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CHAPTER NOTES

Thermal Properties of Matter Class 11 Notes | CBSE Physics Chapter 10

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Thermal Properties of Matter Class 11 Notes | CBSE Physics Chapter 10

Thermal Properties of Matter is Chapter 10 of CBSE Class 11 Physics — the chapter that explains what “hot” and “cold” really mean, why a railway track buckles in summer, and why a sip of tea cools faster than a bowl of soup. It connects temperature, heat, expansion, and the three ways energy travels: conduction, convection, and radiation.

By the end of these notes you will be able to convert between temperature scales, solve linear/area/volume expansion problems, use calorimetry to find specific or latent heat, apply the conduction formula, and tackle Newton’s law of cooling and Stefan-Boltzmann numericals. This is a steady-scoring chapter worth roughly 4–5 marks in boards and a reliable source of one or two questions in NEET and JEE.

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Key Concepts

1. Temperature and Heat

Heat is energy that flows from a hotter body to a colder body because of their temperature difference. **SI unit:** joule (J). Heat is energy in transit — once it is absorbed, we call it internal energy, not heat.

Temperature is the measure of the degree of hotness or coldness of a body. It decides the *direction* of heat flow: energy always moves from high to low temperature until both reach the same value (thermal equilibrium). **SI unit:** kelvin (K).

Key idea: A bucket of warm water can hold more heat than a spark, even though the spark is at a far higher temperature. Heat depends on mass; temperature does not.

2. Thermometry and Temperature Scales

A **thermometer** measures temperature using a property that changes regularly with it — usually the expansion of mercury or alcohol in a glass capillary.

The Three Common Scales

- **Celsius (°C):** ice point 0 °C, steam point 100 °C.
- **Fahrenheit (°F):** ice point 32 °F, steam point 212 °F.
- **Kelvin (K):** the absolute/SI scale; 0 K is absolute zero. $T(K) = t(^{\circ}C) + 273.15$.

Conversion between Celsius and Fahrenheit:

$$(C - 0)/100 = (F - 32)/180, \text{ i.e. } C/5 = (F - 32)/9$$

The **ideal-gas (absolute) scale** is built on the fact that, at constant volume, the pressure of a gas falls linearly with temperature and would reach zero at $-273.15^{\circ}C$ — this defines absolute zero.

3. Thermal Expansion

Most substances expand on heating because the molecules vibrate more vigorously and their average separation increases. There are three kinds, each with its own coefficient.

Type	Formula	Coefficient
Linear (length)	$\Delta L = \alpha L_0 \Delta T$	α = coefficient of linear expansion
Area (superficial)	$\Delta A = \beta A_0 \Delta T$	β = coefficient of area expansion
Volume (cubical)	$\Delta V = \gamma V_0 \Delta T$	γ = coefficient of volume expansion

Relation between the coefficients: $\beta = 2\alpha$ and $\gamma = 3\alpha$, so **$\alpha : \beta : \gamma = 1 : 2 : 3$** .

Units: each coefficient has units of K^{-1} (or $^{\circ}C^{-1}$).

Anomalous Expansion of Water

Water behaves strangely between $0^{\circ}C$ and $4^{\circ}C$: it *contracts* on heating and expands on cooling, reaching its maximum density at $4^{\circ}C$. This is why ice forms on top of a pond while fish survive in the $4^{\circ}C$ water below.

4. Specific Heat Capacity

The **specific heat capacity (c)** is the heat needed to raise the temperature of 1 kg of a substance by 1 K (or $1^{\circ}C$).

$$Q = m c \Delta T$$

- **SI unit:** $\text{J kg}^{-1} \text{K}^{-1}$.
- Water has an unusually large specific heat ($4186 \text{ J kg}^{-1} \text{K}^{-1}$), which is why it is used as a coolant and why coastal climates are mild.

The **heat capacity** of a body is $C = m c$ (unit J K^{-1}) — the heat needed to raise the whole body's temperature by 1 K. The **molar specific heat** is the heat per mole per kelvin.

5. Calorimetry

Calorimetry is the measurement of heat. It rests on the **principle of mixtures**: when bodies at different temperatures are mixed, heat lost by the hotter body equals heat gained by the colder body (assuming no loss to surroundings).

Heat lost = Heat gained

This single equation lets you find an unknown specific heat, mass, or final temperature. The apparatus used is a **calorimeter**, usually a copper vessel because copper has a low specific heat and conducts well.

6. Change of State and Latent Heat

When a substance changes state ($\text{solid} \rightleftharpoons \text{liquid} \rightleftharpoons \text{gas}$), its temperature stays constant even though heat is being added or removed. This "hidden" heat is the **latent heat**.

$Q = m L$

- **Latent heat of fusion (L_f):** heat per kg to convert a solid to liquid at its melting point. For ice, $L_f \approx 3.34 \times 10^5 \text{ J kg}^{-1}$.
- **Latent heat of vaporization (L_v):** heat per kg to convert a liquid to vapour at its boiling point. For water, $L_v \approx 2.26 \times 10^6 \text{ J kg}^{-1}$.
- **SI unit:** J kg^{-1} .

[DIAGRAM: A temperature-vs-heat graph for ice $\rightarrow$ water $\rightarrow$ steam, showing two flat plateaus at 0°C (melting) and 100°C (boiling) where temperature stays constant.]

This is why steam at 100°C scalds far worse than water at 100°C — the steam releases its large latent heat of vaporization on your skin.

7. Heat Transfer: Conduction

Conduction is the transfer of heat through a material without bulk movement of the material itself — energy is passed from molecule to molecule. It is the main mode in solids, especially metals.

For a rod of length L and cross-section A with ends at temperatures T_1 and T_2 , the rate of heat flow is:

$$Q/t = kA(T_1 - T_2)/L$$

- **k** = coefficient of thermal conductivity (unit $\text{W m}^{-1} \text{K}^{-1}$); high for metals, low for wood and air.

- $(T_1 - T_2)/L$ is the **temperature gradient**.
-

8. Heat Transfer: Convection

Convection is the transfer of heat by the actual movement of the heated material itself. It occurs in fluids (liquids and gases) where warm, less-dense regions rise and cooler regions sink, setting up convection currents.

- **Natural convection:** driven by density differences (sea breeze, boiling water).
 - **Forced convection:** the fluid is pushed by a pump or fan (a room heater's blower, blood circulation).
-

9. Heat Transfer: Radiation

Radiation is the transfer of heat by electromagnetic waves and needs *no medium* — this is how the Sun's energy reaches the Earth through empty space.

Every body above 0 K emits thermal radiation. Dark, rough surfaces are good absorbers and good emitters; shiny, polished surfaces are poor absorbers and good reflectors.

10. Blackbody Radiation and Stefan-Boltzmann Law

A **perfectly black body** absorbs all radiation falling on it and is also the best possible emitter. Its emissivity $e = 1$.

The **Stefan-Boltzmann law** states that the energy radiated per unit area per unit time by a black body is proportional to the fourth power of its absolute temperature:

$$E = \sigma T^4 \text{ (for a real body, } E = e\sigma T^4 \text{)}$$

- σ = Stefan's constant = $5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$.
 - The net rate of loss by a body at temperature T in surroundings at T_0 is $E = e\sigma(T^4 - T_0^4)$.
-

11. Wien's Displacement Law

A hot body radiates over many wavelengths, but the wavelength at which it radiates *most strongly* shifts with temperature. **Wien's law** says this peak wavelength is inversely proportional to absolute temperature:

$$\lambda_m T = b$$

- b = Wien's constant = $2.9 \times 10^{-3} \text{ m}\cdot\text{K}$.
 - This is why a heated iron glows dull red first, then orange, then white as it gets hotter — the peak moves to shorter wavelengths.
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12. Newton's Law of Cooling

Newton's law of cooling states that for a small temperature difference, the rate of loss of heat of a body is directly proportional to the difference between its temperature and that of its surroundings.

$$-dT/dt = K(T - T_0)$$

- It is an approximation of the Stefan-Boltzmann law, valid only for small temperature differences.
- A graph of temperature against time is an **exponential decay** curve approaching the surrounding temperature T_0 .

This is why a cup of hot tea cools quickly at first and then more slowly as it nears room temperature.

Weightage in Board & Entrance Exams

Exam	Typical Weightage	Most-Tested Areas
CBSE Board (Class 11)	4–5 marks	Thermal expansion, calorimetry, latent heat, conduction formula
JEE Main / Advanced	1–2 questions	Expansion, conduction in series/parallel, Stefan-Boltzmann, Wien's law
NEET	1–2 questions	Specific & latent heat, modes of heat transfer, Newton's law of cooling

[TABLE: Question-type split — VSA (1 mark): scales, coefficients, definitions; SA (2–3 marks): expansion & calorimetry numericals, conduction; LA (5 marks): radiation laws, Newton's law of cooling derivation.]

Important Definitions

Term	Definition
Heat	Energy in transit due to a temperature difference; SI unit joule
Temperature	Measure of degree of hotness; decides the direction of heat flow; SI unit kelvin
Coefficient of linear expansion (α)	Fractional change in length per unit rise in temperature: $\alpha = \Delta L / (L_0 \Delta T)$
Specific heat capacity (c)	Heat to raise 1 kg of a substance by 1 K: $Q = mc\Delta T$
Heat capacity (C)	Heat to raise the whole body by 1 K: $C = mc$
Latent heat (L)	Heat per unit mass to change state at constant temperature: $Q = mL$
Thermal conductivity (k)	Measure of how readily a material conducts heat: $Q/t = kA\Delta T/L$
Black body	A body that absorbs and emits all radiation ($e = 1$)
Stefan-Boltzmann law	Energy radiated per unit area: $E = \sigma T^4$
Newton's law of cooling	Rate of cooling $\propto$ temperature difference: $-dT/dt = K(T - T_0)$

Solved Examples

Example 1

Convert 37 °C (normal body temperature) to the Fahrenheit and Kelvin scales.

Answer: $F = (9/5)C + 32 = (9/5)(37) + 32 = 66.6 + 32 = \mathbf{98.6\text{ }^\circ\text{F}}$. $T = 37 + 273.15 = \mathbf{310.15\text{ K}}$.

Example 2

A steel rod 1 m long is heated from 20 °C to 120 °C. Find the increase in length. ($\alpha = 1.2 \times 10^{-5}\text{ K}^{-1}$)

Answer: $\Delta L = \alpha L_0 \Delta T = (1.2 \times 10^{-5})(1)(100) = 1.2 \times 10^{-3}\text{ m} = \mathbf{1.2\text{ mm}}$.

Example 3

How much heat is needed to raise the temperature of 2 kg of water from 25 °C to 75 °C? ($c = 4186\text{ J kg}^{-1}\text{ K}^{-1}$)

Answer: $Q = mc\Delta T = 2 \times 4186 \times 50 = \mathbf{4.186 \times 10^5\text{ J}}$.

Example 4

Calculate the heat required to convert 0.5 kg of ice at 0 °C completely into water at 0 °C. ($L_f = 3.34 \times 10^5 \text{ J kg}^{-1}$)

Answer: $Q = mL_f = 0.5 \times 3.34 \times 10^5 = \mathbf{1.67 \times 10^5 \text{ J}}$.

Example 5

One face of a copper slab of area 0.2 m² and thickness 2 cm is kept at 100 °C and the other at 0 °C. Find the rate of heat flow. ($k = 400 \text{ W m}^{-1} \text{ K}^{-1}$)

Answer: $Q/t = kA(T_1 - T_2)/L = (400 \times 0.2 \times 100)/0.02 = 8000/0.02 = \mathbf{4 \times 10^5 \text{ W}}$.

Example 6

The surface temperature of a star is 6000 K. Using Wien's law, find the wavelength at which it radiates most strongly. ($b = 2.9 \times 10^{-3} \text{ m}\cdot\text{K}$)

Answer: $\lambda_m = b/T = (2.9 \times 10^{-3})/6000 = \mathbf{4.83 \times 10^{-7} \text{ m}}$ ($\approx 483 \text{ nm}$, blue-green light).

Important Questions for Board Exams

1-Mark Questions (VSA)

1. Define the coefficient of linear expansion and give its SI unit.
2. Why does water have an anomalous expansion, and at what temperature is its density maximum?
3. Name the mode of heat transfer that does not require a material medium.
4. Why is steam at 100 °C more dangerous than water at 100 °C?
5. What is the value and SI unit of Stefan's constant?

2–3-Mark Questions (SA)

1. Derive the relation $\gamma = 3\alpha$ between the coefficients of volume and linear expansion.
2. State the principle of calorimetry and explain how it is used to find an unknown specific heat.
3. Distinguish between conduction, convection, and radiation with one example of each.
4. State Wien's displacement law and use it to explain the colour change of a heated iron piece.

5-Mark Questions (LA)

1. State and explain Newton's law of cooling. Show how it follows from the Stefan-Boltzmann law for small temperature differences, and sketch the cooling curve.

2. Derive the expression for the rate of heat conduction through a rod and define thermal conductivity. Discuss conductors in series.
 3. Explain blackbody radiation and state the Stefan-Boltzmann law. Find the net rate of heat loss of a body at temperature T placed in surroundings at T_0 .
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Quick Revision Points

- Heat is energy in transit; temperature decides the direction of heat flow
 - Scale conversion: $C/5 = (F - 32)/9$; $T(K) = t(^{\circ}C) + 273.15$
 - Expansion: $\Delta L = \alpha L_0 \Delta T$, $\Delta A = \beta A_0 \Delta T$, $\Delta V = \gamma V_0 \Delta T$ with $\alpha : \beta : \gamma = 1 : 2 : 3$
 - Water has maximum density at $4^{\circ}C$ (anomalous expansion)
 - Specific heat: $Q = mc\Delta T$; water $c = 4186 \text{ J kg}^{-1} \text{ K}^{-1}$
 - Calorimetry: heat lost = heat gained
 - Latent heat: $Q = mL$; ice $L_f \approx 3.34 \times 10^5$, water $L_v \approx 2.26 \times 10^6 \text{ J kg}^{-1}$
 - Conduction: $Q/t = kA(T_1 - T_2)/L$; convection needs fluid movement; radiation needs no medium
 - Stefan-Boltzmann: $E = \sigma T^4$; $\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
 - Wien's law: $\lambda_m T = b$; $b = 2.9 \times 10^{-3} \text{ m}\cdot\text{K}$
 - Newton's law of cooling: $-dT/dt = K(T - T_0)$; exponential decay toward T_0
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Next Chapter: Chapter 11 — Thermodynamics



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