Lecture 28: Heat energy and transport

- 0^{th} law of Thermodynamics
- Heat and temperature change
- Heat transfer

Zero-th Law of Thermodynamics

Two objects in thermal contact, no interaction with the environment → will reach the same temperature after sufficient time.
= Thermal equilibrium.

If two objects are in thermal equilibrium with a third object, they are in thermal equilibrium with each other.

Basis for any temperature measurement

Energy transfer

If two objects are in contact: Energy transfer.

Heat energy transferred because of difference in temperature.
Heat is always flowing from hot object to cold object

If heat is put into an object, its temperature rises.

$$\Delta T = \frac{Q}{m c_{substance}}$$

$c_{substance}$ is called specific heat, heat capacity

Heat

$$Q = mc\Delta T$$

Q is the amount of heat energy that needs to be transferred into mass m of the substance to change its temperature by ΔT.

If Q is positive:
- ΔT is positive (temperature increases)
- Heat energy flows into system

If Q is negative:
- ΔT is negative (temperature decreases)
- Heat flows out of the system

Heat in phase changes

Phase changes (phase transitions) require (+) or release (–) extra amount of heat.

$$\begin{tikzcd}
\text{solid} \arrow[r, shift left, "Q = +mL_f"] & \text{liquid} \arrow[l, shift left, "Q = -mL_f"]
\end{tikzcd}$$

L_f latent heat of fusion

$$\begin{tikzcd}
\text{liquid} \arrow[r, shift left, "Q = +mL_v"] & \text{gas} \arrow[l, shift left, "Q = -mL_v"]
\end{tikzcd}$$

L_v latent heat of vaporization

Example 1

300 g of tea at 70º C are poured into a 120g cup made of aluminum that is at a temperature of 20º C. What is the final temperature?

Example 2

You have 0.25 kg of water at 25 ºC and are adding ice to it that has a temperature of – 20ºC. How much ice is needed to that the final temperature of the mixture is 0ºC and all ice is melted? Neglect the container.

Three mechanisms of heat transfer

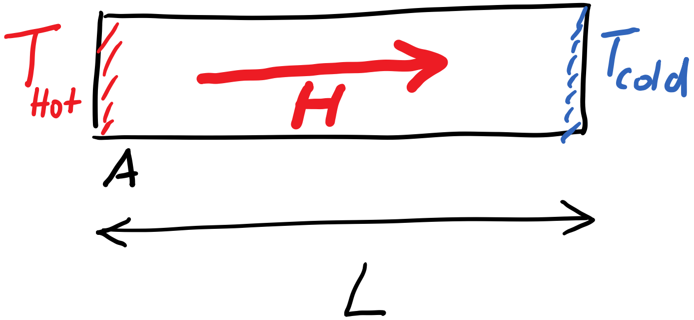
Conduction

Convection

Radiation

Heat conduction

length L
cross sectional area A
temperatures $T_{\boldsymbol{hot}}$ and $T_{\boldsymbol{cold}}$ at ends

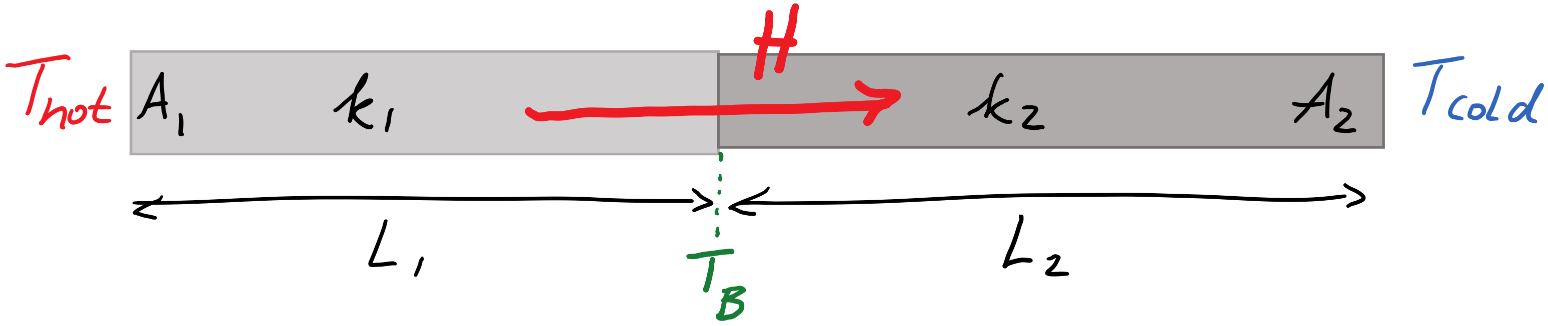


Rate of heat energy flow through area A *in steady state:*

$$\boxed{H = \frac{dQ}{dt} = kA\,\frac{T_{hot} - T_{cold}}{L}}$$

k thermal conductivity, material property

Material boundaries



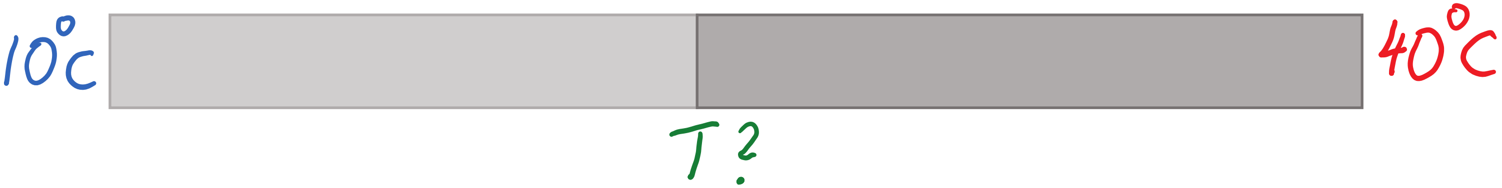
$$H_1 = \frac{k_1 A_1 (T_{hot} - T_B)}{L_1} = H_2 = \frac{k_2 A_2 (T_B - T_{cold})}{L_2}$$

Layers of different materials with different thermal conductivities k_n and thickness L_n:

$$\boxed{H = A\frac{T_{hot} - T_{cold}}{R_{tot}}}$$

$$R_{tot} = \sum R_n \qquad R_n = \frac{L_n}{k_n}$$

Example



A rod of uniform cross section has its left end placed in water of a temperature 10ºC and its right end at 40ºC. The left half of the rod consists of material A with a thermal conductivity of 400 W/mºC, the right half of material B with thermal conductivity of 200 W/mºC. The temperature in the middle of the rod is:

A) 20ºC B) 25º C C) 30.5º C D) 18ºC