08

JEE MAIN · PAPER 1 · PHYSICS

Thermodynamics

Formula & concept sheet

Heat, work and internal energy: the first law, the standard gas processes, and the second law with engines and refrigerators. Each idea is explained in plain words, then the formulas, then how it is used and asked.

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READ ALONGSIDE NCERT XI · Thermodynamics

HOW TO USE THIS SHEET

1. **Skim** — Read the Key ideas, then the formula cards.
2. **Memorise** — Learn the formulas and check every Trap box.
3. **Test** — Do the worked examples, then this chapter's PYQs.
4. **Revise** — Use the last-minute checklist before the exam.

Formula memorise · **Key idea** why it works · **Trap** marks lost here · **PYQ** how it is asked

Practise this chapter with real past-paper questions on Prep Vault. Written for revision, not as a first read.

CHAPTER 08

Thermodynamics

NCERT XI · Thermodynamics

Covers: thermal equilibrium, temperature · heat, work, internal energy · first law · isothermal, adiabatic and other processes · second law · Carnot engine, refrigerator.

1 Temperature, heat and work

Bodies in contact reach **thermal equilibrium**; two bodies each in equilibrium with a third are in equilibrium with each other (the **zeroth law**), which makes temperature meaningful. **Internal energy** depends only on the state; **heat** and **work** depend on the path.

TEMPERATURE SCALES

$$\frac{C}{5} = \frac{F-32}{9} = \frac{K-273}{5}$$

use kelvin in every gas-law and Carnot formula

WORK BY A GAS

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

the area under the P–V curve; positive on expansion

INTERNAL ENERGY, IDEAL GAS

$$\Delta U = nC_V\Delta T$$

for every process, since U depends on T only

2 First law and gas processes

Heat given to a gas raises its internal energy and does work. Here W is the work done **by** the gas: positive on expansion.

FIRST LAW

$$\Delta Q = \Delta U + W$$

some books write $\Delta U = Q + W_{on}$: fix the sign convention first

MOLAR HEAT CAPACITIES

$$C_P - C_V = R, \quad \gamma = \frac{C_P}{C_V}$$

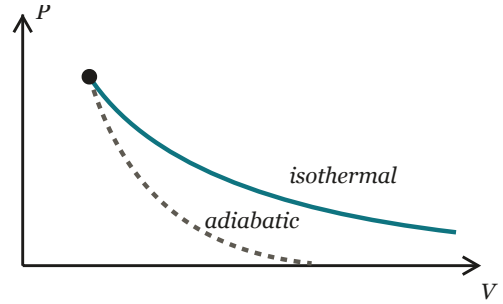
$$C_V = \frac{f}{2}R,\ \gamma = 1 + \frac{2}{f}$$

IDEAL GASES

GAS	C_V	C_P	γ
Monatomic	$\frac{3}{2}R$	$\frac{5}{2}R$	$\frac{5}{3}$
Diatomic	$\frac{5}{2}R$	$\frac{7}{2}R$	$\frac{7}{5}$
Polyatomic	$3R$	$4R$	$\frac{4}{3}$

THE FOUR BASIC PROCESSES (IDEAL GAS, n MOLES)

PROCESS	CONDITION	WORK W	HEAT Q	ΔU
Isochoric	V constant	0	$nC_V\Delta T$	$nC_V\Delta T$
Isobaric	P constant	$P\Delta V = nR\Delta T$	$nC_P\Delta T$	$nC_V\Delta T$
Isothermal	T constant, PV constant	$nRT\ln\frac{V_2}{V_1}$	$= W$	0
Adiabatic	$Q = 0$, PV^γ constant	$\frac{P_1V_1 - P_2V_2}{\gamma - 1} = \frac{nR(T_1 - T_2)}{\gamma - 1}$	0	$-W$



From one state, an adiabatic expansion falls faster than an isothermal one.

ADIABATIC RELATIONS

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

$$TV^{\gamma-1} = \text{const}$$

$$T^\gamma P^{1-\gamma} = \text{const}$$

valid for a reversible adiabatic of an ideal gas

HOW IT IS USED

Name the process first. Work is the area, $\Delta U = nC_V\Delta T$, and the first law gives Q.

ISOBARIC PROCESS

$$\frac{W}{Q} = \frac{R}{C_P} = 1 - \frac{1}{\gamma}$$

$$\frac{\Delta U}{Q} = \frac{1}{\gamma}$$

monatomic: $W/Q = \frac{2}{5}$; diatomic: $\frac{2}{7}$

POLYTROPIC PROCESS, PV^x CONSTANT

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

$$W = \frac{nR\,\Delta T}{1-x}$$

$x = 0$ isobaric, 1 isothermal, γ adiabatic, ∞ isochoric

BULK MODULUS OF A GAS

isothermal $B = P$

adiabatic $B = \gamma P$

gives the speed of sound $\sqrt{\gamma P/\rho}$

CYCLIC PROCESS

$$\Delta U = 0,\ W_{net} = Q_{net}$$

work equals the enclosed area; positive if the cycle runs clockwise

FREE EXPANSION

$$W = 0,\ Q = 0,\ \Delta U = 0$$

an ideal gas keeps its temperature

STRAIGHT-LINE P–V PATH

$$W = \tfrac{1}{2}(P_1 + P_2)\,\Delta V$$

the area of a trapezoid

SLOPES ON THE P–V GRAPH

isothermal $-\dfrac{P}{V}$

adiabatic $-\gamma\dfrac{P}{V}$

the adiabat is steeper by the factor γ

MIXTURE OF GASES

$$\gamma_{mix} = 1 + \frac{n_1 + n_2}{\dfrac{n_1}{\gamma_1 - 1} + \dfrac{n_2}{\gamma_2 - 1}}$$

adding n and C_V for each gas gives the mixture's C_V

WORK IN AN ADIABATIC CHANGE

$$W = -\Delta U = nC_V(T_1 - T_2)$$

a compression ($W < 0$) warms the gas, an expansion cools it

HOW IT IS USED AND ASKED

A process is given as a P–V relation or a graph: find W as the area, ΔU from $nC_V\Delta T$, then Q from the first law. Asked as W/Q for an isobaric process, the heat to warm a gas at constant volume, the temperature after an adiabatic compression, or the net work in a cycle.

3 Second law, engines and refrigerators

Heat flows from hot to cold on its own, never the other way. The **second law** says no engine can turn all the heat it takes into work (Kelvin–Planck), and no cyclic device can move heat from cold to hot without work (Clausius). A **reversible** process can be undone exactly; real processes are irreversible.

ENGINE EFFICIENCY

$$\eta = \frac{W}{Q_H} = 1 - \frac{Q_C}{Q_H}$$

heat Q_H taken from the hot source, Q_C rejected to the cold sink

CARNOT ENGINE

$$\eta = 1 - \frac{T_C}{T_H}$$

the maximum for given temperatures (in kelvin); needs $T_C = 0$ for 100%

REFRIGERATOR

$$\beta = \frac{Q_C}{W} = \frac{T_C}{T_H - T_C}$$

coefficient of performance; $\beta = \dfrac{1-\eta}{\eta}$ for the reversed Carnot engine

CARNOT CYCLE

isothermal expansion at T_H

adiabatic expansion to T_C

isothermal compression at T_C

adiabatic compression to T_H

$$\frac{Q_C}{Q_H} = \frac{T_C}{T_H}$$

TRAP

Temperatures must be in **kelvin** in the Carnot formulas. An adiabatic process is not isothermal: $Q = 0$ but the temperature changes. Check units: $1\ \text{cal} = 4.18$ or $4.2\ \text{J}$ as the paper gives.

4 Worked examples

ISOBARIC HEATING

2 mol of a monatomic gas is heated by $50\ \mathrm{K}$ at constant pressure ($R = 8.31$). W, Q, ΔU?

$W = nR\Delta T = 831\ \mathrm{J}$; $Q = n\frac{5}{2}R\Delta T = 2077\ \mathrm{J}$; $\Delta U = 1246\ \mathrm{J}$

ISOTHERMAL EXPANSION

1 mol at $300\ \mathrm{K}$ expands isothermally to twice its volume. Work done?

$W = RT\ln 2 = 8.31 \times 300 \times 0.693 \approx 1728\ \mathrm{J}$

ADIABATIC COMPRESSION

A diatomic gas ($\gamma = 1.4$) at $300\ \mathrm{K}$ is compressed adiabatically to half its volume. New temperature?

$T_2 = 300 \times 2^{0.4} \approx 396\ \mathrm{K}$

CYCLE WORK

A rectangular cycle: P from 1 to $2 \times 10^5\ \mathrm{Pa}$, V from 1 to 3 litre, run clockwise. Net work?

$W = \Delta P\,\Delta V = 10^5 \times 2 \times 10^{-3} = 200\ \mathrm{J}$

CARNOT ENGINE

Source $600\ \mathrm{K}$, sink $300\ \mathrm{K}$, heat taken $2000\ \mathrm{J}$. Efficiency, work and heat rejected?

$\eta = 1 - \frac{300}{600} = 50\%$; $W = 1000\ \mathrm{J}$; $Q_C = 1000\ \mathrm{J}$

REFRIGERATOR

A Carnot refrigerator works between $270\ \mathrm{K}$ and $300\ \mathrm{K}$. Coefficient of performance, and work to remove $900\ \mathrm{J}$?

$\beta = \dfrac{270}{30} = 9$; $W = \dfrac{900}{9} = 100\ \mathrm{J}$

POLYTROPIC HEAT CAPACITY

A monatomic gas follows $PV^2 = \text{const}$. Its molar heat capacity?

$C = C_V + \dfrac{R}{1-x} = \frac{3}{2}R - R = \frac{1}{2}R$

GAS MIXTURE

One mole of a monatomic and one mole of a diatomic gas are mixed. γ of the mixture?

$\gamma = 1 + \dfrac{2}{\frac{1}{2/3} + \frac{1}{2/5}} = 1 + \dfrac{2}{4} = 1.5$

KEY IDEA

Sort every problem in three steps: (1) which process, so which relation holds; (2) W from the area or the table; (3) $\Delta U = nC_V\Delta T$ and $Q = \Delta U + W$. The first law is never needed for ΔU itself.

5 Last-minute checklist

- $\Delta U = nC_V\Delta T$ for every process of an ideal gas, not only at constant volume.
- Work is the area under the P–V curve; a clockwise loop gives positive net work.
- Adiabatic: $Q = 0$; PV^γ constant; the steeper curve on a P–V diagram.
- Carnot efficiency and refrigerator coefficient use kelvin.
- State the sign convention for W before you use $\Delta Q = \Delta U + W$.

Now test it. Practise this chapter with past-paper and bank questions on Prep Vault. **Practice this chapter →**