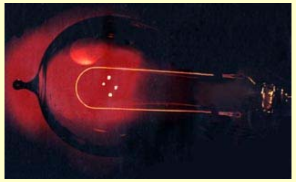
Generation of light – Light sources



Black-body radiation

Black-body radiation

or

Thermal Radiation

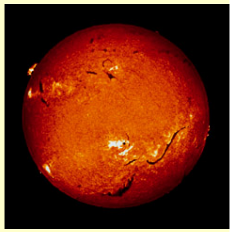
- Experience:

hot bodies emit visible light

Black-body radiation

or

Thermal Radiation



Thermal Radiation

All material *objects ($T > 0$ K) emit electromagnetic radiation independently from the temperature of its environment*

Radiation originates from specific collective internal vibrations of the composing atoms.

Planck (1900)

1. Some of the atomic vibrations lead to **oscillating charge** separations: source of electromegnetic radiation (EMR)
2. If the oscillators can have any energies the spectrum can not be derived
3. Planck supposed that the internal vibrations can only have discrete energies

$$E_n = nhf$$

(n: integer; f: vibrational frequency)

4. EMR absorption and emission changes the quantum state of vibrations by one quantum

Absorptance (or absorption coefficient) is the fraction of incident light that is absorbed by the body

$$\alpha = \frac{J_{\text{absorbed}}}{J_{\text{total incident}}}$$

Varies with the wavelength

Black body absorbs all light that strikes it.

$$\alpha_{\max} = 1$$

Kirchhoff's observation: absorbs more – radiates more

M: radiant emittance [W/m^2]

$$\frac{M_{\lambda i}}{M_{\lambda j}} = \frac{\alpha_{\lambda i}}{\alpha_{\lambda j}}$$

i: arbitrary
j: ideal black body

$$\alpha_{\lambda j} = 1 \qquad \alpha_{\lambda i} < 1$$

$$M_i < M_{\lambda j}$$

Ideal black body has the maximal radiant emittance

$$\alpha_{\lambda(\text{blackbody})} = 1 \qquad \alpha_{\lambda j} < 1$$

$$M_{\lambda j} < M_{\lambda(\text{blackbody})}$$

Ideal black body has the highest radiant emittance

Human body can be considered as a 95% balck body

Emission spectrum of thermal radiation

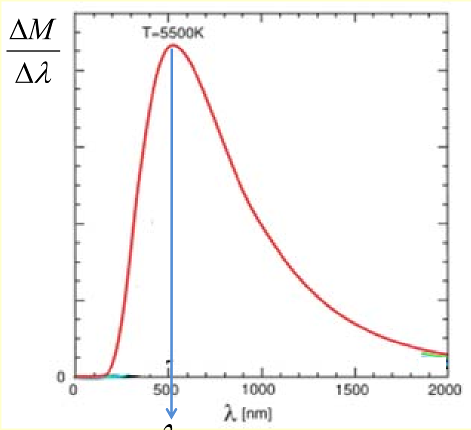
- the spectrum is continuous

- it has one maximum :

λ_{max}

- area below the curve:

$$M = \sigma T^4$$



λ_{max}

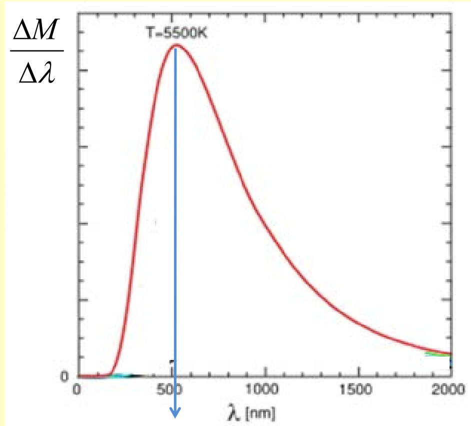
Radiant emittance: total radiant power per unit surface area

Stefan – Boltzmann law

$$M_{blackbody(T)} = \sigma T^4$$

Stefan – Boltzmann constant

$$\sigma = 5.7 \times 10^{-8} [\frac{W}{m^2 K^4}]$$



λ_{max}

The role of thermal radiation in the energy release

$$\Delta M = \sigma (T^4_{object} - T^4_{environment})$$

It is influenced by

- the temperature of the body
- surface area
- the temperature of the environment (temperature of the surrounding objects)

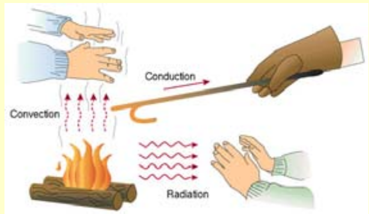
Temperature regulation and heat exchange

heat production + heat uptake = heat loss

Heat production out of thermal regulation

metabolic processes
muscle activity
secretion
...

Heat production for thermal regulation



passive operation

Temperature regulation and heat exchange

heat production + heat uptake = heat loss

Heat production out of thermal regulation
- metabolic processes
- muscle activity
- secretion
- ...

Heat production for thermal regulation

Radiation	$\approx 100W$
Conduction	negligible
Convection	$\approx 10W$
Perspiration	$\approx 10W$

If someone is interested…

The total energy radiated in one day is about 9 MJ (million joules), or 2000 kcal (food calories). Basal metabolic rate for a 40-year-old male is about 35 kcal/(m²·h), which is equivalent to 1700 kcal per day assuming the same 2 m² area. However, the mean metabolic rate of sedentary adults is about 50% to 70% greater than their basal rate

There are other important thermal loss mechanisms, including convection and evaporation. Conduction is negligible. Evaporation (perspiration) is only required if radiation and convection are insufficient to maintain a steady state temperature. Free convection rates are comparable, albeit somewhat lower, than radiative rates.Thus, radiation accounts for about 2/3 of thermal energy loss in cool, still air. Given the approximate nature of many of the assumptions, this can only be taken as a crude estimate. Ambient air motion, causing forced convection, or evaporation reduces the relative importance of radiation as a thermal loss mechanism.
Also, Applying Wien's Law to humans, one finds that the peak wavelength of light emitted by a person is

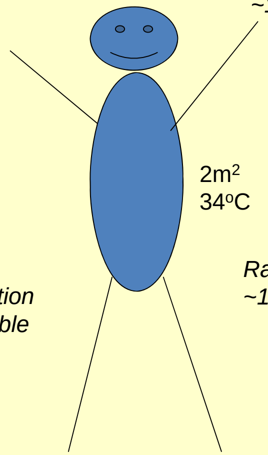
$$\lambda_{peak} = \frac{2.898 \times 10^6 \text{ K} \cdot \text{nm}}{305 \text{ K}} = 9500 \text{ nm}$$

This is why thermal imaging devices designed for human subjects are most sensitive to 7-14 micrometers wavelength

Heat exchange with the environment

Perspiration
~17W

Convection
~11W



2m²
34°C

Conduction
- negligible

Radiation
~133W

Energy exchange with the environment

$$\Delta M = \sigma \cdot (T_{body}^4 - T_{envir.}^4)$$

Exchange depends on T of the environment

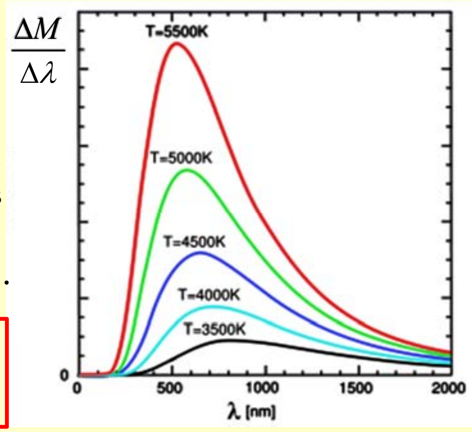
Emission spectrum of thermal radiation at various temperatures

$$T_1 > T_2 > T_3 > T_4 > T_5$$

$$M_1 > M_2 > M_3 > M_4 > M_5$$

$$\lambda_{\max 1} < \lambda_{\max 2} < \lambda_{\max 3} < \ldots$$

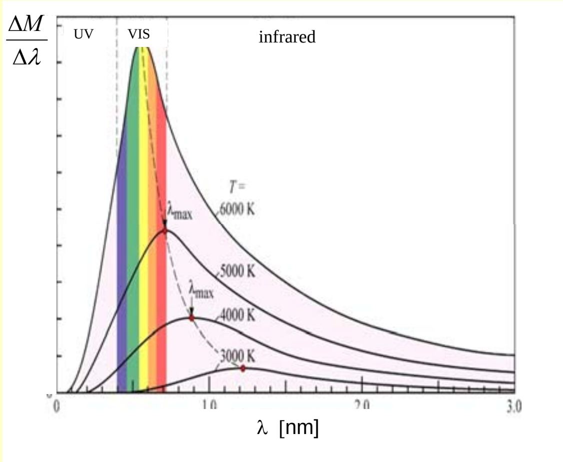
$$T \times \lambda_{\max} = \text{constant}$$



Wien's displacement law

$$T \times \lambda_{max} = \text{constant}$$

$k = 2.898 \times 10^6 [nm \times K]$



The wavelength of maximum intensity shifts to shorter wavelengths when T is increased

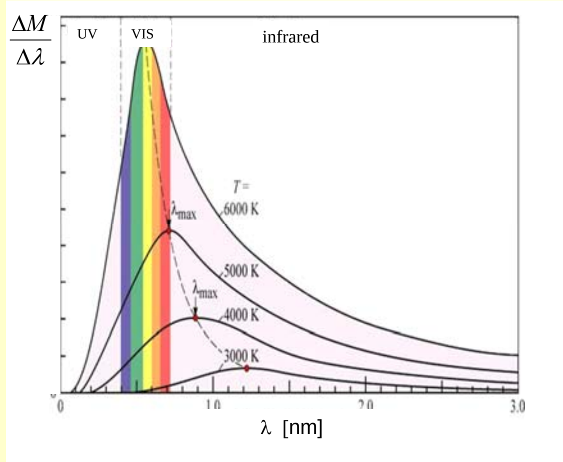
Wien's displacement law

$$T \times \lambda_{max} = \text{constant}$$

$k = 2.898 \times 10^6 [nm \times K]$

$T_{bodysurface} \approx 305[K]$

$\lambda_{max} \approx 9500[nm]$



Under 700 K the emitted radiation is not visible

Subjective colours

480°C	faint red glow
580°C	dark red
730°C	bright red, slightly orange
930°C	bright orange
1100°C	pale yellowish orange
1300°C	yellowish white
>1400°C	white

Applications

1. Medical application – telethermography

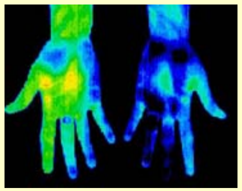
non-invasive imaging technique which can evaluate the body surface thermal gradients

Applying Wien's Law to humans, one finds that the peak wavelength of light emitted by a person is

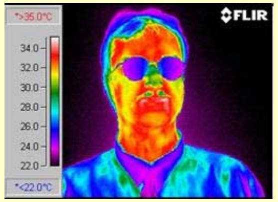
$$\lambda_{peak} = \frac{2.898 \times 10^6 \text{ K} \cdot \text{nm}}{305 \text{ K}} = 9500 \text{ nm}$$

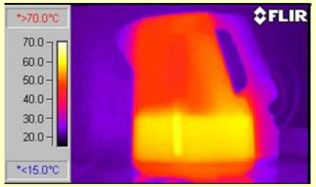
This is why thermal imaging devices designed for human subjects are most sensitive to **7-14 micrometers** wavelength

=> tumours, inflammations, constriction of vessels



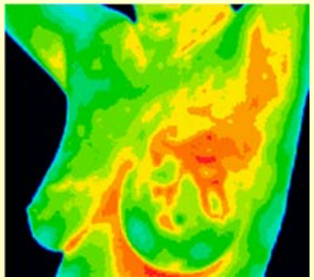
photos by normal and by infra-camera

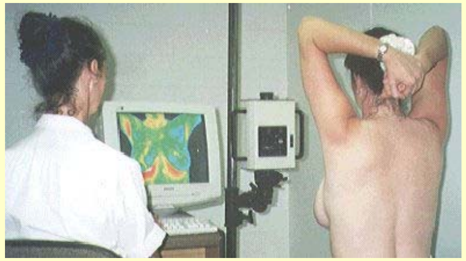




Application fields

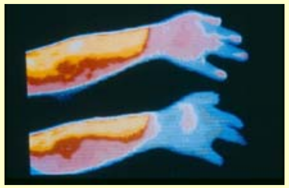
- rheumatology
- diagnostics of breast cancer
- dentistry
- neurology



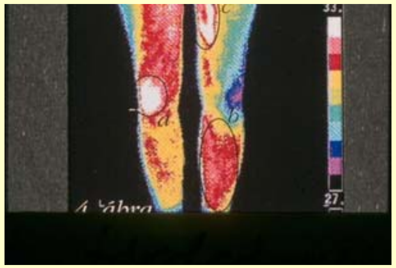


Detection of alterations in blood circulation

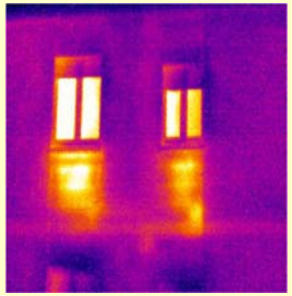
Effect of smoking



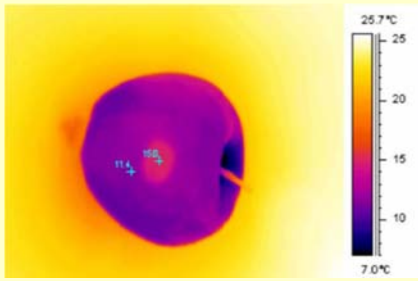
Inflammation and trombosis



2. Non-medical application

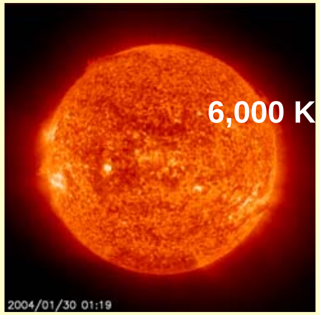


Architecture - insulation techniques



Food industry

Astronomy



	T (K)	λ_{max} (µm)	Spectral range	M (W/m^2)
Sun	6000	0.5	VIS	7 x 10^7
Earth	300	10	infrared	460

Applications

3. Light sources

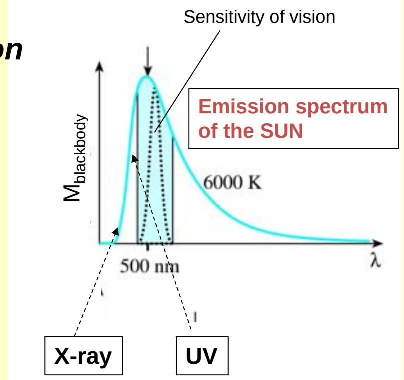
Light sources

based on thermal radiation

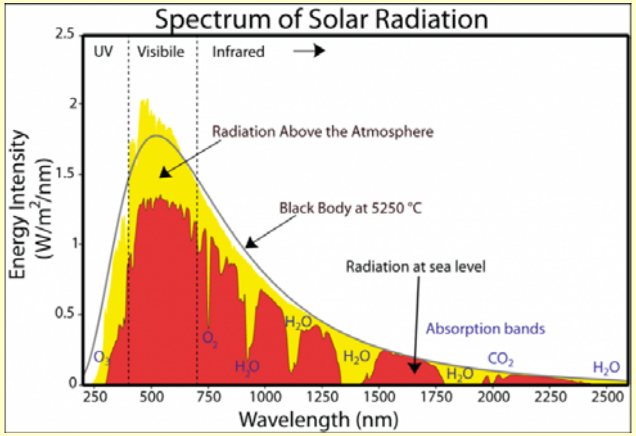
The Sun.

40 % of its thermal radiation falls into the sensitivity range of vision.

Its λ_{max} is close to the highest sensitivity of vision.



Emission spectrum on the Earth:
λ < 290 nm is filtered by the atmosphere



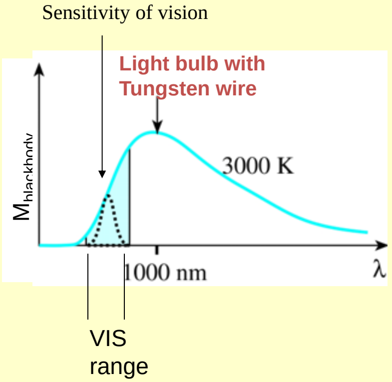
Incandescent lamps

Metal filaments in a glass bulb heated to high temperature to approach the spectrum of the Sun.

Light bulbs
Tungsten at 3000 K

Infralamps
Tungsten at 1300 K

Sollux lamps
High power Tungsten at T>3300 K
with filters for long wavelength IR
and filters for short wavelength
UV -> UVA for tanning



Treatment of

Seasonal Affective Disorder (S.A.D.)

5000 K thermal radiation light source (λ_{max} = 580 nm)
with UV filter
(Sun: about 6000 K, λ_{max} = 480 nm)

Strength of irradiation:
max . 5 - 10 thousand lux

*(regular office ~ 50-100 lux,
bright sunlight ~ 10^5 lux)*

Time period: 10 – 15 minutes / day

Question of the week

Why is not visible the thermal radiation emitted by human body?

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 2.2

- 2.2.1
- 2.2.2
- 2.2.6