FREE EDITION · NOTES + 3 SAMPLE MCQS

CUET · PHYSICS · CLASS XI · CODE 322

Thermodynamics

CUET unit: Thermodynamics

By **UniDrill** · NCERT-grounded study material

WWW.UNIDRILL.IN

📌 Snapshot

- Establishes thermodynamics as a macroscopic science of heat–work inter-conversion, dealing with bulk variables P, V, T, U rather than molecular detail.
- Builds the temperature concept through the Zeroth Law and develops the First Law (conservation of energy) $\Delta Q = \Delta U + \Delta W$, with ΔU as a state variable.
- Defines specific heat capacities for solids and gases, gives Mayer's relation $Cp - Cv = R$, and analyses isothermal, adiabatic, isobaric, isochoric and cyclic processes.
- States the Second Law (Kelvin–Planck and Clausius forms), classifies processes as reversible/irreversible, and derives the Carnot engine efficiency $\eta = 1 - T_2/T_1$ as the upper limit for any heat engine.
- A perennial CUET favourite — pure numerical questions on first-law accounting, isothermal/adiabatic work and Carnot efficiency dominate.

📖 Detailed Notes

2.1 Core concepts

- Thermodynamics is the branch of physics dealing with heat, temperature and inter-conversion of heat and other forms of energy; it is a macroscopic science using few variables like P, V, T, m, composition and U, avoiding the molecular description (NCERT §11.1, p. 227).
- Historically, heat was thought to be a fluid called "caloric" flowing from hotter to colder bodies; Count Rumford's brass-cannon boring experiment (1798) showed heat produced depended on work done and not on the sharpness of the drill, establishing heat as a form of energy (NCERT §11.1, p. 226).
- A system is in thermodynamic equilibrium when its macroscopic variables do not change with time; the nature of the wall — adiabatic (insulating) or diathermic (conducting) — decides whether two systems can reach thermal equilibrium (NCERT §11.2, p. 227–228).
- Zeroth Law of Thermodynamics: two systems in thermal equilibrium with a third system separately are in thermal equilibrium with each other; the common physical quantity having the same value is called temperature T. R.H. Fowler formulated it in 1931, after the First and Second laws were already numbered (NCERT §11.3, p. 228).

- Internal energy U is the sum of kinetic and potential energies of the molecules in the frame in which the centre of mass of the system is at rest; it excludes the bulk kinetic energy of the system and depends only on the state, not on the path (NCERT §11.4, p. 229).
- Heat and work are the two modes of energy transfer that alter U; heat arises from a temperature difference, work is transferred by other means (e.g. moving a piston). Heat and work are NOT state variables — they are "energy in transit" (NCERT §11.4, p. 229–230).
- First Law of Thermodynamics: $\Delta Q = \Delta U + \Delta W$ where ΔQ is heat supplied to the system, ΔW is work done by the system on the surroundings, and ΔU is the change in internal energy. It is the energy-conservation principle applied to thermodynamic systems (NCERT §11.5, p. 230, Eq. 11.1).
- For a gas in a cylinder against constant pressure P, $\Delta W = P\,\Delta V$; hence $\Delta Q = \Delta U + P\,\Delta V$ (NCERT §11.5, p. 231, Eq. 11.3). Worked illustration: for 1 g of water vaporising at atmospheric pressure $\Delta Q = 2256$ J, $\Delta W = 169.2$ J, so $\Delta U = 2086.8$ J — most heat goes into raising U.
- Specific heat capacity $s = (1/m)(\Delta Q/\Delta T)$ and molar specific heat $C = (1/\mu)(\Delta Q/\Delta T)$; both depend on the substance and conditions of heating (NCERT §11.6, p. 231, Eqs. 11.5–11.6).
- For an ideal gas at constant volume $C_v = (\Delta U/\Delta T)$ and at constant pressure $C_p = (\Delta U/\Delta T) + R$, leading to Mayer's relation $C_p - C_v = R$ (NCERT §11.6, p. 232, Eq. 11.8). For a mole of solid using equipartition, $U = 3RT$ giving $C = 3R$, which agrees with experiment at ordinary temperatures (carbon is an exception).
- 1 calorie is defined as the heat needed to raise 1 g of water from 14.5 °C to 15.5 °C; in SI, the specific heat capacity of water is 4186 J kg^{-1} K^{-1}, and 1 cal = 4.186 J (NCERT §11.6, p. 232).
- State variables fall into two kinds — extensive (U, V, M scale with size) and intensive (P, T, ρ remain unchanged on subdivision). The equation of state connects state variables; for an ideal gas $PV = \mu RT$ (NCERT §11.7, p. 232–233).
- A quasi-static process is infinitely slow so the system remains in equilibrium with its surroundings at every stage; the pressure and temperature differ from those of the surroundings only infinitesimally (NCERT §11.8.1, p. 233–234).
- Isothermal process: T fixed, PV = constant (Boyle's law); work done $W = \mu RT \ln(V_2/V_1)$; since $\Delta U = 0$ for an ideal gas, Q = W (NCERT §11.8.2, p. 234, Eq. 11.12). In isothermal expansion the gas absorbs heat and does work; in compression the reverse.
- Adiabatic process: Q = 0, PV^γ = constant where $\gamma = C_p/C_v$; work done $W = (P_1V_1 - P_2V_2)/(\gamma - 1) = \mu R(T_1 - T_2)/(\gamma - 1)$; positive work by the gas lowers its temperature (NCERT §11.8.3, p. 234–235, Eqs. 11.13–11.16).
- Isochoric process: V constant ⇒ W = 0, so all heat absorbed goes to ΔU (and hence temperature change) governed by C_v (NCERT §11.8.4, p. 235).

- Isobaric process: P fixed ⇒ $W = P(V_2 - V_1) = \mu R(T_2 - T_1)$; heat absorbed goes partly into ΔU and partly into work, governed by Cp (NCERT §11.8.5, p. 235, Eq. 11.17).
- Cyclic process: the system returns to its initial state; $\Delta U = 0$, so total Q = total W (NCERT §11.8.6, p. 235).
- Second Law of Thermodynamics — Kelvin-Planck statement: no process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of that heat into work. Clausius statement: no process is possible whose sole result is the transfer of heat from a colder to a hotter body. The two statements are completely equivalent (NCERT §11.9, p. 236).
- A reversible process can be turned back so that both the system and surroundings return to their original states with no other change; it must be quasi-static AND free of dissipative effects like friction and viscosity. Spontaneous natural processes are irreversible (NCERT §11.10, p. 236–237).
- Carnot engine: a reversible heat engine operating between a hot reservoir at T_1 and a cold reservoir at T_2; its cycle has four steps — isothermal expansion at T_1, adiabatic expansion to T_2, isothermal compression at T_2, adiabatic compression back to T_1 (NCERT §11.11, p. 237–238).
- Carnot efficiency: $\eta = 1 - Q_2/Q_1 = 1 - T_2/T_1$; Carnot's theorem proves (a) no engine working between two given temperatures can be more efficient than the Carnot engine, and (b) the Carnot efficiency is independent of the working substance (NCERT §11.11, p. 238–239, Eq. 11.27). The universal relation $Q_1/Q_2 = T_1/T_2$ defines a thermodynamic temperature scale (Eq. 11.28).

2.2 Definitions to memorise

Term	Definition	Page
Thermodynamics	Branch of physics dealing with heat, temperature and inter-conversion of heat with other forms of energy at the macroscopic level.	227
Thermal equilibrium	State in which two systems separated by a diathermic wall show no further spontaneous change in their macroscopic variables.	228
Adiabatic wall	An insulating wall that does not allow flow of heat between the systems it separates.	228
Diathermic wall	A conducting wall that allows heat to flow from one system to another.	228
Zeroth Law	Two systems in thermal equilibrium with a third system separately are in thermal equilibrium with each other.	228
Temperature	The thermodynamic variable whose value is equal for two systems in thermal equilibrium.	228
Internal energy U		229

Term	Definition	Page
	Sum of kinetic and potential energies of the molecular constituents in the frame in which the centre of mass of the system is at rest.	
Heat	Energy transferred between system and surroundings due to a temperature difference; energy in transit, not a state variable.	229
Work (thermodynamic)	Energy transfer brought about by means that do not involve a temperature difference (e.g. moving a piston).	229
First Law of Thermodynamics	$\Delta Q = \Delta U + \Delta W$ — conservation of energy applied to a thermodynamic system.	230
Specific heat capacity s	$s = (1/m)(\Delta Q/\Delta T)$; heat needed per unit mass per unit temperature rise. Unit: $J\ kg^{-1}\ K^{-1}$.	231
Molar specific heat C	$C = (1/\mu)(\Delta Q/\Delta T)$; unit $J\ mol^{-1}\ K^{-1}$.	231
Cp, Cv	Molar specific heats at constant pressure and constant volume; satisfy $C_p - C_v = R$ for an ideal gas.	232
γ (gamma)	Ratio of specific heats, $\gamma = C_p/C_v$; appears in adiabatic relations.	234
Calorie	Heat required to raise 1 g of water from 14.5 °C to 15.5 °C; 1 cal = 4.186 J.	232
Equation of state	Relation connecting the state variables of a system, e.g. $PV = \mu RT$ for an ideal gas.	233
Extensive variable	A variable whose value scales with the size of the system (e.g. U, V, M).	233
Intensive variable	A variable that is independent of the size of the system (e.g. P, T, ρ).	233
Quasi-static process	An infinitely slow process in which the system remains in thermal and mechanical equilibrium with its surroundings at every stage.	234
Isothermal process	A process at constant temperature; for an ideal gas PV = constant.	234
Adiabatic process	A process in which no heat is exchanged with the surroundings ($Q = 0$); PV^{γ} = constant.	234
Isochoric process	A process at constant volume; $W = 0$.	235
Isobaric process	A process at constant pressure; $W = P\Delta V$.	235
Cyclic process	A process in which the system returns to its initial state, so $\Delta U = 0$.	235
Kelvin-Planck statement	No process is possible whose sole result is the absorption of heat from a reservoir and the complete conversion of the heat into work.	236

Term	Definition	Page
Clausius statement	No process is possible whose sole result is the transfer of heat from a colder object to a hotter object.	236
Reversible process	A process that can be turned back so that both the system and surroundings return to their original states with no other change in the universe.	237
Irreversible process	A spontaneous natural process that cannot be reversed without producing some change in the surroundings.	236
Carnot engine	A reversible heat engine working between two reservoirs at T_1 and T_2 via two isothermal and two adiabatic processes.	237
Carnot efficiency	$\eta = 1 - T_2/T_1$; the maximum possible efficiency of a heat engine between two given temperatures.	238

2.3 Diagrams / processes to remember

- Fig. 11.1, p. 227: Two gases A and B separated first by an adiabatic wall (no thermal equilibrium attained) and then by a diathermic wall (equilibrium attained with new P, V values).
- Fig. 11.2, p. 228: Schematic illustrating the Zeroth Law — A and B each in contact with C via conducting walls, then connected directly; they remain in equilibrium.
- Fig. 11.3, p. 229: Internal energy U of a gas as sum of kinetic + potential energies of molecules (translational, rotational, vibrational), and exclusion of bulk motion.
- Fig. 11.4, p. 229: Heat (from temperature difference) and work (via a piston with weight) as two distinct modes of energy transfer.
- Fig. 11.5, p. 232: Variation of specific heat capacity of water with temperature in the range 0–100 °C, motivating the precise calorie definition.
- Fig. 11.6, p. 233: Non-equilibrium states — free expansion of a gas and an explosive chemical reaction — that cannot be described by state variables.
- Fig. 11.7, p. 234: Quasi-static process — surrounding reservoir and external pressure differ from system values only infinitesimally.
- Fig. 11.8, p. 235: P–V curves comparing isothermal and adiabatic processes; the adiabatic curve is steeper because $\gamma > 1$.
- Fig. 11.9, p. 237: Carnot cycle on a P–V diagram showing the four steps — isothermal expansion 1→2, adiabatic expansion 2→3, isothermal compression 3→4, adiabatic compression 4→1.
- Fig. 11.10, p. 239: Irreversible engine I coupled to a reversible refrigerator R — used to prove Carnot's theorem by contradicting the Kelvin-Planck statement.

2.4 Common confusions / NTA trap points

- Heat vs internal energy: a body "contains" internal energy, not heat. Heat is energy in transit during a process, so statements like "a gas in a given state has a certain amount of heat" are meaningless (NCERT §11.4, p. 230).
- Sign convention in First Law: in NCERT, ΔW is the work done BY the system on the surroundings, so $\Delta Q = \Delta U + \Delta W$; isothermal expansion gives $W > 0$ and isothermal compression gives $W < 0$ (NCERT §11.5/§11.8, p. 230, 234). Mixing this up with the "work done on the system" convention is a classic trap.
- Adiabatic ≠ isothermal: in adiabatic $Q = 0$ (the system is insulated) and PV^{γ} = const; in isothermal T = const and PV = const. Don't conflate the two equations or the corresponding work formulas.
- For an isothermal process of an ideal gas $\Delta U = 0$ (because U depends only on T), so $Q = W$; but $\Delta U = 0$ does NOT imply $Q = 0$ (NCERT §11.8.2, p. 234).
- Carnot efficiency uses absolute (Kelvin) temperatures. Plugging in Celsius values is a guaranteed wrong answer (NCERT §11.11, Eq. 11.27, p. 238).
- The Carnot efficiency is independent of the working substance — NTA likes to put "depends on the gas used" as a distractor (NCERT §11.11, p. 239).
- Zeroth Law was formulated AFTER the First and Second Laws (in 1931, by R.H. Fowler) — but logically it precedes them (NCERT §11.3, p. 228).

🎯 Practice MCQs

📊 PYQ Alignment

This chapter is consistently among the most heavily examined in CUET Physics — expect roughly 10–12 questions a year across the subject. Recurring formats are: direct First-Law accounting (Q4, Q3), isothermal work using $W = \mu RT \ln(V_2/V_1)$ (Q7, Q8), adiabatic relations PV^{γ} = const or $TV^{(\gamma-1)}$ = const with a temperature/pressure ratio (Q9, Q10), and Carnot efficiency $\eta = 1 - T_2/T_1$ (Q11), interspersed with statement-based questions on the Zeroth/Second Laws (Q1, Q12) and Mayer's relation (Q5).

CUET 2023–25 — Actual PYQs from this chapter

No PYQs from this chapter appeared in CUET 2023, 2024 or 2025.