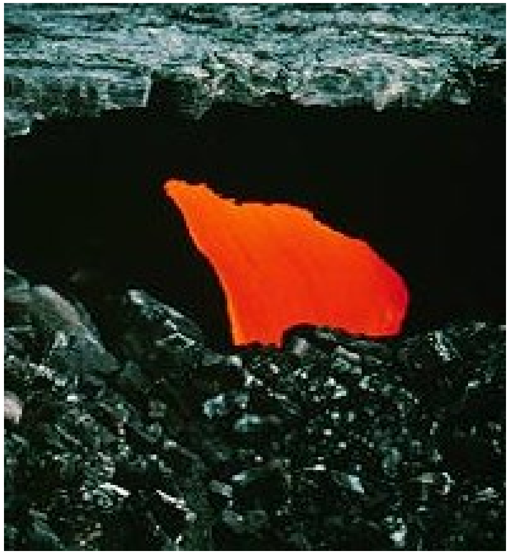
Thermal radiation characteristics and description; emission of the human body, medical applications, infra-diagnostics, Polarization of light.

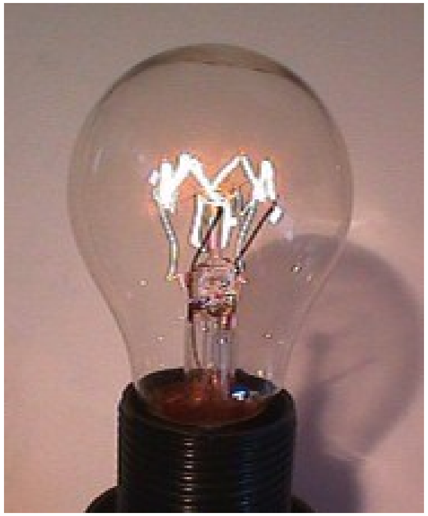
Gusztáv Schay .

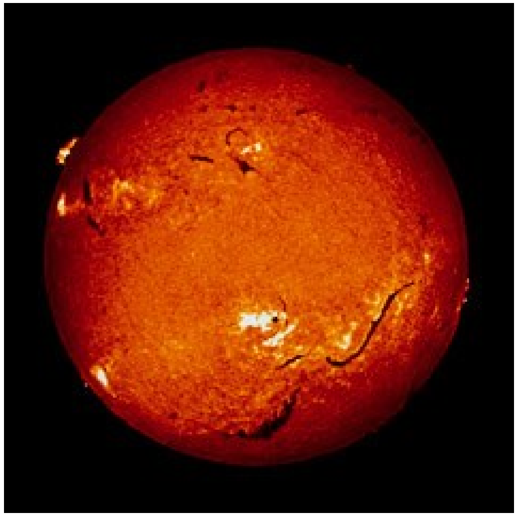
SEMMELWEIS
UNIVERSITY 1769

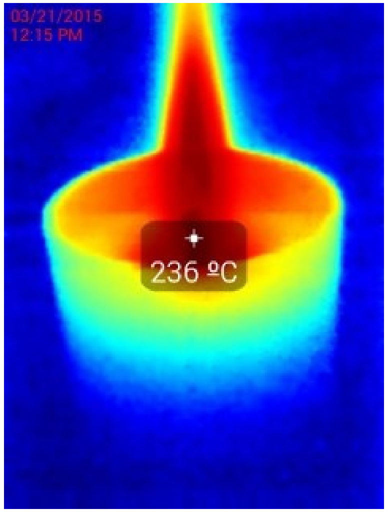
Thermal emission



GLOWING HOT

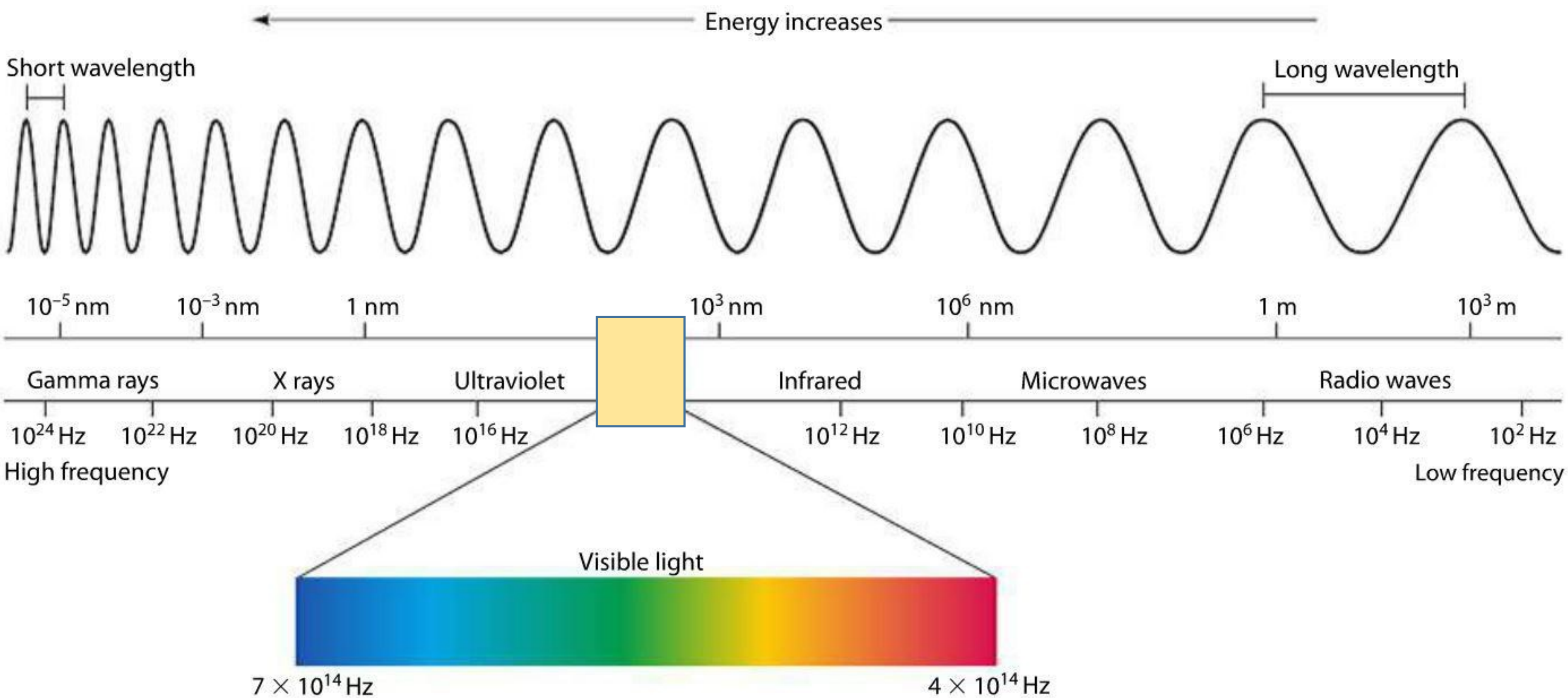






Hot objects emit light.

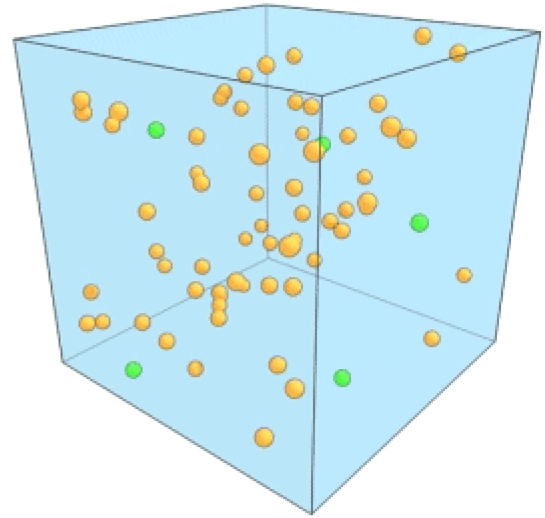
Maybe even colder objects do the same?



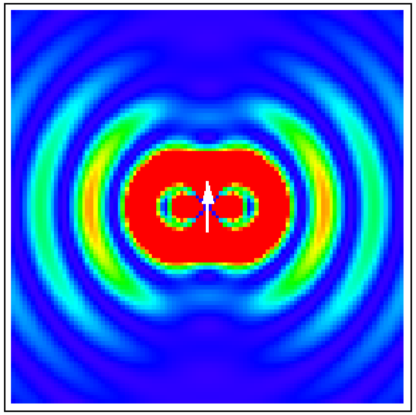
We only see as “Light” a very limited range of the full electromagnetic wave spectrum. But light is also all the others!

ALL objects generate light, IF their temperature is above 0 K.

This is called thermal radiation.



Source: the thermal motion of the atoms, molecules, as they all have charges inside.
Basic Physics course: an accelerating charge creates an electromagnetic field.



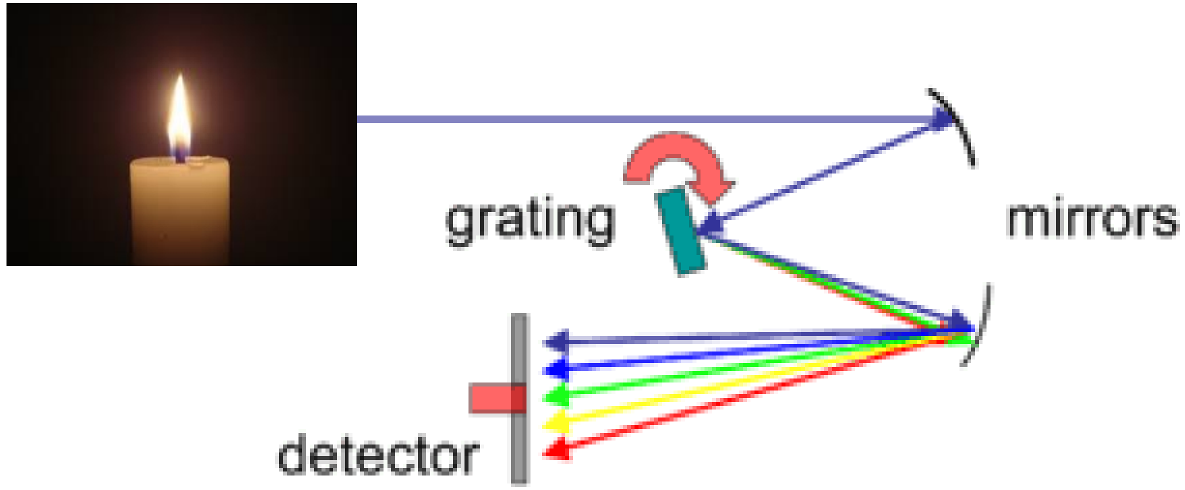
Just for fun: it can be exactly calculated, but this is NOT required here ;)

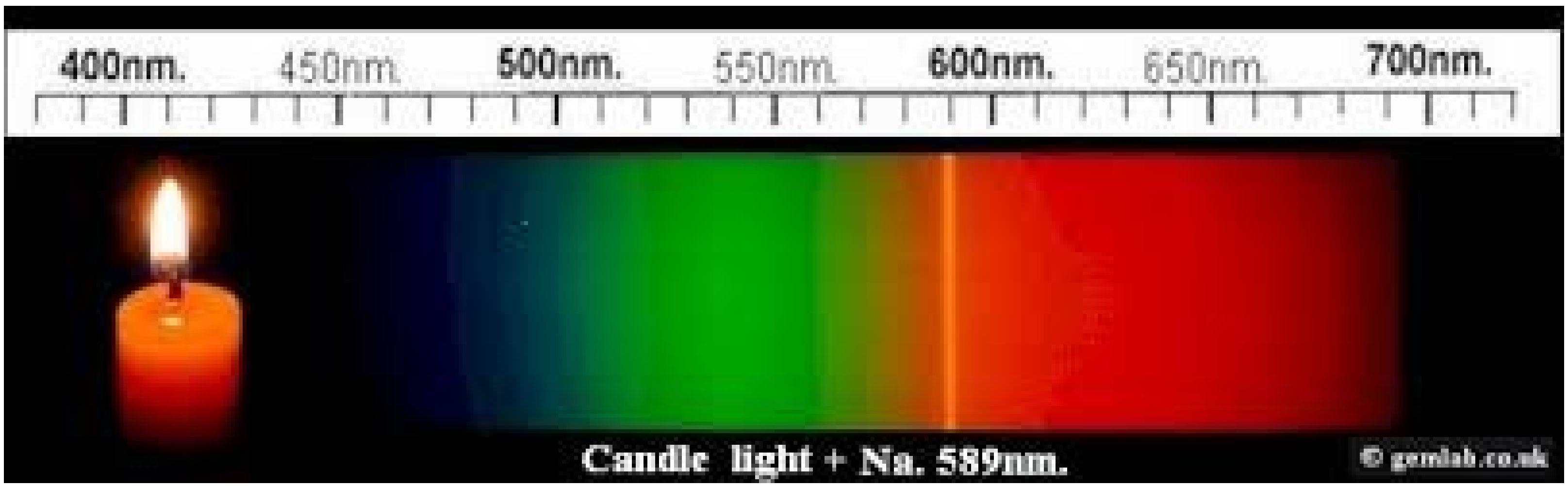
$\mathbf{E}_{rad}(\mathbf{r},t) = -[1/(4\pi\varepsilon_0)]*[q/(c^2r')]*\mathbf{a}_{perp}(t - r'/c)$

charge

acceleration

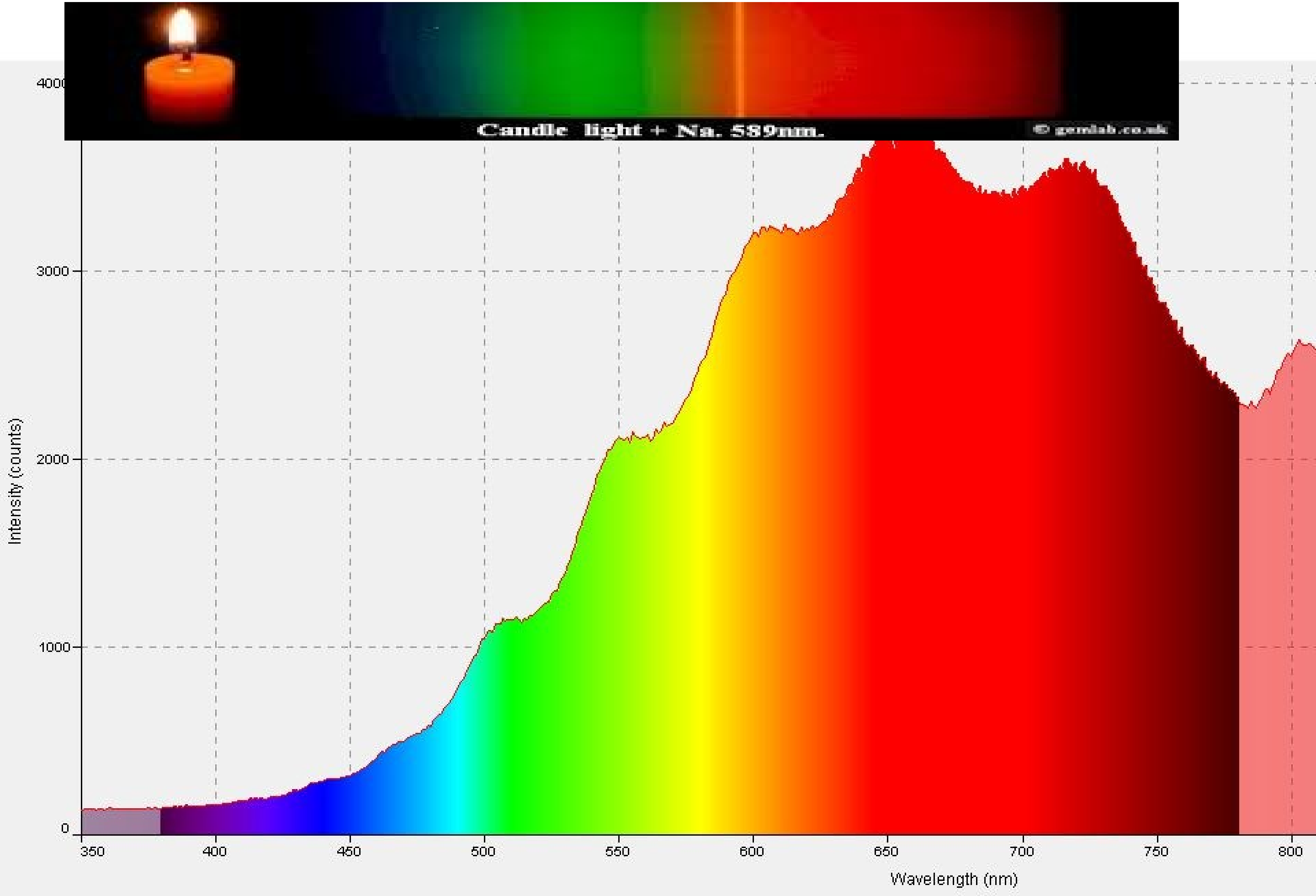
speed of light: $3 \cdot 10^8$ m/s


grating
mirrors
detector

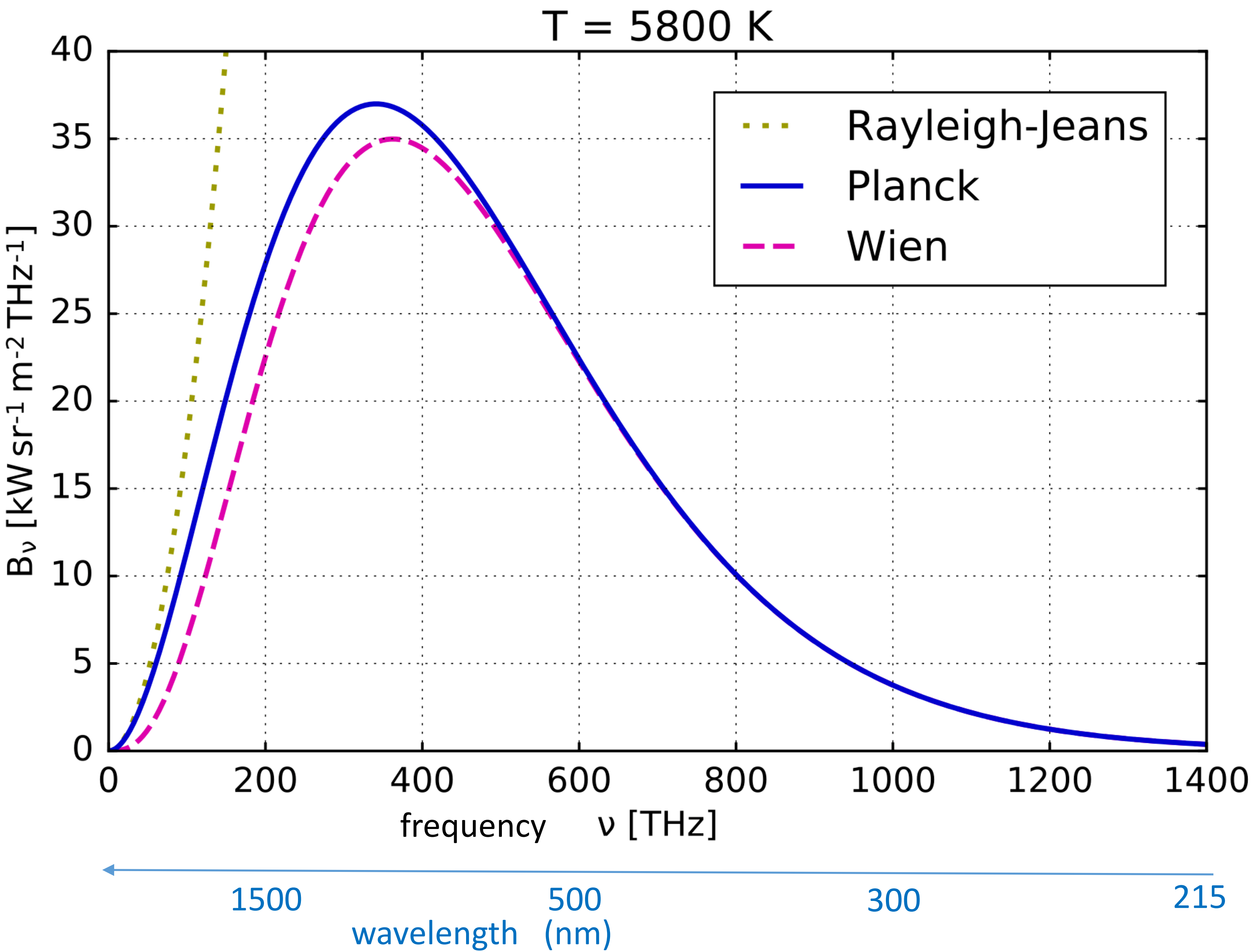

400nm.
450nm.
500nm.
550nm.
600nm.
650nm.
700nm.
Candle light + Na. 589nm.
© gemlab.co.uk

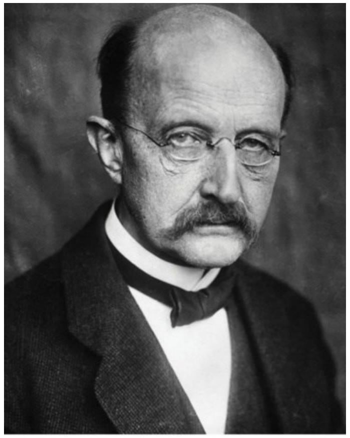
Emission spectrum of a candle flame

(not pure thermal radiation, also other sources of light, see later lectures on lumiunescence)



From classic physics, with a LOT of calculations it is possible to come quite close to the shape of the experimental curve (Planck), BUT NOT close enough!





Max Planck (~ 1900)

He could get the correct shape of the cuve ONLY IF he assumed that the energy of the light-waves is “packaged” into discrete values of h·f, which Einstein later coined as PHOTONS

$$E_n = nhf$$

n: integer

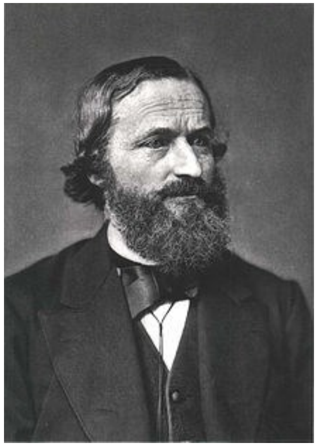
f: vibrational frequency

En is the energy of n photons together, all with the same frequency.
The accelerating charges produce photons with a given frequency

with this, he could get a formula which has the correct shape ☺

$$\rho(f,T)\,df = \frac{8\pi V f^2 df}{c^3}\frac{hf}{e^{hf/kT}-1}$$

Do NOT learn the formula itself!



Gustav Kirchhoff (1824-1887)

If an object absorbs light well, then it also emits light well.

The best emitter is then an absolute black body, which absorbs all light arriving onto the surface.

Als Hindernisse bei der praktischen Anwendung dürften sowohl die Farbenunterschiede der mit dieser Einheit verglichenen Lichtquelle, als auch das schnelle Wachsen der ausgestrahlten Lichtmenge mit steigender Stromstärke bezeichnet werden. Dennoch möchten sich bei Anwendung anderer Lichtquellen zu dem genannten Zweck vielleicht noch gröfsere Schwierigkeiten in den Weg stellen, da sich die Umstände, welche die Leuchtkraft modificiren, schwerlich auf so einfache Bedingungen wie im vorliegenden Falle zurückführen lassen.

IV. *Ueber das Verhältnifs zwischen dem Emissionsvermögen und dem Absorptionsvermögen der Körper für Wärme und Licht;*
von G. Kirchhoff.

Ein Körper, der in einer Hülle sich befindet, deren Temperatur der seinigen gleich ist, ändert durch Wärmestrahlung nicht seine Temperatur, absorbirt also in einer gewissen Zeit eben so viel Strahlen als er aussendet. Schon vor langer Zeit hat man hieraus den Schlufs gezogen, dafs bei derselben Temperatur das Verhältnifs zwischen dem Emissionsvermögen und dem Absorptionsvermögen für alle Körper das gleiche ist. Dabei hat man vorausgesetzt, dafs die Körper nur Strahlen *einer* Gattung aussenden. Dieser Satz ist durch Versuche, namentlich von den Hrn. de la Provostaye und Desains in vielen Fällen bestätigt gefunden, in denen die Gleichartigkeit der ausgesendeten Strahlen wenigstens näherungsweise in sofern vorausgesetzt werden konnte, als die Strahlen dunkle waren. Ob ein ähnlicher Satz gilt, wenn die Körper gleichzeitig Strahlen verschiedener Gattung aussenden, was strenge genommen

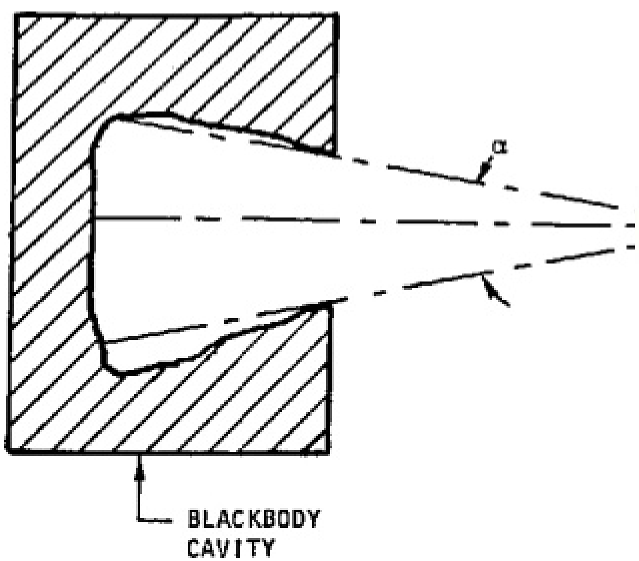
$$\alpha = \frac{J_{absorbed}}{J_{total\ incident}}$$

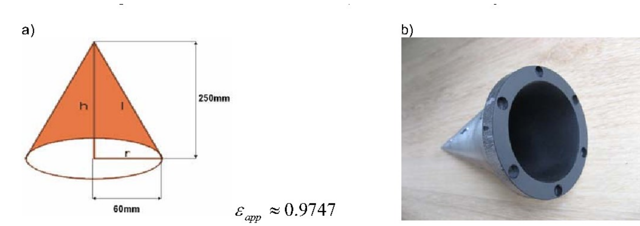
absor**pt**ance

n.B.: $A=\lg(J_0/J_{transmitted})$
this is the absor**b**ance

Total black body: $\alpha=1$

This can be simulated by specially designed boxes with a hole.
The hole itself can act as a black body





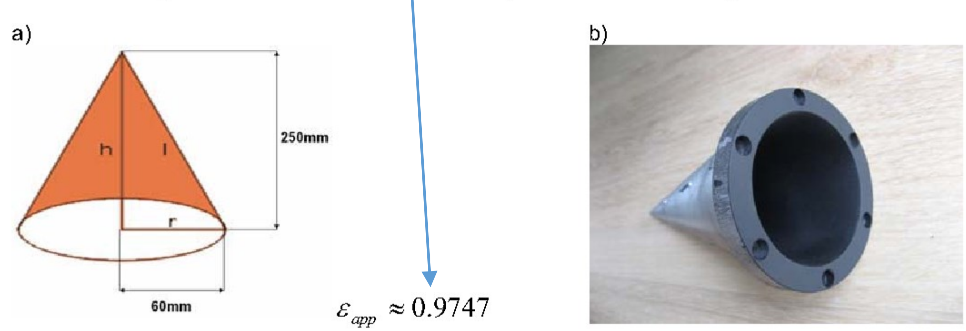
M: radiant emittance (W/m^2)
The emitted power on a unit surface of the emitter body.

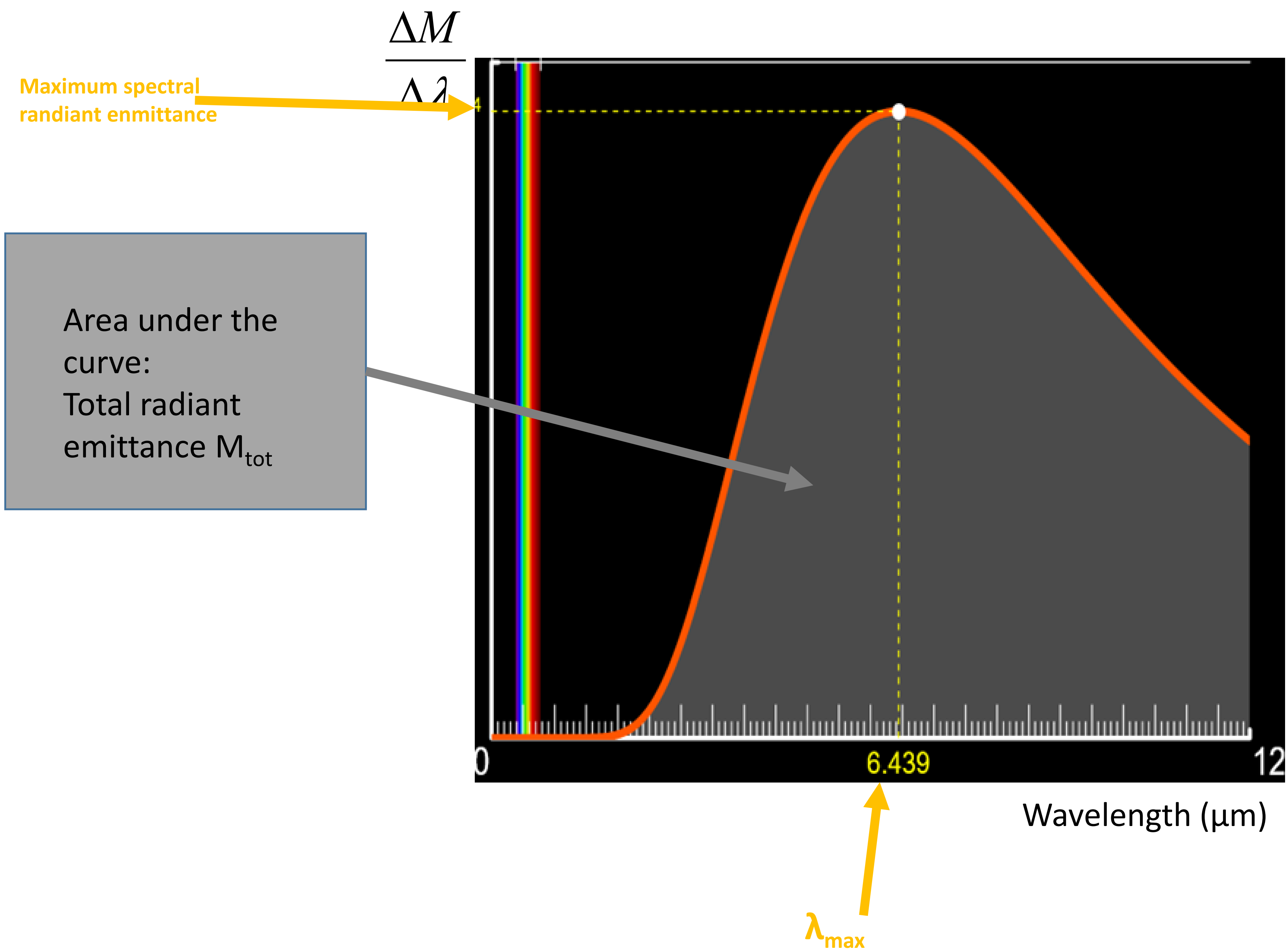
Kirchhoff's law: M/α is constant.

This means, if an object is absorbing all of the radiation, so α=1, then $M=M_{max}$

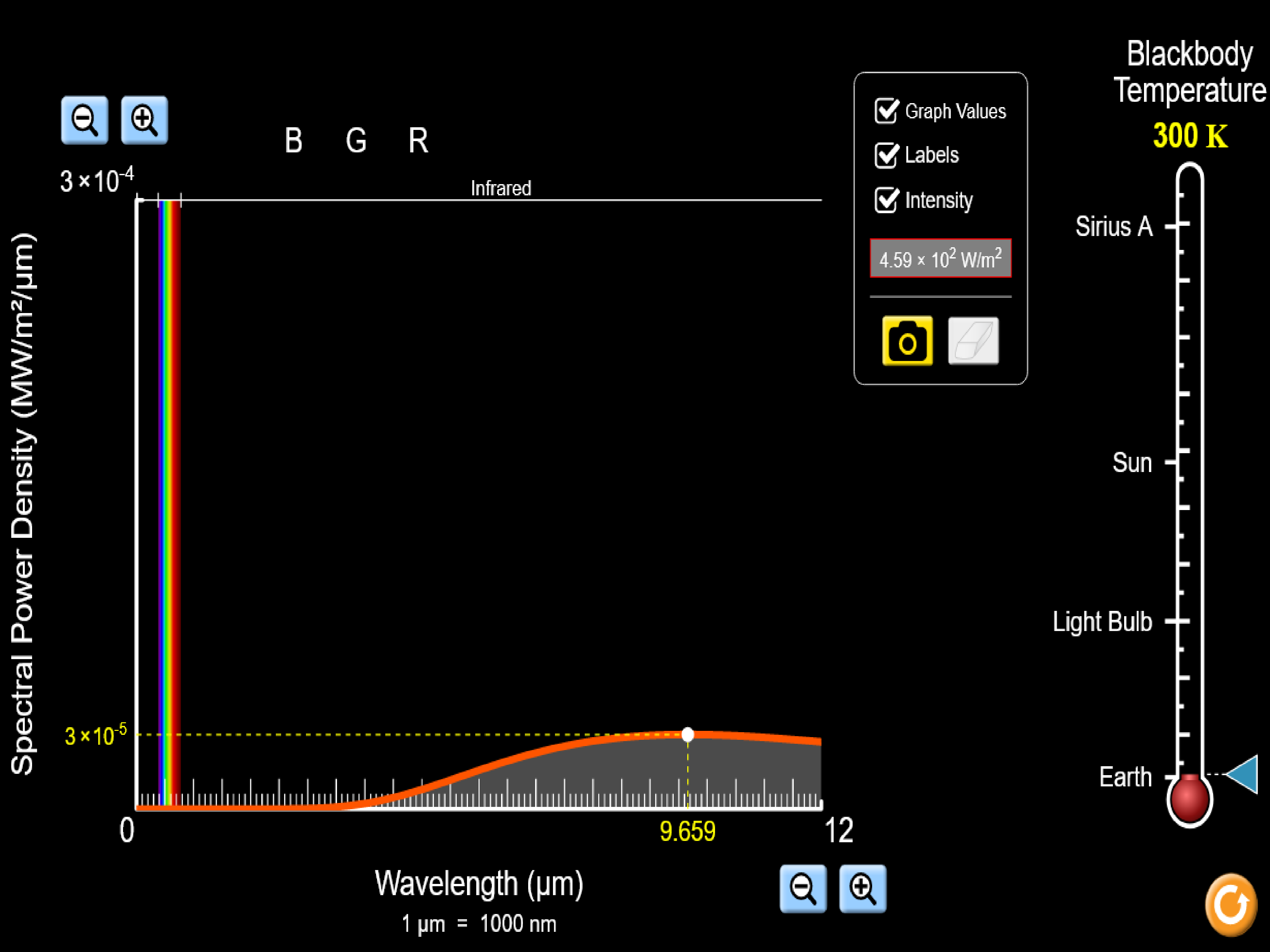
Both M and α depend on the frequency (or wavelength)!
(spectral radiant emittance, M_λ and spectral absorptance α_λ)

How close a body comes to the absolute black body

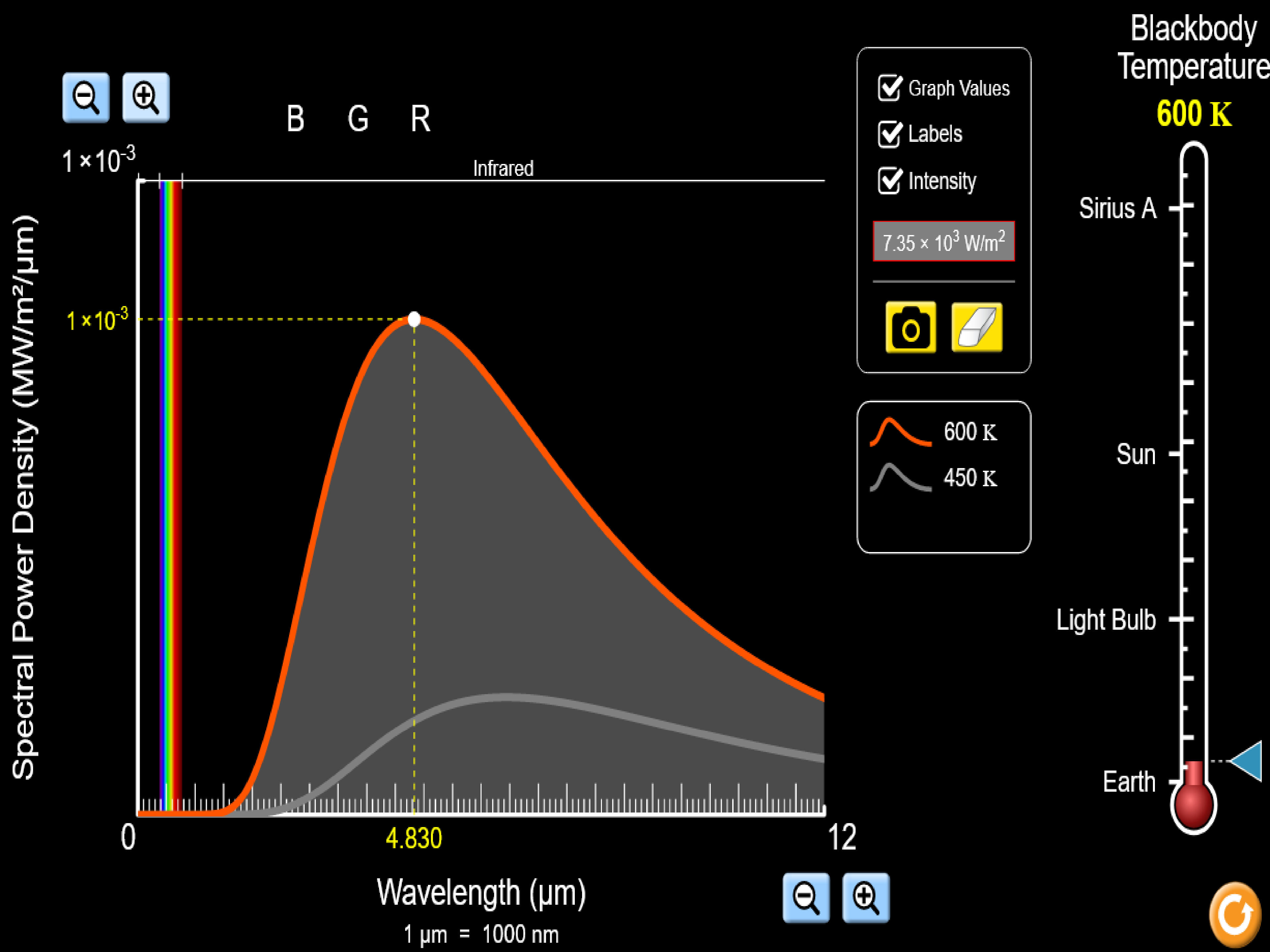




ΔM
Δλ
Maximum spectral randiant enmittance
4
Area under the curve: Total radiant emittance M tot
0
6.439
12
Wavelength (μm)
λmax

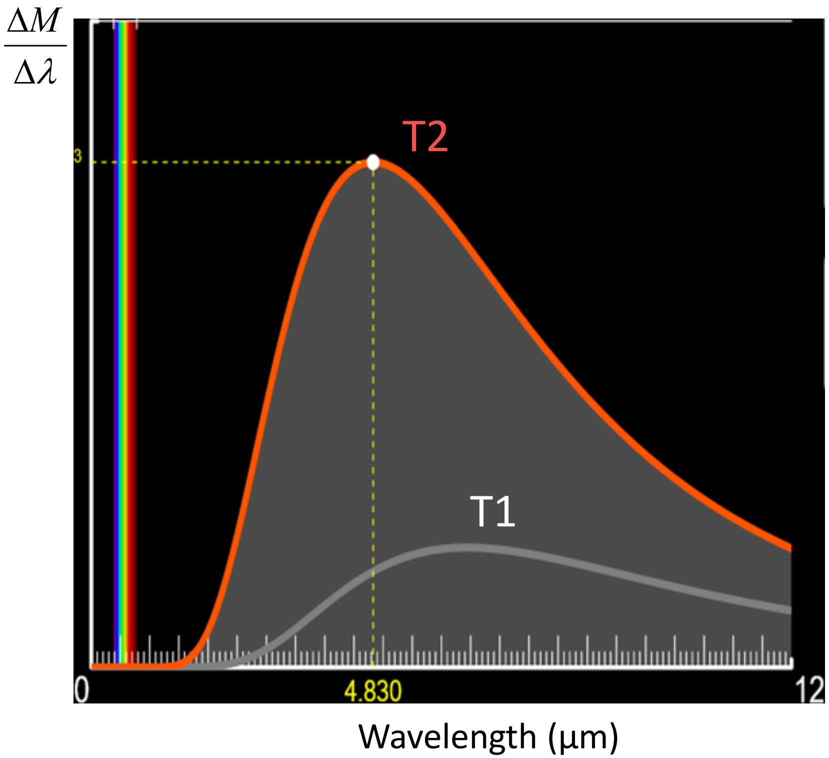

B G R
3 × 10-4
Infrared
3 × 10-5
Spectral Power Density (MW/m²/μm)
0
9.659
12
Wavelength (μm)
1 μm = 1000 nm
Graph Values
Labels
Intensity
4.59 × 10² W/m²
Blackbody Temperature
300 K
Sirius A
Sun
Light Bulb
Earth

B G R
3 × 10-4
Infrared
2 × 10-4
Spectral Power Density (MW/m²/μm)
0
6.439
12
Wavelength (μm)
1 μm = 1000 nm
Graph Values
Labels
Intensity
2.33 × 103 W/m2
Blackbody Temperature
450 K
Sirius A
Sun
Light Bulb
Earth



B G R
1 × 10^-3
Infrared
1 × 10^-3
Spectral Power Density (MW/m²/μm)
0
4.830
12
Wavelength (μm)
1 μm = 1000 nm
Graph Values
Labels
Intensity
7.35 × 10^3 W/m^2
600 K
450 K
Blackbody Temperature
600 K
Sirius A
Sun
Light Bulb
Earth

Two famous laws:



Wien's displacement law

$\lambda_{max} \cdot T = 2.898 \cdot 10^6$ K·nm (Wien's constant)

Stephan-Boltzmann's law

$M_{tot} = \sigma \cdot T^4$

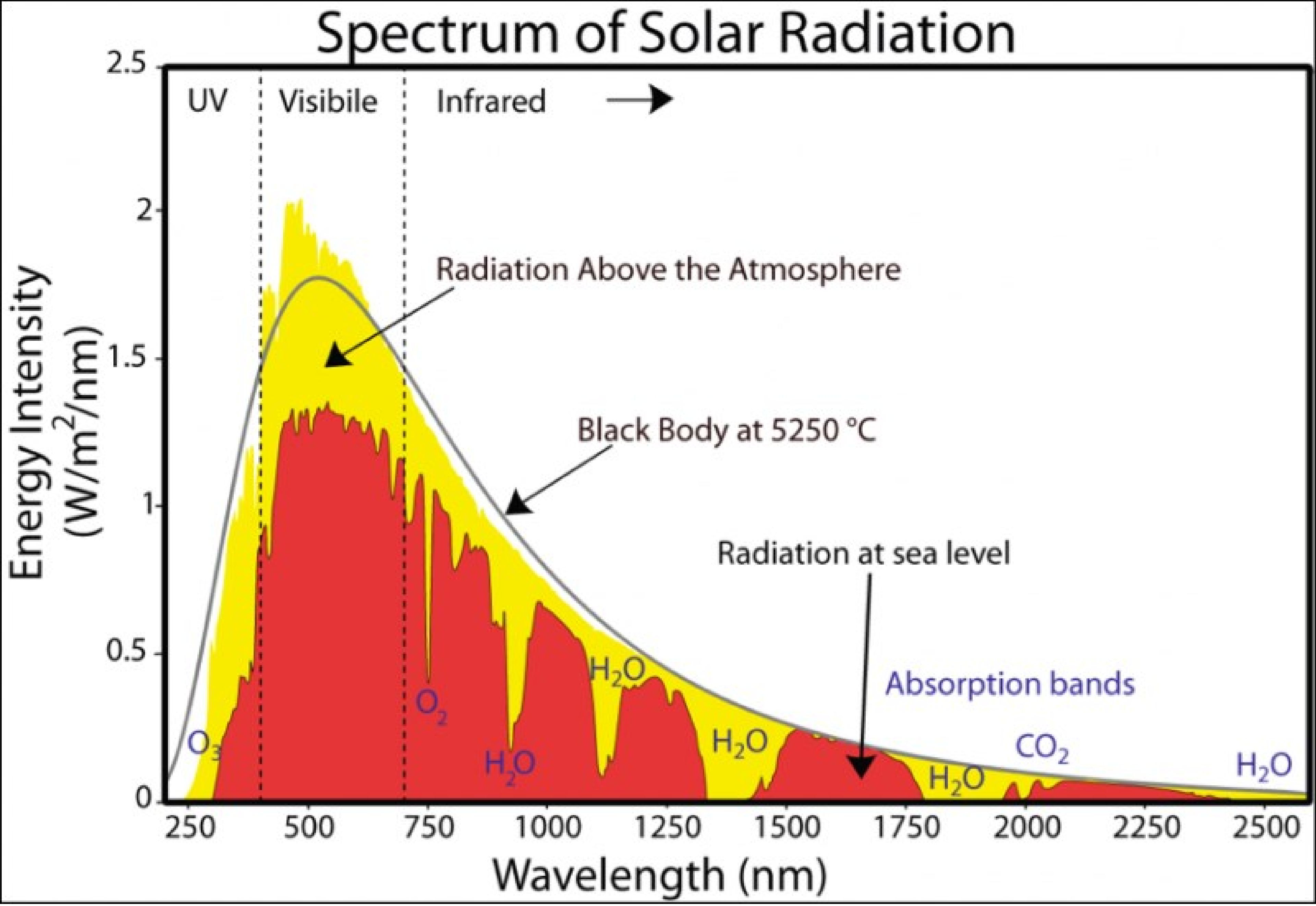
$$\sigma = 5.7 \times 10^{-8} [\frac{W}{m^2 K^4}]$$

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

W/m² !

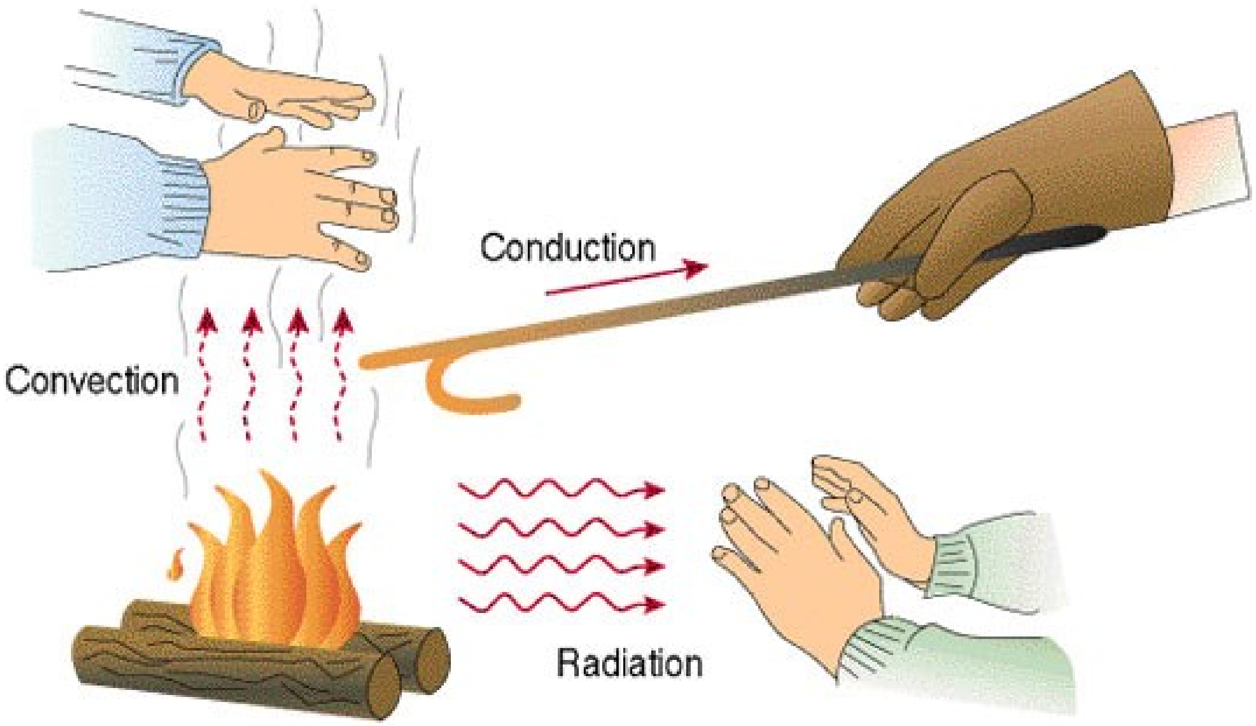
°K

Thermal equilibrium will also be reached through radiation energy exchange.



Spectrum of Solar Radiation
UV
Visibile
Infrared
Radiation Above the Atmosphere
Black Body at 5250 °C
Radiation at sea level
Absorption bands
O_3
O_2
H_2O
H_2O
H_2O
H_2O
CO_2
H_2O
Energy Intensity ($W/m^2/nm$)
Wavelength (nm)
0
0.5
1
1.5
2
2.5
250
500
750
1000
1250
1500
1750
2000
2250
2500

Heat energy exchange possibilities



+ Evaporation
(Perspiration)

For an adult, approx. 2 m² skin area (at room temperature environment):

Radiation → $\approx 100W$

Conduction → $\leq 1\text{W}$

Convection → $\approx 10W$

Perspiration → $\approx 10W$

Most of the metabolic rate (2000kcal/day = 9MJ/day) is used up for radiative heat loss.

Stephan-Boltzmann's law

$M_{tot} = \sigma \cdot T^4$

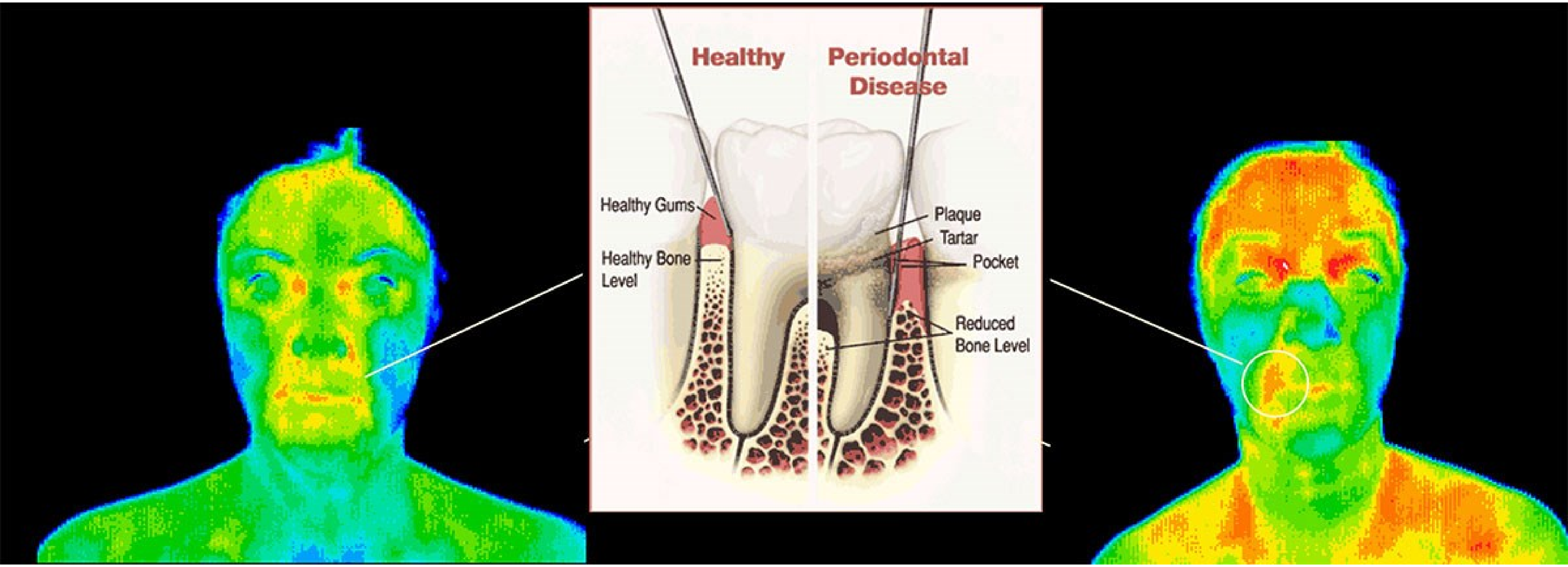
$$\sigma = 5.7 \times 10^{-8} [\frac{W}{m^2 K^4}]$$

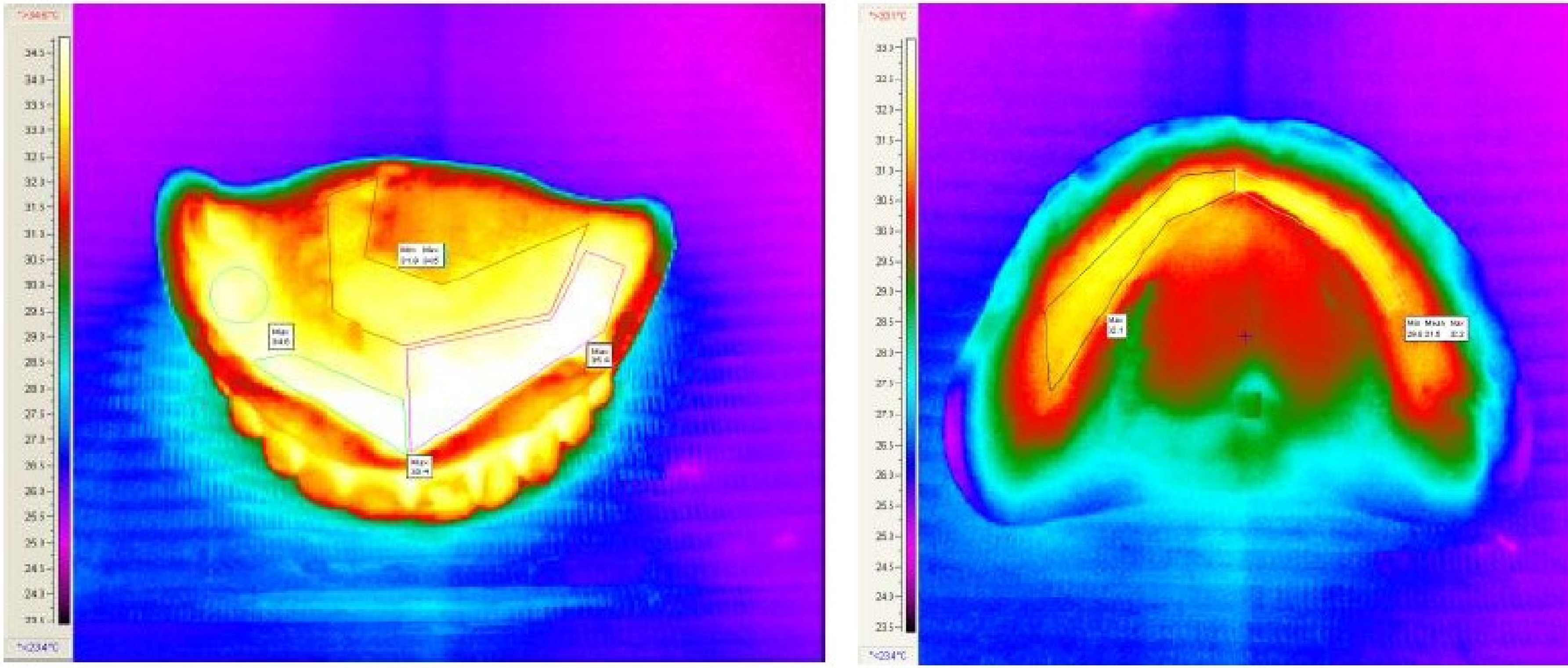
Wien's displacement law

$\lambda_{max} \cdot T = 2.898 \cdot 10^6$ K·nm (Wien's constant) → For human skin surface $\lambda_{max} = 7 \ldots 15$ µm

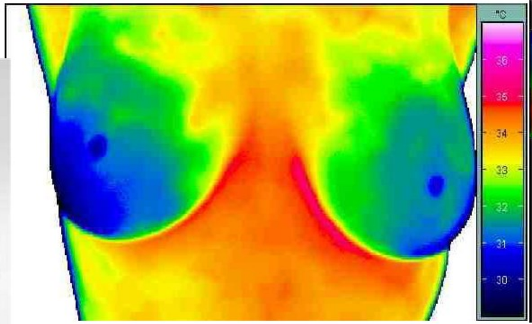
Thermal imaging and sensing is very sensitive!

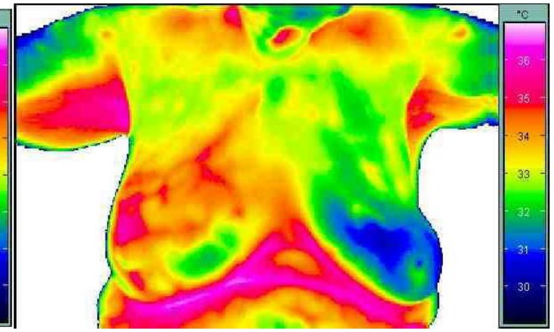
Inflammation, cancer, elevated metabolic rate can be detected.

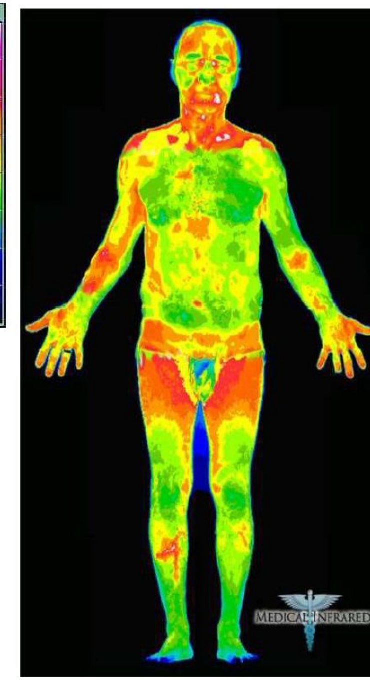


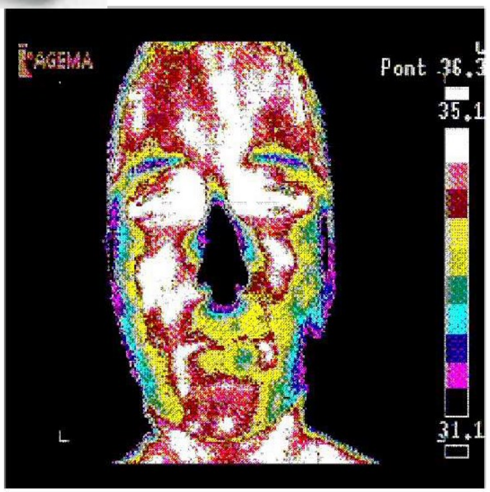


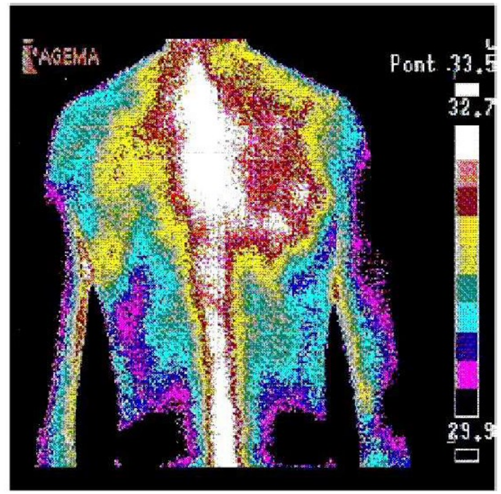
Thermograms of the denture after its removal from the oral cavity

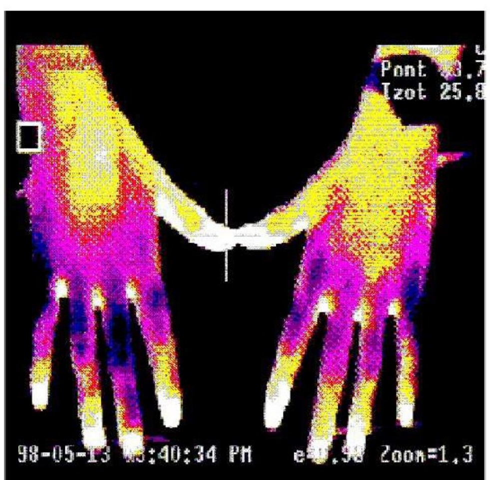

°C
36
35
34
33
32
31
30

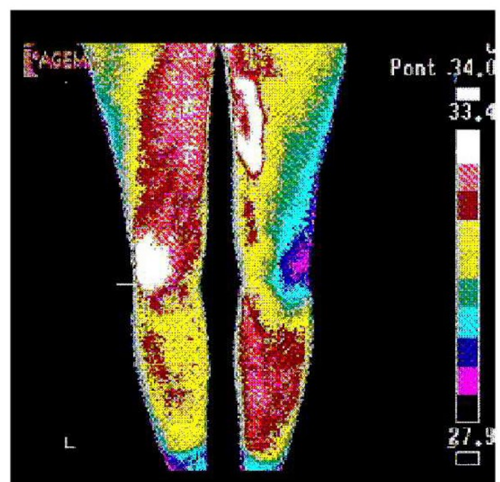

°C
36
35
34
33
32
31
30

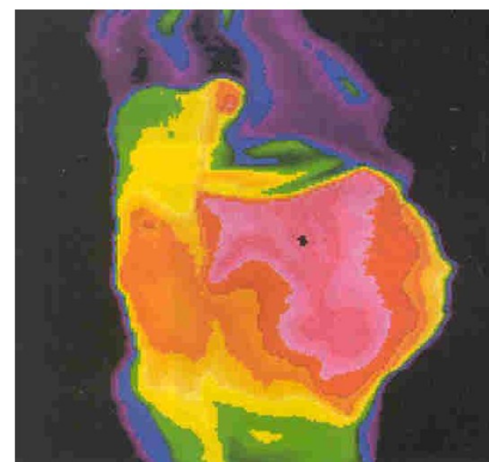

MEDICAL INFRARED

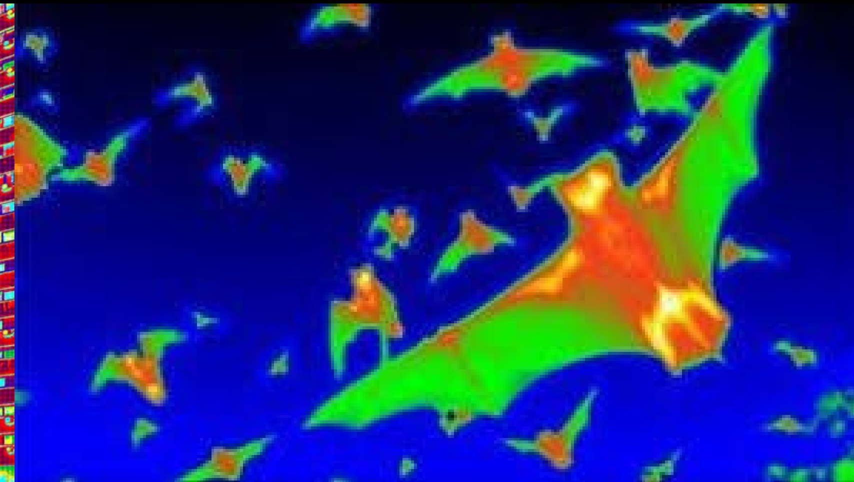

AGEMA
Pont 36.3
35.1
31.1

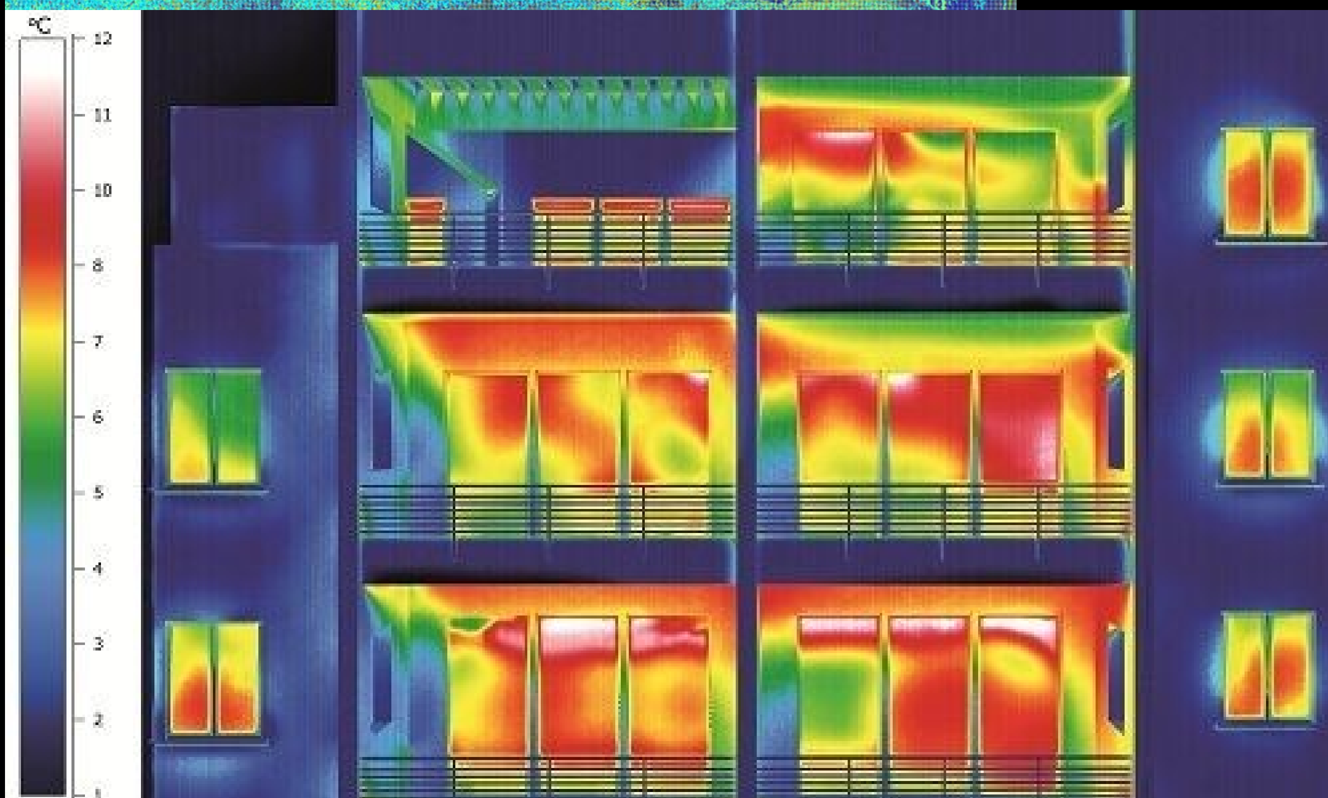

AGEMA
Pont 33.5
32.7
29.9


Izot 25.8
Zoom=1.3


Pont 34.0
33.4
27.9

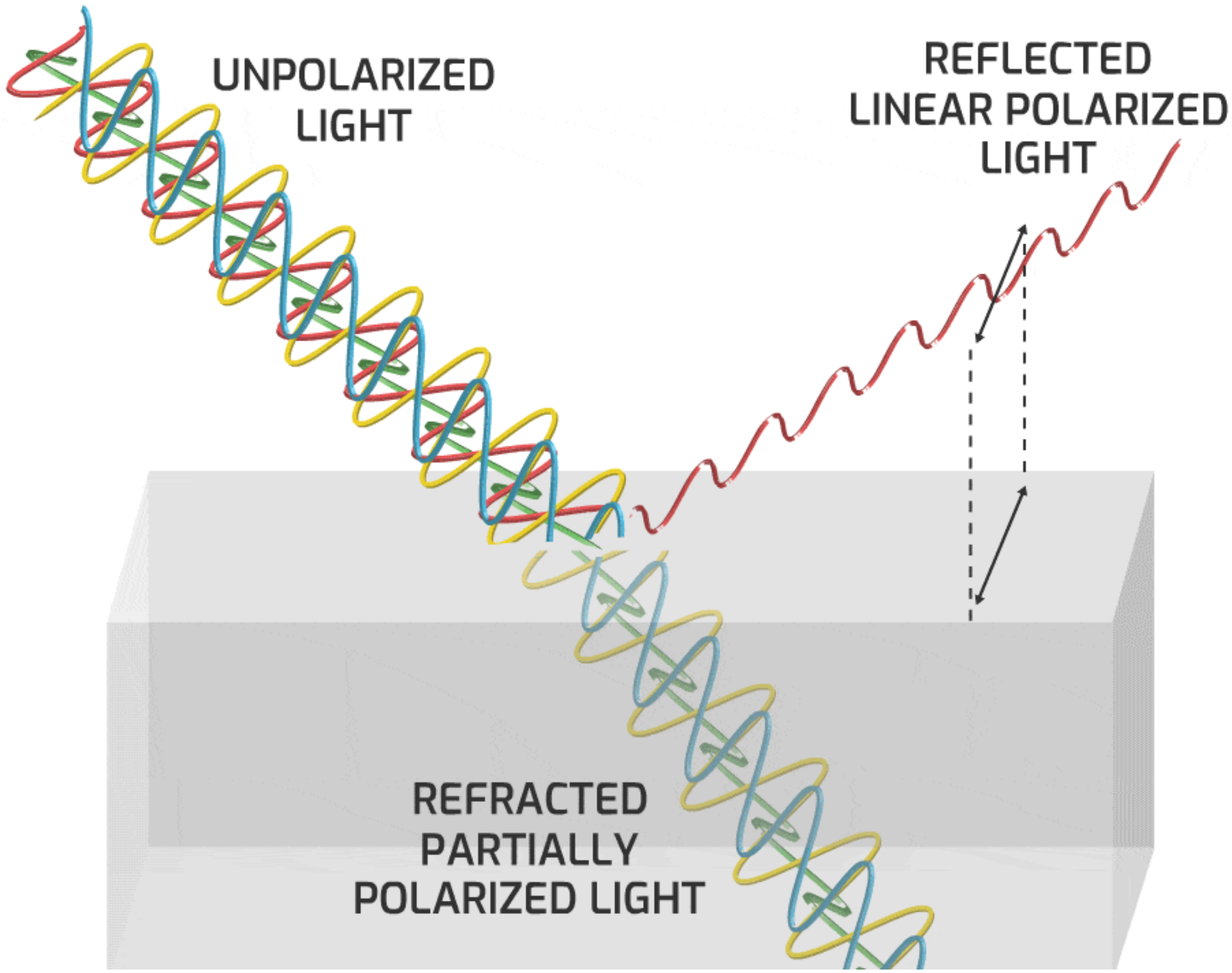




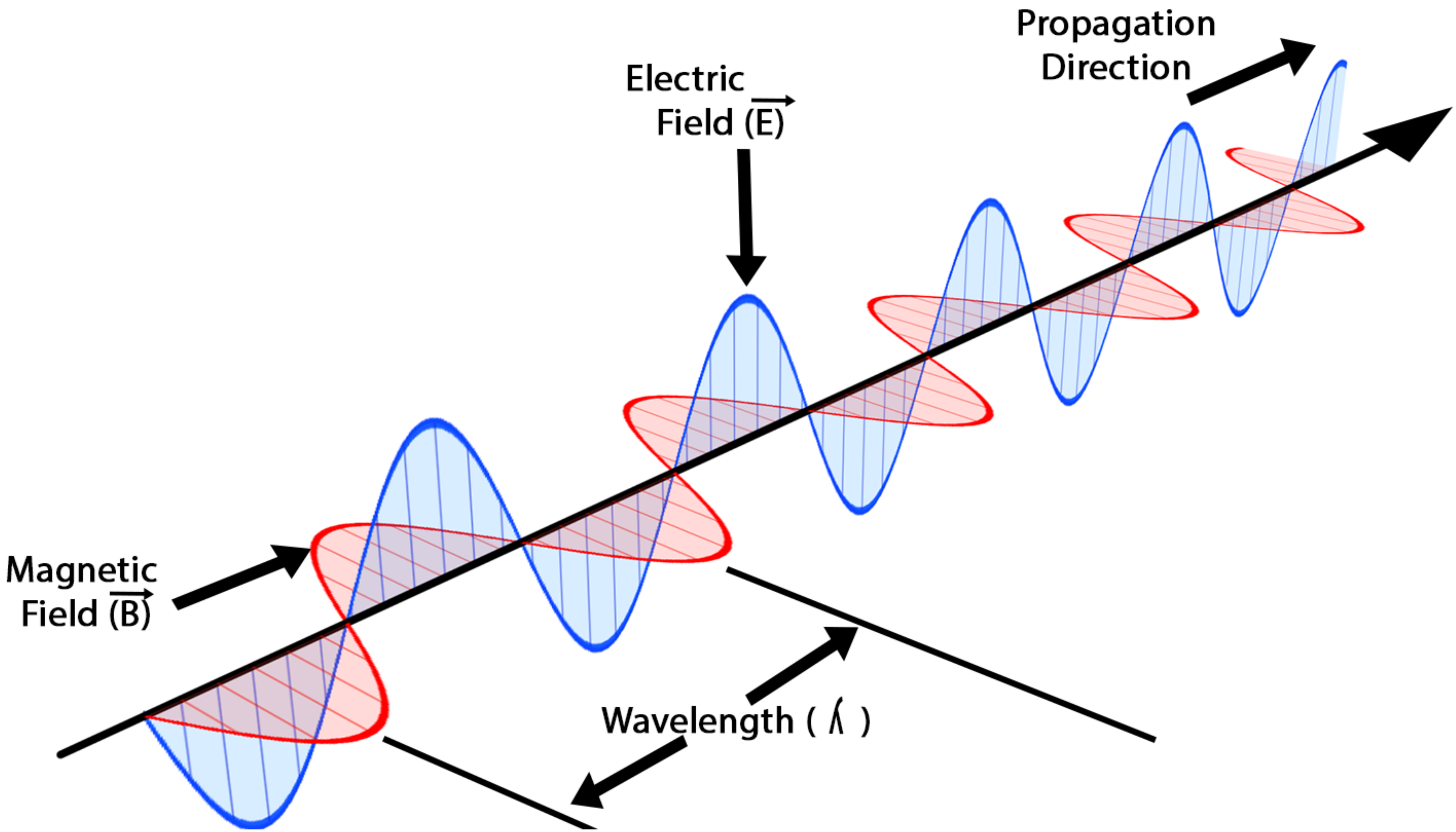

°C
12
11
10
8
7
6
5
4
3
2
1

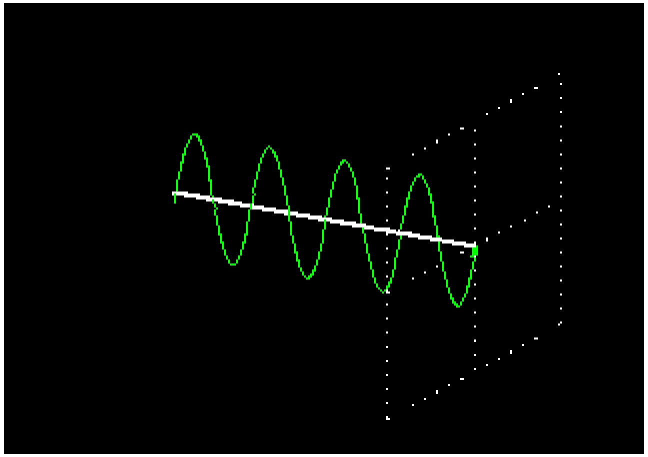
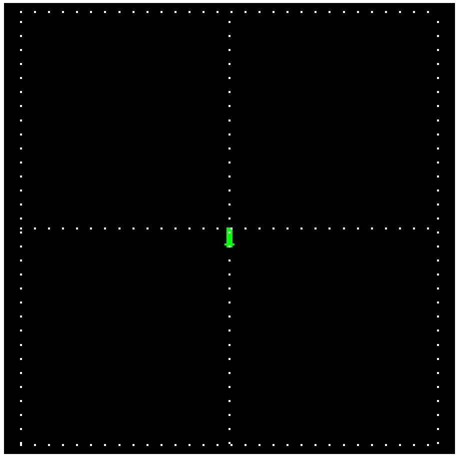

SPL

Polarization of light



Electromagnetic Wave



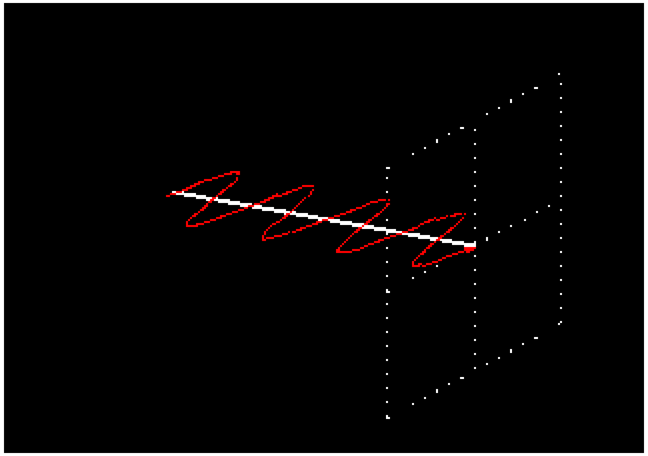
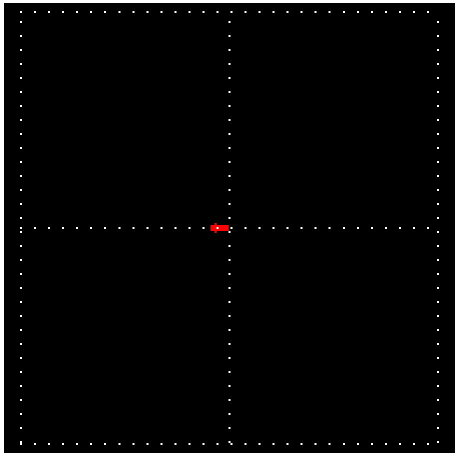



We usually only show the E-field vector, to make the drawing easier to read.

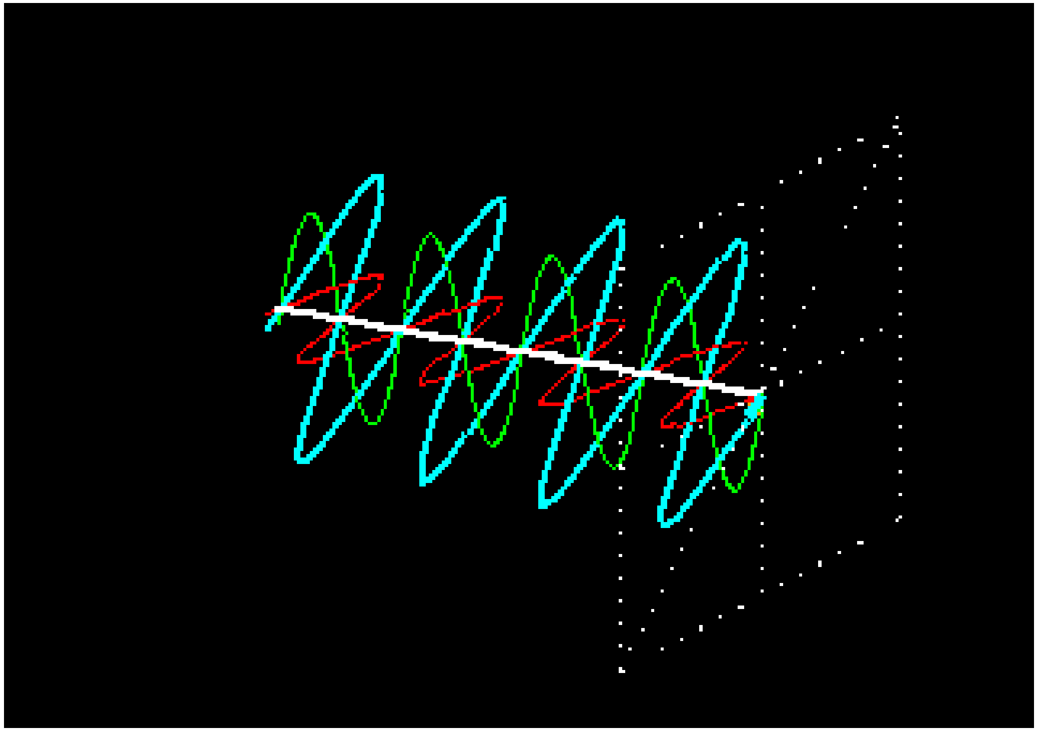
We do imagine the B-field vector to be there, since it is EM-wave!

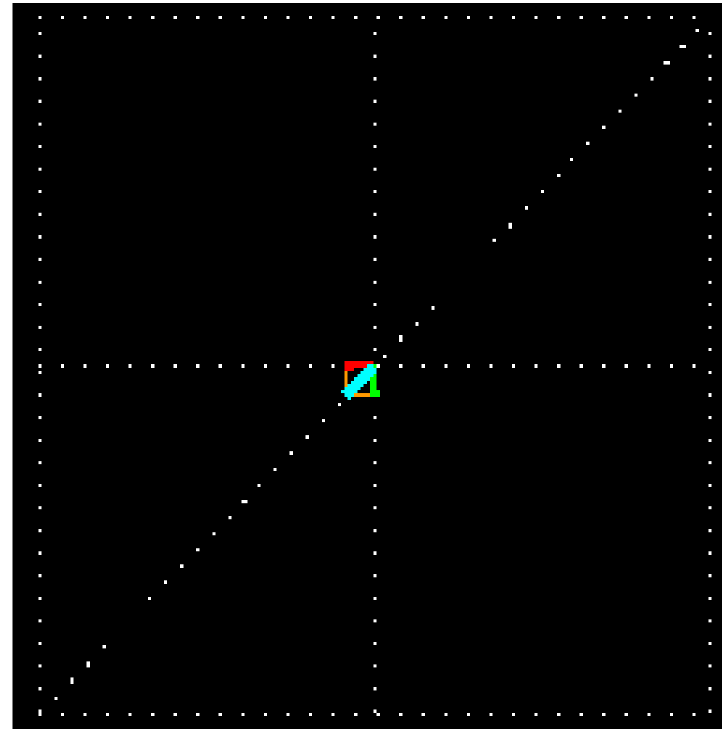
Polarization is the direction of the E-field vector

Linear polarized light: only one direction is possible. (more precisely, along one line)

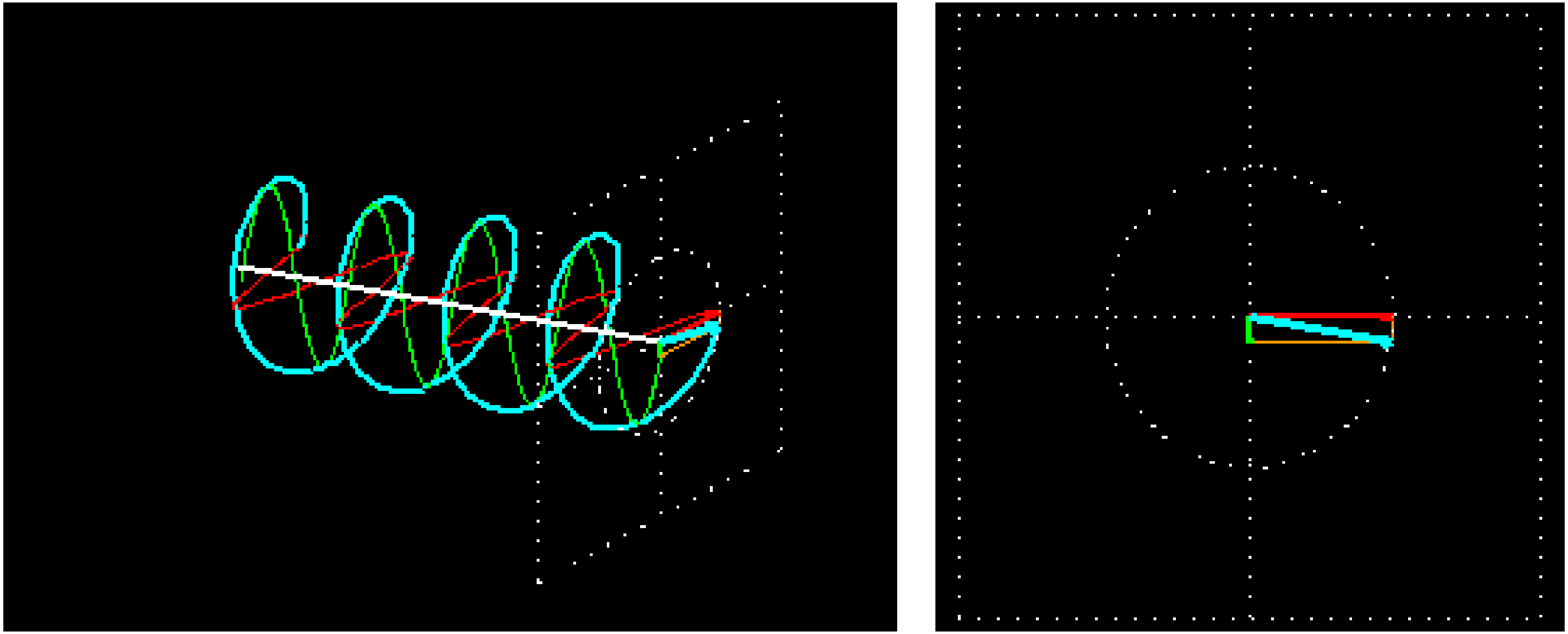



https://cddemo.szialab.org/

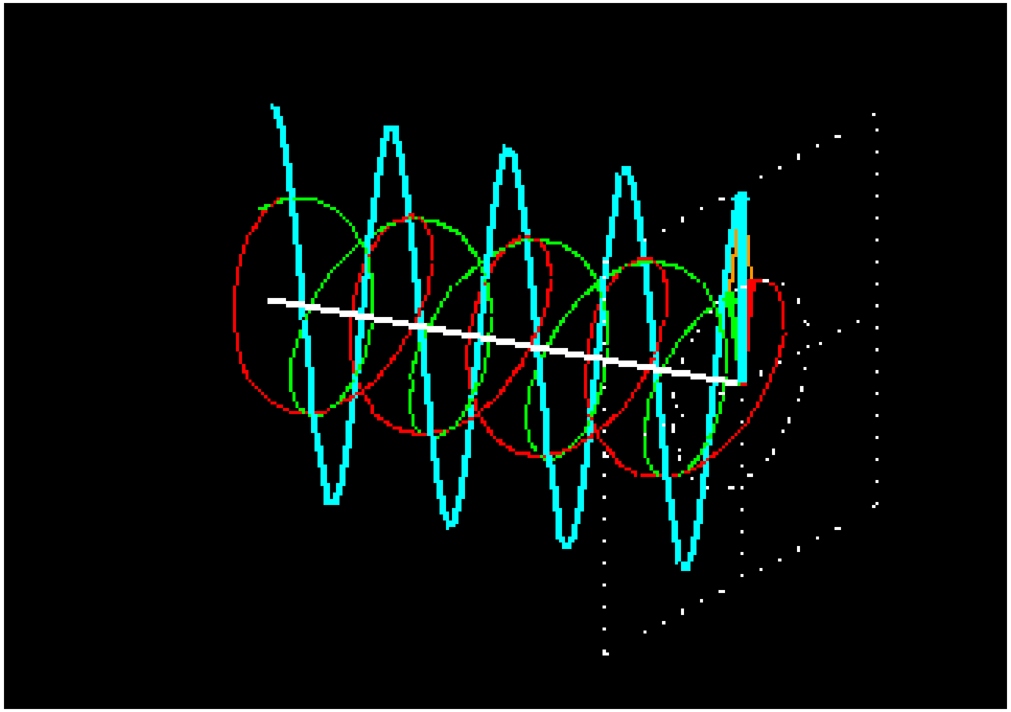


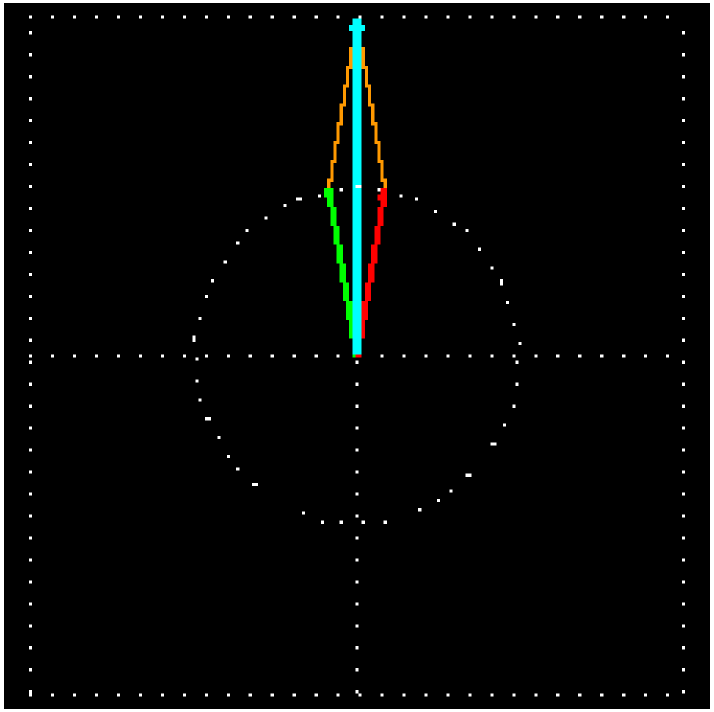


Superposition principle: waves can be freely added together, **the resulting E-field is the vectorial sum of the components**



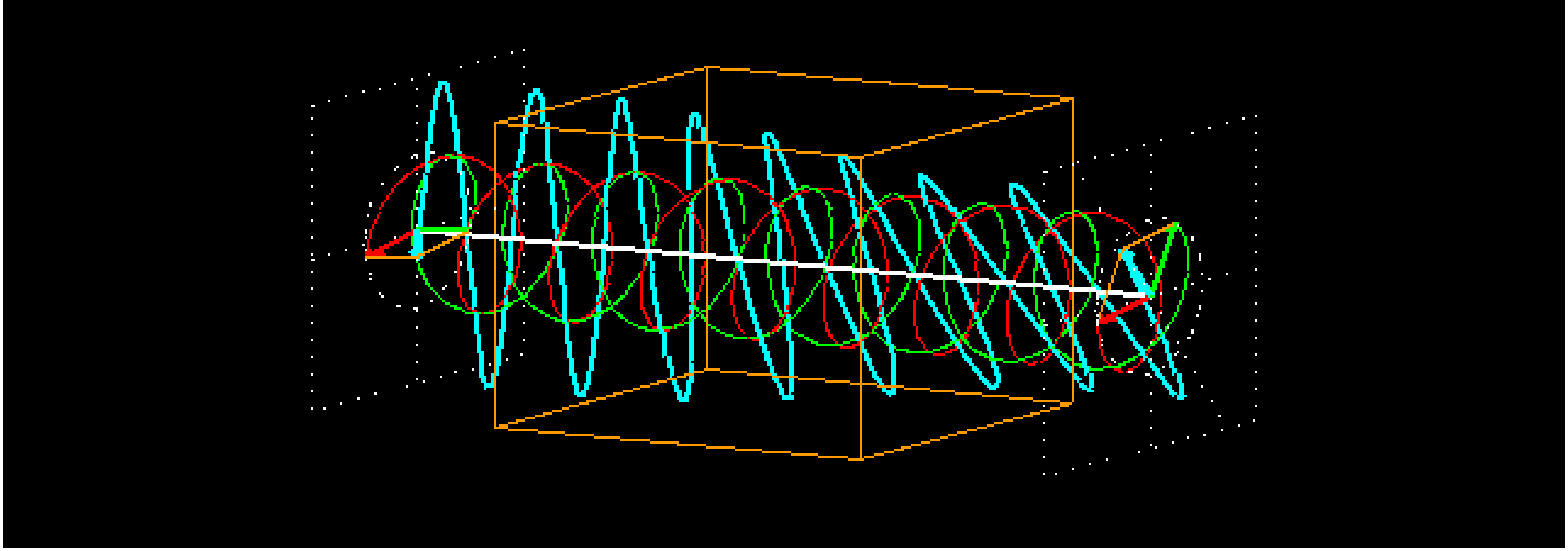
Circular polarized light: it can be the sum of two linear polarized lights.



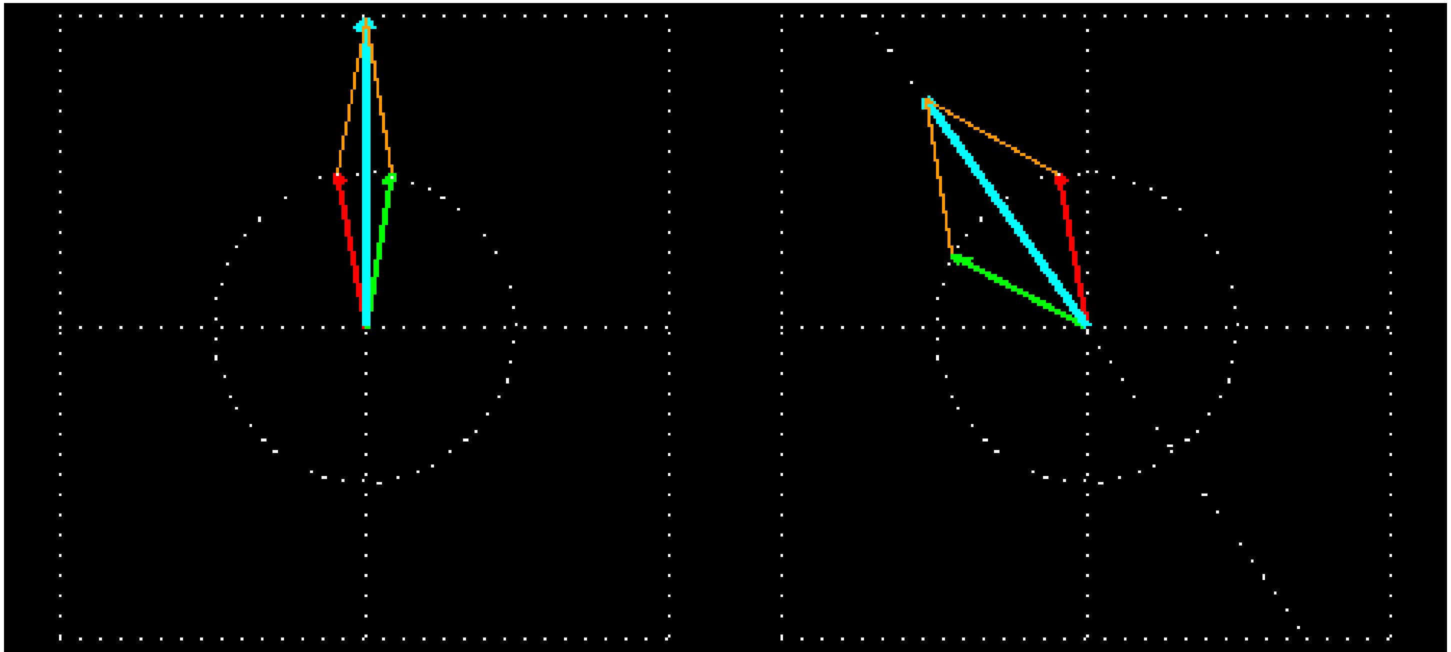


But linear polarized light can be the sum of two circular polarized lights.

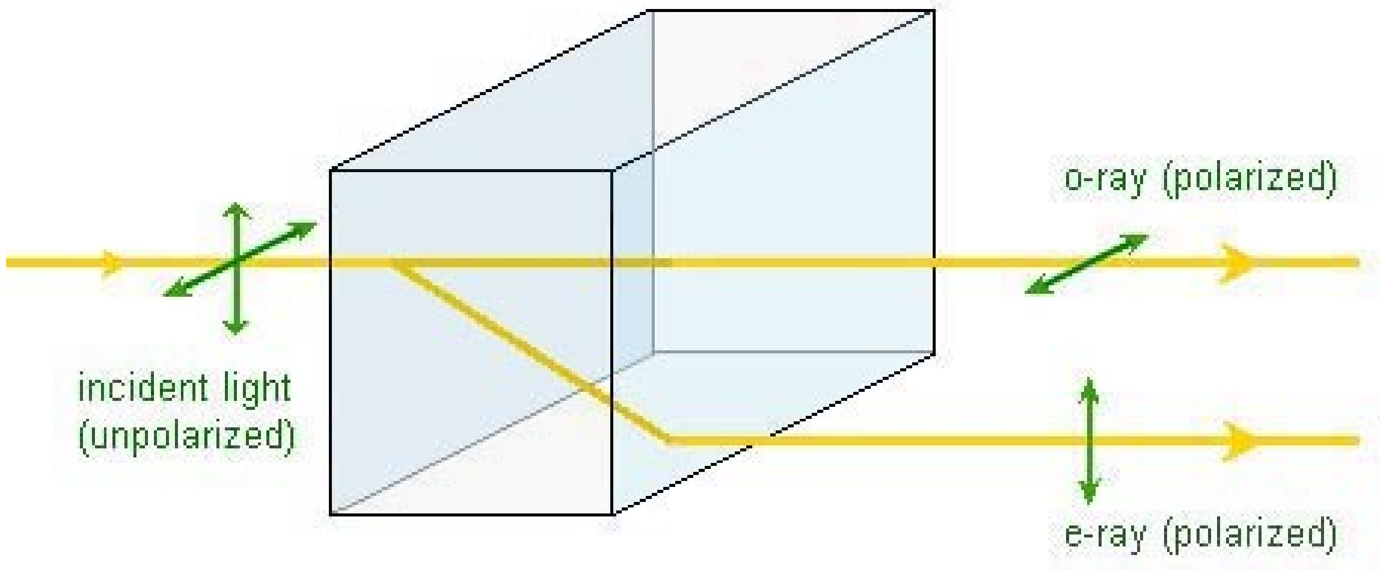
Vector algebra ☺

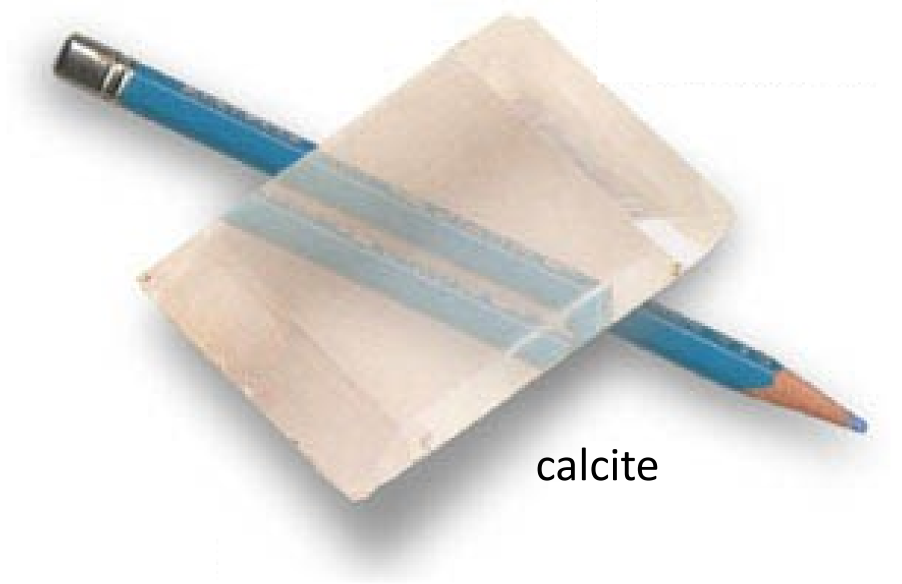


Chiral molecules have two different refractive indices: $n_{left} \neq n_{right}$ **circular birefringence**



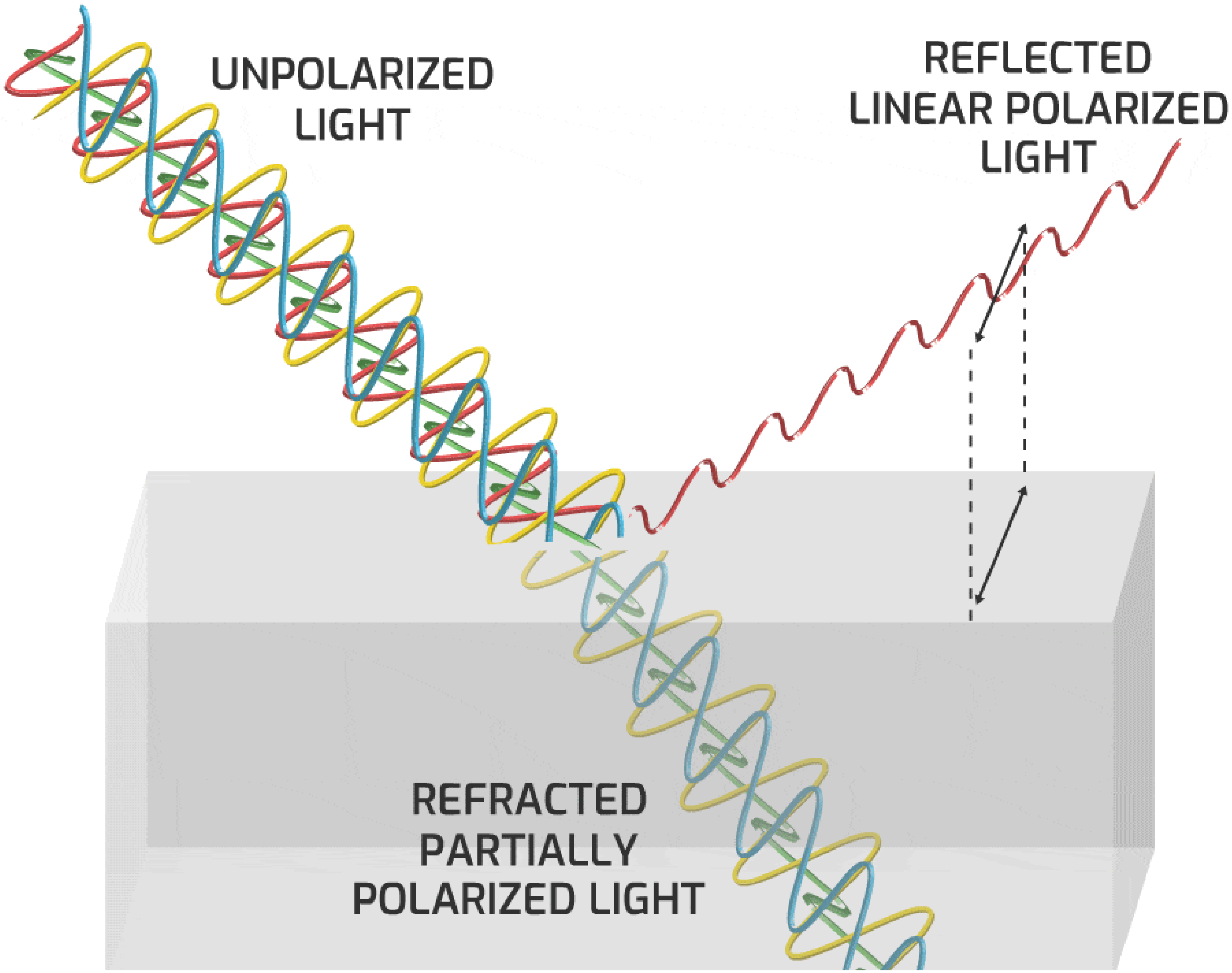
Crystals can also be birefringent



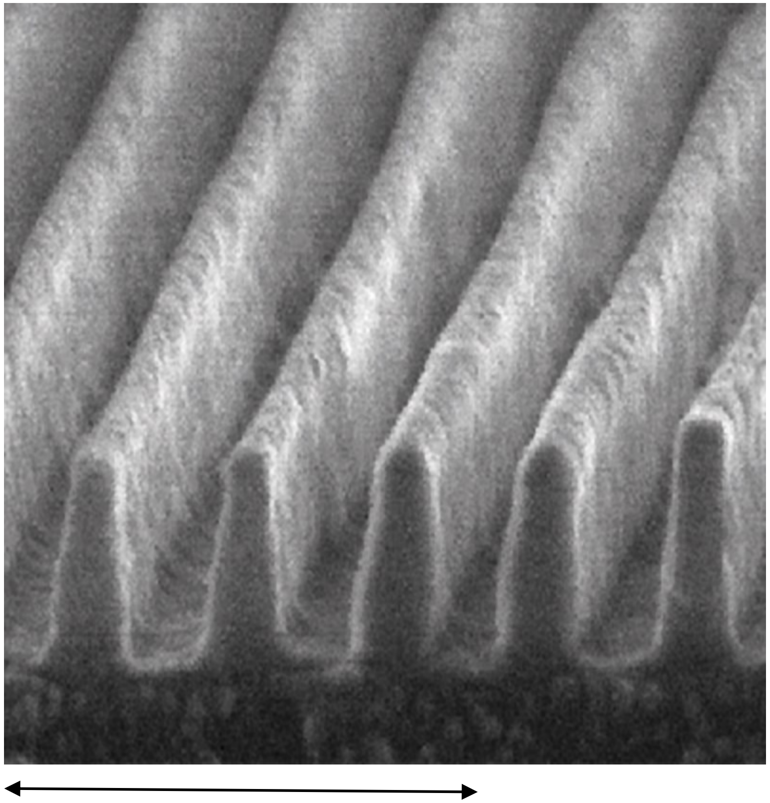


calcite

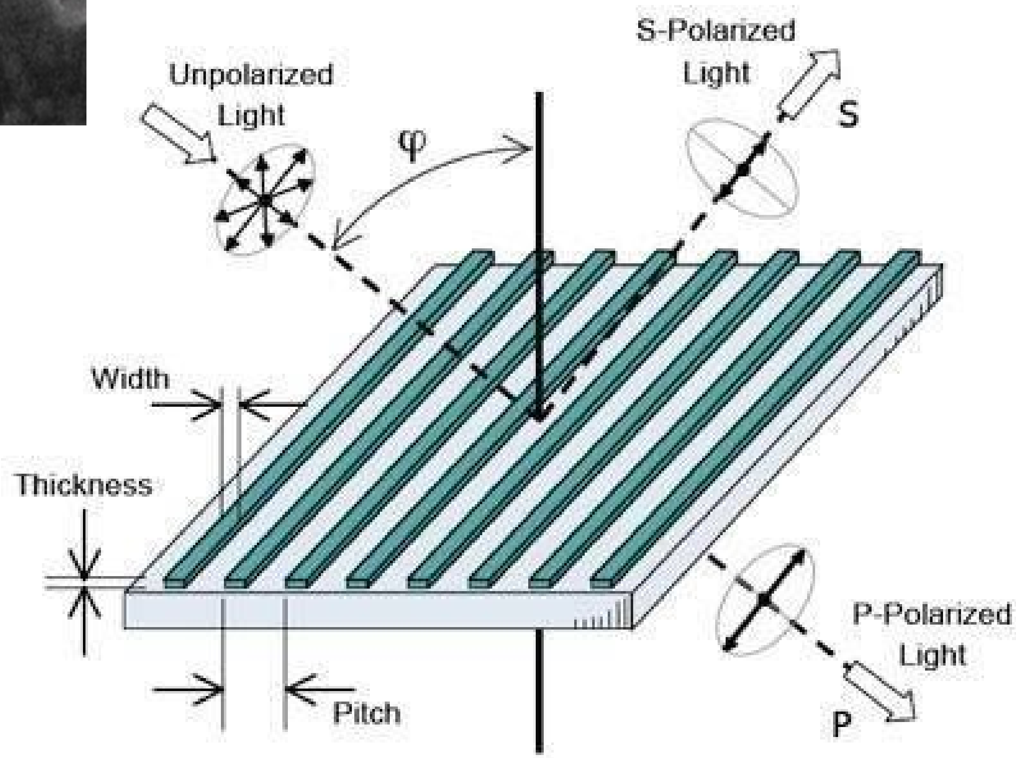
Reflection can also be used to polarize light (Brewster's angle)



Wire-grid polarizer

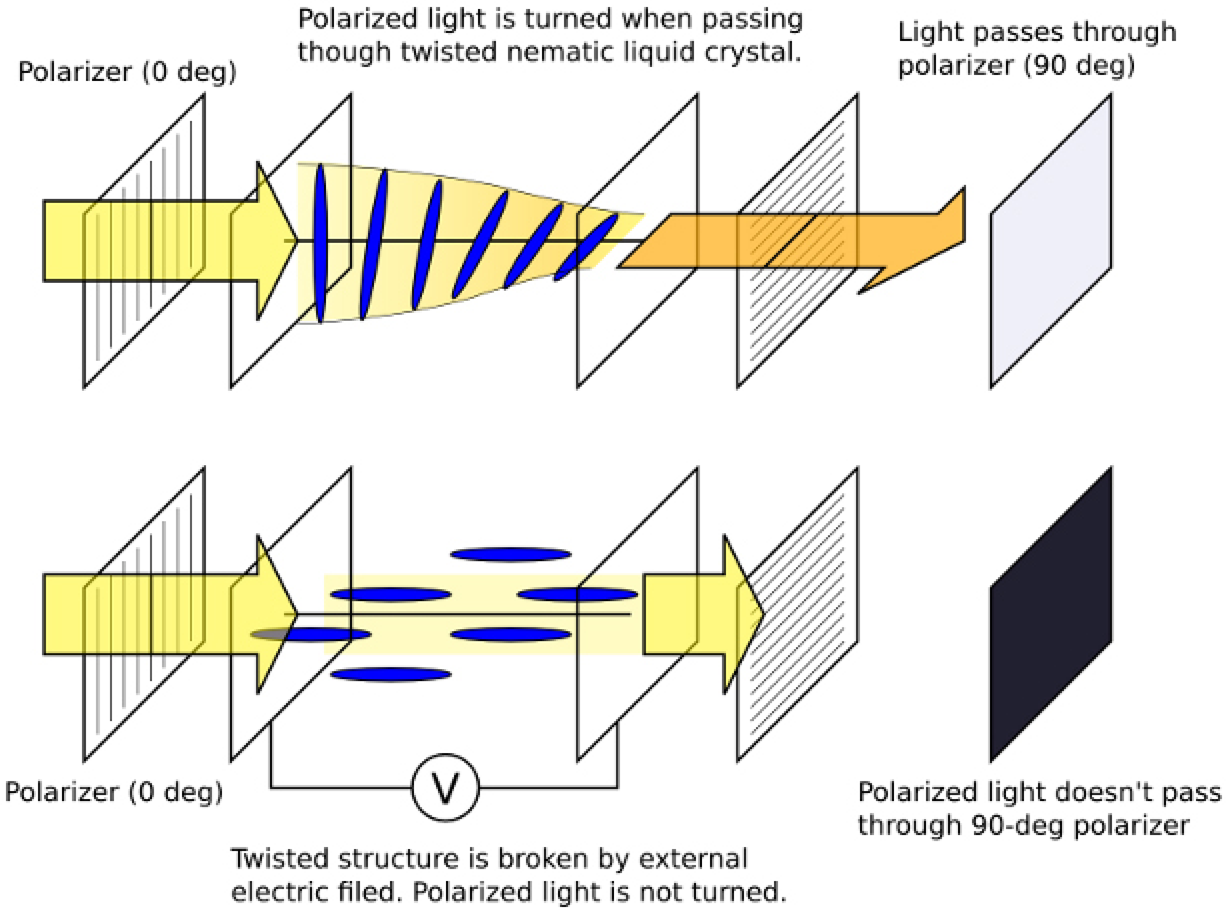


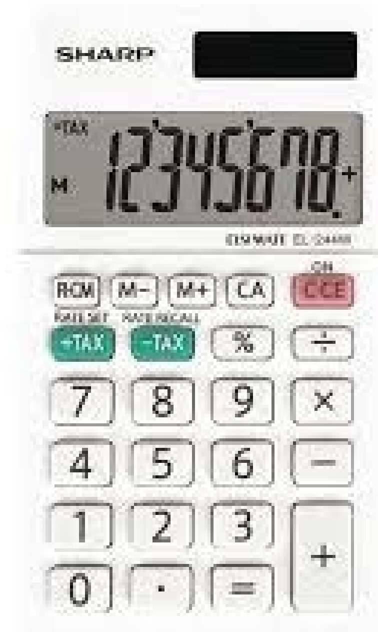
200nm

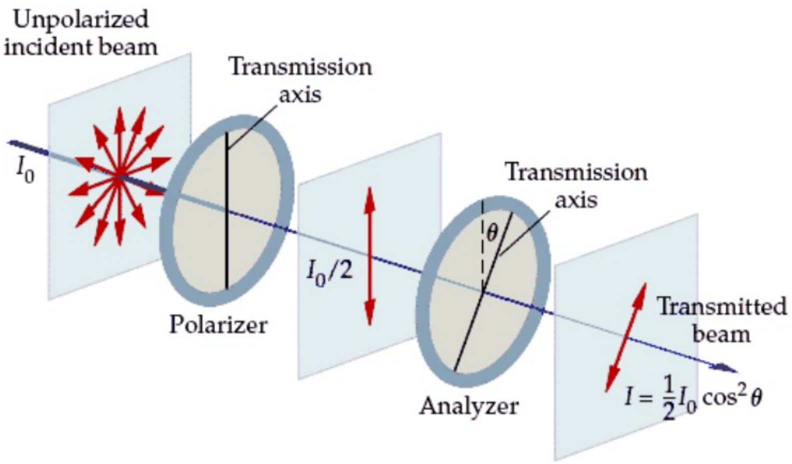


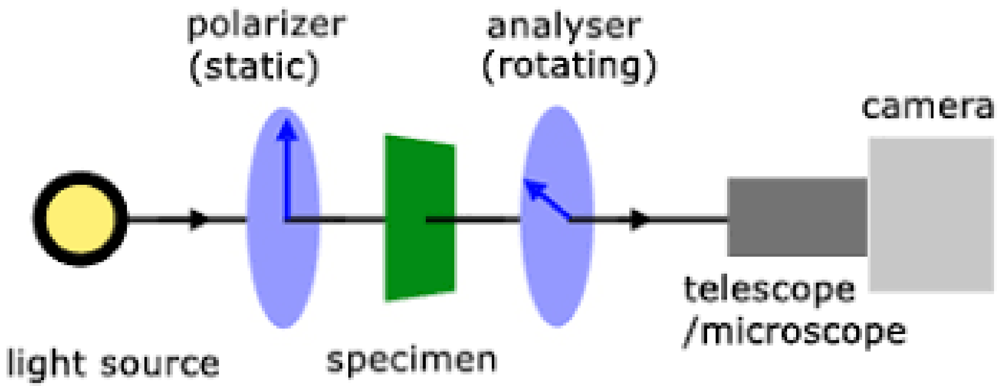
s: “senkrecht” (german) = perpendicular
p: parallel

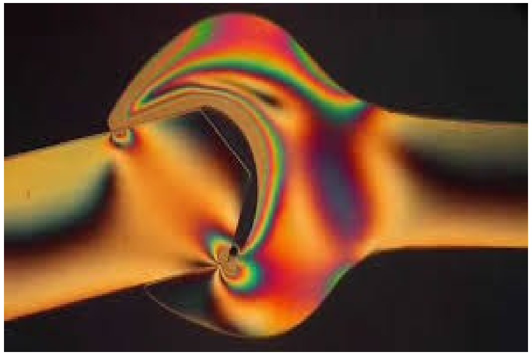
LCD: Liquid Crystal Display

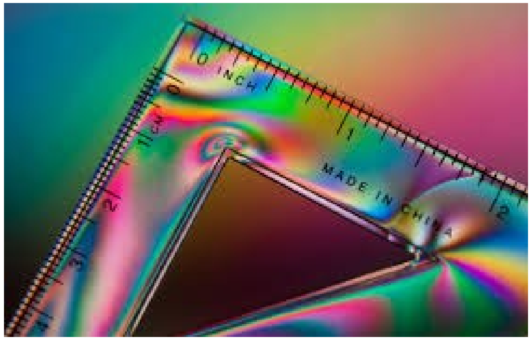




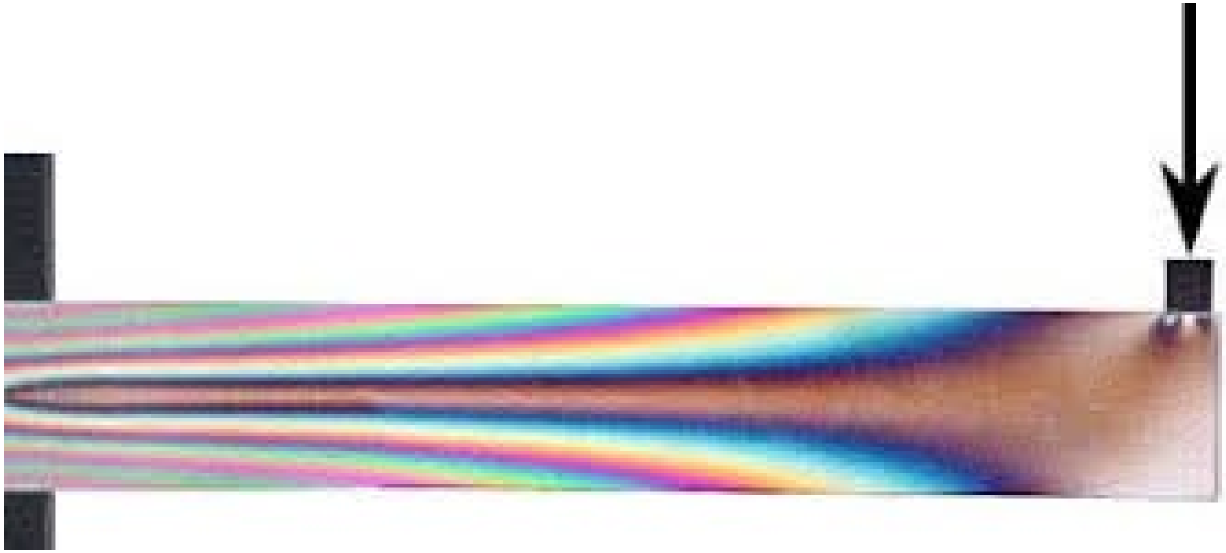


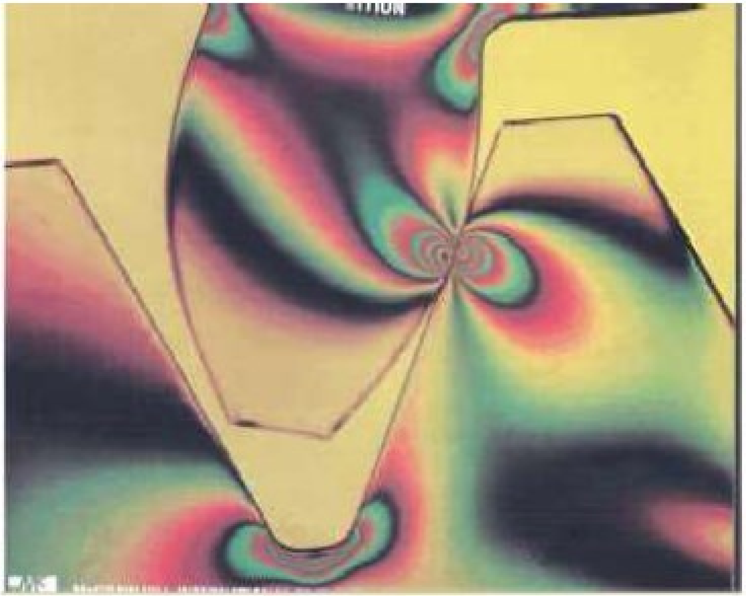


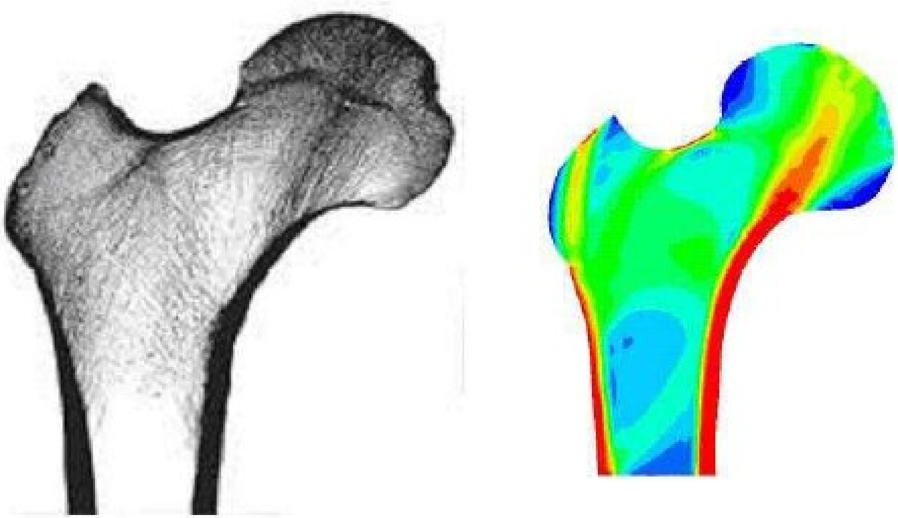


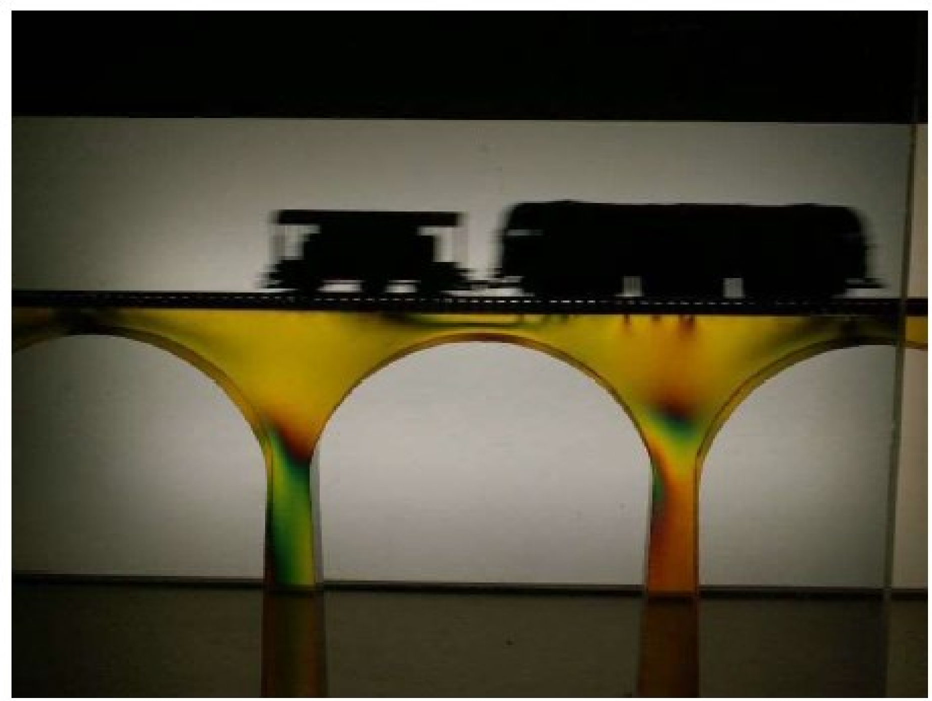


Strain-stress will alter the polarization of the transmitted light

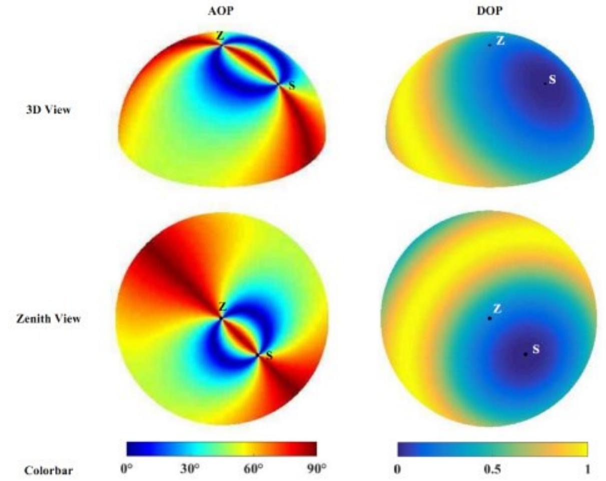


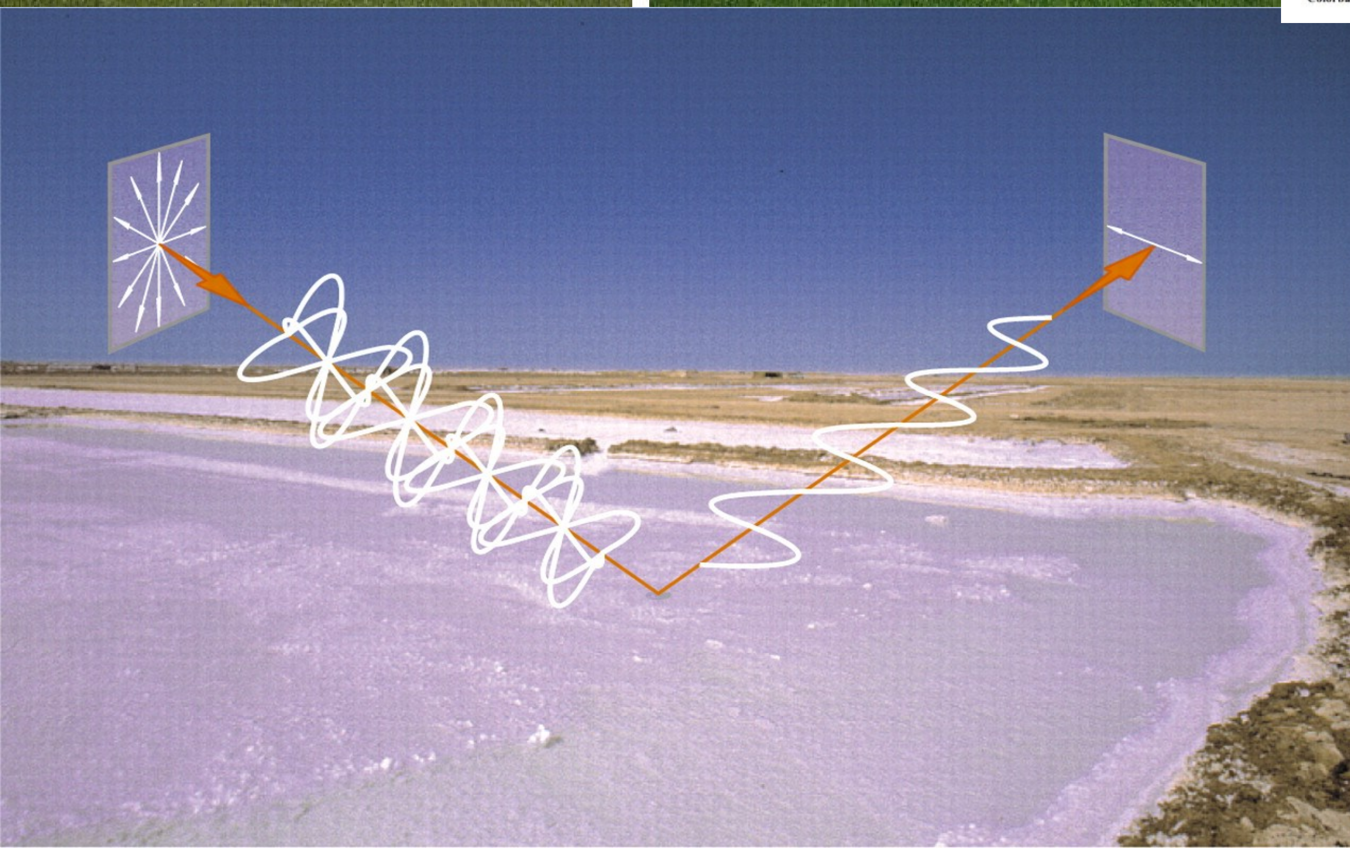


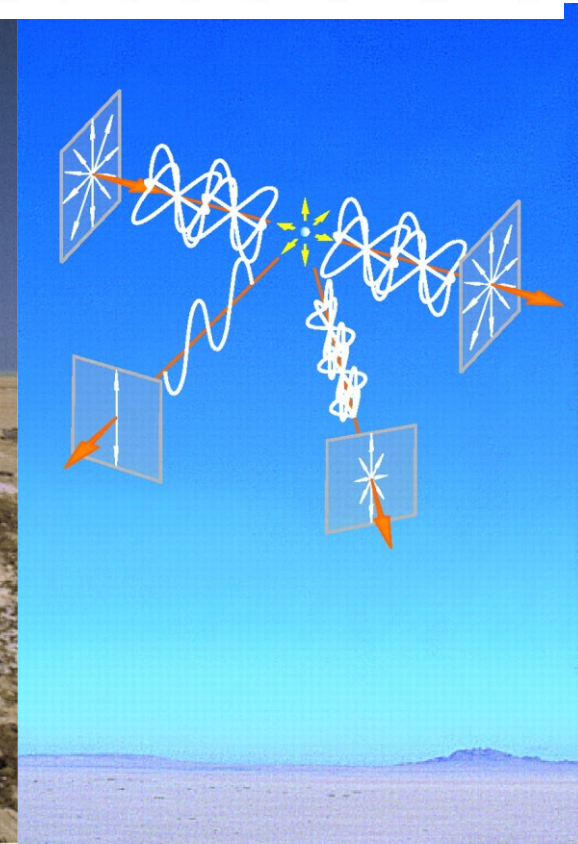


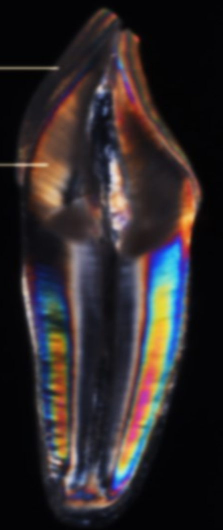


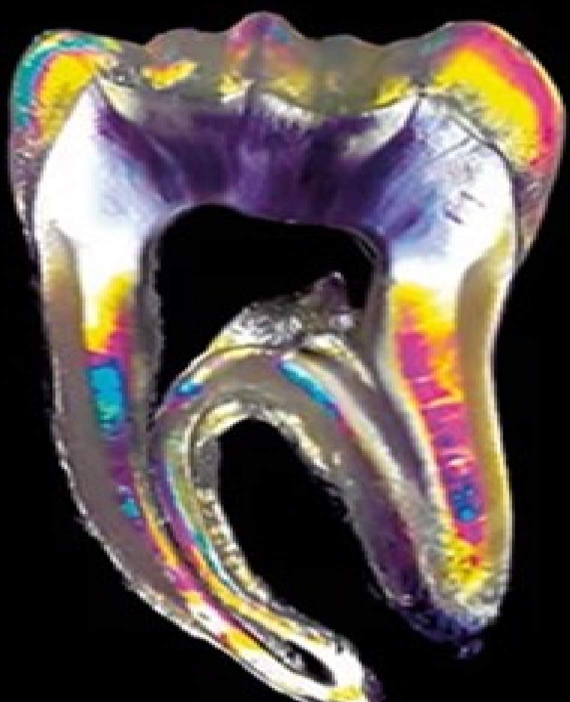
Sky polarization, reflection








Enamel
Dentin




© Renato Ferreira.

Cross polarization dental photography

Color matching in prosthodontics