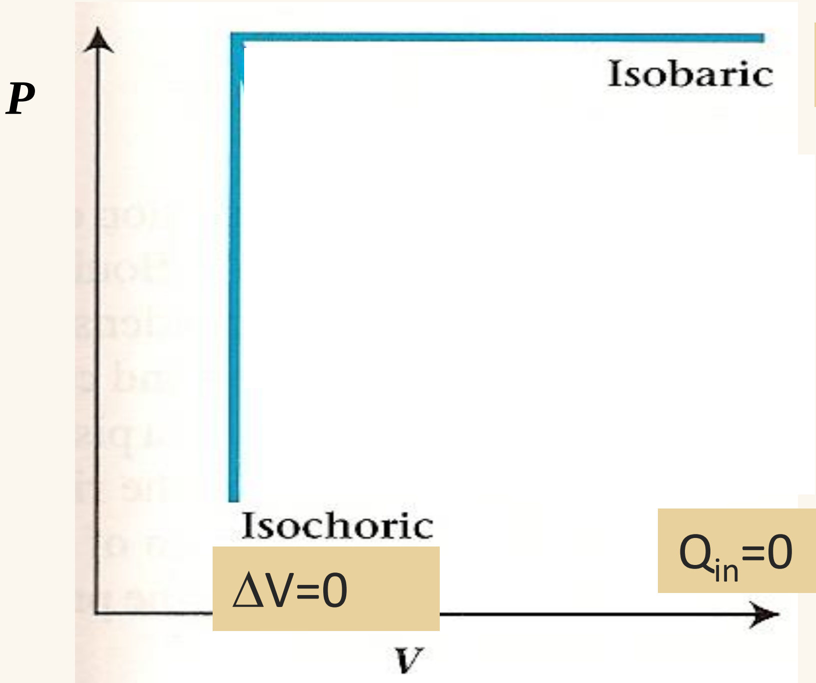
P, V, T, U are state variables.

Defined by a point on the PV diagram.

Q and W are not state variables.

They are a measure of energy that flows into or out of the system, and depend on the ‘route’ taken.

Different Processes



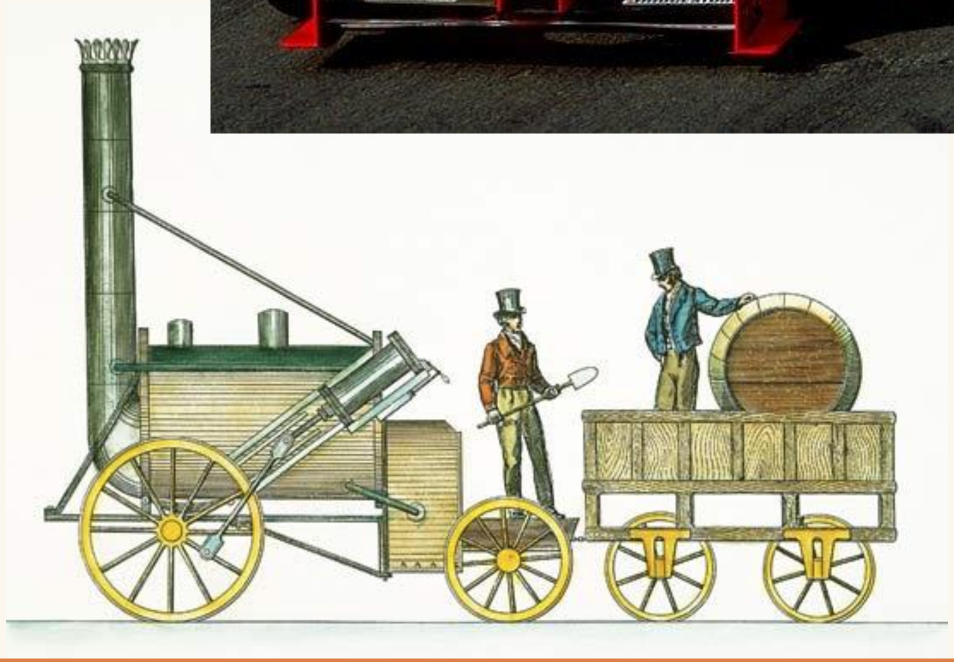
$\Delta P=0$

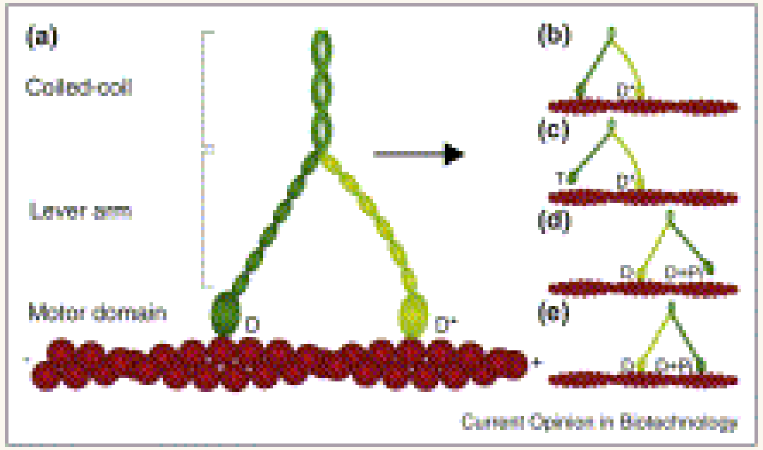
$\Delta T=0$

$Q_{in}=0$

$\Delta V=0$

What have these got in common?





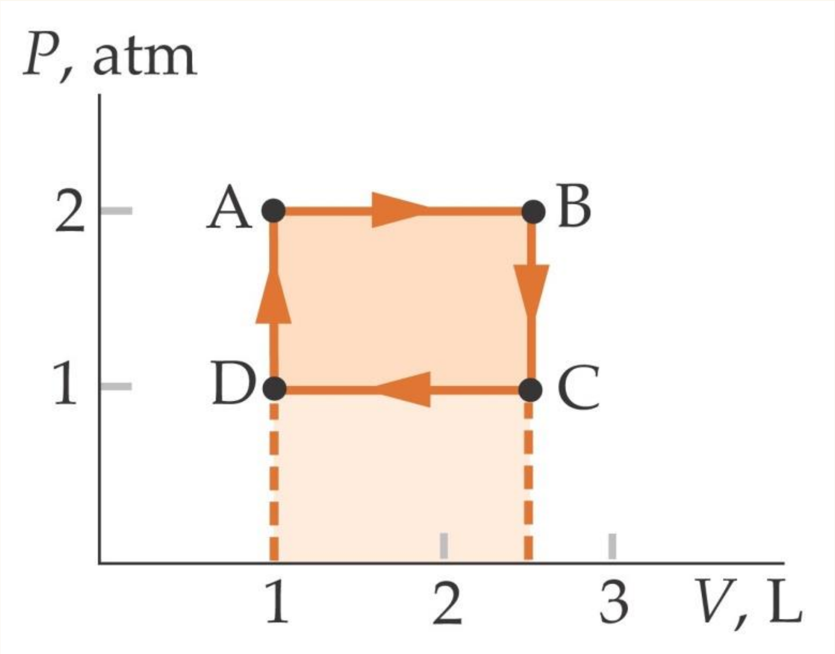
They are all cyclic processes making use of thermodynamics.

Isobaric and Isochoric

Isobaric: $\Delta P = 0$ e.g. open to atmosphere
Isochoric: $\Delta V = 0$ e.g. rigid container

An ideal gas undergoes a cyclic process from point A to B to C to D and back to A. The gas begins at a volume of 1L and a pressure of 2 atm and expands at constant pressure until the volume is 2.5L, after which it is cooled at constant volume until its pressure is 1atm. It is then compressed at constant pressure until its volume is again 1L, after which it is heated at constant volume until it is back in its original state.

Find the total work done by the gas and the total heat added to it during the cycle.



Calculating the work

Find the total work done by the gas during the cycle.

$W_{by} = \int P\,dV$

AB $\quad W_{AB} = P\Delta V = P_A(V_B - V_A)$

$= 2\,\text{atm}(2.5\,\text{L} - 1\,\text{L}) = 2\,\text{atm} \times 1.5\,\text{L}$

$= 2 \times 1.013 \times 10^5 \times 1.5 \times 10^{-3} = \boxed{304\,\text{J}}$

BC $\quad W_{BC} = 0 \quad$ V is constant

CD $\quad W_{CD} = P_C(V_D - V_C) = 1\,\text{atm}(1\,\text{L} - 2.5\,\text{L}) = 1\,\text{atm} \times (-1.5\,\text{L})$

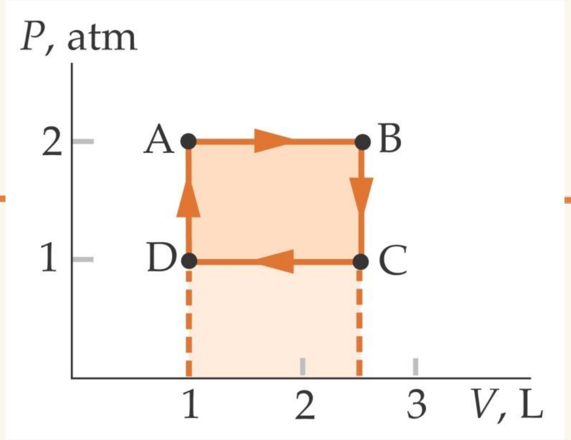
$= \boxed{-152\,\text{J}}$

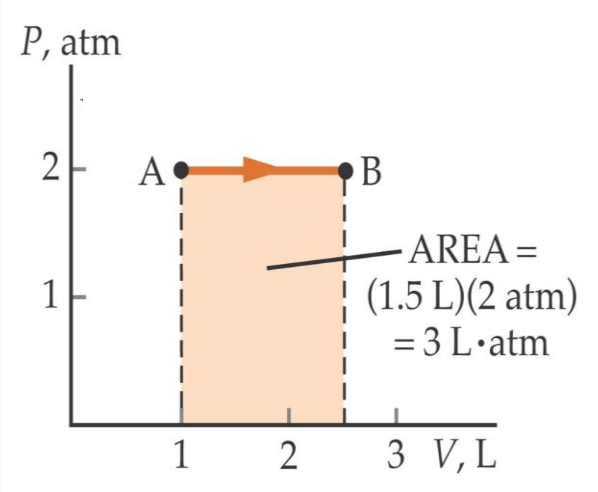
DA $\quad W_{DA} = 0$

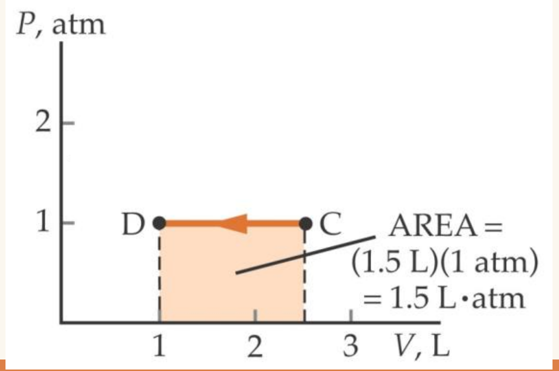
Total work done in cycle $= W_{AB} + W_{BC} + W_{CD} + W_{DA}$

$= 304 + 0 + (-152) + 0$

$= \underline{\underline{152\,\text{J}}}$





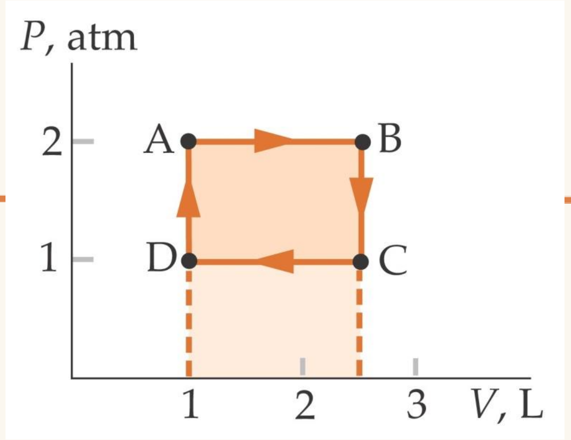


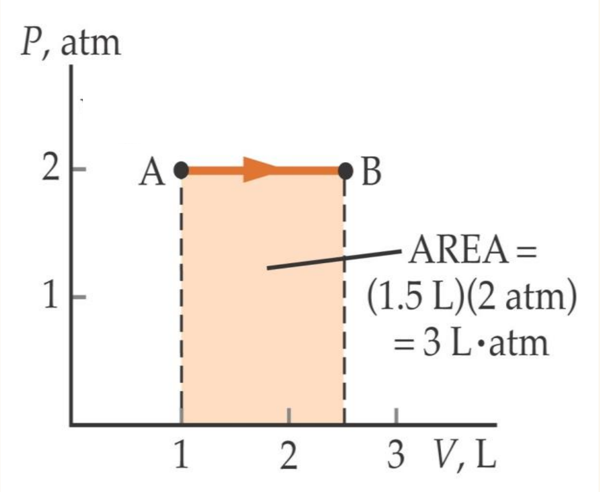
Calculating the work

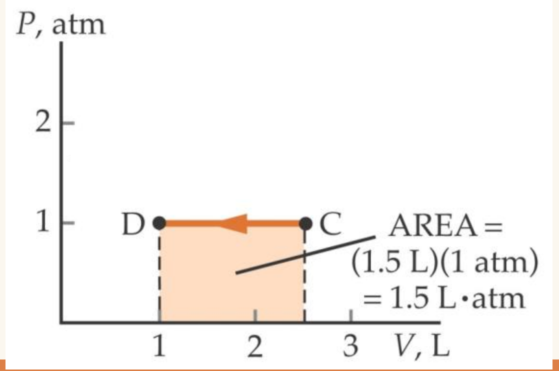
Find the total heat added to it during the cycle.

$$Q_{in} = \Delta U + W_{by} \qquad \text{In cycle } \Delta U = 0$$

$$\therefore\ Q_{in} = W_{by} = \underline{\underline{152\ \text{J}}}$$







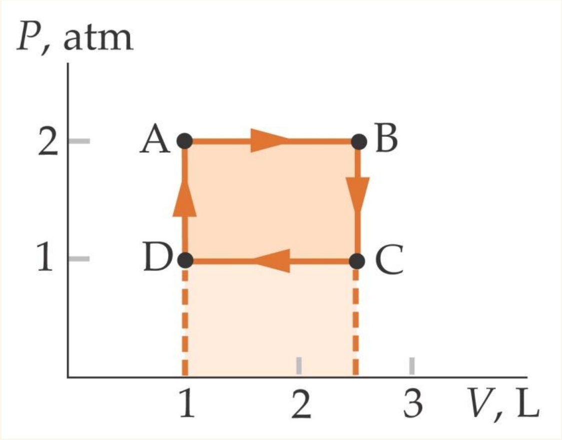
Complete cycle

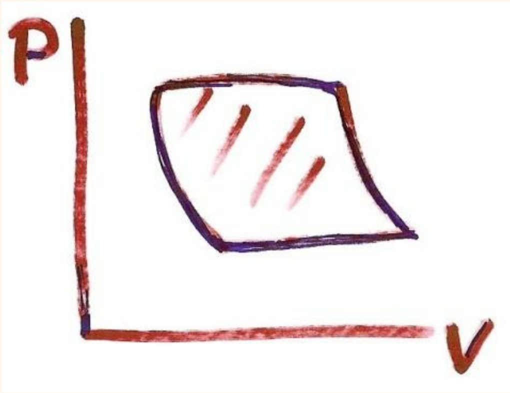
In a complete cycle:-

work done = area enclosed by shape (ABCD)

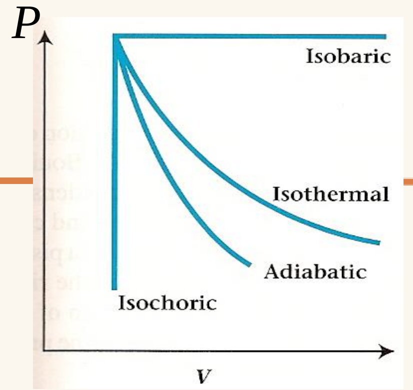
$\Delta U = 0$ $\qquad Q_{in} = W_{by}$

All the heat transfers to the gas doing work in expanding.





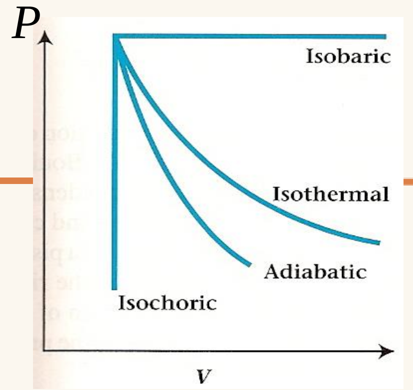
Summary of Isobaric and Isochoric



$$Q_{in} = \Delta U + W_{by} \qquad W_{by} = \int_{V_i}^{V_f} P dV$$

	ISOBARIC $\Delta P=0$	ISOCHORIC $\Delta V=0$	ISOTHERMAL $\Delta T=0$	ADIABATIC $Q_{in}=0$
W_{by}				
Q_{in}				
ΔU				

Summary of Isobaric and Isochoric



$$Q_{in} = \Delta U + W_{by} \qquad W_{by} = \int_{V_i}^{V_f} P dV$$

	ISOBARIC $\Delta P=0$	ISOCHORIC $\Delta V=0$	ISOTHERMAL $\Delta T=0$	ADIABATIC $Q_{in}=0$
W_{by}	$P\Delta V$	0		
Q_{in}	$\Delta U + W_{by}$ $= nc_v'\Delta T + P\Delta V$	ΔU		
ΔU	$nc_v'\Delta T$	$nc_v'\Delta T$		

##/## Join at: **vevox.app** ID: **199-145-020** Question slide

A system is taken from state *a* to state *b* along any of the 3 paths shown.

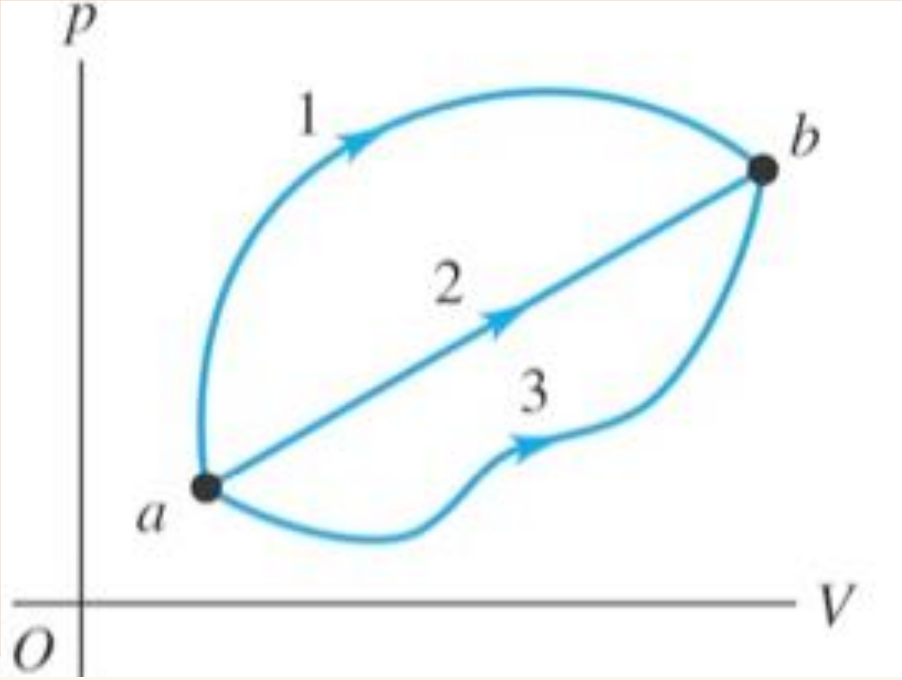
If state *b* has greater internal energy than state *a*, along which path is the heat transfer the greatest?

A path 1

B path 2

C path 3

D same for all three paths



A path 1

##.##%

B path 2

##.##%

C path 3

##.##%

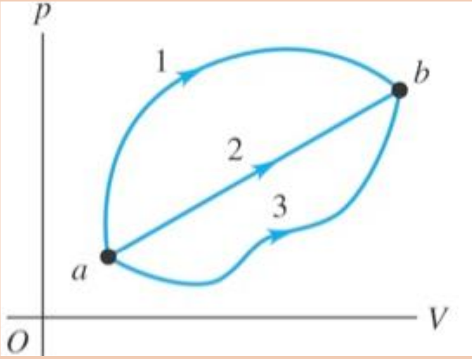
D same for all three paths

##.##%

Answer Q1

A system is taken from state *a* to state *b* along any of the 3 paths shown.

If state *b* has greater internal energy than state *a*, along which path is the heat transfer the greatest?



A path 1

B path 2

C path 3

D same for all three paths

$Q_{in} = \Delta U + W_{by}$

But U is a state variable (defined by point on PV graph)

$\therefore$ all paths have same ΔU.

$\therefore$ difference in Q_{in} depends only on difference in W_{by}

$W_{by} = \int P\,dV$ (ie area under graph)

<u>path 1</u> has largest area, hence largest Q_{in}.

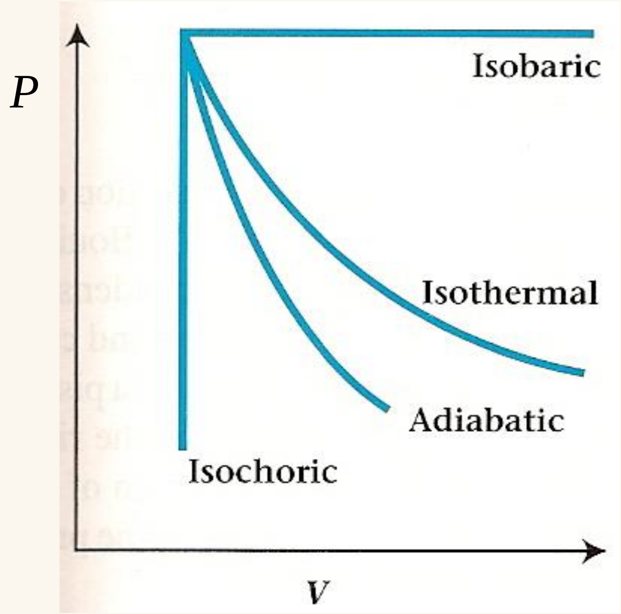
Isothermal

$\Delta T = 0$ SLOW process to allow heat to flow in or out to maintain temperature

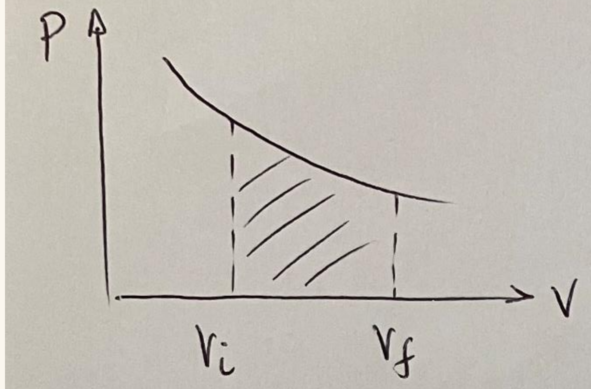
For an ideal gas: $\Delta U = \mathrm{n}c_v'\Delta T$ so for isothermal conditions $\Delta U = 0$

From 1st law $Q_{in} = \Delta U + W_{by}$ we get $Q_{in} = W_{by}$

All the heat entering the system is used to do work.



Isothermal – evaluating the work



$$W_{by} = \int P\,dV$$

For ideal gas $PV = nRT$

so $P = \frac{nRT}{V}$

$$W_{by} = \int_{V_i}^{V_f} \frac{nRT}{V}\,dV$$

$$= nRT \int_{V_i}^{V_f} \frac{1}{V}\,dV$$

$$= nRT\left(\ln V_f - \ln V_i\right)$$

$$W_{by} = nRT \ln\left(\frac{V_f}{V_i}\right)$$

Summary of Isothermal

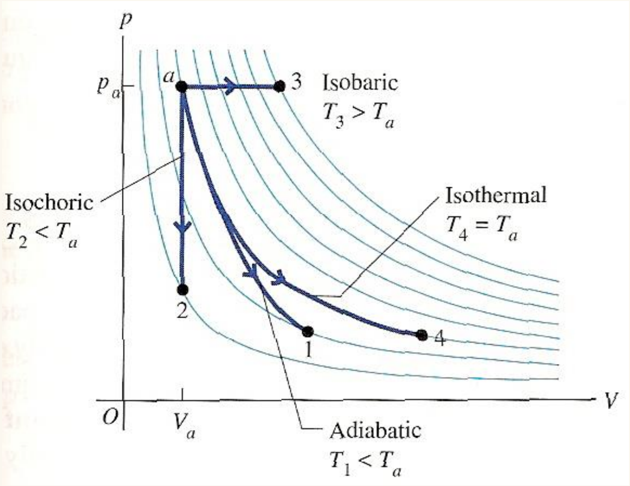
	ISOBARIC $\Delta P=0$	ISOCHORIC $\Delta V=0$	ISOTHERMAL $\Delta T=0$	ADIABATIC $Q_{in}=0$
W_{by}	$P\Delta V$	0		
Q_{in}	$\Delta U + W_{by}$ $= nc_v'\Delta T + P\Delta V$	ΔU		
ΔU	$nc_v'\Delta T$	$nc_v'\Delta T$		

Summary of Isothermal

	ISOBARIC $\Delta P=0$	ISOCHORIC $\Delta V=0$	ISOTHERMAL $\Delta T=0$	ADIABATIC $Q_{in}=0$
W_{by}	$P\Delta V$	0	$nRT\ln\left(\frac{V_f}{V_i}\right)$	
Q_{in}	$\Delta U + W_{by}$ $= nc_v'\Delta T + P\Delta V$	ΔU	W_{by}	
ΔU	$nc_v'\Delta T$	$nc_v'\Delta T$	0	

Summary

Isobaric $\Delta P = 0$
Isochoric $\Delta V = 0$
Isothermal $\Delta T = 0$
Adiabatic $Q_{in} = 0$



$$Q_{in} = \Delta U + W_{by}$$

$$W_{by} = \int_{V_i}^{V_f} PdV$$

P, V, T, U are state variables.

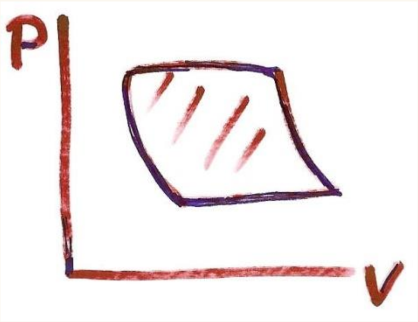
Defined by a point on the PV diagram.

Q and W are not state variables.

In a complete cycle:-

work done = area enclosed by shape

$\Delta U = 0$ $\qquad$ $Q_{in} = W_{by}$



Question 4

A monatomic ideal gas initially at 20 °C and 200 kPa has a volume of 4 L. It is heated at constant pressure until the temperature reaches 80 °C. Find:

(a) The heat added to the gas

(b) The change in internal energy of the gas

(c) The work done by the gas

ANSWERS

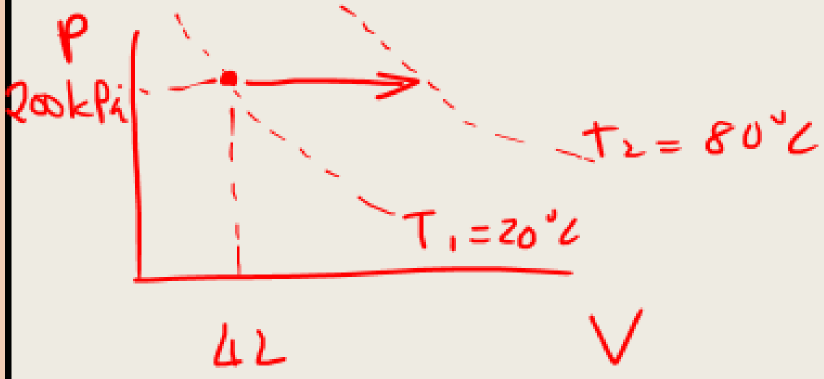
Answer Q4

A monatomic ideal gas initially at 20 °C and 200 kPa has a volume of 4 L. It is heated at constant pressure until the temperature reaches 80 °C. Find:

(a) The heat added to the gas

(b) The change in internal energy of the gas

(c) The work done by the gas



(a) $Q_p = C_p \Delta T = n c_p' \Delta T$ monatomic $c_p' = \frac{5}{2} R$

$Q_p = 0.33 \times \frac{5}{2} \times 8.31 \times (80-20)$ $PV = nRT$

$= 411 \text{ J}$

$n = \frac{PV}{RT} = \frac{200\times10^3 \times 4\times10^{-3}}{8.31 \times (273+20)}$

$n = 0.33$ moles

(b) $\Delta U = C_v \Delta T = n c_v' \Delta T$

$= 0.33 \times \frac{3}{2} \times 8.31 \times 60 = 247 \text{ J}$

(c) 1st law $Q_{in} = \Delta U + W_{by}$ $W_{by} = Q_{in} - \Delta U$

$= 411 - 247 = 164 \text{ J}$