Thermodynamics

Quick Revision

JEE Main | NEET | NCERT

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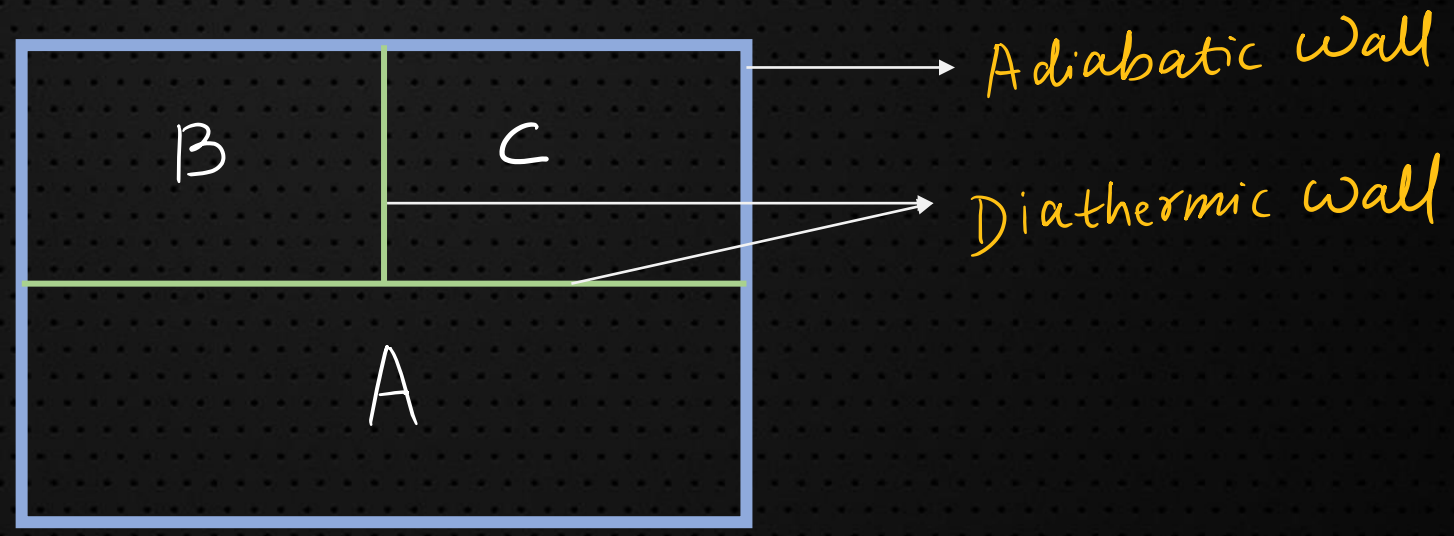
THERMAL EQUILIBRIUM

Two different temperature body in contact exchange heat until common temperature is reached. This is Called state of Thermal Equilibrium

ZEROTH LAW OF THERMODYNAMICS

If two systems (B and C) are separately in thermal equilibrium with a third one (A), then they themselves are in thermal equilibrium with each other.



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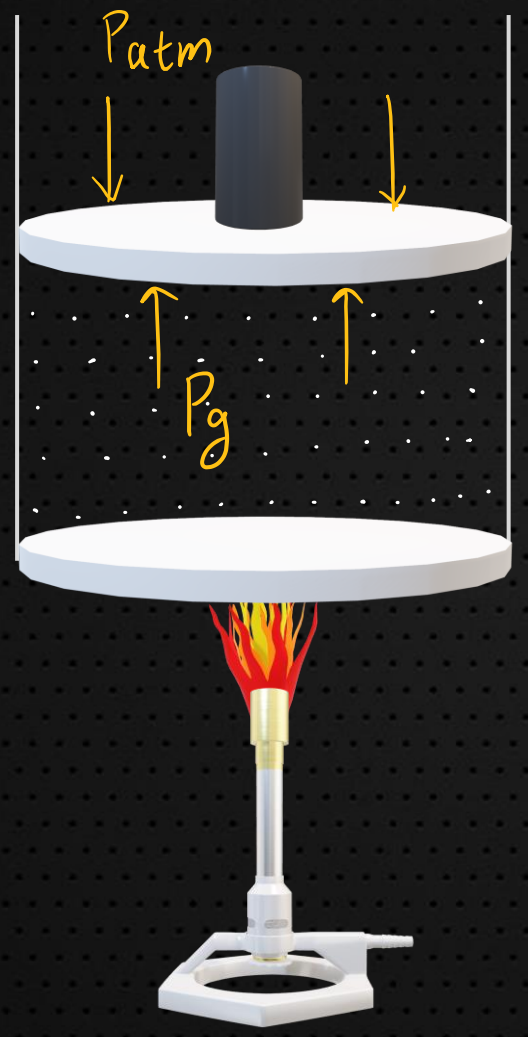
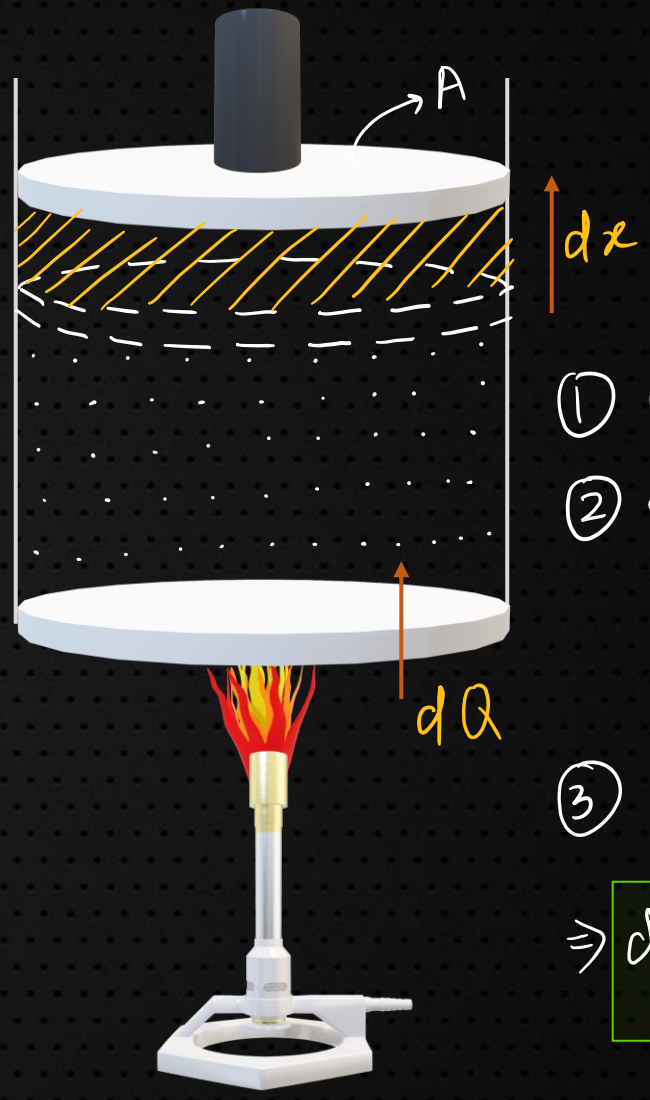
FIRST LAW OF THERMODYNAMICS

$$dQ = dU + dW$$





① dQ

② $dW = P_g A\,dx$

$= \boxed{P_g\,dV}$

③ $U = \frac{fRnT}{2}$

$\Rightarrow \boxed{dU = \frac{fRn\,dT}{2}}$

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FIRST LAW OF THERMODYNAMICS

"SIGN CONVENTION"

(1) If heat is supplied, ΔQ is +VE
If heat is rejected, ΔQ is −VE

(2) If gas does work (volume of gas increases), ΔW is +VE
If work is done on the gas (volume of gas decreases), ΔW is −VE

(3) If Temp° increases, ΔU is +VE
If Temp° decreases, ΔU is −VE

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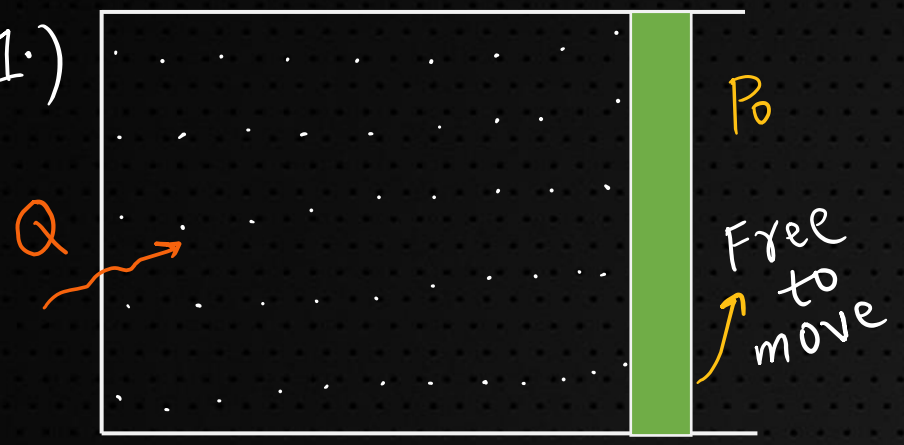
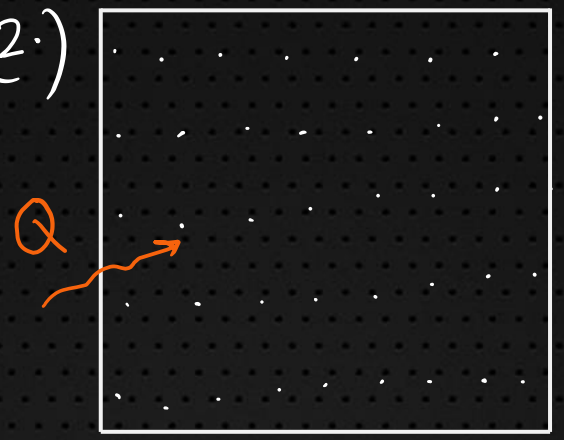
THERMODYNAMIC PROCESS

(1.)



Isobaric Process, $V \propto T$

(2.)

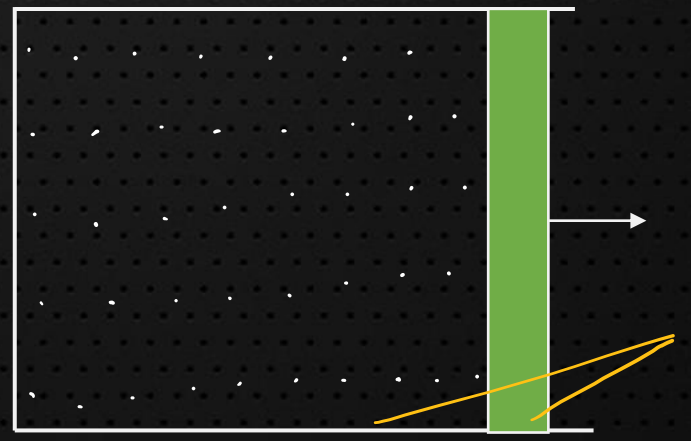


Isochoric Process, $P \propto T$

(3.)

Isothermal Process, $P \propto \frac{1}{V}$

(4.)



Adiabatic Process, $PV^{\gamma} = C$

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MOLAR HEAT CAPACITY, C

Molar heat capacity of a substance is defined as the amount of heat required to raise the temperature of one mole of a substance by a unit degree.

$$C = \frac{dQ}{n\,dT}$$

UNIT: $J\,mol^{-1}\,K^{-1}$

$$\Rightarrow \int dQ = \int_{T_1}^{T_2} nC\,dT$$

$$\Delta Q = nC(T_2 - T_1)$$

$$\Rightarrow \Delta Q = nC\Delta T$$

Const. V → C_V

Const. P → C_P

NOTE:

C depends on the way of heating / process.

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C_p, C_v

(1.) $C_v = \dfrac{dQ}{n\,dT} = \dfrac{du + \cancel{dw}^{\,0}}{n\,dT}$

$= \dfrac{(fRn\,dT)/2}{n\,dT} \Rightarrow \boxed{C_v = \dfrac{fR}{2}}$

Also,

$U = \dfrac{fRnT}{2}$

$\Rightarrow U = nC_vT$

or

$\boxed{du = nC_v\,dT}$

(2.) $C_p = \dfrac{dQ}{n\,dT} = \dfrac{du + dw}{n\,dT} = \dfrac{nC_v\,dT + P\,dV}{n\,dT}$

$\Rightarrow C_p = C_v + \dfrac{P\,dV}{n\,dT}$ $\left(\begin{array}{l} PV = nRT \\ \Rightarrow P\,dV = nR\,dT \end{array}\right)$

$\Rightarrow C_p = C_v + R$

$\boxed{C_p - C_v = R}$

MAYOR'S RELATION

$\boxed{C_p = \left(\dfrac{f+2}{2}\right)R}$

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ADIABATIC CONSTANT, γ

$$\gamma = \frac{C_p}{C_v} \Rightarrow \gamma = 1 + \frac{2}{f} \Rightarrow f = \frac{2}{\gamma - 1}$$

GAS	f	C_p	C_v	γ
Monoatomic	3	$\frac{5R}{2}$	$\frac{3R}{2}$	$5/3$
Diatomic	5	$\frac{7R}{2}$	$\frac{5R}{2}$	$7/5$
NON-LINEAR Polyatomic	6	$4R$	$3R$	$4/3$

* Vibration mode only if mentioned

C_p, C_v in terms of γ and R

$$C_v = \frac{fR}{2} = \frac{R}{\gamma - 1}$$

$$C_p = \gamma C_v = \frac{\gamma R}{\gamma - 1}$$

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C_p, C_v and γ FOR MIXTURE OF GASES

Gases at same temp° T,

n_1	C_{v_1}	C_{p_1}	f_1
n_2	C_{v_2}	C_{p_2}	f_2
n_3	C_{v_3}	C_{p_3}	f_3
⋮	⋮	⋮	⋮

$$C_{v_{mix}} = \frac{n_1 C_{v_1} + n_2 C_{v_2} + \cdots}{n_1 + n_2 + \cdots}$$

$$C_{p_{mix}} = \frac{n_1 C_{p_1} + n_2 C_{p_2} + \cdots}{n_1 + n_2 + \cdots}$$

$$f_{mix} = \frac{n_1 f_1 + n_2 f_2 + \cdots}{n_1 + n_2 + \cdots}$$

$$\gamma_{mix} = \frac{C_{p_{mix}}}{C_{v_{mix}}} \quad \text{or} \quad 1 + \frac{2}{f_{mix}}$$

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PYQ (Uploaded on EDUNITI Channel)

A polyatomic ideal gas has 24 vibrational modes. What is the value of γ ?

(1) 1.03 (2) 1.30

(3) 1.37 (4) 10.3

JEE Main 2021, March 17 Morning

If one mole of the polyatomic gas is having two vibrational modes and β is the ratio of molar specific heats for polyatomic gas $\left(\beta = \frac{C_P}{C_V}\right)$ then the value of β is :

(1) 1.02 (2) 1.2

(3) 1.25 (4) 1.35

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Two moles of an ideal gas with $\frac{C_P}{C_V} = \frac{5}{3}$ are mixed with 3 moles of another ideal gas with $\frac{C_P}{C_V} = \frac{4}{3}$. The value of $\frac{C_P}{C_V}$ for the mixture is

(a) 1.50 (b) 1.45

(c) 1.47 (d) 1.42

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WORK DONE IN VARIOUS PROCESSES

$$\Delta W = \int_{V_1}^{V_2} P\,dV \quad , \quad PV = nRT$$

ISOCHORIC

$V = \text{const.}$

$$\boxed{\Delta W = 0}$$

ISOBARIC

$P = \text{const.}$

$$\boxed{\Delta W = P(V_2 - V_1)}$$

OR

$$\boxed{\Delta W = nR(T_2 - T_1)}$$

ISOTHERMAL

$T = \text{const.}$

$$\boxed{\Delta W = nRT \ln\left(\frac{V_2}{V_1}\right)}$$

OR

$$\boxed{\Delta W = nRT \ln\left(\frac{P_1}{P_2}\right)}$$

ADIABATIC

$\Delta Q = 0$

$$\Rightarrow \Delta W = -\Delta U$$

$$\Rightarrow \Delta W = -nC_V \Delta T$$

$$\boxed{\Delta W = \frac{nR(T_2 - T_1)}{1 - \gamma}}$$

OR

$$\boxed{\Delta W = \frac{P_2V_2 - P_1V_1}{1 - \gamma}}$$

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PYQ (Uploaded on EDUNITI Channel)

n moles of an ideal gas with constant volume heat capacity C_V undergo an isobaric expansion by certain volume. The ratio of the work done in the process, to the heat supplied is

(a) $\frac{4nR}{C_V + nR}$

(b) $\frac{4nR}{C_V - nR}$

(c) $\frac{nR}{C_V - nR}$

(d) $\frac{nR}{C_V + nR}$

JEE Main 2019, April 10 Morning

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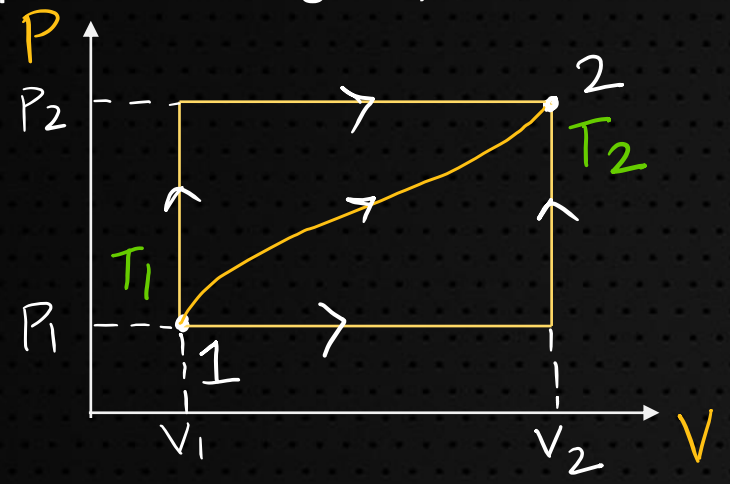
INDICATOR DIAGRAM

When a gas is heated/cooled/compressed etc. thermodynamic parameters Pressure, Volume and Temperature changes. P, V and T combinedly defines the state of a Gas.



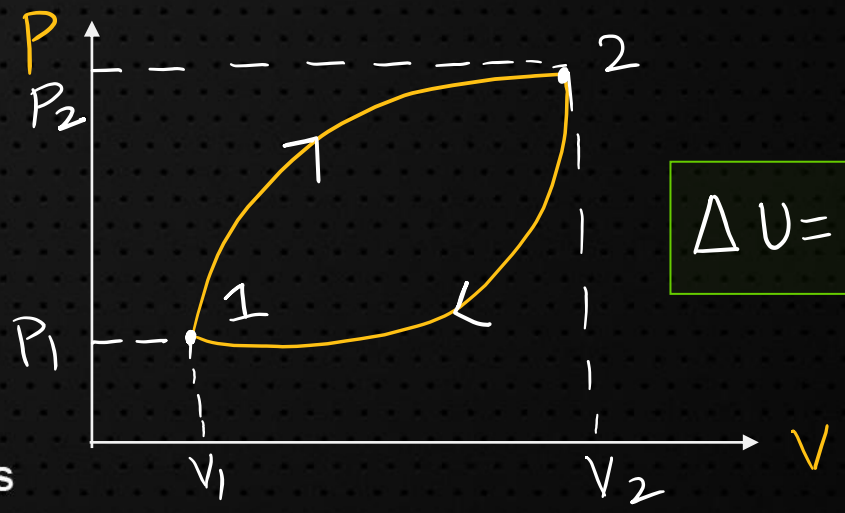
NOTE:

(1.) ΔU is state variable, only depends T_1 and T_2 and not path dependent.

(2.) ΔQ and ΔW both depends on path or how P and V are related.

CYCLIC PROCESSES

A process in which initial and final state are same (state means P, V and T are same)



$\Delta U = 0$

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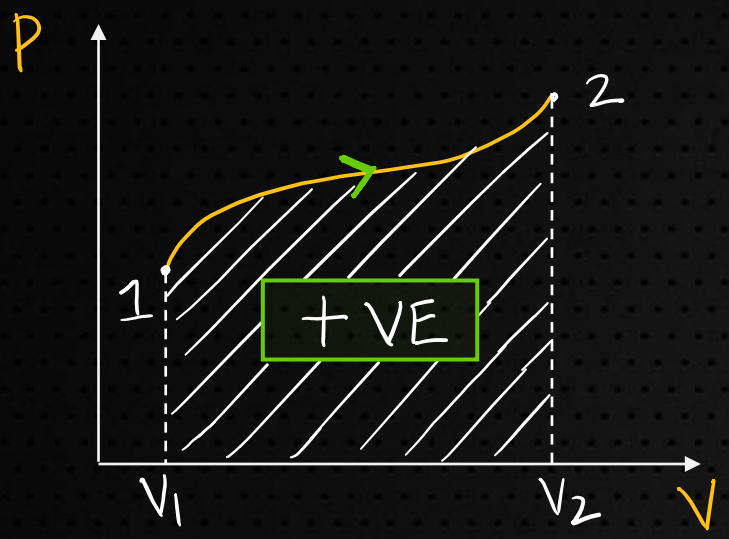
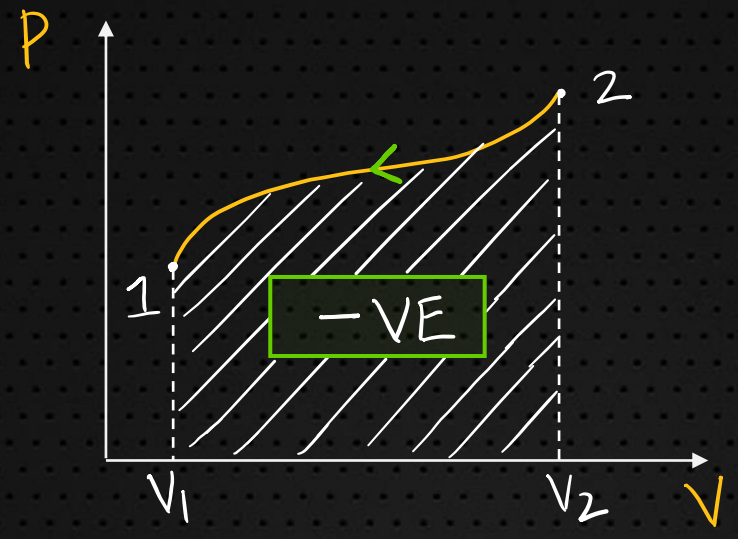
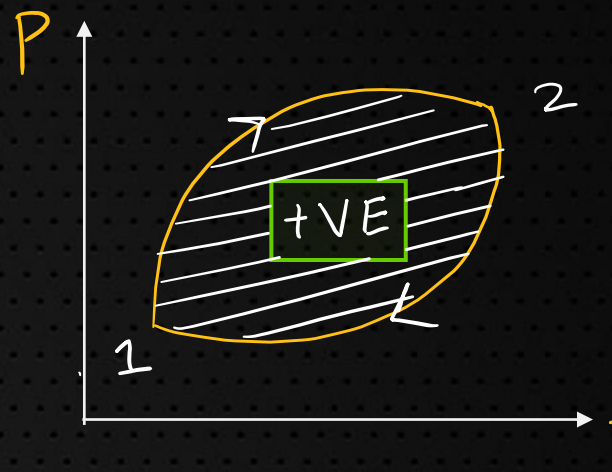
ΔW USING P-V INDICATOR DIAGRAM



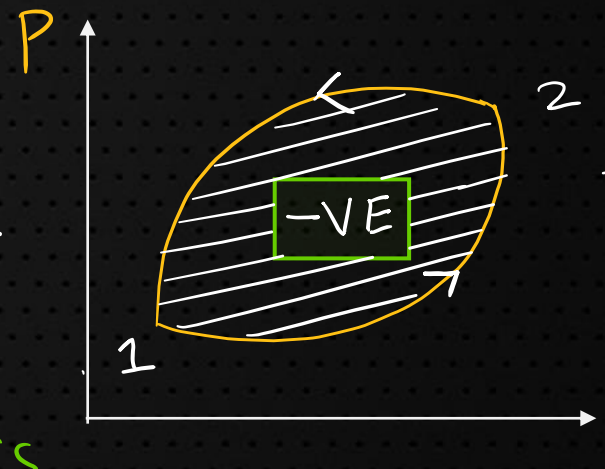




ΔU = 0

ΔQ = ΔW

Heat supplied



ΔQ = ΔW

Heat Rejected

NOTE:

(1.) For Non-cyclic, area is between curve and V-axis.

V ↑ ⇒ ΔW is +VE

(2.) For cyclic, area is of the loop. If clockwise ⇒ ΔW is +VE. (P along y axis and V along x-axis)

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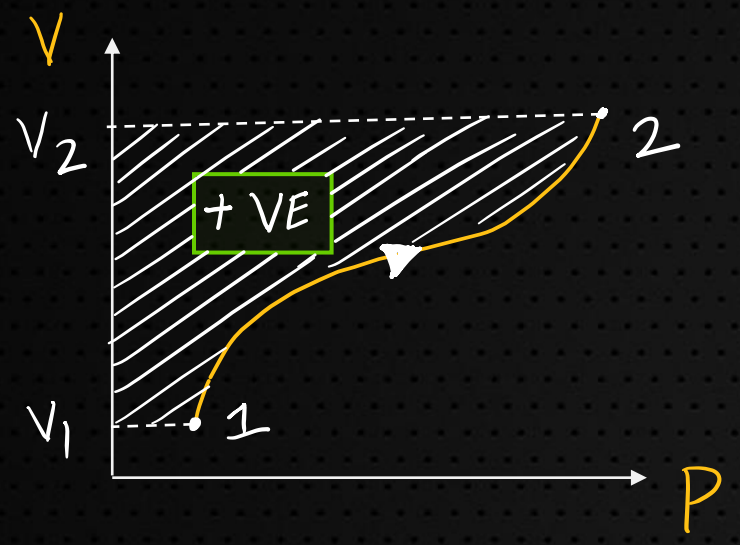
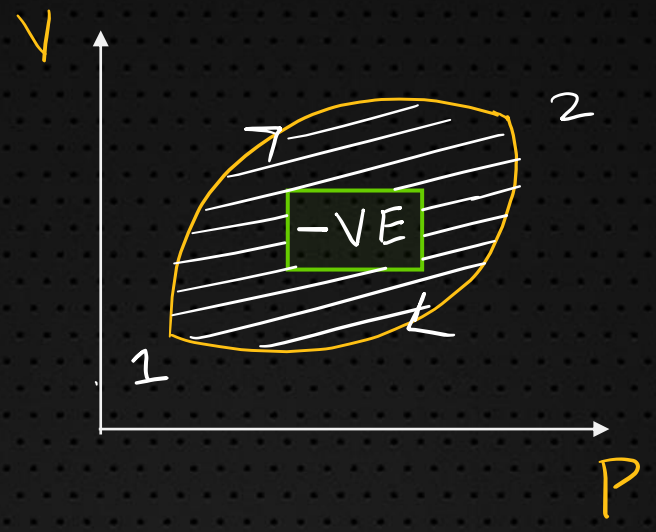
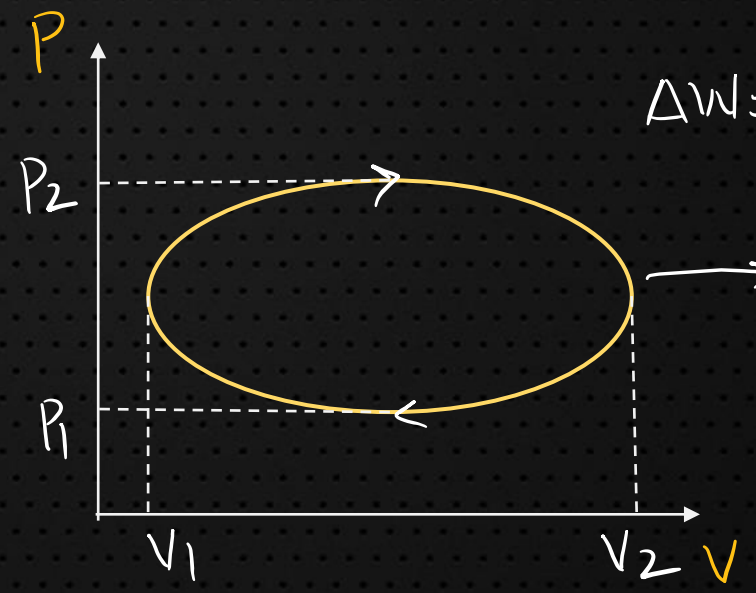
...CONTINUED WITH Ex.





Ex:



$$\Delta W = \pi\left(\frac{V_2 - V_1}{2}\right)\left(\frac{P_2 - P_1}{2}\right)$$

$\longrightarrow$ Ellipse ($A = \pi ab$)

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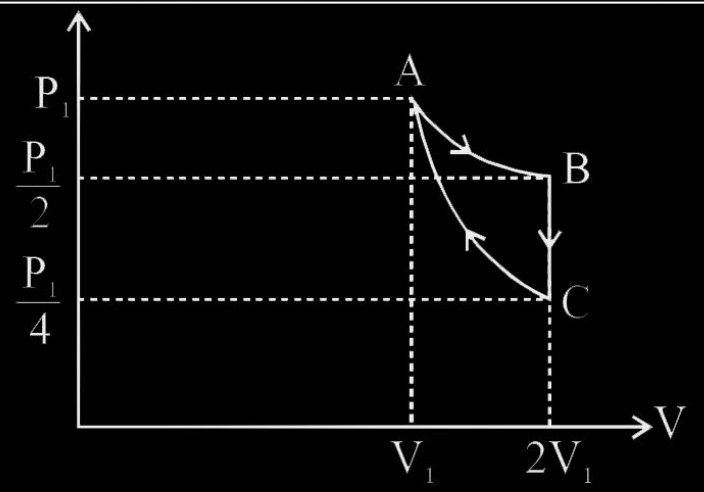
PYQ (Uploaded on EDUNITI Channel)

If one mole of an ideal gas at (P_1, V_1) is allowed to expand reversibly and isothermally (A to B) its pressure is reduced to one-half of the original pressure (see figure). This is followed by a constant volume cooling till its pressure is reduced to one-fourth of the initial value (B→C). Then it is restored to its initial state by a reversible adiabatic compression (C to A). The net workdone by the gas is equal to :



(1) $RT\left(\ln 2 - \frac{1}{2(\gamma-1)}\right)$

(2) $-\frac{RT}{2(\gamma-1)}$

(3) 0

(4) RT ln 2

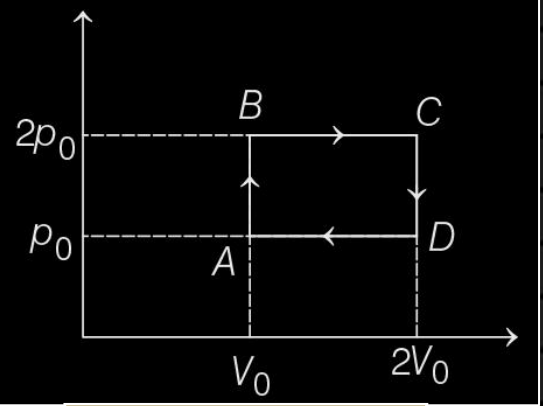
JEE Main 2021, Feb 24 Evening

PYQ (Uploaded on EDUNITI Channel)

The shown p-V diagram represents the thermodynamic cycle of an engine, operating with an ideal monoatomic gas. The amount of heat, extracted from the source in a single cycle is

(a) p_0V_0 (b) $\left(\frac{13}{2}\right)p_0V_0$

(c) $\left(\frac{11}{2}\right)p_0V_0$ (d) $4\,p_0V_0$

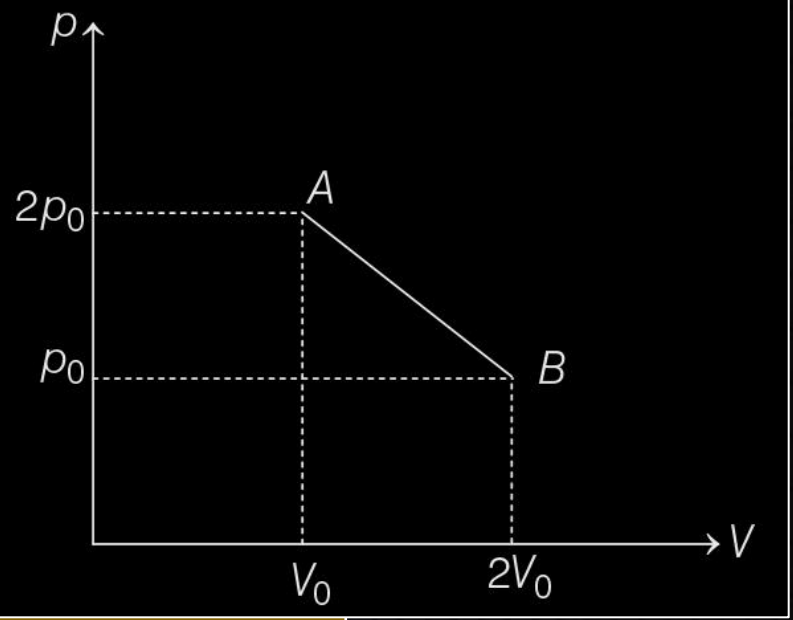


JEE Main 2013

n moles of an ideal gas undergoes a process A and B as shown in the figure. The maximum temperature of the gas during the process will be

(a) $\frac{9}{4}\frac{p_0v_0}{nR}$ (b) $\frac{3}{2}\frac{p_0v_0}{nR}$

(c) $\frac{9}{2}\frac{p_0v_0}{nR}$ (d) $\frac{9p_0v_0}{nR}$



JEE Main 2016

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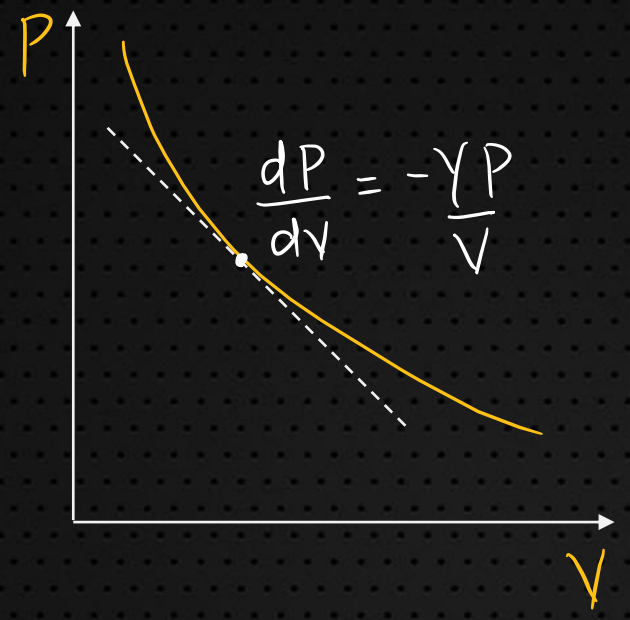
ADIABATIC PROCESS, $\Delta Q = 0$

(1.) $\boxed{PV^{\gamma} = C}$

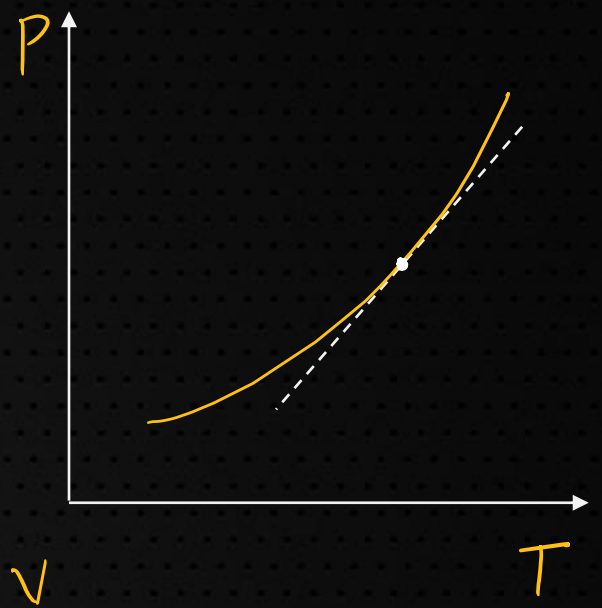
$$\frac{dP}{dV} \cdot V^{\gamma} + P\gamma V^{\gamma-1} = 0$$

$$\Rightarrow \boxed{\frac{dP}{dV} = -\gamma \frac{P}{V}}$$



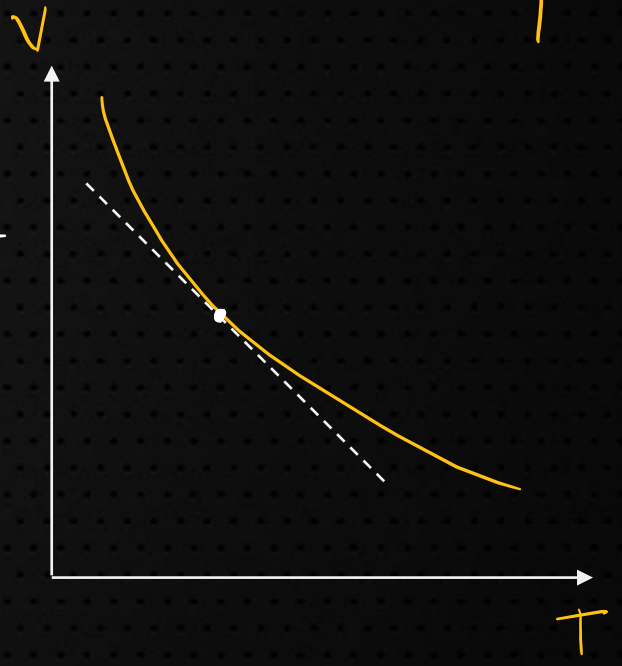
(2.) $\boxed{T^{\gamma} P^{1-\gamma} = C}$

$$\frac{dP}{dT} = \frac{\gamma}{(\gamma-1)} \frac{P}{T}$$



(3.) $\boxed{TV^{\gamma-1} = C}$

$$\frac{dV}{dT} = -\frac{1}{\gamma-1} \frac{V}{T}$$



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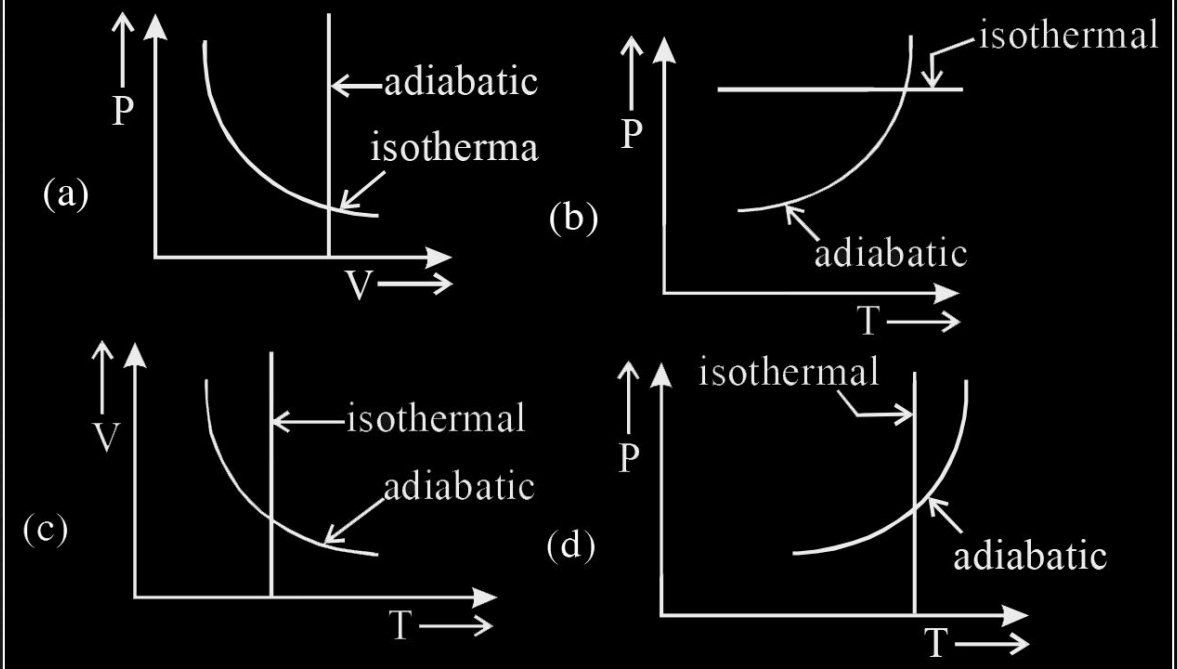
Which one is the correct option for the two different thermodynamic processes ?



(1) (c) and (a)
(2) (c) and (d)
(3) (a) only
(4) (b) and (c)

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ISOTHERMAL V/S ADIABATIC : PV SLOPE

$\hookrightarrow PV = \text{const.}$

$\Rightarrow \frac{dP}{dV} \cdot V + P = 0$

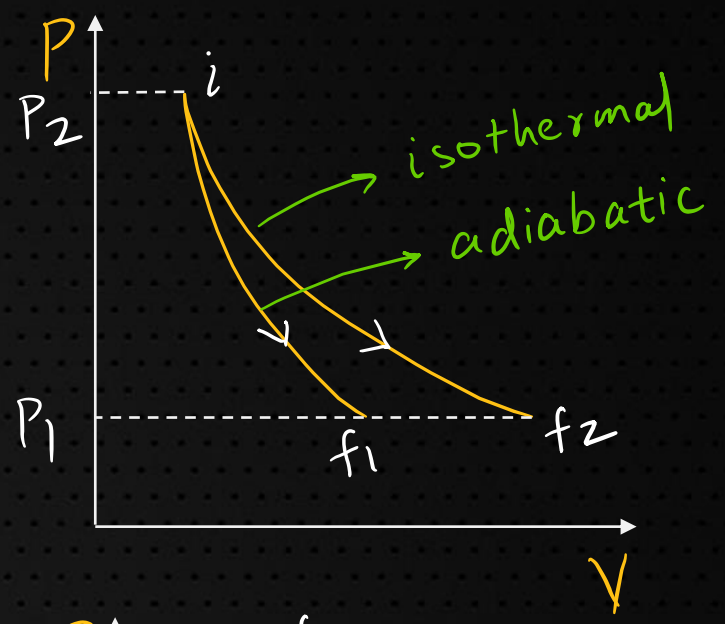
$\Rightarrow \boxed{\frac{dP}{dV} = -\frac{P}{V}}$

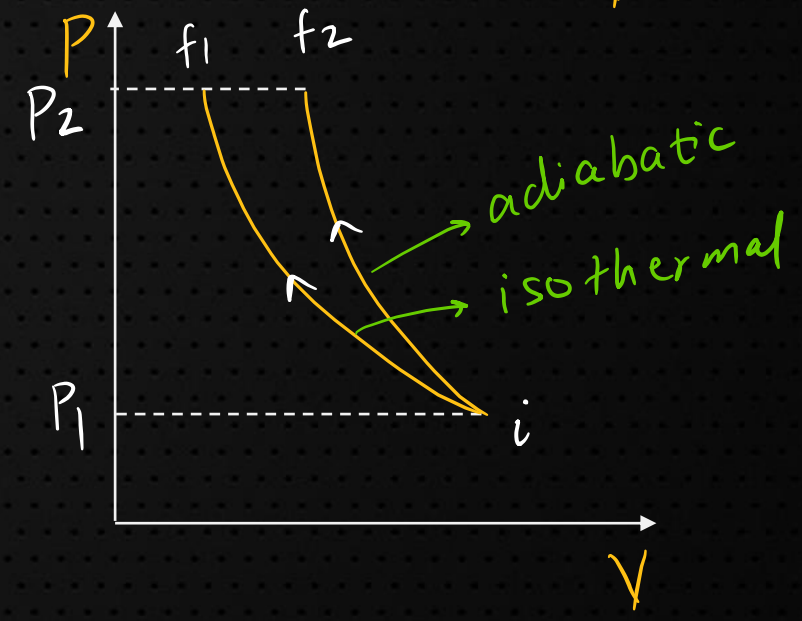
$\hookrightarrow PV^{\gamma} = \text{const.}$

$\Rightarrow \boxed{\frac{dP}{dV} = -\frac{\gamma P}{V}}$

Thus,

$$\left|\frac{dP}{dV}\right|_{ad} > \left|\frac{dP}{dV}\right|_{iso}$$





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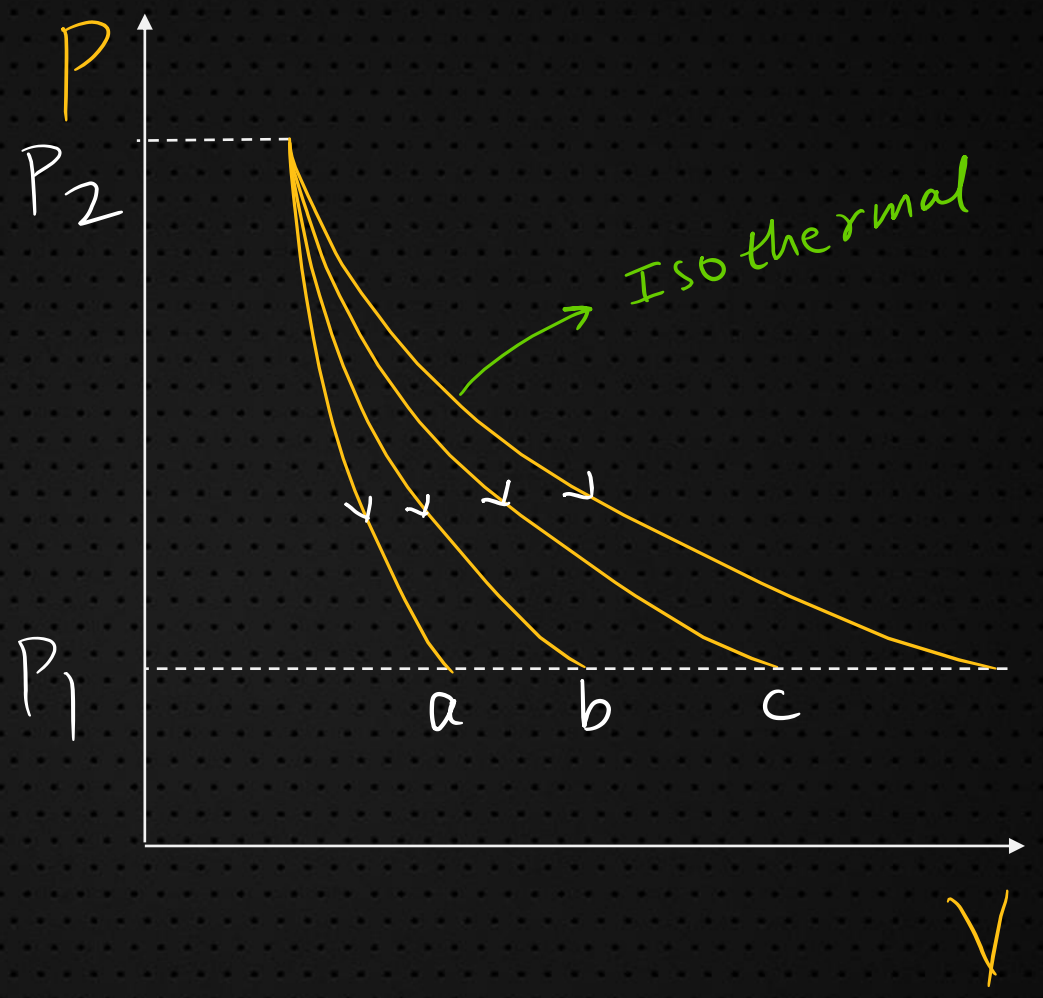
PV SLOPE AMONG GASES

$$\left|\frac{dP}{dV}\right| = \gamma \frac{P}{V} \quad \text{(adiabatic)}$$

a : monoatomic, $\gamma = \frac{5}{3} = 1.67$

b : diatomic, $\gamma = \frac{7}{5} = 1.4$

c : Polyatomic, $\gamma = \frac{4}{3} = 1.3$



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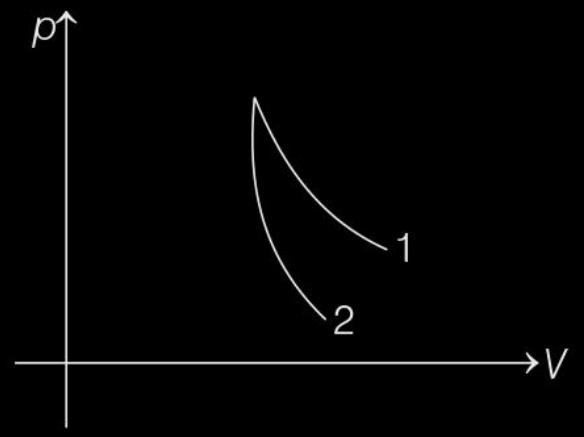
PYQ (Uploaded on EDUNITI Channel)

p-V plots for two gases during adiabatic processes are shown in the figure. Plots 1 and 2 should correspond respectively to



(a) He and O_2
(b) O_2 and He
(c) He and Ar
(d) O_2 and N_2

IITJEE 2001

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REVERSIBLE POLYTROPIC PROCESS

Reversible Processes are Quasi-Static (very slow process such that system is always in thermodynamic Equilibrium) and Non-dissipative (no loss in energy due to friction, viscous force etc.)

$$\boxed{PV^{x} = \text{Const.}}$$

x : Polytropic Index

Molar Heat Capacity

$$\boxed{C = C_V + \frac{R}{1-x}}$$

- $x \to \infty$: $C = C_V$
- $x = 0$: $C = C_V + R = C_P$
- $x = 1$: $C \to \infty$, $T = \text{Const.}$
- $x = \gamma$: $C = 0$

$$\boxed{\Delta Q = nC\Delta T}$$

$$\boxed{\Delta W = \frac{nR(T_2 - T_1)}{1-x}}$$

PYQ (Uploaded on EDUNITI Channel)

An ideal gas undergoes a quasi static, reversible process in which its molar heat capacity C remains constant. If during this process the relation of pressure p and volume V is given by pV^n = constant, then n is given by (Here, C_p and C_V are molar specific heat at constant pressure and constant volume, respectively)

(a) $n = \frac{C_p}{C_V}$ (b) $n = \frac{C - C_p}{C - C_V}$

(c) $n = \frac{C_p - C}{C - C_V}$ (d) $n = \frac{C - C_V}{C - C_p}$

JEE Main 2016

The volume V of a given mass of monoatomic gas changes with temperature T according to the relation $V = KT^{2/3}$. The workdone when temperature changes by 90 K will be xR. The value of x is [R = universal gas constant]

JEE Main 2021, Feb 26 Evening

In a process, temperature and volume of one mole of an ideal monoatomic gas are varied according to the relation $VT = k$, where k is a constant. In this process, the temperature of the gas is increased by ΔT. The amount of heat absorbed by gas is (where, R is gas constant) **(2019 Main, 11 Jan II)**

(a) $\frac{1}{2} kR\Delta T$ (b) $\frac{2k}{3} \Delta T$ (c) $\frac{1}{2} R\Delta T$ (d) $\frac{3}{2} R\Delta T$

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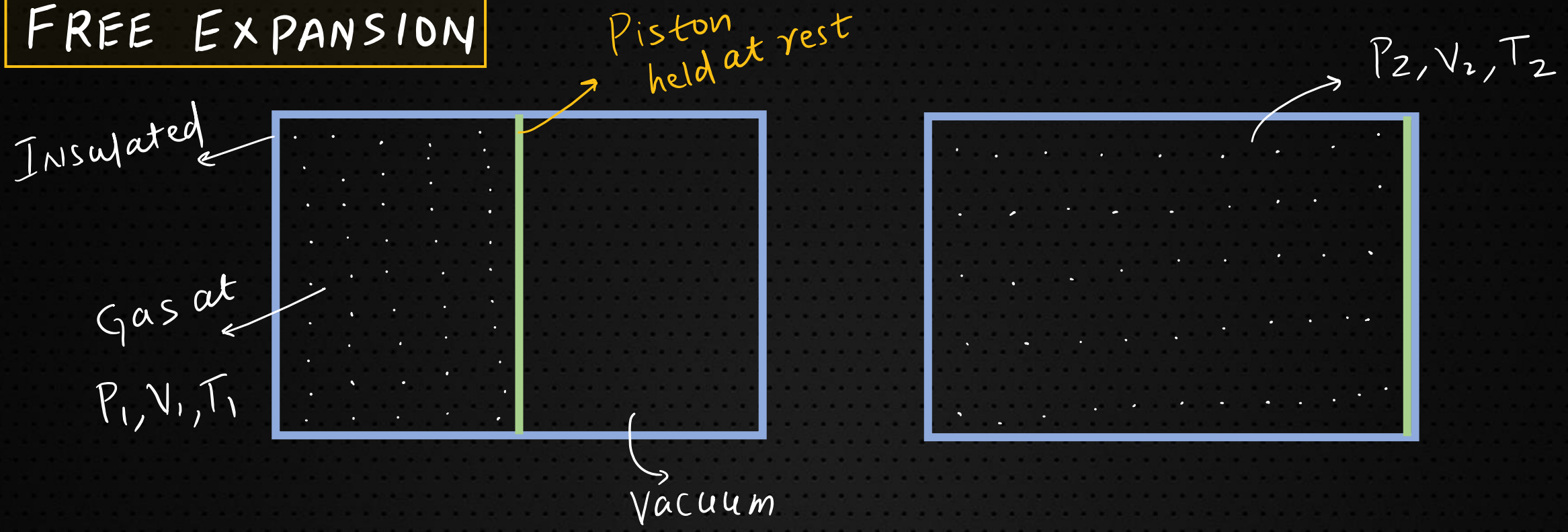
FREE EXPANSION



NOTE:

(1.) If no opposition $\Rightarrow$ $\boxed{\Delta W = 0}$

(2) $\Delta Q = 0 \Rightarrow \Delta U = 0$ or $\boxed{T = \text{const.}} \Rightarrow T_1 = T_2$

(3) $\boxed{P_1V_1 = P_2V_2}$ * Imp for problem solving.

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SECOND LAW OF THERMODYNAMICS

Kelvin-Planck Statement → Impossible to convert 100% heat into work

(Heat Engines: Heat is supplied so that system does work)

Clausius Statement → Heat cannot flow from colder to hotter body without doing any external work.

(Refrigerators: Work is done on the system to extract heat)

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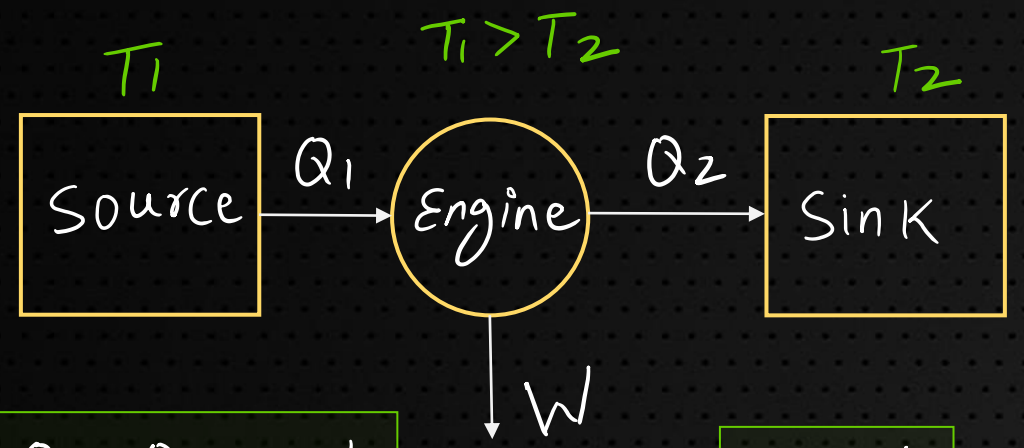
THERMAL EFFICIENCY OF A HEAT ENGINE



$$Q_1 - Q_2 = W$$

$$\eta = \frac{W}{Q_1}$$

or

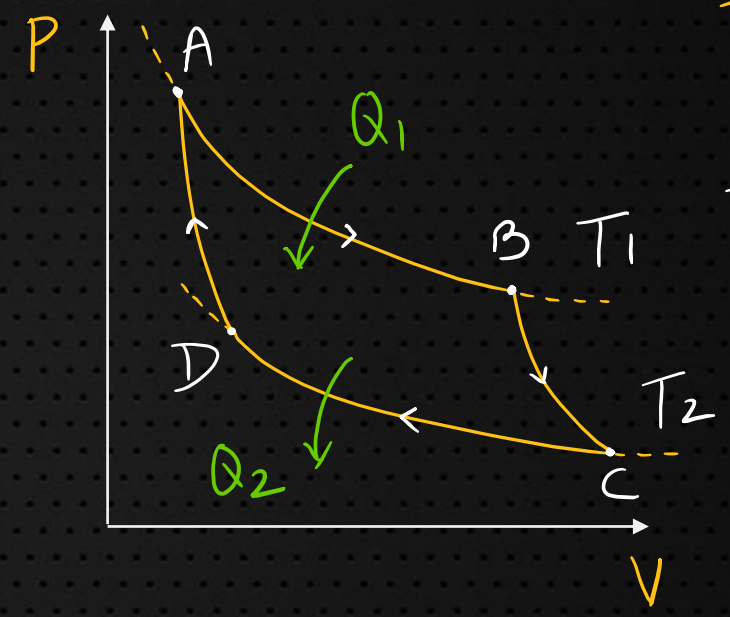
$$\eta = 1 - \frac{Q_2}{Q_1}$$

* Q_1 and Q_2 are magnitudes.

Carnot Engine:

→ Based on Carnot cycle

→ Max. possible η (Ideal case)



T = const. in A→B and C→D

ΔQ = 0 in B→C and D→A

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$$

$$\therefore \quad \eta = 1 - \frac{T_2}{T_1}$$

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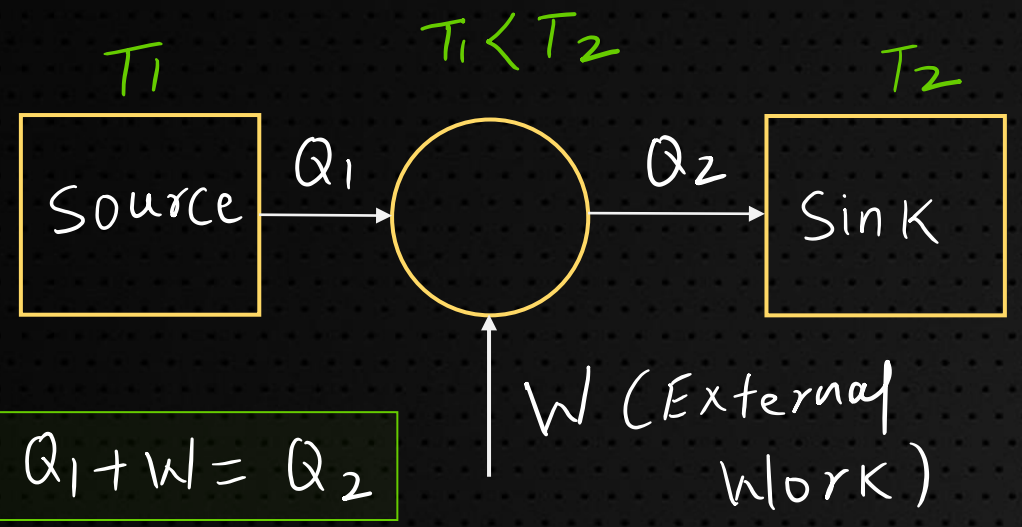
COEFFICIENT OF PERFORMANCE OF A REFRIGERATOR



$$Q_1 + W = Q_2$$

A best refrigeration cycle is one that removes the greatest amount of heat Q_1 from inside the refrigerator for least amount of external work W.

$$COP = \frac{Q_1}{W} = \frac{Q_1}{Q_2 - Q_1}$$

If it follows Carnot Cycle i.e. $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$

$$\Rightarrow COP = \frac{T_1}{T_2 - T_1}$$

PYQ (Uploaded on EDUNITI Channel)

For an ideal heat engine, the temperature of the source is 127°C. In order to have 60% efficiency the temperature of the sink should be _____°C. (Round off to the Nearest Integer)

JEE Main 2021, March 16 Evening

A Carnot's engine working between 400 K and 800 K has a work output of 1200 J per cycle. The amount of heat energy supplied to the engine from the source in each cycle is :

(1) 3200 J (2) 1800 J
(3) 1600 J (4) 2400 J

JEE Main 2021, 17 March Morning

Two Carnot engines A and B are operated in series. The first one, A receives heat at T_1 (= 600 K) and rejects to a reservoir at temperature T_2. The second engine B receives heat rejected by the first engine and in turn rejects to a heat reservoir at T_3 (= 400 K). Calculate the temperature T_2 if the work outputs of the two engines are equal. **(2019 Main, 9 Jan II)**

(a) 600 K (b) 500 K
(c) 400 K (d) 300 K

JEE Main 2019, 9 Jan Evening

EDUNITI - Physics by Mohit Goenka

Now that's how you Revise !

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