Heat Transfer (Sec 19.11)

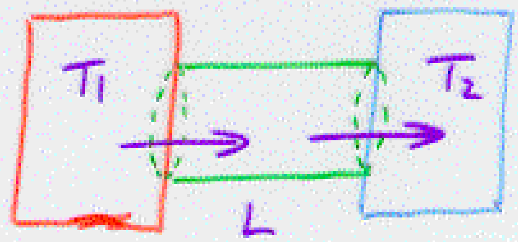
Conduction, Convection, Radiation

① Conduction – heat flows through medium

Conductors (e.g. metal), insulators (e.g. plastic, air)

Thermal Conductivity k [W/m/K] given by:

$$\boxed{\text{Heat flow } H = \frac{dQ}{dt} = K.A.\underbrace{\frac{\Delta T}{L}}_{\text{temp. gradient}}}$$



e.g. Steel wok handle: $A = 1\,cm^2 = 10^{-4}\,m^2$, $L = 0.2\,m$, $\Delta T = 80°C$

$\Rightarrow$ heat flow $H = 14.0 \times 10^{-4} \times \frac{80}{0.2} = 0.56\ W$

OR place tongue on frozen pipe: $L \approx$ skin thickness

$\Rightarrow$ heat conducted quickly!

Note: water conducts much better than air

Human body in 75°F air: OK

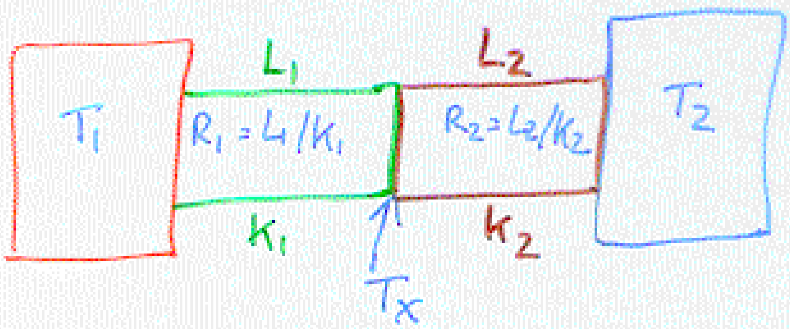
" " 75°F water: cannot generate heat fast enough

$\rightarrow$ death in hours!

Thermal Resistance $\boxed{R = \frac{L}{k}}$ for a given length of conductor/insulator.

Then "heat current" $\frac{H}{A} = \frac{\text{temp. diff.}}{\text{resistance}} = \frac{\Delta T}{R}$

- Useful for "resistors" in series (layers):



Temp. at interface T_x given by: (steady flow)

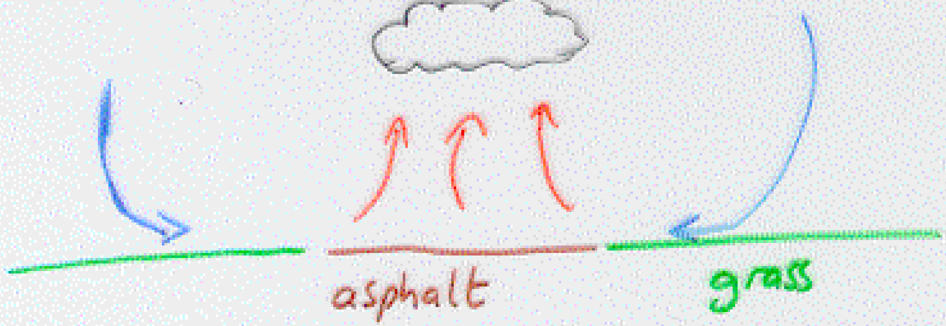
Current $\frac{H}{A} = \frac{T_1 - T_x}{R_1} = \frac{T_x - T_2}{R_2}$

Can show total thermal resistance $R = R_1 + R_2$

i.e. $\frac{H}{A} = \frac{T_1 - T_2}{R}$ (c.f. $I = V/R$ Ohm's law)

② Convection: bulk flow in fluids

e.g. clouds, sun, chimney effect ("backdraft")



As fluid heats up, $\rho \downarrow$ and it rises; cooler fluid takes its place. Rising / falling fluid forms convection cells – hard to model!

③ Electromagnetic radiation (details: Physics 2D):

Radiated power $P_r = \varepsilon A \sigma T^4$

ε = emissivity A = area σ = Boltzmann's constant

(black : $\varepsilon \approx 1$
silver : $\varepsilon \to 0$)

Net energy exchange $P_n = P_r - P_{env}$

$$= \varepsilon A \sigma \left(T_r^4 - T_{env}^4 \right)$$