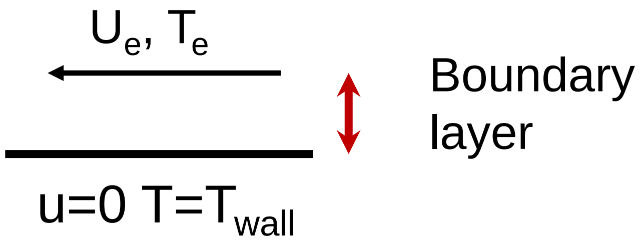
SESA3029 Aerothermodynamics

Lecture 5.4

Radiation heat transfer

Convective heat transfer



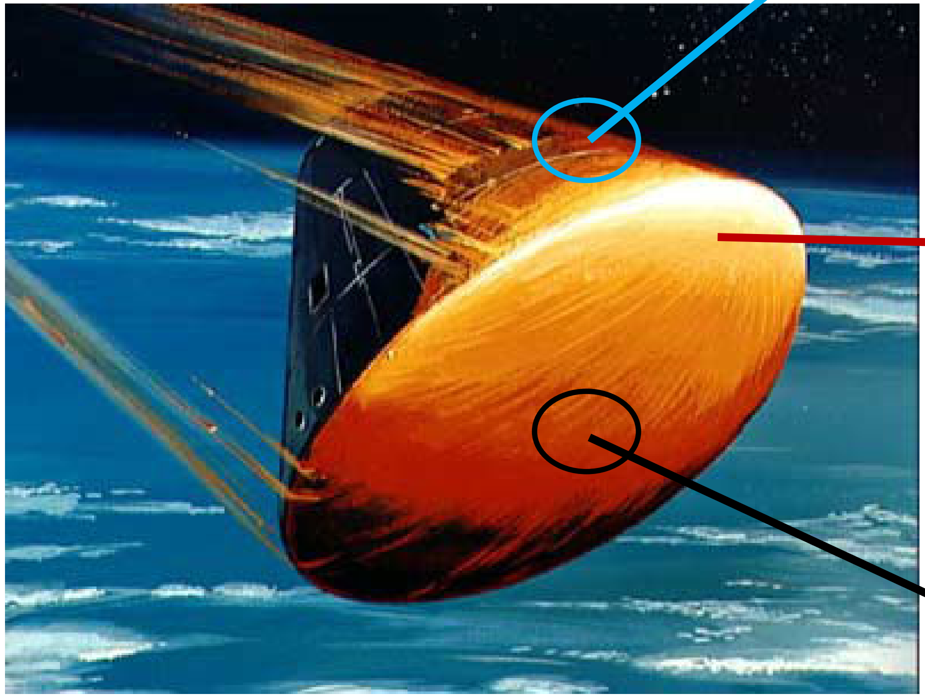
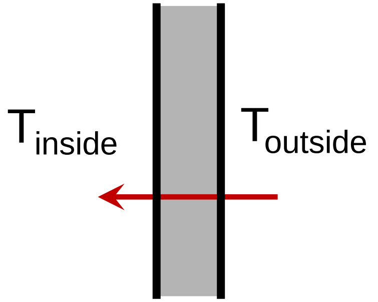


Figure: NASA Artist's impression

Radiation heat transfer



Conduction heat transfer

Radiation

All bodies radiate energy via photons moving with random direction, phase and frequency.

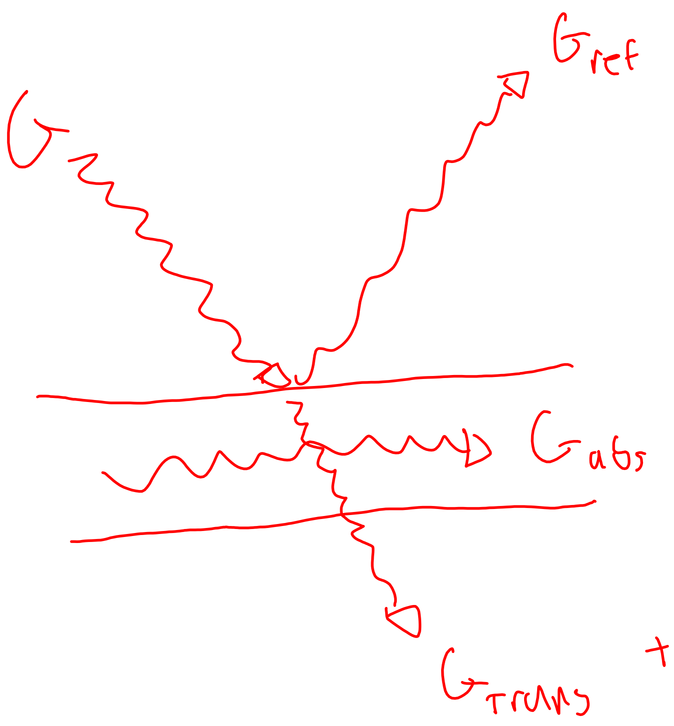
Visible radiation wavelengths

$$0.38\mu m < \lambda < 0.76\mu m$$

ultra violet ← visible → infra red

As photons reach a solid surface they are absorbed, reflected or transmitted through the surface

α absorptivity
ρ reflectivity
τ transmissivity



reflected

absorbed

transmission

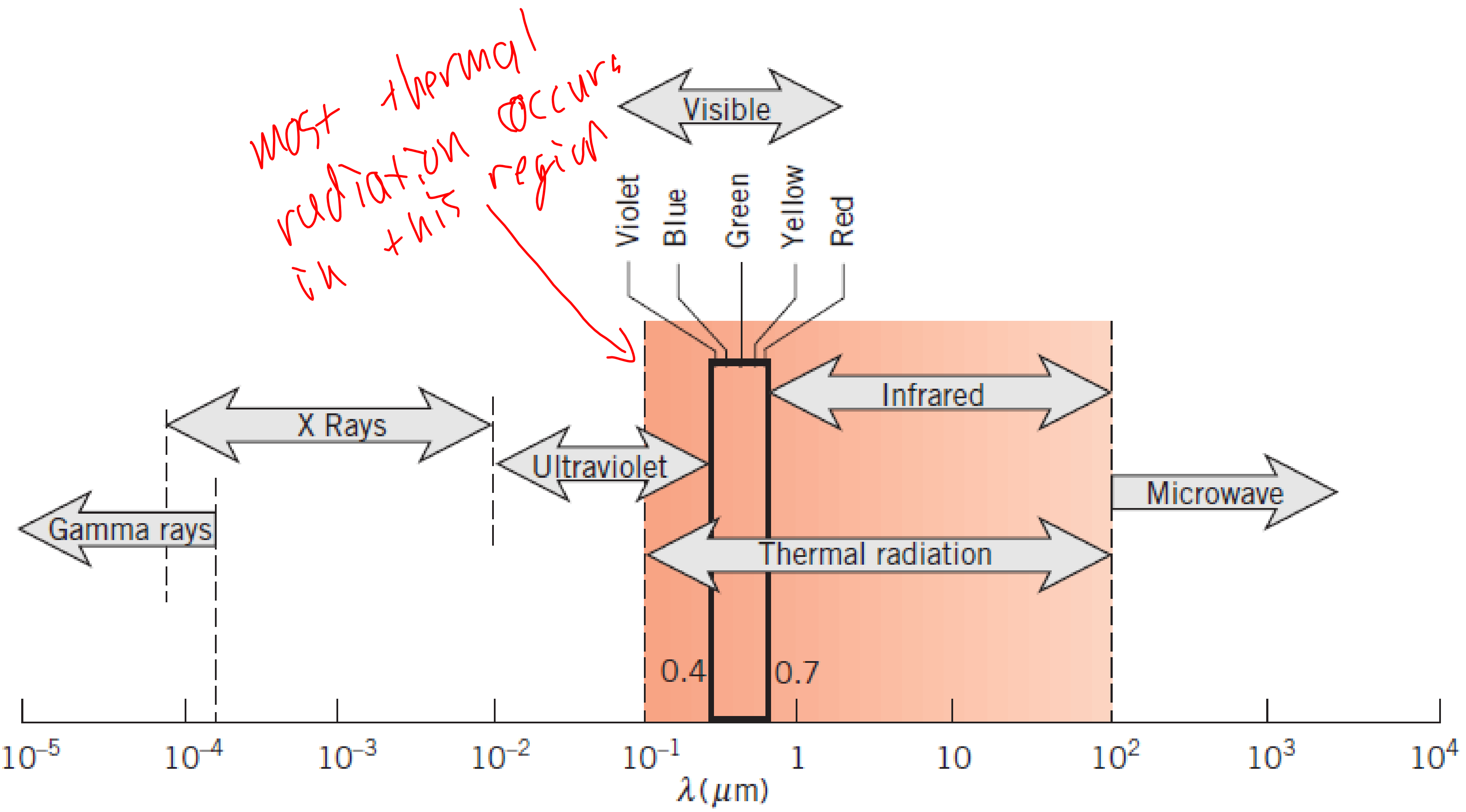
$$G = G_{ref} + G_{abs} + G_{trans}$$

$$\downarrow$$

$$1 = \alpha + \rho + \tau$$

most solids are opaque (hence $\tau = 0$)

Electromagnetic radiation



Bergman et al., Fundamentals of Mass and Heat Transfer.

everything is absorbed.
In equilibrium it transmits as much as it absorbs.

Black and grey body radiation

$E_\lambda(\lambda)$ has nasty function

Energy flux E (W/m^2)
(emissive power)

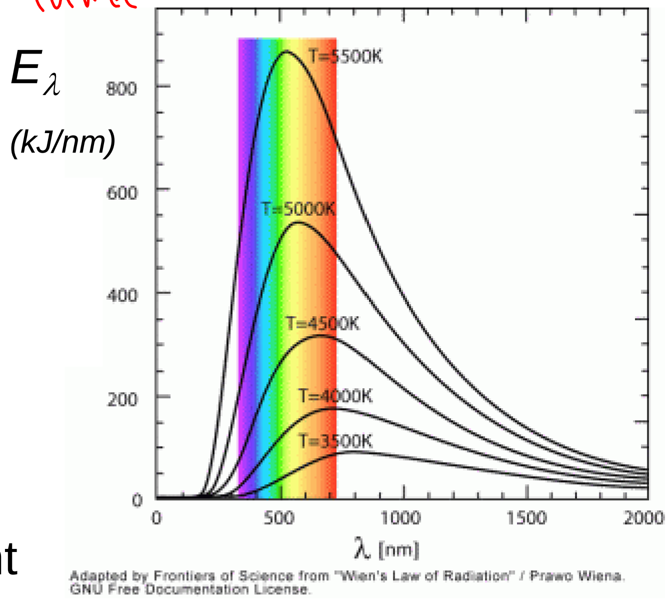
$$E = \int_0^\infty E_\lambda \, d\lambda$$

simplifies a lot

Black body radiation
α=1, ρ=0, τ=0

$$E_b = \sigma T^4$$

σ=Stefan-Boltzmann constant
(=5.669x10^{-8} W/(m^{2}K^4))



Real bodies are 'grey' and we can define an emissivity

$$\varepsilon = \frac{E}{E_b}$$

ε=α for surface in thermal equilibrium

As an approximation we can apply the same factor ε to all frequencies. A more accurate approach would use a measured E_λ.

Example

Find the surface temperature of a space probe, one metre diameter polished aluminium.

Take solar heat input as 1350 W/m^2 and α=0.3

Heat input to the sphere

$$\dot{Q}_{in} = \alpha \dot{q}_{sun} A = 0.3 \times 1350 \times \frac{\pi (1)^2}{4} = 318.1\,\mathrm{W}$$

Thermal equilibrium

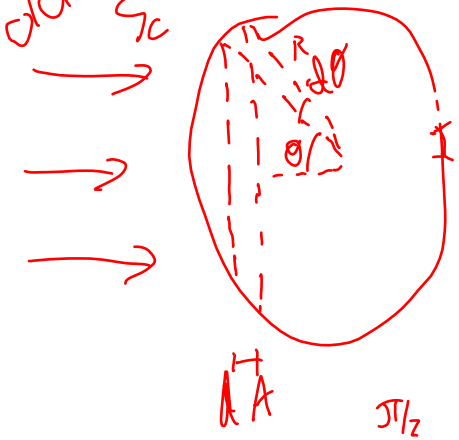
$$\dot{Q}_{in} = \dot{Q}_{out} = \varepsilon \sigma A_{sphere} T^4$$

rearrange and sub in

For polished aluminium ε=0.04 (note that $\alpha \neq \varepsilon$ here, since α is set for solar frequencies, while ε is suitable for lower temperatures)

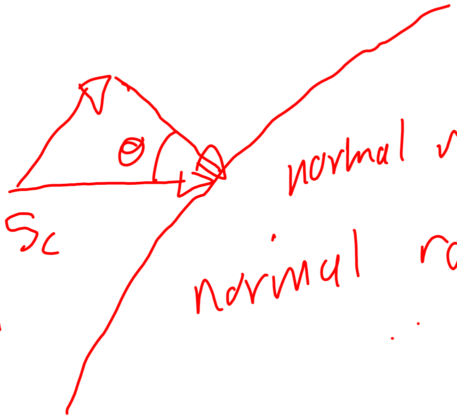
$$T = \left[\frac{318.1}{0.04 \times 5.669 \times 10^{-8} \times 4\pi \times 0.5^2} \right]^{1/4} = 459.7\,\mathrm{K}$$

solar radiation S_c



$dA = 2\pi R^2 \sin\theta$

zoom in on impact



normal rad $= S_c \cos\theta$

normal radiation depends on θ

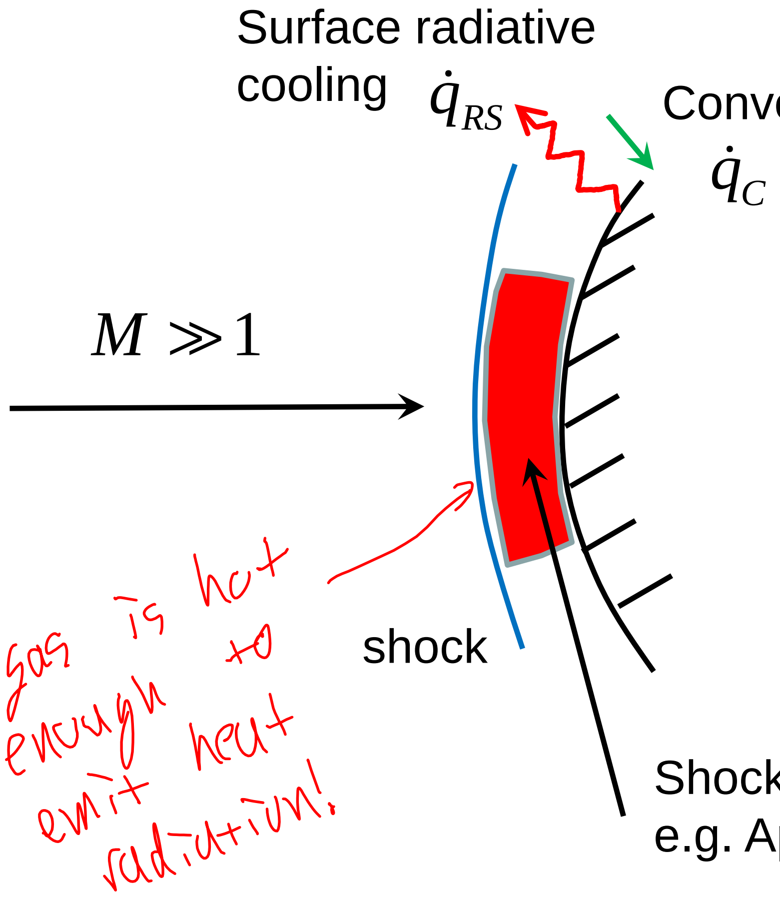
$$= S_c \int_0^{\pi/2} \cos\theta \; 2\pi R^2 \sin\theta \; d\theta$$

$$= S_c \, 2\pi R^2 \int_0^{\pi/2} \sin\theta \cos\theta \; d\theta$$

$$= \underbrace{S_c \pi R^2}_{\text{equals exposed cross sectional area}}$$

Example solution

Radiation issues in atmospheric entry and re-entry



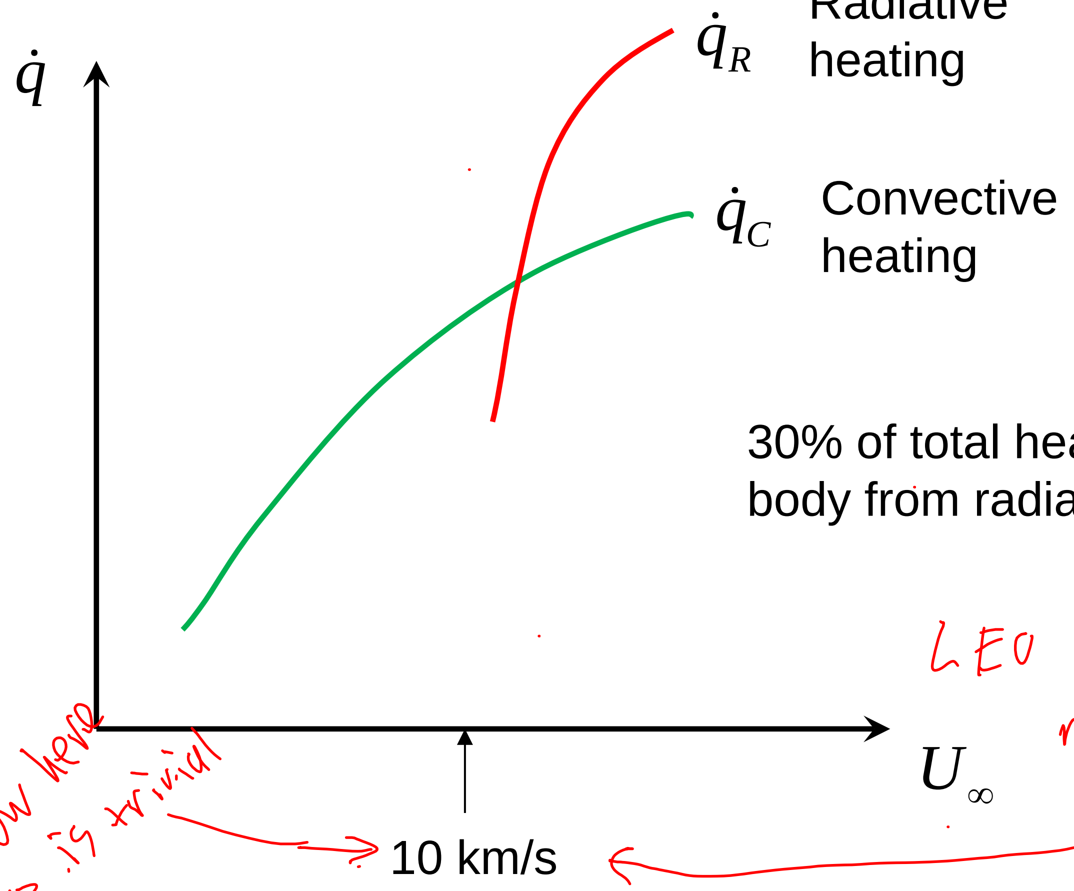
$$\dot{q}_{RS} = \dot{q}_R + \dot{q}_C$$

Surface equilibrium: radiative heat loss balances convective and radiative heating

Shock layer, very high temperatures e.g. Apollo re-entry up to 11,000 K

Additional heating due to radiation

Earth atmosphere example



30% of total heating to body from radiative effects

typical LEO reentry $\dot{q}_c$ is "ignorable"

LEO reentry ~8 km/s
moon reentry ~10 km/s

below here $\dot{q}_R$ is trivial

For more discussion, see Anderson, 'Hypersonic and high-temperature gas dynamics'