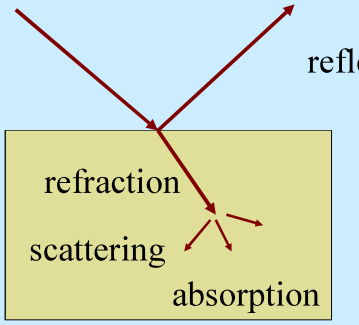
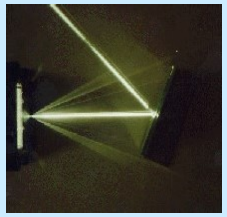
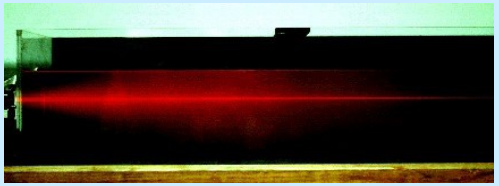
Interaction of light with matter
1.

Interaction of light with matter

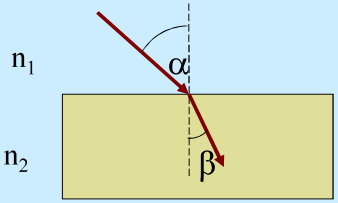






Refraction of light

Fermat's Principle: Light follows the path of least time



$n_1 < n_2$

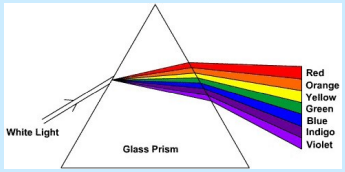
$\alpha > \beta$

Snell's Law

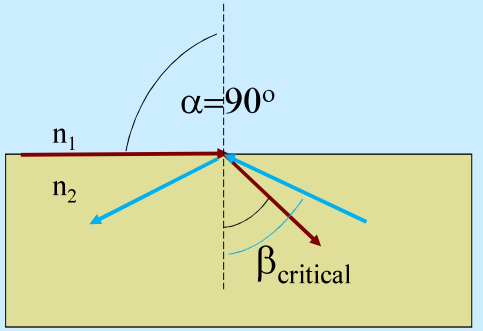
$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

The index of refraction

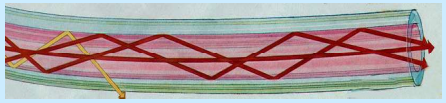
Dispersion of light



Critical angle – total internal reflection



$\beta > \beta_{critical}$

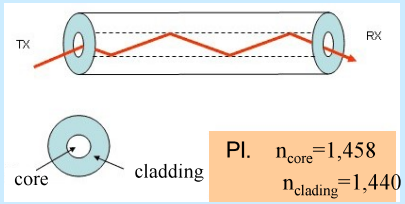


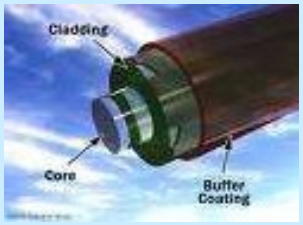
Medical application

Determination of concentration – refractometry

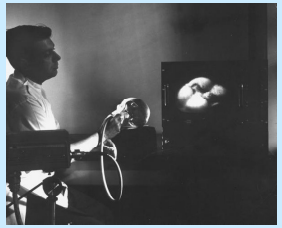
Concentration of solutions is proportional
with their index of refraction .

Optical fibers

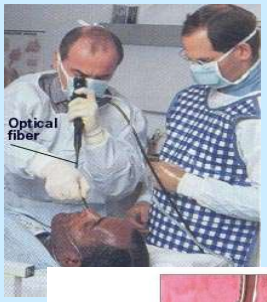


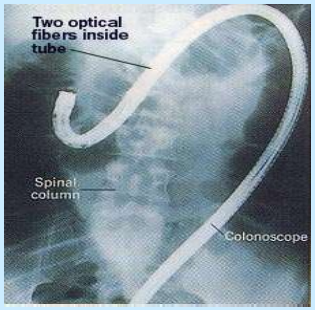


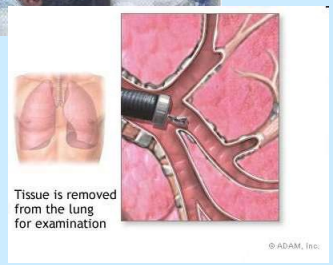
Application in dentistry



Other medical applications





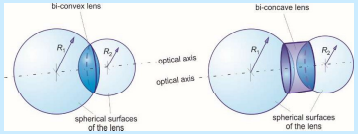


Bronchoscopy

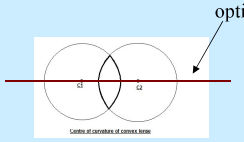
Colonoscopy

Image formation occurs, when light rays emerging from one point converge at another point.

Image formation by thin lenses – Geometrical optics



Optical lenses and their interpretation by spherical surfaces



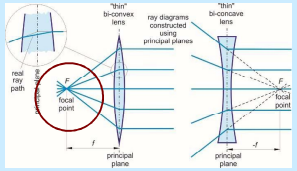
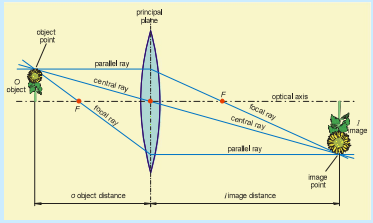
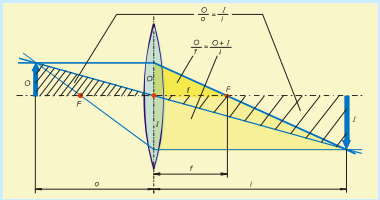


Image formation occurs, when light rays emerging from one point converge at another point.

Image construction by principal rays





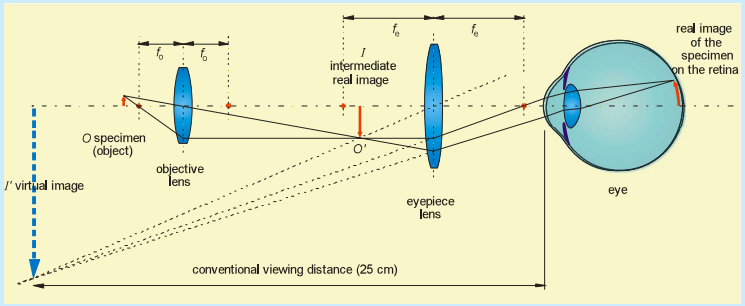
$$M = \frac{I}{O} = \frac{i}{o}$$

$$D = \frac{1}{f} = \frac{1}{o} + \frac{1}{i} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$$

lensmaker's formula.

D - diopter: measure of the optical power of a lens, which is equal to the reciprocal of the focal length measured in meters

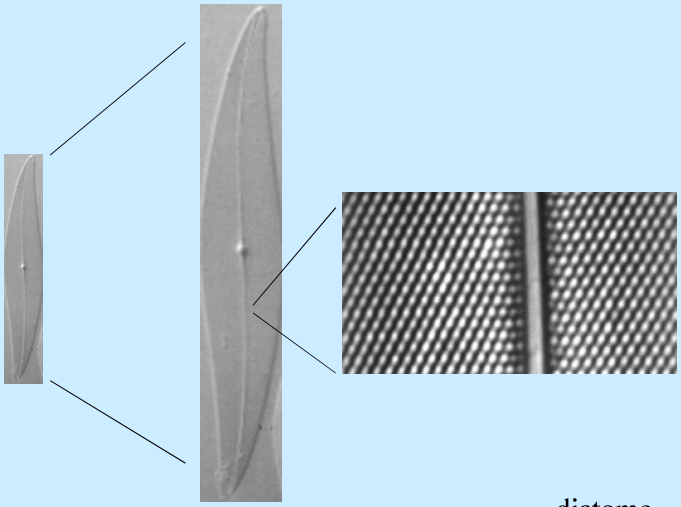
Image formation – **compound microscope**



The image is magnified
reversed
virtual

Magnification vs Resolution

Magnification vs Resolution

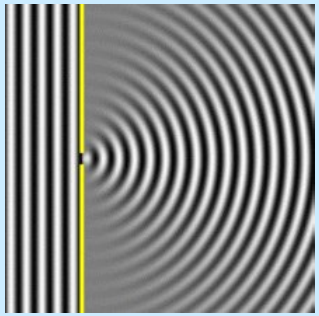


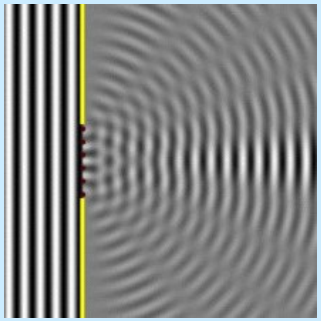
diatome

Limited resolution of microscopy

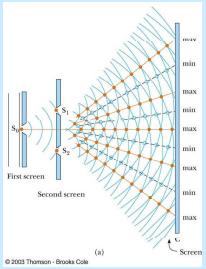
Wave nature of light

Huygens-principle





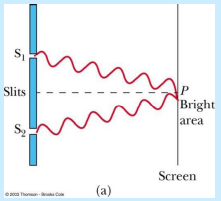
Young experiment

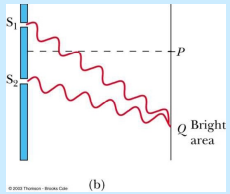


Where are the bright areas?

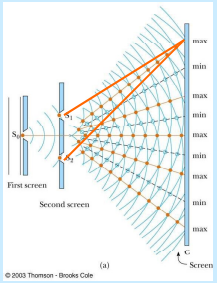
Constructive interference

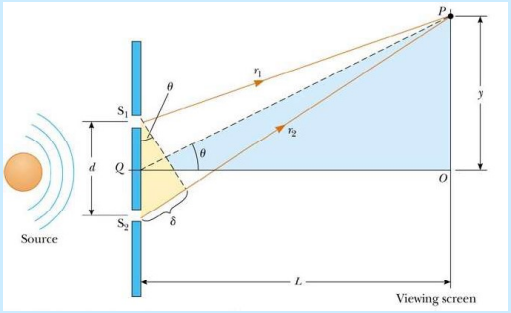
If the distences from the slits
- are equal
or
- their difference is equal n *λ





Young experiment

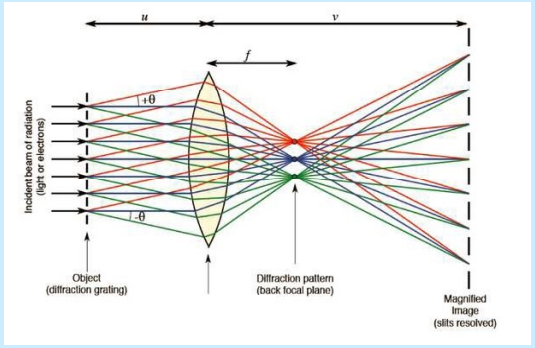




$$\delta = d \cdot \sin\Theta = k \cdot \lambda$$

$$d = \frac{\lambda}{n \sin\Theta}$$

Diffraction pattern in the microscope



$$d = 0{,}61\frac{\lambda}{n \sin\Theta}$$

ABBE'S PRINCIPLE: An optical system can resolve only those details of the specimen, which diffract light rays in a way that **besides the principal maximum at least the first order diffraction rays** are allowed to contribute to the image formation.

To decrease the limit of resolution – shorter wavelength – ¿matter wave?

Electron microscope

$\lambda = h / mv$

$v = \sqrt{\frac{2eU}{m_e}}$

U : 10 – 100 kV

λ ~ 2 pm

Limit of resolution

Light microscope

λ ~ 400 pm

Electron microscope

λ ~ 2 pm

$d = 0{,}61\frac{\lambda}{n \sin\Theta} \Longrightarrow d = \lambda / NA$

NA ~ 2

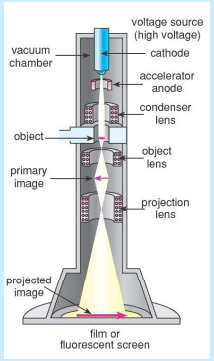
NA ~ 10^{-3}

Limit of resolution ~ **200 nm**

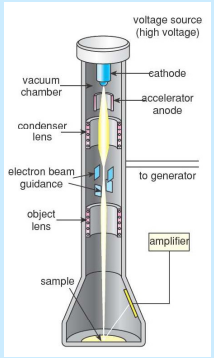
Limit of resolutiom ~ **0,2 - 0,5 nm**

Structure of electron microscopes

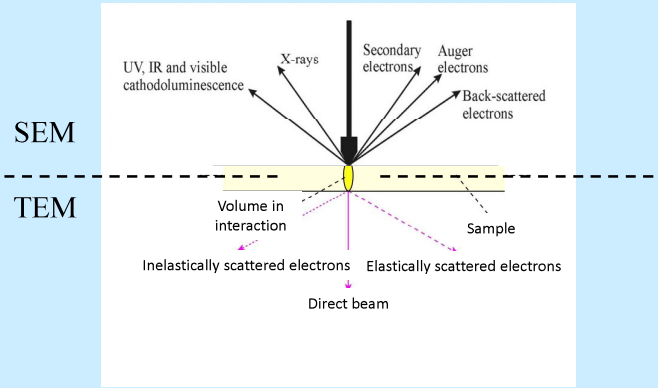
Transmission electron microscope
TEM



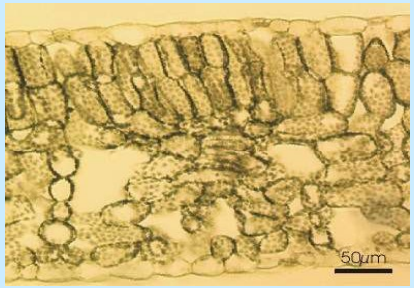
Scanning electron microscope
SEM



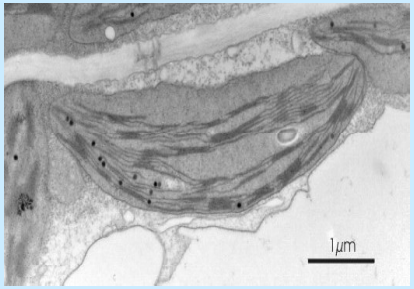
Interactions of electron beam



Light microscope vs Electron mikroscope

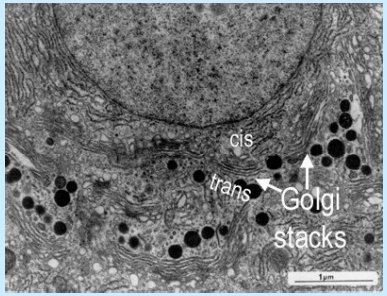


Semi-thin section of a spinach leaf in the light microscope.

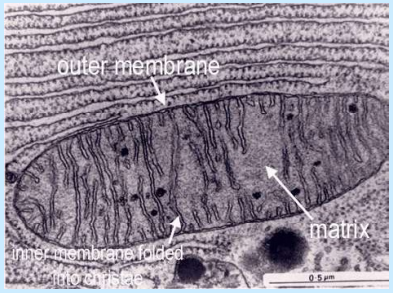


TEM micrograph: ultra-thin section of a spinach cell (chloroplast).

TEM



An electron micrograph showing golgi stacks

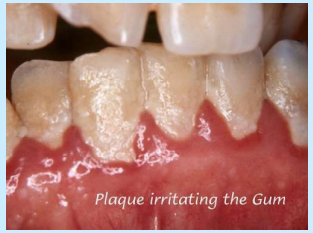


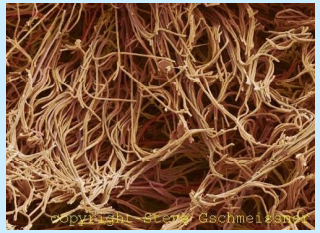
An electron micrograph showing mitochondrium

SEM

Brush your teeth often because this is what the surface of a tooth with a form of plaque looks like.

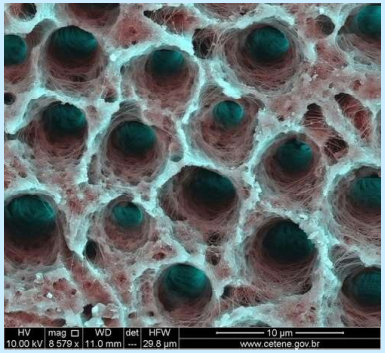
SEM





Scanning Electron Microscope image of bacteria in dental plaque magnified 30000 times !

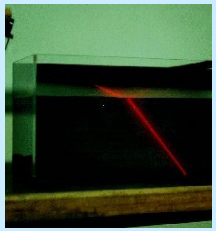
SEM

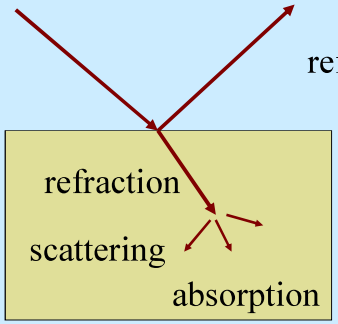


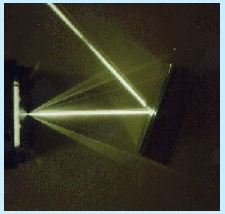
Dentin is found in teeth and comprises tiny channels called dentinal tubules. This images shows those tubules.

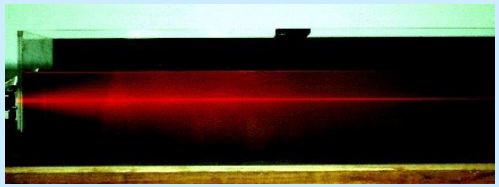
Interaction of light with matter 2.

Interaction of light with matter

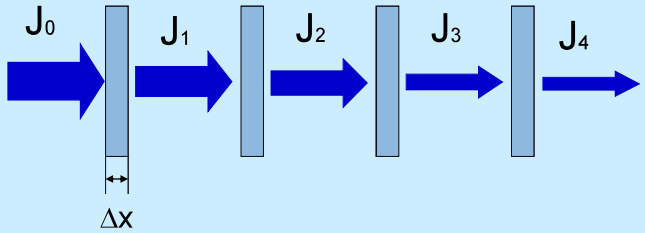








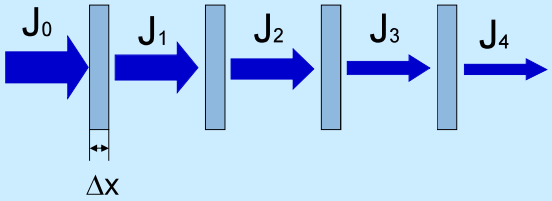
Absorption



Intensity of radiation is attenuated when passing through material

Law of attenuation

$$\Delta J = J_0 - J_1 = J_1 - J_2 = ...$$



$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

Differential form

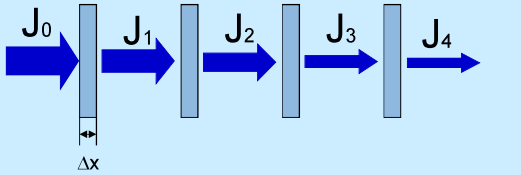
J : incident intensity [W/m^2]

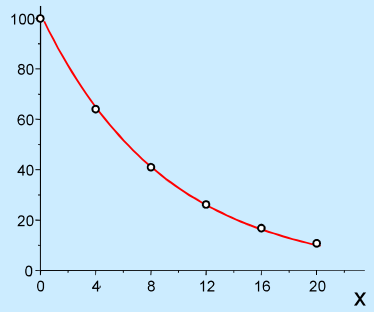
ΔJ : change of intesity after passing trough Δx thickness

μ: attenuation coefficient [1/m]

The decrease is proportional to the thickness of absorber Δx and J what is the initial intensity.

Law of attenuation





$$\frac{\Delta J}{\Delta x} = -\mu \times J$$

solution

$$J = J_0 e^{-\mu x}$$

Macroscopic function

Integral form

Exponential law of radiation attenuation

$$J = J_0 e^{-\mu x}$$

J is exponential function of the thickness of the layer.

J_0 : incident intensity [W/m^2]

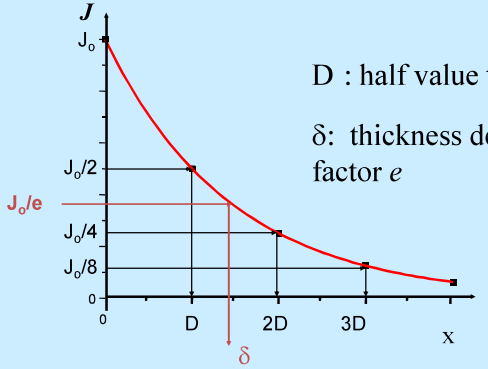
J : intesity after passing trough *x* thickness

μ: attenuation coefficient [1/m]

Linear attenuation (absorption) coefficient depends on
photon energy
quality (atomic number) of absorber
density of absorber

Graphical representation

$$J = J_0 e^{-\mu x}$$



D : half value thickness

δ: thickness decreasing the intensity by a factor *e*

Both D and δ depend on photon energy, quality (atomic number) of absorber, density of absorber

Definition of attenuation coefficient

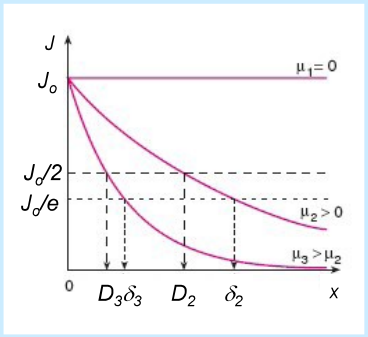
$$J = J_0 e^{-\mu x}$$

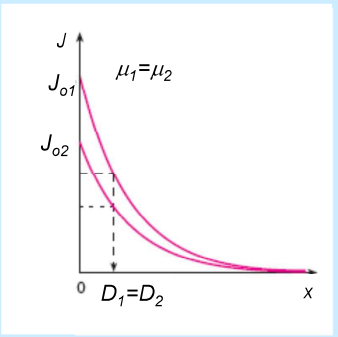
If x = D $\longrightarrow$ $J_0 / 2 = J_0 e^{-\mu D}$

$$\mu = \frac{\ln 2}{D} = \frac{0.693}{D}$$

If x = δ $\longrightarrow$ $J_0 / e = J_0 e^{-\mu \delta}$

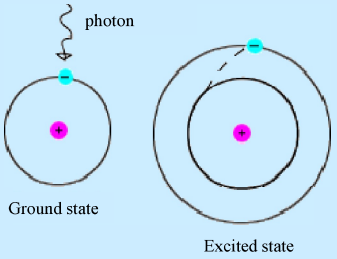
$$\mu = \frac{1}{\delta}$$





Mechanism of light absorption

Repetition: structure of atom

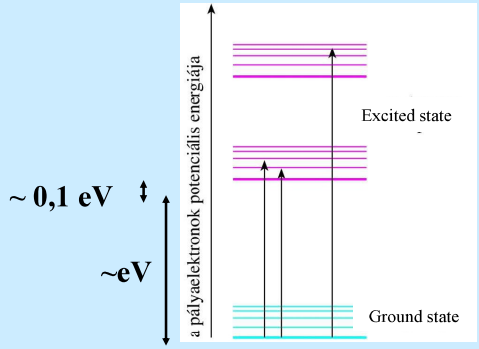


$$hf = \Delta E = E_{n+1} - E_n$$

E_{VIS}= 1.6 – 3.1 *eV*

Excitation of outer shell electrons

Electronic and vibronic energy levels



Molecules can absorb photons in a certain energy range

Fate of excited electron will be discussed later

Question of the week

What is (are) the precondition(s) of total internal reflection in the core of optical fiber?

Related chapters

Damjanovich, Fidy, Szöllősi: Medical Biophysics

II. 1.1.
- 1.1.1
- 1.1.3

II. 2. 1.
- 2.1.1
- 2.1.2
- 2.1.3
- 2.1.4
- 2.1.5
- 2.1.8

VI. 2.
- 2.1.
- 2.2.

X.5.