Thermal transport, calorimetry and expansion

GRE undergraduate preparation · local supported objectives

Thermal transport, calorimetry and expansion

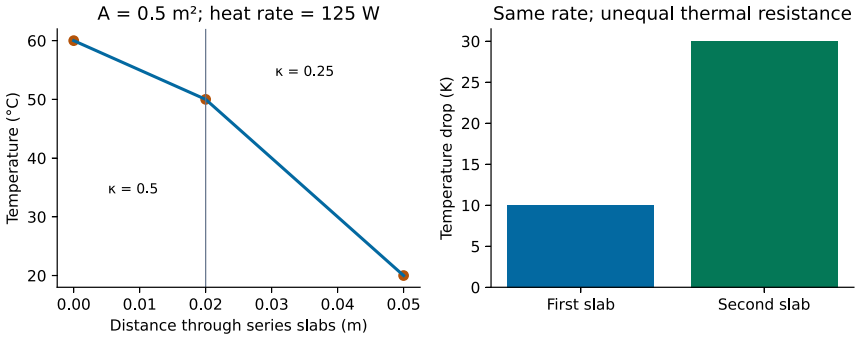
- Use **conduction 热传导** and **thermal resistance 热阻** through layers.
- Balance heat in mixing problems with **specific heat capacity 比热容** and **latent heat**.
- Use **thermal expansion 热膨胀** and **thermal stress 热应力**.
- Use radiation and Newton's law of cooling.

Conduction and thermal resistance

- Layers in series carry the same $\dot{Q}$, and their resistances add, like resistors in series.
- Each layer's temperature drop is $\dot{Q}R_{\text{th}}$, so the layer with more resistance takes the bigger drop.
- Parallel paths share the same ΔT, and their heat rates add.

$$\dot{Q} = \frac{\kappa A \, \Delta T}{L} = \frac{\Delta T}{R_{\text{th}}}, \qquad R_{\text{th}} = \frac{L}{\kappa A}$$

Figure: Conduction and thermal resistance



- The same heat current crosses both slabs; the slab with more **thermal resistance** takes the larger drop
- Read the axes and units first.

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Calorimetry and latent heat

- Include the container if its heat capacity is given.
- At a phase change, heat $Q = m\ell$ changes the phase, not the temperature.
- First check whether there is enough heat to complete the phase change; if not, the final state is a mixture at the transition temperature.

Expansion and thermal stress

- Areas expand by 2α and volumes by 3α (for small changes).
- A hole in a plate grows when the plate is heated, as if it were made of the same material.
- A rod held between fixed walls cannot expand, so it feels a stress $-Y\alpha\,\Delta T$, where Y is Young's modulus.

$$\Delta L = \alpha L\,\Delta T$$

Radiation and cooling

- Net radiated power: $\varepsilon\sigma A(T^4 - T_{\text{env}}^4)$, with temperatures in kelvin. Doubling the absolute temperature gives 16 times the emission.
- Newton's law of cooling: for small temperature differences, the excess $T - T_{\text{env}}$ decays exponentially with time constant $C/(hA)$.

Worked example: a two-layer wall

- $R_1 = 0.020/(0.50 \times 0.50) = 0.080$ K/W and $R_2 = 0.030/(0.25 \times 0.50) = 0.24$ K/W.
- $\dot{Q} = 40/0.32 = 125$ W.
- Drops: $125 \times 0.080 = 10$ K and $125 \times 0.24 = 30$ K, so the interface is at 50 °C.

Worked example: ice in warm water

- Melting all the ice needs $0.20 \times 334 = 67$ kJ; cooling the water to 0 °C would release $1.0 \times 4.18 \times 40 = 167$ kJ. So all the ice melts.
- Balance: $1.0(4.18)(40 - T) = 66.8 + 0.20(4.18)\,T$, so $T = 20$ °C.
- A 2.0 m steel rod ($\alpha = 1.0 \times 10^{-5}$ K^{-1}) heated by 50 K grows 1.0 mm; clamped, with $Y = 100$ GPa, it feels 50 MPa of compression.

Common errors

- Giving both layers of a wall the same temperature drop.
- Ignoring the **latent heat**, or letting the temperature change during a phase change.
- Thinking a hole shrinks when a plate is heated.

Common errors (2)

- Using degrees Celsius in the radiation law.
- Applying Newton's law of cooling to the temperature instead of the excess over the surroundings.

Key terms

- **latent heat**: Heat that changes a phase without changing the temperature.
- **calorimetry**: Measuring heat by balancing the heat gained and lost in an isolated system.
- **conduction**: Heat flow through a material from hot to cold, without the material moving.
- **thermal resistance**: $L/(\kappa A)$, the temperature drop per watt of heat flow.

Check yourself

- 2.0 kg of water at 80 °C is mixed with 1.0 kg at 20 °C. What is the final temperature?
- A body's absolute temperature doubles. By what factor does its radiated power grow?
- A metal plate with a hole in it is heated. What happens to the hole?