FREE NOTES · NCERT + JEE/NEET LEVEL

Thermal Properties of Matter

Temperature scales, thermal expansion, specific heat, calorimetry, latent heat, conduction, convection, radiation and Newton's law of cooling, with everyday examples and solved numericals.

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01 Heat vs temperature

	Heat	Temperature
What it is	**Energy** that flows because of a temperature difference	A **measure** of how hot or cold something is
Unit	joule (J), calorie (1 cal = 4.186 J)	kelvin (K), °C, °F
Flows	From higher to lower temperature	—

A hot spoon and a hot bucket of water can be at the same temperature, but the bucket holds far more heat (energy).

02 Temperature scales

$$(C - 0)/100 = (F - 32)/180 = (K - 273.15)/100$$

For any scale: (reading - lower fixed point)/(upper - lower) is the same on all scales.

Scale	Ice melts	Water boils
Celsius	0 °C	100 °C
Fahrenheit	32 °F	212 °F
Kelvin	273.15 K	373.15 K

REMEMBER

-40 °C = -40 °F (the two are equal). A change of 1 °C = 1 K = 1.8 °F. Kelvin has no negative values (absolute zero = 0 K = -273.15 °C).

Ideal gas equation: $PV = \mu RT$ (μ = moles, R = 8.314 J/mol·K). This is the basis of the constant-volume gas thermometer.

03 Thermal expansion

Most things expand when heated because atoms vibrate more and their average spacing increases.

Type	Formula	Coefficient
Linear (length)	$\Delta L = \alpha\, L\, \Delta T$	α
Area	$\Delta A = \beta\, A\, \Delta T$	$\beta = 2\alpha$
Volume	$\Delta V = \gamma\, V\, \Delta T$	$\gamma = 3\alpha$

RELATION

$\alpha : \beta : \gamma = 1 : 2 : 3$. For an ideal gas at constant pressure, $\gamma = 1/T$.

IN EVERYDAY LIFE

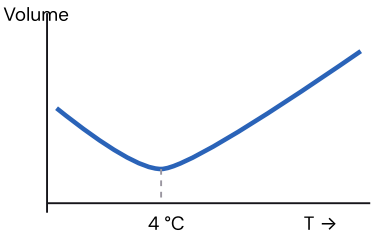
- Gaps are left in railway tracks and bridges.
- A bimetallic strip (two metals joined) bends with the higher-α metal on the **outside** when heated. Used in thermostats and fire alarms.
- Put a tight jar lid in hot water: the lid expands more and opens.
- A pendulum clock runs slow in summer (length increases, T increases).
- Heat a plate with a hole: the hole also gets **bigger** (like zooming a photo).

04 Anomalous expansion of water

Heated from 0 °C to 4 °C, water **contracts**; above 4 °C it expands. So **water is densest at 4 °C**.

WHY IT MATTERS

In winter a lake freezes at the top while 4 °C water stays at the bottom, so fish survive. Ice is lighter, floats, and insulates the water below.



Minimum volume at 4 °C ⇒ maximum density

05 Specific heat & calorimetry

HEAT AND TEMPERATURE CHANGE

$$Q = m\,s\,\Delta T$$

s = specific heat (J/kg·K): heat to raise 1 kg by 1 K. Water's s = 4186 J/kg·K (= 1 cal/g·°C), very high. Heat capacity = ms.

MOLAR SPECIFIC HEAT

$$C = Q/(\mu\,\Delta T)$$

Gases have two: C_p (constant pressure) and C_v (constant volume). $C_p - C_v = R$ (Mayer). For solids $C \approx 3R$ (Dulong-Petit).

PRINCIPLE OF CALORIMETRY

In an isolated system: **heat given by the hot body = heat taken by the cold body**. $m_1 s_1 (T_1 - T) = m_2 s_2 (T - T_2)$.

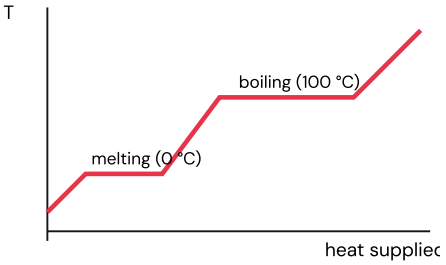
Because water's s is high: it's used as a car radiator coolant and in hot-water bottles, and coastal climates are mild (they don't heat quickly by day or cool quickly at night).

06 Change of state & latent heat

$$Q = m\,L$$

During a change of state the **temperature stays constant**; the heat only breaks bonds. Ice $L_f = 3.33 \times 10^5$ J/kg (80 cal/g), steam $L_v = 22.6 \times 10^5$ J/kg (540 cal/g).

That's why a steam burn is worse than one from boiling water: steam first gives up an extra 540 cal/g.



Flat parts: latent heat (T constant)

- **Higher pressure** raises the boiling point (~120 °C in a pressure cooker) and slightly lowers the melting point of ice (**regelation**: a wire passes through ice; ice skating).
- Lower pressure on mountains ⇒ water boils below 100 °C ⇒ food takes longer to cook.
- **Sublimation:** solid directly to gas (camphor, dry ice, naphthalene).
- **Triple point** of water: 273.16 K and 0.006 atm, where all three states coexist.

07 Conduction

Heat passing through a material by atoms colliding, without the material moving. Happens in solids (especially metals, because of free electrons).

FOURIER'S LAW

$$H = dQ/dt = K\,A\,(T_1 - T_2)\,/\,L$$

K = thermal conductivity (W/m·K). Silver/copper have high K; wood, air and wool have low K.

THERMAL RESISTANCE

$$R = L\,/\,(K\,A)$$

Like current: H = ΔT/R. Series: R = R_1 + R_2. Parallel: 1/R = 1/R_1 + 1/R_2.

TWO RODS IN SERIES (SAME A)

Junction temperature: $T = (K_1T_1/L_1 + K_2T_2/L_2)/(K_1/L_1 + K_2/L_2)$. For equal lengths, equivalent K = $2K_1K_2/(K_1 + K_2)$. In parallel (same L and A), K = $(K_1 + K_2)/2$.

Examples: cooking pots have copper bottoms and plastic handles; woollen clothes keep us warm in winter (trapped air is a good insulator); an igloo is warm inside.

08 Convection

Heat carried by the **movement of the fluid itself**. Warm fluid becomes lighter and rises, cool fluid sinks: a **convection current**. Only in liquids and gases.

- **Natural:** sea breeze (by day, wind blows from sea to land), land breeze (reverse at night), trade winds, monsoon.
- **Forced:** fan, AC, car radiator pump, blood circulation.
- Heaters are placed low in a room and ACs high.

09 Radiation

Heat carried by electromagnetic waves (infrared). **Needs no medium**, works in vacuum, travels at the speed of light. The Sun's heat reaches us this way.

STEFAN-BOLTZMANN LAW

$$H = e\,\sigma\,A\,T^4$$

σ = 5.67 × 10^{-8} W/m²K⁴, e = emissivity (black body e = 1). Net loss to surroundings at T_o: $e\sigma A(T^4 - T_0{}^4)$.

WIEN'S DISPLACEMENT LAW

$$\lambda_m\,T = b$$

b = 2.9 × 10^{-3} m·K. Hotter objects peak at shorter wavelengths: red → yellow → white → blue. A blue star is hotter than a red one.

KIRCHHOFF'S IDEA

A good absorber is also a good emitter. Black surfaces absorb and emit more. Hence dark clothes in winter, white in summer. Thermos flask: shiny walls (less radiation), vacuum (no conduction or convection).

10 Newton's law of cooling

$$dT/dt = -k\,(T - T_0)$$

Rate of cooling is proportional to the **temperature difference** (when the difference is small). T_o = temperature of the surroundings.

EXAM SHORTCUT (AVERAGE FORM)

$$(T_1 - T_2)/t = k\,[\,(T_1 + T_2)/2 - T_0\,]$$

Find k from the first set of data, then use it for the second.

Exact solution: $T - T_0 = (T_i - T_0)$ e^(−kt), an exponentially falling graph.

11 JEE Extra + Tricks

JEE LEVEL

- Expansion: $\beta = 2\alpha$, $\gamma = 3\alpha$ (isotropic solid). Water is densest at 4 °C (anomalous expansion).
- Newton's law of cooling (average form): $(T_1 - T_2)/t = k[(T_1 + T_2)/2 - T_s]$.
- Wien's law $\lambda_m T = b$ (2.9×10^{-3} m K); Stefan's law $E = \sigma e A T^4$.
- Conduction through slabs in series: $R = L/(KA)$ add like resistors; equivalent K for equal lengths in series = $2K_1K_2/(K_1 + K_2)$.
- Calorimetry trick: heat lost = heat gained; always check if all ice melts (compare heat needed to melt ice vs heat available).

12 Solved numericals

Q1. Convert 98.6 °F to °C and K.
C = (98.6 − 32) × 5/9 = 37 °C. K = 310.15 K. **Ans: 37 °C, ≈ 310 K**

Q2. A 1 m steel rod ($\alpha = 1.2 \times 10^{-5}$ /°C) is heated by 100 °C. Increase in length?
$\Delta L = 1 \times 1.2 \times 10^{-5} \times 100 = 1.2 \times 10^{-3}$ m. **Ans: 1.2 mm**

Q3. 200 g of water at 80 °C is mixed with 300 g at 20 °C. Final temperature?
200(80 − T) = 300(T − 20) ⇒ 16000 + 6000 = 500T ⇒ T = 44 °C. **Ans: 44 °C**

Q4. Heat needed to turn 100 g of ice at −10 °C into steam at 100 °C? (s_{ice} = 0.5, s_{water} = 1 cal/g°C)
Warm ice: 100 × 0.5 × 10 = 500. Melt: 100 × 80 = 8000. Water 0→100: 10000. Boil: 100 × 540 = 54000. Total = 72500 cal. **Ans: 72.5 kcal ≈ 3.03×10^5 J**

Q5. A copper rod (K = 400) 50 cm long, area 10 cm², ends at 100 °C and 0 °C. Rate of heat flow?
$H = 400 \times 10^{-3} \times 100/0.5 = 80$ W. **Ans: 80 W**

Q6. The Sun's $\lambda_m \approx 480$ nm. Its surface temperature?
$T = b/\lambda_m = 2.9 \times 10^{-3}/(4.8 \times 10^{-7}) \approx 6000$ K. **Ans: ≈ 6000 K**

Q7. A body cools from 80 °C to 60 °C in 5 min (room at 20 °C). Time to cool from 60 °C to 40 °C?
20/5 = k(70 − 20) ⇒ k = 0.08. 20/t = 0.08(50 − 20) = 2.4 ⇒ t ≈ 8.3 min. **Ans: ≈ 8.3 min**

13 Common mistakes

- Putting °C into Stefan's law. Always use T^4 in **kelvin**.
- Thinking temperature rises while latent heat is absorbed.
- Thinking a hole in a plate shrinks on heating (it grows).
- Writing $\beta = \alpha^2$ or $\gamma = \alpha^3$. Correct: $\beta = 2\alpha$, $\gamma = 3\alpha$.
- Forgetting the heat for a phase change (melting ice) in calorimetry.
- Using the initial temperature instead of the average in Newton's cooling.

14 Formula sheet

Scales	$C/100 = (F - 32)/180 = (K - 273)/100$
Expansion	$\Delta L = \alpha L \Delta T$, $\beta = 2\alpha$, $\gamma = 3\alpha$
Heat	$Q = ms\Delta T$, $Q = mL$
Calorimetry	heat lost = heat gained
Mayer	$C_p - C_v = R$
Conduction	$H = KA\Delta T/L$, $R = L/KA$
Stefan	$H = e\sigma AT^4$
Wien	$\lambda_m T = 2.9 \times 10^{-3}$ m·K
Newton's cooling	$dT/dt = -k(T - T_0)$
Latent heats (water)	80 cal/g (fusion), 540 cal/g (vaporisation)

15 Practice questions

1. At what temperature is the Fahrenheit reading twice the Celsius reading?
2. A cube has $\alpha = 2 \times 10^{-5}$. % change in volume when heated by 50 °C?
3. A black body's temperature doubles. Radiated power?
4. Two rods of equal length with K and 2K in series. Equivalent K?
5. Heat to convert 10 g of ice at 0 °C into water at 0 °C?

ANSWERS

1) $F = 2C \Rightarrow C = 160$ °C ($F = 320$ °F) · 2) $\gamma\Delta T = 6 \times 10^{-5} \times 50 = 0.3\%$ · 3) 16 times · 4) $2 \times K \times 2K/(K + 2K) = 4K/3$ · 5) 800 cal

16 Quick revision: 5 minutes before the exam

TEMPERATURE & EXPANSION

- −40 °C = −40 °F.
- $\alpha : \beta : \gamma = 1 : 2 : 3$.
- Water is densest at 4 °C.
- Bimetal: higher-α metal outside.

HEAT

- $Q = ms\Delta T$; $Q = mL$ (T constant).
- Water $s = 1$ cal/g°C (highest).
- $L_f = 80$, $L_v = 540$ cal/g.
- Pressure ↑ ⇒ boiling point ↑.

TRANSFER

- $H = KA\Delta T/L$; $R = L/KA$.
- Convection only in fluids.
- Radiation works in vacuum.

RADIATION & COOLING

- $H \propto T^4$ (kelvin!).
- $\lambda_m T$ = constant.
- Good absorber = good emitter.
- $dT/dt \propto (T - T_o)$.

Have a doubt? Ask the AI Doubt Solver at padhaiadda.netlify.app, or take the mock test on this chapter.