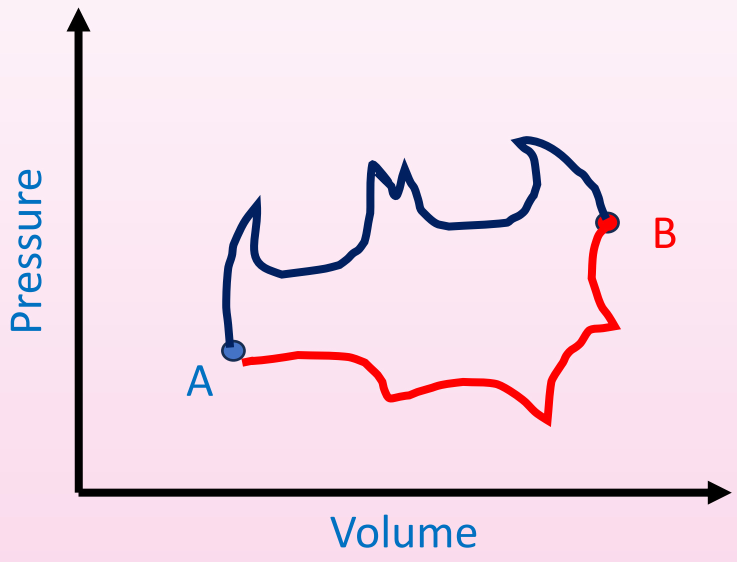
Recap from last time



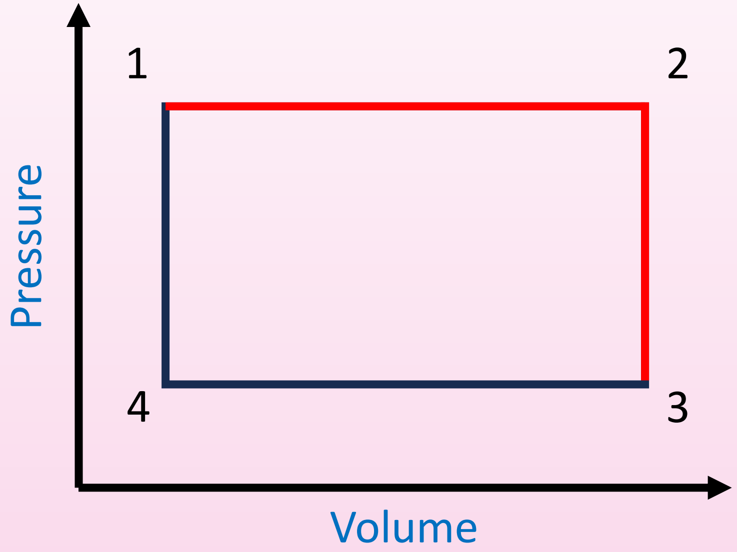
Going from A to B via two paths, red and blue

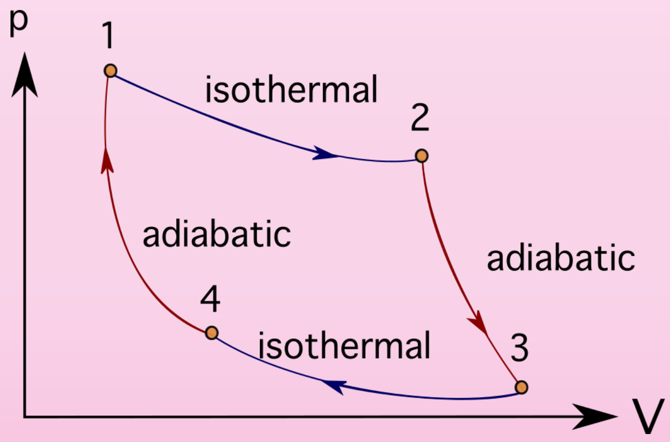
The change in internal energy, ΔU, is equal for both paths

The work done by the system, W_{by}, is greater for the blue path than the red

The heat transferred into the system, Q_{in}, is greater for the blue path than the red as well

Recap from last time

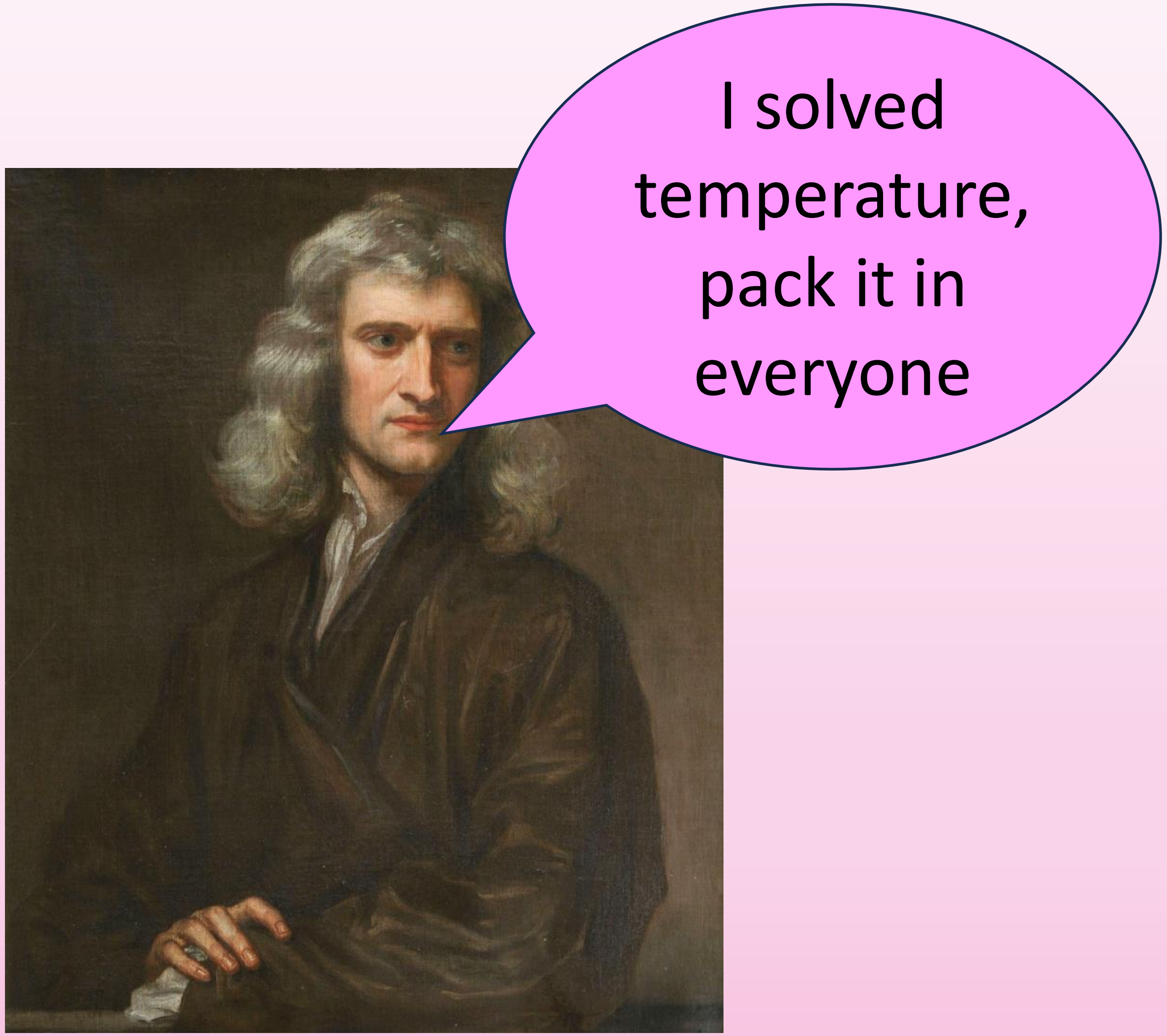




Rules for cycles:

1) $\Delta U = 0$ for a full cycle ALWAYS
2) Work done given by area inside loop
3) Clockwise for positive work, anticlockwise for negative work
4) Q_{in} and W_{on} must sum to zero (as $\Delta U = 0$)

Newton’s law of cooling



Newton’s law of cooling states that:

“The rate of heat loss of a body is directly proportional to the difference in the temperatures between the body and its environment”

Thermal transport

Conduction: Heat is transmitted directly from one material to an adjoining material (or one part of a material to a different part of itself) if there is a temperature difference between the two, without movement of the material

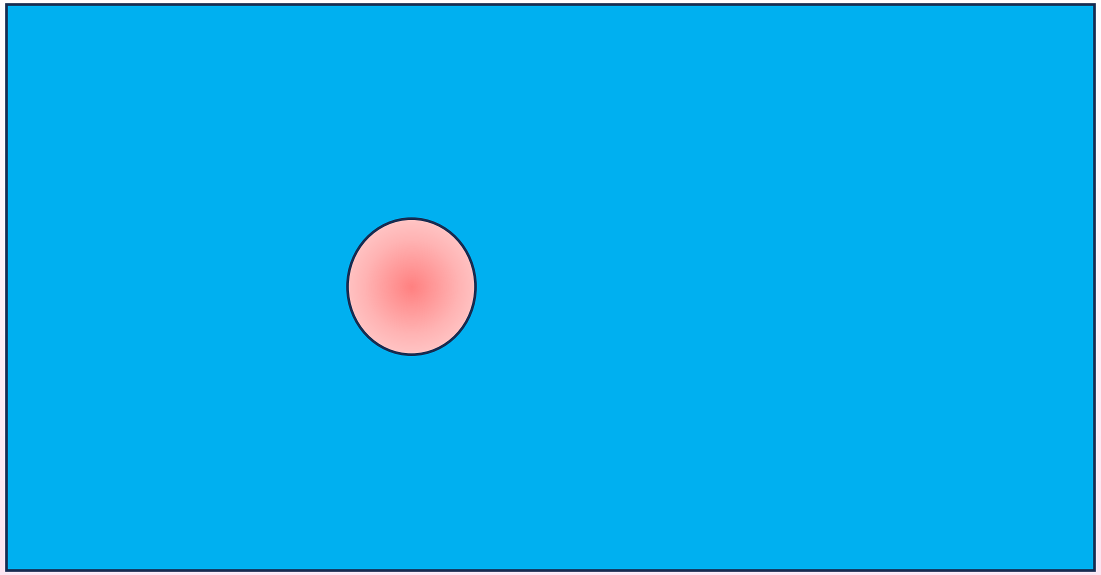
Convection: Movement of particles through a substance (typically constituent particles of a fluid) that take their heat energy with them

Radiation: Emission of electromagnetic radiation by all bodies that have heat (i.e. all bodies) which depends on their temperature

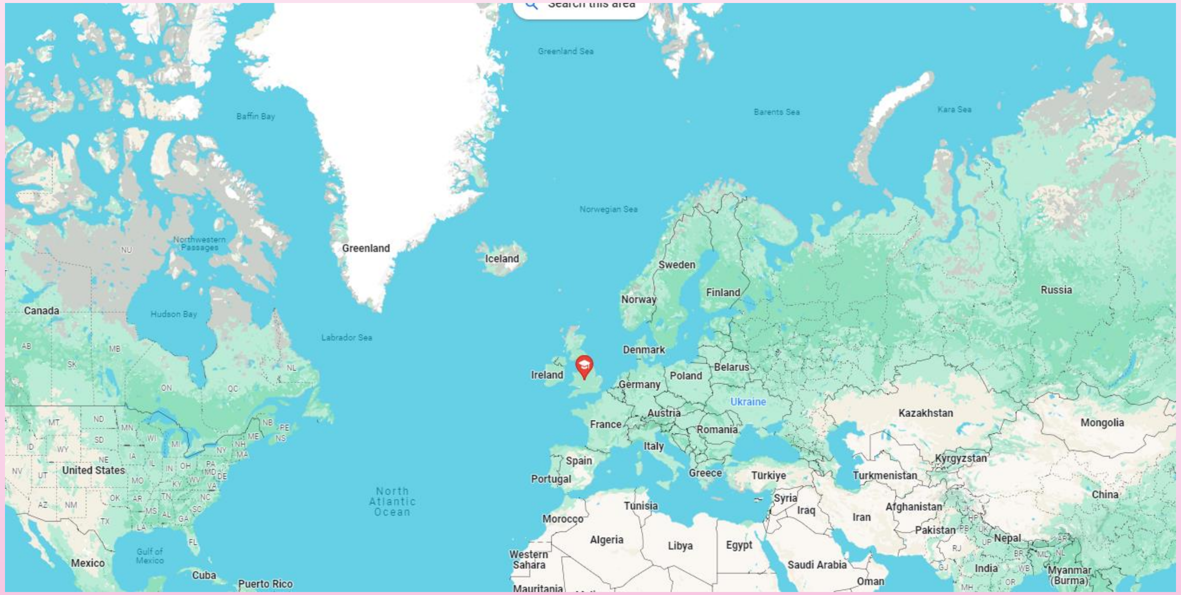
Heat baths

A heat bath is an object that has a sufficiently large value of heat capacity C such that a large change in heat energy will change its temperature negligibly:

$$\Delta Q = C\Delta T$$

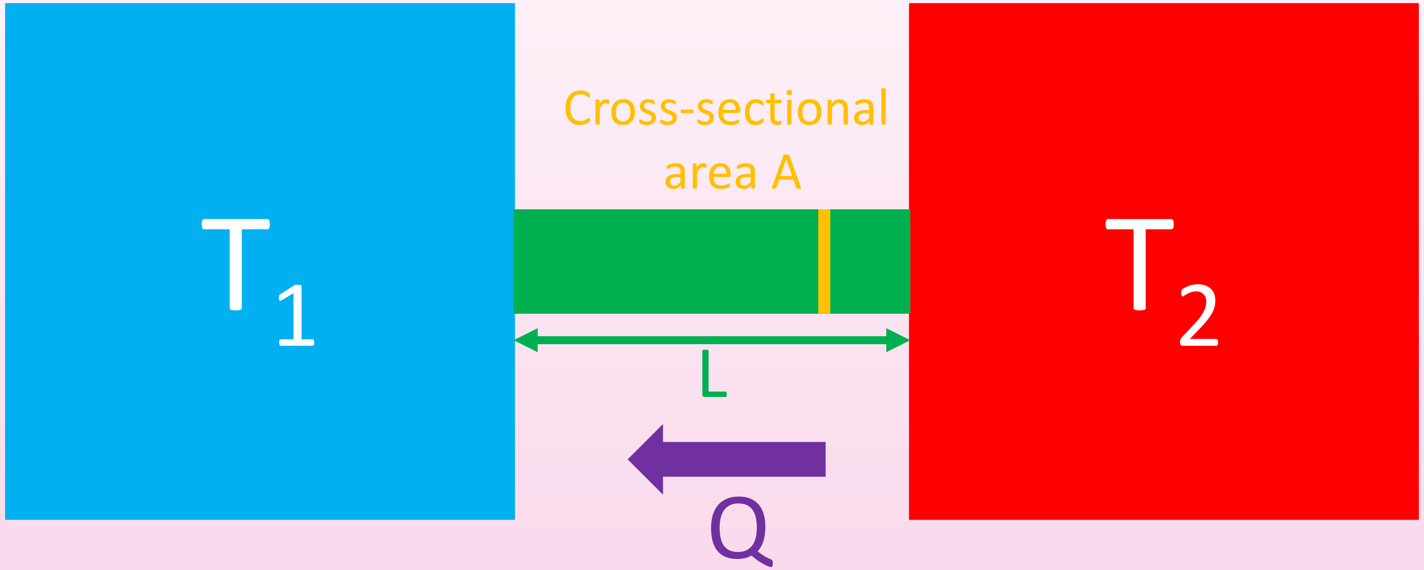


e.g. a hot object placed into a large volume of water



e.g. the Law building placed into a large volume of planet

Conduction

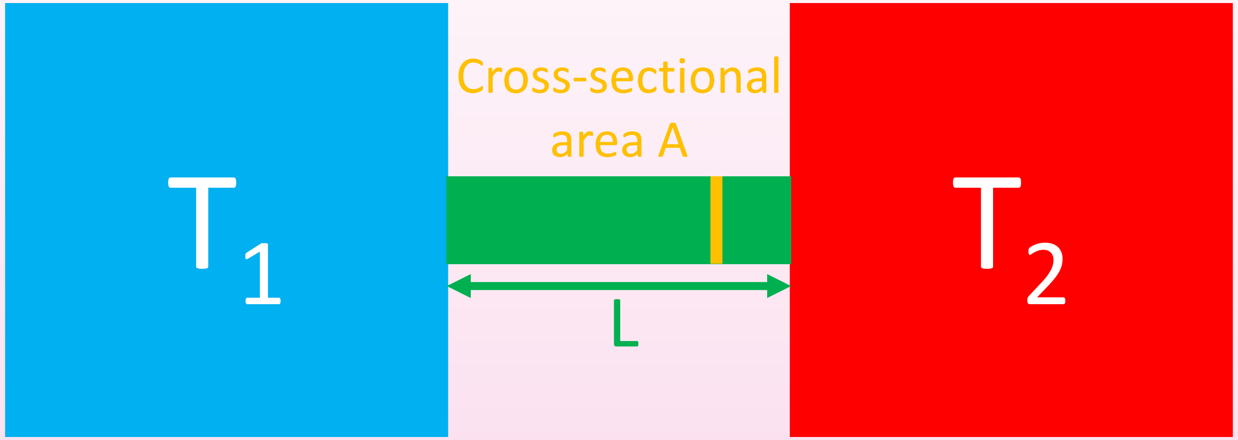


Suppose we have a small uniform conducting rod of length A and cross-sectional area A linking two heat baths of temperature T_1 and T_2

$\frac{dQ}{dt} = \dot{Q}$ is the same across all points along the rod for steady state (unchanging wrt time) system

But what does $\dot{Q}$ depend on?

Conduction



$$\dot{Q} = \kappa A \frac{\mathrm{d}T}{\mathrm{d}x}$$

Fourier's Law

Can show that $\frac{\mathrm{d}T}{\mathrm{d}x} = \frac{T_2 - T_1}{L}$

Newton's law of cooling seemingly obeyed!

$\dot{Q}$ for a small section dx of the rod depends on:

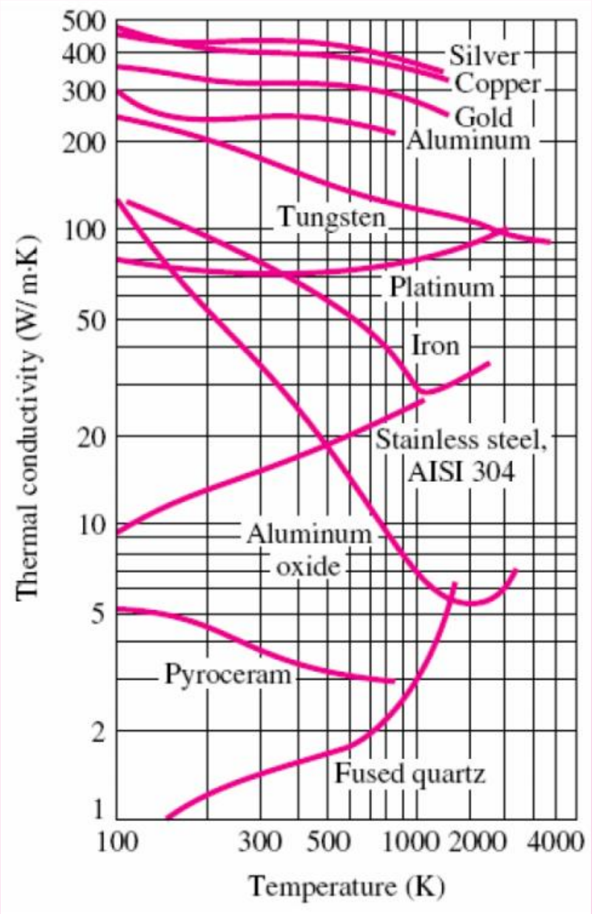
1) Temperature change $\mathrm{d}T$ of the small section

2) Cross-sectional area of the conductor, A

3) The "thermal conductivity" of the rod, κ (metals better at transferring heat than insulators, for example)

units of W m^{-1} K^{-1}

Breakdown of Newton's law of cooling



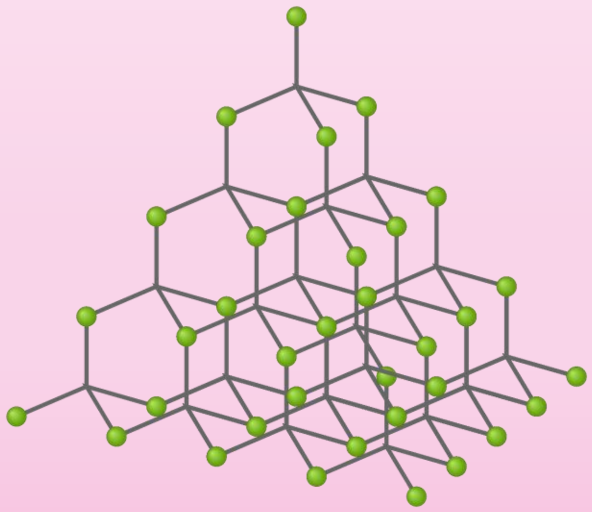
https://physics.stackexchange.com/questions/330158/why-does-the-thermal-conductivity-of-pure-metals-decrease-with-increase-in-tem

If for $\dot{Q} = \kappa A \frac{T_2 - T_1}{L}$ we find that κ varies with temperature, Newton's law of cooling (direct proportionality between temperature difference and rate of flow of heat) is no longer true

Thermal conductivity due to two sources: movement of electrons or movement of phonons

Thermal conductivity

Material	Thermal conductivity (κ) (W m^{-1} K^{-1})
Diamond (natural)	2200
Copper	400
Air	0.02
Aerogel	0.003



Diamond's rigidity is the cause of its high thermal conductivity

High frequency vibrations (phonons) are able to propagate through the material


green

Thermal conductivity

Material	Thermal conductivity (κ) (W m^{-1} K^{-1})
Diamond	1000
Copper	400
Air	0.02
Aerogel	0.003

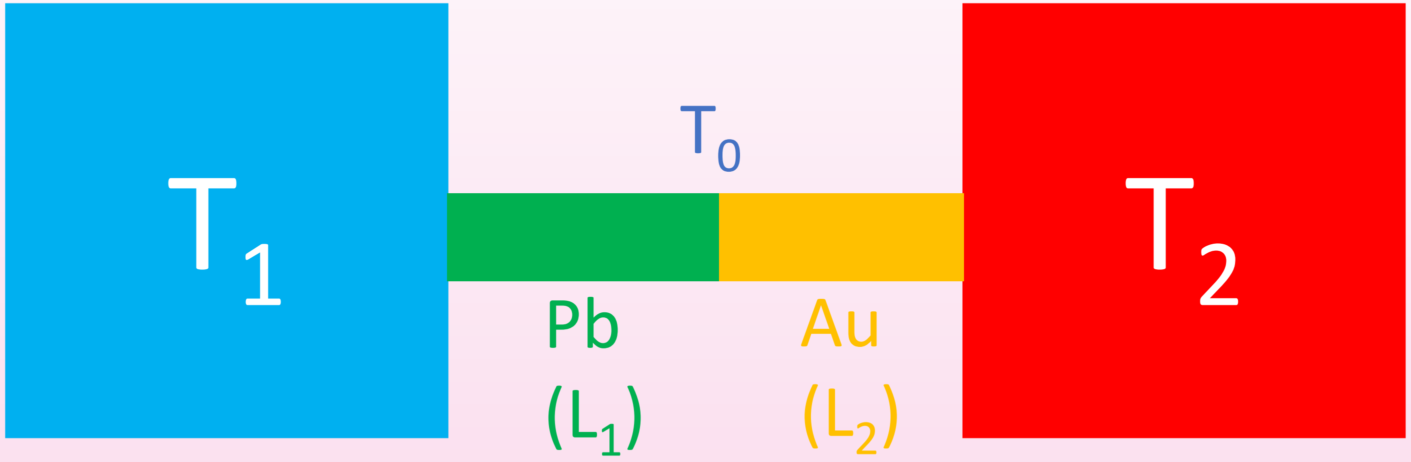
Can also define

Thermal resistivity $\rho = 1/\kappa$

Thermal conductance $K = \kappa A/L$

Thermal resistance $R = L/(\kappa A)$

More complicated conduction cases



Thermal resistances add like electrical resistances in series! R = $R_1 + R_2$

Problem 4.6 **Series and parallel thermal conductors**
Consider two thermal conductances, with thermal conductivities κ_1 and κ_2, cross-sectional areas A_1 and A_2 and lengths L_1 and L_2.

Initially connect them in *series* between two heat baths at T_1 and T_2.

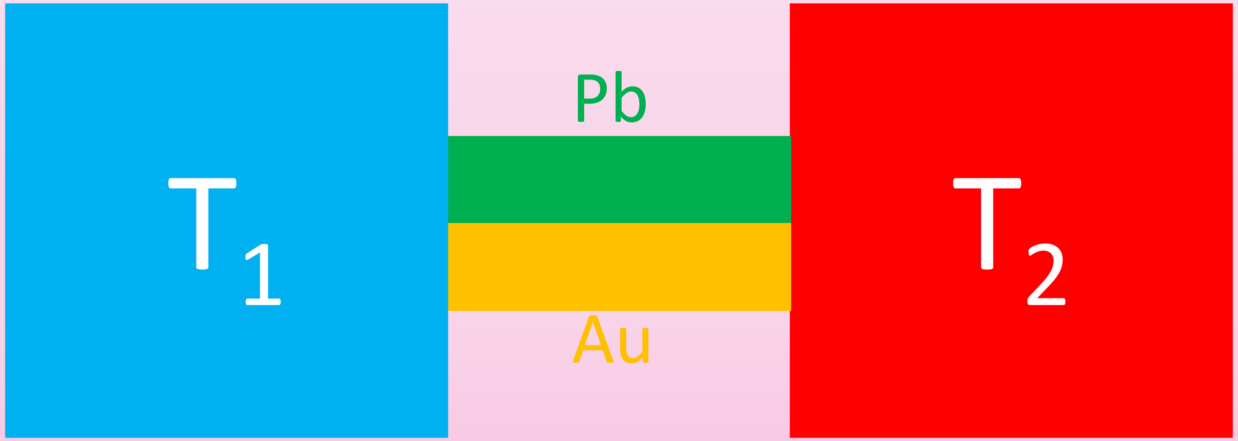
1. What is the condition that no heat builds up at the boundary between them and hence there is a steady state heat flow?
2. Deduce the temperature at the interface between the two materials.

More complicated conduction cases

Now put them in *parallel* between the two heat baths, disregarding the inconvenient difference in lengths.

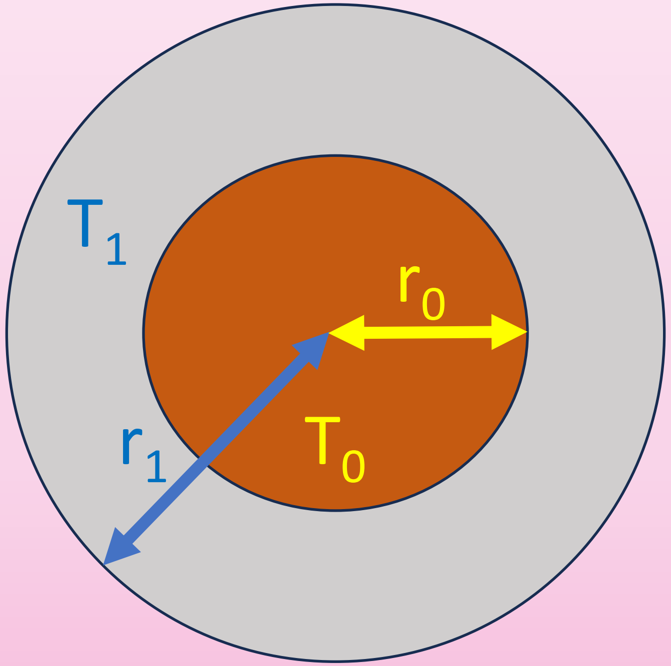
3. What is the heat flow through each conductor? And what is the total thermal conductor? Is this consistent, physically, with the factor of A in the expression for the thermal flux of a single conductor?

Thermal resistances add like electrical resistances in parallel! $1/R = 1/R_1 + 1/R_2$



Pipe lagging example

Pipe lagging is foam insulation around a metal pipe carrying (usually) hot fluid (pretty important to stop heat loss!)



$\kappa = 0.05$ W m^{-1} K^{-1}

Length L
normal to screen

$$\dot{Q} = -\kappa A \frac{\mathrm{d}T}{\mathrm{d}r}$$

$$\dot{Q} = \frac{2\pi\kappa L(T_0 - T_1)}{\ln\left(\frac{r_1}{r_0}\right)}$$

Summary

Briefly described the mechanisms by which heat can transfer between two bodies

Described conduction in more detail and discussed why certain bodies are good thermal conductors (and others aren’t)

Saw that thermal resistance acts very similarly to electrical resistance (which shouldn’t be a surprise – they weren’t named by accident)