
1st Law of Thermodynamics

Temperature Scales → Absolute vs empirical, Kelvin Scale √

→ Coversion between scales √

→ Zeroth Law of Thermodynamics √

↓

Internal Energy √

↓

Specific Heat Capacity → Latent heat – Melting, Vaporization, Kinetic Theory √

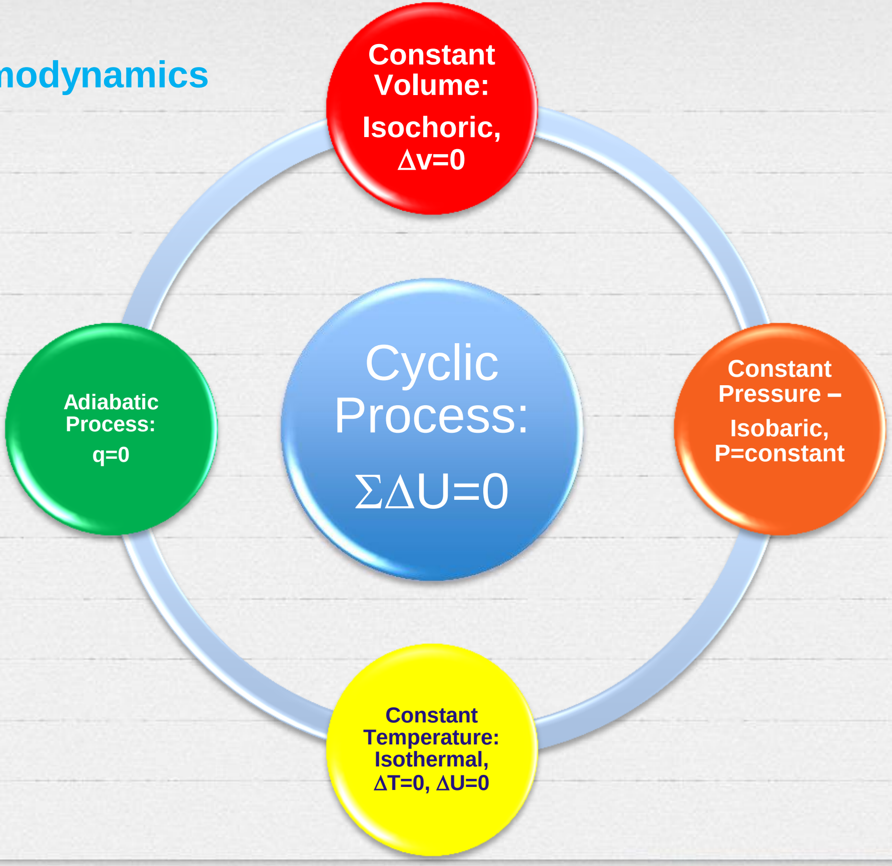
↓

Ideal Gas → Gas Laws, Equation of State √

↓

1^{st} Law & Thermal Processes → Constant Volume, Pressure, Temp., Adiabatic, Cyclic Processes

First Law of Thermodynamics



Engage

Demo- Focus on the idea of Pressure and Volume changes

Retrieve

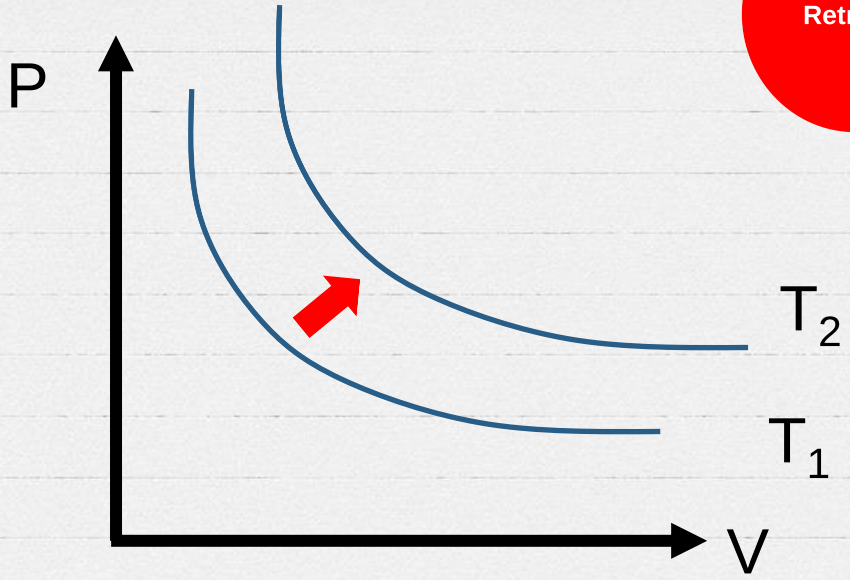
PV= nRT

P = RT(1/V)

Y = k (1/ x)

Where k = RT

When T increases, the curve shifts away from the origin



1^{St} Law Of Thermodynamics

Essential Questions

- What is conservation of energy?
- What is internal energy?
- How to increase the internal energy?

1st Law of Thermodynamics

In words:

The increase in the internal energy of a system is the sum of the work done on the system and the heat supplied to the system.

In word equation

Increase in internal energy of the system, ΔU = Heat supplied **to** system, q + Work done **on** system, w

In equation

$$\Delta U = q + w$$

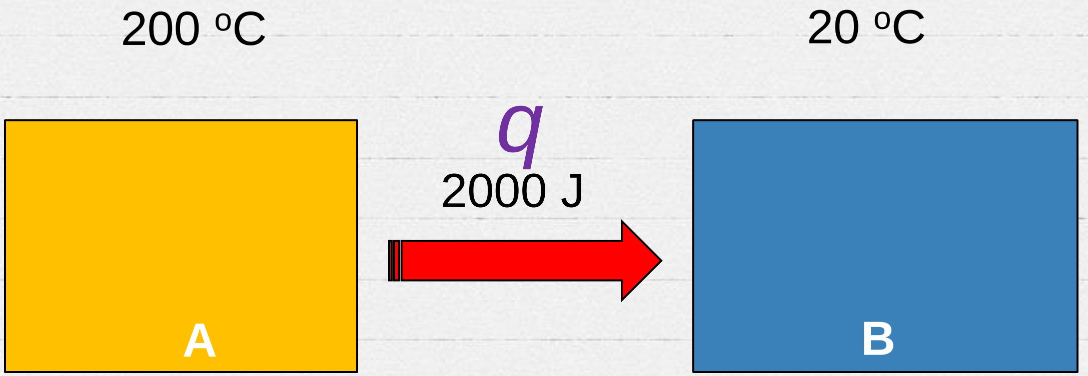
Why use "increase" instead of "change" in internal energy?

$$\Delta U = q + w$$

The first law of Thermodynamics also shows the conservation of energy.

Explanation of Heat

Heat is the thermal energy transferred from one system to another due to a temperature difference.



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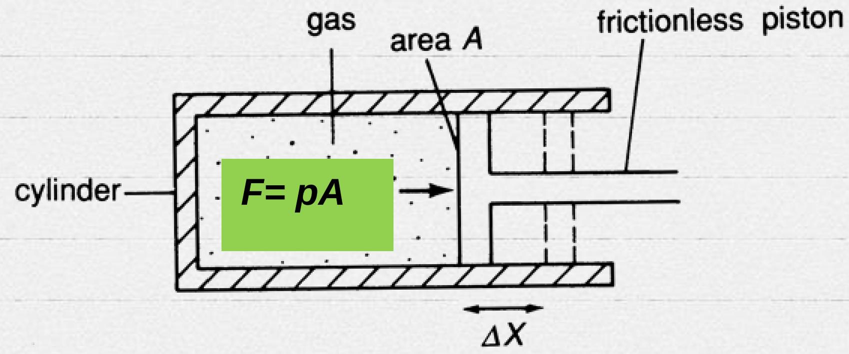
Explanation of Work

Work is the mechanical energy transferred from one system to another by means of a force.



Recall w = F.x

Increase in internal energy of the system, ΔU = Heat supplied **to** system, q + Work done **on** system, w

q is defined as <u>heat supplied to gas</u>
q is +ve: Heat supplied to system or Heat absorbed by system
q is –ve : Heat is given out or taken out.

w is defined as <u>work done on gas</u>
w (+ve) : work done on gas (compression)
w (-ve): work done by gas (expansion)

9.1
Work done by expanding gas

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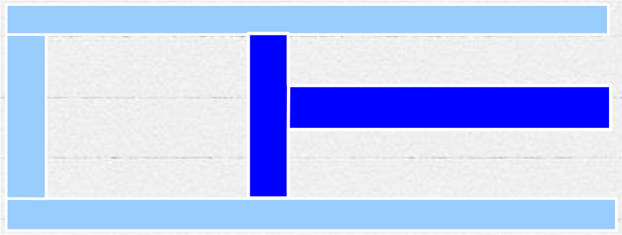
Work done by Expanding Gas

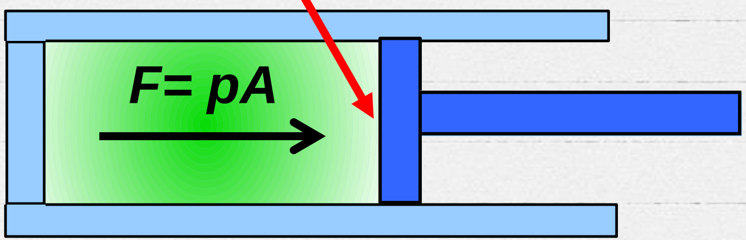
System (gas)



environment

Frictionless piston

Area A



Recall: Work done= F.x

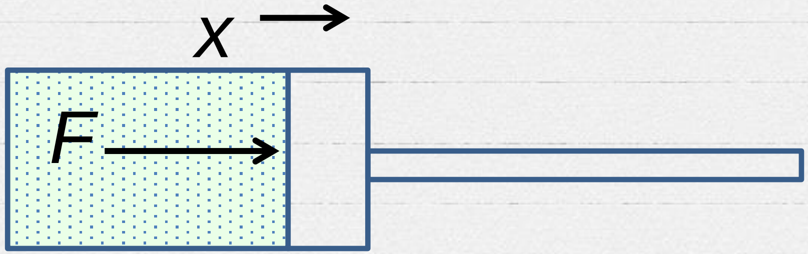
Incremental workdoneby gas= (pA) .dx

= p (Adx)

= pdV

Work done by gas, w_g

(Expansion Process)

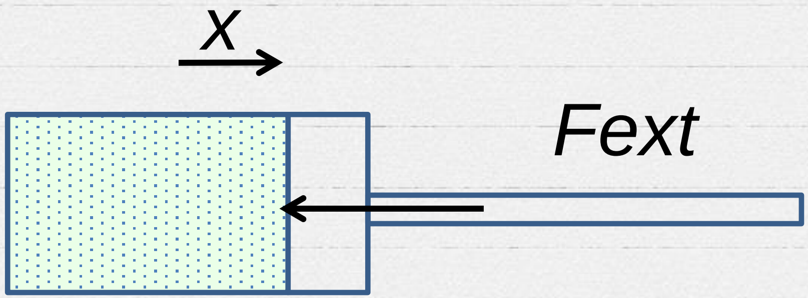


$$w_g = \int p\,dV$$

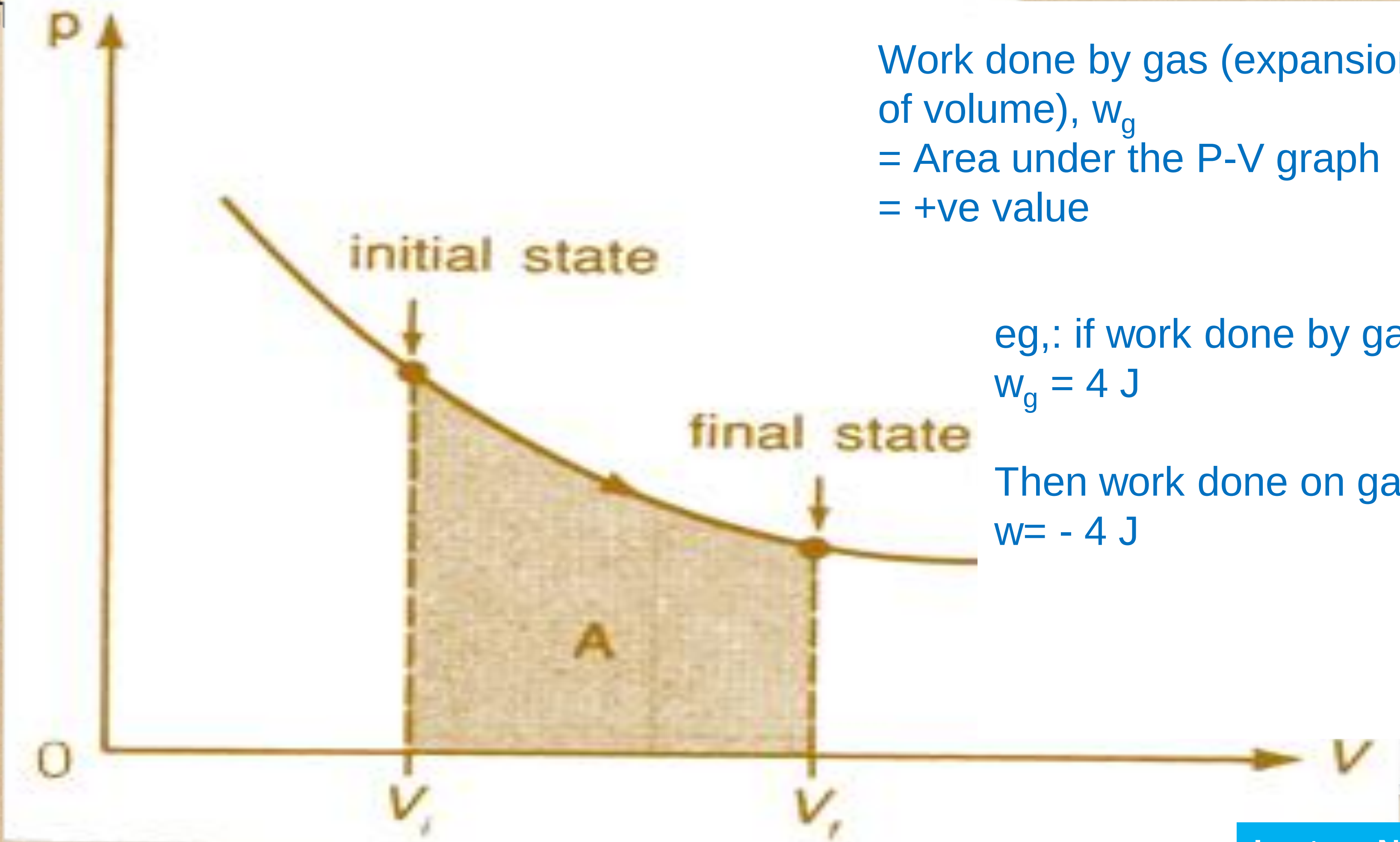
(+ve value)

Work done on gas, w

(Expansion Process)



$$w = -\int pdV \quad \text{(-ve value)}$$

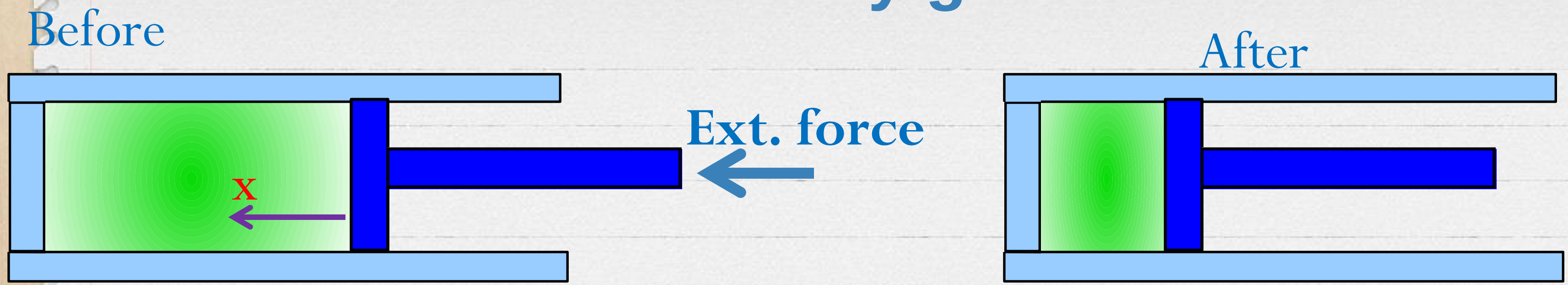


Work done by gas (expansion of volume), w_g
= Area under the P-V graph
= +ve value

eg,: if work done by gas, w_g = 4 J

Then work done on gas, w= - 4 J

work done on or by gas?



Volume compression:

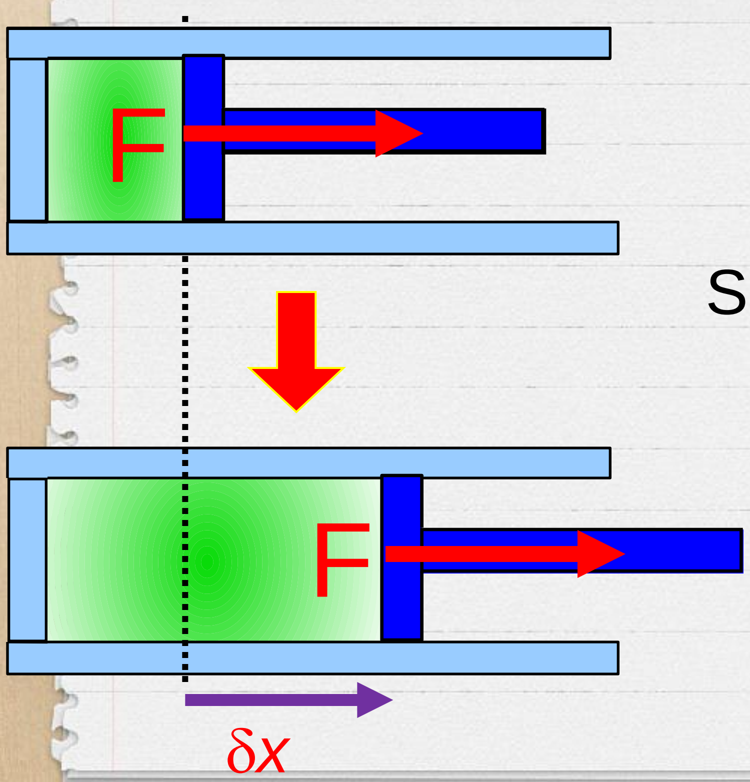
Work done on gas (w > 0)

Volume expansion:

Force exerted by gas

Work done by gas, w_g is +ve (w < 0)

Work done by Expanding Gas



Work done BY system

$$W = F.\delta x$$

Since Pressure = Force (F)/Area (A),

$$W = (P.A)\delta x$$

$$W = P.\delta V$$

Work done BY the gas,

$$W = \int P\,dV$$

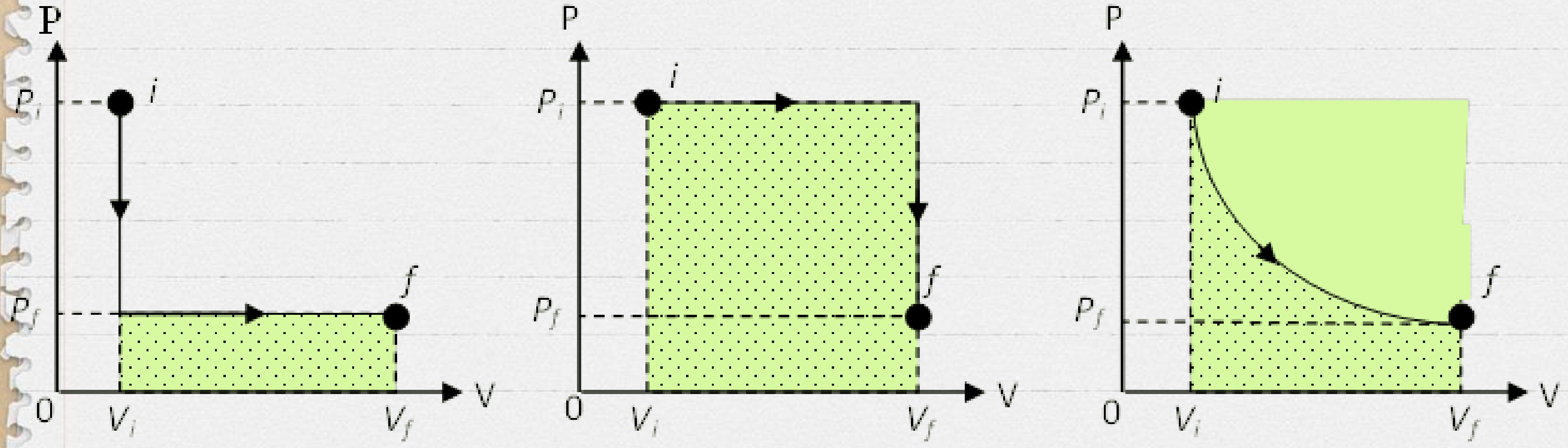
Work done BY the gas, $w = \int \mathrm{P}\,\mathrm{d}\mathrm{V}$

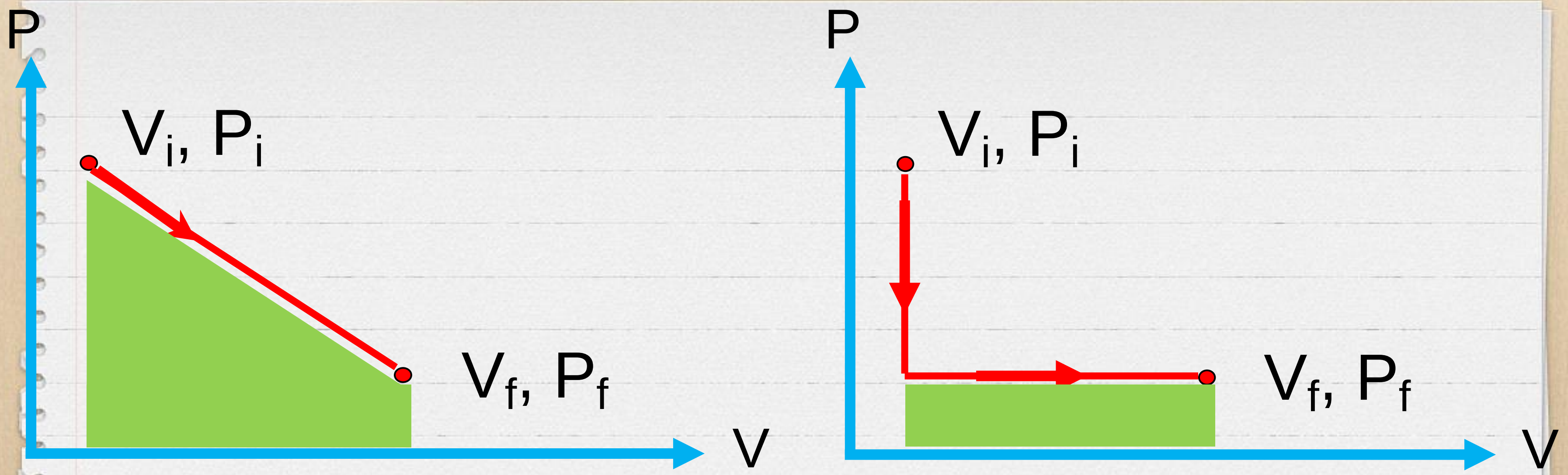
Work done ON the gas, $w = -\int \mathrm{P}\,\mathrm{d}\mathrm{V}$

If P is constant, $w = -P(V_f - V_i) = -P\Delta V$

Work done on gas by using different path:

As the gas goes from an initial state (pi,vi) to another state (pf,vf) by different paths due to different thermodynamic processes will lead to different values of work done.





We see that the work done on a system depends not only on the initial and final states but also on the path of the process.

If a system of gas is taken through a round trip, i.e., a cyclic process, then the net work done is given by the area enclosed.

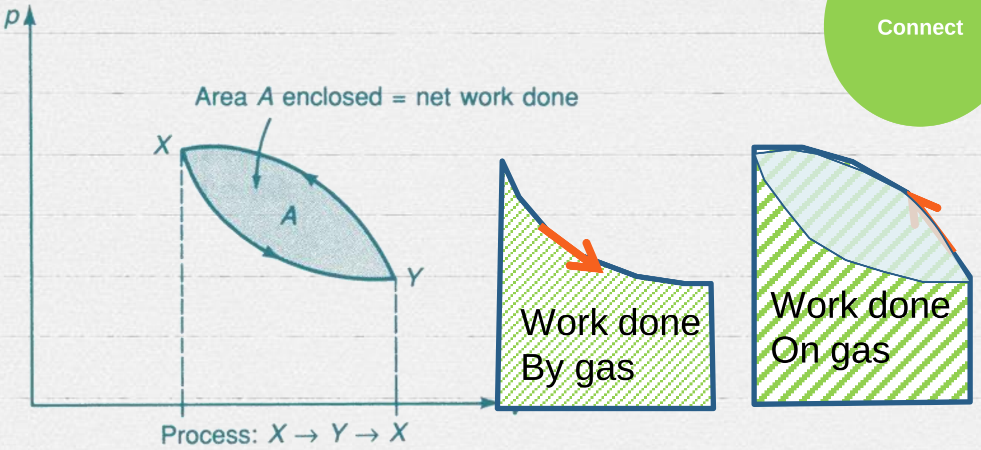
Connect

Assume start and end point is X:
$\Delta U = 0$ (no change in state)

By 1st Law of Thermodynamics:
$\Delta U = q + w$
$0 = \Sigma q + \Sigma w$

Does Net Work done depend on path of the processes?
Thought Process:
Σw = non –zero = +ve
$\Sigma U = \Sigma q + \Sigma w$
0 = (?) + (+ve)
0 = (-ve) + (+ve)

Hence net q is also non –zero and must depend on path of the processes.



Area under the graph of work done on gas is greater than the area under the graph of work done by gas, hence net work done is positive.

: Inference: Anti-clockwise cycle =>

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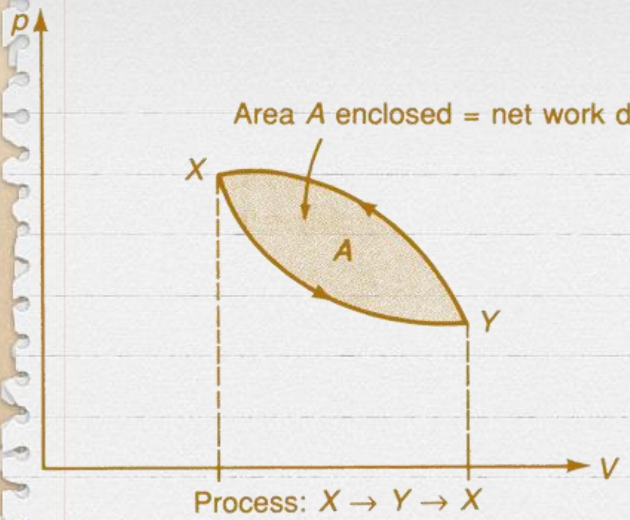
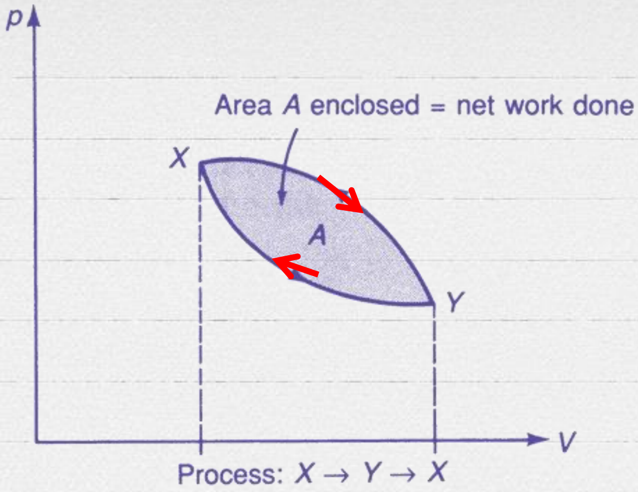
Inference:



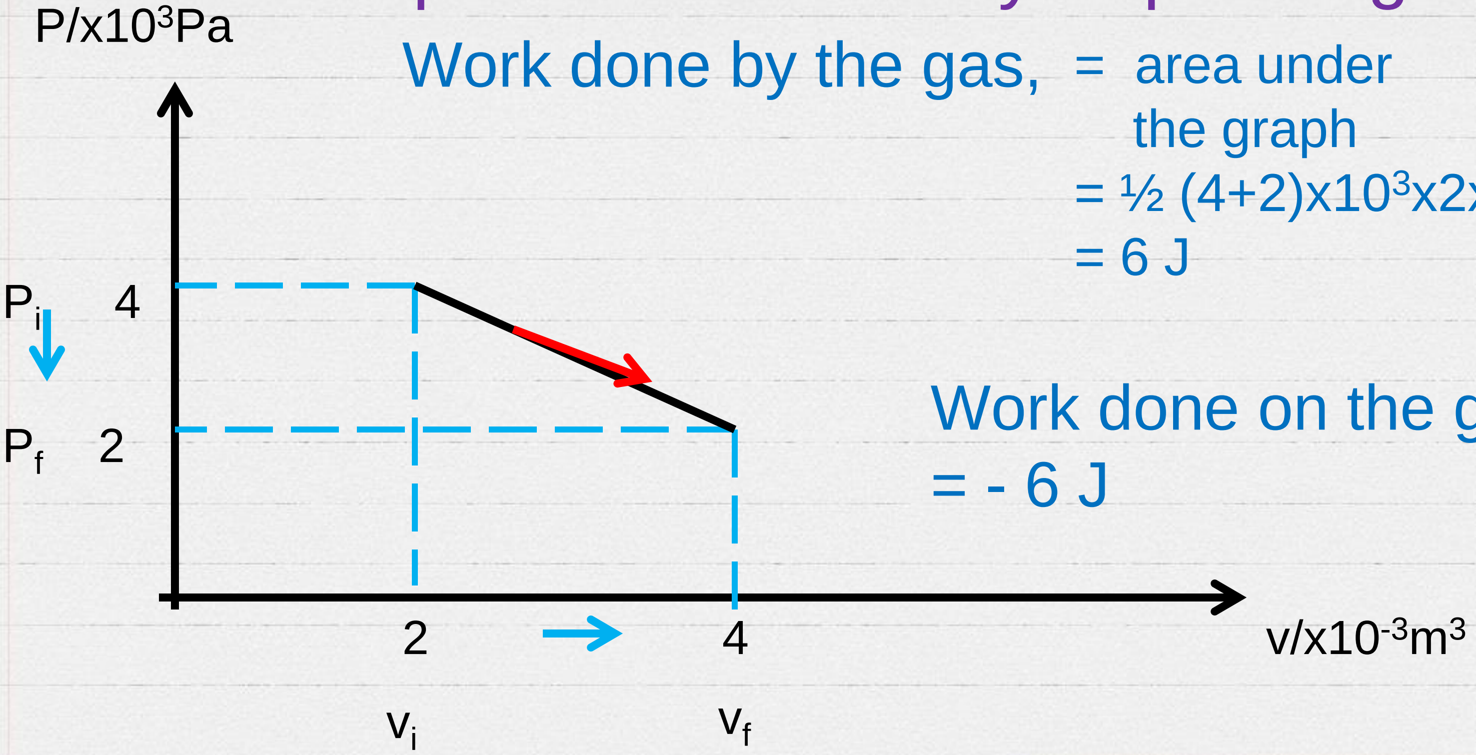


Connect

Anti-clockwise cycle
=> net work done is positive

Clockwise cycle
=> net work done is negative

Example: Work done by Expanding Gas



Work done by the gas, = area under the graph

$= \frac{1}{2}(4+2)\times10^{3}\times2\times10^{-3}$

$= 6\ J$

Work done on the gas

$= -6\ J$

9.2
Internal energy in Thermodynamic processes

Internal Energy of a system, *U*

-depends only on the **state of the system**

State of the system is defined by:

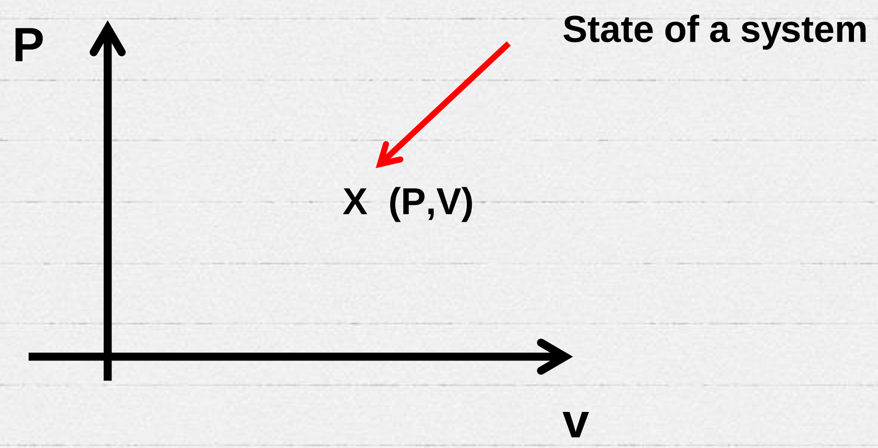
-Pressure P,

-Volume V and

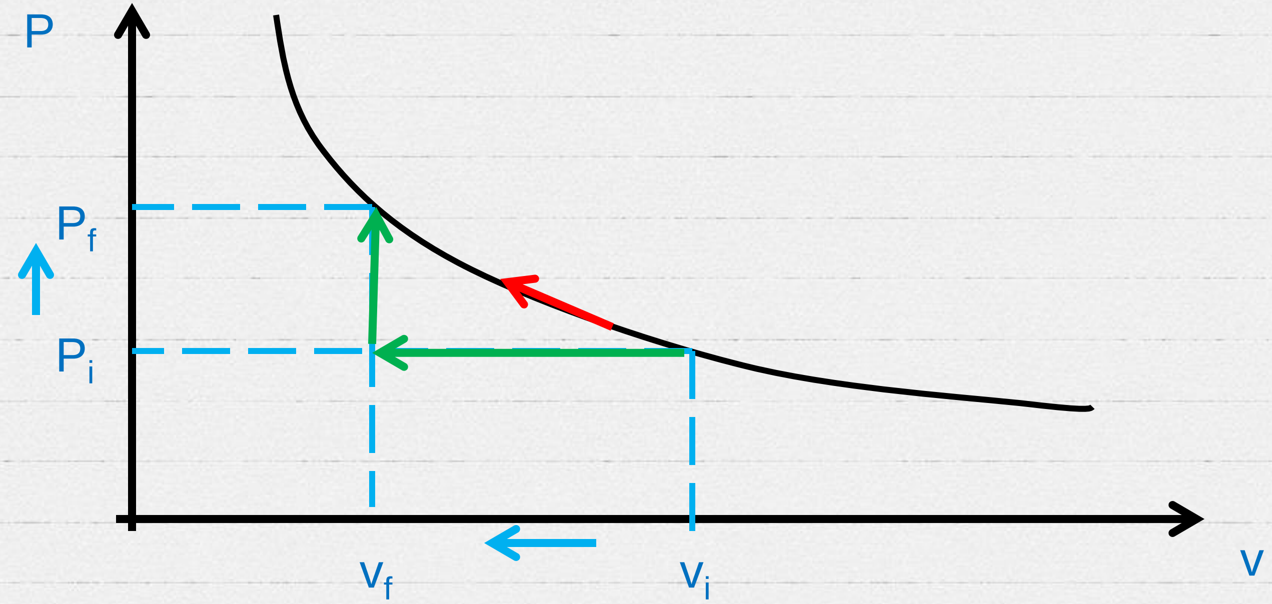
-temperature T.

and is **independent** of the <u>path of the process</u>

Internal energy of a system depends only on the state of the system.

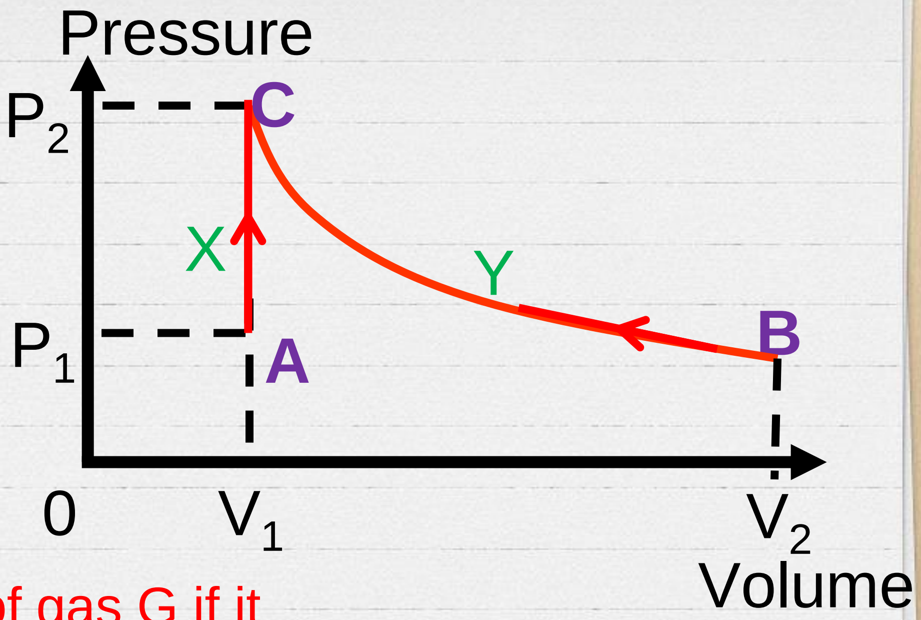


Important - Change in internal energy depends on both the initial state and final state of the system and not the processes in between.



Checkpoint

Gas G initially at state **A**.
Undergoes process X to reach state **C**.
Internal energy of gas G at state **C** = U_C



What will be the internal energy of gas G if it undergoes process Y to reach state **C** from **B**?

U_c

Change in Internal Energy, ΔU

Ideal Gas

Internal energy, $U = 3/2\ nRT$ Change in internal energy, $\Delta U = 3/2\ nR(T_f - T_i)$	Internal energy, $U = 3/2\ PV$ (since $PV = nRT$) Change in internal energy, $\Delta U = 3/2\ (P_fV_f - P_iV_i)$

Change in Internal Energy, ΔU

ii) If system is **not** an ideal gas, use

$$\Delta U = q + w$$

9.3 Thermodynamic processes & the First Law of Thermodynamics

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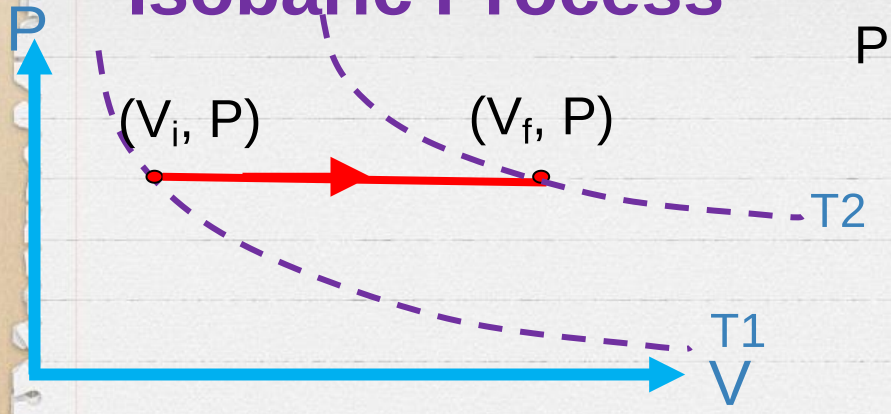
Isobaric Process



Pressure remains constant

P = constant (amend lecture notes)

Work done on system

$$w = -P[V_f - V_i]$$

By First Law of Thermodynamics,

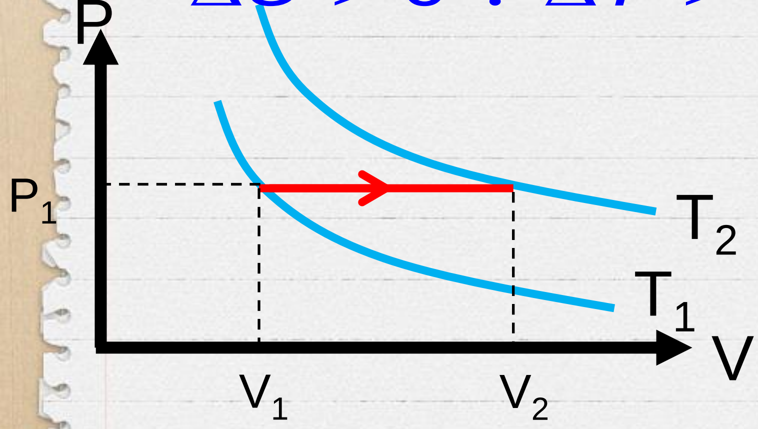
$$\Delta U = q + w$$

Thought process:

(+ve)=(?) +(-ve)

Isobaric expansion

$$\Delta U > 0 \because \Delta T > 0$$



$\Delta U = q + w$

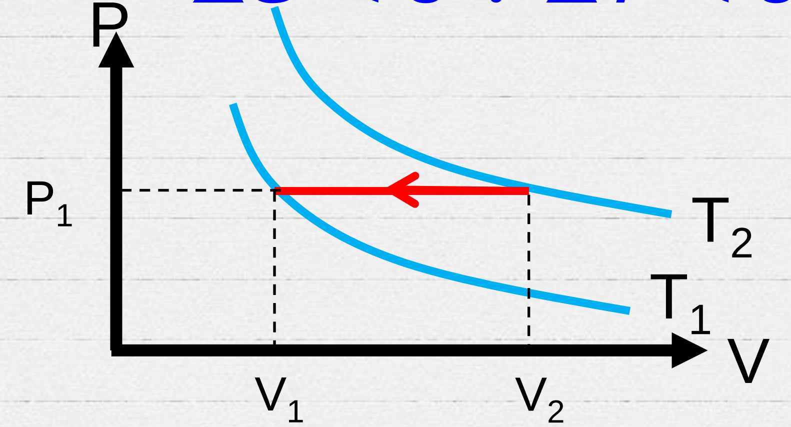
Thought Process:

(+ve) = (?)+ (-ve)

(+ve) = (+ve)+ (-ve)

Isobaric compression

$$\Delta U < 0 \because \Delta T < 0$$



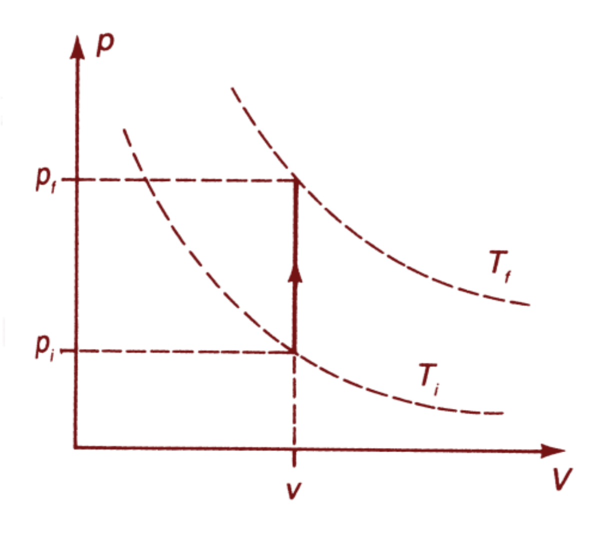
$\Delta U = q + w$

Thought Process:

(-ve) = (?)+ (+ve)

(-ve) = (-ve)+ (+ve)

Isochoric Process



Volume remains constant.

$$\Delta V = 0$$

Work done on System

$$w = p\Delta V = 0$$

By First Law,

$$\Delta U = q + \overset{0}{\cancel{w}} = q$$

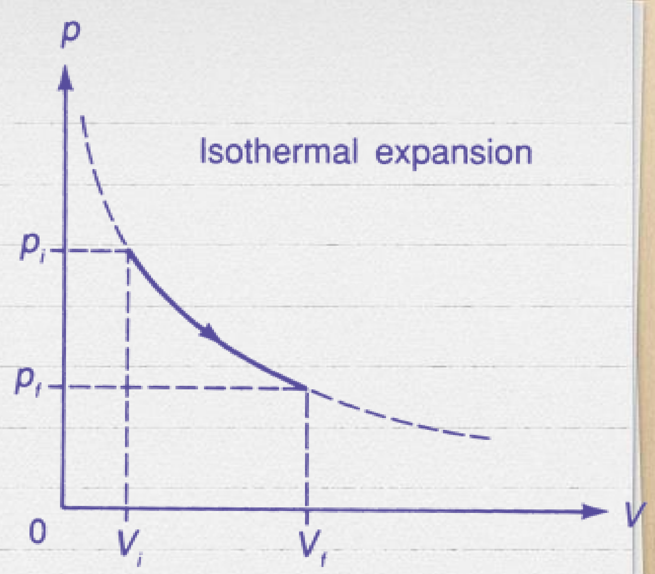
All the heat absorbed by the system is used in increasing the internal energy of the system.

- ✗ *Given that w is zero, in order for ΔU to be positive, q must be positive.*

- ✗ *This means that heat must be supplied to the gas or taken in by the gas so that the isochoric process can be completed.*
- ✗ *This can be interpreted that all the heat absorbed by the system is used in increasing the internal energy of the system.*

Isothermal Process

Constant Temperature, $\Delta T = 0$



$\Delta U = 3/2\ nR\Delta T$

$\Delta U = 0$

By first law of thermodynamics,

$\Delta U = q + w$

$0 = q + w$

Thought Process:

$0 = (?) + (-)$ *{expansion: w is negative}*

Since w is negative, in order for ΔU to be zero, q must be positive.

Work done equation for Isothermal Process – Not required to memorise but important to know

$$w = -\int_{V_i}^{V_f} pdV$$

$$w = -\int_{V_i}^{V_f} \frac{nRT}{V} dV$$

Since $pV = nRT$

$$w = -nRTln\frac{V_f}{V_i}$$

Adiabatic Process

No heat flow in or out, $q = 0$

By first law of thermodynamics,

$\Delta U = q + w$

$= w$

Under adiabatic condition, q =0.

Using the first law of thermodynamics:

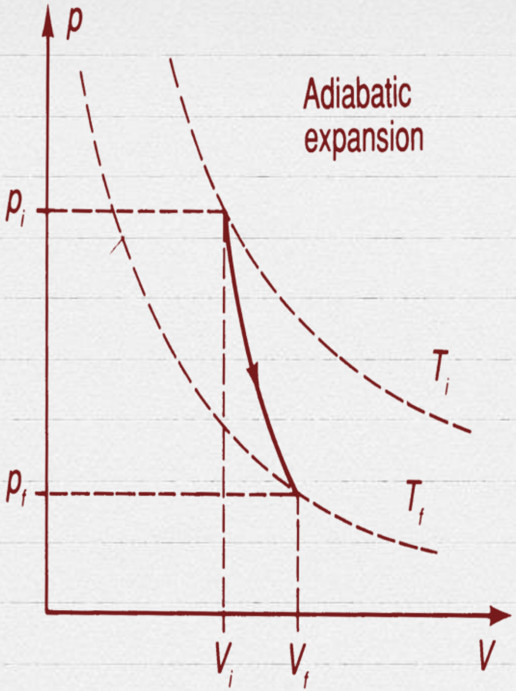
$\Delta U = q + w$

Thought Process:

$\Delta U = 0 + (-)$

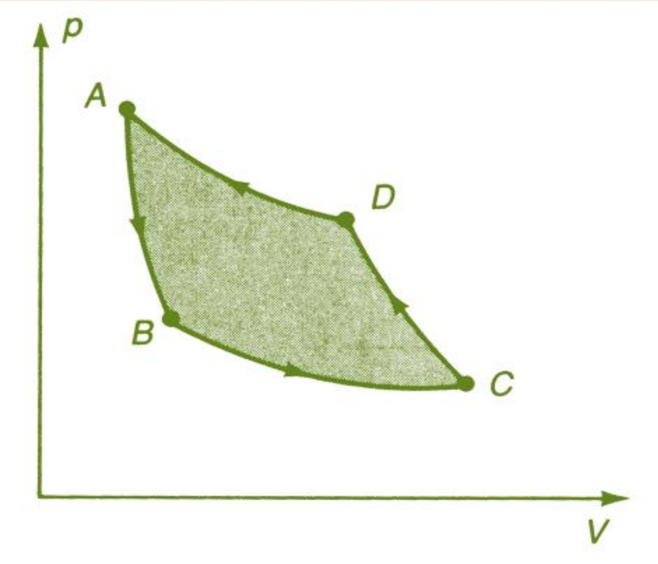
$\Delta U = (\text{-ve})$

Hence increase in internal energy is negative. The final temperature is lower.



Cyclic Process

Assume that the start state and end state is A.



Initial State = Final State

$\Delta U = 0$

By first law of thermodynamics,

$\Sigma\Delta U = \Sigma q + \Sigma w$

$0 = \Sigma q + \Sigma w$

$\Sigma q = -\Sigma w$

Create

It can be seen that the process CDA is the work done on the gas.
Area under the graph ABC is the work done by the gas.

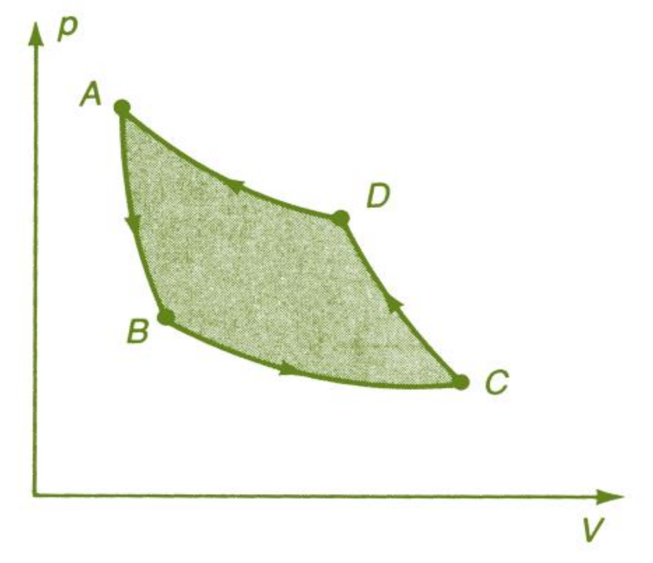
The area under the graph CDA is larger than area under the graph ABC.

Hence there is a net work done on the gas. Hence Σw is positive.

Since there is no change in state in a cyclic process, $\Sigma U = 0$.

Using the first law of thermodynamics:

$\Sigma\Delta U = \Sigma q + \Sigma w$
$0 = (?) + (+)$

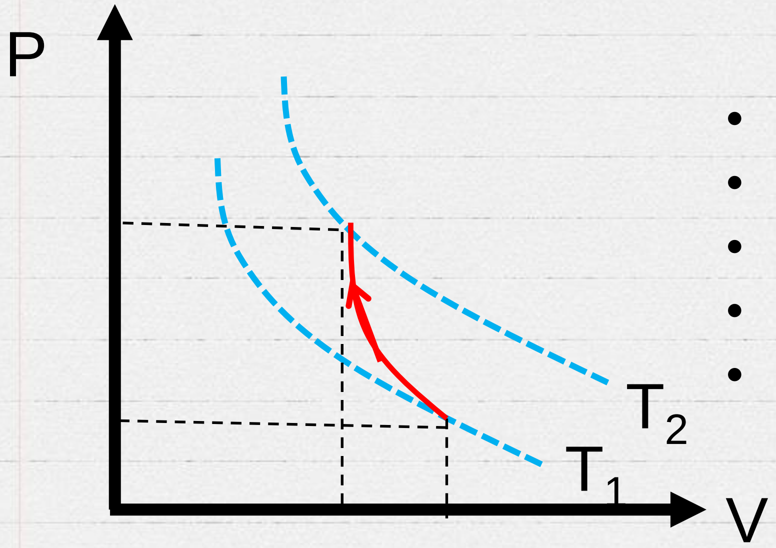


In order for internal energy to be unchanged, $\Sigma\Delta U = 0$, given that net work done on the gas is positive, <u>the net thermal energy supplied to the system must be negative</u>.

Adiabatic Process: $q = 0$

- Cylinder with plunger
- Small tissue paper or fibre or cotton wool
- Rapid volume reduction, pressure increase
- No time for heat exchange with surrounding
- $\Delta U = q + w$
- $\Delta U = 0 + w$
- w is +ve, hence ΔU is +ve
- ΔU +ve => temperature increased
- Ignition temperature is reached, tissue paper combust.

Create



- Rapid volume reduction, pressure increase
- No time for heat exchange with surrounding
- $\Delta U = q + w$
- $\Delta U = 0 + w$
- w is +ve, hence ΔU is +ve
- ΔU +ve => temperature increased
- Note: graph of adiabatic of process is steeper than the isotherms.