

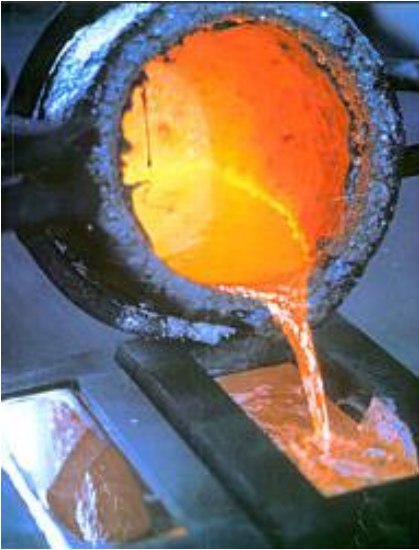
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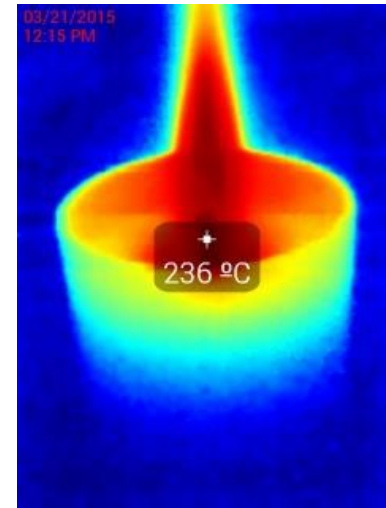
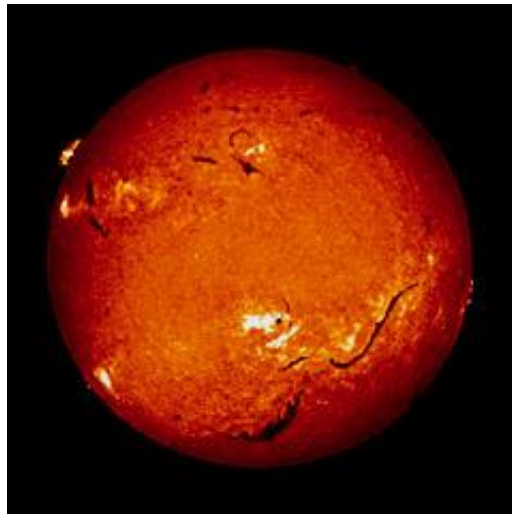
Thermal radiation characteristics and description; emission of the human body, medical applications, infra-diagnostics, Polarization of light.

Gusztáv Schay

Thermal emission



GLOWING HOT

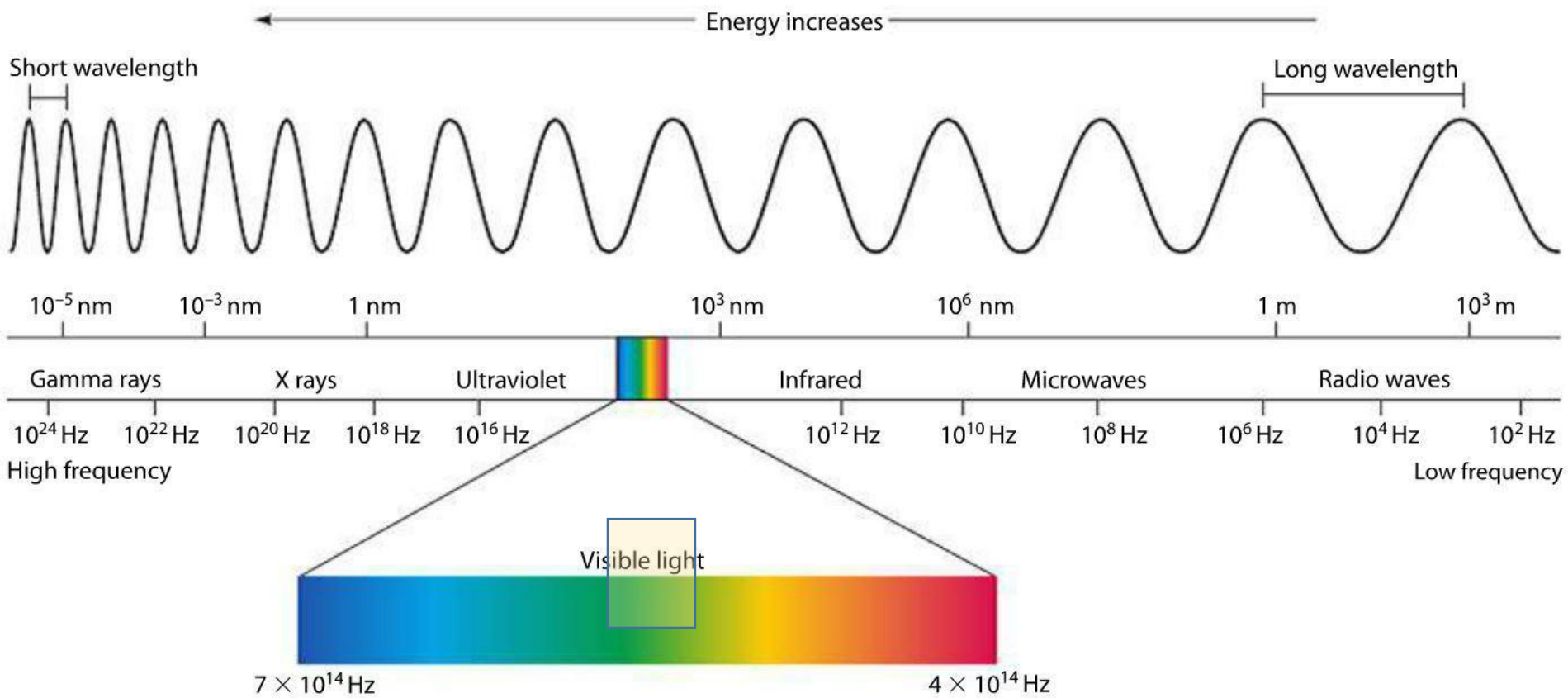




Hot objects emit light.

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.**

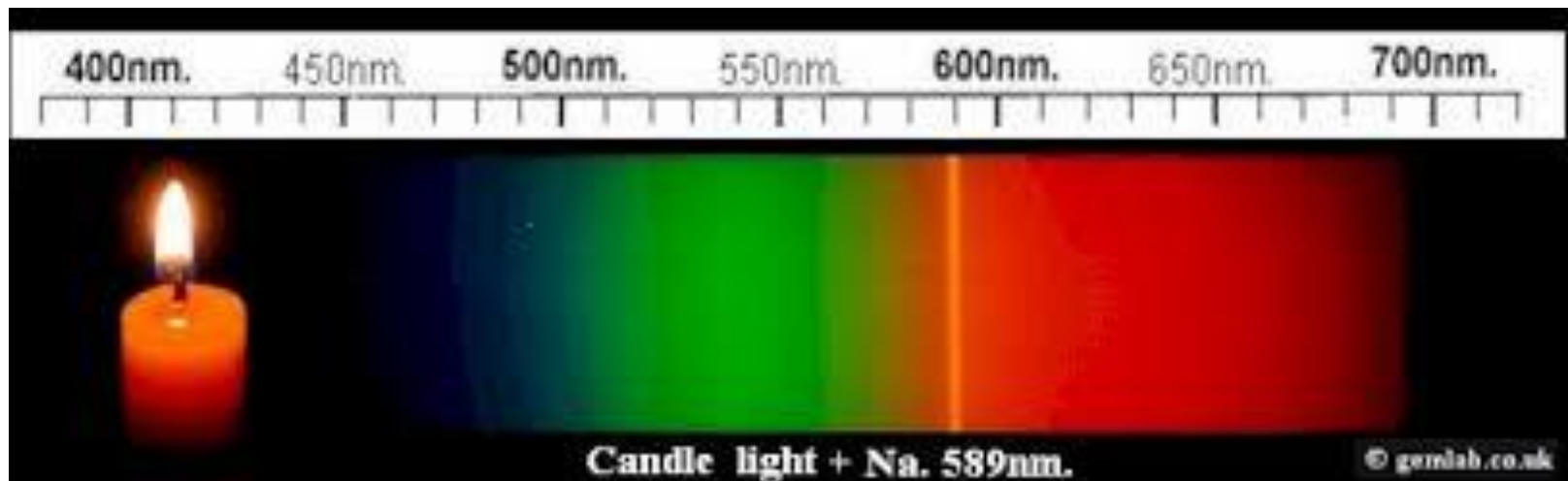
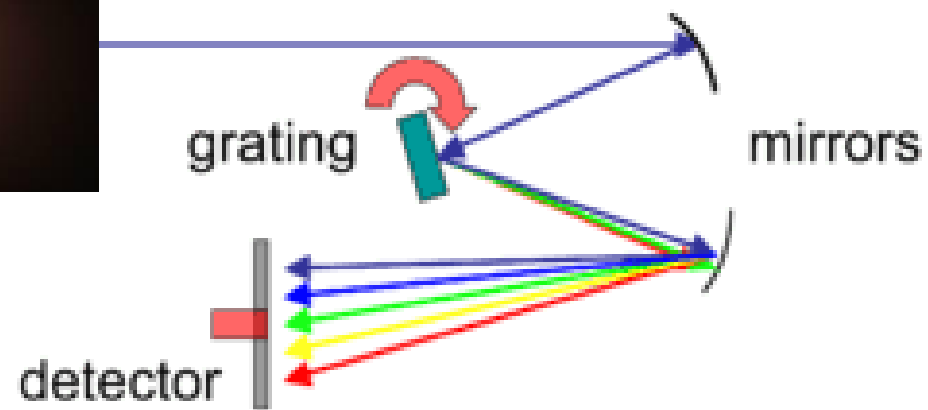
Just for fun: it can be exactly calculated, but this is NOT required here ;)

$$\mathbf{E}_{\text{rad}}(\mathbf{r}, t) = -[1/(4\pi\epsilon_0)] * [\dot{q}/(c^2 r')] * \mathbf{a}_{\text{perp}}(t - r'/c)$$

charge

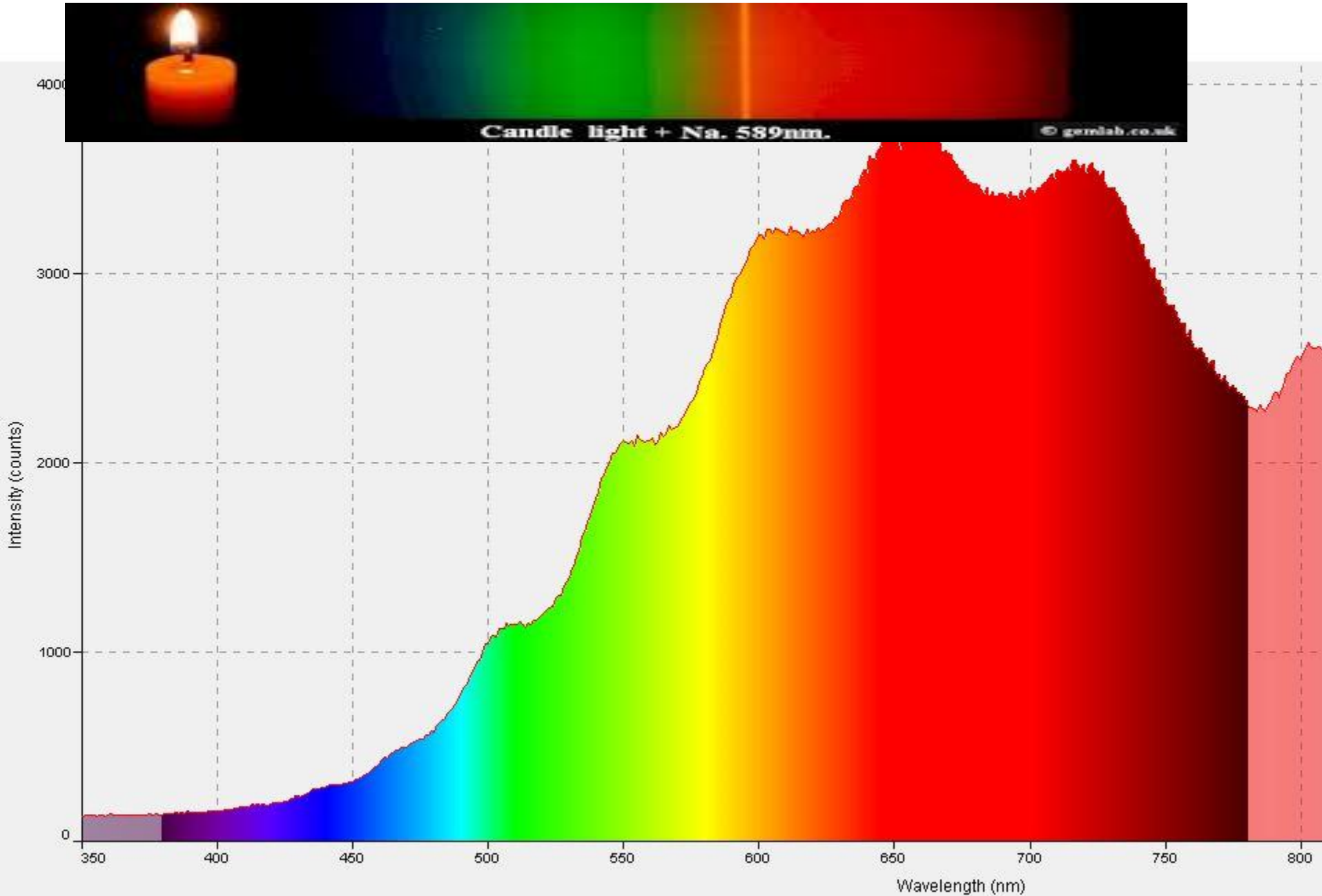
acceleration

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

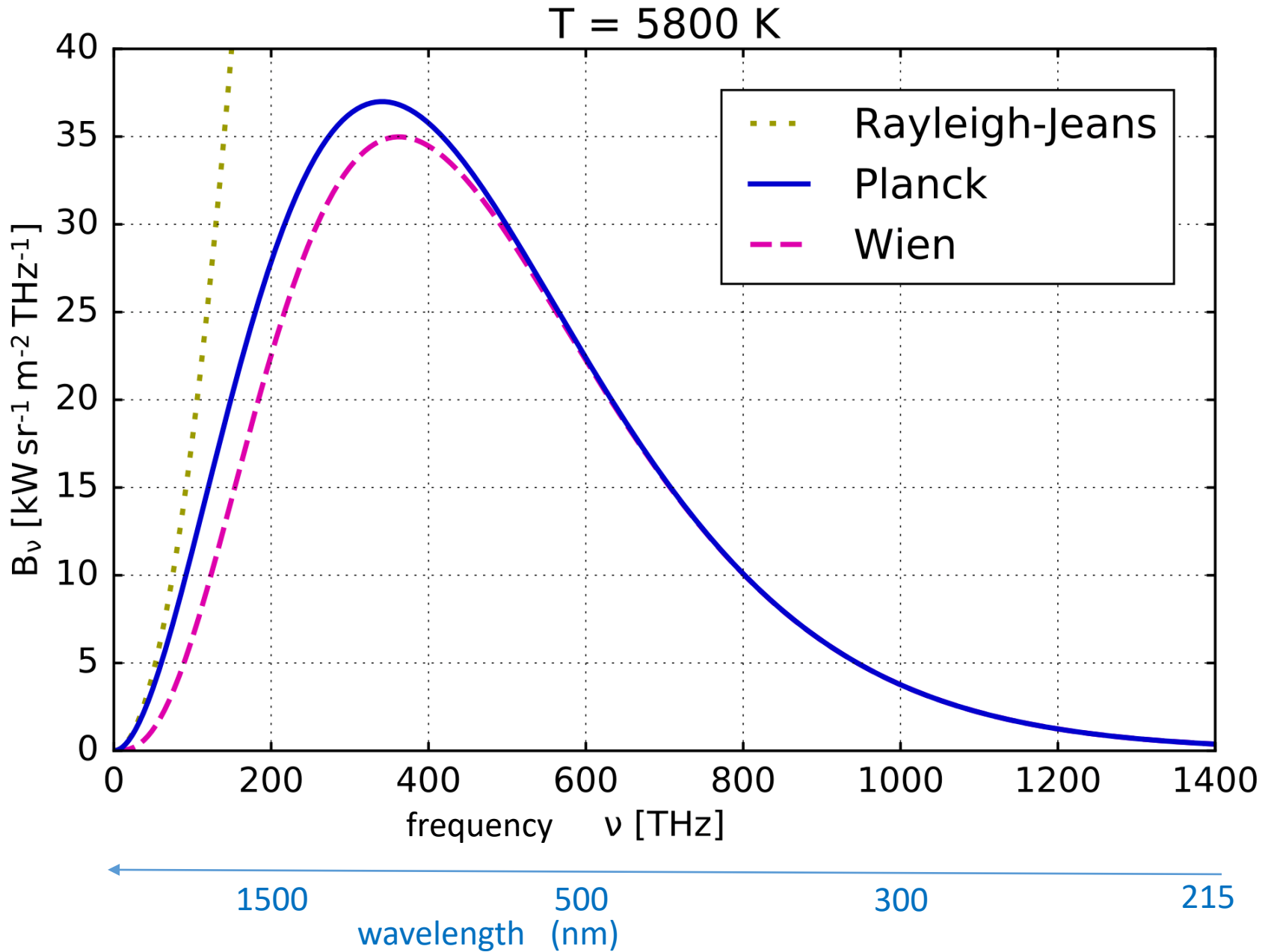


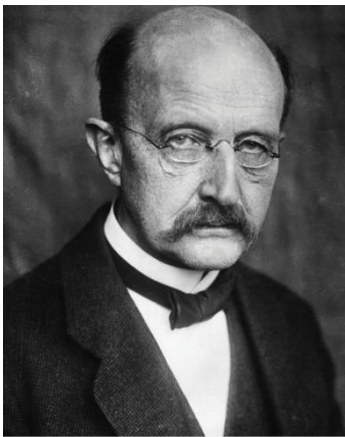
Emission spectrum of a candle flame

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



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 curve ONLY IF he assumed that the energy of the light-waves is “packaged” into discrete values of $h \cdot f$, which Einstein later coined as PHOTONS

$$E_n = nhf$$

vibrational frequency

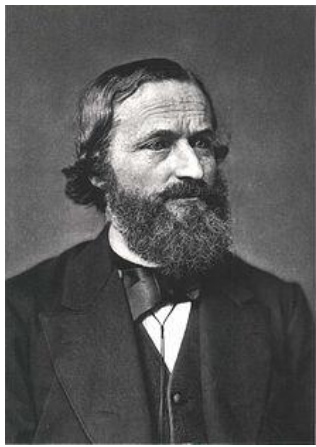
integer

E_n 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.

275

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 größere 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 Verhältniß 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 Schluß gezogen, daß bei derselben Temperatur das Verhältniß zwischen dem Emissionsvermögen und dem Absorptionsvermögen für alle Körper das gleiche ist. Dabei hat man vorausgesetzt, daß 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 streng genommen

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

absorptance

n.B.: $A = \lg(J_0/J_{\text{transmitted}})$
this is the absorbance

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

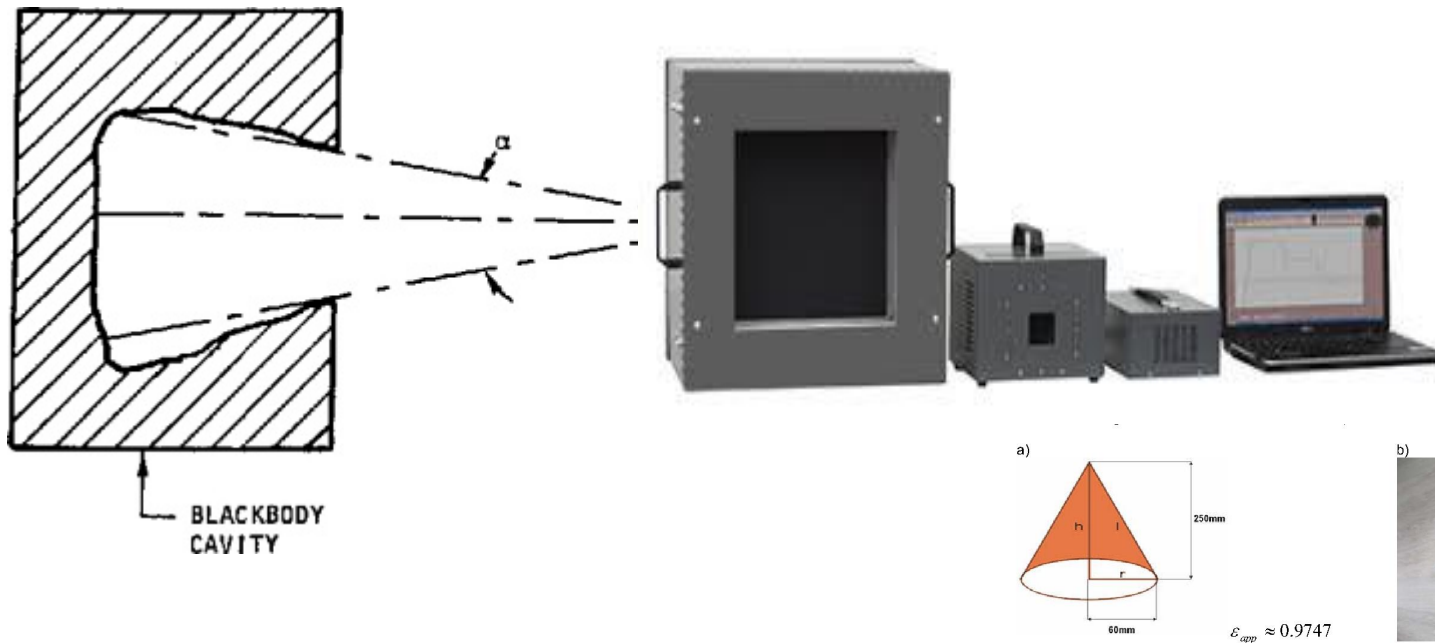


Fig. 2. Geometry of the cone radiator with its geometrical parameters (a) and the manufactured cone (b).

M: radiant emittance (W/m^2)

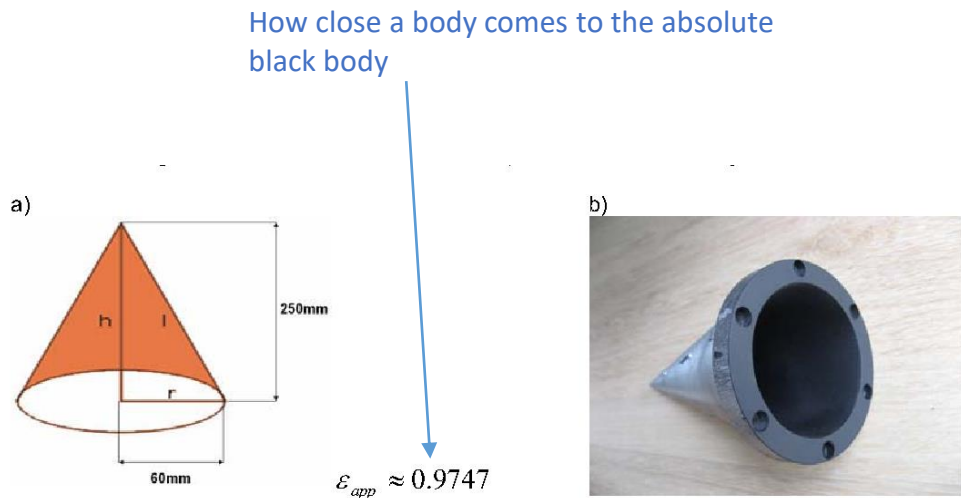
The emitted power on a unit surface of the emitter body.

Kirchhoff's law: M/α is constant.

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

Both M and α depend on the frequency (or wavelength)!

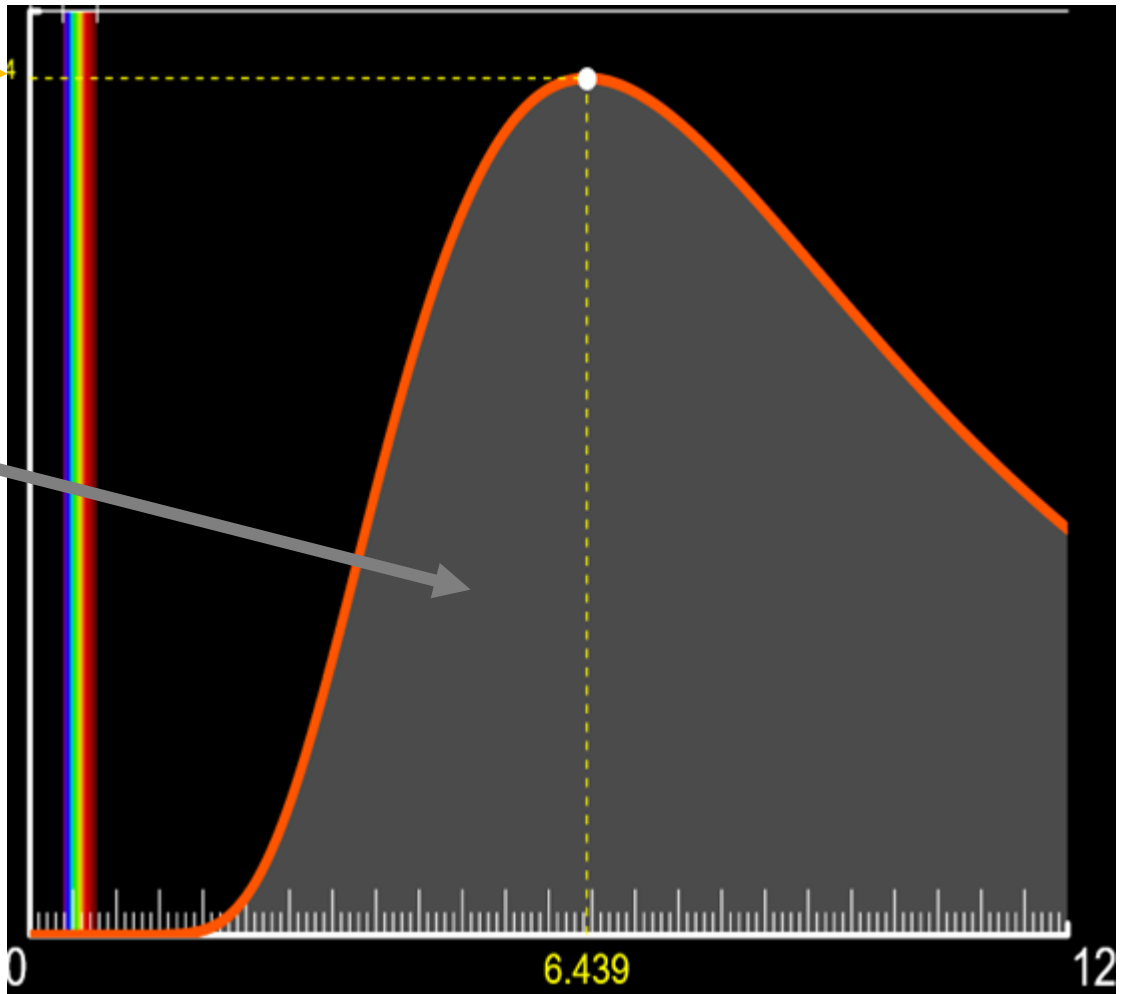
(spectral radiant emittance, M_λ and spectral absorptance α_λ)



$$\frac{\Delta M}{\Delta \lambda}$$

Maximum spectral
radiant emittance

Area under the
curve:
Total radiant
emittance M_{tot}



6.439

Wavelength (μm)

λ_{max}

Spectral Power Density (MW/m²/μm)



B G R

3×10^{-4}

Infrared

☒ Graph Values

☒ Labels

☒ Intensity

$4.59 \times 10^2 \text{ W/m}^2$



3×10^{-5}

0

9.659

12

Wavelength (μm)

1 μm = 1000 nm



Blackbody
Temperature

300 K

Sirius A

Sun

Light Bulb

Earth



Spectral Power Density (MW/m²/μm)



B G R

3×10^{-4}

2×10^{-4}

Infrared

☒ Graph Values

☒ Labels

☒ Intensity

$2.33 \times 10^3 \text{ W/m}^2$



0

6.439

12

Wavelength (μm)

1 μm = 1000 nm



Blackbody
Temperature

450 K

Sirius A

Sun

Light Bulb

Earth



Spectral Power Density (MW/m²/μm)



B G R

1×10^{-3}

Infrared

1×10^{-3}

0

4.830

12

Wavelength (μm)

1 μm = 1000 nm

☒ Graph Values

☒ Labels

☒ Intensity

$7.35 \times 10^3 \text{ W/m}^2$



600 K

450 K

Blackbody
Temperature

600 K

Sirius A

Sun

Light Bulb

Earth



Two famous laws:

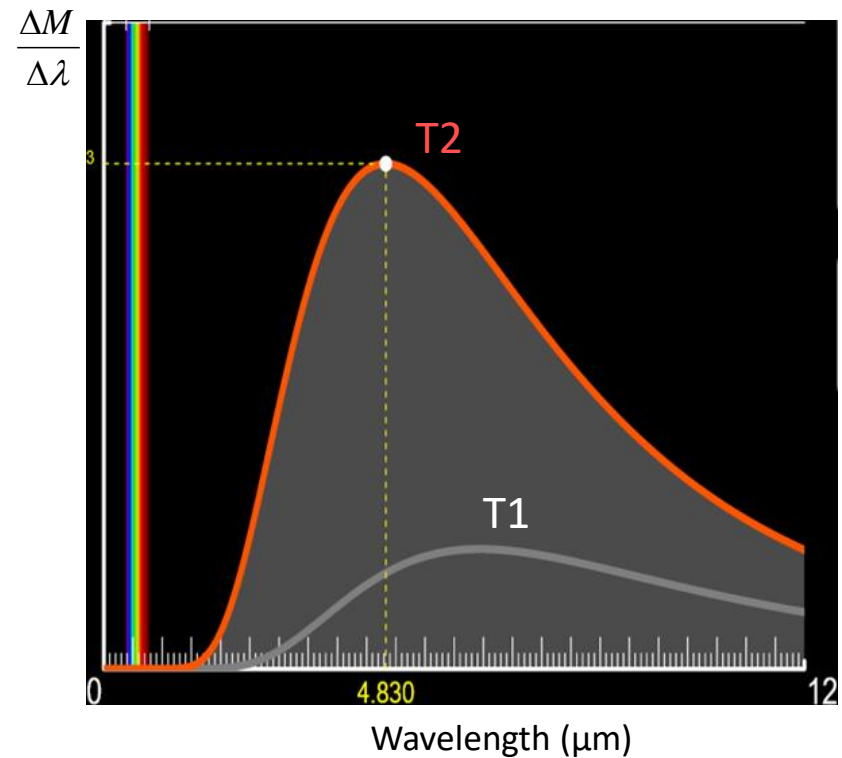
Wien's displacement law

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

Stephan-Boltzmann's law

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

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

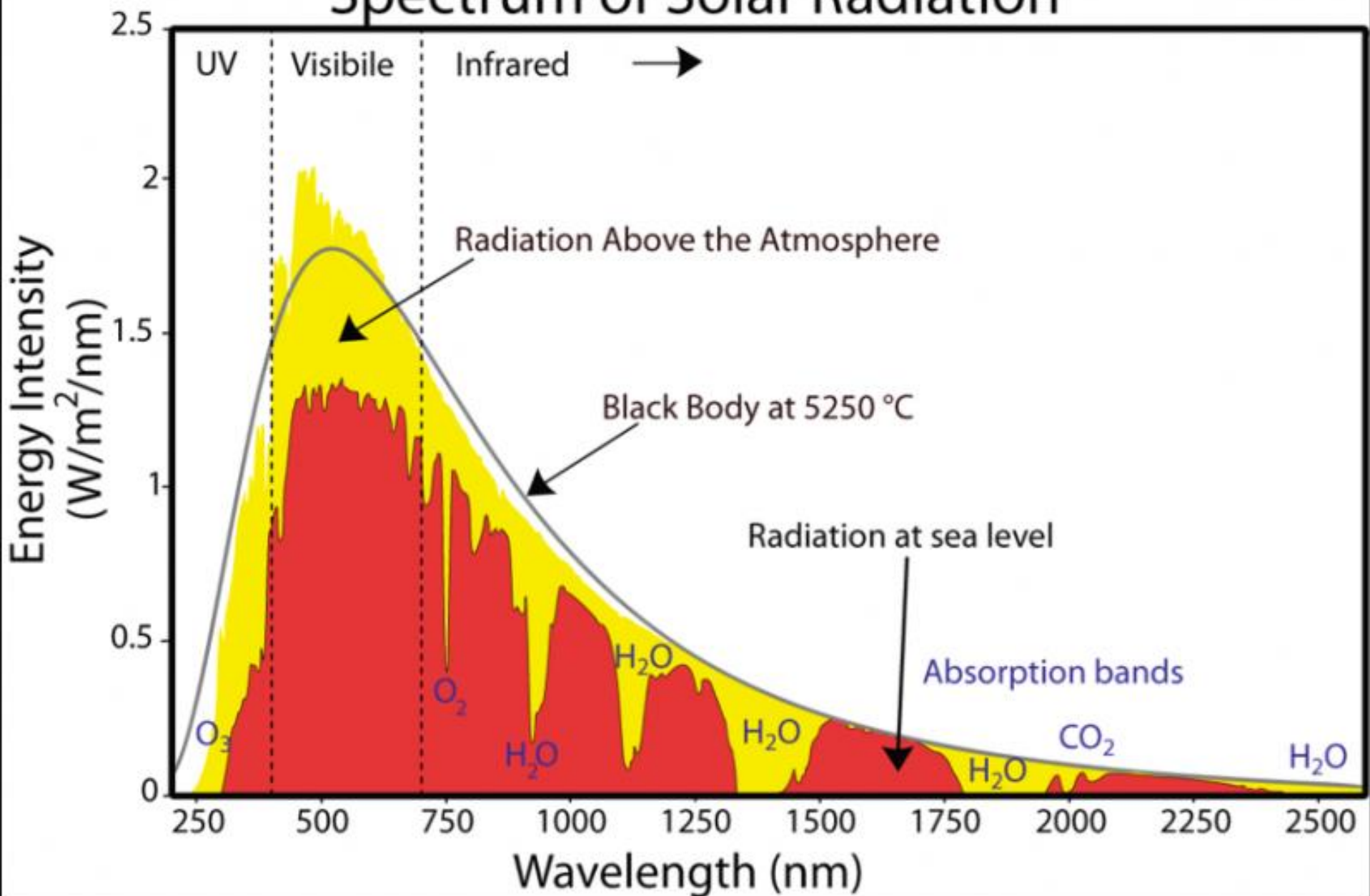


$$\Delta M = \sigma (T_{\text{object}}^4 - T_{\text{environment}}^4)$$

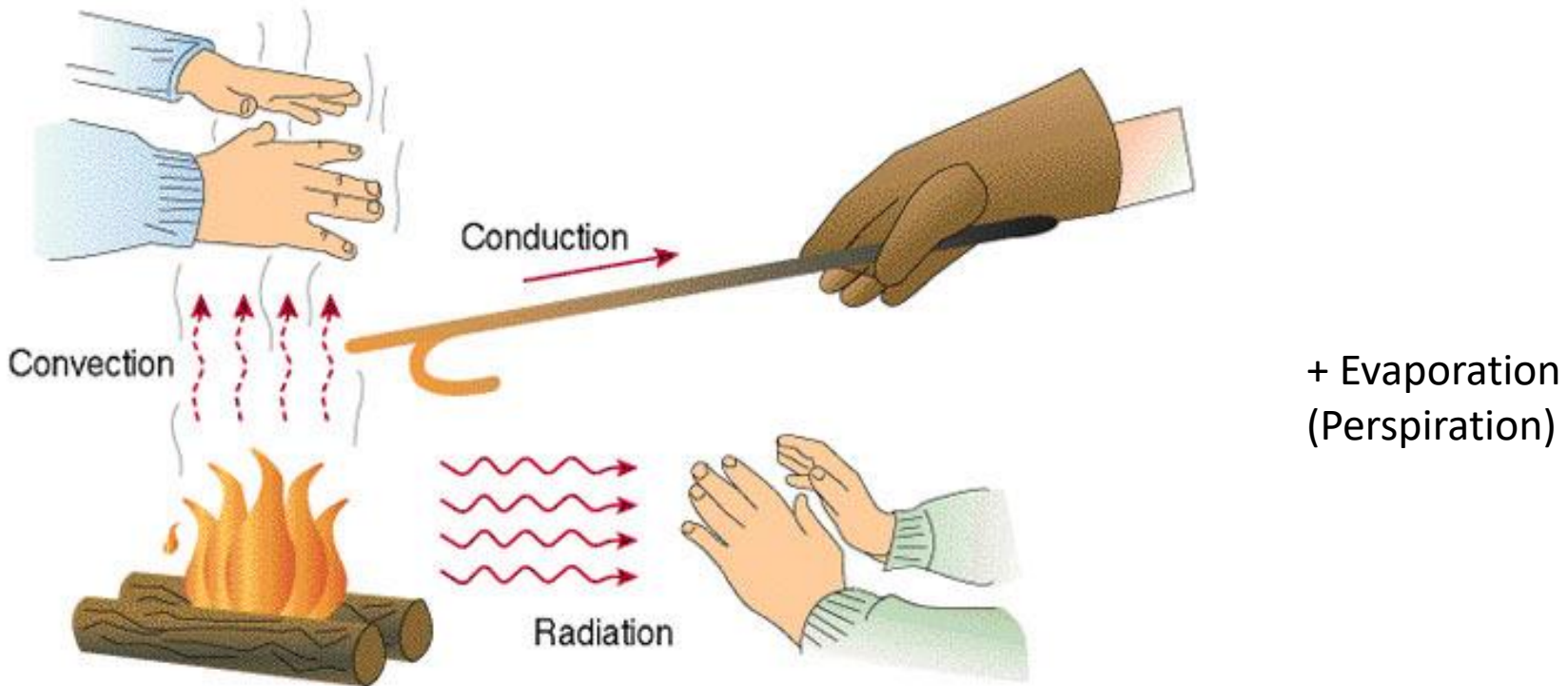
\uparrow W/m² ! \nwarrow °K

Thermal equilibrium will also be reached through radiation energy exchange.

Spectrum of Solar Radiation



Heat energy exchange possibilities



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

Radiation	→	$\approx 100W$
Conduction	→	$\leq 1W$
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

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

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

Wien's displacement law

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



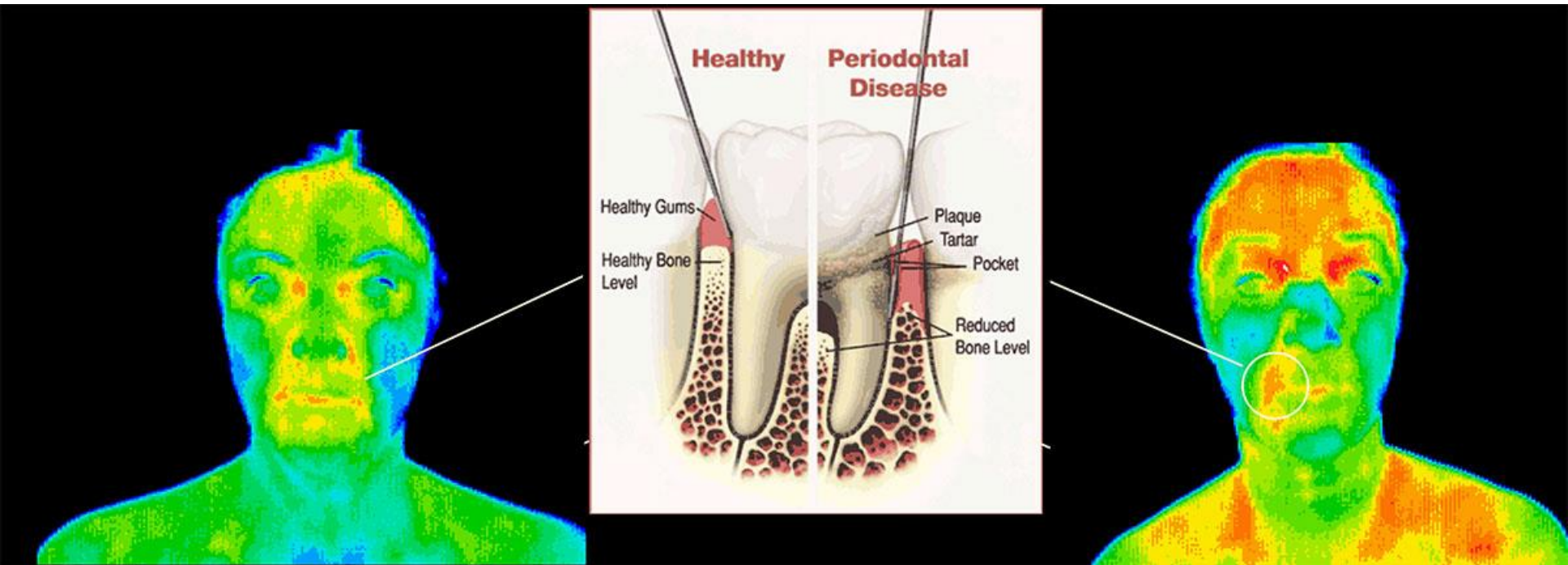
For human skin surface

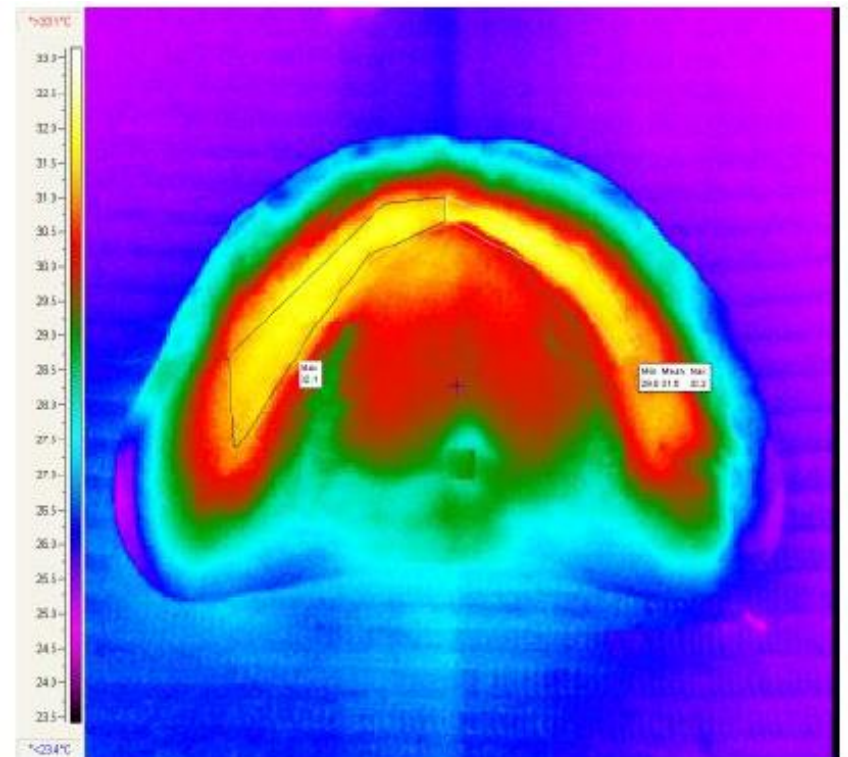
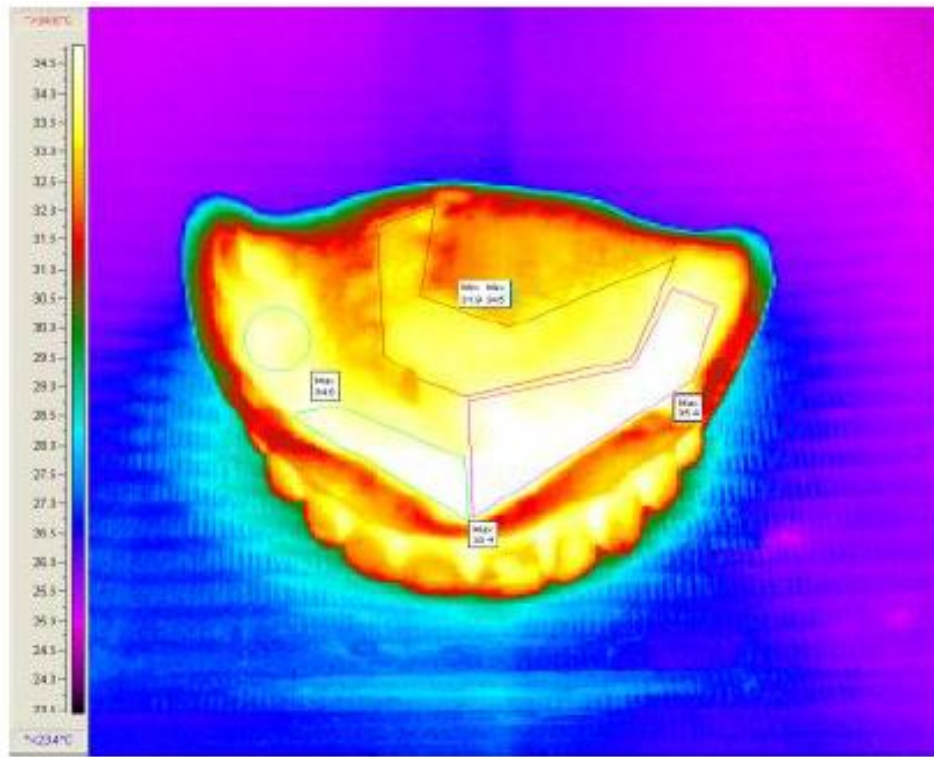
$$\lambda_{\text{max}} = 7 \dots 15 \mu\text{m}$$

Thermal imaging and sensing is very sensitive!

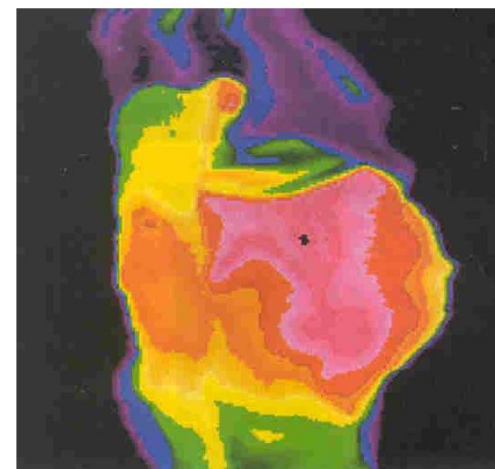
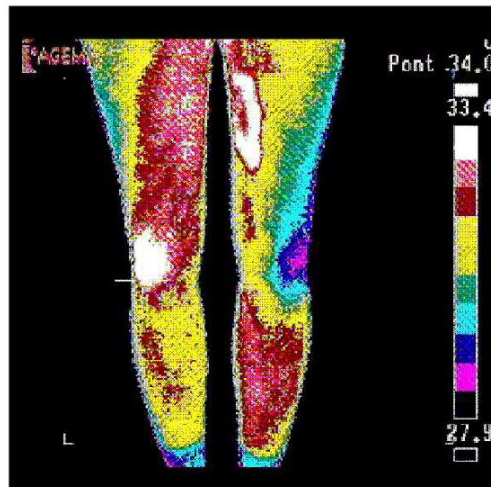
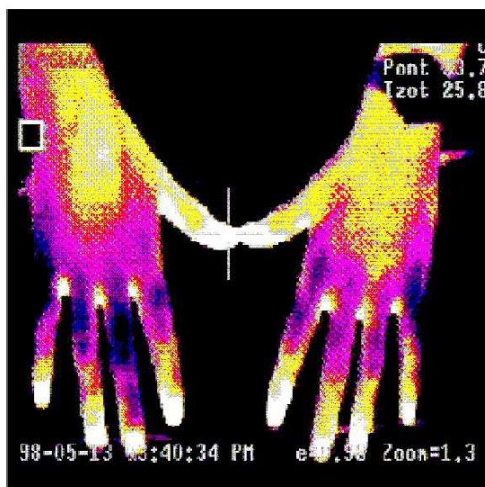
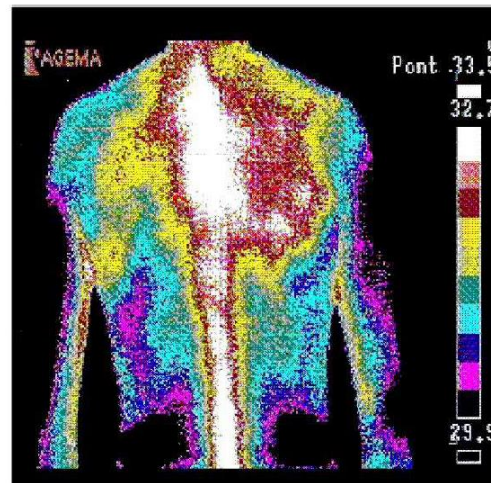
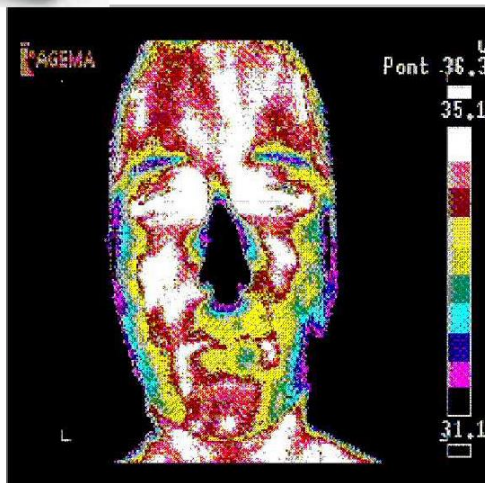
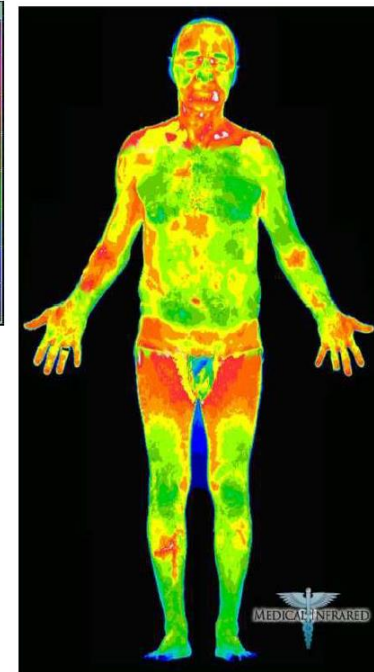
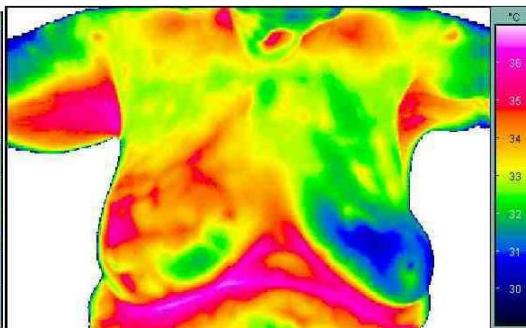
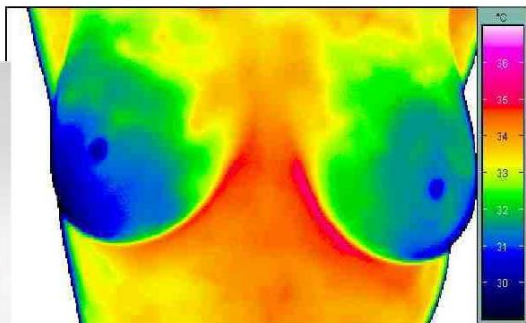


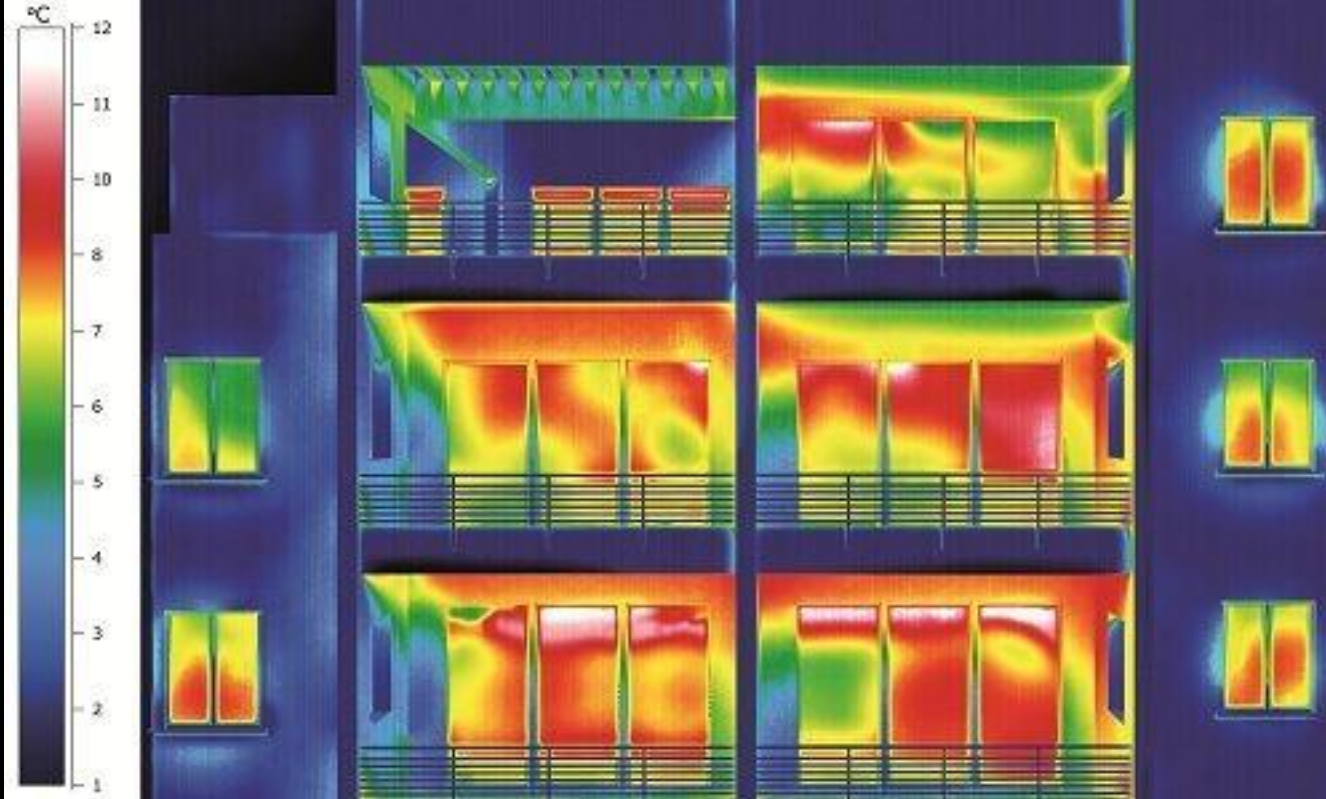
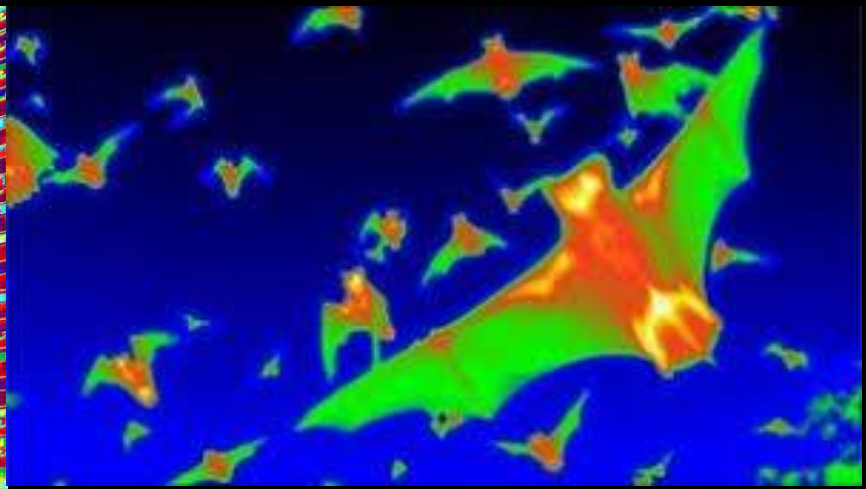
Inflammation, cancer, elevated metabolic rate can be detected.



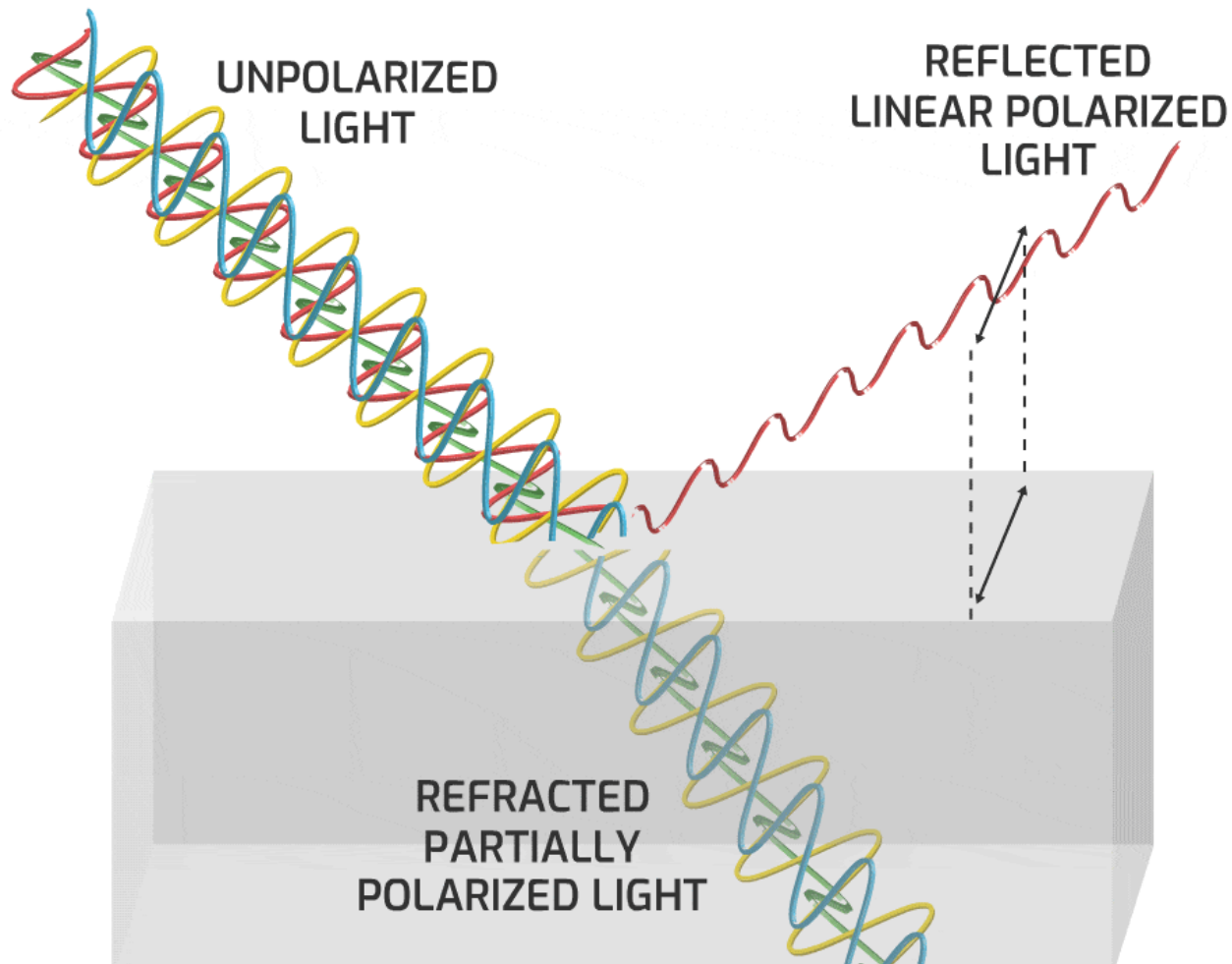


Thermograms of the denture after its removal from the oral cavity

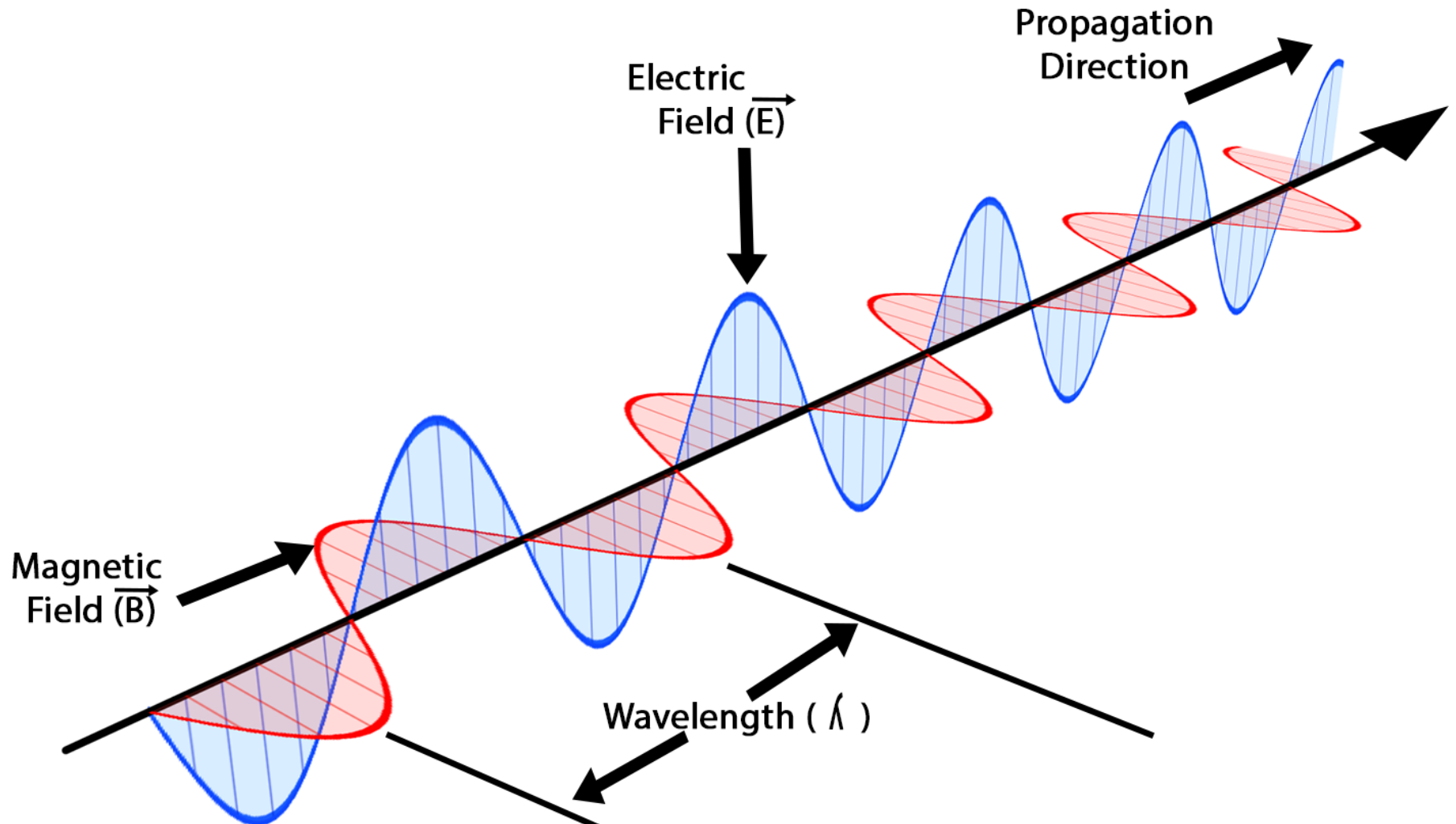


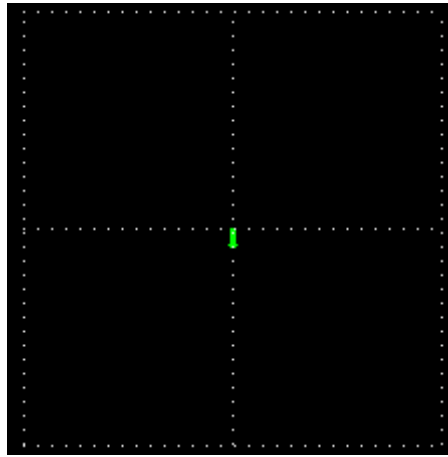
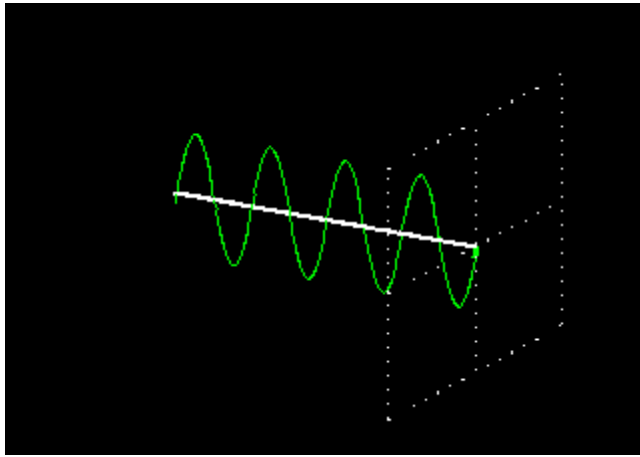


Polarization of light



Electromagnetic Wave



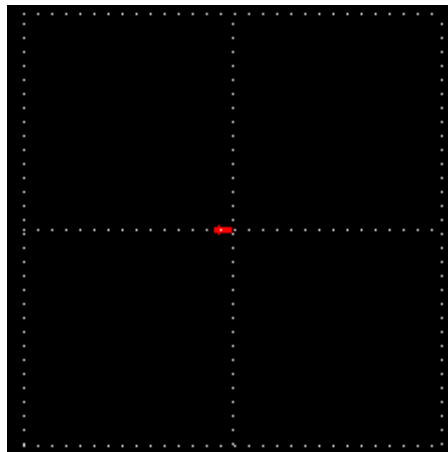
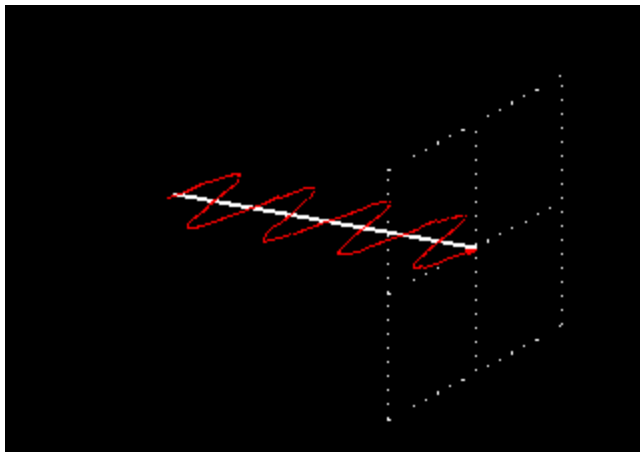


We usually only show the E-field vector, to make the drawing easier to read.

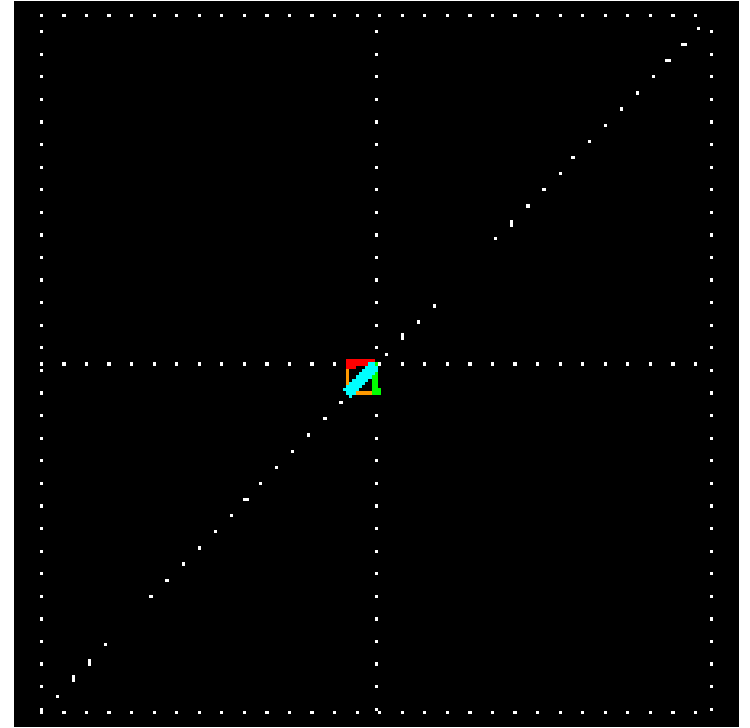
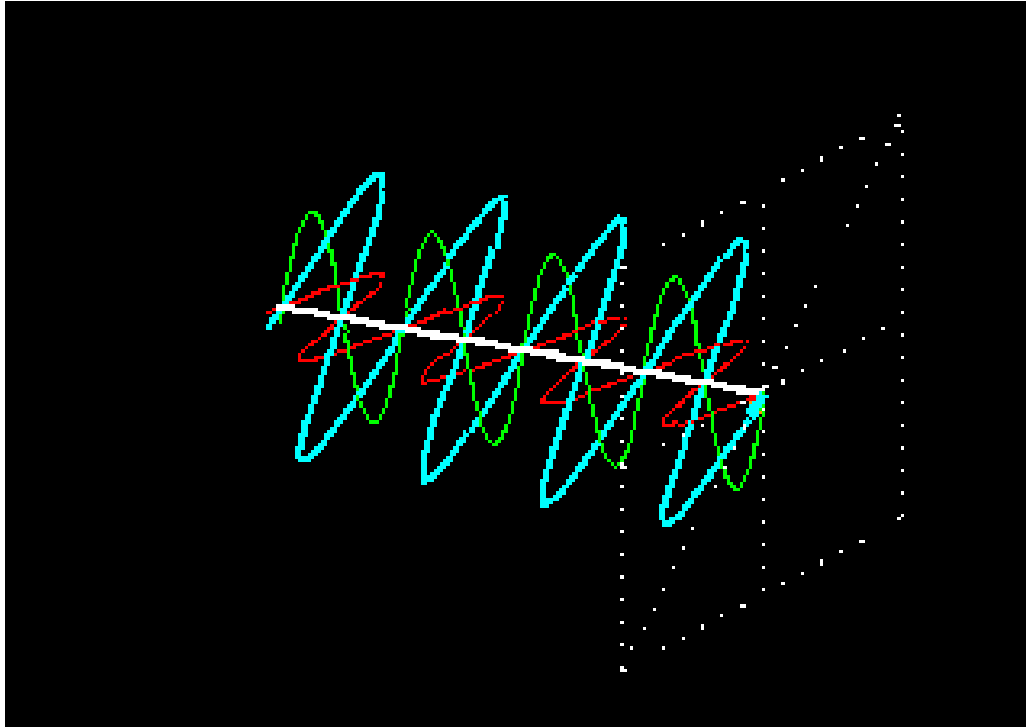
We do imagine the B-field vector to be there, since it is EM-wave!

Polarization is the direction of the E-field vector

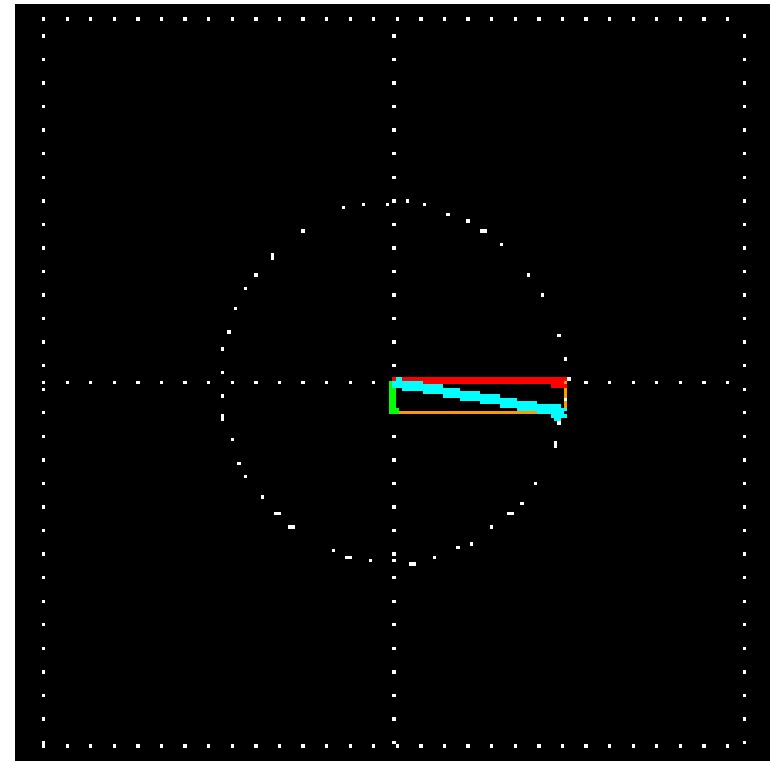
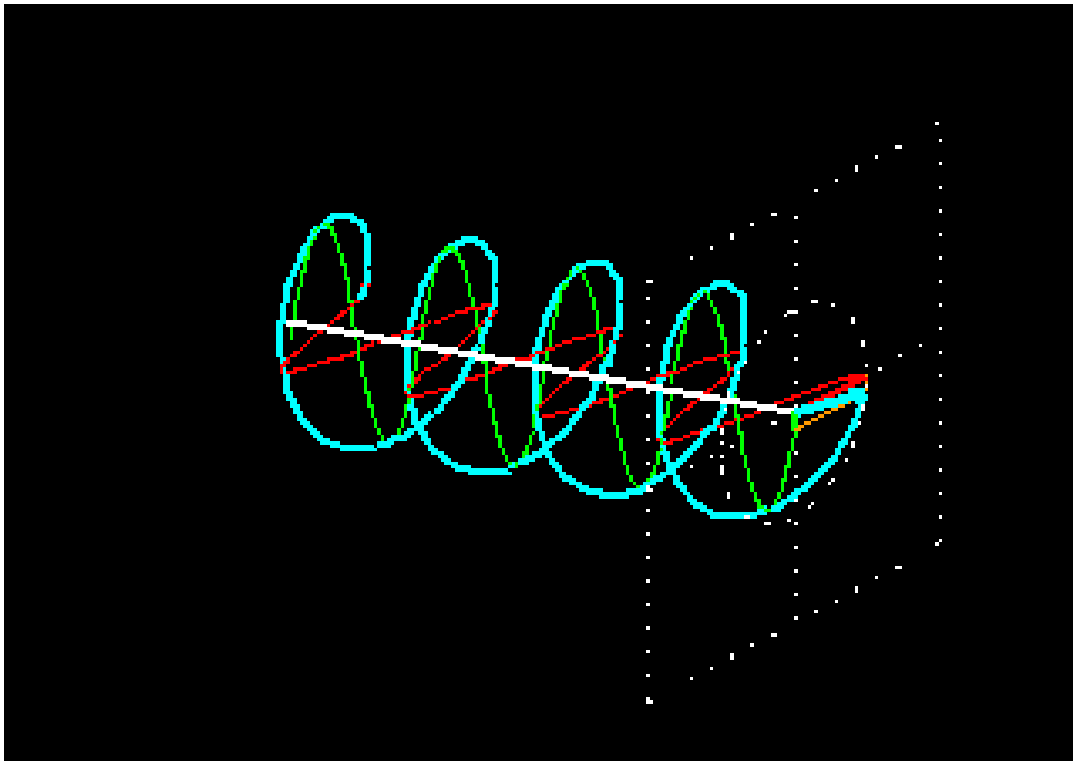
Linear polarized light: only one direction is possible. (more precisely, along one line)



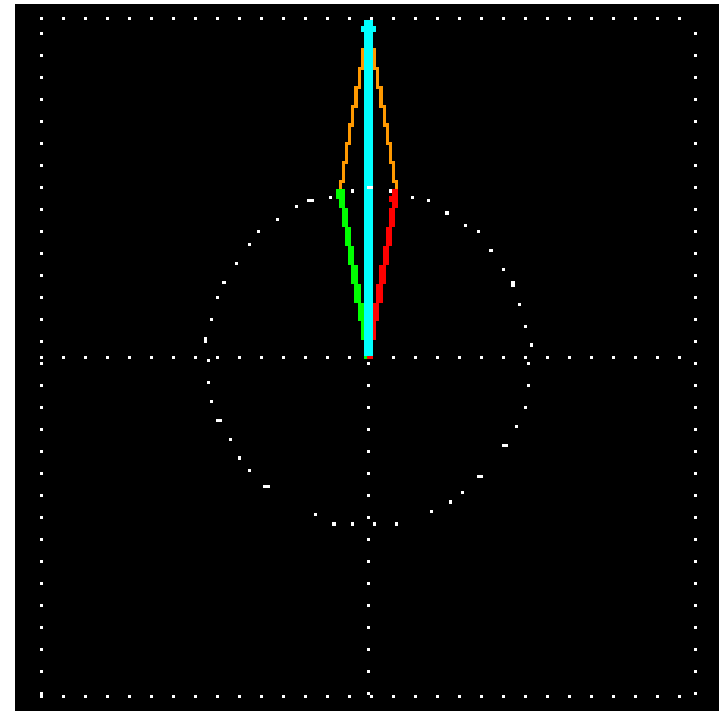
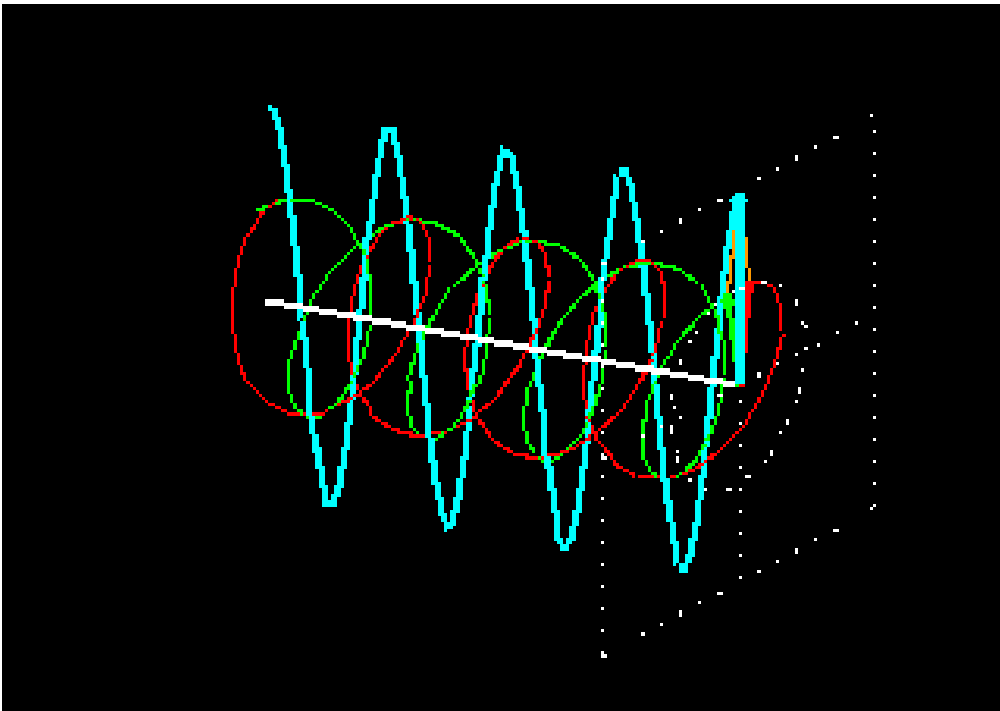
<https://cddemo.szialab.org/>



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

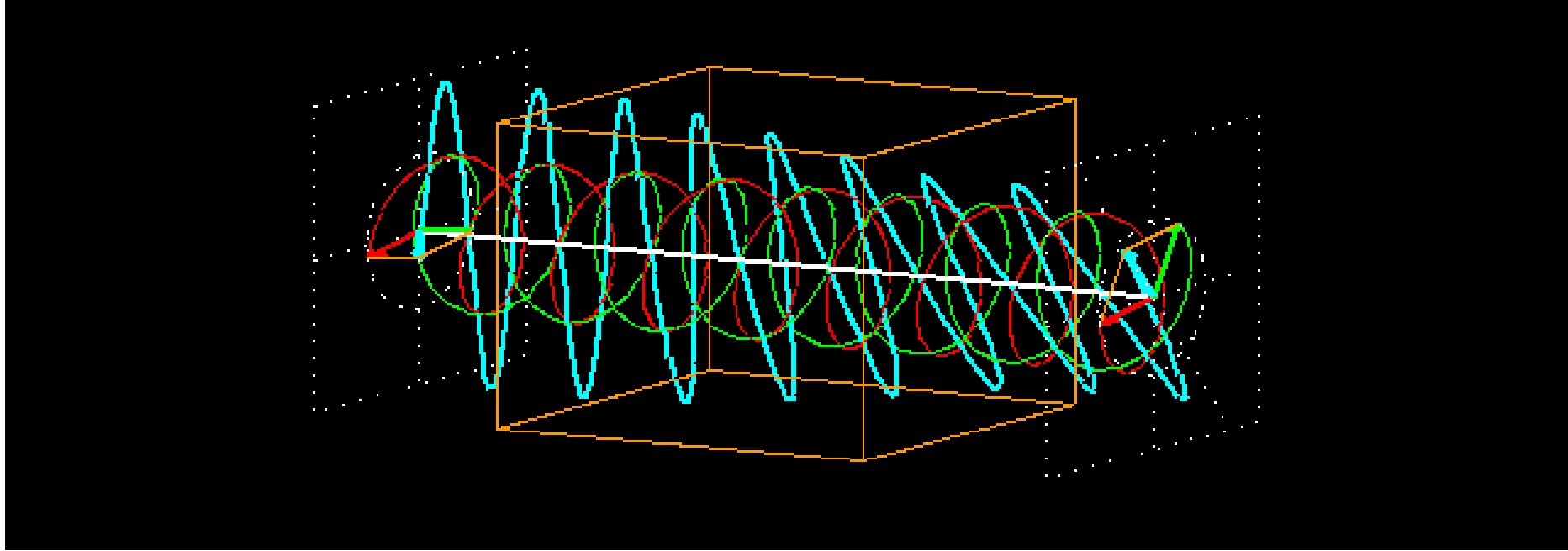


Circular polarized light: it can be the sum of two linear polarized lights.

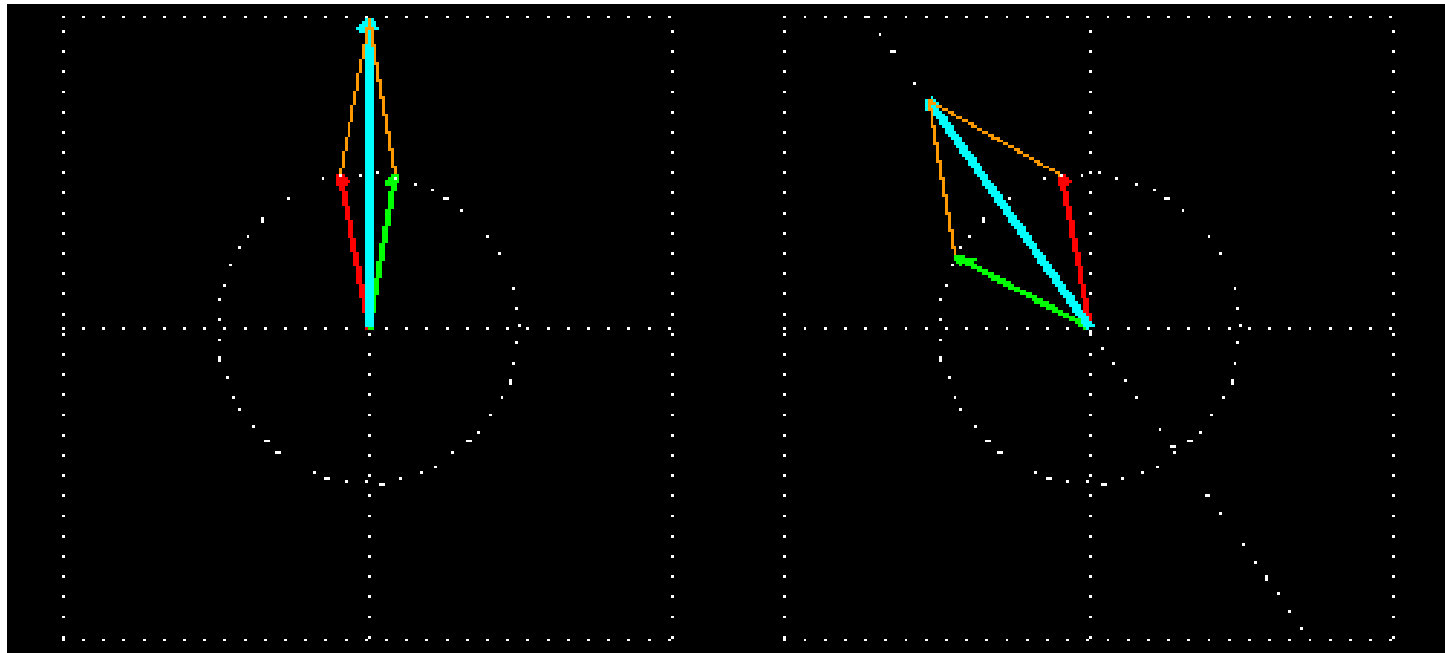


But linear polarized light can be the sum of two circular polarized lights.

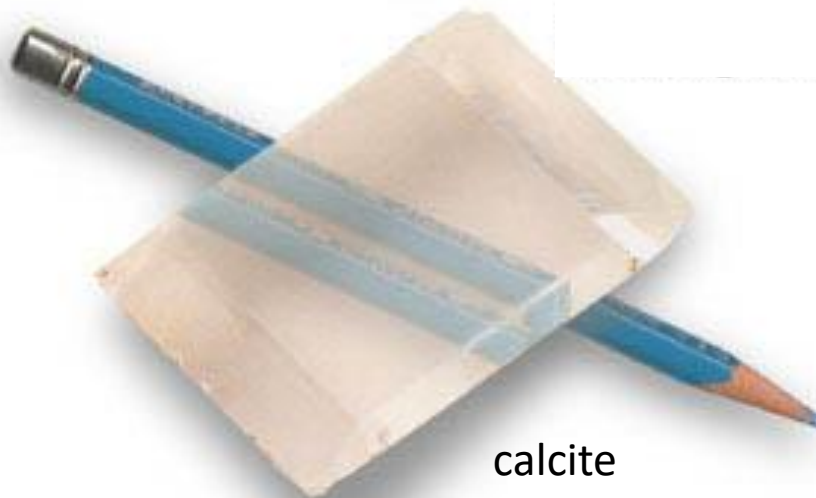
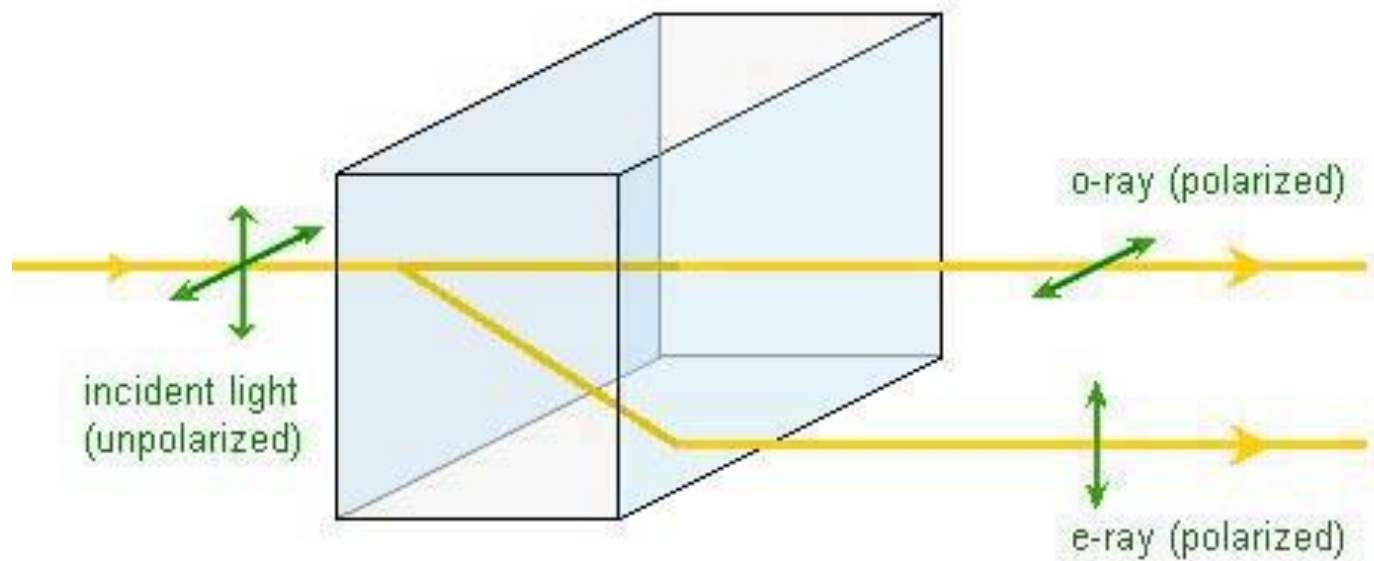
Vector algebra 😊



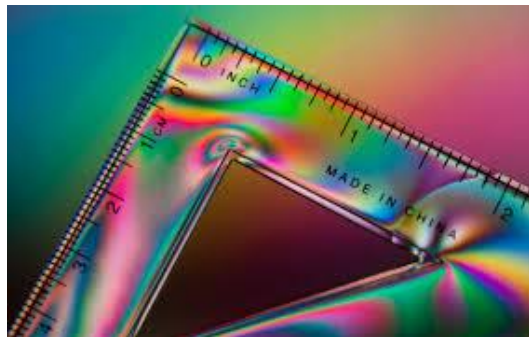
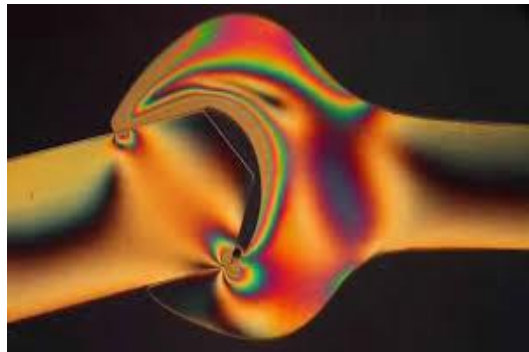
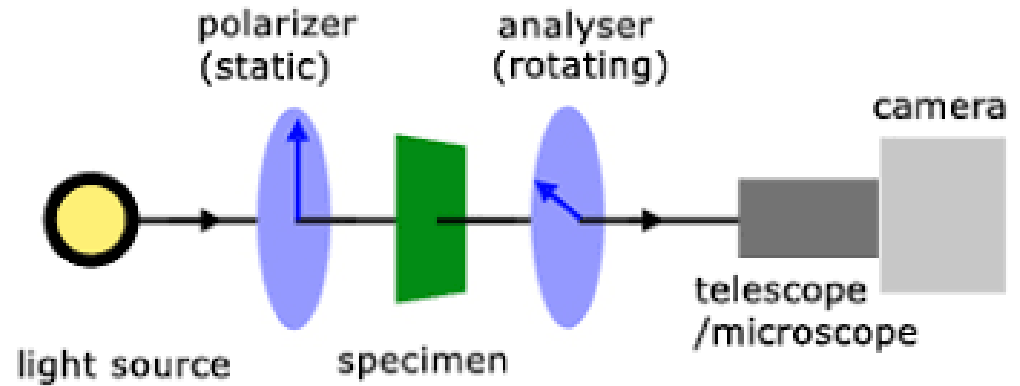
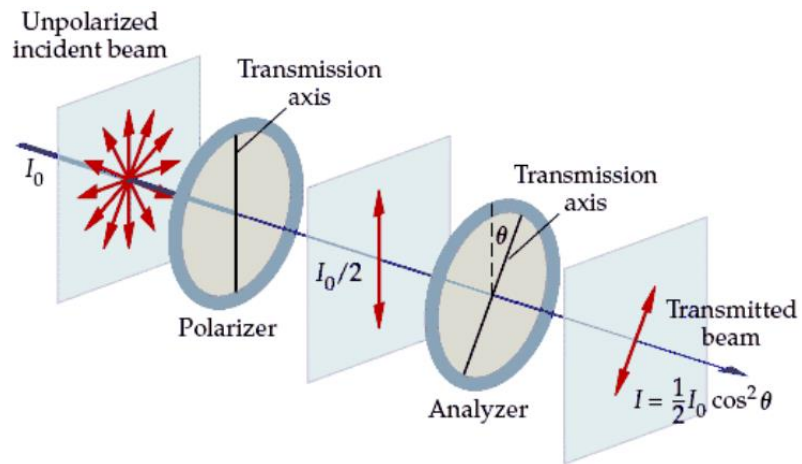
Chiral molecules have two different refractive indices: $n_{\text{left}} \neq n_{\text{right}}$ **circular birefringence**



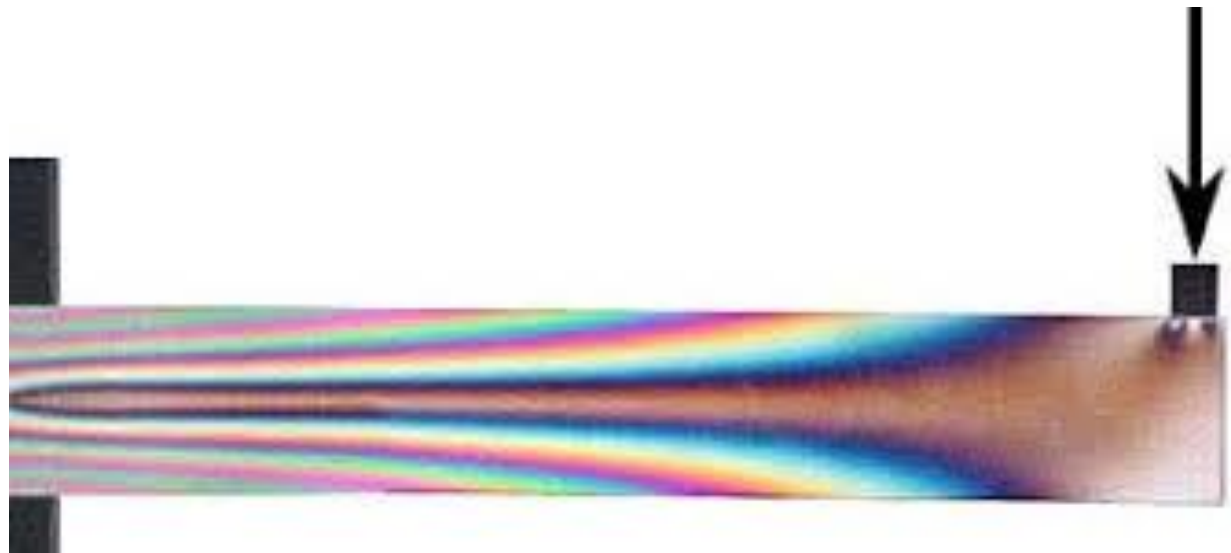
Crystals can also be birefringent

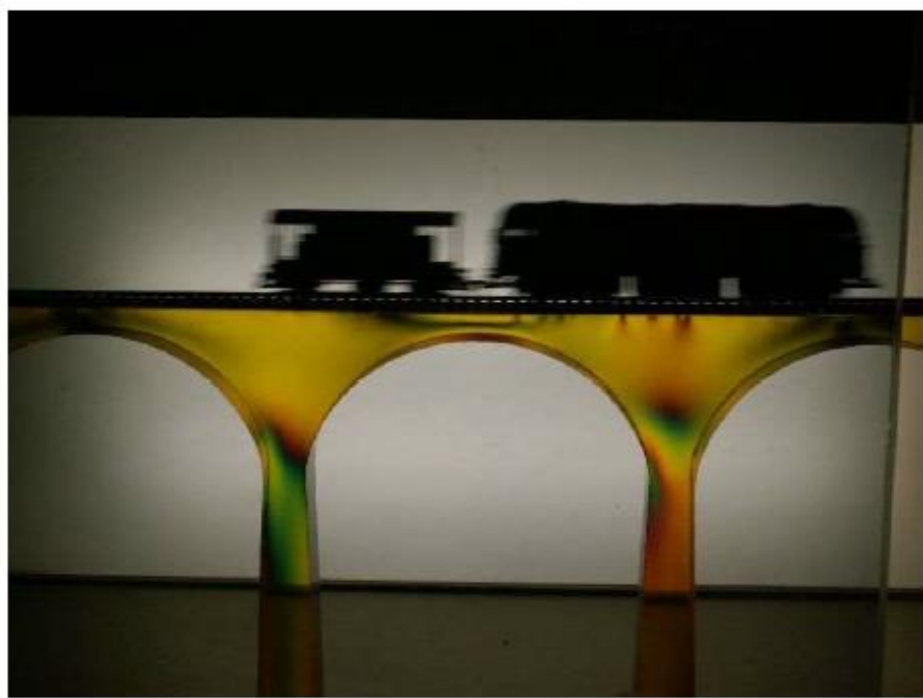
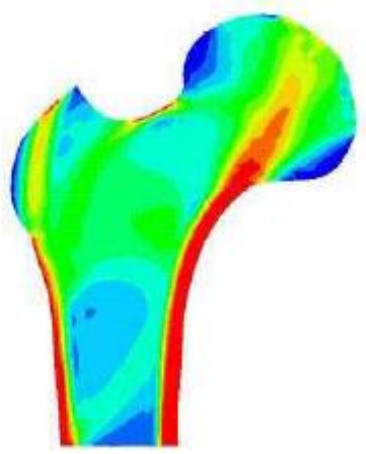
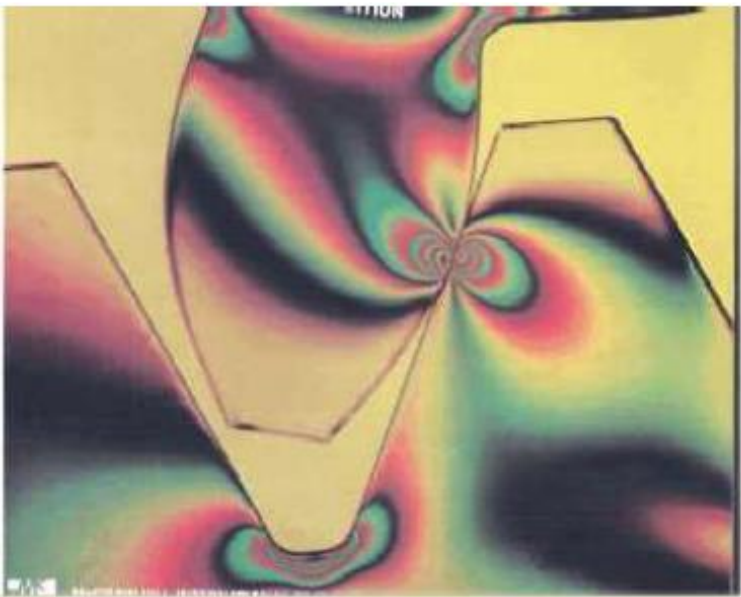


calcite



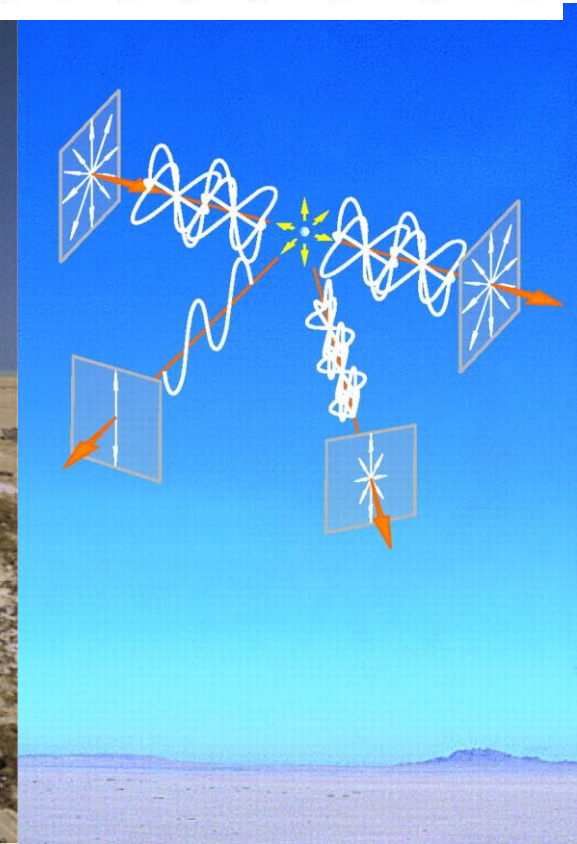
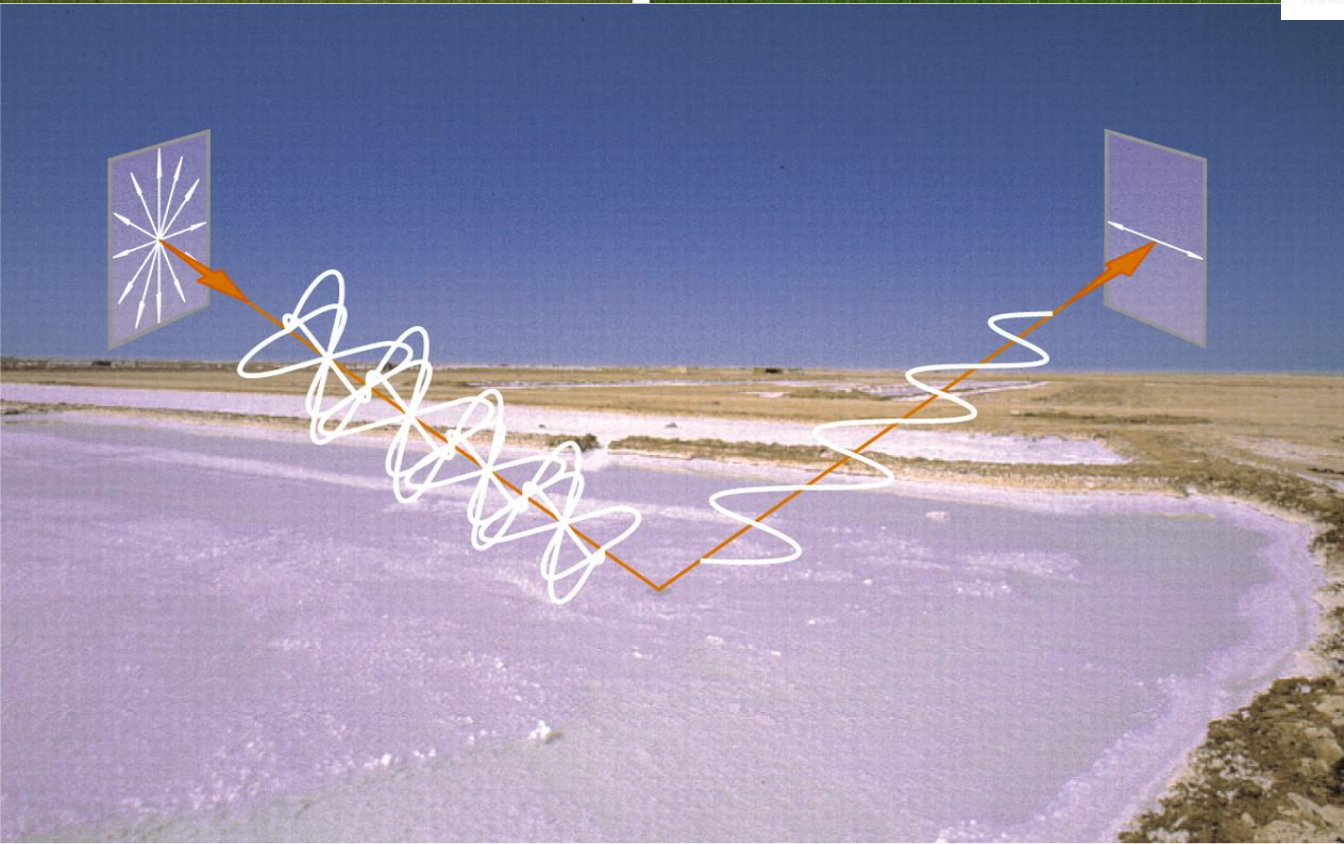
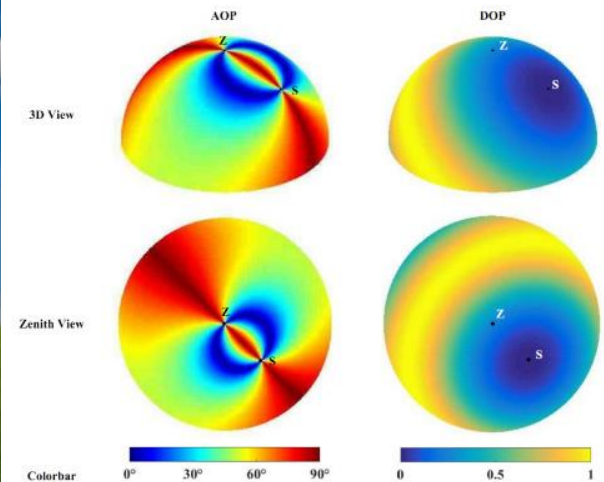
Strain-stress will alter the polarization of the transmitted light





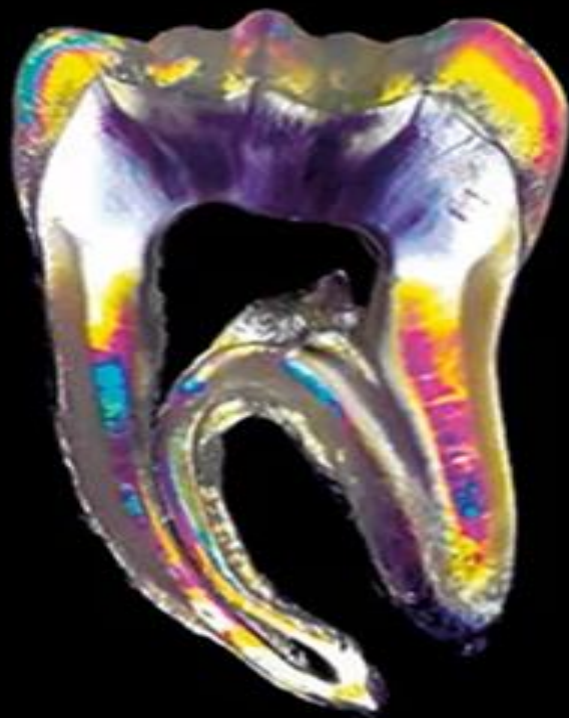


Sky polarization, reflection



Enamel

Dentin



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Cross polarization dental photography

Color matching in prosthodontics

