Electromagnetic (blackbody) radiation

C28W10
G 14.8
28.2

When a hot coffee cup cools → how does it happen?

A) it radiates energy (like the sun)

B) air molecules which get in contact carry away energy
→ convection cooling

c) other mechanisms? → evaporative cooling
liquid → steam removes energy
we can stimulate this by blowing
the steam away

Why is it warm when the sun shines?

This must be process (A), as there is very little medium between sun and earth.

Sun is fuelled by thermonuclear fusion ($H + H + 2n \rightarrow {}_2He^4$ by a complicated cycle of reactions)

At the surface we have visible-light and $T \sim 5780$ K

(Nuclear gamma and X ray photons created in the core where the fusion reaction takes place scatter as they travel to the surface ⟶ many photons of lower energy $E = hf$ are created; different stars of similar type have different surface temperatures).

Solar surface (area A) emits radiation into space

emissivity; set e=1

$$\text{Power} = \frac{\text{Energy transfer}}{\text{unit time}} = \frac{\text{Heat}}{\text{u. time}} = \frac{Q}{t} = \sigma e A T^4$$

$5.67 \times 10^{-8} \frac{W}{m^2 K^4}$

temperature

Stefan - Boltzmann law

experimental discovery

theoretical explanation

Measurement: oven glow → measure temp
arc lamp → measure radiation output
filament (know electric power!)

The S-B law gives the total power output, from all frequencies (wavelengths) radiated:

- thermal (infrared)
- visible
- ultraviolet
- x rays
- γ "

Observation:

hotter emitter → light is ~blue
less hot → light is ~red
} white

incandescent bulb on a dimmer: observe red → yellow → white

We see the colour associated with the wavelength (frequency) at which the power output is maximal.

Wien formula (observation + theor. expl.) $\lambda_{max} = \frac{2.90 \times 10^{-3} \ m \cdot K}{T}$

Absorption of radiation

It follows the same law as emission*.

good emitter = good absorber (continue with $e \lesssim 1$)

$\uparrow$ blackbody value

*) why? The absorber is typically at a different temperature than the emitter (earth surface $\lesssim 300$ K)

Absorber emits and re-radiates. if it is at a const. temperature → absorption from sun (source) + re-emission into space balance each other

if it wasn't re-emitting same amount → it would heat up or cool.

Look at Example 14.13 to understand:

Sun emits $\left.\frac{Q}{t}\right|_{Sun} \sim 4.6 \times 10^{26}$ W

Earth absorbs / emits $\left.\frac{Q}{t}\right|_{Earth} \sim 2.1 \times 10^{17}$ W

→ it misses one important aspect: albedo
some of the sun's rad. is reflected back and not absorbed!
≈ 30% for earth

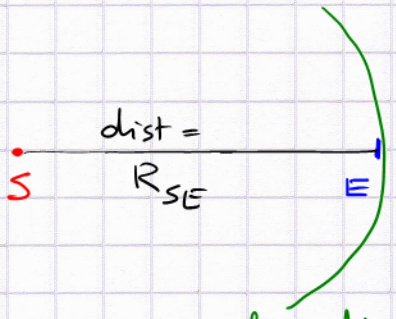
The almost 10 orders of magnitude come from the ratio

$$\frac{\pi r_E^2}{4\pi R_{SE}^2} = \frac{\text{cross section of E exposed to rad.. from S}}{\text{total surface area of sphere @ sun-earth distance}}$$

The radiated power travels as a spherical shell

→ as it gets further away the intensity $\sim \frac{1}{\text{dist.}^2}$

fundamental property of electromagnetic radiation from a point source.



sphere of radius R_{SE} has area $4\pi R_{SE}^2$

The earth's "average" surface temp. of $T \approx 20°C = 293\,K$ can be explained by applying

$$\left.\frac{Q}{t}\right|_{Earth} = \sigma \underset{\overset{\uparrow}{=1}}{\varepsilon} (4\pi r_E)^2 T_E^4$$

and solving for T_E.

Wikipedia: includes albedo effect → $T_E \approx 0°C$!

Q: how is the radiated power at a given temp. T distributed over the allowed wavelengths / frequencies?

→ Fig 28.7 (log. λ-axis linear relative intensity)
Fig 14.32 (double-log plot)

Applications

1) night goggles → objects that differ in temperature from their surroundings → pick up their radiation

2) glowing object's radiation; 3) cosmological black body radiation

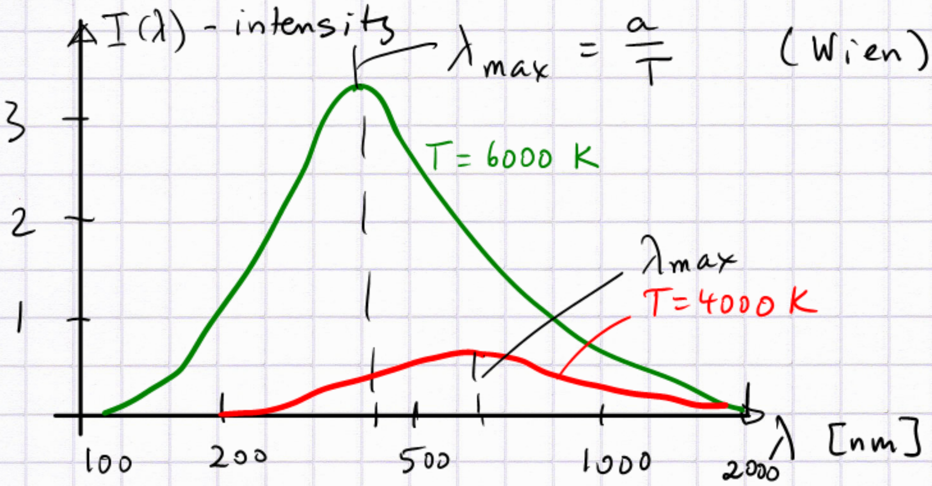
Thermodynamic theory is based on the following principles

(A) Energy of radiation $E = hf = h\frac{c}{\lambda}$ is quantized

(B) $E = kT$ $k =$ Boltzmann constant $\approx 1.38 \times 10^{-23} \frac{J}{K}$ $\left(\text{or } \frac{Nm}{K}\right)$

For radiators at given temperature T we can ask a deeper question than what's provided by the Stefan-Boltzmann law:

How is the radiated power distributed over wavelengths?



(log scale; $f \to c/\lambda$)

shape? Planck's law:

$$I(f) \sim \frac{f^2 \cdot hf}{\exp\left(\frac{hf}{kT}\right) - 1}$$

is "non-classical"

1901 precursor to Einstein's work on photoeffect

- The shape of this curve depends on the dimensionless parameter $x = \frac{hf}{kT} = \frac{h\frac{c}{\lambda}}{kT}$
- with increasing T: λ_{max} decreases; total area under curve scales like T^4 (Stefan-Boltzmann)