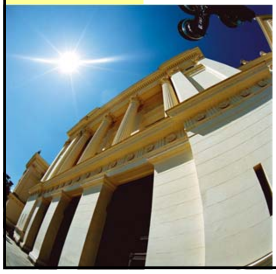
Multispectral Imaging
Spectroscopic Equipment

Stefan Andersson-Engels



Spectroscopic Equipment

Light source

- Sun
- Lamps
- Lasers
- Synchrotron

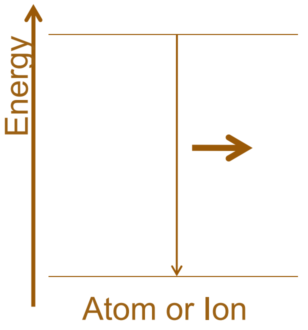
Analyzer

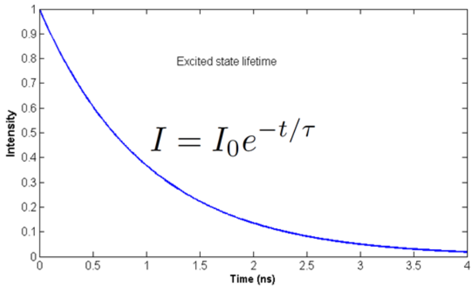
- Spectrometers

Detector

- Diodes
- Photo multiplier tube
- CCDs
- Image intensifiers

Line light sources





$$I = I_0 e^{-t/\tau}$$

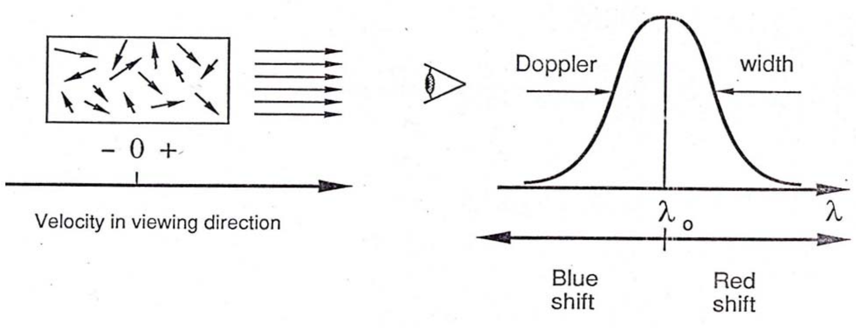
Natural line width

$$\Delta\nu_n = \frac{1}{2\pi\tau}$$

Biophotonics@LundUniversity

LUND UNIVERSITY

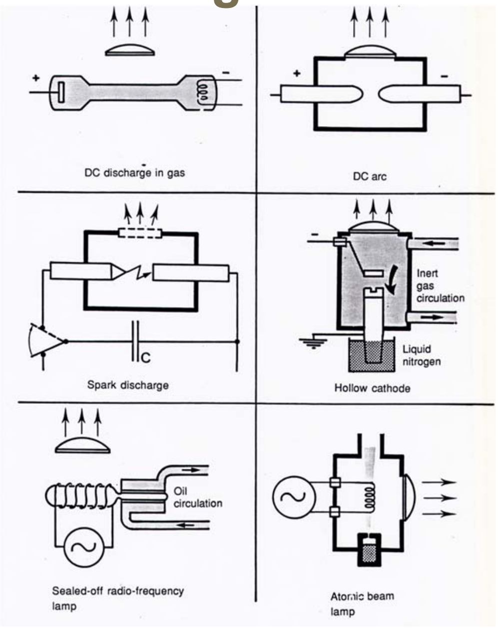
Doppler broadening



Biophotonics@LundUniversity

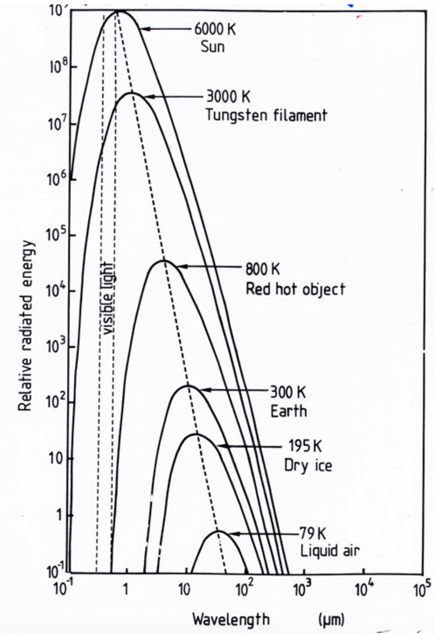
LUND UNIVERSITY

Line Light Sources



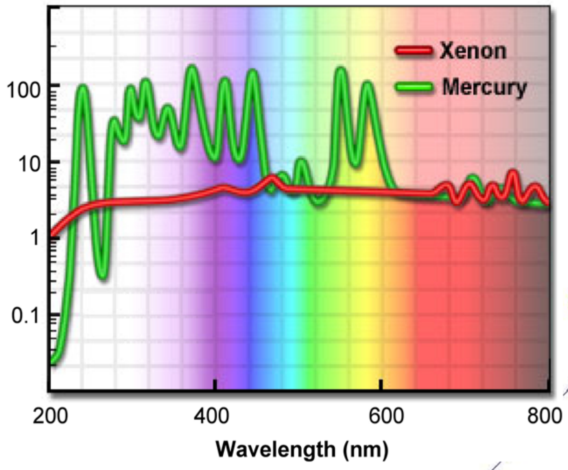
Biophotonics@LundUniversity

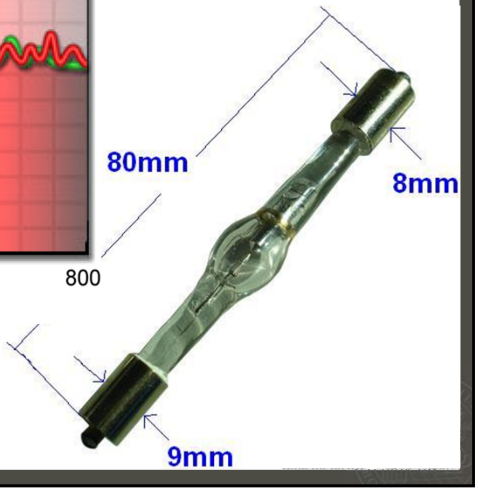
Planck radiator



Biophotonics@LundUniversity

High-pressure lamps

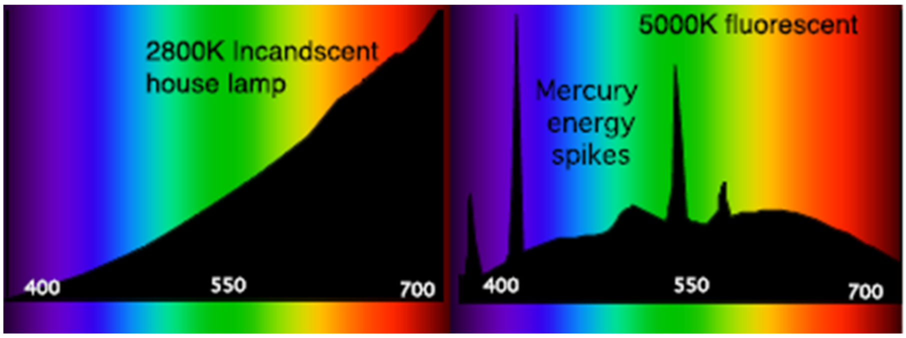




Biophotonics@LundUniversity

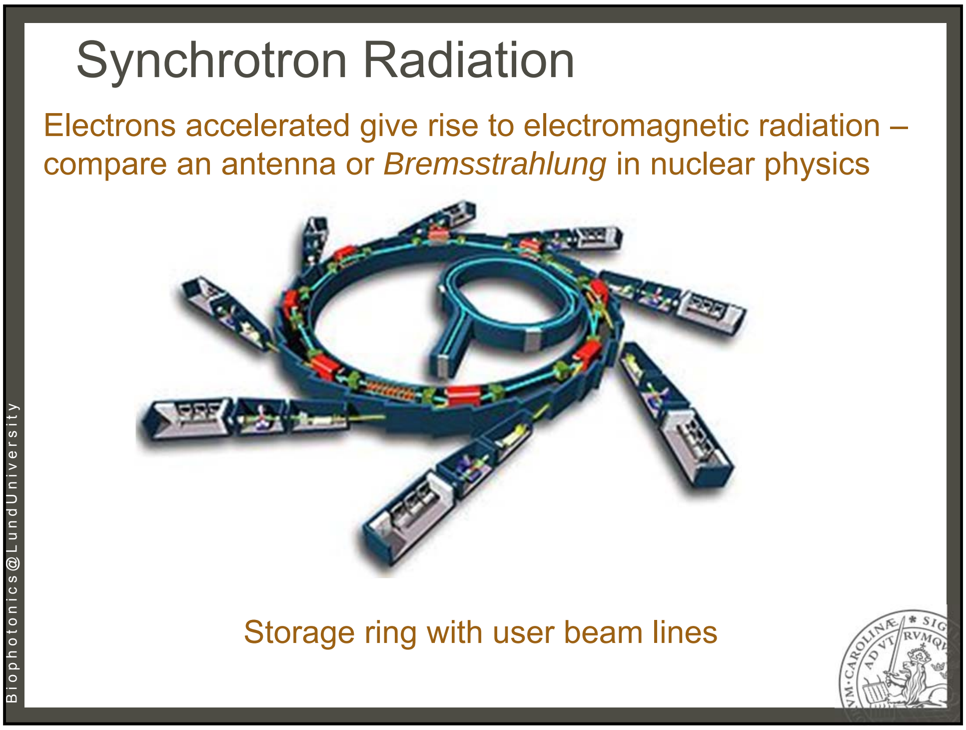
2013-10-31

Spectra of light sources



Biophotonics@LundUniversity

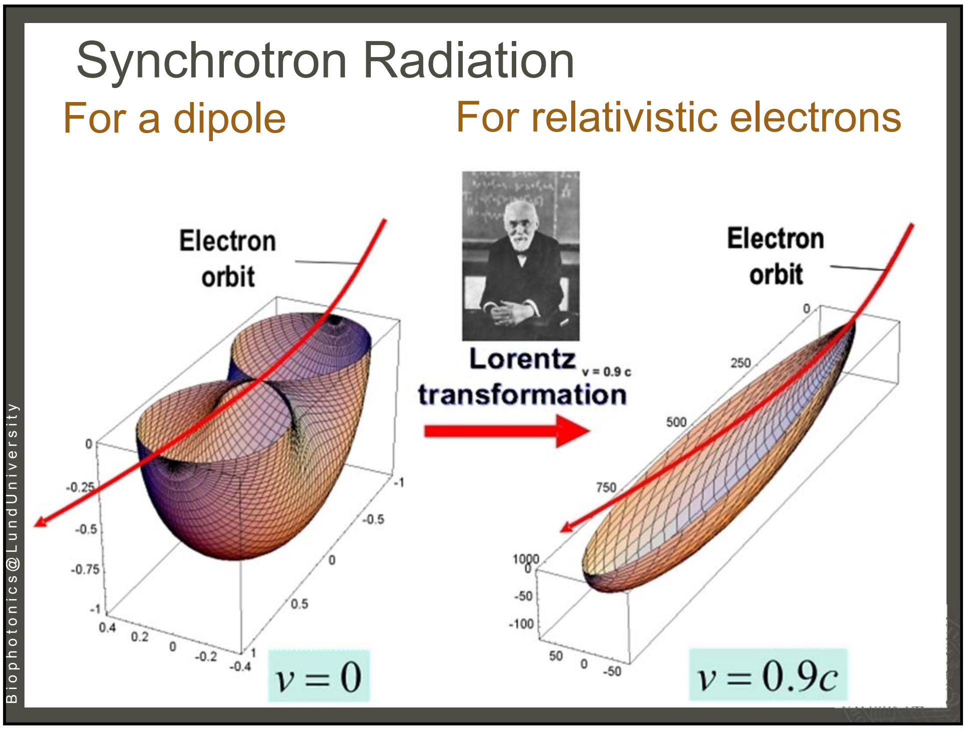
LUND UNIVERSITY



Synchrotron Radiation

Electrons accelerated give rise to electromagnetic radiation – compare an antenna or *Bremsstrahlung* in nuclear physics

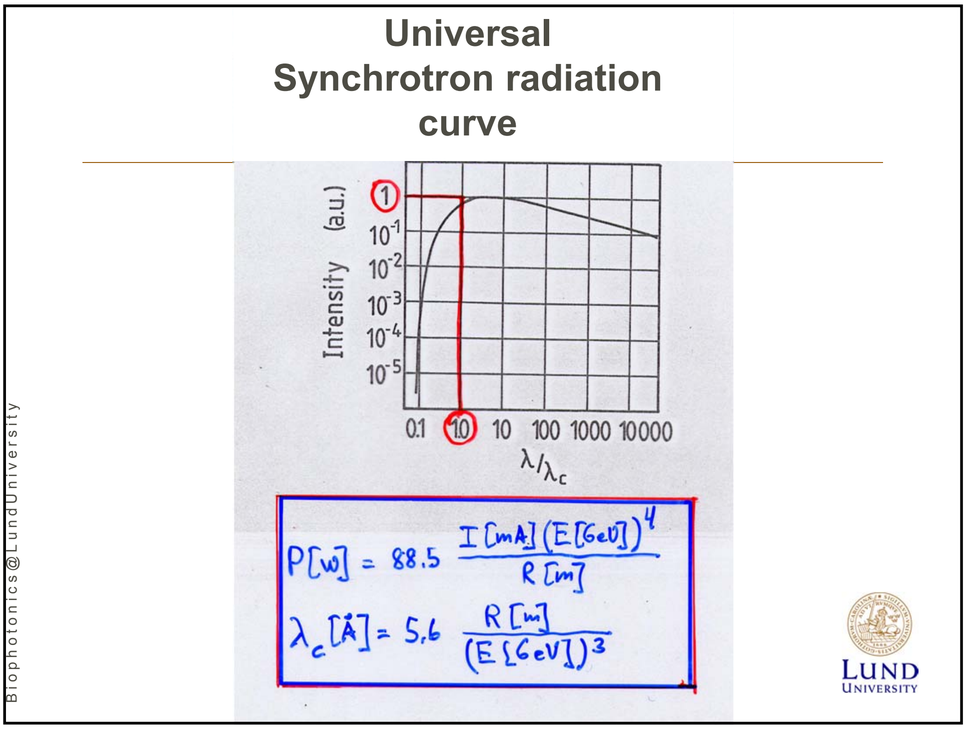
Storage ring with user beam lines



Synchrotron Radiation

For a dipole

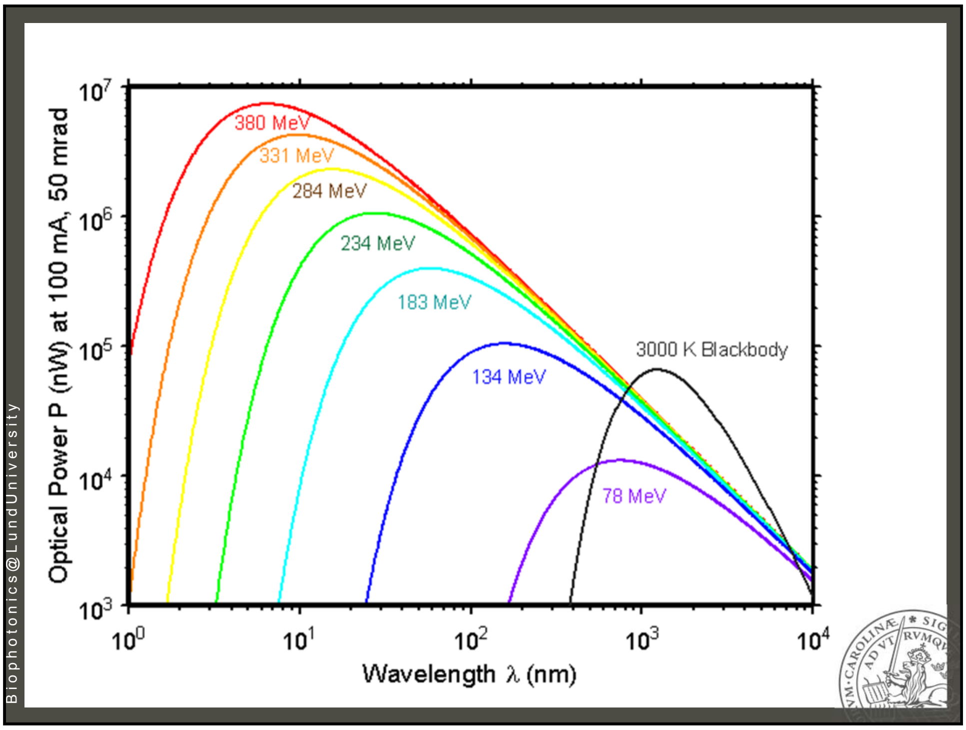
For relativistic electrons



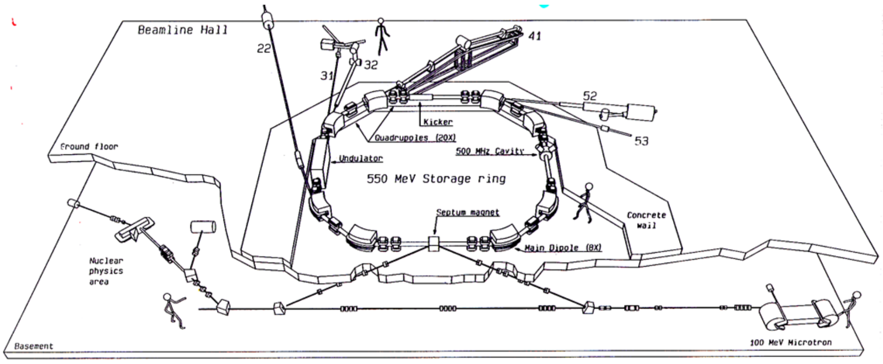
Universal Synchrotron radiation curve

$$P[W] = 88.5 \frac{I[mA]\,(E[GeV])^4}{R[m]}$$

$$\lambda_c[\text{Å}] = 5.6 \frac{R[m]}{(E[GeV])^3}$$

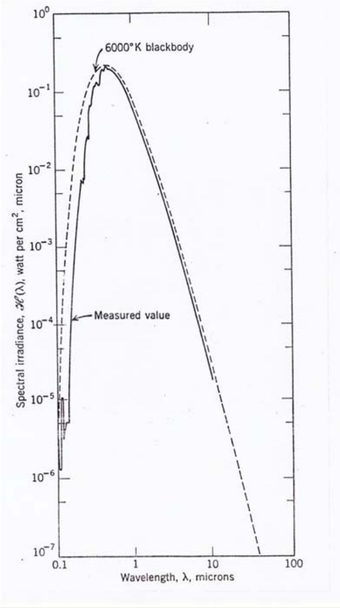


MAX-lab Synchrotron radiation storage ring, 550 MeV

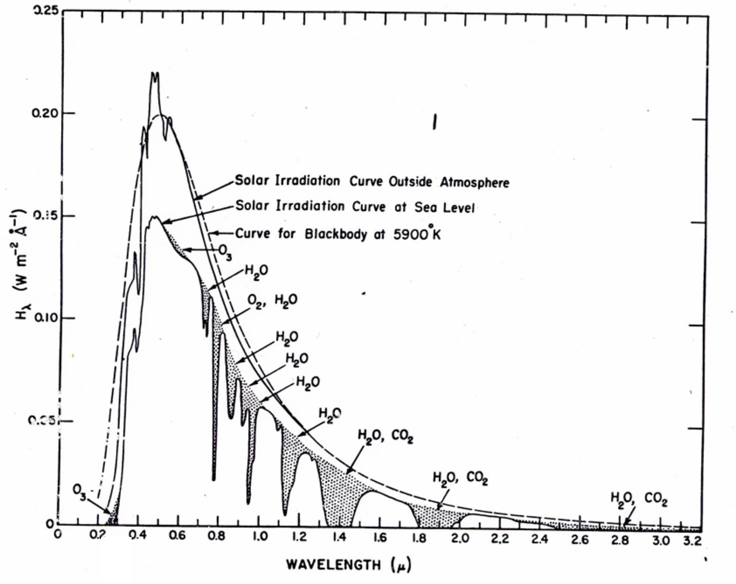


Max IV, Lund - 3GeV Ring

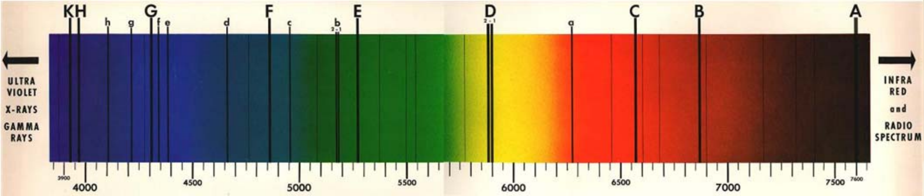
Spectral distribution of sunlight



Sun spectrum



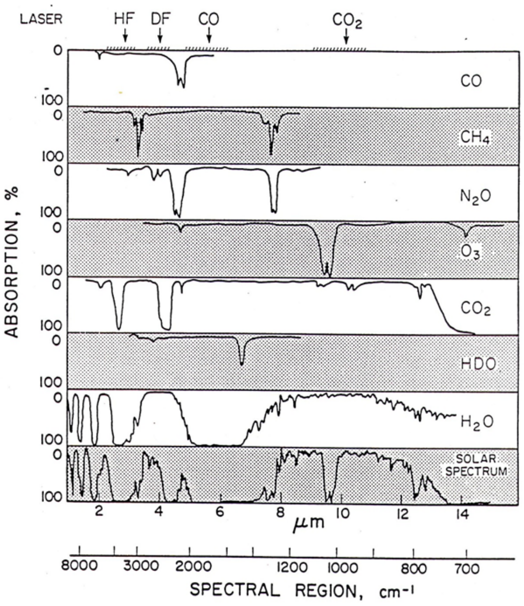
Fraunhofer-lines and corresponding absorbing substance

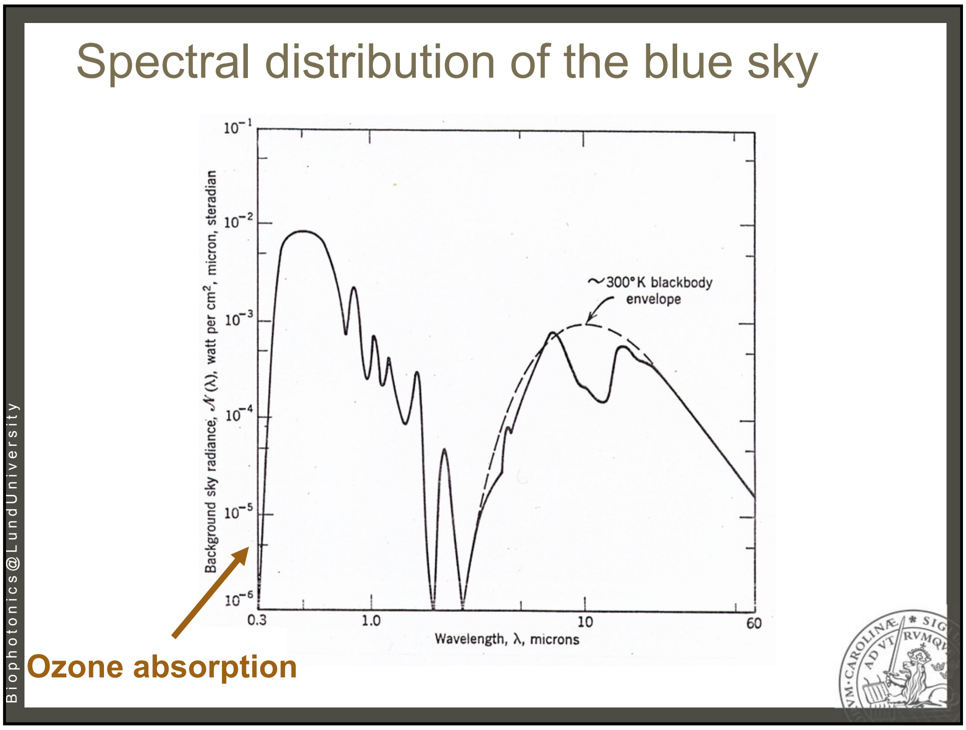


Lines	**Due To**	**Wavelengths (Å)**
A - (band)	O_2	7594 - 7621
B - (band)	O_2	6867 - 6884
C	H	6563
a - (band)	O_2	6276 - 6287
D - 1, 2	Na	5896 & 5890
E	Fe	5270
b - 1, 2	Mg	5184 & 5173
c	Fe	4958

Lines	**Due To**	**Wavelengths (Å)**
F	H	4861
d	Fe	4668
e	Fe	4384
f	H	4340
G	Fe & Ca	4308
g	Ca	4227
h	H	4102
H	Ca	3968
K	Ca	3934

Atmospheric vertical absorption and its origin

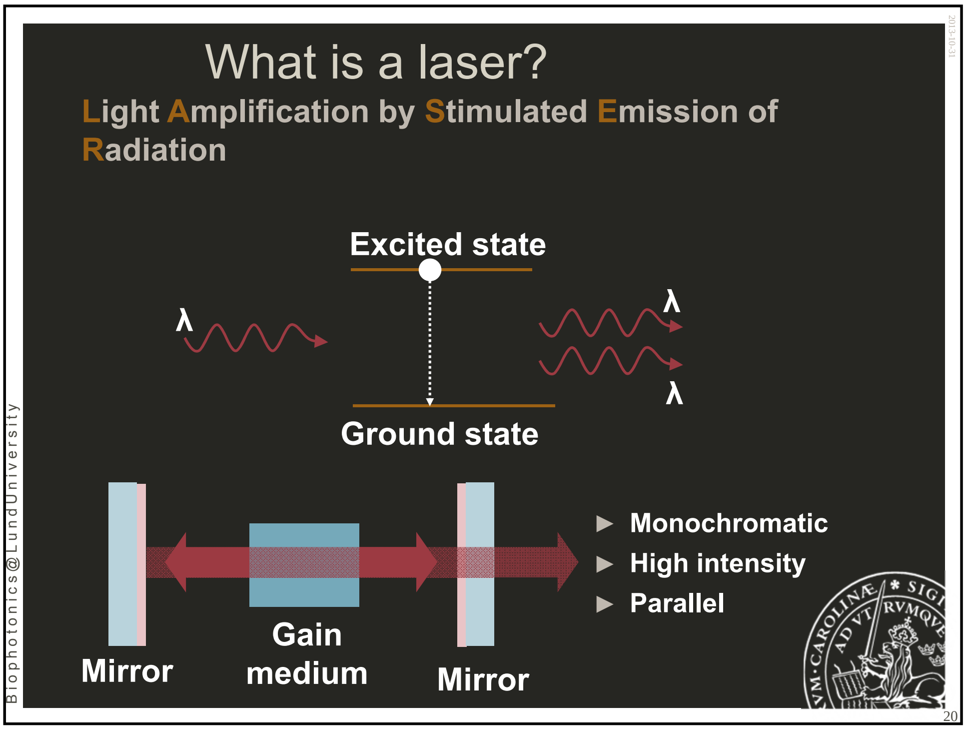




Spectral distribution of the blue sky

Ozone absorption

Biophotonics@LundUniversity



What is a laser?

Light **A**mplification by **S**timulated **E**mission of **R**adiation

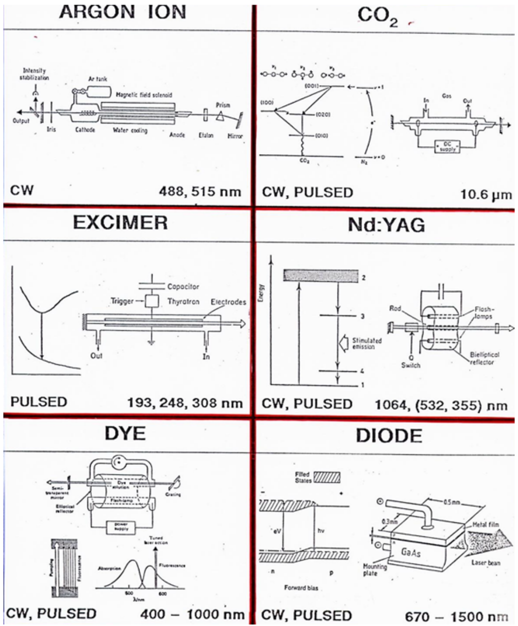
- Monochromatic
- High intensity
- Parallel

Biophotonics@LundUniversity

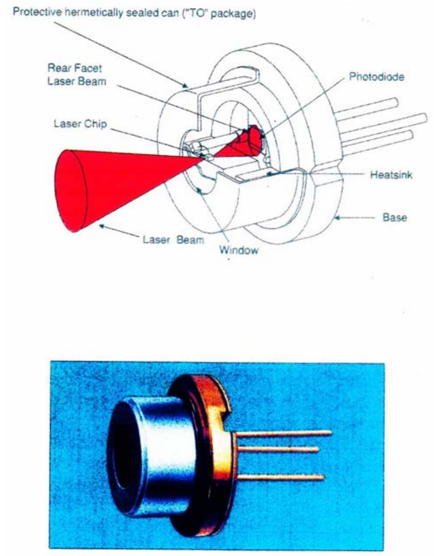
2013-10-31

20

Different lasers

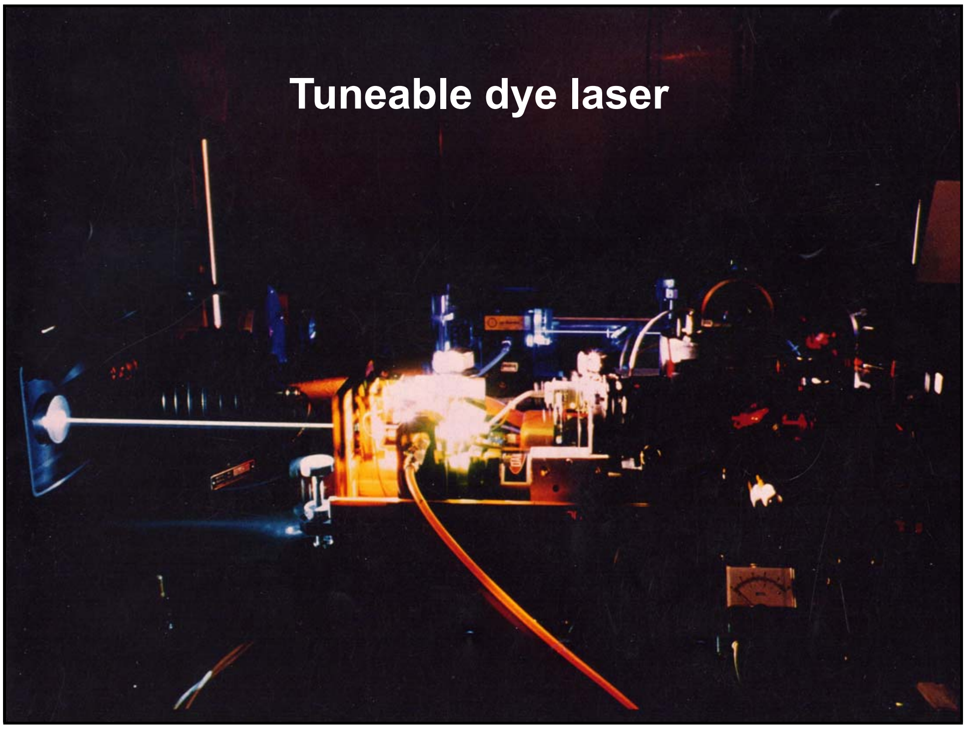


Laser Diodes

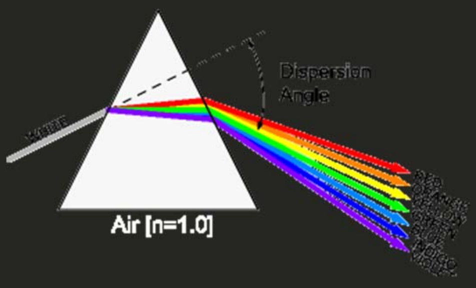


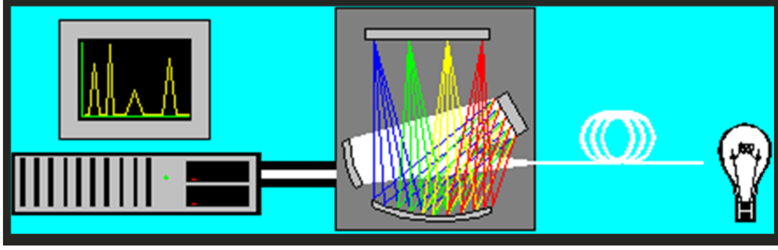
A typical compact disc style laser diode.

Tuneable dye laser



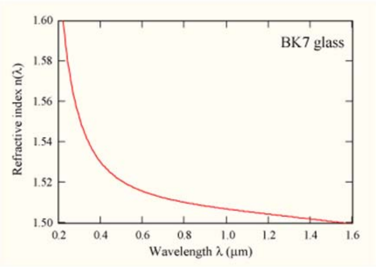
Light Dispersion

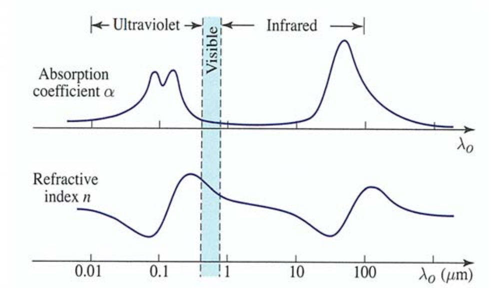




Biophotonics@LundUniversity

The Prism Spectrometer





$$n^2 \approx 1 + \sum_i \chi_{0i}\frac{\nu_i^2}{\nu_i^2-\nu^2} = 1 + \sum_i \chi_{0i}\frac{\lambda^2}{\lambda^2-\lambda_i^2}$$

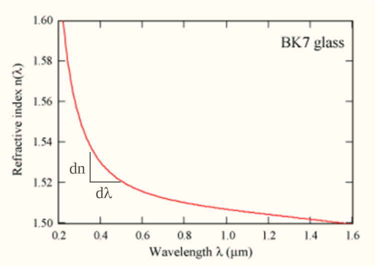
Fused silica

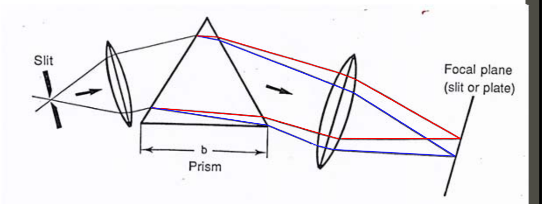
$$n^2 = 1 + \frac{0.6962\lambda^2}{\lambda^2-(0.06840)^2} + \frac{0.4079\lambda^2}{\lambda^2-(0.1162)^2} + \frac{0.8975\lambda^2}{\lambda^2-(9.8962)^2}$$

Biophotonics@LundUniversity

W. Sellmeier, Annalen der Physik und Chemie 143, 271 (1871)

The Prism Spectrometer



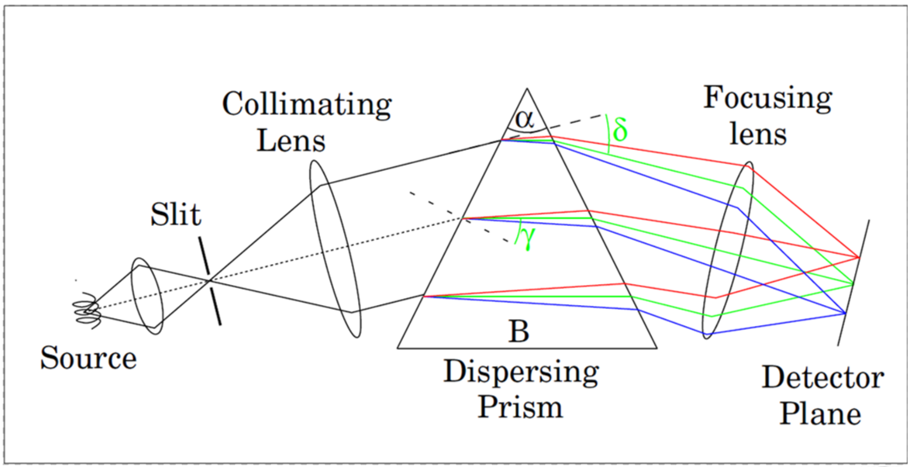


$$\mathcal{R} = \frac{\lambda}{\delta\lambda} = b\frac{dn}{d\lambda}$$

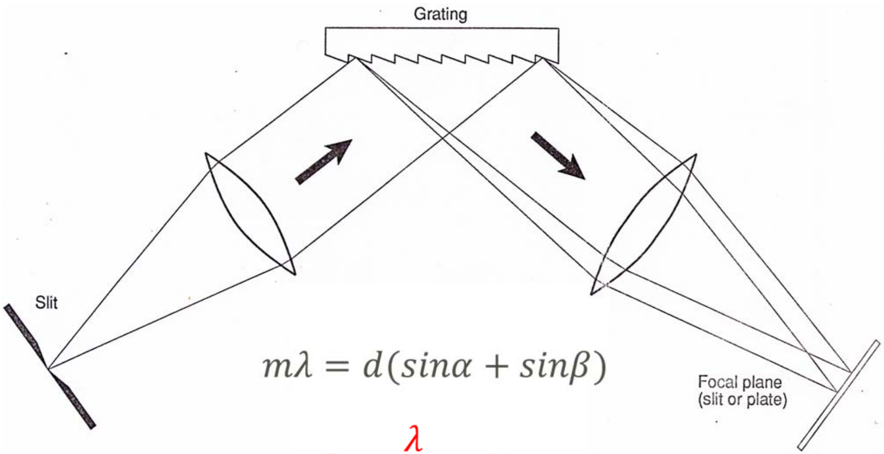
Biophotonics@LundUniversity

W. Sellmeier, Annalen der Physik und Chemie 143, 271 (1871)

The Prism Spectrometer

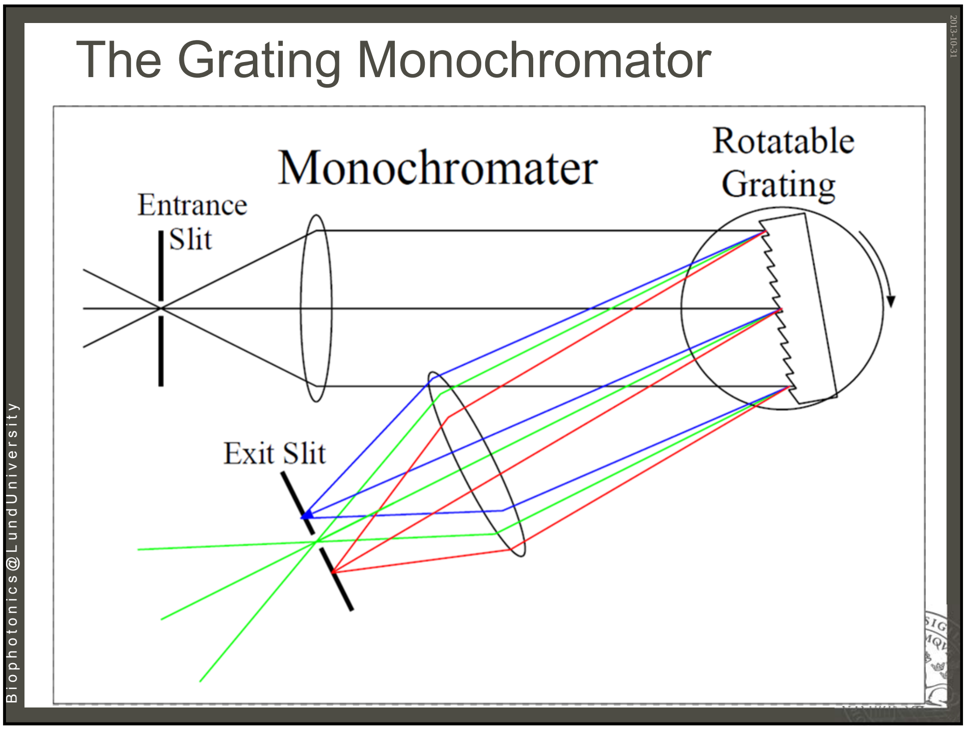


Grating spectrometer

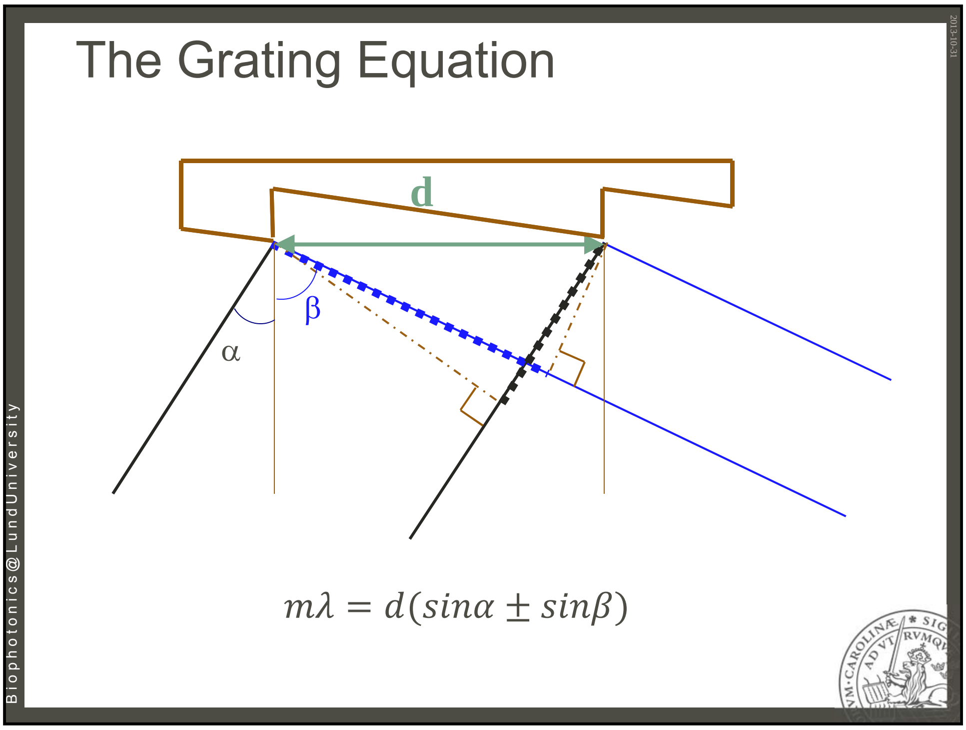


$$m\lambda = d(\sin\alpha + \sin\beta)$$

$$\mathcal{R} = \frac{\lambda}{\delta\lambda} = N \cdot m$$



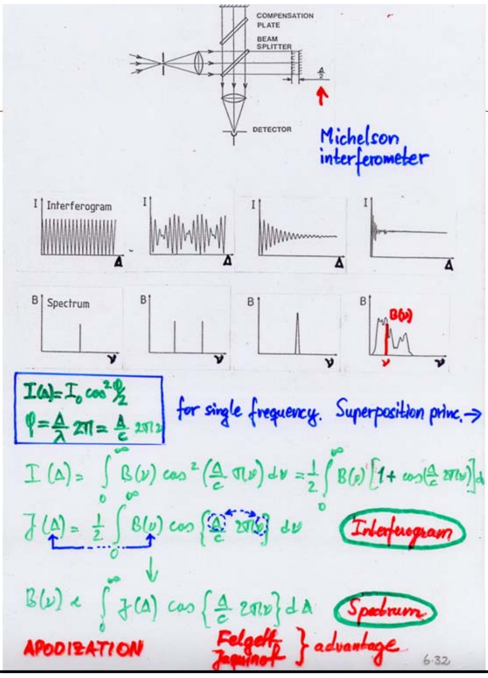
The Grating Monochromator



The Grating Equation

$$m\lambda = d(sin\alpha \pm sin\beta)$$

Fourier transform spectrometer



$$I(\Delta) = I_0 \cos^2 \frac{\varphi}{2}$$
$$\varphi = \frac{\Delta}{\lambda} 2\pi = \frac{\Delta}{c} 2\pi\nu$$

for single frequency. Superposition princ. →

$$I(\Delta) = \int_0^\infty B(\nu) \cos^2\left(\frac{\Delta}{c}\pi\nu\right) d\nu = \frac{1}{2}\int_0^\infty B(\nu)\left[1+\cos\left(\frac{\Delta}{c}2\pi\nu\right)\right] d\nu$$

$$J(\Delta) = \frac{1}{2}\int_0^\infty B(\nu) \cos\left\{\frac{\Delta}{c} 2\pi\nu\right\} d\nu$$ Interferogram

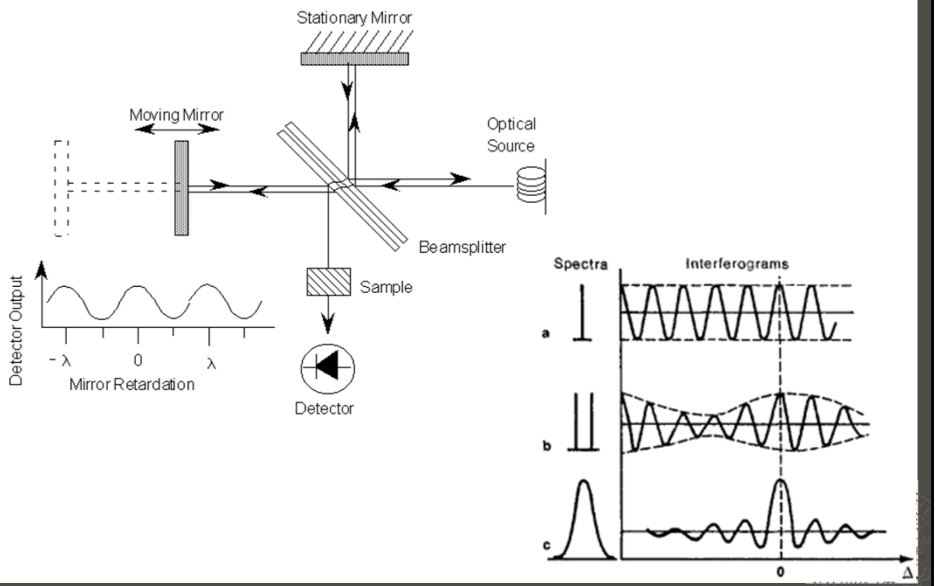
$$B(\nu) \propto \int_0^\infty J(\Delta) \cos\left\{\frac{\Delta}{c} 2\pi\nu\right\} d\Delta$$ Spectrum

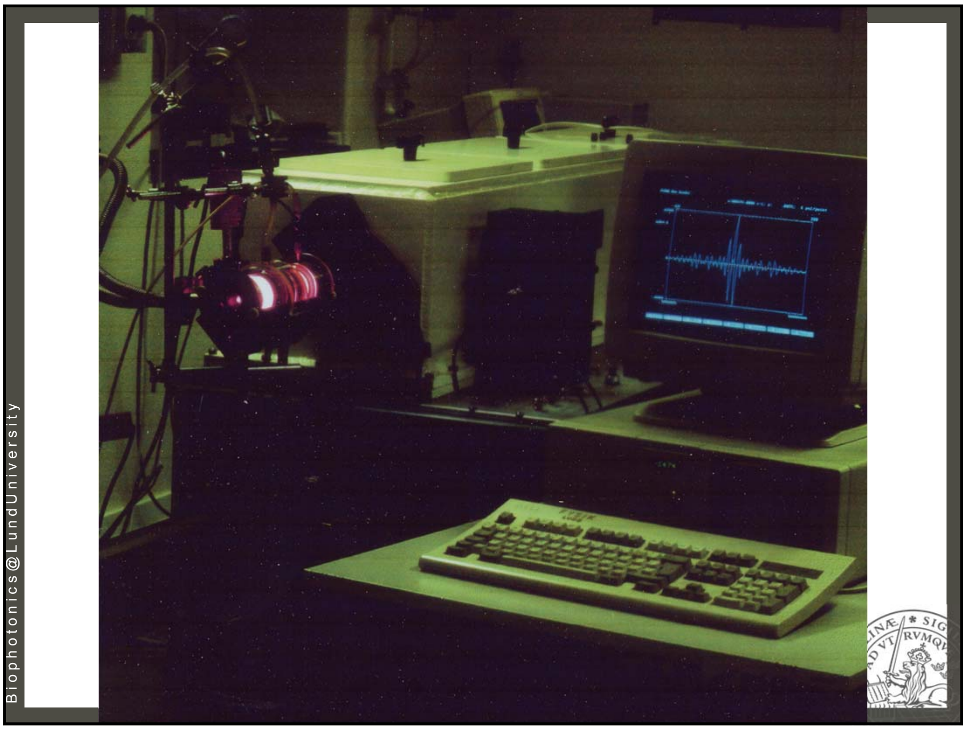
APODIZATION

Felgett
Jaquinot } advantage

6.32

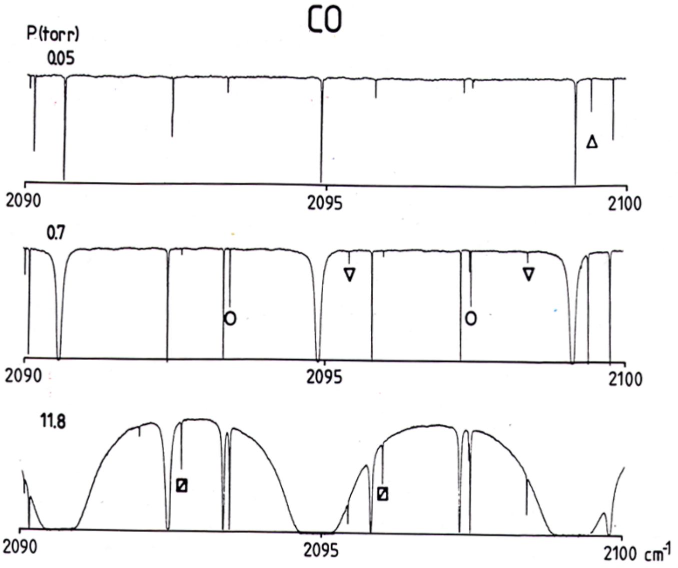
FTIR





Biophotonics@LundUniversity

The Fourier Transform Spectrum



Photographic films

Emulsion deposited on plastic or glass
- microscopic crystals of *silver halide* in gelatin AgCl; AgBr and AgI

When exposed to light, latent image forms
- silver ions reduced to metallic silver

Developer is a reducing agent e.g. quinol
- reduces ions to metal
  - preferentially where granule contains nucleus of metallic silver
- $2Ag^+ + C_6H_4(OH)_2$

$= 2Ag + C_6H_4O_2 + 2H^+$

Film

Dark parts are where light has fallen

  Negative

Fixing film dissolves silver halide

$$Ag^+ + S_2O_3^{2-} = AgS_2O_3^-$$

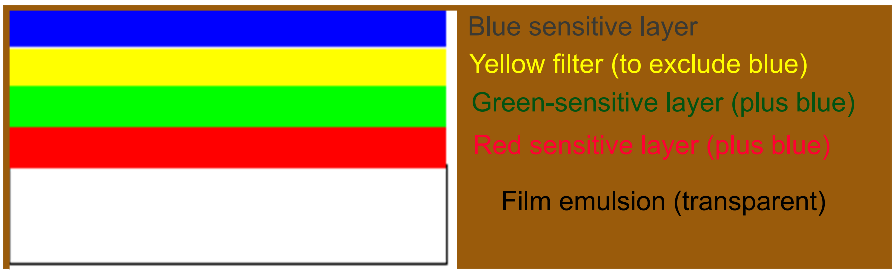
Positive print

  shine light through negative onto paper coated with silver halide.

  Developed & fixed

as for film

Colour film

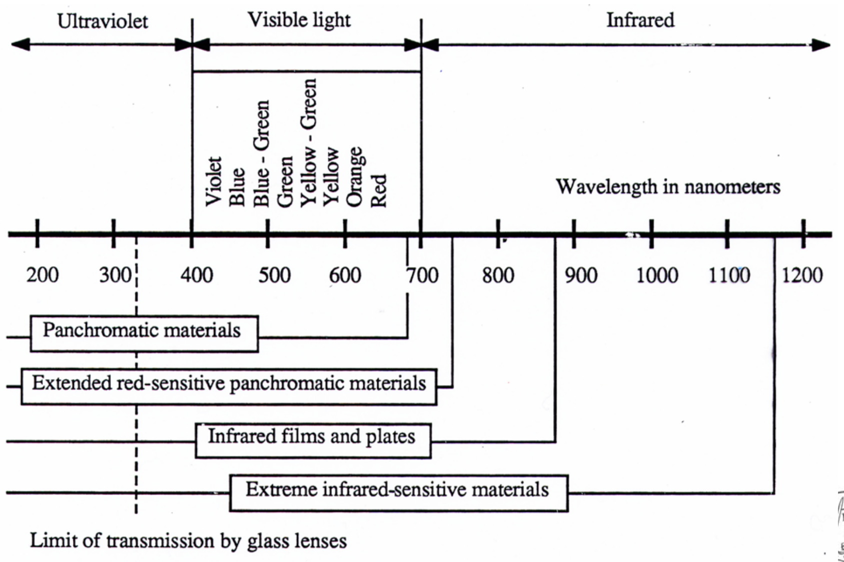


Colour films use 3 layers of silver halide

  layers sensitised with different colour dye

  layers separated by colour filters

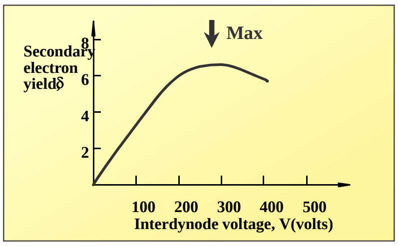
Photographic films

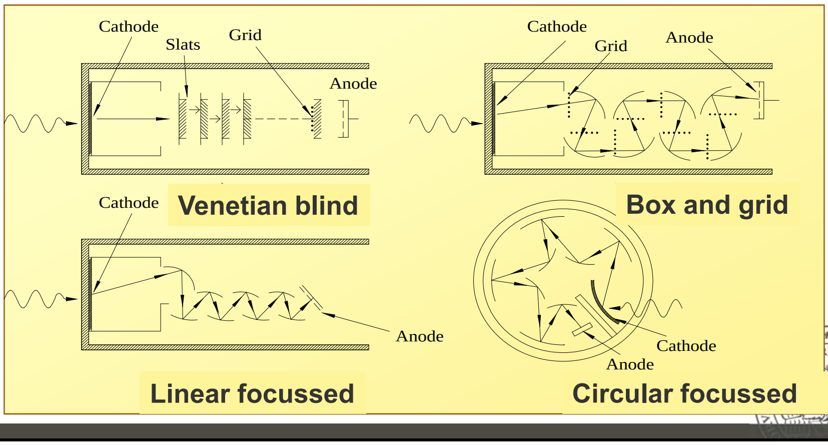


PMT types

Photocathode
Na_2KSbCs
AgOCs

Dynode
For electron multiplications
CsSb





CCD Cameras

Light focused onto CCD chip

Each capacitor results in one *pixel*

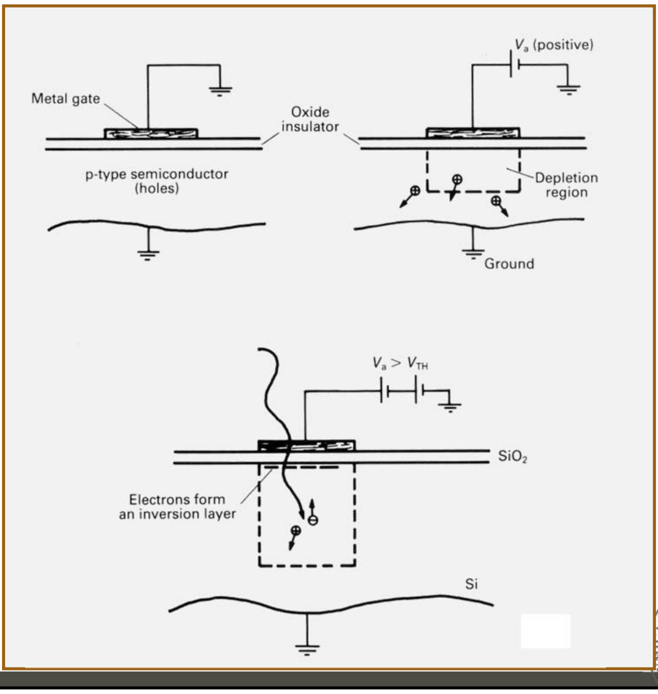
- a pixel is a picture element with no internal detail

Number of pixels on the chip determines resolution of camera

- Commonly 3-5 Megapixels
- up to 13 Mpixels

Biophotonics@LundUniversity

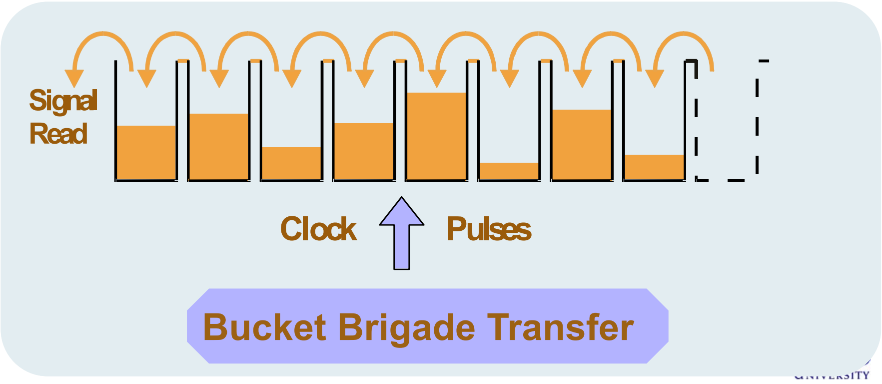
CCD



Biophotonics@LundUniversity

Readout of a CCD

Charge moved though chip by ***bucket brigade transfer*** charge on final capacitor is read off



Signal Read

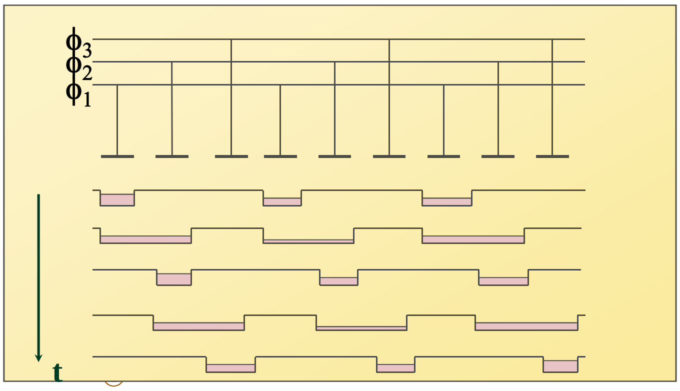
Clock **Pulses**

Bucket Brigade Transfer

Biophotonics@LundUniversity

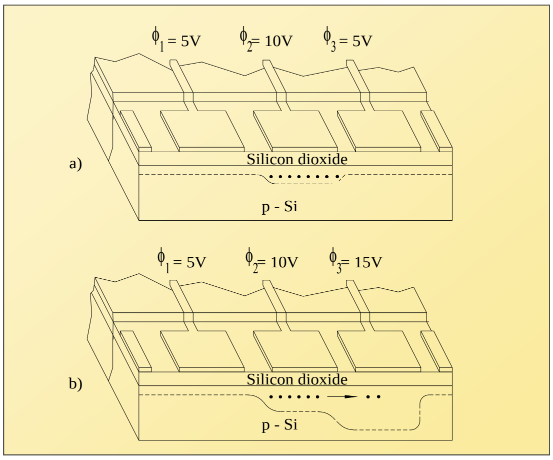
CCD camera readout

Schematic potential well diagram for transport of photo-charges along one direction in the CCD-chip



Biophotonics@LundUniversity

CCD - Charge Coupled Device



The information is read out by stepwise transferring by manipulating the potential wells.

Biophotonics@LundUniversity

CMOS Cameras

Recently, CMOS's have become more used in cheap cameras instead of CCD's

CMOS stands for Complementary Metal Oxide Semiconductor.

Each pixel has a circuit on the chip to convert the charge to a voltage. The camera often also include an analogue-to-digital converter.

Biophotonics@LundUniversity

Applications of CMOS cameras

Advantages
- Compact
- Cheap
- Low power
- Fast readout
- Plug & Play

Disadvantages
- Nonuniform
- Dark areas

Biophotonics@LundUniversity

LUND UNIVERSITY

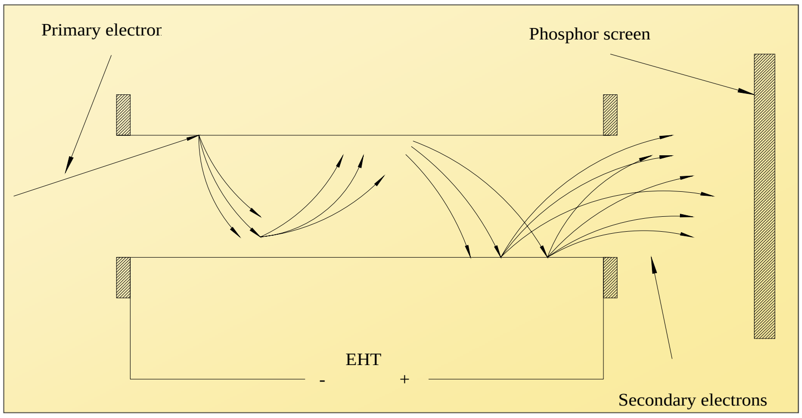
Infrared array detectors

InGaAs arrays are required for spectral analysis in the near to middle infrared (0.9 - 2.6 μ m). High performance multi-channel detectors for this spectral region are a **recent development**. The vast majority of detectors sold today are based on silicon technology which only operates on the shorter wavelength side of the NIR region (< 1.1 μ m).

Biophotonics@LundUniversity

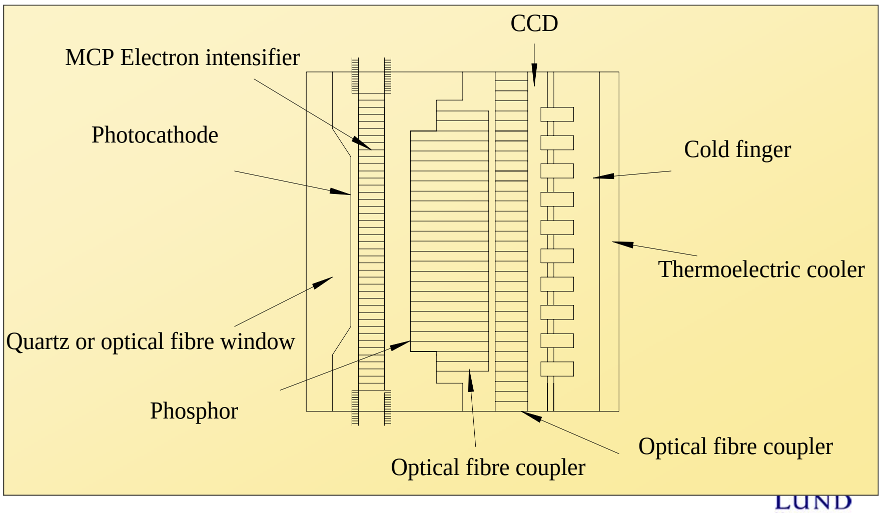
LUND UNIVERSITY

Micro-channel plate image intensifier



LUND UNIVERSITY

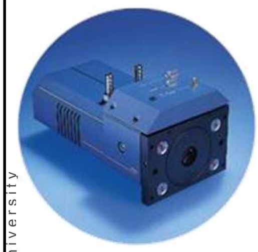
MCP



LUND UNIVERSITY

Image Intensified CCD Cameras

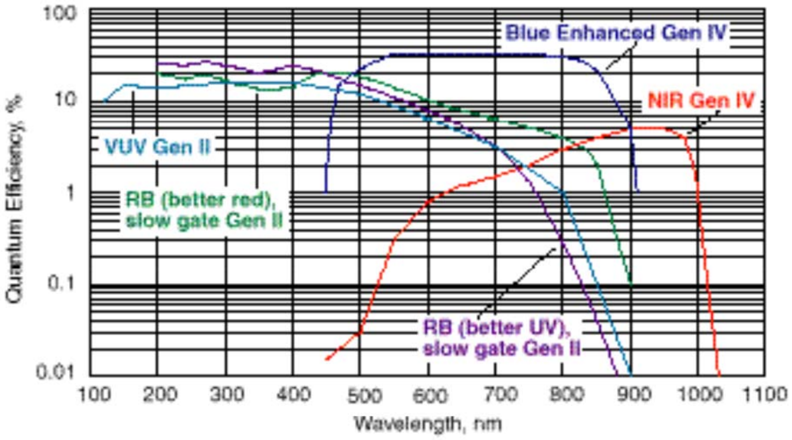
The features of the new ICCD range include:



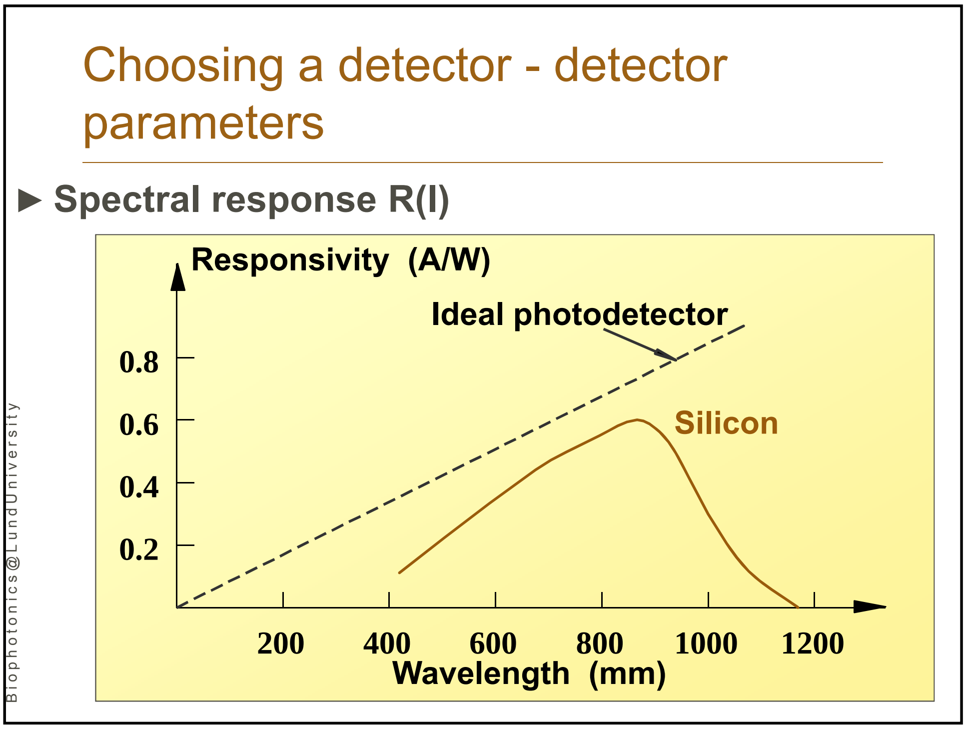
- Single photon sensitivity
- 15 bit dynamic range in a single scan
- Gating withs in the order of ns (ps with special image intensifiers)
- Compact head and controller
- A wide selection of photocathode options
- Easy interfacing to delay generators and lasers
- Modern sealed design - no nitrogen flush
- Thermoelectric air-cooled convenience

Biophotonics@LundUniversity

Spectral response of ICCDs

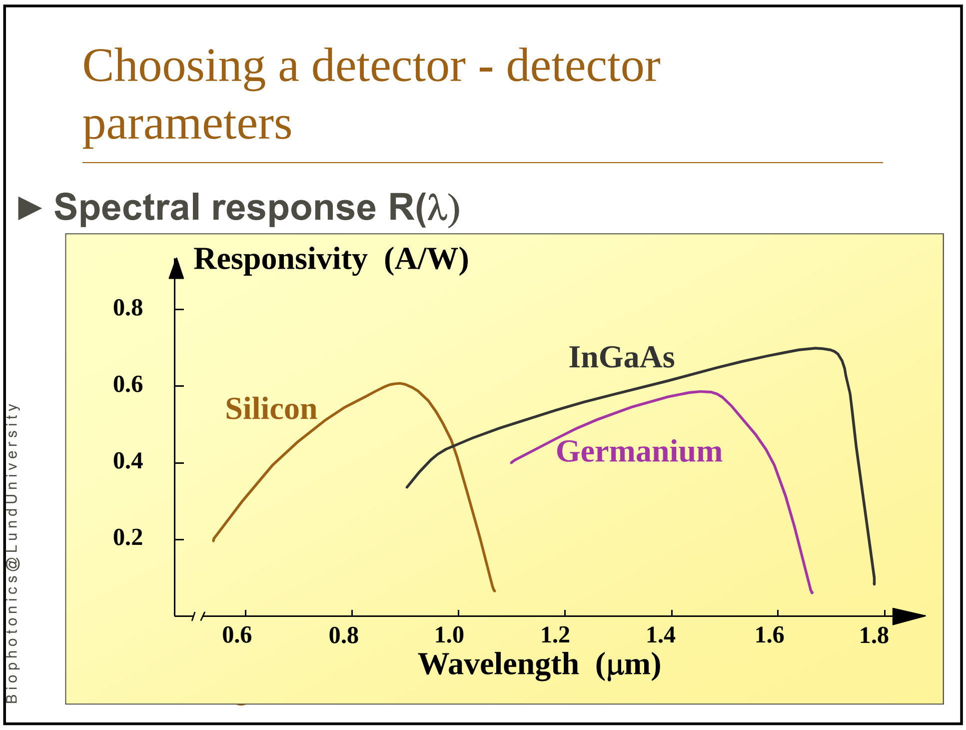


Biophotonics@LundUniversity



Choosing a detector - detector parameters

- Spectral response R(l)



Choosing a detector - detector parameters

- Spectral response R(λ)

Choosing a detector - detector parameters

- ▶ **Spectral response R(λ)**
- **Sensitivity S(λ) = signal/optical power [V/W] or [A/W]**
- **Signal-to-noise = S/N = Vsignal/Vnoise**

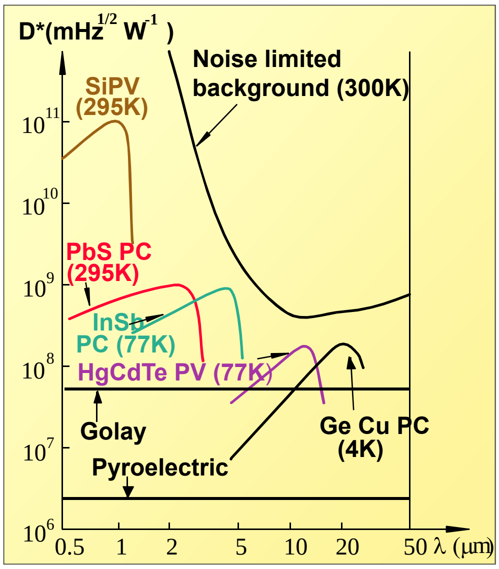
NEP = Noise Equivalent Power ==> if P = NEP then S/N = 1

$\mathrm{NEP}^* = \mathrm{NEP}/\sqrt{\mathrm{A}\cdot\Delta\mathrm{f}}$ **Normalized NEP**

$\mathrm{D}^* = 1/\mathrm{NEP}^*$ **Specific detectivity** $\left[\mathrm{m}\sqrt{\mathrm{Hz}}/\mathrm{W}\right]$

LUND UNIVERSITY

Example



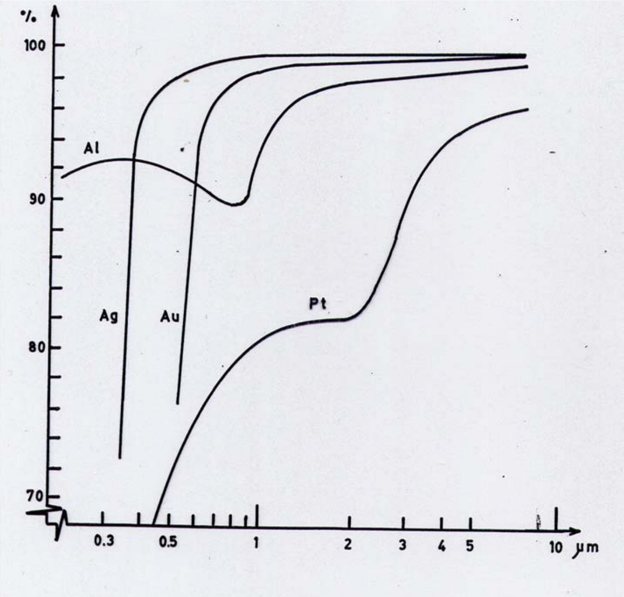
Calculate the minimum detectable signal at l = 4 mm. Choose an InSb detector. Size 100 mm², bandwith 1 kHz

$$D^* = \frac{1}{NEP^*} = \frac{\sqrt{A\Delta f}}{NEP} \Rightarrow$$

$$NEP = \frac{\sqrt{A\Delta f}}{D^*} =$$

$$\frac{\sqrt{100\cdot 10^{-6}\cdot 1000}}{10^9} = 3\cdot 10^{-10} W$$

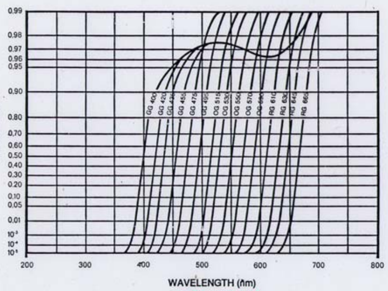
Metal mirrors



Biophotonics@LundUniversity

LUND
UNIVERSITY

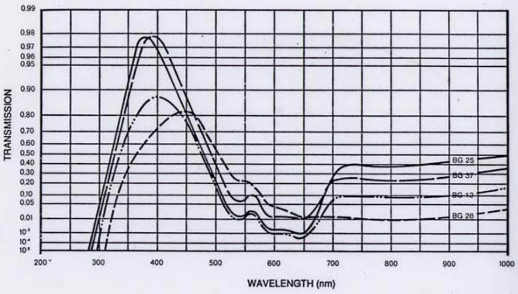
Coloured glass filters



$\leftarrow x$

CdS_xSe_{1-x}

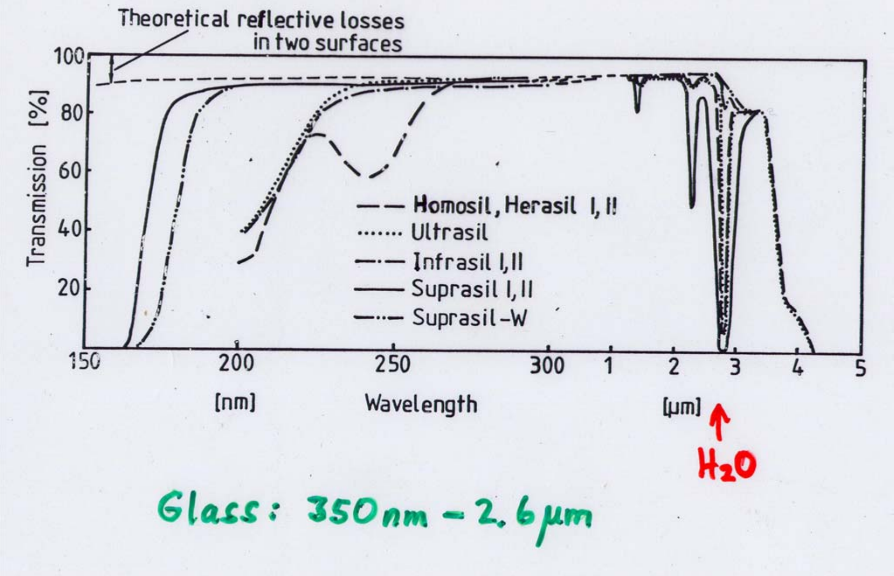
100 Å
diameter



Bi

UNIVERSITY

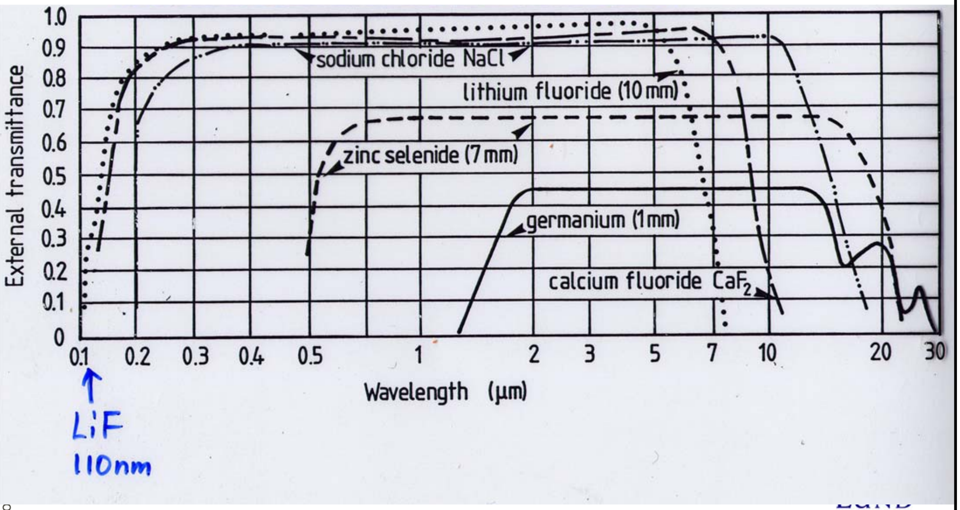
Quartz transmission



H_2O

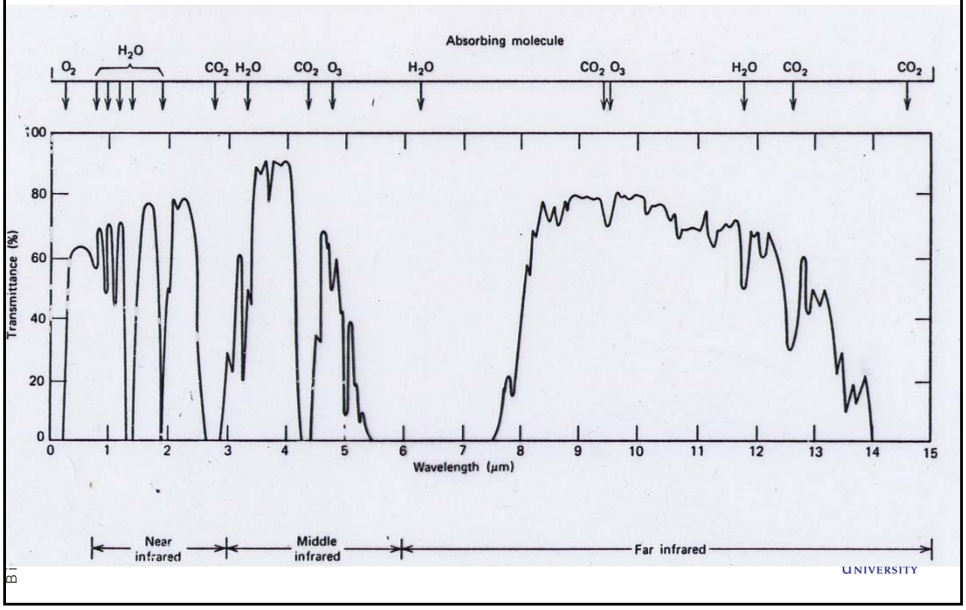
Glass: 350nm – 2.6µm

Optical material transmission

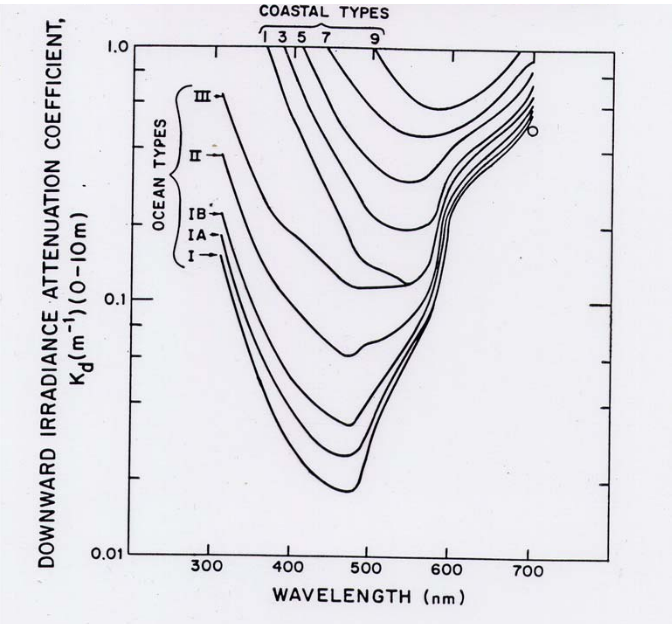


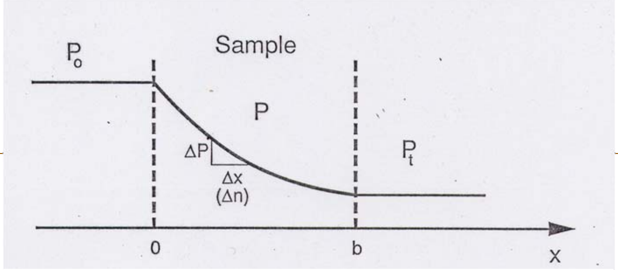
LiF
110nm

Atmospheric horizontal transmission



Water absorption





The Beer-Lambert law

$$\ln \frac{P_o}{P_t} = k_1 \cdot b \cdot c$$

$$A = \log_{10} \frac{P_o}{P_t} = 0.434 \ln \frac{P_o}{P_t}$$

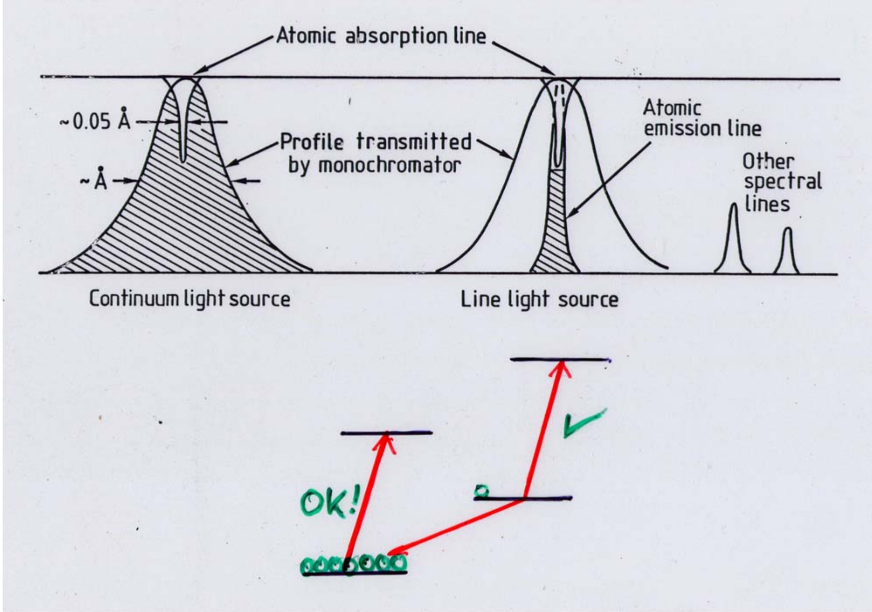
$$\boxed{A \propto c}$$

$$T = \frac{P_t}{P_o}$$

Biophotonics@LundUniversity

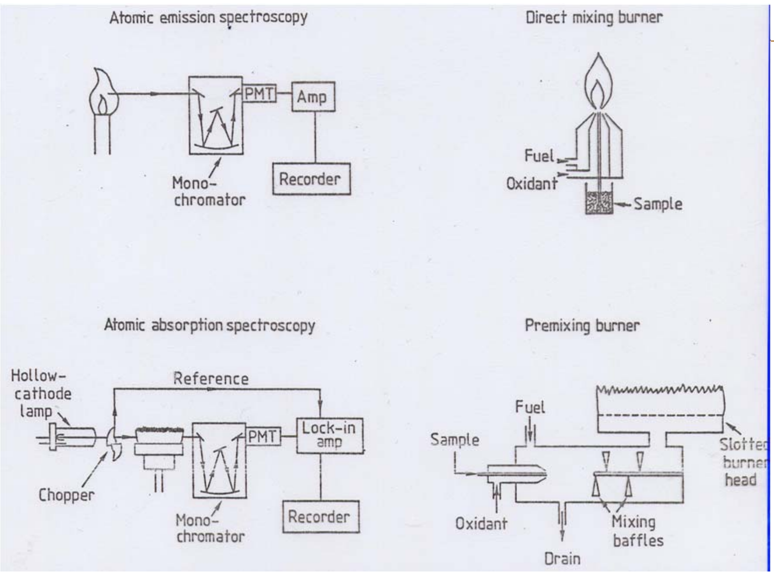
LUND UNIVERSITY

Atomic absorption spectroscopy

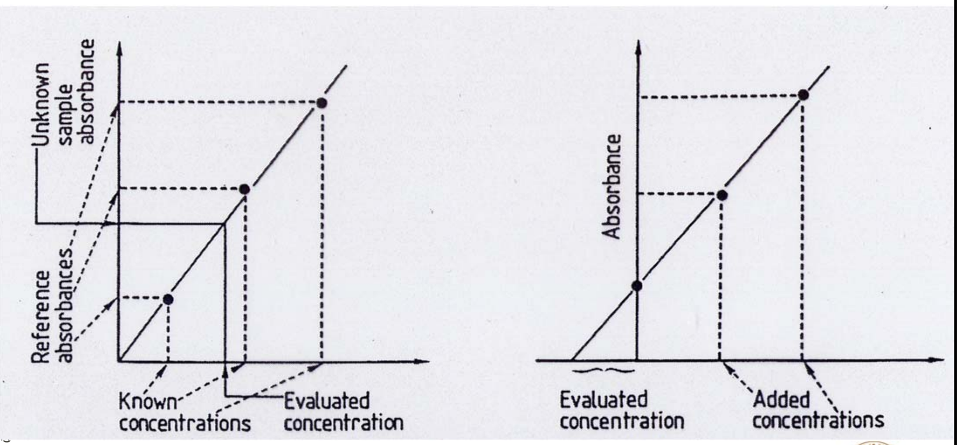


Biophotonics@LundUniversity

Analytical flame spectroscopy



Analytical calibration



Standard solutions **Standard addition**