

Introduction to Heat Transfer

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Fundamentals, mechanisms, and key concepts for engineering and science students

1. What Is Heat Transfer?

Definition	Explanation
Heat transfer	The movement of thermal energy from a region of higher temperature to a region of lower temperature.
System boundary	The surface (real or imagined) that separates the system (where we track energy) from its surroundings.
Driving force	Temperature difference (ΔT) between two points.

Key point: Heat transfer does **not** create or destroy energy; it merely relocates it. The total energy of an isolated system remains constant (first law of thermodynamics).

2. Modes of Heat Transfer

Mode	Physical Mechanism	Governing Law	Typical Applications
Conduction	Molecular/atomic vibration and electron motion in solids and stationary fluids.	Fourier's Law: $\mathbf{q} = -k \nabla T$ (heat flux $\mathbf{q}$, thermal conductivity k , temperature gradient ∇T)	Heat exchangers, building walls, electronic components.
Convection	Bulk fluid motion carries heat; includes both forced (pump/fan) and natural (buoyancy) flow.	Newton's Law of Cooling: $\mathbf{q} = h A (T_s - T_\infty)$ (heat transfer coefficient h , area A , surface temperature T_s , fluid temperature T_∞)	HVAC systems, cooling of turbines, oceanic/atmospheric circulation.
Radiation	Emission of electromagnetic waves (infrared) from any body with temperature $> 0\text{K}$.	Stefan-Boltzmann Law: $\mathbf{q} = \epsilon A (T^4 - T_{\text{surr}}^4)$ (emissivity ϵ , Stefan-Boltzmann constant $\sigma = 5.67 \times 10^{-8} \text{W/m}^2\text{K}^4$)	Solar heating, furnace walls, spacecraft thermal control.

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All three modes can act simultaneously; the dominant mode depends on geometry, material, and operating conditions.

3. Fundamental Concepts

3.1 Temperature & Thermodynamic Temperature

- **Temperature (°C, °F)** – practical scale for engineering.
- **Absolute temperature (K)** – required in heat transfer formulas (e.g., radiation).

3.2 Thermal Conductivity (k)

- Material property (W/m·K).
- **Metals:** high k (e.g., copper ≈ 400 W/m·K).
- **Insulators:** low k (e.g., polystyrene ≈ 0.03 W/m·K).

3.3 Heat Transfer Coefficient (h)

- Represents combined effects of convection and surface resistance.
- Units: W/m²·K.
- Determined experimentally or via empirical correlations (e.g., Nusselt number relationships).

3.4 Thermal Resistance (R)

- Analogy to electrical resistance: $R = \Delta T / Q$.
- For conduction through a slab: $R_{\text{cond}} = L/(kA)$.
- For convection: $R_{\text{conv}} = 1/(hA)$.
- For radiation (linearized): $R_{\text{rad}} = 1/(h_{\text{rad}}A)$.

3.5 Dimensionless Numbers (used in correlations)

Number	Physical Meaning	Typical Form
Re (Reynolds)	Ratio of inertial to viscous forces (flow regime)	$Re = \rho V D / \mu$