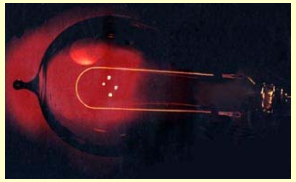
## *Generation of light – Light sources*



Black-body radiation

Luminescence

Laser

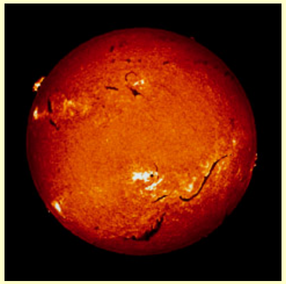
## Black-body radiation

or

## Thermal Radiation

- Experience: hot bodies

emit
visible light



## 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

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

***Black body absorbs all light that strikes it.***

$$\alpha_{max} = 1$$

Kirchhoff's observation: absorbs more – radiates more

$M$: radiant emittance [W/m$^2$]

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

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

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

**Ideal black body has the maximal radiant emittance**

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

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

**Ideal black body has the highest radiant emittance**

Human body can be considered as a 95% balck body

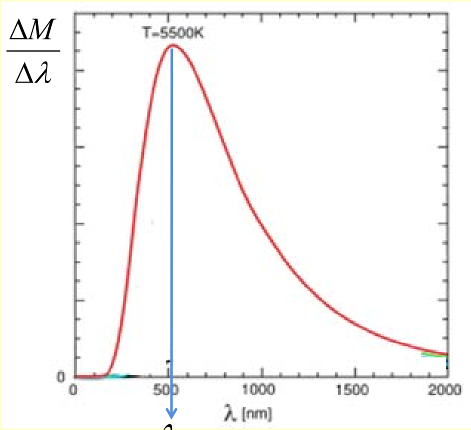
## Emission spectrum of thermal radiation

- the spectrum is continuous
- it has one maximum :

$\lambda_{max}$

- area below the curve:

$$M = \sigma T^4$$



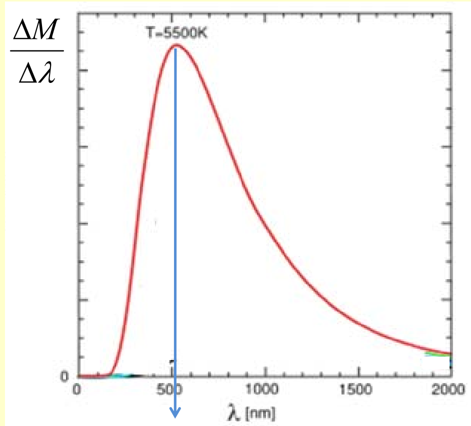

$\lambda_{max}$

## Stefan – Boltzmann law

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

Stefan – Boltzmann constant

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




$\lambda_{max}$

## 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**

**Radiation**
Conduction
Convection

**passive operation**

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

## *If someone is interested…*

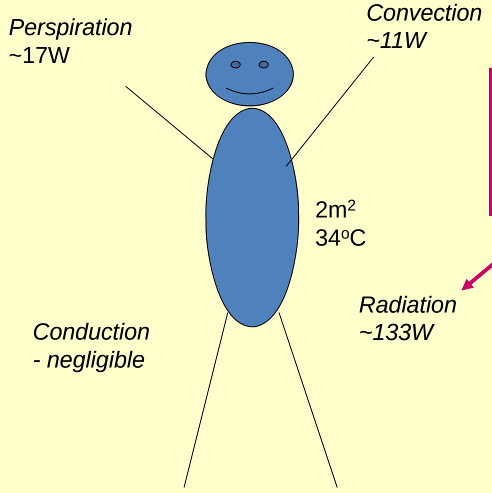
The total energy radiated in one day is about 9 MJ (million joules), or 2000 kcal (food calories). Basal metabolic rate for a 40-year-old male is about 35 kcal/(m²·h), which is equivalent to 1700 kcal per day assuming the same 2 m² area. However, the mean metabolic rate of sedentary adults is about 50%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

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

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

## *Heat exchange with the environment*




*Energy exchange with the environment*

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

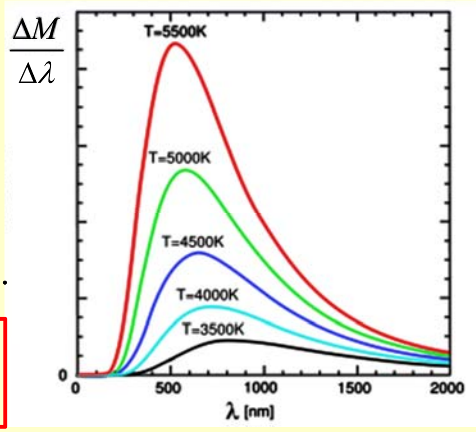
## **Emission spectrum of thermal radiation at various temperatures**

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

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

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

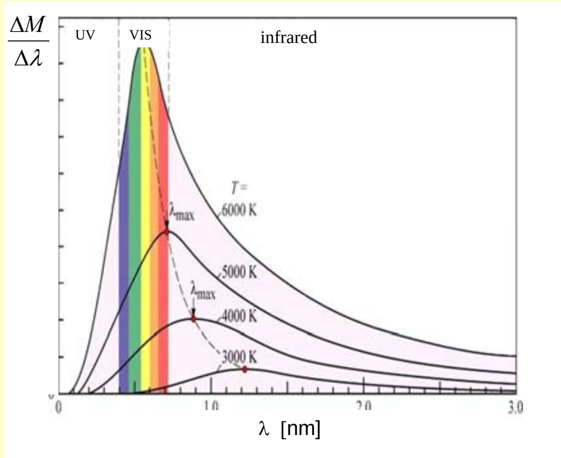
$$\mathrm{T} \times \lambda_{\max} = \mathrm{constant}$$




## **Wien's displacement law**

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

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



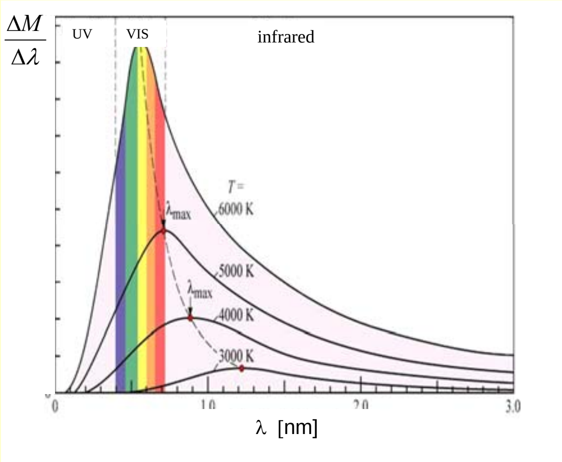
## Wien's displacement law

$$T \times \lambda_{max} = \text{cons tan t}$$

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

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

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




## Subjective colours

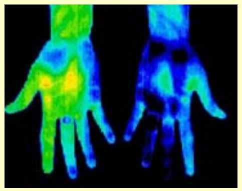
| | |
|---|---|
| 480ºC | faint red glow |
| 580ºC | dark red |
| 730ºC | bright red, slightly orange |
| 930ºC | bright orange |
| 1100ºC | pale yellowish orange |
| 1300ºC | yellowish white |
| >1400ºC | white |

# Applications

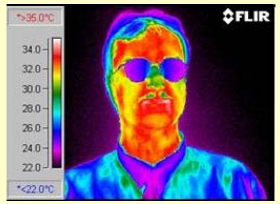
## 1. Medical application – telethermography

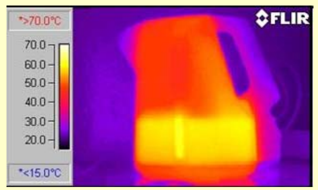
non-invasive imaging technique which can evaluate the body surface thermal gradients

=> tumours, inflammations, constriction of vessels



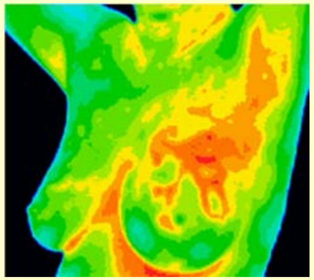
photos by normal and by infra-camera

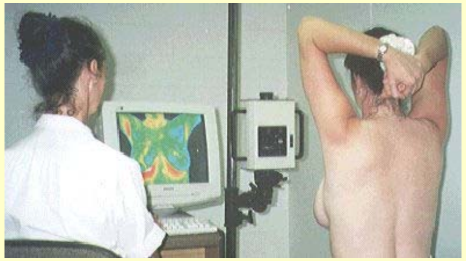


Application fields

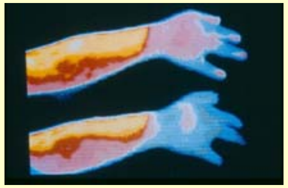
- rheumatology
- diagnostics of breast cancer
- dentistry
- neurology



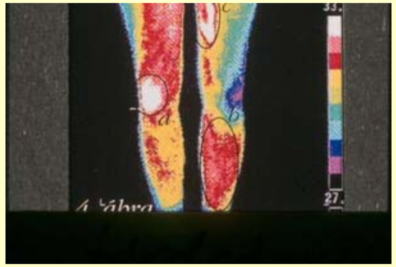


alterations in blood circulation

Effect of smoking

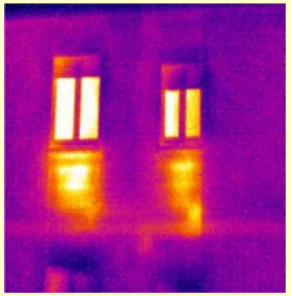


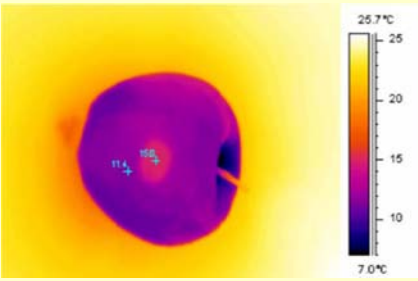
Inflammation and trombosis



## 2. Non-medical application

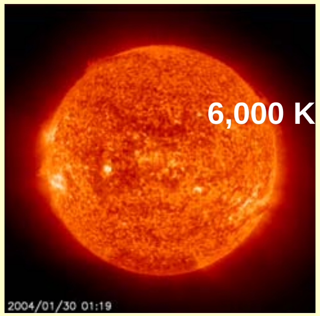
Architecture - insulation techniques






Food industry

Astronomy





| | T (K) | $\lambda_{max}$ (μm) | Spectral range | M (W/m²) |
|---|---|---|---|---|
| Sun | 6000 | 0.5 | VIS | $7 \times 10^7$ |
| Earth | 300 | 10 | infrared | 460 |

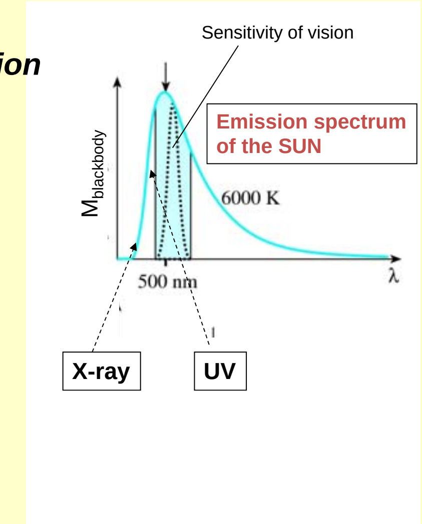
# Applications

## 3. Light sources


## *Light sources*

### ***based on thermal radiation***

**The Sun.**



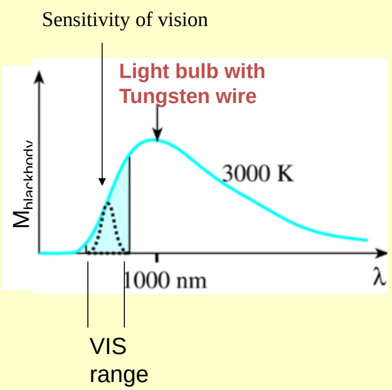

**Incandescent lamps**

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

Light bulbs

Infralamps

Sollux lamps




Treatment of

Seasonal Affective Disorder (S.A.D.)

**Strength of irradiation**: max . 5 - 10 thousands lux

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

**Time period**: 10 – 15 minutes / day

*Damjanovich, Fidy, Szöllősi: Medical Biophysics*

II. 2.2

2.2.1

2.2.2

2.2.6