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CHAPTER NOTES

Thermodynamics Class 11 Notes | CBSE Physics Chapter 11

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Thermodynamics Class 11 Notes | CBSE Physics

Chapter 11

Thermodynamics is Chapter 11 of CBSE Class 11 Physics — the chapter that explains how heat, work, and energy flow between a system and its surroundings. From a car engine to a refrigerator to the steam that once powered the industrial revolution, every heat machine runs on the laws you will learn here. Master these notes and you can predict whether a process is possible, how efficient an engine can ever be, and why heat refuses to flow uphill on its own.

By the end of these notes you will be able to apply the first law of thermodynamics to any process, distinguish isothermal from adiabatic changes, use the relation $C_p - C_v = R$, and calculate the efficiency of a Carnot engine. This is a high-weightage chapter carrying roughly 8–10 marks in boards, and a favourite source of questions in JEE and NEET.

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Key Concepts

1. Thermodynamic System, Surroundings and State Variables

A **thermodynamic system** is the part of the universe we choose to study — for example, the gas trapped inside a cylinder. Everything outside it that can exchange energy or matter with it is called the **surroundings**, and the imaginary boundary between them is the **wall**.

The condition of a system is described by measurable quantities called **thermodynamic state variables** — pressure (P), volume (V), temperature (T), and internal energy (U). These depend only on the present state, not on how the system reached it.

- **Extensive variables** depend on the amount of matter: volume, internal energy, mass.
 - **Intensive variables** do not depend on the amount: pressure, temperature, density.
-

2. Thermal Equilibrium and the Zeroth Law

Two systems are in **thermal equilibrium** when they are at the same temperature, so there is no net flow of heat between them when they are placed in contact.

The **Zeroth Law of Thermodynamics** states: if two systems A and B are each in thermal equilibrium with a third system C, then A and B are in thermal equilibrium with each other.

Key idea: The zeroth law tells us that temperature is the property that decides the direction of heat flow — it is what gives temperature its physical meaning.

3. Heat, Internal Energy and Work

Internal energy (U) is the total energy stored inside a system — the sum of the kinetic and potential energies of all its molecules. For an ideal gas it depends only on temperature.

Heat (Q) is energy transferred between a system and its surroundings *because of a temperature difference*. **Work (W)** is energy transferred when the system pushes its boundary through a distance.

- Heat and work are **path functions** — they depend on the route taken between two states.
 - Internal energy is a **state function** — it depends only on the initial and final states.
 - **SI unit** of all three (Q, W, U): the joule (J).
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4. Work Done by a Gas

When a gas expands and pushes a piston, it does work on the surroundings. For a small volume change dV at pressure P , the work done is:

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

- On a P - V diagram, the work done equals the **area under the curve**.
 - Work done *by* the gas (expansion) is positive; work done *on* the gas (compression) is negative.
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5. First Law of Thermodynamics

The first law is simply the law of conservation of energy applied to heat. The heat supplied to a system is used partly to increase its internal energy and partly to do external work.

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

- ΔQ is positive when heat is **added** to the system.
- ΔW is positive when work is done **by** the system.
- ΔU is positive when the internal energy (and temperature) increases.

Sign convention matters: always decide first whether heat is going in and whether the gas is expanding before substituting numbers.

6. Specific Heat Capacity

Specific heat capacity is the heat required to raise the temperature of unit mass of a substance by 1 K. **Molar specific heat (C)** uses one mole instead of unit mass.

For a gas, the specific heat depends on the conditions, so there are two principal values:

- C_p — molar specific heat at constant pressure.
- C_v — molar specific heat at constant volume.

Since heating a gas at constant pressure also does work pushing back the surroundings, C_p is always greater than C_v .

7. Mayer's Relation ($C_p - C_v = R$)

For one mole of an ideal gas, the two molar specific heats are linked by **Mayer's relation**:

$$C_p - C_v = R$$

where $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ is the universal gas constant. The extra R represents the work done by the gas when it expands at constant pressure.

The **ratio of specific heats** $\gamma = C_p/C_v$ is an important number: $\gamma = 5/3$ for a monatomic gas and $7/5$ for a diatomic gas.

8. Thermodynamic Processes

A **thermodynamic process** is any operation that changes a system from one state to another. Four special processes are central to this chapter.

Process	Constant Quantity	First-Law Result
Isothermal	Temperature ($\Delta U = 0$)	$\Delta Q = \Delta W = nRT \ln(V_2/V_1)$
Adiabatic	No heat exchange ($\Delta Q = 0$)	$\Delta W = -\Delta U$; $PV^\gamma = \text{constant}$
Isobaric	Pressure	$\Delta W = P\Delta V = nR\Delta T$
Isochoric	Volume ($\Delta W = 0$)	$\Delta Q = \Delta U = nC_v\Delta T$

[DIAGRAM: A P–V diagram showing four curves from the same starting point — a flat horizontal line (isobaric), a vertical line (isochoric), a gentle hyperbola (isothermal), and a steeper hyperbola (adiabatic).]

9. Isothermal and Adiabatic Processes in Detail

In an **isothermal process** the temperature is held constant, so the gas obeys Boyle's law $PV = \text{constant}$ and all the heat supplied is converted into work.

$$W_{\text{iso}} = nRT \ln(V_2/V_1) = 2.303 nRT \log(V_2/V_1)$$

In an **adiabatic process** no heat enters or leaves ($\Delta Q = 0$), so any work done comes entirely from the internal energy — the gas cools on expansion and heats on compression.

- $PV^\gamma = \text{constant}$ and $TV^{\gamma-1} = \text{constant}$
- $W_{\text{adia}} = (P_1V_1 - P_2V_2)/(\gamma - 1) = nR(T_1 - T_2)/(\gamma - 1)$

Important: on a P–V diagram an adiabatic curve is always steeper than an isothermal curve through the same point.

10. Reversible and Irreversible Processes

A **reversible process** is an idealised process carried out so slowly (quasi-statically) that the system stays in equilibrium throughout and can be exactly retraced, leaving no change in the surroundings.

An **irreversible process** cannot be retraced — almost every real process (sudden expansion, friction, heat flow across a finite temperature gap) is irreversible.

Key idea: a truly reversible process is a useful limit that no real engine ever reaches, but it sets the ceiling on efficiency.

11. Second Law of Thermodynamics

The first law allows energy conversions but says nothing about their *direction*. The **second law** supplies that missing direction.

- **Kelvin–Planck statement:** no engine can convert heat completely into work in a cyclic process — some heat must always be rejected.
- **Clausius statement:** heat cannot flow on its own from a colder body to a hotter body.

The two statements are equivalent, and together they forbid a 100% efficient engine and a perfect refrigerator.

12. Carnot Engine and Efficiency

A **heat engine** takes heat Q_1 from a hot source at T_1 , converts part of it into work W , and rejects the rest Q_2 to a cold sink at T_2 .

$$\text{Efficiency } \eta = W/Q_1 = 1 - Q_2/Q_1$$

The **Carnot engine** is an ideal reversible engine working in a cycle of two isothermal and two adiabatic processes. Its efficiency is the maximum any engine can have between the same two temperatures:

$\eta = 1 - T_2/T_1$ (temperatures in kelvin)

- Carnot efficiency depends only on the two temperatures, not on the working substance.
- Efficiency is 100% only if $T_2 = 0$ K, which is unattainable.

[DIAGRAM: An energy-flow block diagram — source at T_1 giving Q_1 to the engine, engine delivering work W , and rejecting Q_2 to the sink at T_2 .]

13. Refrigerator and Heat Pump

A **refrigerator** is a heat engine run in reverse: external work W is used to pull heat Q_2 from a cold body and dump Q_1 into a warmer room.

Its performance is measured by the **coefficient of performance (COP)**:

$$\beta = Q_2/W = Q_2/(Q_1 - Q_2) = T_2/(T_1 - T_2)$$

- A higher COP means a more efficient refrigerator.
- Because work is needed, the Clausius statement of the second law is obeyed — heat never flows from cold to hot without an external agent.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	8–10 marks	First law, isothermal/adiabatic work, $C_p - C_v = R$, Carnot efficiency
JEE Main / Advanced	2–4 questions	P–V work, adiabatic relations, efficiency, mixed processes
NEET	2–3 questions	First law sign convention, Carnot engine, refrigerator COP

[TABLE: Question-type split — VSA (1 mark): laws & definitions; SA (2–3 marks): first-law numericals, $C_p - C_v = R$, process identification; LA (5 marks): Carnot cycle derivation, efficiency and COP problems.]

Important Definitions

Term	Definition
Internal energy (U)	Total kinetic + potential energy of all molecules; a state function
Heat (Q)	Energy transferred due to a temperature difference
Work (W)	Energy transferred when a system moves its boundary: $W = \int P \, dV$
Zeroth law	Bodies in thermal equilibrium with a third body are in equilibrium with each other
First law	$\Delta Q = \Delta U + \Delta W$ — conservation of energy for heat processes
Isothermal process	Process at constant temperature; $\Delta U = 0$, so $\Delta Q = \Delta W$
Adiabatic process	Process with no heat exchange; $\Delta Q = 0$, $PV^\gamma = \text{constant}$
Mayer's relation	$C_p - C_v = R$ for one mole of an ideal gas
Second law	Heat cannot fully convert to work in a cycle; no spontaneous cold-to-hot flow
Carnot efficiency	Maximum engine efficiency: $\eta = 1 - T_2/T_1$
Coefficient of performance	Refrigerator measure: $\beta = T_2/(T_1 - T_2)$

Solved Examples

Example 1

A gas absorbs 200 J of heat and does 80 J of work on its surroundings. Find the change in its internal energy.

Answer: $\Delta U = \Delta Q - \Delta W = 200 - 80 = \mathbf{120 \text{ J}}$ (internal energy increases).

Example 2

One mole of an ideal gas expands isothermally at 300 K from volume V to $2V$. Find the work done. ($R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$)

Answer: $W = nRT \ln(V_2/V_1) = 1 \times 8.314 \times 300 \times \ln 2 = 2494.2 \times 0.693 = \approx \mathbf{1729 \text{ J}}$.

Example 3

A Carnot engine works between a source at 500 K and a sink at 300 K. Find its efficiency.

Answer: $\eta = 1 - T_2/T_1 = 1 - 300/500 = 1 - 0.6 = 0.4 = \mathbf{40\%}$.

Example 4

In an adiabatic process the internal energy of a gas decreases by 150 J. How much work is done by the gas?

Answer: For an adiabatic process $\Delta Q = 0$, so $\Delta W = -\Delta U = -(-150) = \mathbf{150\ J}$ (work is done by the gas at the cost of its internal energy).

Example 5

The molar specific heat of a gas at constant volume is $C_V = 20.8\ \text{J mol}^{-1}\ \text{K}^{-1}$. Find C_p and γ . ($R = 8.314$)

Answer: $C_p = C_V + R = 20.8 + 8.314 = \mathbf{29.1\ J\ mol}^{-1}\ \mathbf{K}^{-1}$. $\gamma = C_p/C_V = 29.1/20.8 = \approx \mathbf{1.4}$ (a diatomic gas).

Example 6

A refrigerator maintains its interior at 270 K while the room is at 300 K. Find the maximum coefficient of performance.

Answer: $\beta = T_2/(T_1 - T_2) = 270/(300 - 270) = 270/30 = \mathbf{9}$.

Important Questions for Board Exams

1-Mark Questions (VSA)

1. State the zeroth law of thermodynamics.
2. Why is the internal energy of an ideal gas a function of temperature only?
3. What is the value of work done in an isochoric process?
4. Name the process in which no heat is exchanged with the surroundings.
5. Can the efficiency of a heat engine ever be 100%? Justify.

2–3-Mark Questions (SA)

1. State the first law of thermodynamics and explain the sign convention used for ΔQ , ΔW and ΔU .
2. Distinguish between isothermal and adiabatic processes with one example of each.
3. Derive the relation $C_p - C_V = R$ for one mole of an ideal gas.
4. Why is C_p greater than C_V for a gas? Explain physically.

5-Mark Questions (LA)

1. Describe the four strokes of a Carnot cycle and derive the expression for its efficiency $\eta = 1 - T_2/T_1$.
 2. State both the Kelvin–Planck and Clausius statements of the second law and show that they are equivalent.
 3. Explain the working of a refrigerator and derive its coefficient of performance in terms of T_1 and T_2 .
-

Quick Revision Points

- State variables: P, V, T, U — depend only on the present state
 - Zeroth law defines temperature; bodies at the same temperature are in thermal equilibrium
 - First law: $\Delta Q = \Delta U + \Delta W$ (conservation of energy)
 - Heat and work are path functions; internal energy is a state function
 - Isothermal: $\Delta U = 0, \Delta Q = \Delta W = nRT \ln(V_2/V_1)$
 - Adiabatic: $\Delta Q = 0, PV^\gamma = \text{constant}, \Delta W = nR(T_1 - T_2)/(\gamma - 1)$
 - Isobaric: $\Delta W = P\Delta V$; Isochoric: $\Delta W = 0, \Delta Q = nC_v\Delta T$
 - Mayer's relation: $C_p - C_v = R$; $\gamma = C_p/C_v$ (5/3 monatomic, 7/5 diatomic)
 - Second law: no 100% engine; heat will not flow cold $\rightarrow$ hot on its own
 - Heat engine efficiency: $\eta = 1 - Q_2/Q_1$; Carnot: $\eta = 1 - T_2/T_1$
 - Refrigerator COP: $\beta = T_2/(T_1 - T_2)$
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Next Chapter: Chapter 12 — Kinetic Theory



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