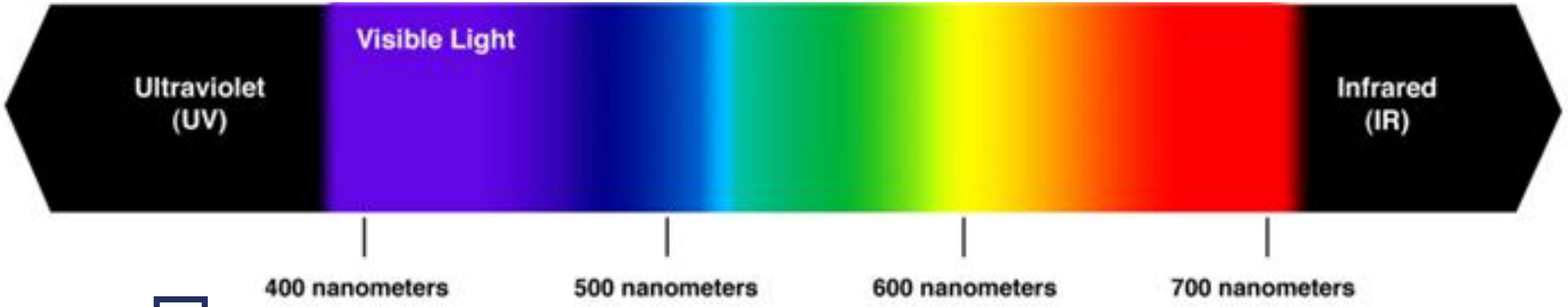
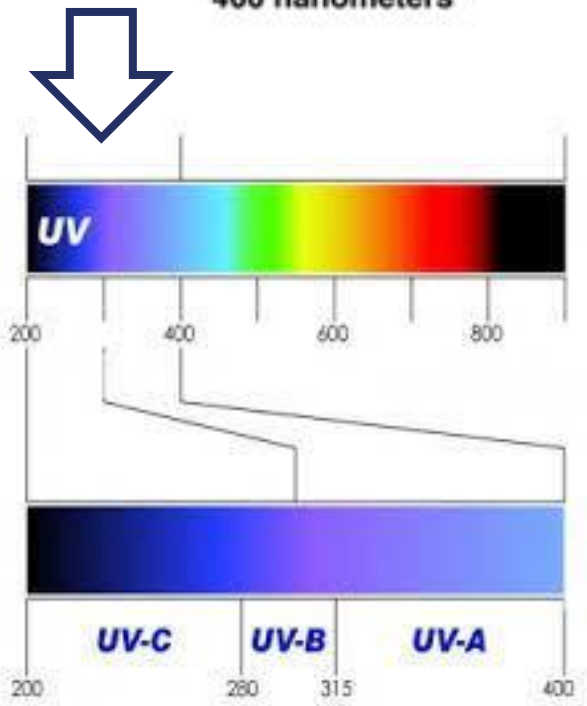
Biological effects of light

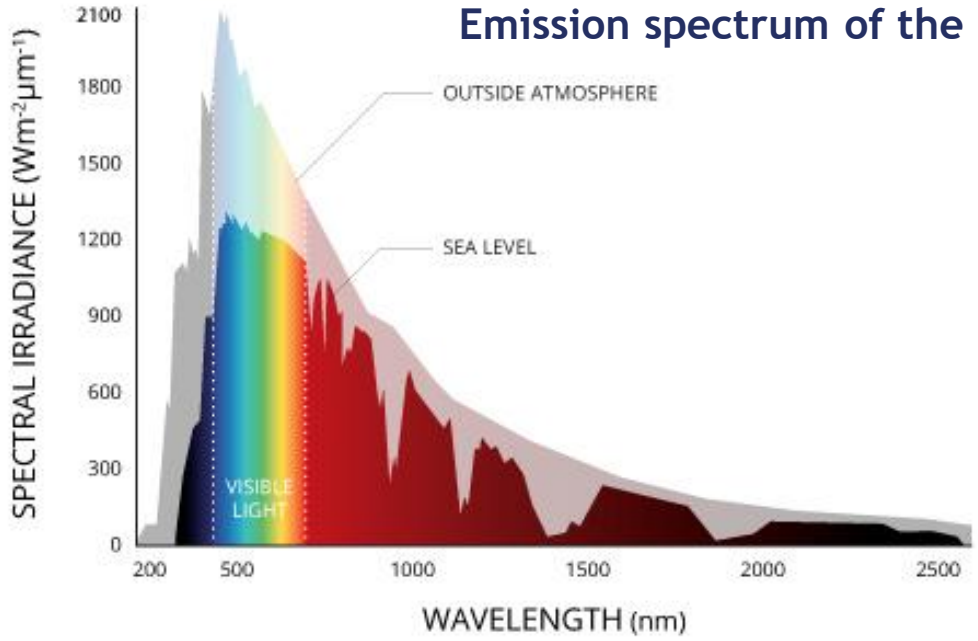
Dóra Haluszka, PhD

Optical regions of electromagnetic spectrum





Emission spectrum of the Sun



Steps leading to photobiological alterations

Photophysical processes
(absorption of light)

Photochemical reaction

Photobiological
processes/consequences

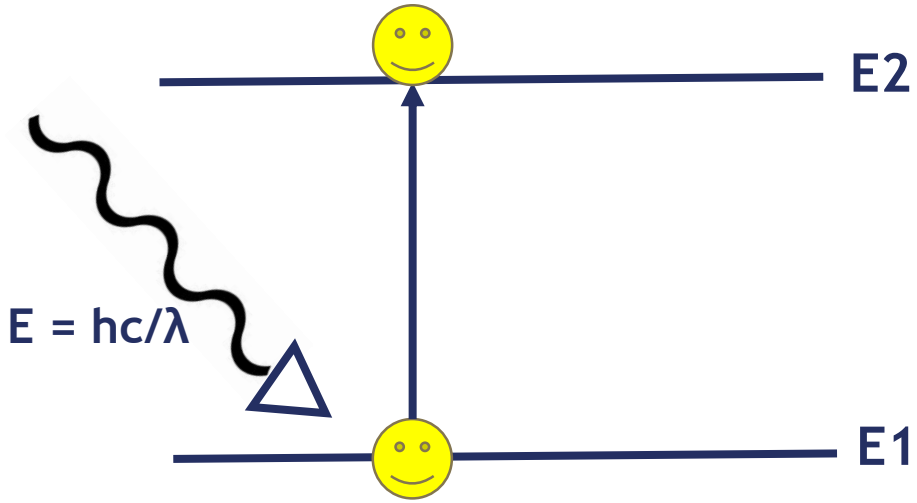
Absorption of light photons in the absorbing molecules is a precondition of photobiological processes!

Precondition of light absorption

Absorbing atom/molecule

Proper wavelenght

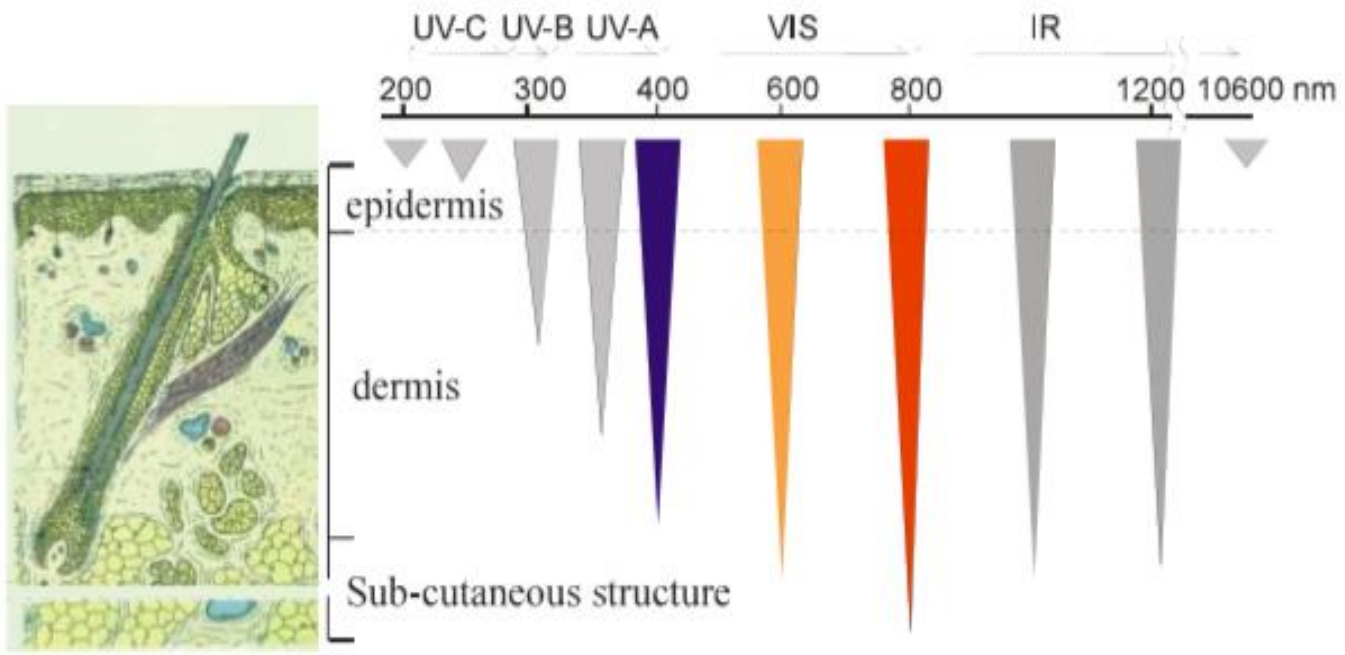
matching

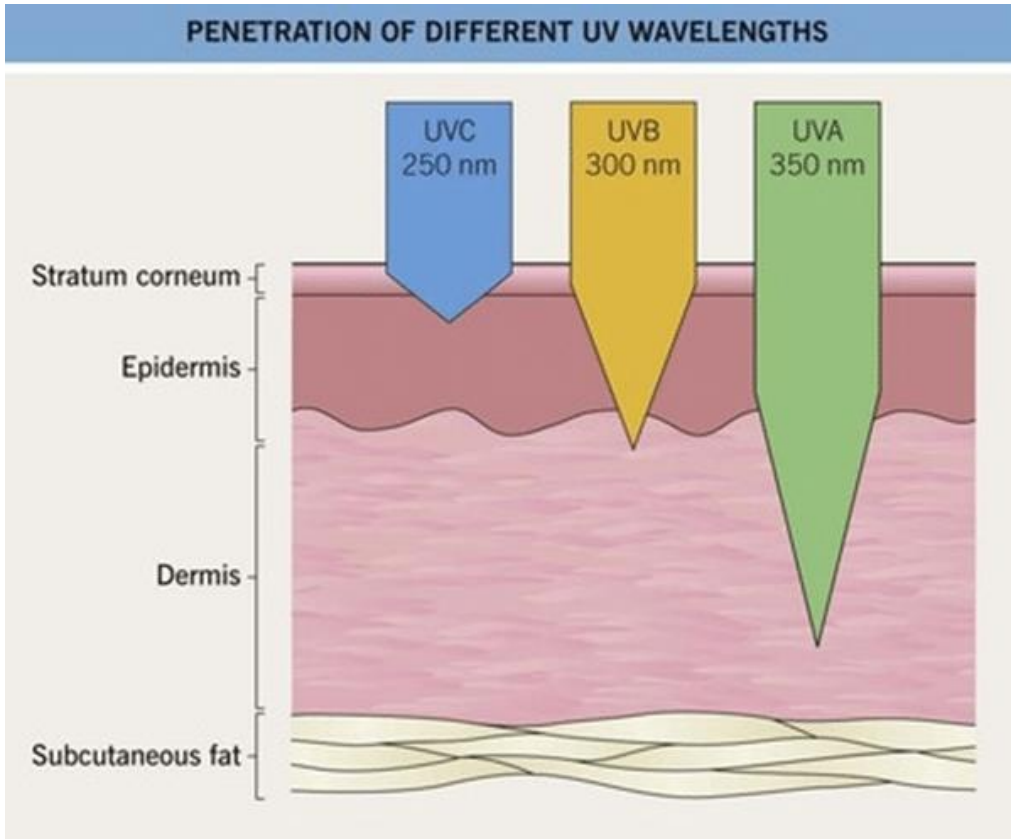


Important rule: the energy of incident photon must be equal to excitation energy!

$$E_2\text{-}E_1 = \frac{hc}{\lambda}$$

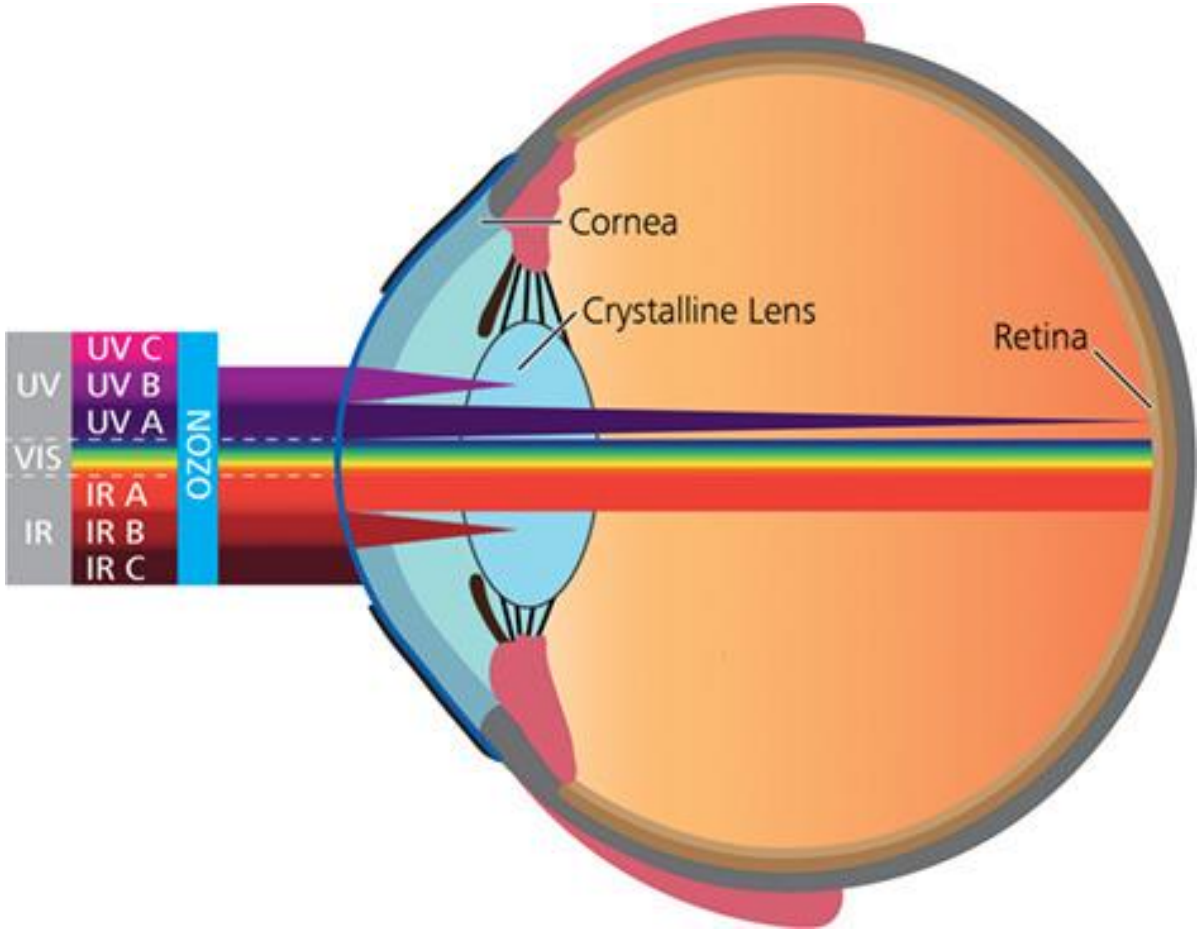
Light penetration in the skin





Penetration ability of light in tissue highly depends on its wavelenght!

Light penetration in the eye



The penetration ability of light highly depends on its wavelenght (absorption, reflection)

Light absorbers (chromophores) in human tissues

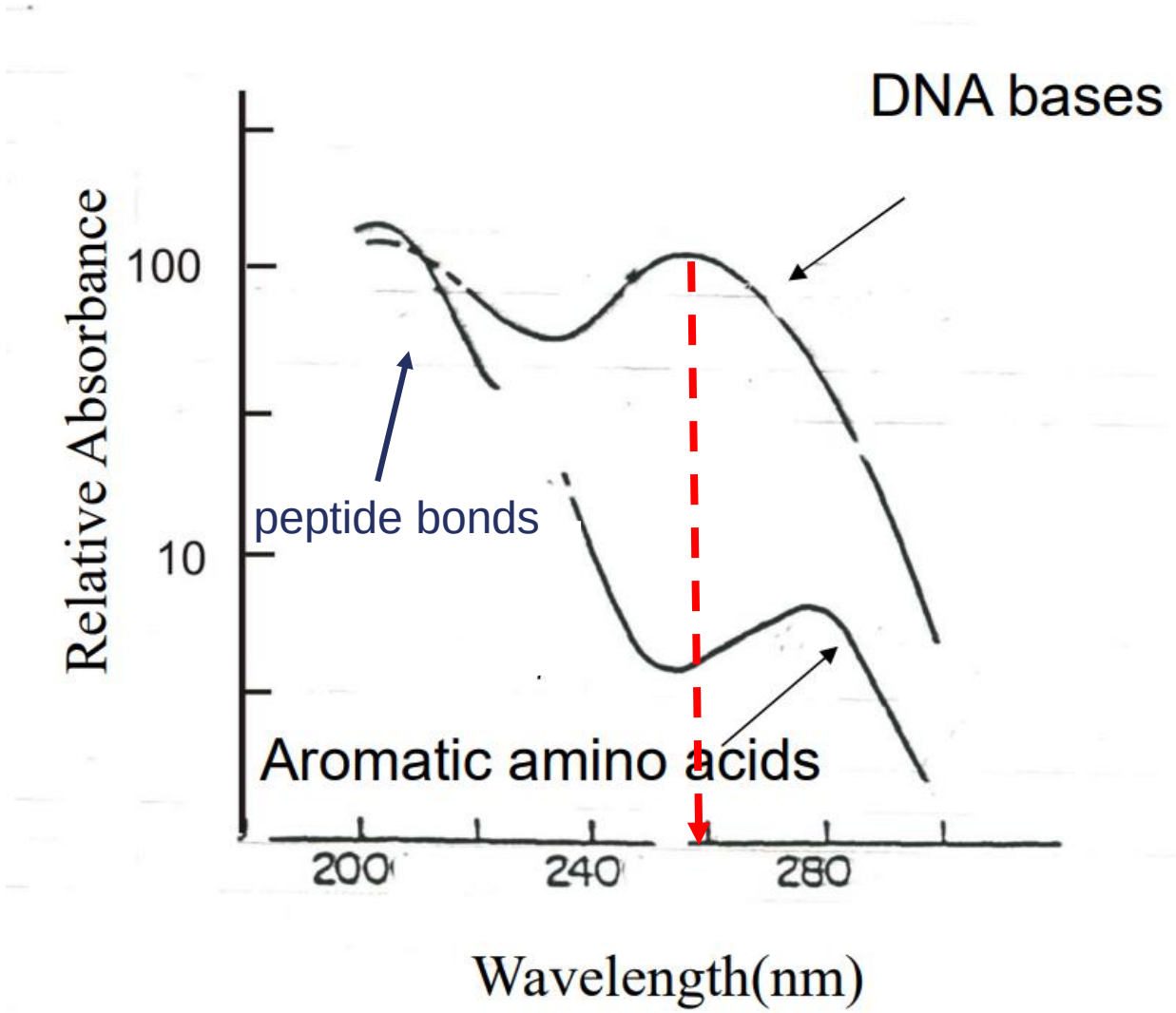
Endogenous chromophores

Nucleic acids
Proteins
Nucleotids (NADH, ATP)
Flavonoids
Melanin
Opsins

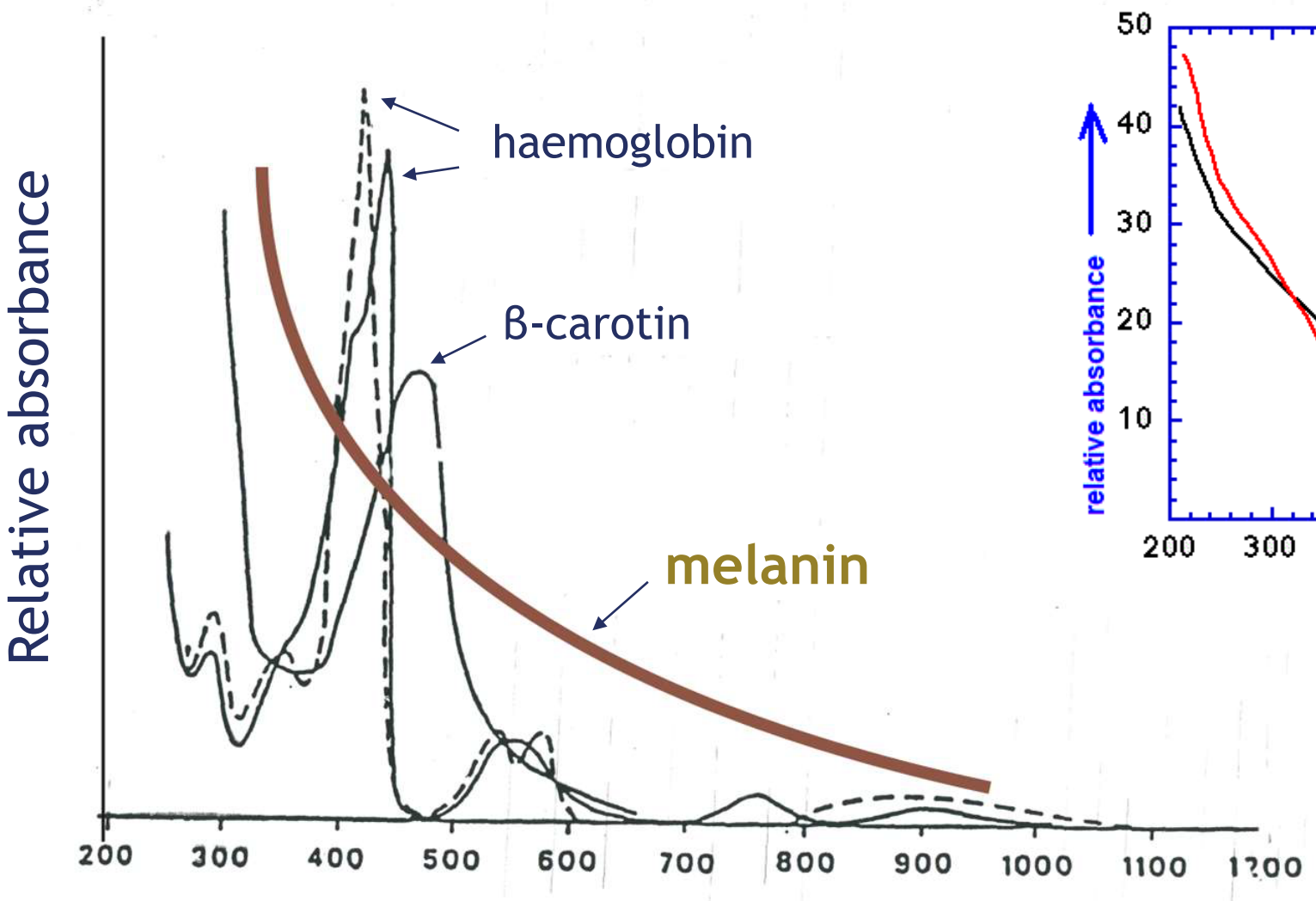
Exogenous chromophores

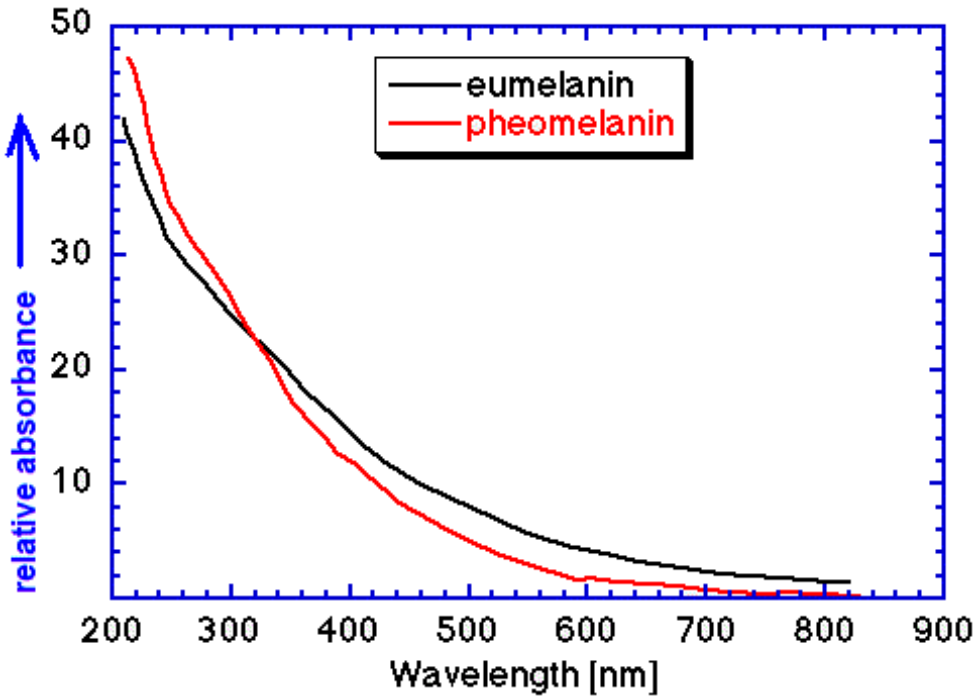
Food coloring dyes
Cosmetics
Drugs

Absorption spectra of endogenous chromophores I.



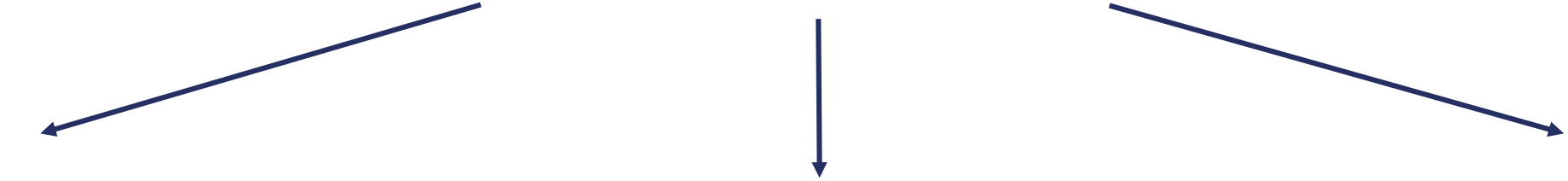
Absorption spectra of endogenous chromophores I.





Consequence of light absorption: excited state

relaxation of excited state



Light emission

Photochemical reaction

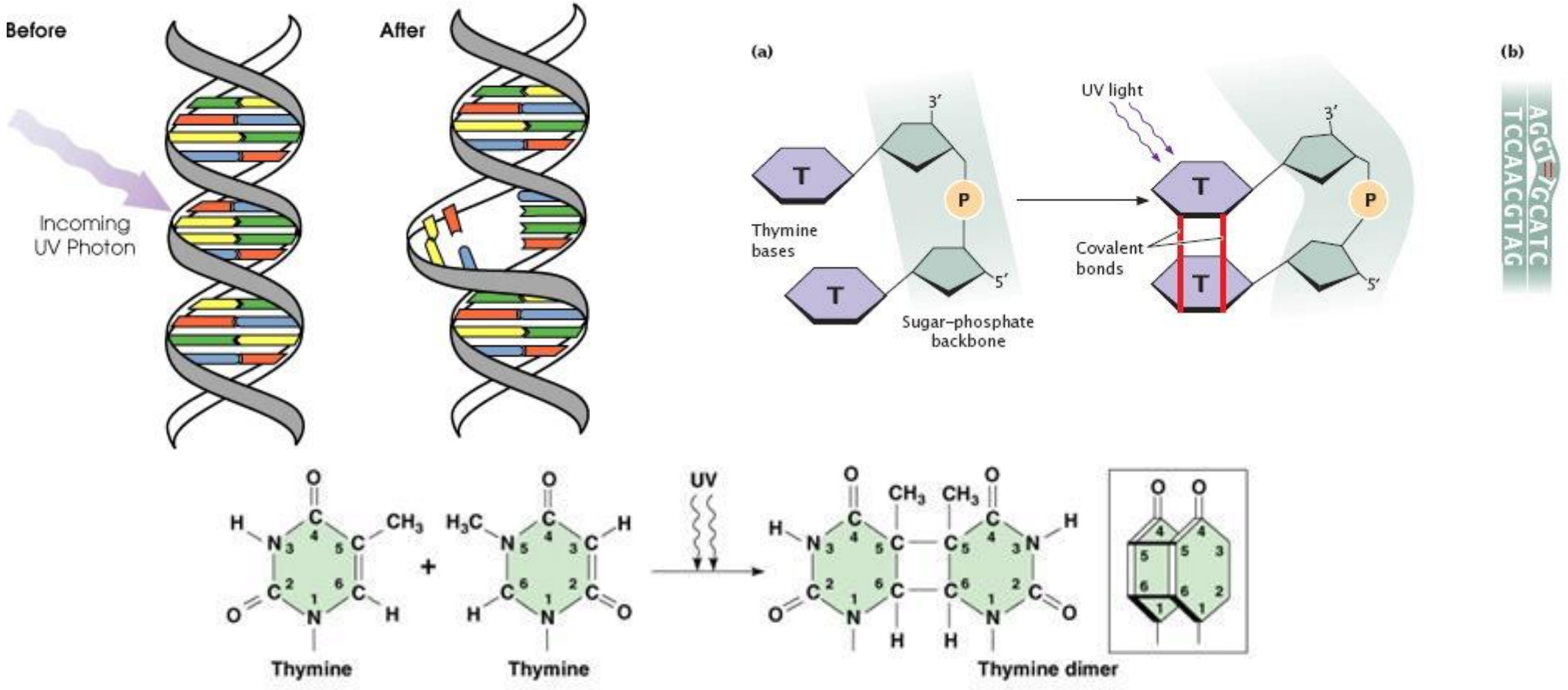
Thermal relaxation

Quantum yield (Φ) : is the number of events (e.g., number of photochemical reactions) divided by the number of photons absorbed by the system.

$$\Sigma\Phi = 1$$

Direct photochemical reaction

Formation of DNA damage – pirimidin dimers (thymine)

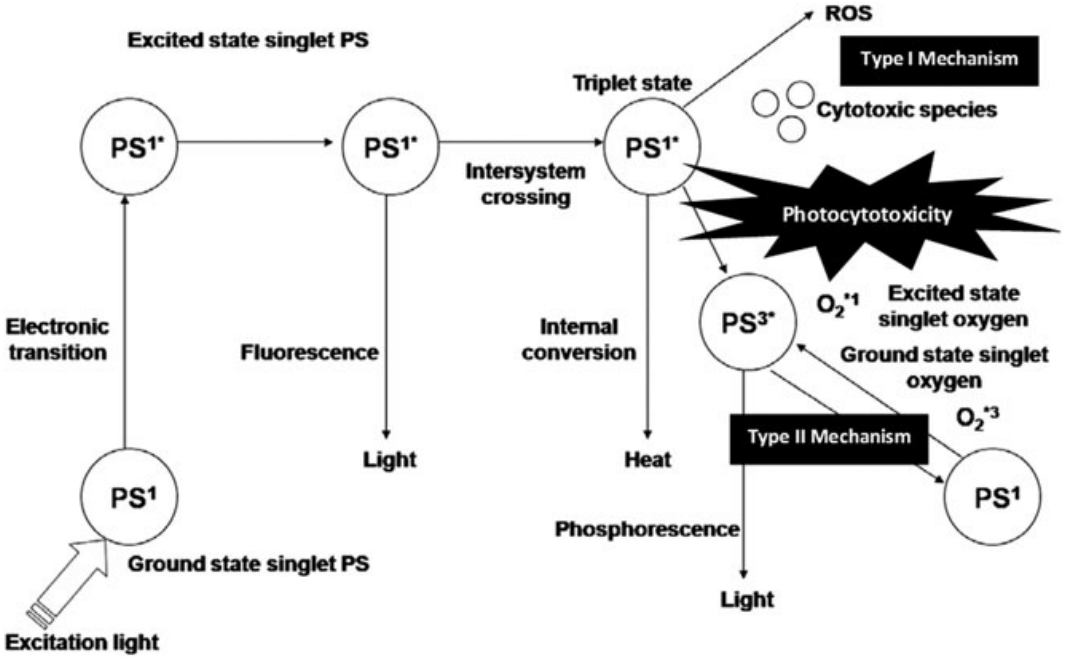


Indirect photochemical reactions

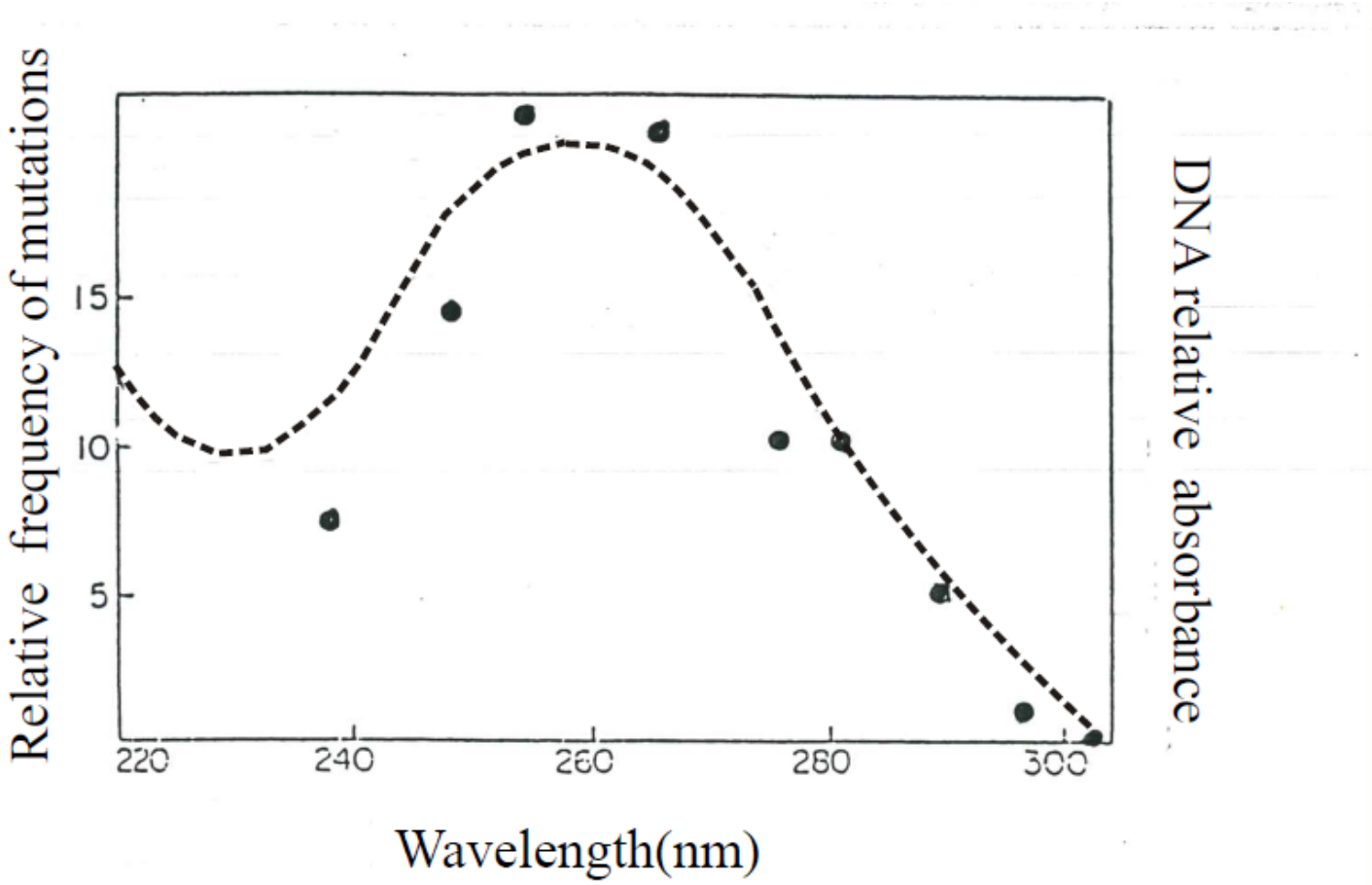
1. step: excitation of photosensitizing compound (PS) by light

2. step: generation of *reactive free radicals* by **electron transfer - acceptor molecule is H_2O**
   or
   generation of *reactive oxygen* species by **energy transfer - acceptor molecule is O_2**

3. step: oxidative damage of cellular structures



Spectral distribution of photobiological efficiency – **efficiency spectrum**



Efficiency varies with the wavelength

Mutations are induced by the photons absorbed in DNA

Reciprocity

$$J_{(\lambda)}\left[\frac{J}{s}m^2\right] \cdot t\,[s] = D_{(\lambda)}\left[\frac{J}{m^2}\right]$$

The result depends only on the incident dose ($D_{(\lambda)}$) or
on intensity **(J)** and on time **(t)** separately?

Reciprocity is valid for photochemical reactions but not for photobiological results.

Beneficial vs. harmful effects of sunlight

sunburn
wrinkles
age-related pigmentation
skin cancer
immunsuppression

visions
vitamin-D production
pigmentation
daily and annual rhythms
therapeutic applications

Effects of sunlight – spatial distribution

local effects

skin
eyes
target regions of therapies

systemic effects

Effects of sunlight – temporal distribution

short-term

sunburn
immuno-suppression

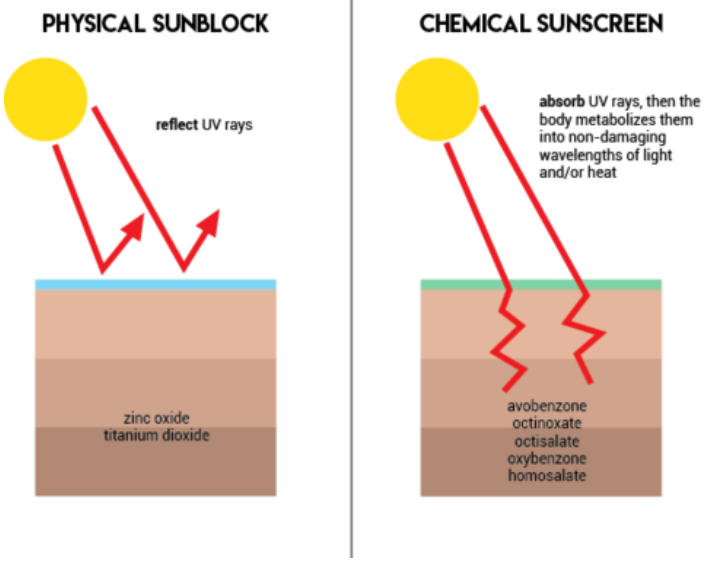
long-term

photoageing
hiperpigmentation
skin cancer

Sunburn

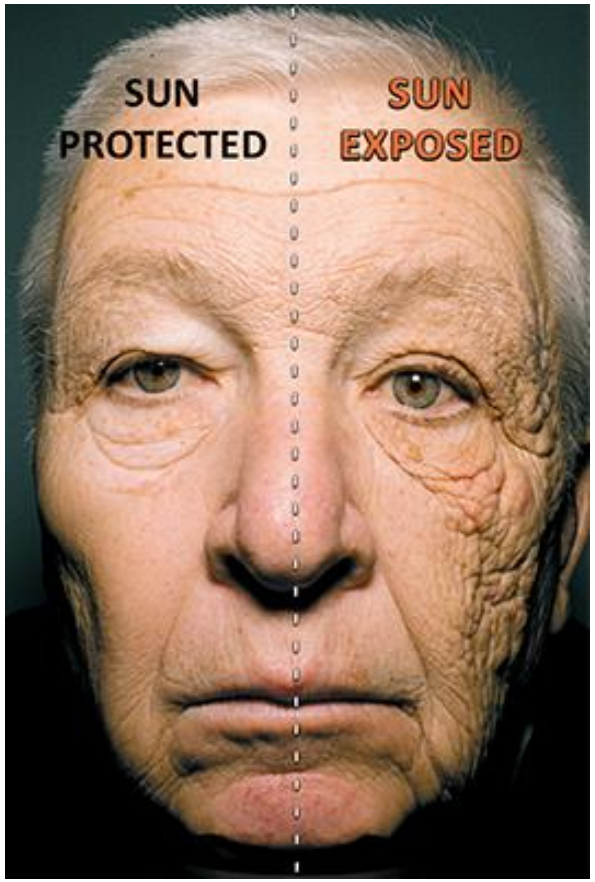
UV protection!

- Physical (sunblock): TiO_2, ZnO – scattering, reflection
- Chemical (sunscreen): absorption of UV light



Photoaging

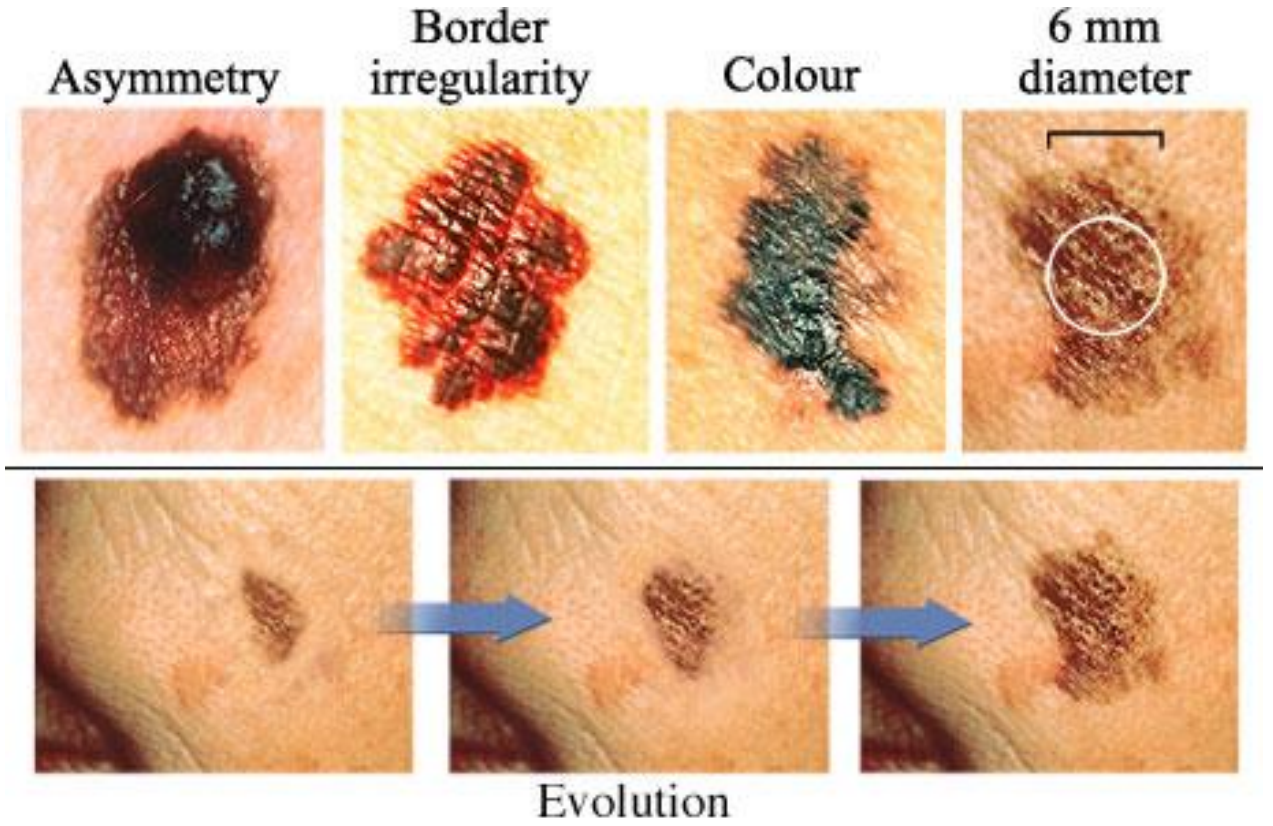
Unilateral Dermatoheliosis



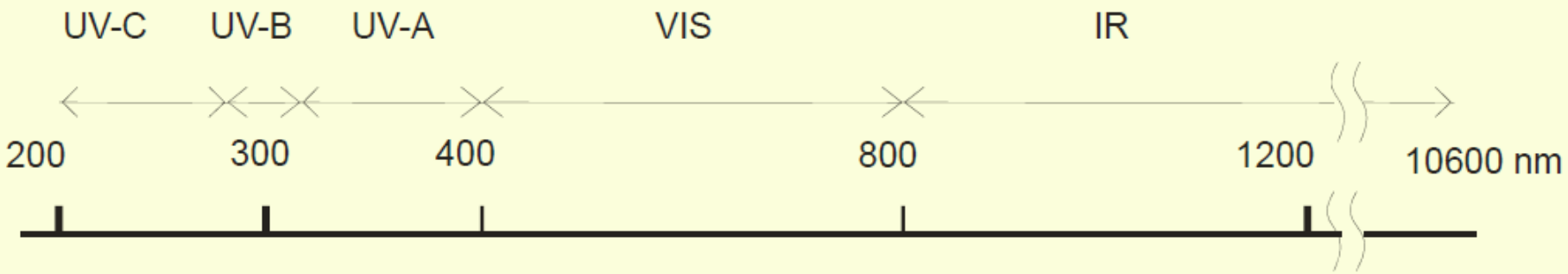
https://www.nejm.org/doi/full/10.1056/NEJMicm1104059

Skin cancer – melanoma malignum

ABCD rule!



Penetration distance and localization of damages - EYE



corneal burns
(photokeratitis)

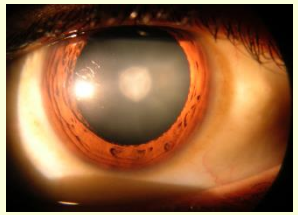
„pink eye”
(conjunctivitis)

corneal burns

cataracta
cloudy area in the lens

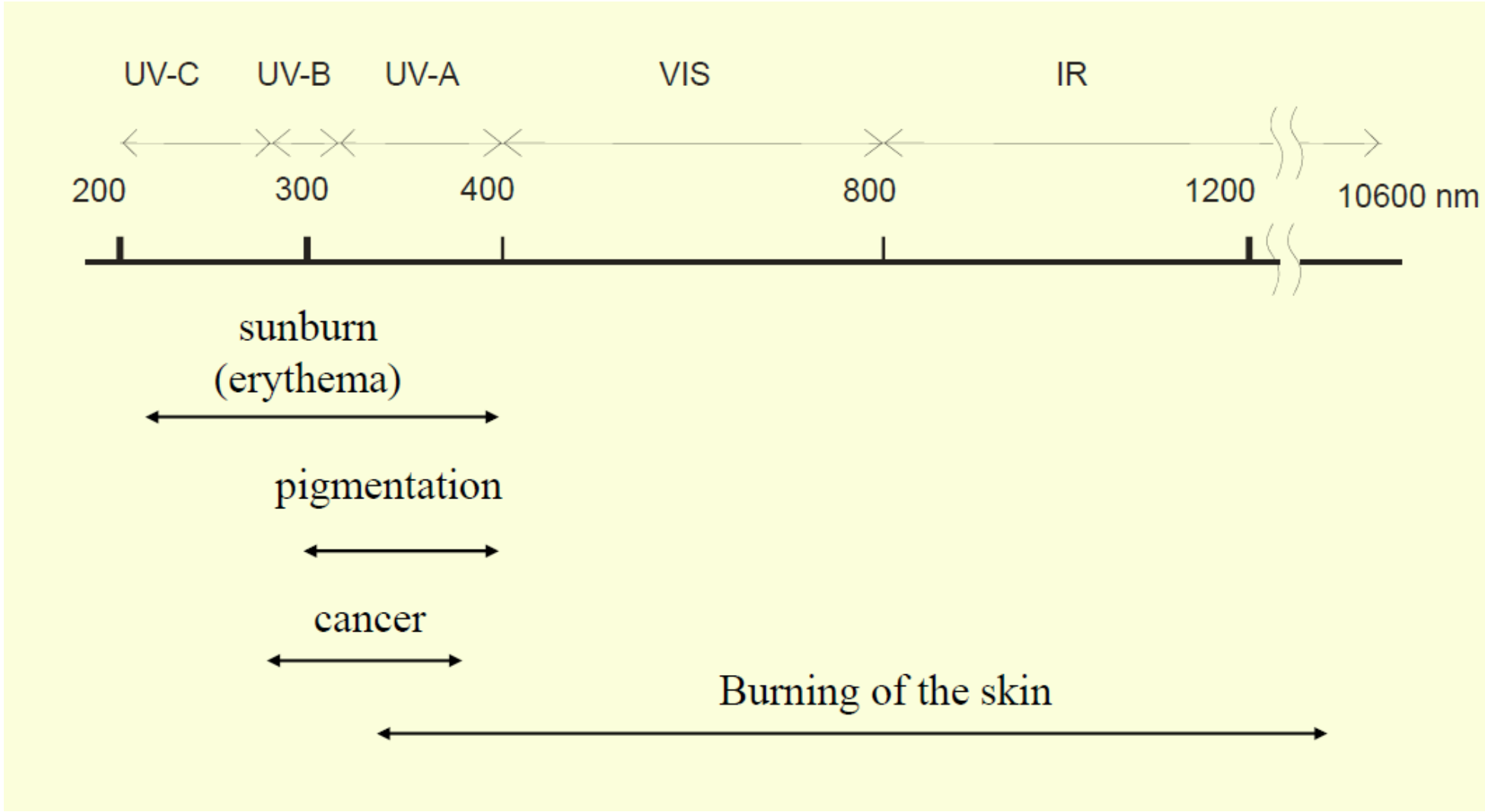
vision

cataracta
cloudy area in the lens



retinal burns

Penetration distance and localization of damages - SKIN



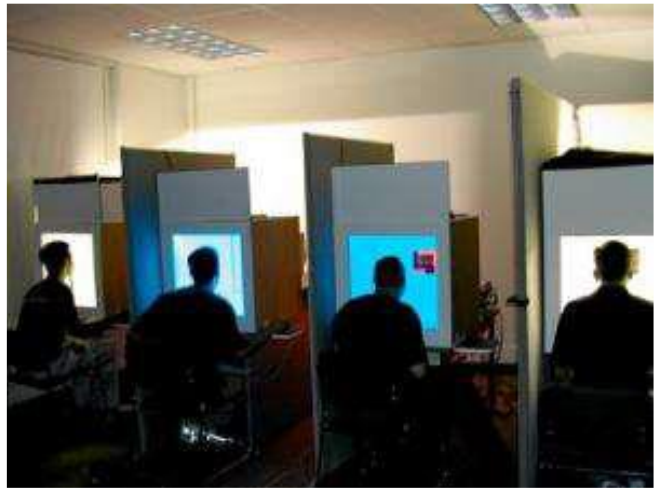
Daily and annual periodicity of biological functions

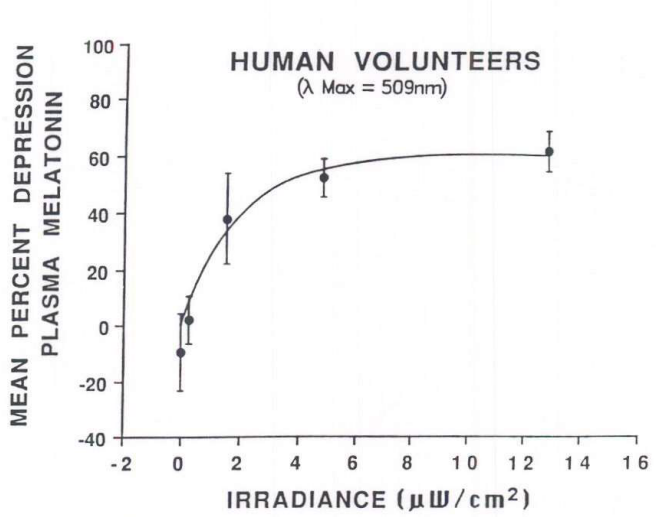
temperature
hormon production
digestion
sleep-wake cycle

Role of light on circadian rhythm

Seasonal Affective Disorder (S.A.D.)

Background of SAD: high serum level of melatonin hormone





Melatonin level is regulated by the intensity, wavelenght and time period of incident light into the eye

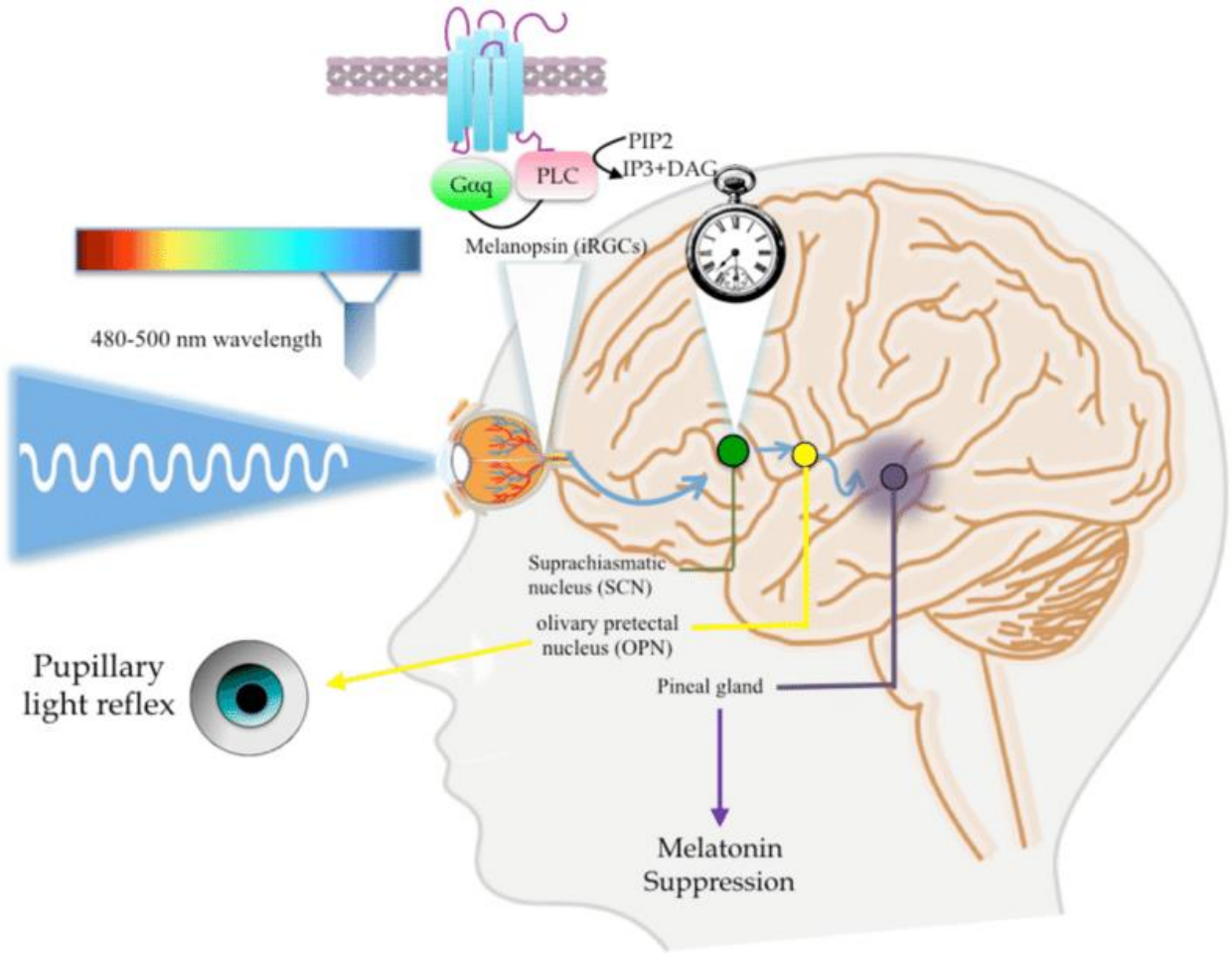
Melatonin level regulation is independent from vision – blindness do not inhibit this process

https://www.verywellhealth.com/seasonal-affective-disorder-sad-5084382

A new type of photosensitive cells (RGC) in retina

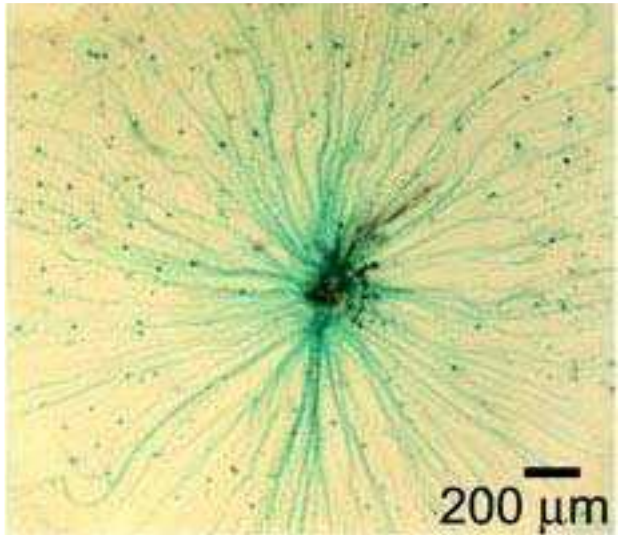
non-visual pigment:
„melanopsin”

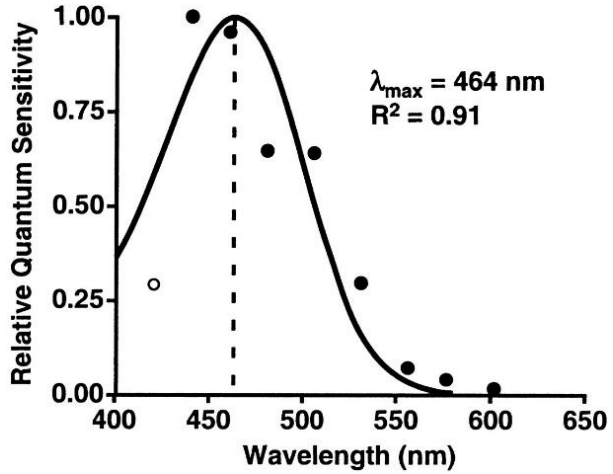
Retinal ganglion cells are particularly sensitive to the absorption of short-wavelength (blue) visible light and communicate information directly to the area of the brain called the suprachiasmatic nucleus (SCN), also known as the central "body clock", in mammals



Melanopsin

Retinal ganglion cell





Action spectrum of melatonin

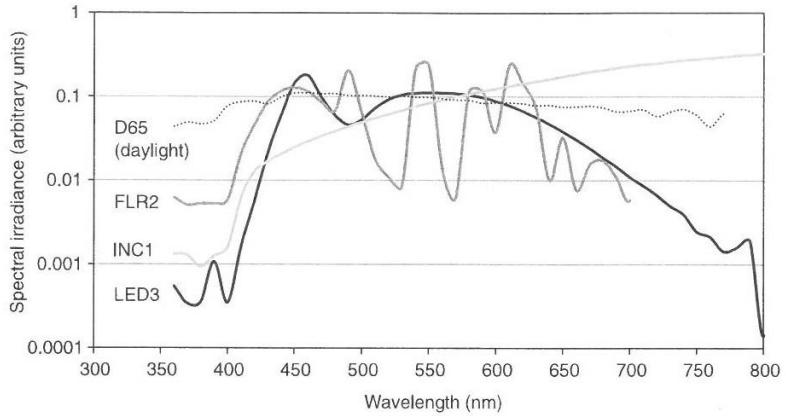


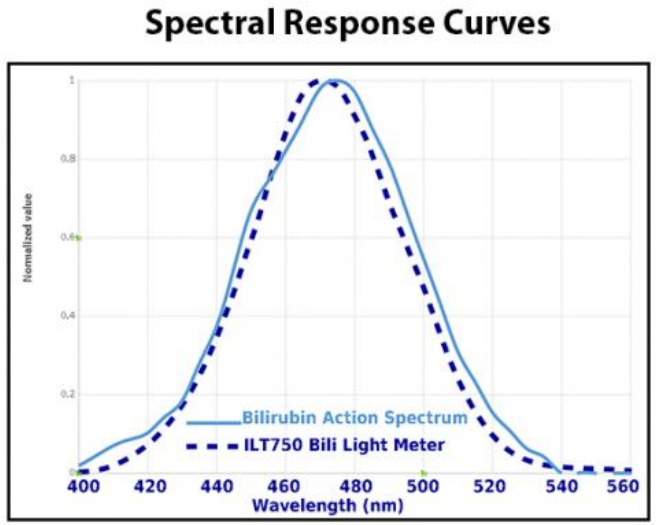
Figure 2 Typical spectra of seasonal affective disorder (SAD) lamps, sunrise simulators and daylight bulbs for light emitting diodes (LED3), fluorescent (FLR2), incandescent (INC1) lamps and the CIE standard illuminant D65,[24] representing natural daylight. The spectra are normalised for equal illuminance, and plotted in 10-nm steps

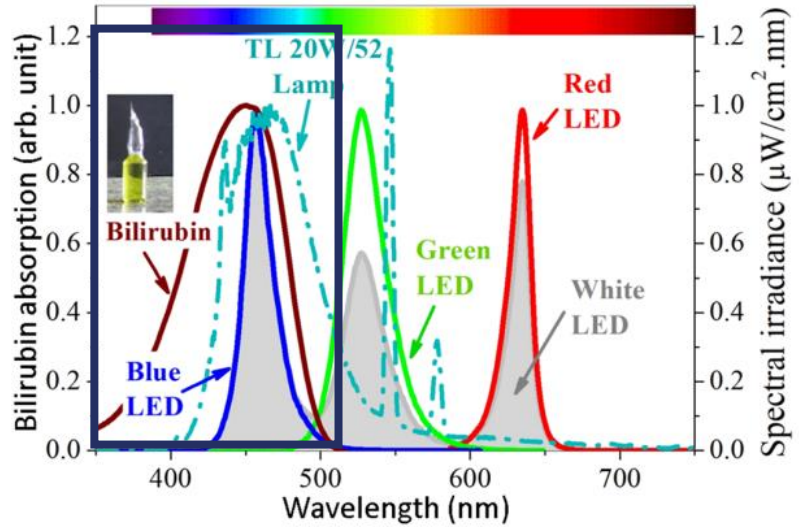
Examples for therapeutic application of light

Phototherapy : light + endogenous chromophores
therapy by **light**

Photochemotherapy: light + exogenous chromophres
Therapy by **drug + light**

Newborn jaundice (hyperbilirubinemia)

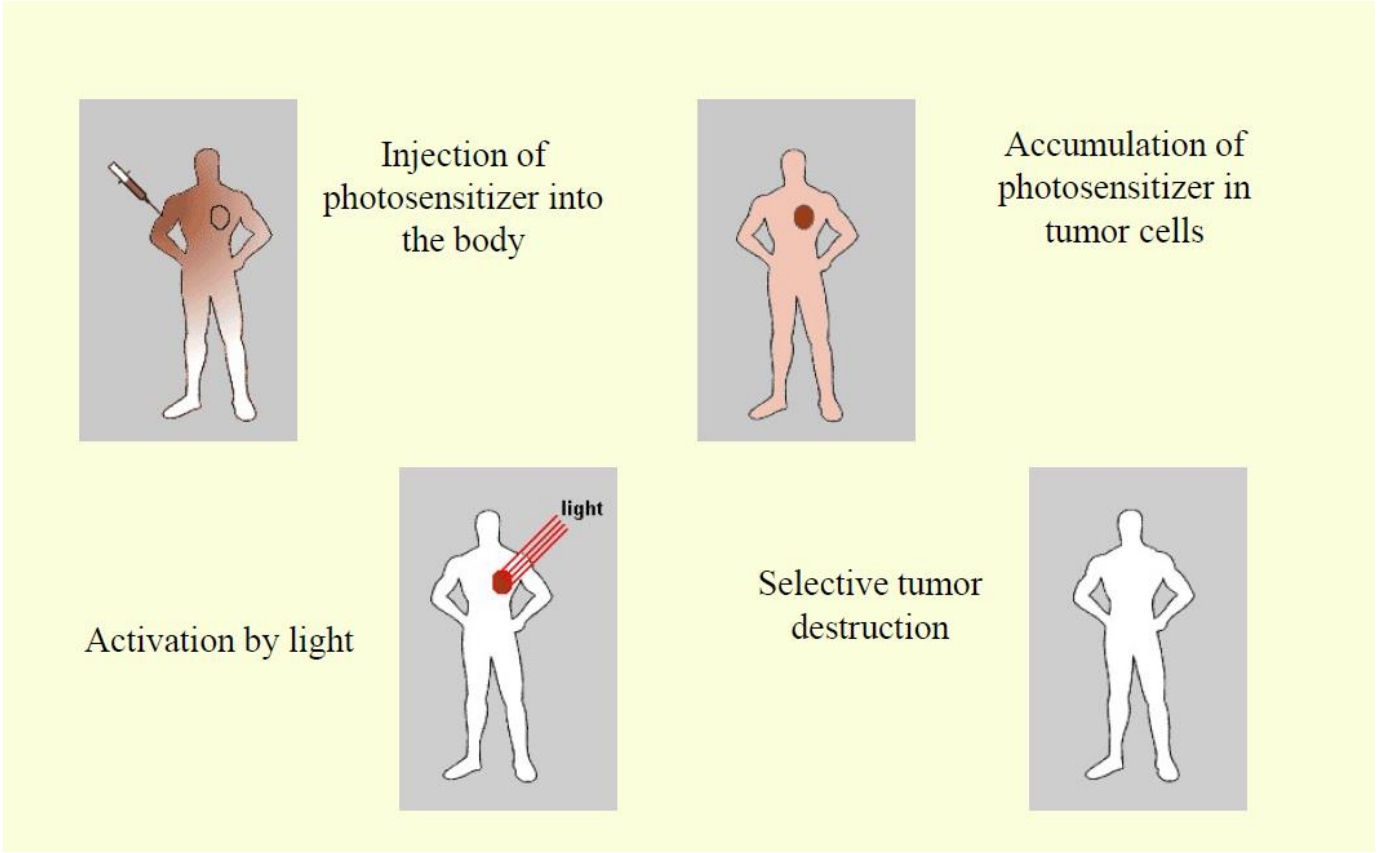




https://aip.scitation.org/doi/pdf/10.1063/5.0046430

Photodynamic therapy (PDT)

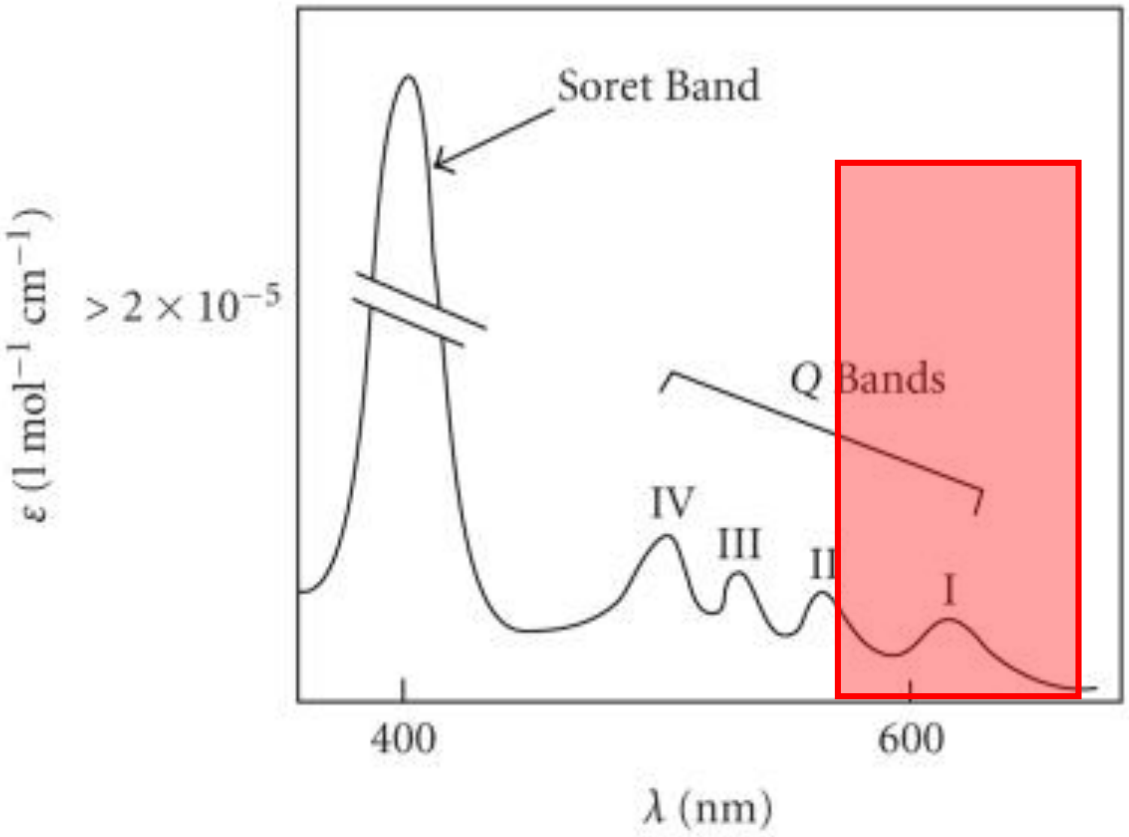
Light induced inactivation of photosensitized cells in the presence of molecular oxygen

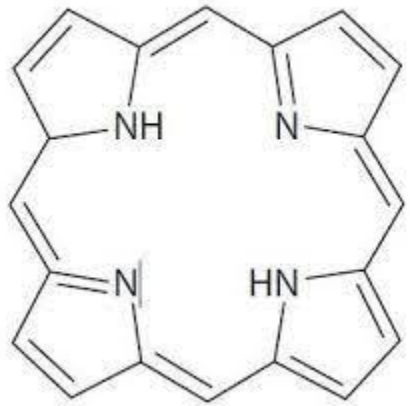


Indirect photochemical reaction

electron transfer – free radicals
energy transfer – reactive oxygen

Absorption spectrum of porphyrins





Problem: at 400 nm high absorbance but poor penetration ability
Selection of another absorption maximum – application of longer wavelenght

Application fields of PDT – malignant tumors

Dermatology
Urology: bladder cancer
Gastroenterology: oesophagus
Neurosurgey
Head and neck surgery (Otorhinolaryngology)
Pulmonology

Application fields of PDT – non-malignant diseases

Macula degeneration
Psoriasis
Arteriosclerosis – plaque removal
Photoinactivation of microorganisms

Treatment of oral squamous cell carcinoma (OSCC) with PDT

Fig. 1 Pre-PDT picture of a woman with a superficial T2N0 oral SCC.

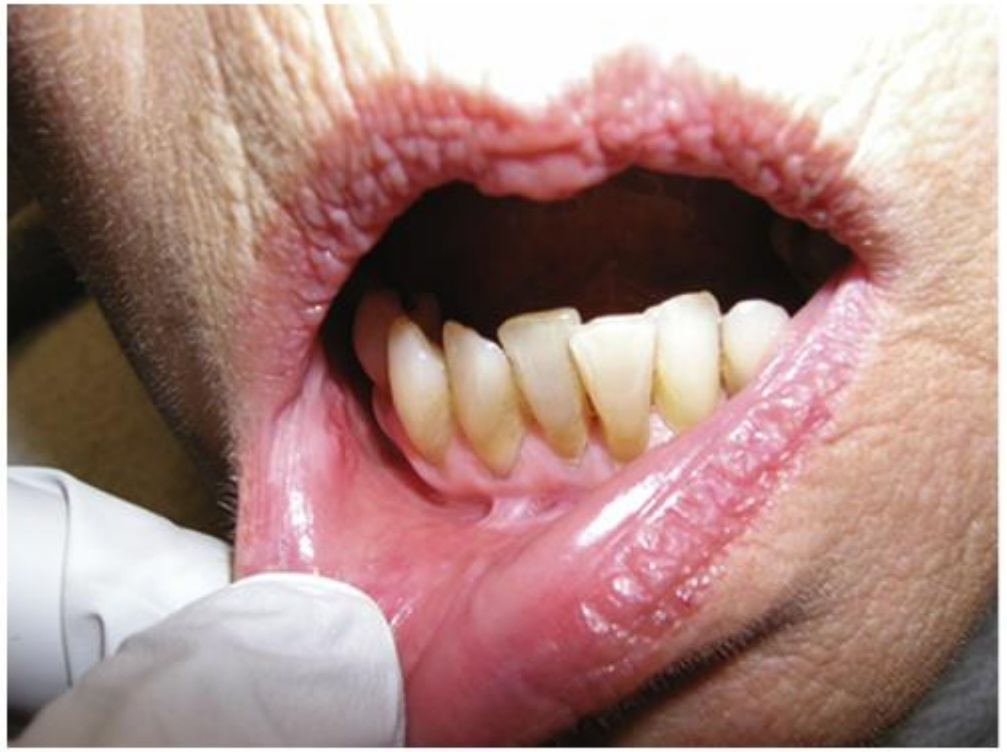


Fig. 2 Post-treatment (Fig. 1 patient), 6 months after PDT.

https://doi.org/10.1016/j.wjorl.2016.05.011

Antimicrobial PDT of periodontitis

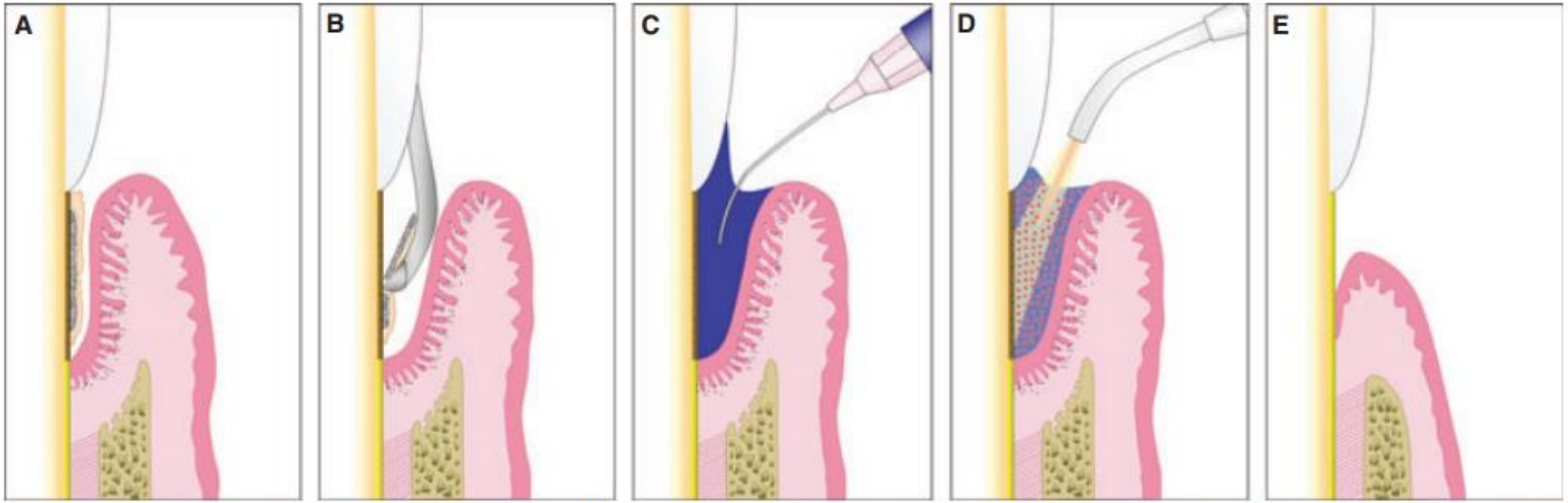


Fig. 2. Diagram showing the steps of application of antimicrobial photodynamic therapy in the treatment of periodontitis. (A) Periodontally diseased site before treatment. (B) Mechanical debridement using hand curettes. (C) Application of the photosensitizer via syringe at the diseased site that contains residual bacteria. Occasionally, excess dye solution is removed using water spray. (D) Photosensitization is performed using an intensive light by a special tip applied in the pocket. Singlet oxygen and other very reactive agents that are toxic to bacteria are produced, resulting in photochemical disinfection of the periodontal pocket. (E) Improved wound healing in the treated site.

https://onlinelibrary.wiley.com/doi/epdf/10.1111/j.1600-0757.2009.00302.x

Checklist

- Biologically relevant ranges of electromagnetic spectrum
- Preconditions of light absorption
- Penetration ability of light in various tissues (skin, eyes)
- Most important types of endogenous chromophores and their absorption specra
- Direct, indirect photochemical reactions
- Efficiency spectrum
- Examples for the biological effects of light
- Examples for therapeutic application of light (phototherapy, photochemotherapy)