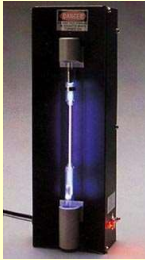
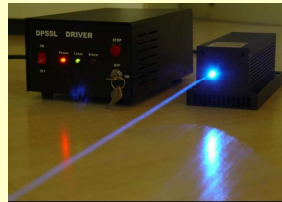
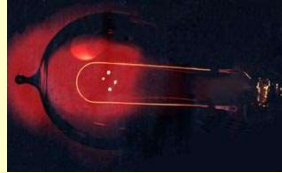


## Generation of light - Light sources



Black-body radiation



Black-body radiation

or

Thermal Radiation

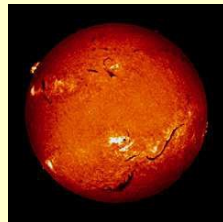
### • Experience:



hot bodies emit  
visible light



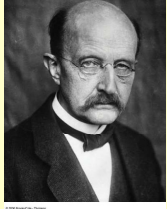
Black-body radiation  
or  
Thermal Radiation



## Thermal Radiation

*All **material** objects ( $T > 0\text{ K}$ ) 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 electromagnetic 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**

$$E_n = nhf$$

$\nwarrow$  integer       $\swarrow$  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.**

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

Kirchhoff's observation: absorbs more – radiates more

$$M: \text{radiant emittance [W/m}^2\text{]} \quad \frac{M_{\lambda i}}{M_{\lambda j}} = \frac{\alpha_{\lambda i}}{\alpha_{\lambda j}} \quad \begin{array}{l} i: \text{arbitrary} \\ j: \text{ideal black body} \end{array}$$

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

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

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

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

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

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

Human body can be considered as a 95% black body

## Emission spectrum of thermal radiation

- the spectrum is continuous

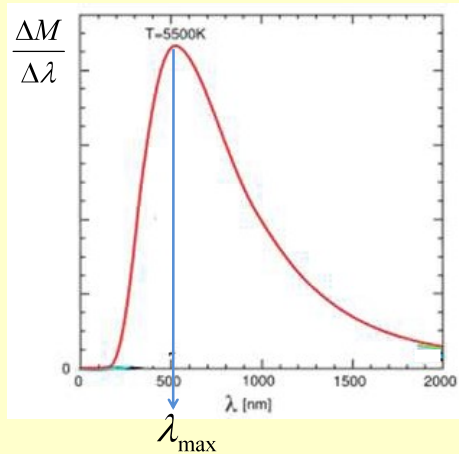
- it has one maximum :

$$\lambda_{\max}$$

- area below the curve:

$$M = \sigma T^4$$

**Radiant emittance:** total radiant power per unit surface area

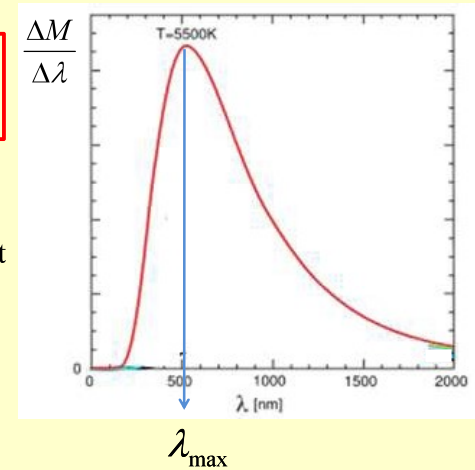


## Stefan – Boltzmann law

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

Stefan – Boltzmann constant

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



## The role of thermal radiation in the energy release

$$\Delta M = \sigma(T_{\text{object}}^4 - T_{\text{environment}}^4)$$

It is influenced by

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

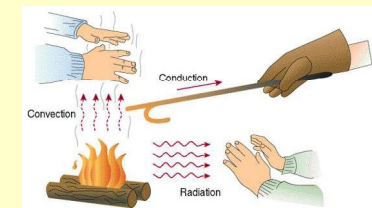
## Temperature regulation and heat exchange

$$\text{heat production} + \text{heat uptake} = \text{heat loss}$$

Heat production out of thermal regulation

metabolic processes  
muscle activity  
secretion  
...

**Heat production for thermal regulation**



**passive operation**

## Temperature regulation and heat exchange

$$\text{heat production} + \text{heat uptake} = \text{heat loss}$$

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...

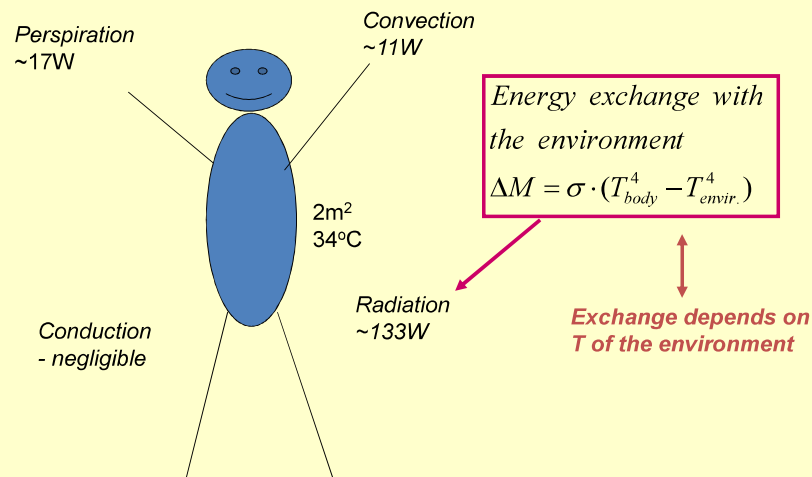
The total energy radiated in one day is about 9 MJ (million [joules](#)), or 2000 kcal (food [calories](#)). [Basal metabolic rate](#) for a 40-year-old male is about 35 kcal/(m<sup>2</sup>·h), which is equivalent to 1700 kcal per day assuming the same 2 m<sup>2</sup> area. However, the mean metabolic 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



Calculate the **net energy loss** due to thermal radiation in 1 hour for a person, with a surface area of 0.8 m<sup>2</sup> if the ambient temperature is 20 °C. The temperature of the skin surface is 27 °C.

$$T_1 = 300K$$

$$T_2 = 293K$$

$$\sigma = 5.7 \cdot 10^{-8} \text{ Wm}^{-2}\text{K}^{-4}$$

$$\Delta M = \sigma(T_1^4 - T_2^4)$$

$$\Delta M = \sigma(T_1^4 - T_2^4)$$

$$\Delta M = 41,6 \text{ Wm}^{-2}$$

$$E = \Delta M \cdot T \cdot A$$

$$E = 119 \text{ J}$$

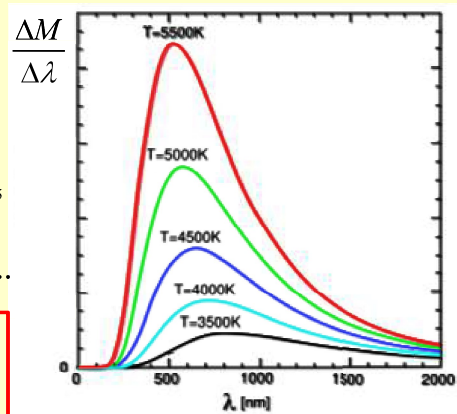
## Emission spectrum of thermal radiation at various temperatures

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

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

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

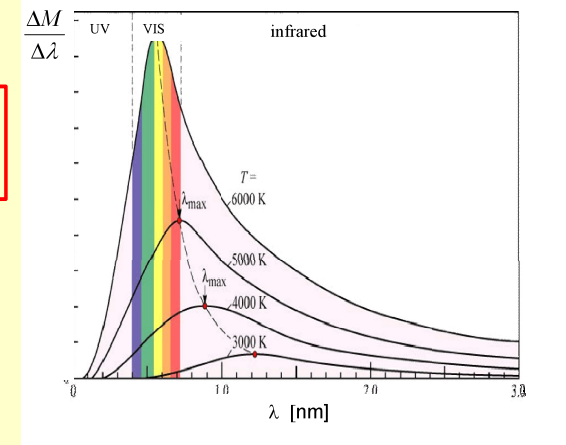
$$T \times \lambda_{\max} = \text{const tan t}$$



## Wien's displacement law

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

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



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

## Wien's displacement law

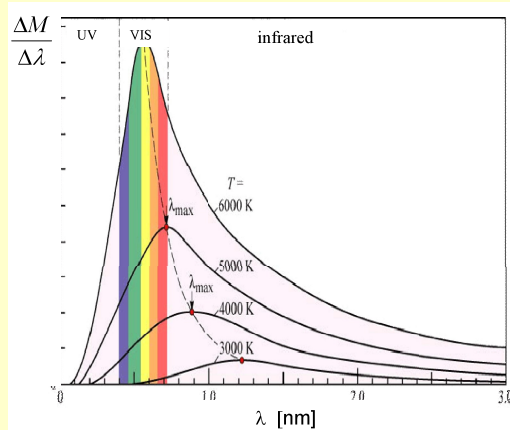
$$T \times \lambda_{\max} = \text{const tan t}$$

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

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

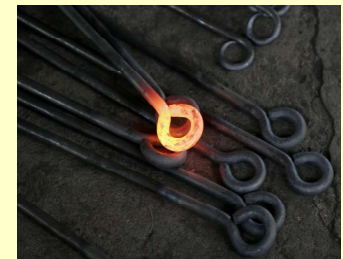
$$\lambda_{\max} \approx 9500[nm]$$

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

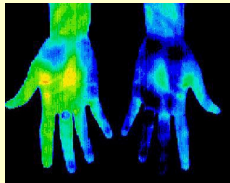
non-invasive imaging technique which can evaluate the body surface thermal gradients

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

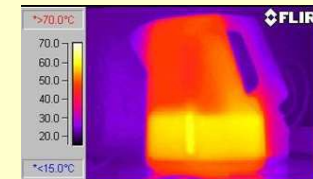
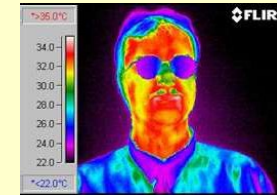
$$\lambda_{peak} = \frac{2.898 \times 10^6 \text{ K} \cdot \text{nm}}{305 \text{ K}} = 9500 \text{ nm}$$

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



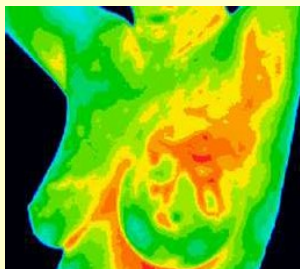
## Application fields

rheumatology

diagnostics of breast cancer

dentistry

neurology

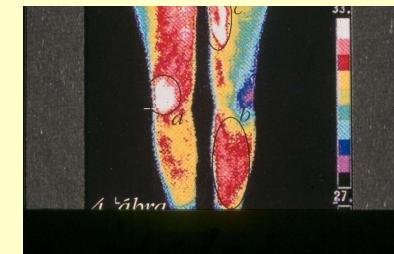


## Detection of alterations in blood circulation

Effect of smoking



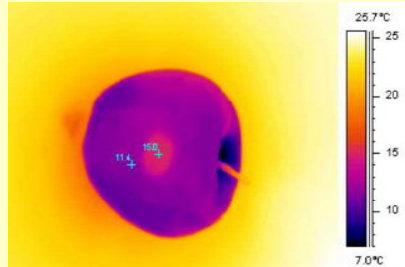
Inflammation and trombosis





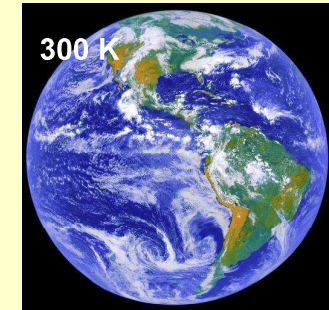
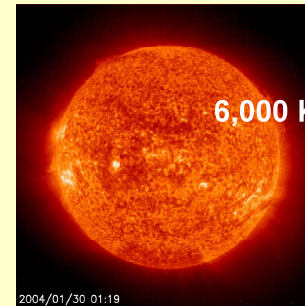
## 2. Non-medical application

Architecture - insulation techniques



Food industry

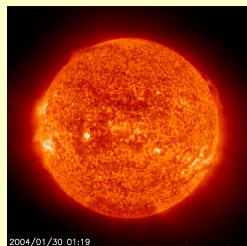
Astronomy



	T (K)	$\lambda_{\max}$ ( $\mu\text{m}$ )	Spectral range	M (W/m <sup>2</sup> )
Sun	6000	0.5	VIS	$7 \times 10^7$
Earth	300	10	infrared	460

## Applications

### 3. Light sources



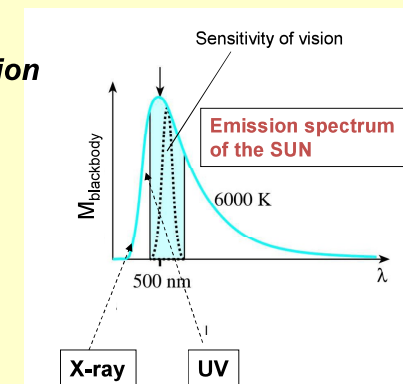
### Light sources

#### based on thermal radiation

##### The Sun.

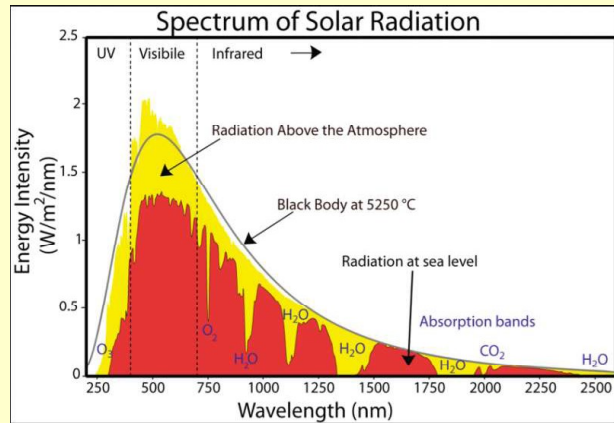
40 % of its thermal radiation falls into the sensitivity range of vision.

Its  $\lambda_{\max}$  is close to the highest sensitivity of vision.



Emission spectrum on the Earth:

$\lambda < 290 \text{ nm}$  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

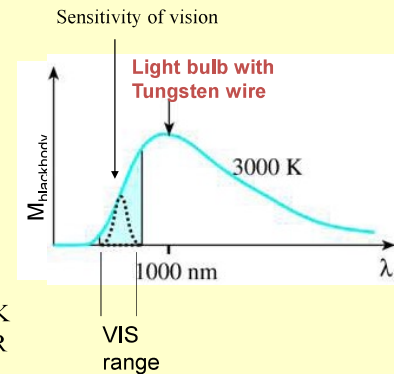
Tungsten at 3000 K

Infralamps

Tungsten at 1300 K

Sollux lamps

High power Tungsten at  $T > 3300 \text{ K}$   
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 ( $\lambda_{\text{max}} = 580 \text{ nm}$ )  
with UV filter

(Sun: about 6000 K,  $\lambda_{\text{max}} = 480 \text{ nm}$ )



#### Strength of irradiation:

max . 5 - 10 thousand lux

(regular office ~ 50-100 lux,  
bright sunlight ~  $10^5 \text{ lux}$ )

**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