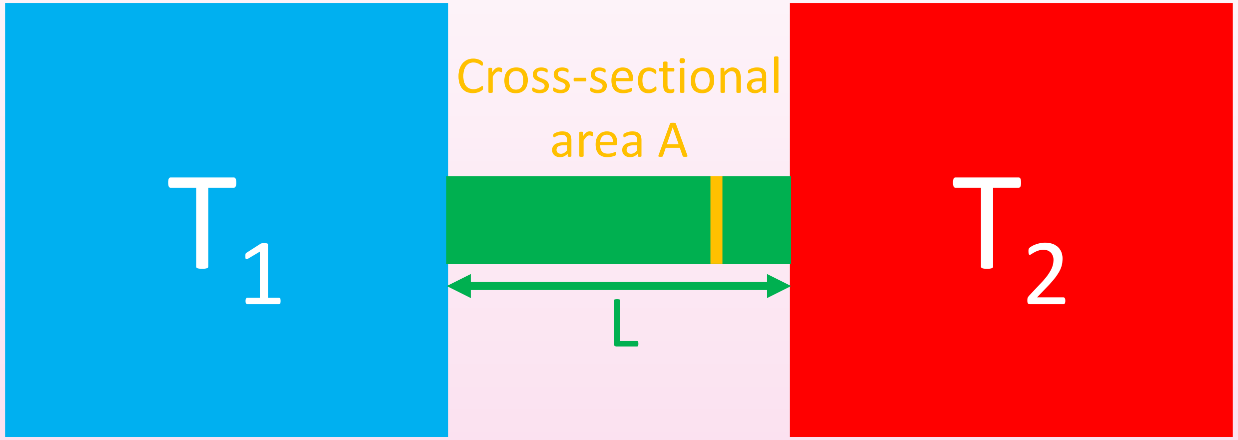
Recap from last time

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

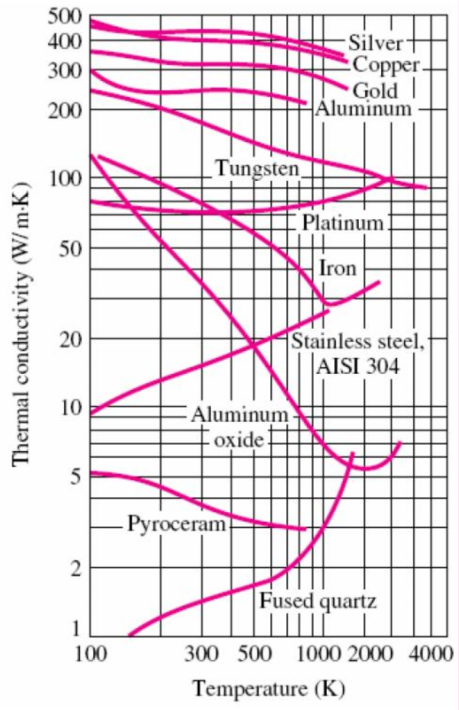
Recap from last time



$$\dot{Q} = \kappa A \frac{\mathrm{d}T}{\mathrm{d}x}$$ Fourier's Law

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

Conduction determined by two physical processes – transfer of heat via movement of electrons or via phonons



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

Recap from last time

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

Can also define

Thermal resistivity $\rho = 1/\kappa$

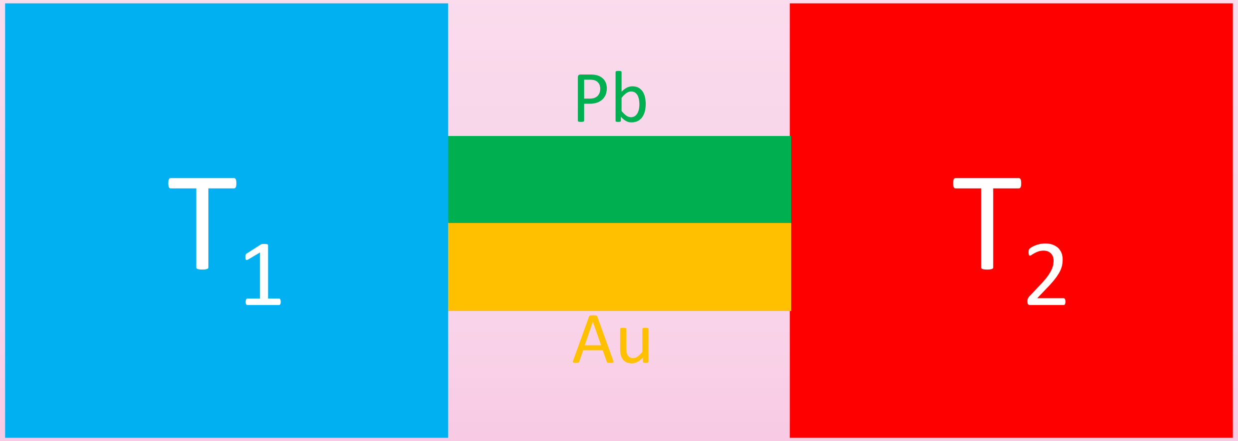
Thermal conductance $K = \kappa A/L$

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

More complicated conduction cases

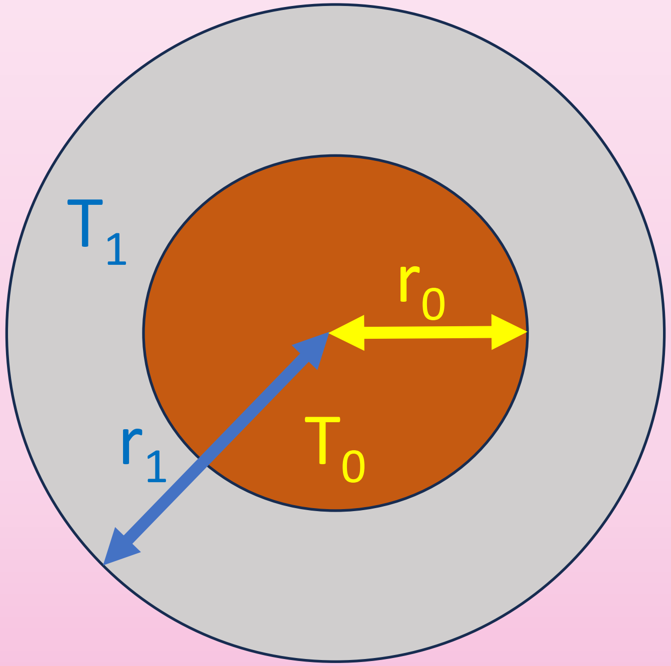
Thermal resistances add like electrical resistances in series! $R = R_1 + R_2$

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!)



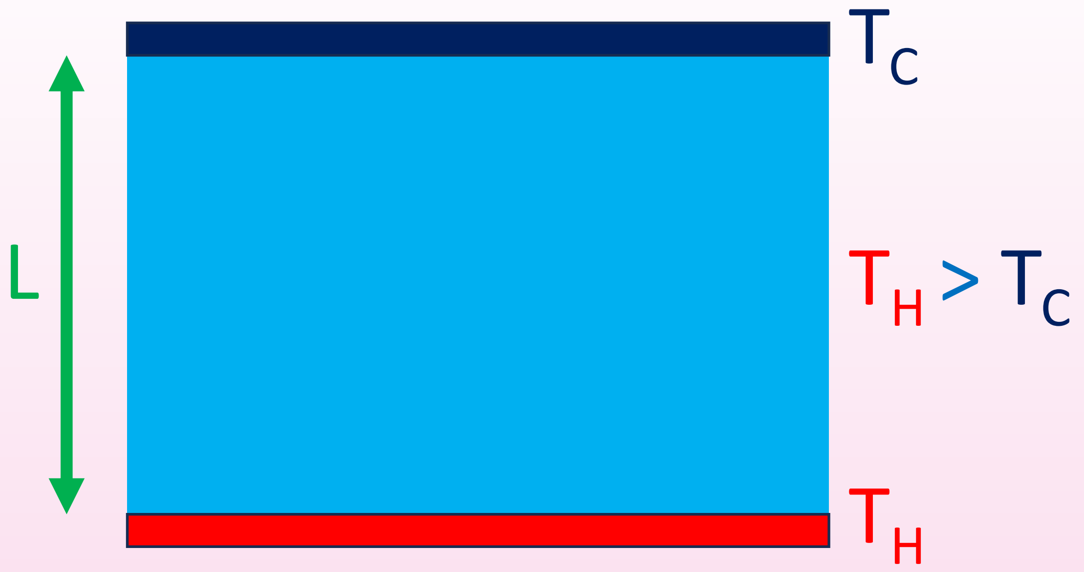
$\kappa = 0.05\ \mathrm{W\ m^{-1}\ K^{-1}}$

Length L
normal to screen

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

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

Convection



Imagine a fluid suspended between two plates, with respective temperatures T_C and T_H, separated by a distance L

What governs whether convection occurs?

1) Buoyancy (β) $= \frac{1}{V}\left(\frac{\partial V}{\partial T}\right)_P$
2) Thermal conductivity (κ)
3) Viscosity (η)

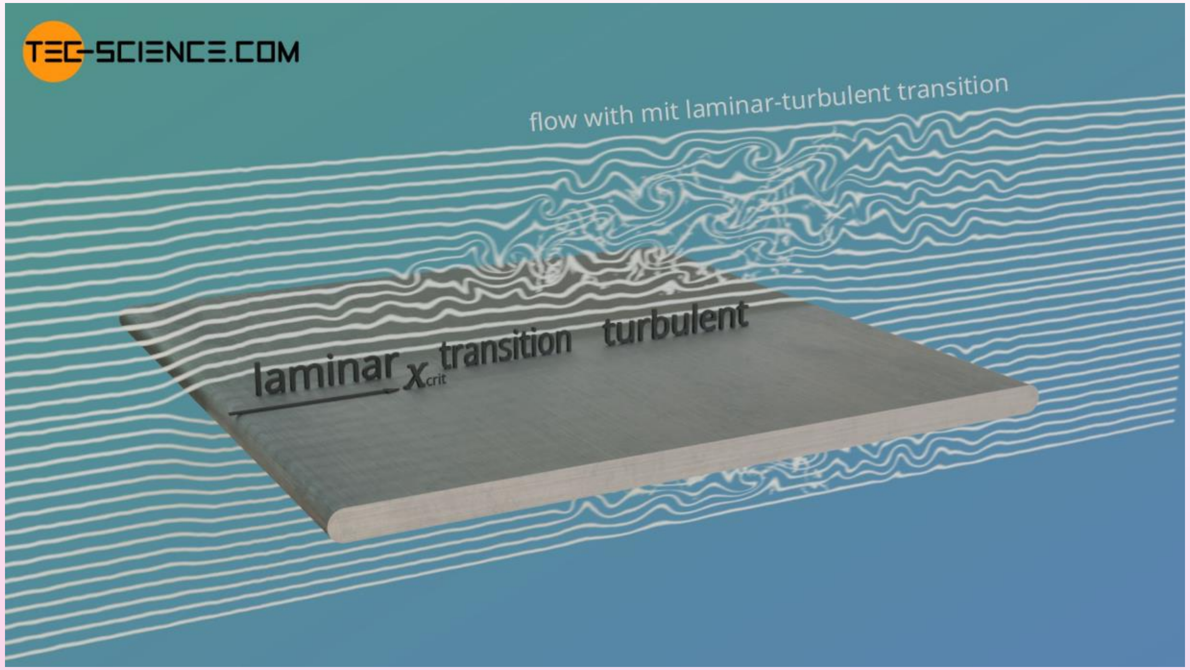
Rayleigh number, $\mathrm{Ra} = \frac{\rho L^3 (\beta (T_H - T_C)) g}{\eta \alpha}$

$$\alpha = \frac{\kappa}{\rho c_P}$$

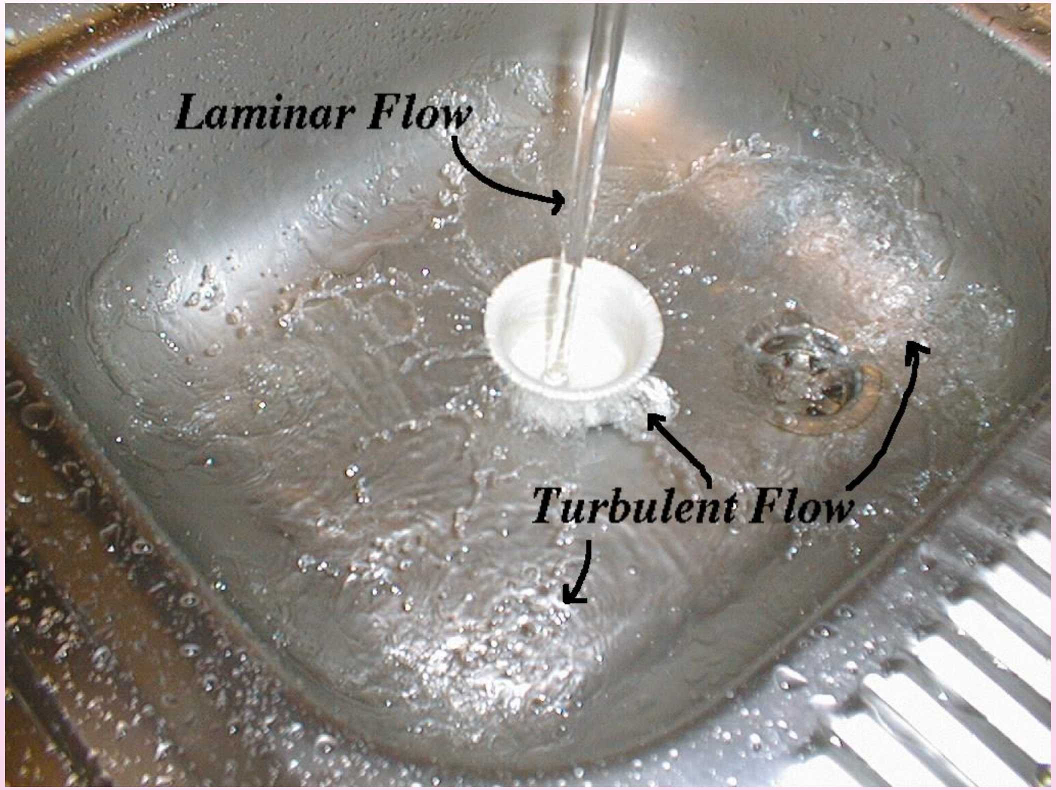
If $R_a > 1000$ then convection occurs

If $R_a > 100000$ convection is turbulent

Turbulent flow

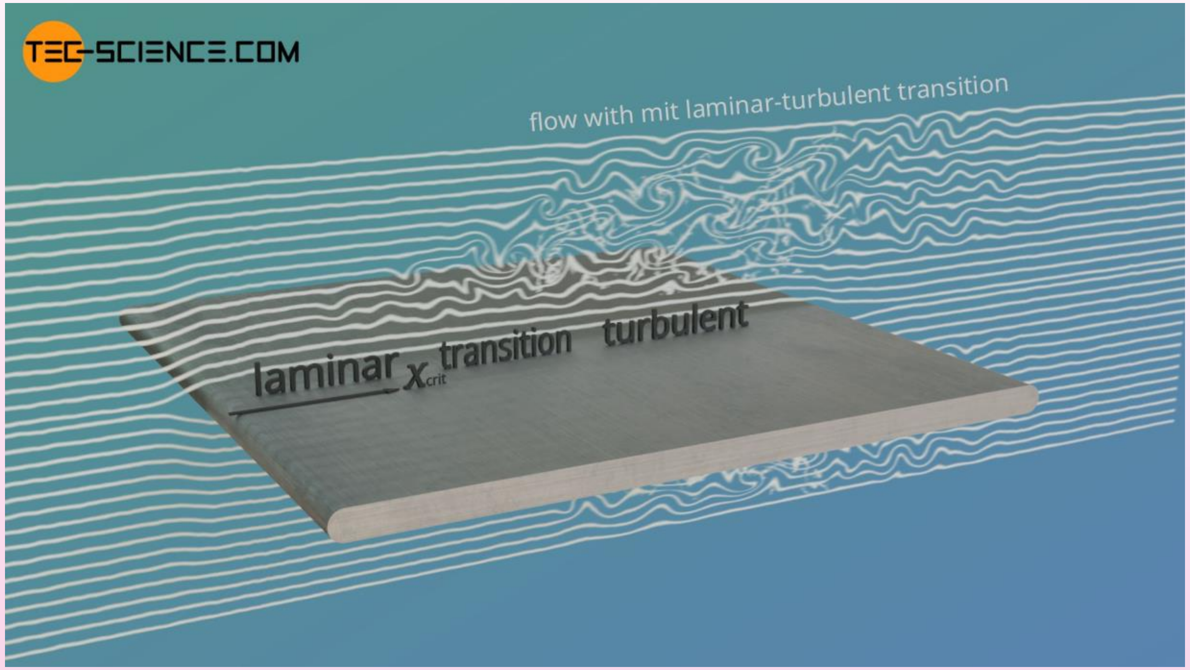


https://www.tec-science.com/wp-content/uploads/2021/04/en-gases-liquids-fluid-mechanics-nusselt-number-calculation-plate-laminar-turbulent-1.jpg



https://www.cora.nwra.com/~werne/eos/images/turbulent.jpg

Turbulent flow



https://www.tec-science.com/wp-content/uploads/2021/04/en-gases-liquids-fluid-mechanics-nusselt-number-calculation-plate-laminar-turbulent-1.jpg

https://physics.aps.org/articles/v2/74

Double glazing

Rayleigh number, $\mathrm{Ra} = \dfrac{\rho L^3 (\beta (T_H - T_C)) g}{\eta \alpha}$ $\qquad \alpha = \dfrac{\kappa}{\rho c_P}$

ρ = 1.2 kg m^{-3}

β = 3.7 x 10^{-3} K^{-1}

c_P = 1 kJ kg^{-1} K^{-1}

κ = 24 mW m^{-1} K^{-1}

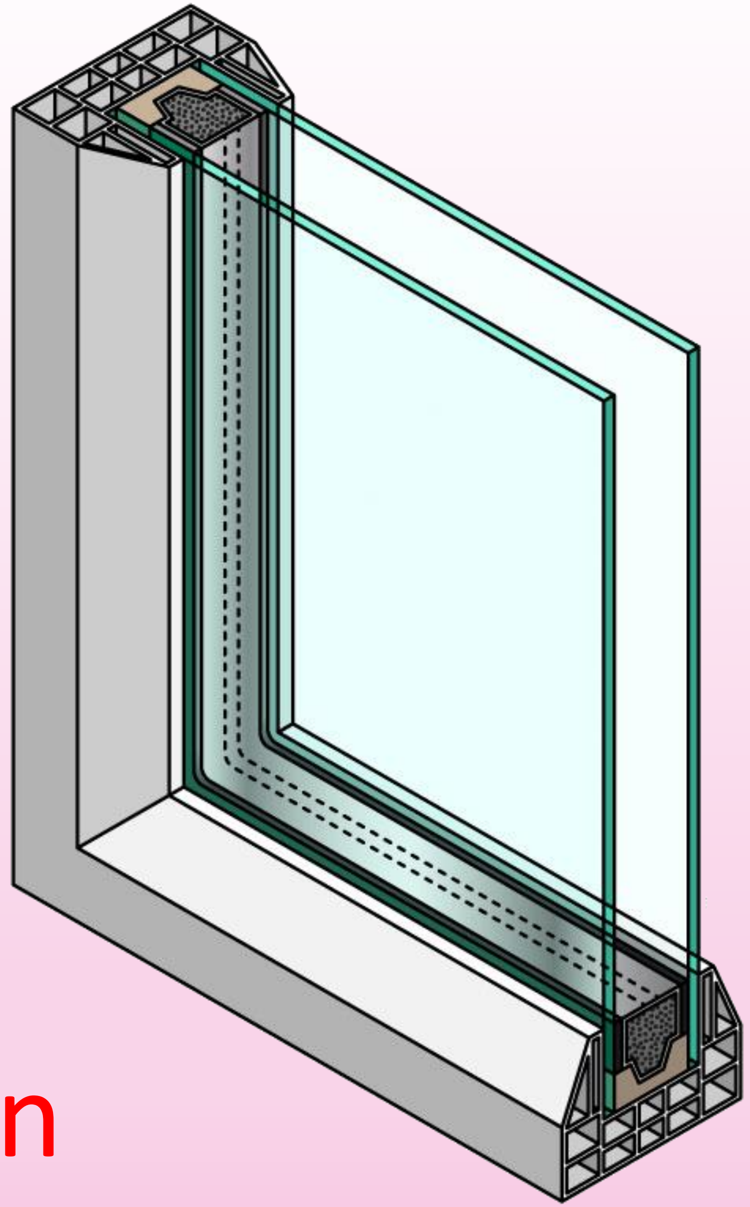
L = 5 mm

η = 17 µPa s

T_H = 298 K, T_C = 278 K

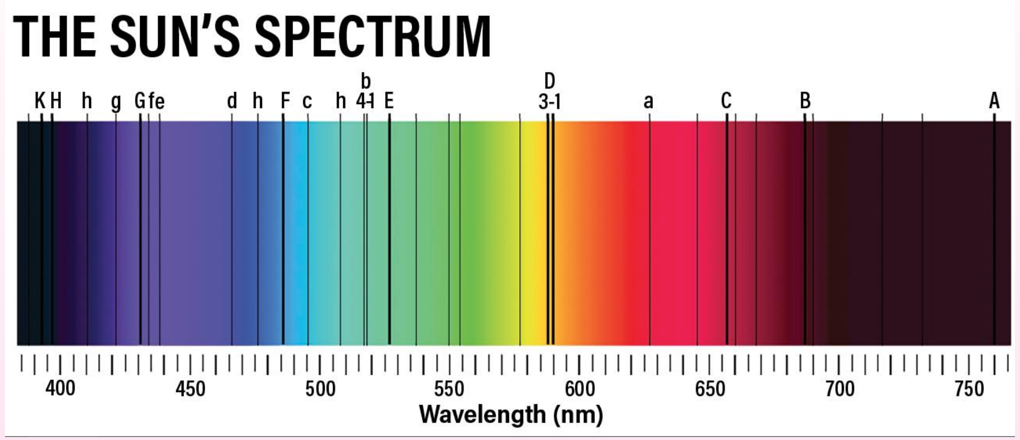
$\mathrm{Ra} = 230$

No convection

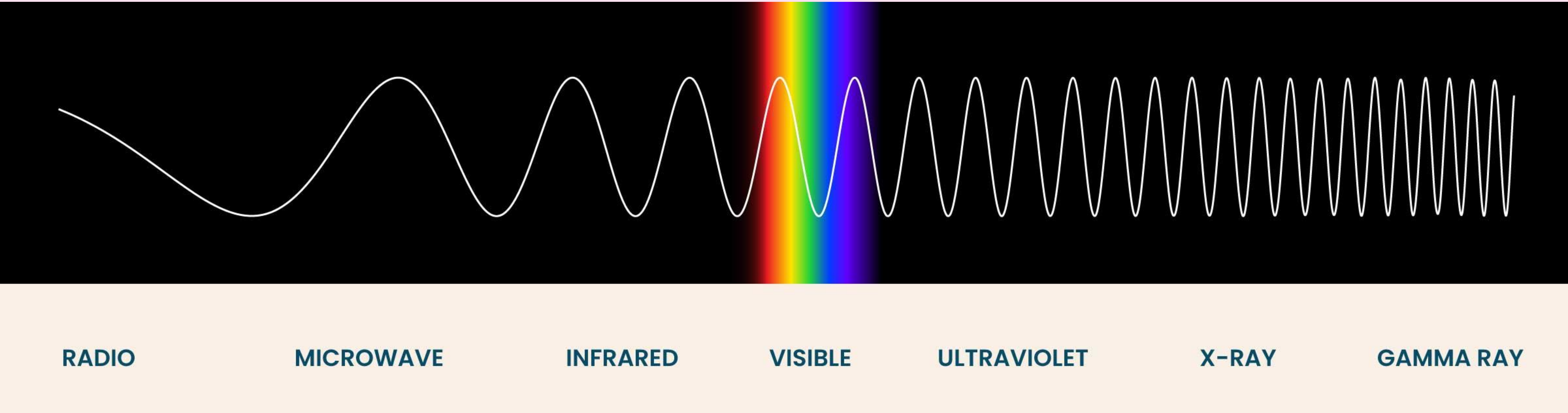


Thermal radiation

All bodies emit electromagnetic radiation that is characteristic of the body's temperature (and NOT the temperature of its surroundings)



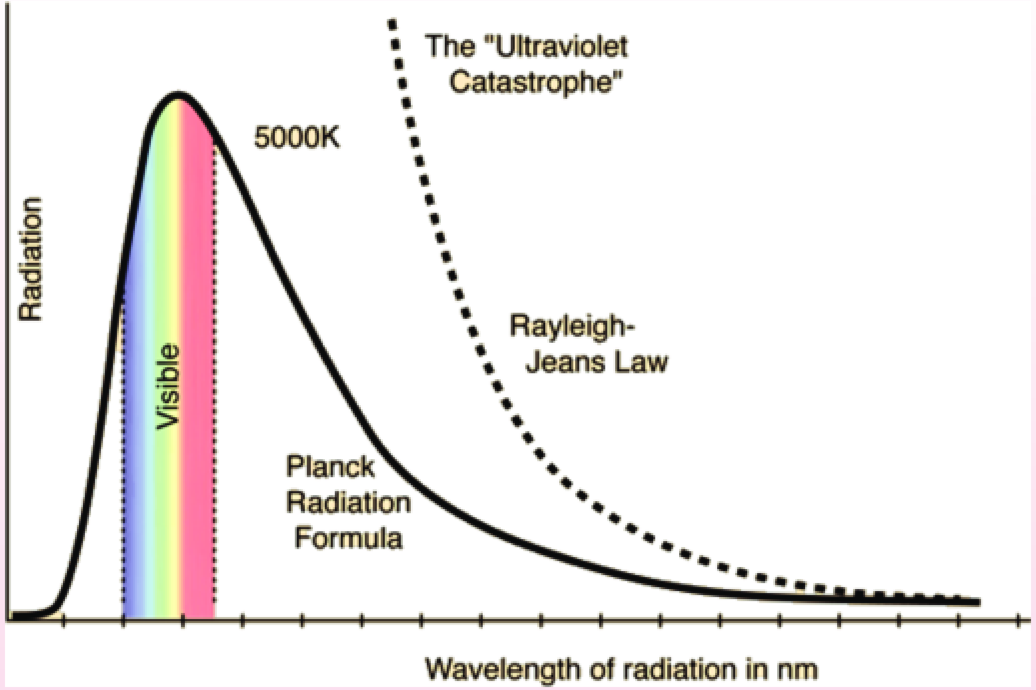
https://www.astronomy.com/wp-content/uploads/sites/2/2021/09/sunspec.png



Black bodies

Black bodies emit and absorb EM radiation of all wavelengths, without reflecting any (unlike a white body, which reflect all light incident on them)

If a black body is in thermal equilibrium with its surroundings (both at some temperature T), they emit exactly the same power spectrum as they absorb



http://dx.doi.org/10.1590/1806-9126-rbef-2023-0093

Rayleigh-Jeans law $$u(\lambda, T) = \frac{8\pi k_B T}{\lambda^4}$$

u is the power emitted per unit area
T is temperature
λ is the wavelength of the emitted light

Predicts that for low wavelengths, infinite energy is released – Ultraviolet catastrophe

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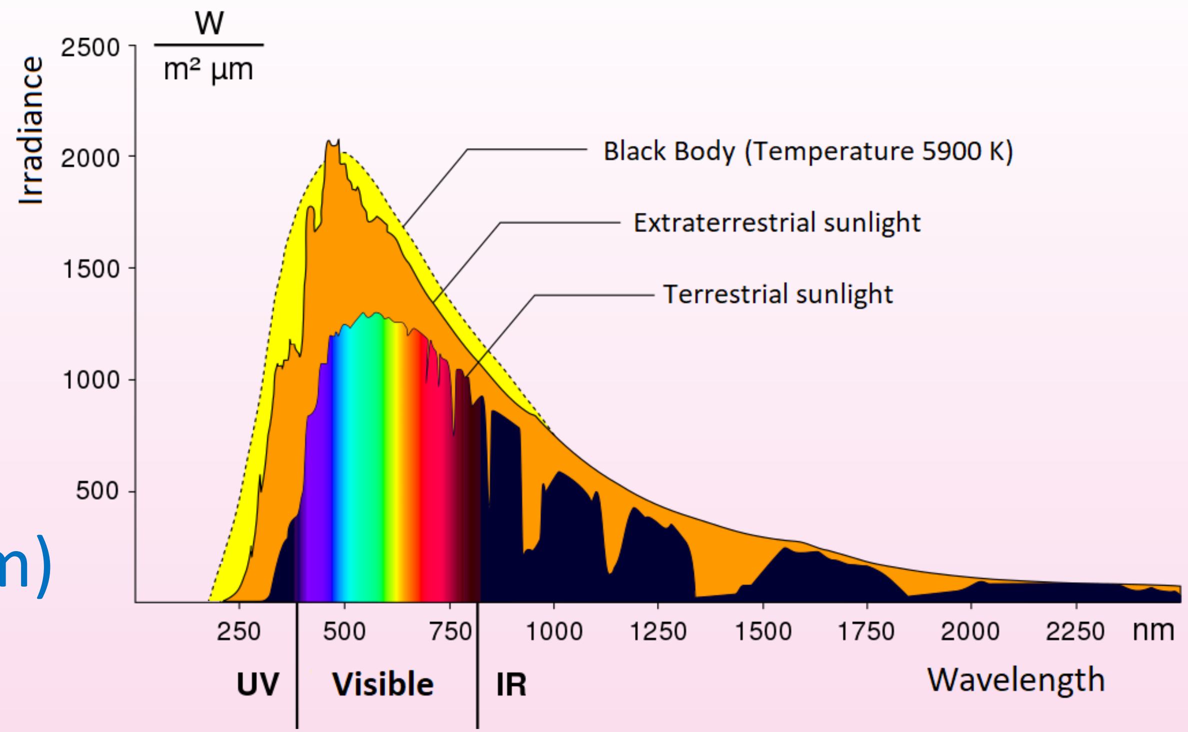


If a black body is in thermal equilibrium with its surroundings (both at some temperature T), they emit exactly the same power spectrum as they absorb

Planck's law

$$u(\lambda, T) = \frac{8\pi hc}{\lambda^5} \frac{1}{\left(e^{-\left(\frac{hc}{\lambda k_B T}\right)} - 1\right)}$$

Non-examinable
(don't call me a hero)

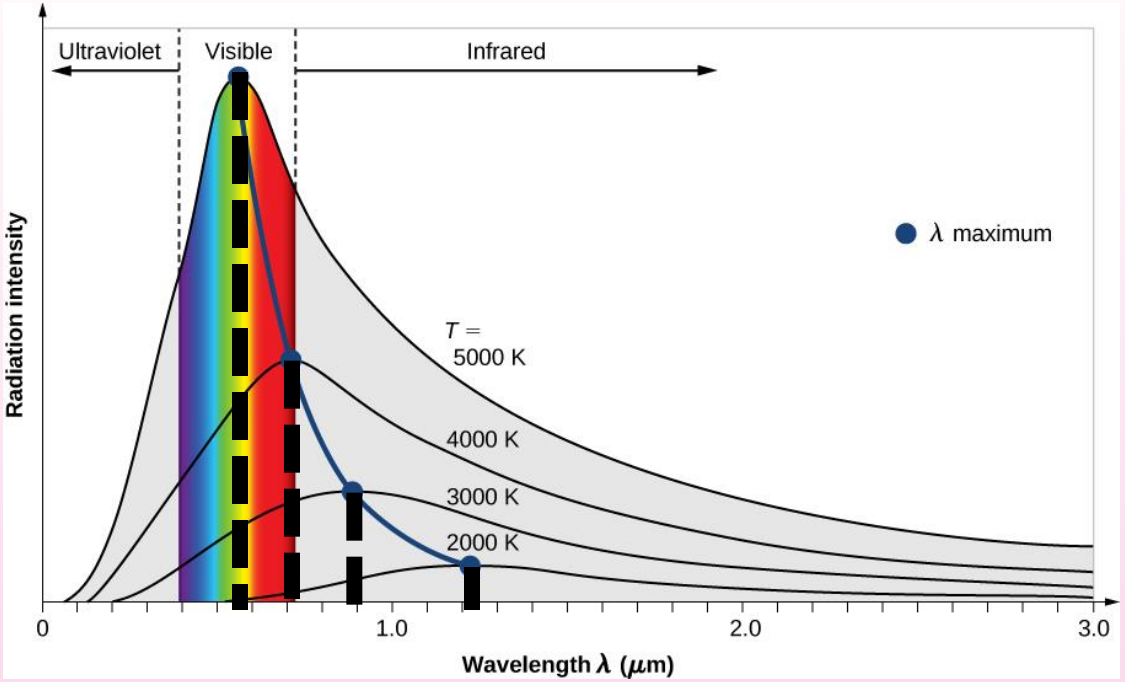
Non-black bodies characterised by emissivity, ε (fraction of black body spectrum absorbed)

Wien approximation

By finding the maximum of the spectrum (through differentiation), you can find the wavelength corresponding to the maximal power output

$$\lambda_{max} \approx \frac{hc}{5k_BT} \approx \frac{2.9\times10^{-3}\ \mathrm{mK}}{T}$$

Wavelength at the maximum is inversely proportional to temperature of the body!



https://phys.libretexts.org/@api/deki/files/15630/CNX_UPhysics_39_01_BBradcurve.jpg?revision=1

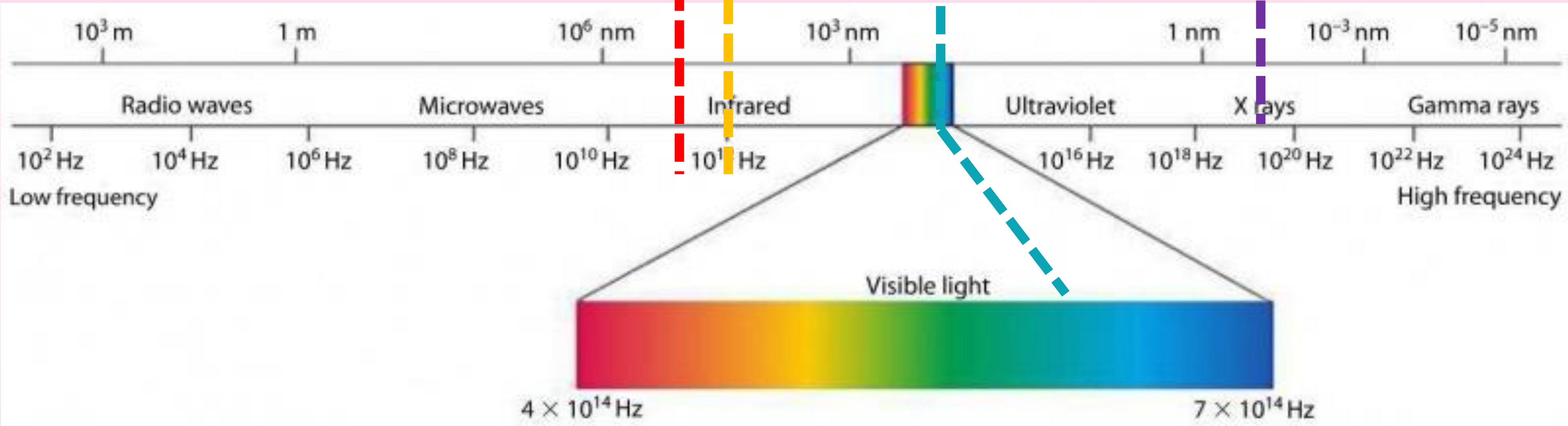
Some useful values

Surface of the sun:
$\lambda_{max} \sim 500$ nm

Core of the sun:
$\lambda_{max} \sim 0.1$ nm

Room temperature:
$\lambda_{max} \sim 10$ µm

500 °C
$\lambda_{max} \sim 4$ µm



https://wiki.travellerrpg.com/Electromagnetic_Spectrum

Stefan-Boltzmann law

Can integrate the whole spectrum (from Planck's law) to work out the total energy emitted per unit time, $\dot{Q}$:

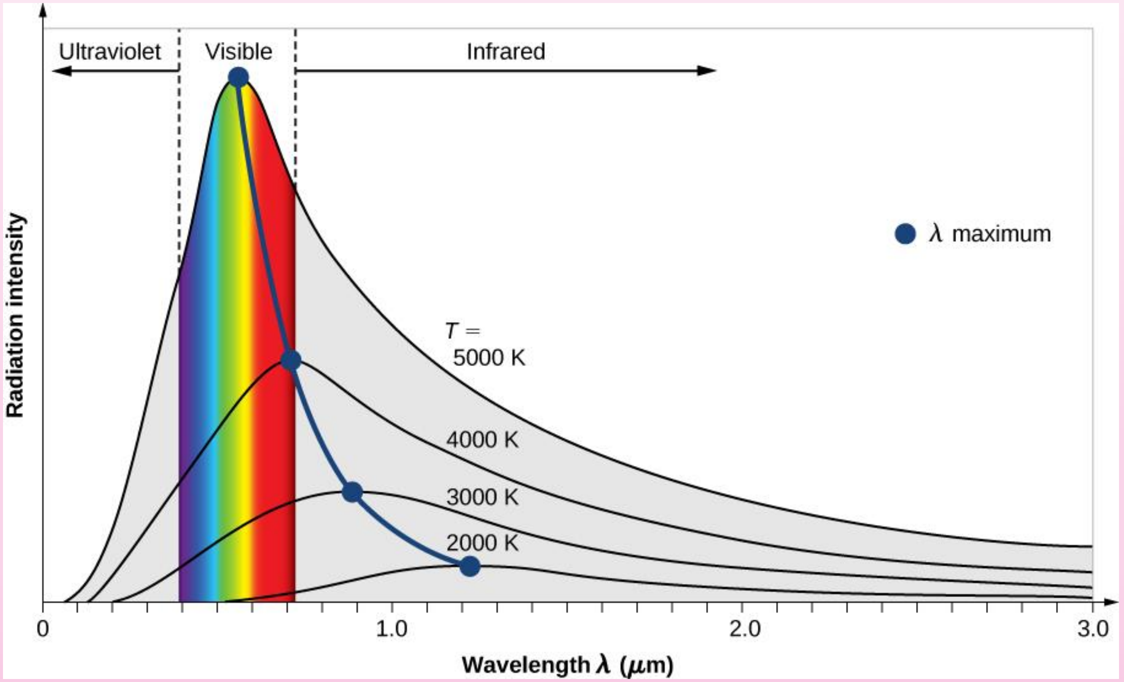
$$\dot{Q} = \varepsilon\sigma A T^4$$

Temperature

Emissivity
(=1 for a black body)

Stefan's constant
5.67 x 10^{-8} W m^{-2} K^{-1}

Surface area of body
(that is radiating power)



https://phys.libretexts.org/@api/deki/files/15630/CNX_UPhysics_39_01_BBradcurve.jpg?revision=1