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CUET · PHYSICS · CLASS XI · CODE 322

Thermal Properties of Matter

CUET unit: Thermal Properties of Matter

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📌 Snapshot

- Establishes the physical distinction between heat (energy transferred by virtue of temperature difference) and temperature (a measure of hotness), and develops the three temperature scales (Celsius, Fahrenheit, Kelvin) with their conversions.
- Develops the ideal-gas equation PV = μRT and shows how a constant-volume gas thermometer leads to the absolute (Kelvin) scale with zero at −273.15 °C.
- Quantifies thermal expansion of solids, liquids and gases (αl, αv = 3αl, area expansion 2αl) and notes water's anomalous expansion with maximum density at 4 °C.
- Introduces specific heat capacity, molar specific heat capacity, latent heat of fusion and vaporisation, and the principle of calorimetry (heat lost = heat gained).
- Covers the three modes of heat transfer — conduction (H = KA(TC − TD)/L), convection, and radiation (Stefan-Boltzmann law H = AeσT^4, Wien's displacement law λmT = constant) — and ends with Newton's law of cooling.

📖 Detailed Notes

2.1 Core concepts

- Temperature is a relative measure of the hotness or coldness of a body; heat is the form of energy transferred between two systems (or a system and its surroundings) by virtue of a temperature difference. SI unit of heat is the joule (J); SI unit of temperature is the kelvin (K), with degree Celsius (°C) as a common unit (NCERT §10.2, p. 203).
- Thermometers exploit a physical property that varies with temperature; common liquid-in-glass thermometers use mercury or alcohol whose volume varies linearly with temperature. Calibration uses two fixed points: the ice point and the steam point of water (NCERT §10.3, p. 203).
- On the Fahrenheit scale the ice and steam points are 32 °F and 212 °F (180 equal intervals); on Celsius they are 0 °C and 100 °C (100 intervals). The conversion is (tF − 32)/180 = tC/100 (NCERT §10.3, Eq. 10.1, p. 203).
- A constant-volume gas thermometer uses P ∝ T and gives the same reading regardless of which low-density gas is used; extrapolating P–T lines for different

gases meets the T-axis at the same point, –273.15 °C, which is taken as absolute zero (0 K) on the Kelvin scale (NCERT §10.4, pp. 203–204).

- Boyle's law (PV = constant, T fixed) and Charles' law (V/T = constant, P fixed) combine into the ideal-gas equation PV = μRT, where μ is the number of moles and R = 8.31 J mol^{-1} K^{-1} is the universal gas constant (NCERT §10.4, Eq. 10.2, p. 204).
- Kelvin and Celsius scales have the same unit size but different origins: T = tC + 273.15 (NCERT §10.4, Eq. 10.3, p. 204).
- Most substances expand on heating and contract on cooling. For a long rod: Δl/l = αl ΔT, where αl is the coefficient of linear expansion (a material constant) (NCERT §10.5, Eq. 10.4, p. 205).
- For a rectangular sheet, the coefficient of area expansion equals 2αl (the $(\alpha l\ \Delta T)^2$ term being negligible); for a cube, the coefficient of volume expansion αv = 3αl (NCERT §10.5, Eqs. 10.7–10.9, pp. 207–208).
- Liquids and gases are described by ΔV/V = αv ΔT. Gases expand much more than solids/liquids; for an ideal gas at constant pressure αv = 1/T, so at 0 °C, αv ≈ 3.7 × 10^{-3} K^{-1} (NCERT §10.5, Eq. 10.6, p. 206).
- Water shows anomalous behaviour: between 0 °C and 4 °C it contracts on heating, so water has its maximum density at 4 °C. This makes lakes freeze at the top first, preserving aquatic life (NCERT §10.5, pp. 206–207).
- If thermal expansion of a rod is prevented by rigid supports, a compressive thermal stress is set up; for a steel rail with αl = 1.2 × 10^{-5} K^{-1} and ΔT = 10 °C, the strain is 1.2 × 10^{-4} and thermal stress is 2.4 × 10^{7} N m^{-2} (NCERT §10.5, p. 207).
- Heat capacity S = ΔQ/ΔT; specific heat capacity s = (1/m)(ΔQ/ΔT) is the heat needed to change unit mass by one unit of temperature. SI unit: J kg^{-1} K^{-1} (NCERT §10.6, Eqs. 10.10–10.11, p. 208).
- Water has an unusually high specific heat capacity of 4186 J kg^{-1} K^{-1} — the highest in Table 10.3 — which is why water is used as a coolant in radiators and as a heater in hot-water bags, and why sea breezes have a cooling effect (NCERT §10.6, Table 10.3, p. 209).
- Molar specific heat capacity C = (1/μ)(ΔQ/ΔT); for gases one distinguishes Cp (constant pressure) and Cv (constant volume) (NCERT §10.6, Eq. 10.12, pp. 208–209).
- Calorimetry: in an isolated system, heat lost by the hotter body equals heat gained by the colder body. A calorimeter is a metallic vessel (copper/aluminium) kept inside an insulating jacket (NCERT §10.7, pp. 209–210).
- During a change of state (melting/fusion, freezing, vaporisation, condensation, sublimation) temperature remains constant; both phases coexist in thermal equilibrium. The temperature at which solid–liquid coexist is the melting point; liquid–vapour coexist at the boiling point (NCERT §10.8, pp. 210–212).

- Latent heat $L = Q/m$ is the heat per unit mass required for a change of state at constant T and P. SI unit: J kg^{-1}. For water $L_f = 3.33 \times 10^5$ J kg^{-1} and $L_v = 22.6 \times 10^5$ J kg^{-1} — so steam at 100 °C carries 22.6×10^5 J kg^{-1} more energy than water at 100 °C, explaining why steam burns are more serious (NCERT §10.8.1, Eq. 10.13, Table 10.5, p. 213).
- Boiling point increases with pressure (pressure cooker) and decreases with reduced pressure (cooking is difficult on hills); regelation (refreezing under pressure) makes skating possible (NCERT §10.8, pp. 211–212).
- Three modes of heat transfer: conduction, convection, radiation (NCERT §10.9, p. 214).
- Conduction: in steady state, $H = KA(T_C - T_D)/L$, where K is thermal conductivity (SI unit J s^{-1} m^{-1} K^{-1} = W m^{-1} K^{-1}). Metals have large K (silver 406, copper 385); gases are poor conductors (air 0.024) (NCERT §10.9.1, Eq. 10.14, Table 10.6, pp. 214–215).
- Convection is heat transfer by bulk motion of matter and is possible only in fluids; it can be natural (gravity-driven, e.g., sea breeze, trade winds) or forced (pumps, heart, automobile cooling) (NCERT §10.9.2, pp. 217–218).
- Radiation requires no medium; energy is carried by electromagnetic waves at speed 3×10^8 m s^{-1}. Stefan-Boltzmann law for a perfect radiator: $H = A\sigma T^4$ with $\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}; for a real body $H = Ae\sigma T^4$ where e is emissivity (e = 1 for perfect radiator). For a body at T with surroundings at T_s, net loss is $H = e\sigma A(T^4 - T_s^4)$ (NCERT §10.9.3, Eqs. 10.16–10.18, pp. 218–219).
- Blackbody radiation has a continuous spectrum. Wien's displacement law: $\lambda_m T$ = constant = 2.9×10^{-3} m K. This explains why heated iron turns dull red → reddish yellow → white-hot, and lets us estimate Sun's surface temperature ≈ 6060 K from λ_m = 4753 Å (NCERT §10.9.4, Eq. 10.15, pp. 218–219).
- A Dewar flask reduces all three modes: silvered walls reflect radiation, evacuated space cuts conduction and convection (NCERT §10.9.3, p. 218).
- Newton's law of cooling: for small temperature differences, $-dQ/dt = k(T_2 - T_1)$. Integrating gives $\log_e(T_2 - T_1) = -Kt + c$, so a plot of $\log_e(T_2 - T_1)$ against t is a straight line with negative slope (NCERT §10.10, Eqs. 10.19–10.23, pp. 220–221).
- **Triple point of water**, the unique combination of pressure (4.58 mm Hg) and temperature (273.16 K) at which all three phases of water — ice, water and vapour — coexist in thermal equilibrium, is the modern SI defining point of the kelvin (NCERT §10.4, p. 204; Points to Ponder, p. 222).
- **Anomalous expansion of water** has profound ecological significance: as a lake cools, the densest (4 °C) water sinks while colder (less dense) water floats on top, eventually freezing into an insulating ice cap that protects fish and other aquatic life in the comparatively warmer (≈4 °C) water below (NCERT §10.5, p. 206–207).
- **Mayer's relation $C_p - C_v = R$** for an ideal gas follows from the first law plus the ideal-gas equation: the extra $C_p - C_v$ accounts for the work done by the gas during

a constant-pressure expansion. Cp and Cv are introduced individually here; their algebraic relation is fully developed in the next NCERT chapter (NCERT §10.6, p. 208–209).

- **Black-body** is an idealised body that absorbs (and re-emits) all incident radiation. Stefan-Boltzmann emission $H = A\sigma T^4$ refers to a perfect black-body (e = 1); for real bodies the emissivity e (0 < e < 1) multiplies the law. Wien's displacement $\lambda\_m T = b$ ($b \approx 2.9 \times 10^{-3}$ m K) tracks the peak of the spectrum (NCERT §10.9.3–10.9.4, p. 218–219).

2.2 Definitions to memorise

Term	Definition	Page
Heat	Form of energy transferred between systems (or system and surroundings) by virtue of temperature difference; SI unit J	203
Temperature	Relative measure of hotness/coldness; SI unit kelvin (K)	203
Absolute zero	The temperature −273.15 °C = 0 K, found by extrapolating P–T lines for low-density gases to P = 0	204
Ideal-gas equation	$PV = \mu RT$, with R = 8.31 J mol^{-1} K^{-1}	204
Coefficient of linear expansion (αl)	$\Delta l/l = \alpha l\ \Delta T$; characteristic of material	205
Coefficient of volume expansion (αv)	$\Delta V/V = \alpha v\ \Delta T$; for solids $\alpha v = 3\alpha l$; for ideal gas $\alpha v = 1/T$	205–206
Anomalous expansion of water	Water contracts on heating between 0 °C and 4 °C; maximum density at 4 °C	206
Thermal stress	Stress developed when expansion/contraction of a rigidly clamped rod is prevented	207
Specific heat capacity (s)	$s = (1/m)(\Delta Q/\Delta T)$; SI unit J kg^{-1} K^{-1}	208
Molar specific heat capacity (C)	$C = (1/\mu)(\Delta Q/\Delta T)$; SI unit J mol^{-1} K^{-1}	208–209
Calorimetry principle	In an isolated system, heat lost by hotter body = heat gained by colder body	209
Melting point	Temperature at which solid and liquid phases coexist in thermal equilibrium	210
Boiling point	Temperature at which liquid and vapour phases coexist in thermal equilibrium	211
Latent heat (L)	L = Q/m; heat per unit mass required for a change of state at constant T, P	213
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Term	Definition	Page
Latent heat of fusion (L_f)	Latent heat for solid → liquid change; L_f(water) = 3.33 × 10^5 J kg^{-1}	
Latent heat of vaporisation (L_v)	Latent heat for liquid → vapour change; L_v(water) = 22.6 × 10^5 J kg^{-1}	213
Sublimation	Direct solid → vapour change (e.g., dry ice, iodine)	212
Conduction	Heat transfer between adjacent parts of a body due to temperature difference, without flow of matter	214
Thermal conductivity (K)	Constant in $H = KA(T_C - T_D)/L$; SI unit W m^{-1} K^{-1}	215
Convection	Heat transfer by bulk motion of matter; possible only in fluids	217
Radiation	Energy transfer by electromagnetic waves; needs no medium	218
Stefan-Boltzmann law	$H = Ae\sigma T^4$ (e = emissivity); σ = 5.67 × 10^{-8} W m^{-2} K^{-4}	219
Wien's displacement law	$\lambda_m T$ = 2.9 × 10^{-3} m K	218
Newton's law of cooling	$-dQ/dt \propto (T_2 - T_1)$ for small temperature differences	220
Triple point of water	273.16 K, 4.58 mm Hg — the unique state where ice, water and vapour coexist	204
Heat capacity (S)	$S = \Delta Q/\Delta T$; SI unit J K^{-1}	208
C_p / C_v	Molar specific heat at constant pressure / volume; difference is R for ideal gas	208–209
Emissivity (e)	Fraction by which a real body radiates compared with a perfect black body	219
Regelation	Refreezing of water on release of high pressure; explains skating on ice	212
Coefficient of area expansion	$\Delta A/A = 2\alpha_l \Delta T$ for isotropic solids	208
Universal gas constant (R)	R = 8.31 J mol^{-1} K^{-1}	204

2.3 Diagrams / processes to remember

- **Fig. 10.1** (p. 203): Straight-line plot of Fahrenheit t_F versus Celsius t_C — basis of conversion equation $(t_F - 32)/180 = t_C/100$.
- **Fig. 10.2 and 10.3** (p. 204): P–T lines for low-density gases at constant volume; all extrapolations meet at absolute zero (–273.15 °C).

- **Fig. 10.4** (p. 204): Side-by-side comparison of Kelvin, Celsius and Fahrenheit scales.
- **Fig. 10.5** (p. 205): Linear, area and volume expansion sketches with the relations $\Delta l/l = \alpha l \, \Delta T$, $\Delta A/A = 2\alpha l \, \Delta T$, $\Delta V/V = 3\alpha l \, \Delta T$.
- **Fig. 10.7** (p. 206): Volume and density of water versus temperature, showing the dip in volume (peak in density) at 4 °C — anomalous expansion of water.
- **Fig. 10.9** (p. 211): Temperature vs time when ice is heated steadily — flat plateaus at 0 °C (melting) and 100 °C (boiling) where latent heat is absorbed.
- **Fig. 10.12** (p. 213): Temperature vs heat for water at 1 atm, showing slopes (specific heats of ice, water, steam) and flat segments of length Lf and Lv.
- **Fig. 10.14** (p. 215): Steady-state conduction along an insulated bar between reservoirs at TC and TD.
- **Fig. 10.17** (p. 217): Convection cycles — day-time sea breeze (warm air rises over land) and reversed night-time circulation.
- **Fig. 10.18** (p. 218): Blackbody emission curves at different temperatures — λm shifts to shorter wavelengths as T rises (Wien's law).
- **Fig. 10.19** (p. 220): Cooling curve T2 – T1 versus t — exponential decay (Newton's law of cooling).
- **Fig. 10.20** (p. 220): Verification of Newton's law of cooling — straight-line plot of loge(T2 – T1) versus t with negative slope.

2.4 Common confusions / NTA trap points

- **Tc = T − 273.15, not −273.16.** The triple point of water is defined as 273.16 K, but the offset between Celsius and Kelvin is 273.15 (NCERT §10.4, p. 204).
- **$\alpha v = 3\alpha l$ applies only to isotropic solids** (and to liquids by definition of αv). For gases $\alpha v = 1/T$ at constant pressure and depends on T (NCERT §10.5, Eq. 10.6, p. 206).
- **Anomalous expansion of water is between 0 ° C and 4 ° C** (not "below 0 °C" or "below 4 °C for all temperatures") — maximum density is at 4 °C (NCERT §10.5, p. 206).
- **Steam at 100 ° C carries 22.6×10^5 J kg^{-1} more heat than water at 100 ° C**; that is why steam burns are more serious than burns from boiling water — a frequent assertion–reason trap (NCERT §10.8.1, p. 213).
- **Stefan-Boltzmann law uses absolute (Kelvin) temperature**, not Celsius, and net loss has $(T^4 - Ts^4)$, not $(T - Ts)^4$ (NCERT §10.9.3, Eq. 10.18, p. 219).
- **Newton's law of cooling holds only for small differences in temperature** between body and surroundings (NCERT §10.10, p. 220).
- **Convection requires a fluid (and gravity for natural convection); conduction does not need bulk motion; radiation does not need any medium.** Mixing these up is a classic NTA distractor (NCERT §10.9, pp. 214–218).

- **Stress = Y × αl × ΔT** for a clamped rod whose expansion is prevented — **independent** of the rod's length. Many students wrongly include L in the formula.
- **Latent heat is absorbed at constant T**, so heating curves for water show two horizontal plateaus (at 0 °C and 100 °C). Sloped segments give specific heat; plateau lengths give latent heat.
- **Boiling vs evaporation**: boiling is bulk vaporisation at the boiling point; evaporation occurs at any temperature from the surface, and is what drives sweat-based cooling.
- **K (thermal conductivity) ≠ k (Newton's-law cooling constant)**; they have different units ($W\ m^{-1}\ K^{-1}$ vs s^{-1}) and arise from unrelated phenomena. The same letter "k" causes confusion in problems.

2.5 Key formulas table

Quantity	Symbol / Formula	NCERT reference
Celsius–Fahrenheit conversion	$(t_F - 32)/180 = t_C/100$	§10.3, Eq. 10.1, p. 203
Kelvin–Celsius conversion	$T = t_C + 273.15$	§10.4, Eq. 10.3, p. 204
Ideal gas equation	$PV = \mu RT$	§10.4, Eq. 10.2, p. 204
Linear expansion	$\Delta l/l = \alpha_l\ \Delta T$	§10.5, Eq. 10.4, p. 205
Area expansion	$\Delta A/A = 2\alpha_l\ \Delta T$	§10.5, p. 208
Volume expansion (solid)	$\Delta V/V = 3\alpha_l\ \Delta T$	§10.5, Eq. 10.9, p. 208
Volume expansion (ideal gas)	$\alpha_v = 1/T$	§10.5, Eq. 10.6, p. 206
Thermal stress	$\sigma = Y\ \alpha_l\ \Delta T$	§10.5, p. 207
Specific heat capacity	$s = (1/m)\ \Delta Q/\Delta T$	§10.6, Eq. 10.11, p. 208
Molar specific heat	$C = (1/\mu)\ \Delta Q/\Delta T$	§10.6, Eq. 10.12, p. 209
Calorimetry	Heat lost = heat gained	§10.7, p. 209
Latent heat	$Q = m\ L$	§10.8.1, Eq. 10.13, p. 213
L_f (water)	$3.33 \times 10^5\ J\ kg^{-1}$	§10.8.1, p. 213
L_v (water)	$22.6 \times 10^5\ J\ kg^{-1}$	§10.8.1, p. 213
Conduction (steady)	$H = KA(T_C - T_D)/L$	§10.9.1, Eq. 10.14, p. 215
Stefan-Boltzmann	$H = A\ e\ \sigma\ T^4$	§10.9.3, Eq. 10.16, p. 219
Stefan-Boltzmann (net)	$H_{net} = e\ \sigma\ A\ (T^4 - T_s^4)$	§10.9.3, Eq. 10.18, p. 219
Wien's displacement	$\lambda_m\ T = 2.9 \times 10^{-3}\ m\ K$	§10.9.4, Eq. 10.15, p. 218
Newton's law of cooling	$-dQ/dt = k\ (T_2 - T_1)$	§10.10, Eq. 10.19, p. 220
Cooling-curve integrated form	$\ln(T_2 - T_1) = -Kt + c$	§10.10, Eq. 10.23, p. 221

🎯 Practice MCQs

📊 PYQ Alignment

Thermal Properties of Matter is one of the most heavily tested CUET Physics units, typically supplying 8–10 MCQs per paper across CUET 2023–25. Recurring question types include numerical problems on temperature-scale conversion, linear/volume expansion ($\Delta L = \alpha L \Delta T$), specific heat and calorimetry (heat lost = heat gained), latent heat of fusion/vaporisation of water, steady-state heat conduction ($H = KA\Delta T/L$), Stefan-Boltzmann law ($H \propto T^4$), Wien's displacement law ($\lambda_m T = b$), and statement-based questions on the three modes of heat transfer and Newton's law of cooling.

CUET 2023–25 — Actual PYQs from this chapter

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