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Introduction

Thermodynamics Overview

- Study of heat, temperature, and energy conversion.
- Macroscopic science: deals with bulk systems, not molecular details.
- State variables: pressure (P), volume (V), temperature (T), internal energy (U), entropy (S).
- Focus on internal state changes, not motion of the system as a whole.
- Example: Kinetic energy of a bullet converts to heat on impact, raising temperature.
- Temperature relates to internal disordered motion energy, not bulk motion.

Solved Examples

Ex 1

- A bullet of mass 0.01 kg moving at 300 m/s stops in wood. Calculate kinetic energy converted to heat.
  - Formula: $KE = \frac{1}{2}mv^2$
  - Calculation: $KE = 0.5 \times 0.01 \times 300^2 = 450\ \text{J}$

Practice Set

- Q1: Thermodynamics studies
  - A) Molecular motion
  - B) Bulk system heat and energy
  - C) Particle forces
  - D) Electric currents
- Q2: Which is NOT a thermodynamic state variable?
  - A) Pressure
  - B) Volume
  - C) Velocity of system
  - D) Temperature
- Q3: When a bullet stops in wood, kinetic energy converts to
  - A) Mechanical energy
  - B) Heat energy

    - C) Potential energy
    - D) Electrical energy

Answer Key

- Q1: B - Thermodynamics deals with heat and energy in bulk systems.
- Q2: C - Velocity of the system is not a thermodynamic state variable.
- Q3: B - Kinetic energy converts into heat energy raising temperature.

Memory Aids

- Thermodynamics = Heat + Energy conversion in bulk systems.
- State variables: P, V, T, U, S.
- Temperature = internal motion energy, not bulk motion.

Thermal Equilibrium

Definition and Conditions

- Thermodynamic equilibrium: Macroscopic variables (P, T, V, mass, composition) constant over time.
- Thermal equilibrium: No net heat flow between systems in thermal contact.

Solved Examples

Ex 1

- Two bodies at temperatures 300 K and 300 K are brought into contact.
    - Heat flow? None, since temperatures are equal.

Practice Set

- Q1: Thermodynamic equilibrium means
  - A) Variables change with time
  - B) Variables constant with time
  - C) Heat flows continuously
  - D) System moves as a whole
- Q2: Two systems in thermal equilibrium have
  - A) Different temperatures
  - B) No net heat flow
  - C) Different pressures
  - D) Different volumes
- Q3: If heat flows between two bodies, they are
  - A) In thermal equilibrium
  - B) Not in thermal equilibrium
  - C) At same temperature
  - D) Isolated systems

Answer Key

- Q1: B - Equilibrium means variables do not change with time.
- Q2: B - Thermal equilibrium means no net heat flow.
- Q3: B - Heat flow indicates systems are not in thermal equilibrium.

Memory Aids

- Equilibrium = steady state, no change in variables.
- Thermal equilibrium = equal temperature, no heat flow.

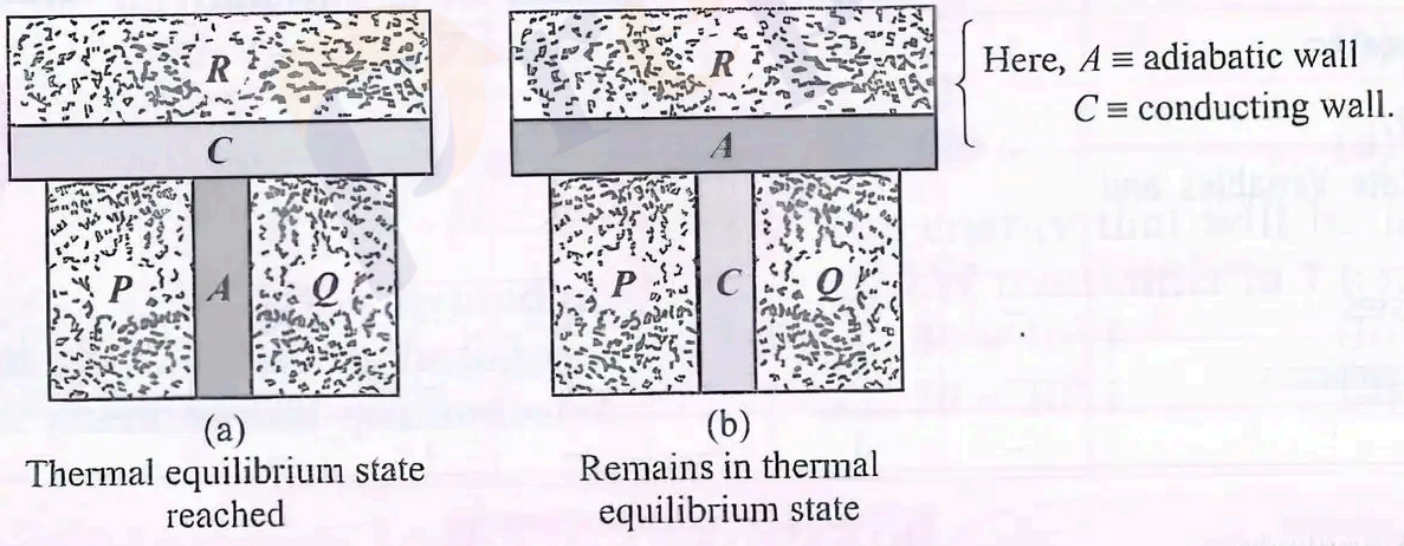
Zeroth Law of Thermodynamics

Fundamental Concept

- States: If two systems (P and Q) are each in thermal equilibrium with a third system (R), then P and Q are in thermal equilibrium with each other.
- Establishes the concept of temperature as a measurable and transitive property.
- Thermal equilibrium means no net heat flow between systems.

Thermal Equilibrium Setup

- System consists of three regions: P, Q, and R.
- Initially, P and Q reach thermal equilibrium with R through conducting walls.
- Replacing the adiabatic wall between P and Q with a conducting wall shows P and Q remain in thermal equilibrium.
- Adiabatic wall: no heat transfer; Conducting wall: allows heat transfer.



Solved Examples

- **Ex 1:** If system P is in thermal equilibrium with R at 300 K, and Q is also in thermal equilibrium with R, what is the temperature of Q?
  - Since P and Q are in thermal equilibrium with R, by zeroth law, P and Q are in thermal equilibrium.
  - Therefore, temperature of Q = temperature of P = 300 K.

Practice Set

- **Q1:** What does the zeroth law of thermodynamics establish?
  - A) Conservation of energy
  - B) Concept of temperature
  - C) Entropy increase
  - D) Heat capacity
- **Q2:** If system P is in thermal equilibrium with R at 350 K, and Q is also in thermal equilibrium with R, what is the temperature of Q?
  - A) 300 K
  - B) 350 K
  - C) 400 K
  - D) Cannot be determined
- **Q3:** In the given system, if the wall between P and Q is adiabatic and both are in equilibrium with R, what happens when the wall is replaced by a conducting wall?
  - A) P and Q will exchange heat and reach different temperatures
  - B) P and Q remain in thermal equilibrium
  - C) Heat flows from R to P and Q
  - D) System loses thermal equilibrium

Answer Key

- **Q1:** B - Zeroth law defines temperature as a transitive property through thermal equilibrium.
- **Q2:** B - By zeroth law, Q must have the same temperature as P and R, i.e., 350 K.
- **Q3:** B - Conducting wall allows heat transfer, confirming P and Q remain in thermal equilibrium.

Memory Aids

- "Zeroth law links temperatures via a third system."
- Thermal equilibrium is transitive: if A = C and B = C, then A = B.
- Adiabatic wall = no heat transfer; Conducting wall = heat transfer allowed.

Heat

Definition and Transfer

- Heat is a form of energy transferred due to temperature difference.
- Flows from higher to lower temperature regions.
- SI unit: Joule (J).

Solved Examples

- **Ex 1:** Calculate heat transferred when temperature difference exists.
  - Use formula: Q = m c ΔT
  - Given mass (m), specific heat (c), and temperature change (ΔT)
  - Calculate Q in Joules.

Practice Set

- Q1: Heat transfer occurs due to
  - A) Pressure difference
  - B) Temperature difference
  - C) Volume difference
  - D) Mass difference
- Q2: Heat is measured in
  - A) Newton
  - B) Joule
  - C) Watt
  - D) Pascal
- Q3: Heat flows from
  - A) Low to high temperature
  - B) High to low temperature
  - C) Equal temperatures
  - D) None of these

Answer Key

- Q1: B - Heat transfer is due to temperature difference.
- Q2: B - Heat is energy, unit is Joule.
- Q3: B - Heat flows from high to low temperature.

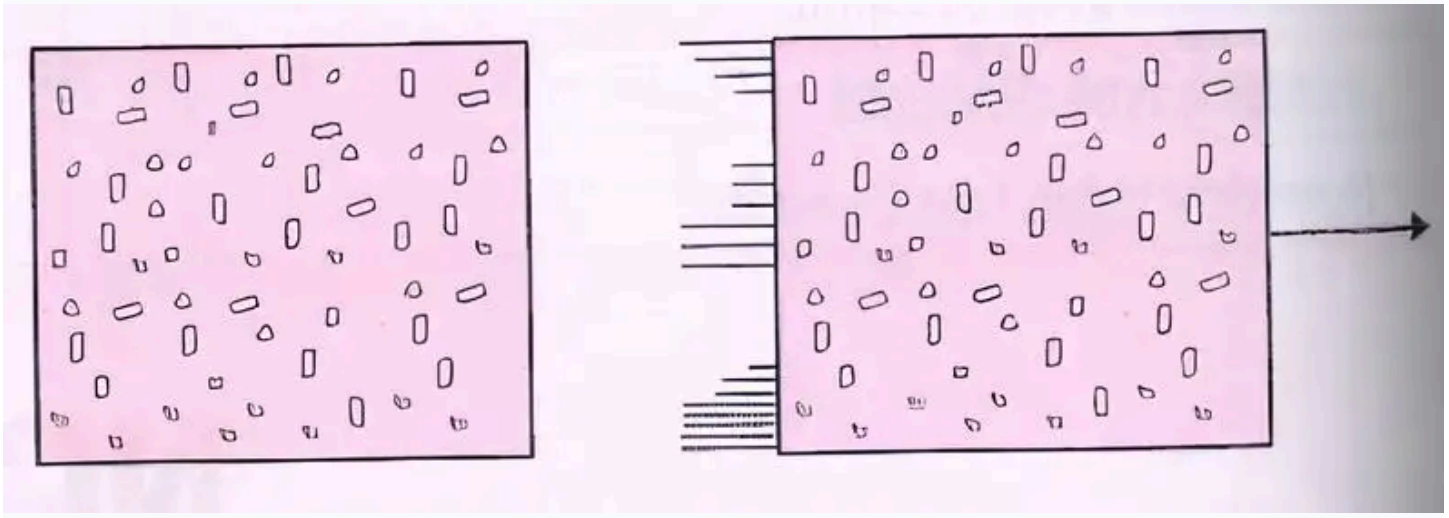
Memory Aids

- Heat = energy transfer by temperature difference.
- Unit Joule (J) like work and energy.
- Heat flows from hot to cold.

Internal Energy

Definition and Properties

- Sum of kinetic and potential energies of molecules inside a system.
- Excludes overall kinetic energy of the system as a whole.
- For ideal gas, depends only on temperature.
- For real gas, depends on temperature and volume.
- Includes molecular motions: translational, rotational, vibrational.



Solved Examples

- **Ex 1:** Internal energy change for ideal gas
  - Use $\Delta U = nC_V\Delta T$
  - Given moles (n), molar heat capacity at constant volume (C_V), and temperature change (ΔT)
  - Calculate ΔU in Joules.

Practice Set

- Q1: Internal energy excludes
  - A) Molecular kinetic energy
  - B) Molecular potential energy
  - C) Overall kinetic energy of system
  - D) Vibrational energy
- Q2: For ideal gas, internal energy depends on
  - A) Volume only
  - B) Temperature only
  - C) Pressure only
  - D) Temperature and volume
- Q3: Internal energy includes
  - A) Translational motion energy
  - B) Rotational motion energy
  - C) Vibrational motion energy
  - D) All of the above

Answer Key

- Q1: C - Overall kinetic energy of system is excluded.
- Q2: B - Ideal gas internal energy depends only on temperature.
- Q3: D - Includes all molecular motion energies.

Memory Aids

- Internal energy = molecular kinetic + potential energies.

- Ideal gas: depends only on temperature.
- Exclude system's bulk kinetic energy.

Work

Definition and Modes

- Work is energy transfer by mechanical means.
- Examples: moving piston, raising/lowering weights.
- SI unit: Joule (J).

Solved Examples

- **Ex 1:** Work done by gas expanding
  - Use formula: $W = P\Delta V$
  - Given pressure (P) and volume change (ΔV)
  - Calculate work in Joules.

Practice Set

- Q1: Work is energy transfer by
  - A) Heat only
  - B) Mechanical means
  - C) Radiation
  - D) Chemical reaction
- Q2: Work done by gas is given by
  - A) $P\Delta V$
  - B) $mc\Delta T$
  - C) Fd
  - D) mgh
- Q3: Unit of work is
  - A) Watt
  - B) Newton
  - C) Joule
  - D) Pascal

Answer Key

- Q1: B - Work is mechanical energy transfer.
- Q2: A - Work done by gas = pressure × volume change.
- Q3: C - Work unit is Joule.

Memory Aids

- Work = energy transfer by mechanical action.
- Formula: $W = P\Delta V$ for gases.
- Unit Joule same as energy and heat.

Heat and Work Energy Transfer

Key Concept

- Heat and work are distinct modes of energy transfer.
- Both cause change in internal energy of a system.
- Heat: transfer due to temperature difference.
- Work: transfer by mechanical means.

Solved Examples

- **Ex 1:** Calculate change in internal energy
  - Use first law: $\Delta U = Q - W$
  - Given heat added (Q) and work done by system (W)
  - Calculate ΔU in Joules.

Practice Set

- Q1: Heat and work are
  - A) Same mode of energy transfer

    - B) Distinct modes of energy transfer
    - C) Forms of potential energy
    - D) Forms of kinetic energy
- Q2: Change in internal energy depends on
    - A) Heat only
    - B) Work only
    - C) Heat and work
    - D) Neither heat nor work
- Q3: First law of thermodynamics is
    - A) $\Delta U = Q + W$
    - B) $\Delta U = Q - W$
    - C) $\Delta U = W - Q$
    - D) $\Delta U = 0$

Answer Key

- Q1: B - Heat and work are distinct energy transfer modes.
- Q2: C - Internal energy change depends on both heat and work.
- Q3: B - First law: $\Delta U = Q - W$.

Memory Aids

- Heat and work change internal energy.
- First law: $\Delta U = Q - W$.
- Heat by temperature difference, work by mechanical means.

First Law of Thermodynamics

Concept and Formula

- Energy conservation applied to thermodynamic systems.
- Energy supplied as heat (ΔQ) partly increases internal energy (ΔU) and partly does work (ΔW).
- Mathematical form: $\Delta Q = \Delta U + \Delta W$.
- Rearranged: $\Delta Q - \Delta W = \Delta U$.

- ΔQ and ΔW depend on the path; $\Delta Q - \Delta W$ is path independent.
- For $\Delta U = 0$, $\Delta Q = \Delta W$.
- Work done at constant pressure: $\Delta W = P\Delta V$ so $\Delta Q = \Delta U + P\Delta V$.

Solved Examples

- **Ex 1:** Heat supplied $\Delta Q = 500\,J$, work done $\Delta W = 200\,J$. Find ΔU.
  - Use $\Delta U = \Delta Q - \Delta W = 500 - 200 = 300\,J$.
- **Ex 2:** Gas expands at constant pressure $P = 2 \times 10^5\,Pa$, volume change $\Delta V = 0.001\,m^3$, $\Delta U = 0$. Find heat supplied ΔQ.
  - Work done $\Delta W = P\Delta V = 2 \times 10^5 \times 0.001 = 200\,J$.
  - Since $\Delta U = 0$, $\Delta Q = \Delta W = 200\,J$.

Practice Set

- Q1: If $\Delta Q = 400\,J$ and $\Delta U = 150\,J$, work done by the system is:
  - A) 550 J
  - B) 250 J
  - C) 150 J
  - D) 400 J
- Q2: For an isothermal process, $\Delta U = 0$. If the gas does 300 J work, heat supplied is:
  - A) 0 J
  - B) 300 J
  - C) -300 J
  - D) 600 J
- Q3: A gas absorbs 500 J heat, internal energy increases by 200 J. Work done by the gas is:
  - A) 700 J
  - B) 300 J
  - C) -300 J
  - D) 200 J

Answer Key

- Q1: B) 250 J — Using $\Delta W = \Delta Q - \Delta U = 400 - 150 = 250\,J$.
- Q2: B) 300 J — For isothermal, $\Delta U = 0$, so $\Delta Q = \Delta W = 300\,J$.

- Q3: B) 300 J — Work done $= \Delta Q - \Delta U = 500 - 200 = 300\,J$.

Memory Aids

- First law: Heat in = Increase in internal energy + Work done.
- Formula: $\Delta Q = \Delta U + \Delta W$.
- Work done by gas (expansion) is positive; on gas (compression) is negative.
- Heat absorbed positive; heat released negative.

Sign Conventions Used in Thermodynamics

Key Points

- Heat absorbed by system: positive $\Delta Q > 0$.
- Heat rejected by system: negative $\Delta Q < 0$.
- Internal energy increases with temperature rise: $\Delta U > 0$.
- Internal energy decreases with temperature fall: $\Delta U < 0$.
- Work done by gas during expansion: positive $\Delta W > 0$.
- Work done on gas during compression: negative $\Delta W < 0$.

Solved Examples

- **Ex 1:** Gas absorbs 100 J heat and expands doing 60 J work. Find ΔU.
  - $\Delta U = \Delta Q - \Delta W = 100 - 60 = 40\,J$ (positive).
- **Ex 2:** Gas compressed with 50 J work done on it, releasing 20 J heat. Find ΔU.
  - Work done by system $\Delta W = -50\,J$, heat supplied $\Delta Q = -20\,J$.
  - $\Delta U = \Delta Q - \Delta W = -20 - (-50) = 30\,J$ (positive).

Practice Set

- Q1: Heat rejected by system is:
  - A) Positive
  - B) Negative
  - C) Zero

    - D) Undefined
- Q2: When gas expands, work done is:
    - A) Negative
    - B) Positive
    - C) Zero
    - D) Depends on temperature
- Q3: If temperature falls, internal energy change is:
    - A) Positive
    - B) Negative
    - C) Zero
    - D) Cannot say

Answer Key

- Q1: B) Negative — Heat rejected means heat leaves system, negative sign.
- Q2: B) Positive — Expansion means work done by system, positive.
- Q3: B) Negative — Temperature fall decreases internal energy.

Memory Aids

- Heat in (+), heat out (-).
- Expansion work (+), compression work (-).
- Temp rise (+ΔU), temp fall (-ΔU).

Specific Heat Capacity

Definition and Formula

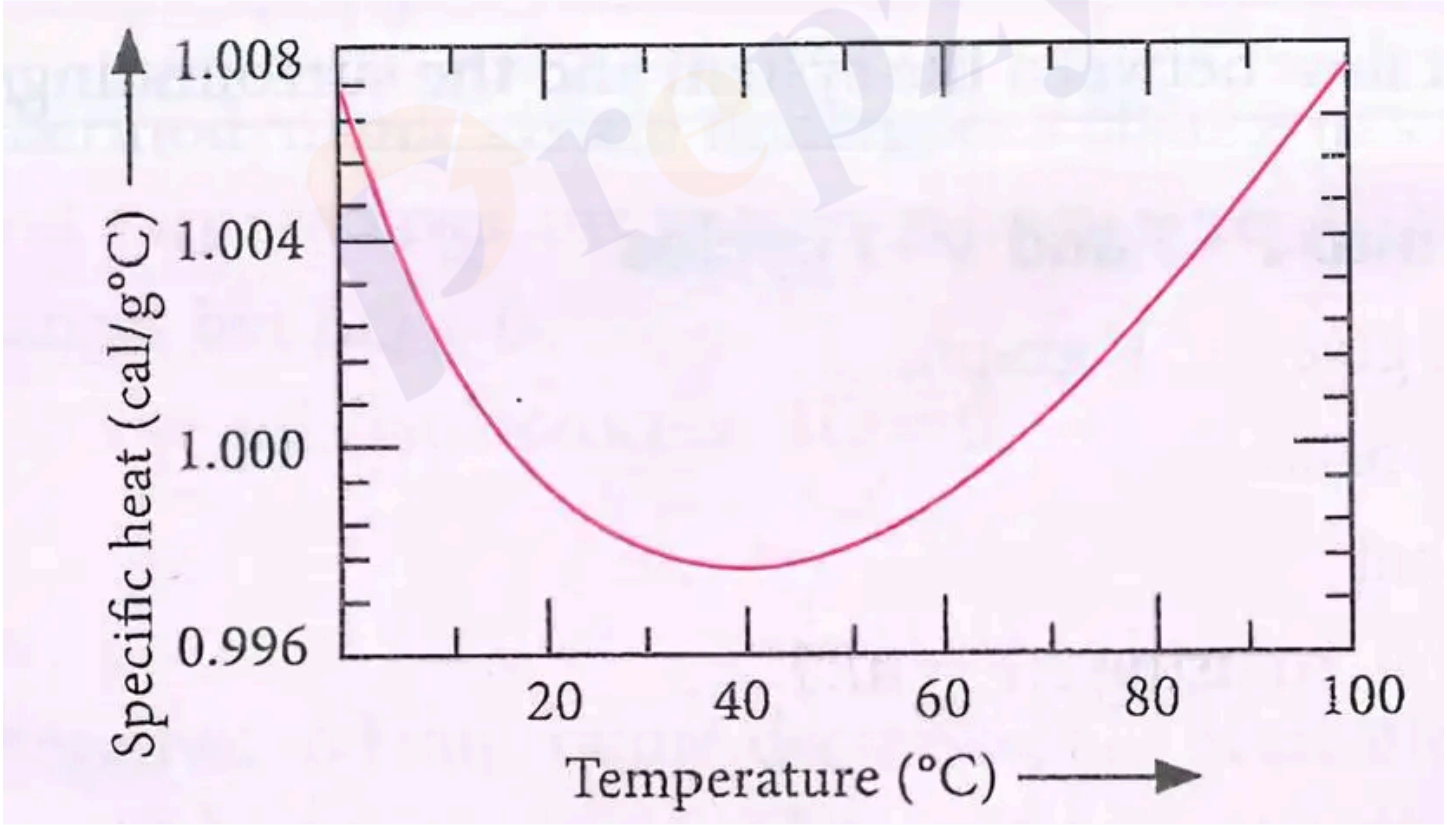
- Heat absorbed or evolved per unit mass for 1°C temperature change.
- Formula: **Q = ms\Delta T = ms(T_f - T_i)**
- Specific heat capacity: **s = \frac{Q}{m\Delta T}**

Molar Specific Heat for Solid

- Heat required to raise 1 mole temperature by 1°C.
- Formula: **$C = \frac{H}{\mu} = \frac{1}{\mu} \frac{\Delta Q}{\Delta T}$**, where H = heat capacity.
- For N atoms vibrating, average energy per oscillator in 3D: **$3k_B T$**.
- Total energy per mole: **$U = 3k_B T \times N_A = 3RT$**.
- Molar specific heat: **$C = \frac{\Delta Q}{\Delta T} = \frac{\Delta U}{\Delta T} = 3R$** (valid at room temperature, except carbon).

Specific Heat Capacity of Water

- Varies slightly with temperature.
- Graph shows U-shaped curve: decreases till ~40°C, then increases.
- One calorie = heat to raise 1 g water from 14.5°C to 15.5°C.



Solved Examples

- **Ex 1:** Calculate heat to raise 2 kg water by 10°C, s = 4200 J/kg°C.
  - Q = ms\Delta T = 2 \times 4200 \times 10 = 84000 J

- **Ex 2:** Find molar specific heat if heat capacity H = 60 J/°C and molar mass $\mu = 20$ g/mol.
  - C = H/\mu = 60/20 = 3 J/mol°C

Practice Set

- Q1: Specific heat capacity is the heat required to raise the temperature of
  - A) 1 mole of substance by 1°C
  - B) 1 gram of substance by 1°C
  - C) 1 kg of substance by 1°C
  - D) 1 liter of substance by 1°C
- Q2: Molar specific heat of a solid is
  - A) Heat to raise 1 g by 1°C
  - B) Heat to raise 1 mole by 1°C
  - C) Heat to raise 1 kg by 1°C
  - D) Heat to raise 1 atom by 1°C
- Q3: Total energy of 1 mole solid vibrating atoms at temperature T is
  - A) 3k_B T
  - B) 3RT
  - C) k_B T
  - D) RT

Answer Key

- Q1: B - Specific heat capacity is per gram per degree Celsius.
- Q2: B - Molar specific heat is heat for 1 mole per degree.
- Q3: B - Total energy for 1 mole is 3RT.

Memory Aids

- Specific heat: Q = ms\Delta T
- Molar heat: C = H/\mu
- Energy per mole: U = 3RT
- Water's specific heat varies with temperature (U-shaped curve).

Relation Specific Heat Constant Volume Pressure

First Law and Definitions

- Heat absorbed: **\Delta Q = \Delta U_{int} + P\Delta V**
- At constant volume ($\Delta V = 0$): **C_v = \left(\frac{\Delta Q}{\Delta T}\right)_v = \left(\frac{\Delta U_{int}}{\Delta T}\right)**
- Internal energy depends only on temperature for ideal gas.

Heat at Constant Pressure

- At constant pressure: **C_p = \left(\frac{\Delta Q}{\Delta T}\right)_p = C_v + P\left(\frac{\Delta V}{\Delta T}\right)_p**
- Difference: **C_p - C_v = P\left(\frac{\Delta V}{\Delta T}\right)_p**
- Using ideal gas law for 1 mole: **P\left(\frac{\Delta V}{\Delta T}\right)_p = R**
- Mayer's relation: **C_p - C_v = R**

Solved Examples

- **Ex 1:** For 1 mole ideal gas, if *C_v = 12.5 J/mol°C*, find *C_p*.
  - C_p = C_v + R = 12.5 + 8.31 = 20.81 J/mol°C
- **Ex 2:** Calculate *C_p - C_v* for ideal gas.
  - C_p - C_v = R = 8.31 J/mol°C

Practice Set

- Q1: Mayer's relation is
  - A) C_p + C_v = R
  - B) C_p - C_v = R
  - C) C_v - C_p = R
  - D) C_p \times C_v = R
- Q2: At constant volume, heat capacity is
  - A) C_p
  - B) C_v

    - C) R
    - D) 0
- Q3: For 1 mole ideal gas, P(\Delta V/\Delta T)_p equals
    - A) 0
    - B) R
    - C) C_p
    - D) C_v

Answer Key

- Q1: B - Mayer's relation states C_p - C_v = R.
- Q2: B - At constant volume, heat capacity is C_v.
- Q3: B - From ideal gas law, P(\Delta V/\Delta T)_p = R.

Memory Aids

- Mayer's relation: C_p - C_v = R
- At constant volume: C_v = (\Delta U/\Delta T)
- At constant pressure: C_p = C_v + R

Thermodynamic State Variables

Definition and Types

- Thermodynamic state variables describe equilibrium states of a system.
- Two types: **Extensive** and **Intensive**.
- **Extensive variables** depend on system size (e.g., volume V, internal energy U, mass μ).
- **Intensive variables** do not depend on system size (e.g., pressure P, temperature T).
- Product of an intensive and an extensive variable is extensive (e.g., P × V is extensive).

Solved Examples

- **Ex 1:** Identify if pressure and volume are intensive or extensive.
    - Pressure (P) is intensive.

- Volume (V) is extensive.

Practice Set

- Q1: Which of the following is an intensive variable?
  - A. Volume
  - B. Mass
  - C. Temperature
  - D. Internal energy
- Q2: The product of an intensive and an extensive variable is:
  - A. Intensive
  - B. Extensive
  - C. Neither
  - D. Depends on variables
- Q3: Which of the following is an extensive variable?
  - A. Pressure
  - B. Temperature
  - C. Volume
  - D. Density

Answer Key

- Q1: C - Temperature is intensive; it does not depend on system size.
- Q2: B - Product of intensive and extensive variables is extensive.
- Q3: C - Volume is extensive; it depends on system size.

Memory Aids

- Intensive: "I" for Independent of size (P, T).
- Extensive: "E" for Extends with size (V, U, μ).
- Product rule: Intensive × Extensive = Extensive.

Equation of State

Ideal Gas Equation

- Relates thermodynamic state variables: pressure (P), volume (V), temperature (T), and amount of substance (μ).
- Ideal gas equation: **PV = μRT**
- R = universal gas constant (8.314 J/mol·K)
- Valid for ideal gases under equilibrium.

Solved Examples

- **Ex 1:** Calculate pressure of 2 mol ideal gas at 300 K in 10 L container.
  - Given: μ=2 mol, T=300 K, V=10 L = 0.01 m^3, R=8.314 J/mol·K
  - Use PV = μRT → P = μRT/V
  - P = (2 × 8.314 × 300) / 0.01 = 498840 Pa = 498.84 kPa

Practice Set

- Q1: For 1 mol ideal gas at 273 K and 22.4 L, pressure is:
  - A. 1 atm
  - B. 2 atm
  - C. 0.5 atm
  - D. 3 atm
- Q2: If volume doubles at constant temperature and moles, pressure:
  - A. Doubles
  - B. Halves
  - C. Remains same
  - D. Quadruples
- Q3: Calculate volume of 3 mol gas at 300 K and 2 atm.
  - A. 36.9 L
  - B. 22.4 L
  - C. 44.8 L
  - D. 11.2 L

Answer Key

- Q1: A - Standard molar volume at STP is 22.4 L at 1 atm.
- Q2: B - P inversely proportional to V at constant T and μ.
- Q3: A - V = μRT/P = (3 × 0.0821 × 300)/2 = 36.9 L (using R=0.0821 L·atm/mol·K)

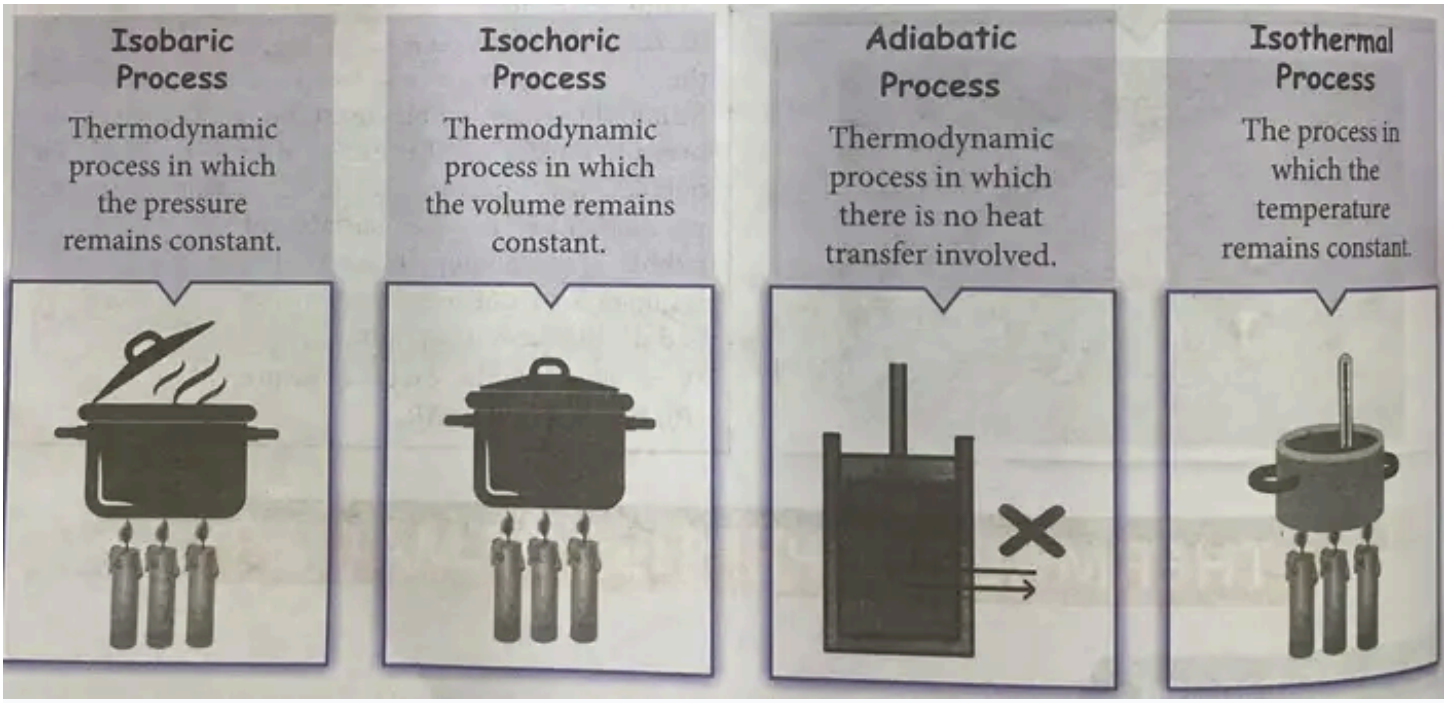
Memory Aids

- Ideal gas: PV = μRT
- At STP: 1 mol gas occupies 22.4 L
- Pressure inversely ∝ volume at constant T and μ

Thermodynamic Processes

Key Concepts

- **Quasi static process:** Infinitely slow process maintaining equilibrium at every stage (P, T, V change slowly).
- **Cyclic process:** Series of changes returning system to initial state; ΔU = 0, ΔT = 0 (temperature constant).
- Types of processes: Isobaric (P constant), Isochoric (V constant), Adiabatic (Q = 0), Isothermal (T constant).



Solved Examples

- **Ex 1:** For a cyclic process, find ΔU if initial and final internal energies are equal.
  Answer: ΔU = 0
- **Ex 2:** Identify process where temperature remains constant.
  Answer: Isothermal process

Practice Set

- Q1: What is the change in internal energy in a cyclic process?
  A. Positive
  B. Negative
  C. Zero
  D. Depends on process
- Q2: Which process keeps volume constant?
  A. Isobaric
  B. Isochoric
  C. Adiabatic
  D. Isothermal
- Q3: In a quasi static process, the system is always in:
  A. Non-equilibrium state
  B. Equilibrium state

C. Rapid change

D. Isolated state

Answer Key

- Q1: C - ΔU = 0 in cyclic process as system returns to initial state.
- Q2: B - Isochoric process keeps volume constant.
- Q3: B - Quasi static process maintains equilibrium at every stage.

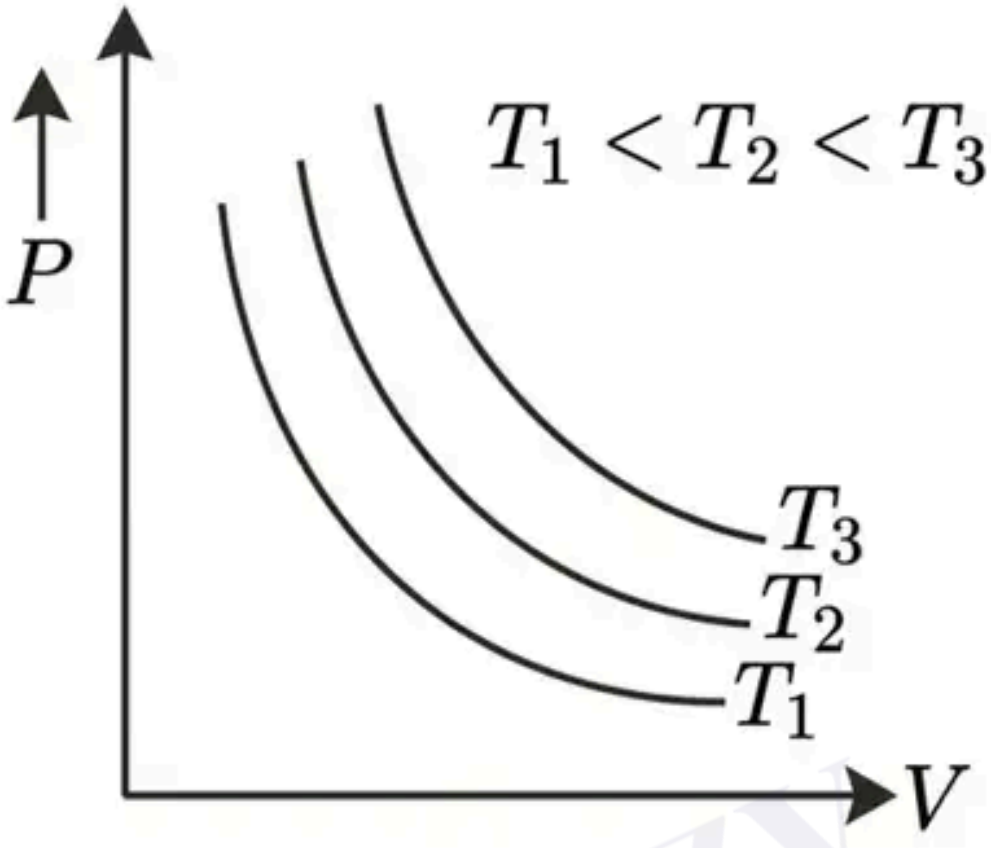
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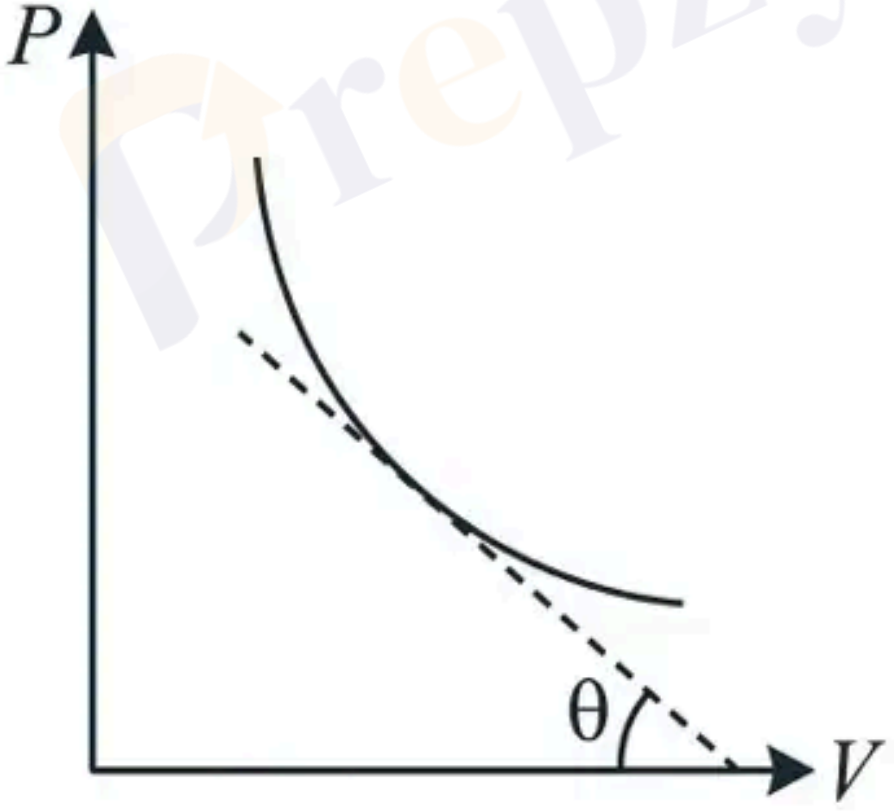
- Cycle → ΔU = 0, T constant
- Quasi static = slow equilibrium
- Isobaric = P constant, Isochoric = V constant

Isothermal Process

Key Concepts

- Temperature remains constant: ΔT = 0
- First law: ΔU = 0, so ΔQ = ΔW (heat supplied = work done)
- Equation: PV = constant (Boyle's law)
- Indicator diagram: P-V curve is rectangular hyperbola (isotherm)
- Slope of curve: $\frac{dP}{dV} = -\frac{P}{V}$
- Work done: $W = nRT \ln \frac{V_f}{V_i} = nRT \ln \frac{P_i}{P_f}$
- Specific heat: Infinite ($C = \frac{Q}{m\Delta T} = \infty$)


$T_1 < T_2 < T_3$
P
T_3
T_2
T_1
V


P
θ
V

Solved Examples

- **Ex 1:** Calculate work done when 1 mole of ideal gas expands isothermally from 10 L to 20 L at 300 K.
  Use $W = nRT \ln \frac{V_f}{V_i}$.
  Answer: $W = 1 \times 8.314 \times 300 \times \ln 2 \approx 1728 \text{ J}$

Practice Set

- Q1: In isothermal process, what is the change in internal energy?
  A. Positive
  B. Negative
  C. Zero
  D. Depends on volume
- Q2: Work done in isothermal expansion is:
  A. Zero
  B. Equal to heat absorbed
  C. Negative
  D. Equal to change in internal energy
- Q3: Which law is obeyed in isothermal process?
  A. Charles's law
  B. Boyle's law
  C. Gay-Lussac's law
  D. Avogadro's law

Answer Key

- Q1: C - ΔU = 0 as temperature is constant.
- Q2: B - Work done equals heat absorbed (ΔQ = ΔW).
- Q3: B - Boyle's law (PV = constant) applies.

Memory Aids

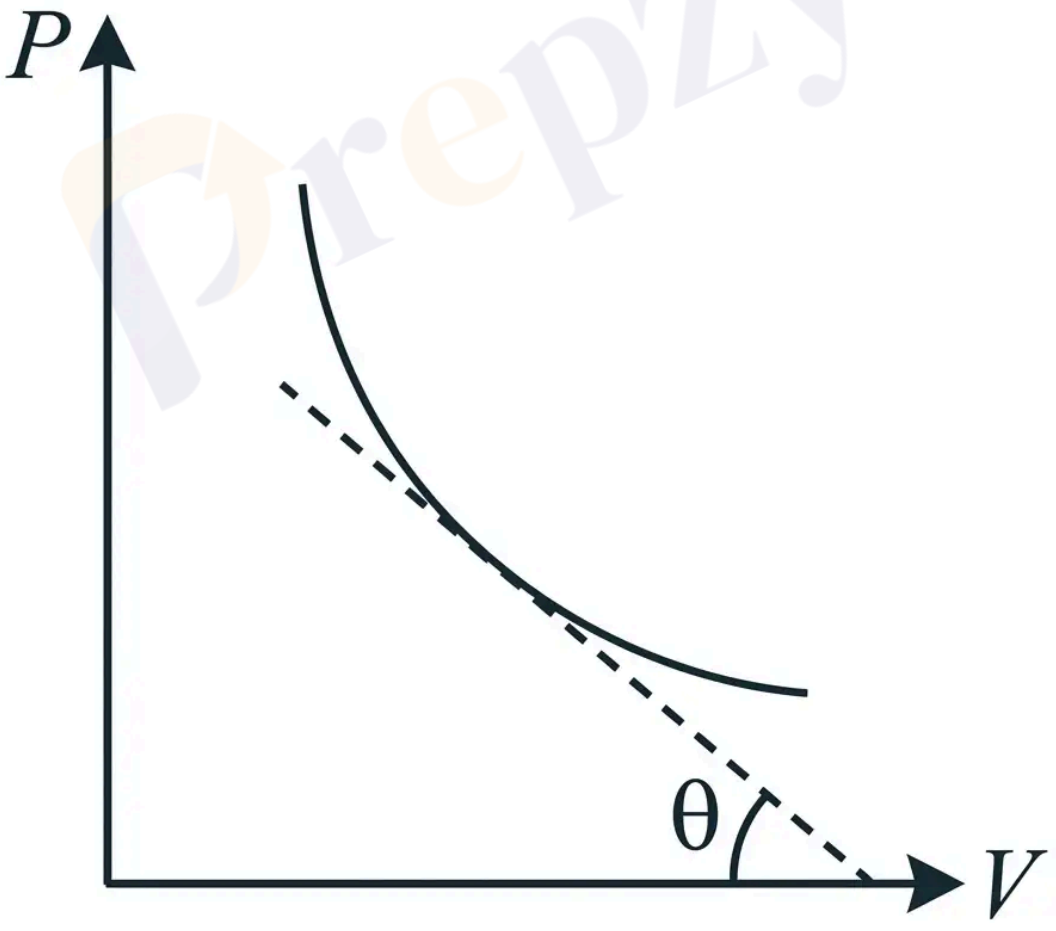
- Isothermal = T constant
- Work = heat absorbed

- PV = constant (Boyle's law)

Adiabatic Process

Key Concepts

- No heat exchange: ΔQ = 0
- First law: ΔU = -ΔW
- Temperature changes with work done (expansion cools, compression heats)
- Equation: $PV^{\gamma} = \text{constant}, \gamma = \frac{C_p}{C_v}$
- Slope of curve: $\frac{dP}{dV} = -\gamma\frac{P}{V}$ (steeper than isothermal)
- Specific heat: Zero ($C = 0$)
- Work done: $W = \frac{nR(T_1 - T_2)}{\gamma - 1} = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$



Solved Examples

- **Ex 1:** Calculate work done during adiabatic compression of 1 mole of gas from 2 L to 1 L with initial pressure 1 atm, $\gamma = 1.4$.
  Use $W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$.
  Answer: Calculate P_2 using $P_1V_1^{\gamma} = P_2V_2^{\gamma}$, then find W.

Practice Set

- Q1: In adiabatic process, heat exchanged is:
  A. Positive
  B. Negative
  C. Zero
  D. Depends on volume
- Q2: Which equation represents adiabatic process?
  A. PV = constant
  B. PV^\gamma = constant
  C. V/T = constant
  D. P/T = constant
- Q3: Specific heat in adiabatic process is:
  A. Infinite
  B. Zero
  C. Equal to C_p
  D. Equal to C_v

Answer Key

- Q1: C - No heat exchange (ΔQ = 0).
- Q2: B - Poisson's law: $PV^{\gamma} = \text{constant}$.
- Q3: B - Specific heat is zero as no heat is absorbed or released.

Memory Aids

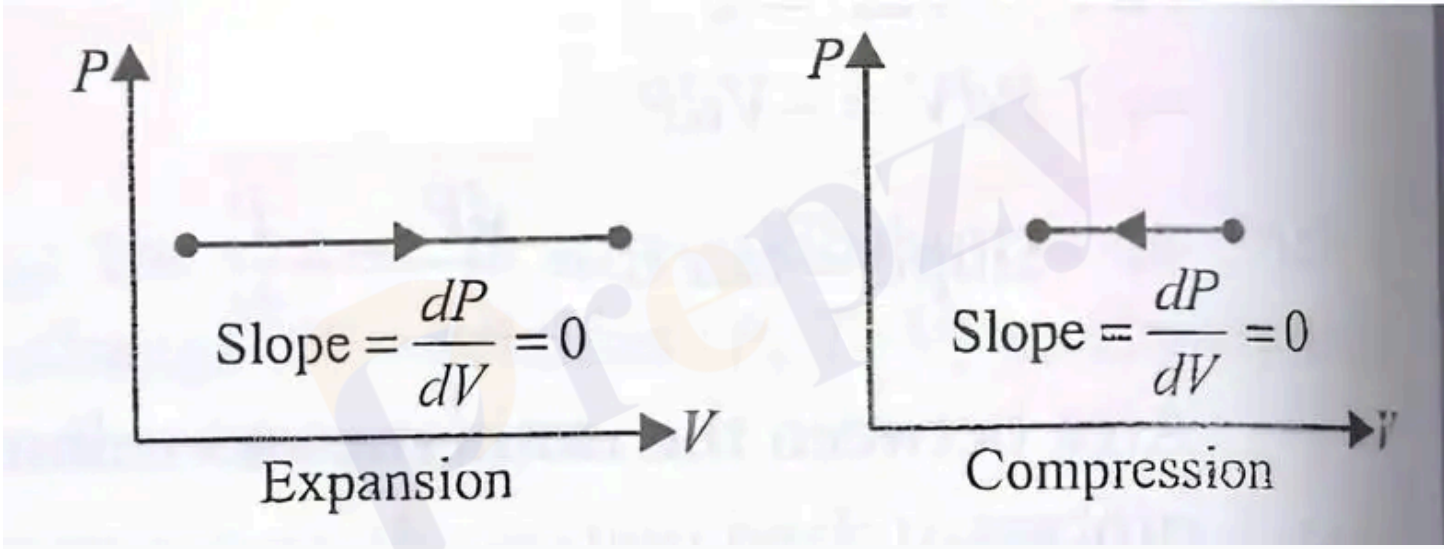
- Adiabatic = No heat exchange
- Work changes internal energy

- PV^γ = constant (Poisson's law)

Isobaric Process

Key Concepts

- Pressure remains constant
- In expansion: ΔU > 0, ΔW > 0, ΔQ > 0
- In compression: ΔU < 0, ΔW < 0, ΔQ < 0
- Specific heat: $C_p = \left(\frac{f}{2} + 1\right)R$
- Work done: $\Delta W = P(V_f - V_i) = \mu R(T_f - T_i)$



Solved Examples

- **Ex 1:** Calculate work done when 1 mole gas expands at constant pressure 2 atm from 5 L to 10 L.
  Use $\Delta W = P\Delta V$.
  Answer: $\Delta W = 2 \times (10 - 5) = 10\ \text{atm·L} = 1013\ \text{J}$

Practice Set

- Q1: In isobaric process, pressure is:
  A. Constant

B. Increasing
C. Decreasing
D. Variable

- Q2: Work done in isobaric expansion is:
  A. Zero
  B. Positive
  C. Negative
  D. Depends on temperature
- Q3: Specific heat at constant pressure is:
  A. C_v
  B. C_p
  C. Zero
  D. Infinite

Answer Key

- Q1: A - Pressure remains constant in isobaric process.
- Q2: B - Work done is positive during expansion.
- Q3: B - Specific heat at constant pressure is C_p.

Memory Aids

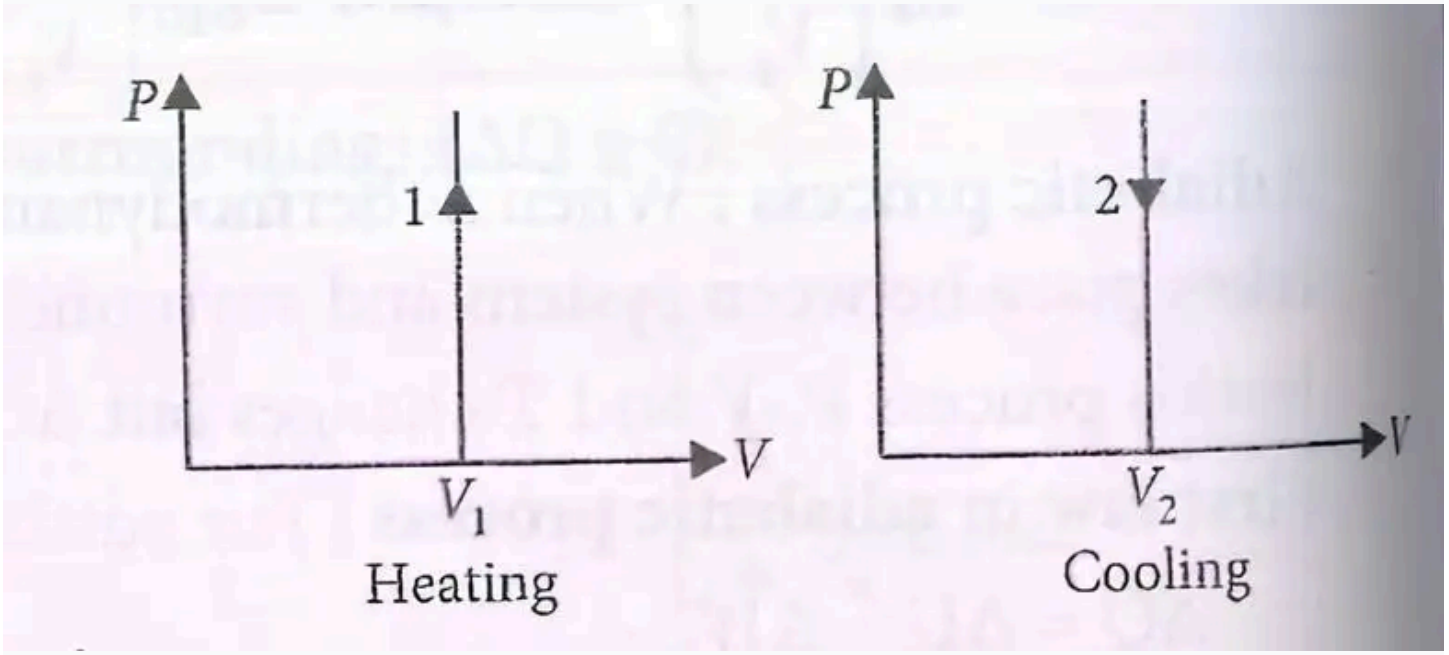
- Isobaric = P constant
- Work = PΔV
- Heat changes internal energy and does work

Isochoric Process

Key Concepts

- Volume remains constant
- Slope of indicator diagram: $\frac{dP}{dV} = \infty$
- Isometric heating: Pressure and temperature increase, ΔQ > 0, ΔU > 0
- Isometric cooling: Pressure and temperature decrease, ΔQ < 0, ΔU < 0
- Specific heat: $C_v = \frac{f}{2}R$

- Work done: $\Delta W = 0$ (since volume constant)



Solved Examples

- **Ex 1:** Calculate work done in isochoric heating.
  Answer: $\Delta W = 0$

Practice Set

- Q1: In isochoric process, volume is:
  A. Constant
  B. Increasing
  C. Decreasing
  D. Variable
- Q2: Work done in isochoric process is:
  A. Positive
  B. Negative
  C. Zero
  D. Depends on pressure
- Q3: Specific heat at constant volume is:
  A. C_p
  B. C_v
  C. Zero
  D. Infinite

Answer Key

- Q1: A - Volume remains constant in isochoric process.
- Q2: C - Work done is zero as volume does not change.
- Q3: B - Specific heat at constant volume is C_v.

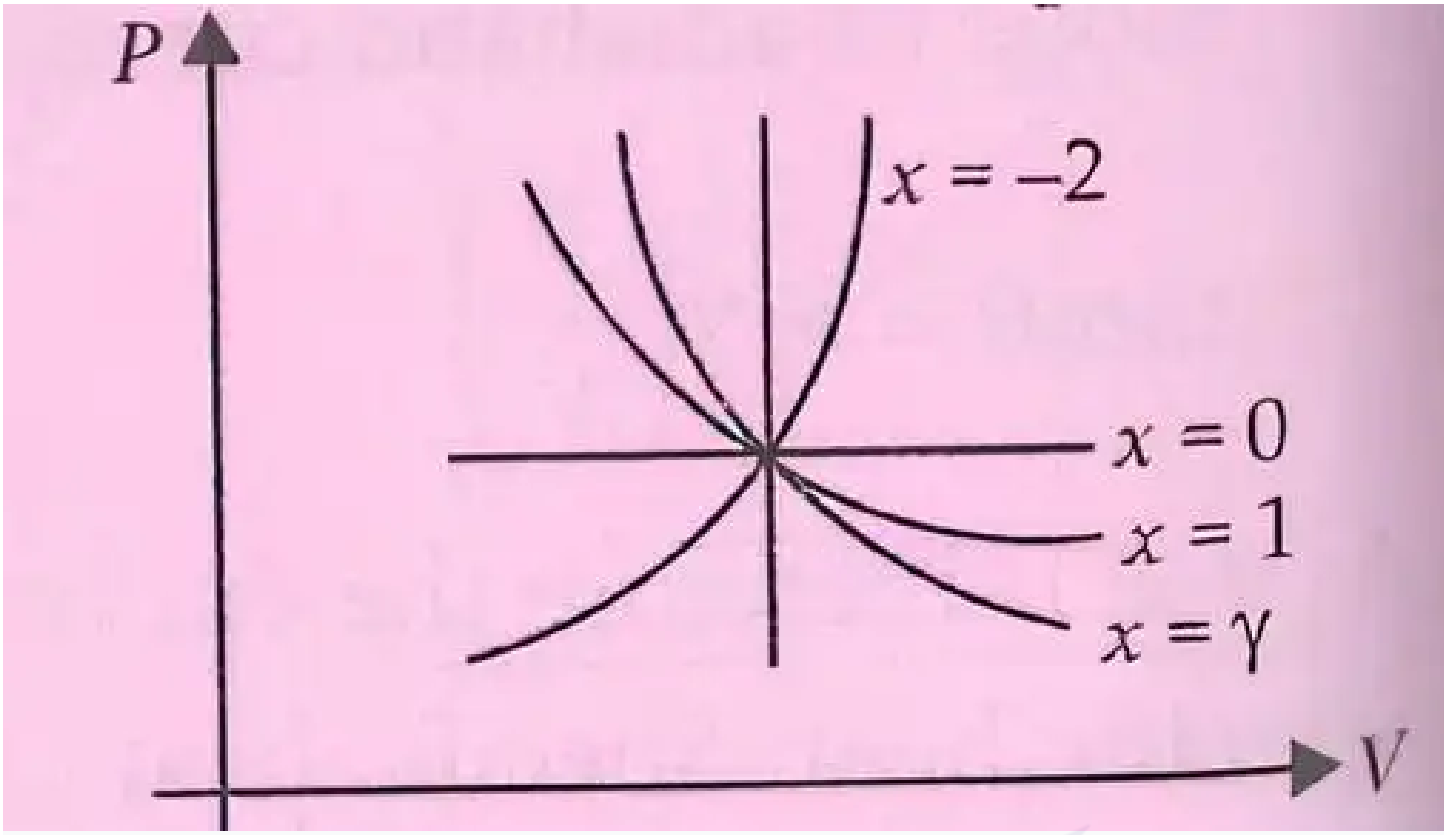
Memory Aids

- Isochoric = V constant
- Work done = 0
- Heat changes internal energy only

Polytropic Process

Key Concepts

- Follows equation: $PV^x = \text{constant}$, where x is polytropic index
- Special cases: $x = 0$ (isobaric), $x = 1$ (isothermal), $x = \gamma$ (adiabatic)
- Other relations: $TV^{x-1} = \text{constant}$, $P^{1-x}T^x = \text{constant}$
- Work done: $W = \frac{nR(T_1-T_2)}{x-1} = \frac{P_1V_1-P_2V_2}{x-1}$ for $x \neq 1$
- Molar heat capacity: $C = C_v - \frac{R}{x-1} = \frac{R}{\gamma-1} - \frac{R}{x-1}$



Solved Examples

- **Ex 1:** Identify the process type for $x = 1$.
  Answer: Isothermal process
- **Ex 2:** Calculate work done for polytropic process with given P_1, V_1, P_2, V_2, x.
  Use $W = \frac{P_1V_1 - P_2V_2}{x-1}$.

Practice Set

- Q1: For $x = 0$, the process is:
  A. Isothermal
  B. Isobaric
  C. Adiabatic
  D. Isochoric
- Q2: Work done in polytropic process is:
  A. $\frac{nR(T_1 - T_2)}{x-1}$
  B. Zero
  C. $nRT \ln \frac{V_f}{V_i}$
  D. $P(V_f - V_i)$

- Q3: Molar heat capacity for polytropic process is:
  A. $C_v + \frac{R}{x-1}$
  B. $C_v - \frac{R}{x-1}$
  C. C_p
  D. Zero

Answer Key

- Q1: B - For x=0, P=constant (isobaric).
- Q2: A - Work done formula for polytropic process.
- Q3: B - Molar heat capacity formula for polytropic process.

Memory Aids

- Polytropic: PV^x = constant
- x=0: Isobaric, x=1: Isothermal, x=γ: Adiabatic
- Work and heat capacity depend on x

Second Law of Thermodynamics

Key Points

- The second law restricts processes allowed by the first law.
- No heat engine can have efficiency $\eta = 1$ (100% efficiency).
- No refrigerator can have an infinite coefficient of performance (COP).

Solved Examples

- **Ex 1:** Calculate maximum efficiency of a heat engine operating between 500 K and 300 K.
  - Use $\eta_{max} = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{500} = 0.4 = 40\%$

Practice Set

- Q1: Which of the following is impossible according to the second law?
  - A. Heat engine with 100% efficiency
  - B. Refrigerator with finite COP
  - C. Heat transfer from hot to cold spontaneously
  - D. Work done by expanding gas
- Q2: The second law implies that
  - A. Energy can be created
  - B. Heat engines can convert all heat to work
  - C. Some heat must be rejected to sink
  - D. Refrigerators can have infinite COP
- Q3: A heat engine absorbs 600 J from a hot reservoir and rejects 400 J to a cold reservoir. Its efficiency is
  - A. 33.3%
  - B. 40%
  - C. 66.7%
  - D. 50%

Answer Key

- Q1: A - 100% efficiency violates the second law.
- Q2: C - Some heat must be rejected; full conversion is impossible.
- Q3: A - Efficiency = $\frac{W}{Q_1} = \frac{600-400}{600} = \frac{200}{600} = 33.3\%$

Memory Aids

- Efficiency $\eta < 1$
- Heat flows hot to cold naturally
- Work output < heat input

Kelvin-Planck Statement

Key Points

- No process can convert all absorbed heat from a reservoir into work alone.
- Heat engine must reject some heat to a cooler sink.
- Mathematically, $\eta = \frac{W}{Q_1} < 1$.

Solved Examples

- **Ex 1:** A heat engine absorbs 1000 J heat and does 700 J work. Is it violating Kelvin-Planck?
  - Efficiency = $\frac{700}{1000} = 0.7 < 1$ → No violation.

Practice Set

- Q1: Kelvin-Planck statement forbids
  - A. 100% efficient heat engine
  - B. Refrigerator operation
  - C. Heat transfer from cold to hot
  - D. Work done by gas expansion
- Q2: If a heat engine absorbs 500 J and does 500 J work, what happens?
  - A. Allowed by Kelvin-Planck
  - B. Violates Kelvin-Planck
  - C. Allowed by Clausius
  - D. Violates first law
- Q3: Which is true for Kelvin-Planck?
  - A. $\eta = 1$ possible
  - B. Some heat must be rejected
  - C. Heat flows cold to hot
  - D. Work input required

Answer Key

- Q1: A - 100% efficient heat engine is impossible.

- Q2: B - Complete conversion of heat to work is forbidden.
- Q3: B - Heat engine must reject some heat.

Memory Aids

- "No 100% heat to work"
- Heat engine rejects heat
- Efficiency always < 1

Clausius Statement

Key Points

- Heat cannot spontaneously flow from a colder to a hotter body.
- Refrigerators require work input to transfer heat from cold to hot.
- Heat transfer from cold to hot without work violates this law.

Solved Examples

- **Ex 1:** Heat $Q = 200$ J moves from 270 K to 300 K with 50 J work input. Is this allowed?
  - Yes, work input enables heat transfer from cold to hot.

Practice Set

- Q1: Clausius statement forbids
  - A. Heat flow hot to cold
  - B. Heat flow cold to hot without work
  - C. Work done on gas
  - D. Heat engine operation
- Q2: Which device requires work to transfer heat from cold to hot?
  - A. Heat engine
  - B. Refrigerator
  - C. Thermal conductor
  - D. Adiabatic system

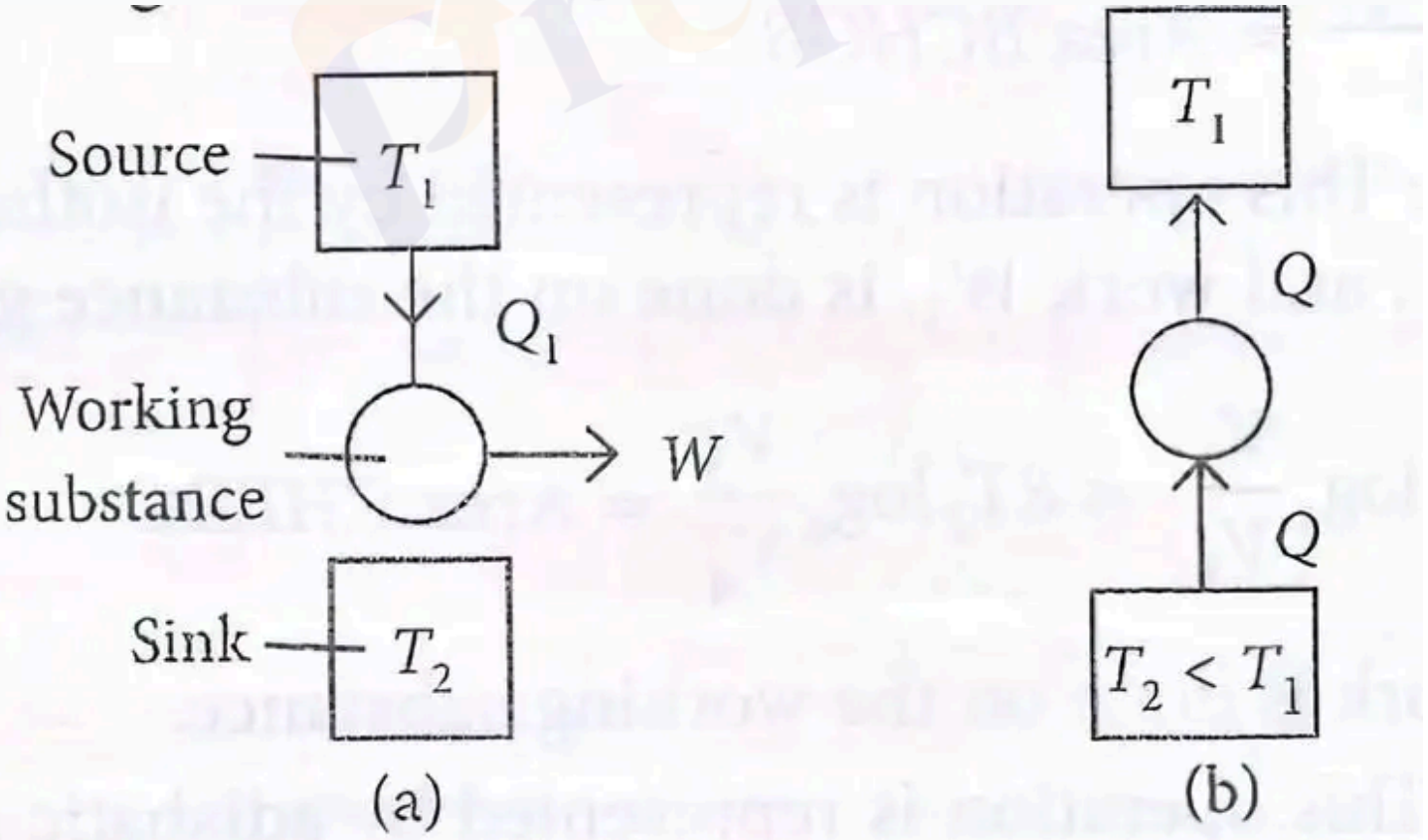
- Q3: Heat flows spontaneously from 280 K to 300 K. What is true?
  - A. Violates Clausius
  - B. Allowed naturally
  - C. Requires work
  - D. Impossible

Answer Key

- Q1: B - Heat cannot flow cold to hot without work.
- Q2: B - Refrigerator moves heat from cold to hot using work.
- Q3: B - Heat flows hot to cold naturally.

Memory Aids

- "Heat flows hot to cold"
- Refrigerator needs work
- Cold to hot needs energy



Heat Engines and Refrigerators

Key Points

- **Heat Engine (a):**
  - Heat Q_1 absorbed from hot source at temperature T_1.
  - Work W done by the engine.
  - Heat Q_2 rejected to cold sink at temperature T_2.
- **Refrigerator or Heat Pump (b):**
  - Heat Q absorbed from cold source at temperature $T_2 < T_1$.
  - Work done on system to transfer heat to hot reservoir at T_1.

Solved Examples

- **Ex 1:** Calculate efficiency of heat engine absorbing 800 J and rejecting 500 J.
  - Work done $W = 800 - 500 = 300$ J
  - Efficiency $\eta = \frac{W}{Q_1} = \frac{300}{800} = 0.375 = 37.5\%$
- **Ex 2:** Calculate COP of refrigerator absorbing 200 J from cold reservoir and work input 50 J.
  - COP $= \frac{Q}{W} = \frac{200}{50} = 4$

Practice Set

- Q1: In a heat engine, heat rejected is 400 J and heat absorbed is 1000 J. Efficiency is
  - A. 40%
  - B. 60%
  - C. 50%
  - D. 30%
- Q2: A refrigerator absorbs 300 J heat from cold reservoir and work done is 100 J. COP is
  - A. 3
  - B. 4
  - C. 2
  - D. 1
- Q3: Which is true for refrigerators?
  - A. They convert heat fully to work
  - B. They transfer heat from cold to hot using work
  - C. They operate without work input

- D. They violate second law

Answer Key

- Q1: A - Efficiency = $\frac{1000-400}{1000} = 0.6 = 60\%$
- Q2: A - COP = $\frac{300}{100} = 3$
- Q3: B - Refrigerators use work to transfer heat from cold to hot.

Memory Aids

- Heat engine: $\eta = 1 - \frac{Q_2}{Q_1}$
- Refrigerator: COP = $\frac{Q}{W}$
- Work input needed for cold to hot heat transfer

Reversible and Irreversible Processes

Reversible process

- A reversible process can be reversed by infinitesimal changes in external conditions.
- Pressure and temperature of the working substance must closely match surroundings at all times.
- Processes must be carried out infinitely slowly (quasi-static).
- Engine parts must be frictionless.
- No energy loss by conduction, convection, or radiation.
- Ideal case; real processes always have some energy loss.

Solved Examples

- **Ex 1:** A gas expands slowly and reversibly at temperature 300 K. What is the condition for reversibility?
  Answer: Pressure and temperature of gas ≈ surroundings; process is quasi-static and frictionless.

Practice Set

- Q1: Which condition is NOT required for a reversible process?
  A. Infinitely slow process
  B. Frictionless parts
  C. Large temperature difference with surroundings
  D. No energy loss
- Q2: A reversible process is characterized by:
  A. Rapid changes
  B. Finite temperature difference
  C. Infinitesimal changes in external conditions
  D. Presence of friction
- Q3: Which of the following is true for a reversible heat engine?
  A. Operates with friction
  B. Has energy loss by radiation
  C. Pressure of working substance equals surroundings
  D. Operates rapidly

Answer Key

- Q1: C - Large temperature difference causes irreversibility.
- Q2: C - Reversible processes involve infinitesimal changes.
- Q3: C - Pressure equality is essential for reversibility.

Memory Aids

- Reversible = Infinitesimal changes + No friction + No energy loss.
- Slow and steady = reversible.

Irreversible Process

Irreversible process

- All natural processes are irreversible.

- Thermodynamic equilibrium conditions (mechanical, thermal, chemical) are not met.
- Processes are not quasi-static (not infinitely slow).
- Dissipative effects like friction, viscosity, electric resistance are present.
- Example: Spontaneous expansion of gas into vacuum.

Solved Examples

- **Ex 1:** Gas expands spontaneously into evacuated space. Is this reversible?
  Answer: No, due to dissipative effects and non-equilibrium.

Practice Set

- Q1: Which is a cause of irreversibility?
  A. Friction
  B. Infinitesimal changes
  C. No energy loss
  D. Quasi-static process
- Q2: Natural processes are generally:
  A. Reversible
  B. Irreversible
  C. Frictionless
  D. Infinitely slow
- Q3: Spontaneous expansion of gas into vacuum is:
  A. Reversible
  B. Irreversible
  C. Frictionless
  D. Quasi-static

Answer Key

- Q1: A - Friction causes energy dissipation and irreversibility.
- Q2: B - Natural processes are irreversible.
- Q3: B - Spontaneous expansion is irreversible.

Memory Aids

- Irreversible = Friction + Dissipation + Non-equilibrium.
- Natural processes ≠ reversible.

Carnot Engine

Definition and Characteristics

- Theoretical ideal heat engine with no practical imperfections.
- Has maximum possible efficiency.
- Cannot be realized in practice.

Solved Examples

- **Ex 1:** Calculate efficiency if T1 = 600 K and T2 = 300 K.
  - Use formula $\eta = 1 - \frac{T_2}{T_1} = 1 - \frac{300}{600} = 0.5 = 50\%$

Practice Set

- Q1: What is the nature of Carnot engine?
  - A) Practical engine
  - B) Ideal engine with maximum efficiency
  - C) Engine with losses
  - D) Real engine
- Q2: Carnot engine efficiency depends on?
  - A) Working substance
  - B) Temperature of source and sink
  - C) Pressure only
  - D) Volume only
- Q3: If T1 = 500 K and T2 = 400 K, efficiency is?
  - A) 0.2
  - B) 0.1
  - C) 0.3

- D) 0.4

Answer Key

- Q1: B - Carnot engine is an ideal engine with maximum efficiency.
- Q2: B - Efficiency depends only on temperatures of source and sink.
- Q3: B - $\eta = 1 - \frac{400}{500} = 0.2 = 20\%$

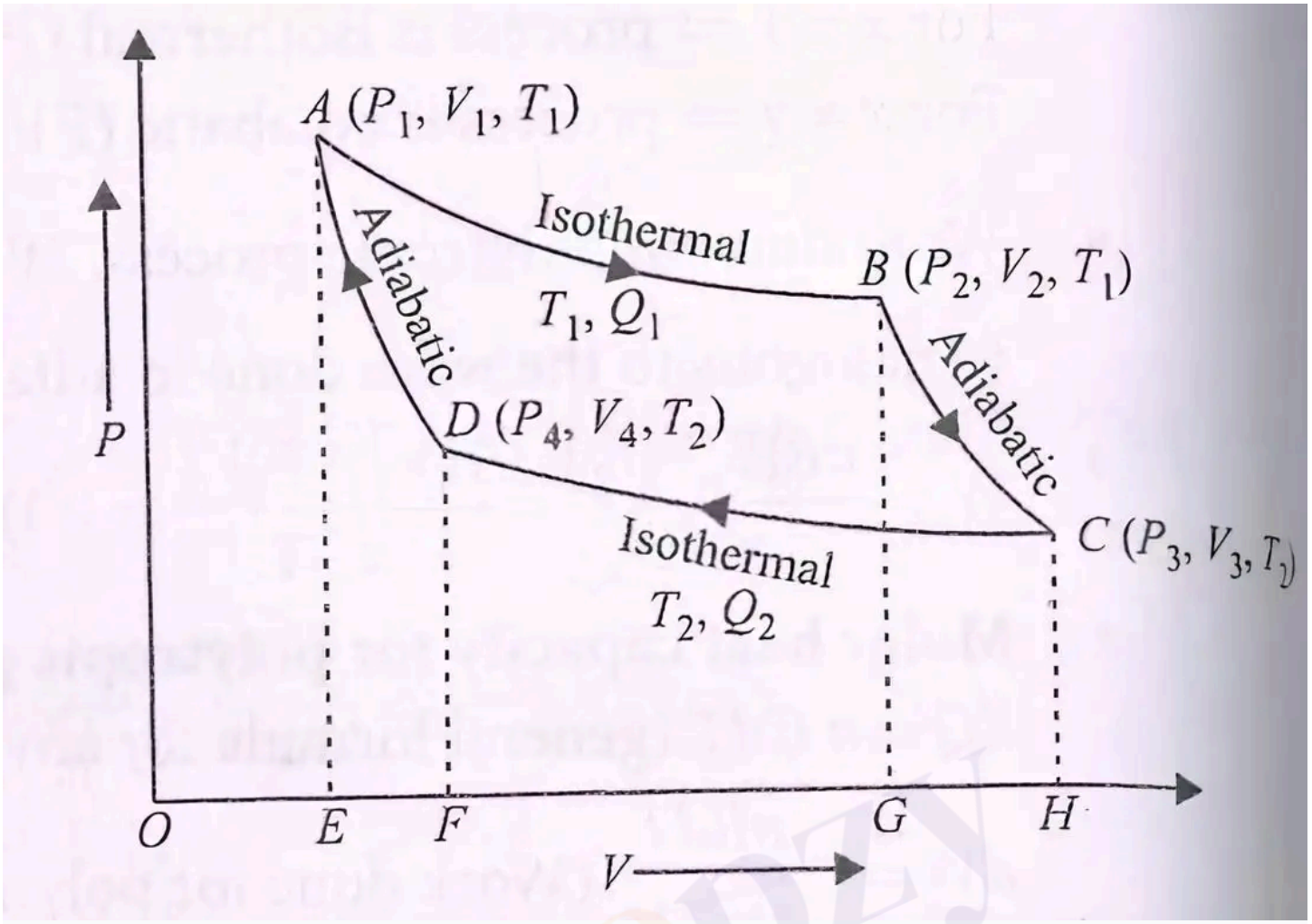
Memory Aids

- Efficiency $\eta = 1 - \frac{T_2}{T_1}$
- Maximum efficiency engine is ideal Carnot engine.

Carnot Cycle

Cycle Description

- Four quasi-static processes: two isothermal and two adiabatic.
- States: A, B, C, D with specific P, V, T.
- Path: A → B (isothermal expansion), B → C (adiabatic expansion), C → D (isothermal compression), D → A (adiabatic compression).
- Work done = area enclosed in P-V diagram.



Solved Examples

- **Ex 1:** Identify processes in Carnot cycle from P-V diagram.
  - AB and CD: Isothermal (constant T)
  - BC and DA: Adiabatic (no heat exchange)

Practice Set

- Q1: Which process in Carnot cycle occurs at constant temperature?
  - A) AB and BC
  - B) AB and CD
  - C) BC and DA
  - D) CD and DA
- Q2: During which process is no heat exchanged?
  - A) AB
  - B) BC
  - C) CD

    - D) AB and CD
- Q3: The net work done in Carnot cycle is represented by?
    - A) Area under AB
    - B) Area under BC
    - C) Area enclosed by ABCD
    - D) Area under CD

Answer Key

- Q1: B - AB and CD are isothermal processes.
- Q2: B - BC and DA are adiabatic with no heat exchange.
- Q3: C - Net work done equals area enclosed by ABCD.

Memory Aids

- Isothermal: constant T, heat exchange occurs.
- Adiabatic: no heat exchange, temperature changes.
- Cycle path: A-B-C-D-A.

Isothermal Expansion

Process Details

- Gas expands at constant temperature T_1 absorbing heat Q_1 from source.
- Work done by gas $W_1 = Q_1 = RT_1 \ln \frac{V_2}{V_1}$.
- Heat supplied maintains temperature during expansion.

Solved Examples

- **Ex 1:** Calculate work done if $R = 8.31\text{J/mol. K}, T_1 = 300K, V_2 = 4V_1$.
    - $W_1 = 8.31 \times 300 \times \ln 4 = 8.31 \times 300 \times 1.386 = 3453.5\text{J}$

Practice Set

- Q1: During isothermal expansion, temperature is?
  - A) Increasing
  - B) Constant
  - C) Decreasing
  - D) Variable
- Q2: Work done in isothermal expansion is?
  - A) Zero
  - B) $RT_1 \ln \frac{V_2}{V_1}$
  - C) $P\Delta V$
  - D) $C_V \Delta T$
- Q3: Heat absorbed during isothermal expansion is?
  - A) Zero
  - B) Equal to work done
  - C) Greater than work done
  - D) Less than work done

Answer Key

- Q1: B - Temperature remains constant.
- Q2: B - Work done formula for isothermal expansion.
- Q3: B - Heat absorbed equals work done in isothermal process.

Memory Aids

- Isothermal: $Q = W = RT \ln \frac{V_2}{V_1}$
- Temperature constant during expansion.

Adiabatic Expansion

Process Details

- No heat exchange (Q=0).

- Temperature falls from T_1 to T_2.
- Work done $W_2 = \frac{R(T_1 - T_2)}{\gamma - 1}$.
- Follows $PV^\gamma = \text{constant}$.

Solved Examples

- **Ex 1:** Calculate work done if $R = 8.31, T_1 = 400K, T_2 = 300K, \gamma = 1.4$.
  - $W_2 = \frac{8.31(400-300)}{1.4-1} = \frac{8.31 \times 100}{0.4} = 2077.5\text{J}$

Practice Set

- Q1: Heat exchange in adiabatic expansion is?
  - A) Positive
  - B) Negative
  - C) Zero
  - D) Variable
- Q2: Work done in adiabatic expansion is?
  - A) Zero
  - B) $\frac{R(T_1 - T_2)}{\gamma - 1}$
  - C) $RT \ln \frac{V_2}{V_1}$
  - D) $C_P \Delta T$
- Q3: Temperature change in adiabatic expansion is?
  - A) Increases
  - B) Constant
  - C) Decreases
  - D) No change

Answer Key

- Q1: C - No heat exchange in adiabatic process.
- Q2: B - Work done formula for adiabatic expansion.
- Q3: C - Temperature decreases during expansion.

Memory Aids

- Adiabatic: $Q = 0$, $W = \frac{R(T_1 - T_2)}{\gamma - 1}$
- Temperature falls during expansion.

Isothermal Compression

Process Details

- Gas compresses at constant temperature T_2.
- Heat Q_2 is rejected to sink.
- Work done on gas $W_3 = Q_2 = RT_2 \ln \frac{V_3}{V_4}$.
- Negative work indicates work done on the system.

Solved Examples

- **Ex 1:** Calculate heat rejected if $R = 8.31, T_2 = 300K, V_3 = 4V_4$.
  - $Q_2 = 8.31 \times 300 \times \ln 4 = 3453.5\text{J}$

Practice Set

- Q1: During isothermal compression, temperature is?
  - A) Increasing
  - B) Constant
  - C) Decreasing
  - D) Variable
- Q2: Work done in isothermal compression is?
  - A) $-RT_2 \ln \frac{V_4}{V_3}$
  - B) Zero
  - C) $RT_2 \ln \frac{V_3}{V_4}$
  - D) $C_V \Delta T$
- Q3: Heat rejected during isothermal compression is?
  - A) Zero
  - B) Equal to work done on gas

- C) Greater than work done
- D) Less than work done

Answer Key

- Q1: B - Temperature remains constant.
- Q2: A - Work done is negative of expansion formula.
- Q3: B - Heat rejected equals work done on gas.

Memory Aids

- Isothermal compression: $Q = W = RT \ln \frac{V_3}{V_4}$
- Work done on gas is negative of expansion work.

Adiabatic Compression

Process Details

- No heat exchange (Q=0).
- Work done on gas $W_4 = \frac{R(T_1 - T_2)}{\gamma - 1}$.
- Temperature rises from T_2 to T_1.

Solved Examples

- **Ex 1:** Calculate work done if $R = 8.31, T_1 = 400K, T_2 = 300K, \gamma = 1.4$.
  - $W_4 = \frac{8.31(400-300)}{1.4-1} = 2077.5\text{J}$

Practice Set

- Q1: Heat exchange in adiabatic compression is?
  - A) Positive
  - B) Negative

    - C) Zero
    - D) Variable
- Q2: Work done in adiabatic compression is?
    - A) Zero
    - B) $\frac{R(T_1-T_2)}{\gamma-1}$
    - C) $RT \ln \frac{V_2}{V_1}$
    - D) $C_P \Delta T$
- Q3: Temperature change in adiabatic compression is?
    - A) Increases
    - B) Constant
    - C) Decreases
    - D) No change

Answer Key

- Q1: C - No heat exchange in adiabatic process.
- Q2: B - Work done formula for adiabatic compression.
- Q3: A - Temperature increases during compression.

Memory Aids

- Adiabatic: $Q = 0$, $W = \frac{R(T_1-T_2)}{\gamma-1}$
- Temperature rises during compression.

Net Work Done

Calculation

- Total work $W = W_1 + W_2 + W_3 + W_4$.
- Since W_2 and W_4 cancel, $W = W_1 - W_3$.
- Net work done equals area enclosed by ABCD in P-V diagram.

Solved Examples

- **Ex 1:** If $W_1 = 500J$ and $W_3 = 300J$, find net work.
  - $W = 500 - 300 = 200J$

Practice Set

- Q1: Net work done in Carnot cycle is?
  - A) $W_1 + W_3$
  - B) $W_1 - W_3$
  - C) $W_2 + W_4$
  - D) Zero
- Q2: Which works cancel out in net work calculation?
  - A) W_1 and W_3
  - B) W_2 and W_4
  - C) W_1 and W_4
  - D) W_3 and W_2
- Q3: Area representing net work done is?
  - A) ABGEA
  - B) BCHGB
  - C) ABCD
  - D) CHFDC

Answer Key

- Q1: B - Net work is $W_1 - W_3$.
- Q2: B - W_2 and W_4 cancel each other.
- Q3: C - Area ABCD represents net work done.

Memory Aids

- Net work = area enclosed by cycle.
- Adiabatic works cancel out.

Efficiency of Carnot Engine

Formula and Explanation

- Efficiency $\eta = \frac{W}{Q_1} = 1 - \frac{Q_2}{Q_1}$.
- Using volumes and temperatures, $\eta = 1 - \frac{T_2}{T_1}$.
- All reversible engines between same temperatures have same efficiency.
- No engine can be more efficient than Carnot engine.

Solved Examples

- **Ex 1:** Calculate efficiency if $T_1 = 600K, T_2 = 300K$.
  - $\eta = 1 - \frac{300}{600} = 0.5 = 50\%$

Practice Set

- Q1: Efficiency formula of Carnot engine is?
  - A) $1 - \frac{T_1}{T_2}$
  - B) $1 - \frac{T_2}{T_1}$
  - C) $\frac{T_2}{T_1}$
  - D) $\frac{T_1}{T_2}$
- Q2: Which engine has maximum efficiency?
  - A) Diesel engine
  - B) Carnot engine
  - C) Otto engine
  - D) Real engine
- Q3: If $T_1 = 500K, T_2 = 400K$, efficiency is?
  - A) 0.2
  - B) 0.1
  - C) 0.3
  - D) 0.4

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Answer Key

- Q1: B - Efficiency is $1 - \frac{T_2}{T_1}$.
- Q2: B - Carnot engine is ideal with maximum efficiency.
- Q3: B - $\eta = 1 - \frac{400}{500} = 0.2 = 20\%$.

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- Efficiency $\eta = 1 - \frac{T_2}{T_1}$
- Carnot engine is ideal and most efficient.