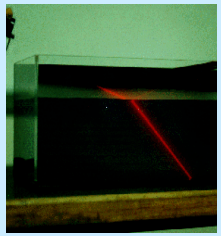
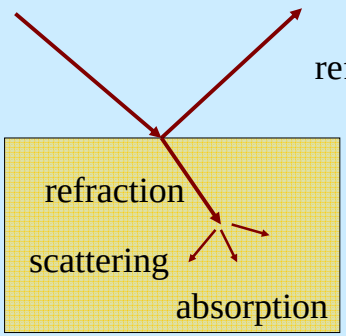
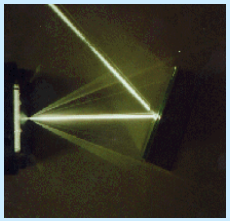
Interaction of light with matter
1.

Interaction of light with matter

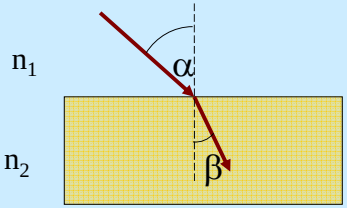






Refraction of light

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



$n_1 < n_2$

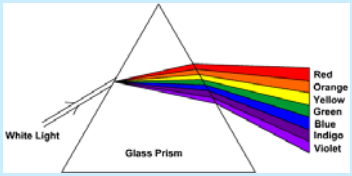
$\alpha > \beta$

Snell's Law

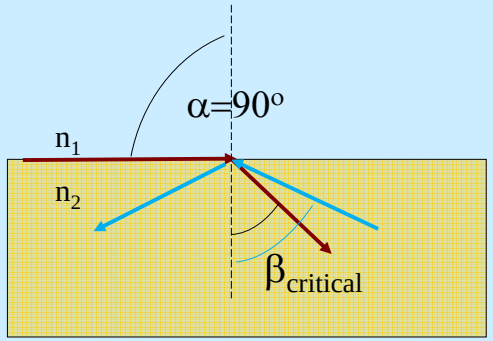
$$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

The index of refraction

Dispersion of light



Critical angle – total internal reflection



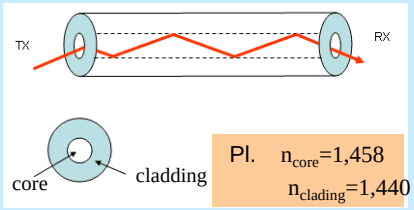
$\beta > \beta_{critical}$

Medical application

Determination of concentration – refractometry

Concentration of solutions is proportional
with their index of refraction .

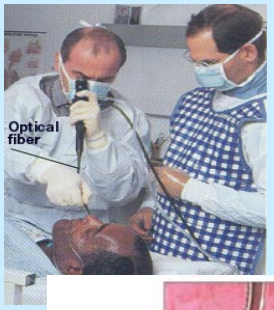
Optical fibers



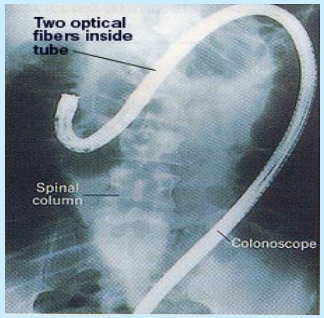
Pl. n_{core}=1,458
$n_{cladding}$=1,440

Application in dentistry

Other medical applications



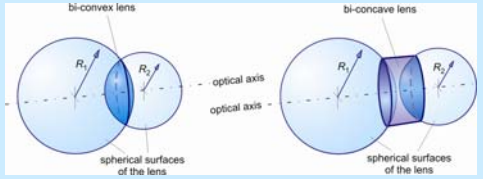
Bronchoscopy



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

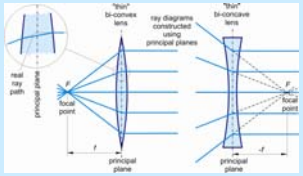
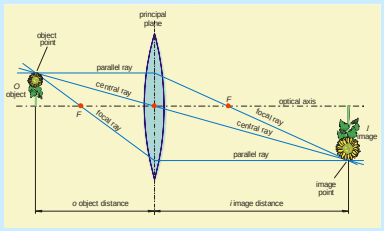


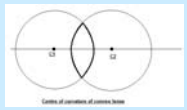
Image formation (thin lens approximation)

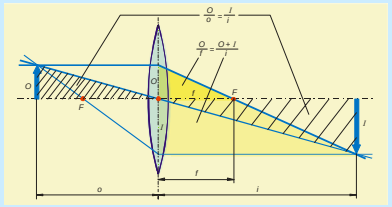
Image construction
by principal rays



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

the radii of curvature



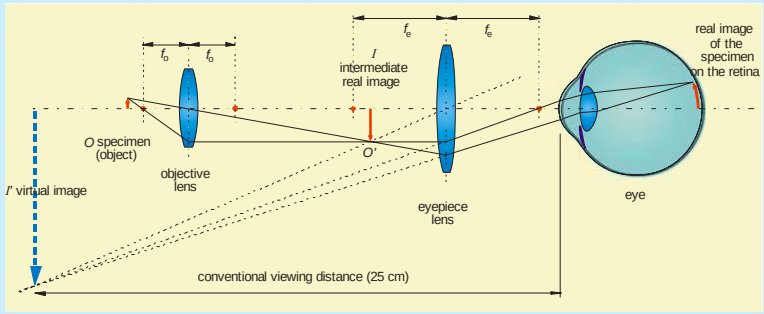


lensmaker's formula.

$$D = \frac{1}{f} = \frac{1}{o} + \frac{1}{i} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

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

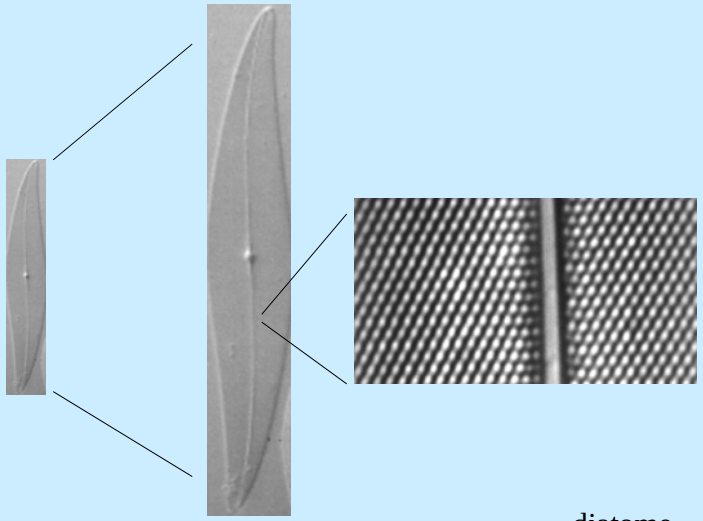
Image formation – compound microscope



The image is magnified
reversed
virtual

Magnification vs Resolution

Magnification vs Resolution

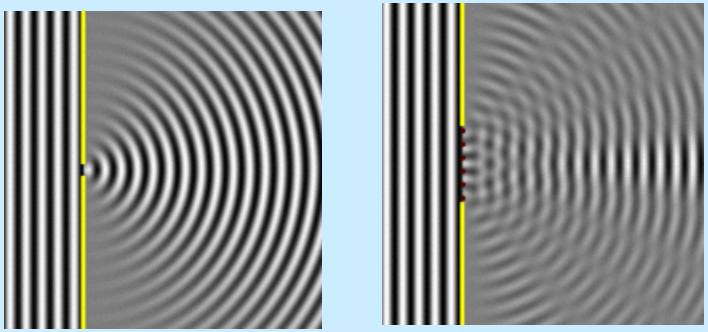


diatome

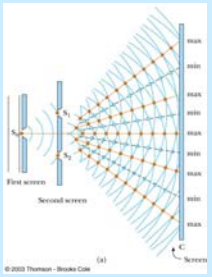
Limited resolution of microscopy

Wave nature of light

Huygens-principle



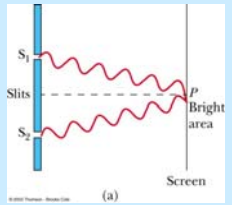
Young experiment

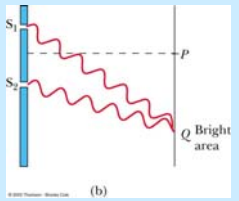


Where are the bright areas?

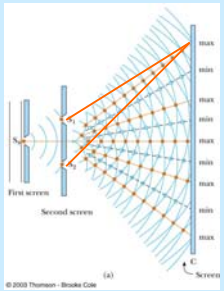
Constructive interference

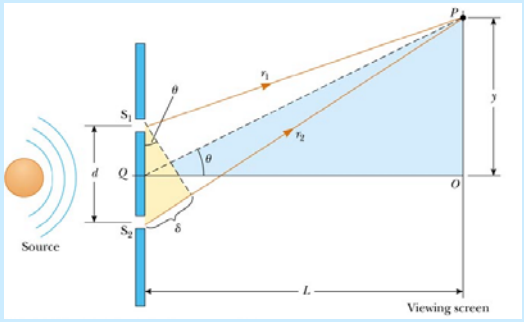
If the distences from the slits
- are equal
or
- their difference is equal n *λ





Young experiment

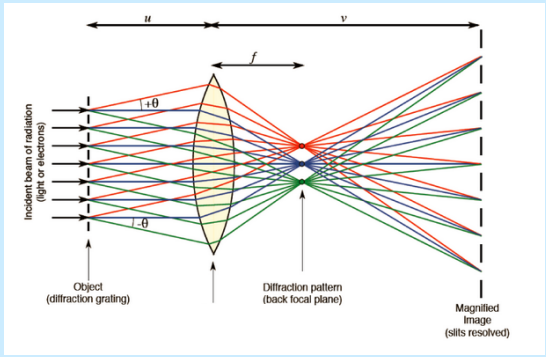




$$\delta = d \cdot \sin\Theta = k \cdot \lambda$$

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

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

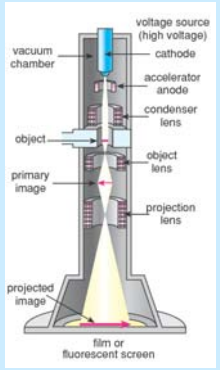
NA ~ 10^{-3}

Limit of resolution ~ **200 nm**

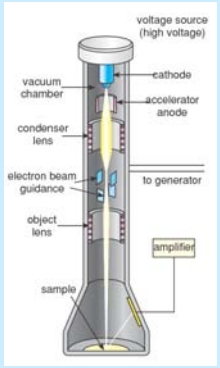
Limit of resolutiom ~ **0,2 - 0,5 nm**

Structure of electron microscopes

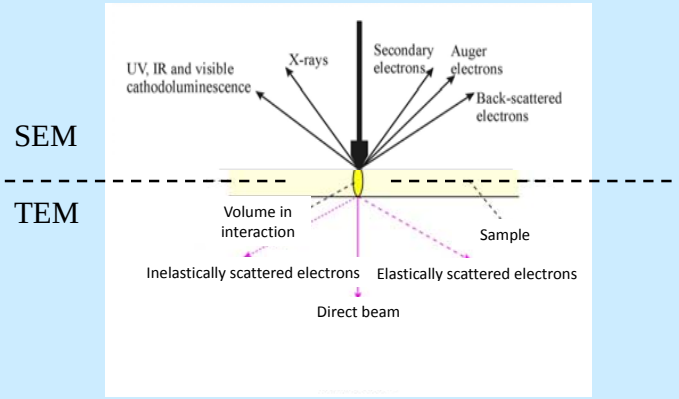
Transmission electron microscope
TEM



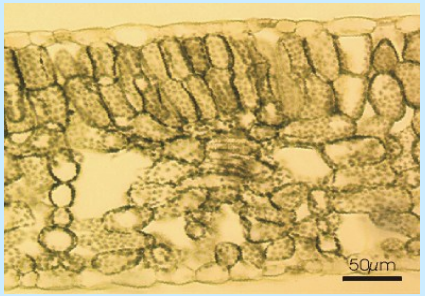
Scanning electron microscope
SEM



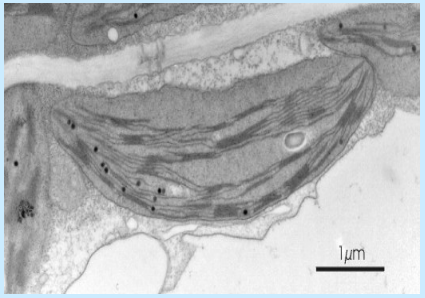
Interactions of electron beam



Light microscope vs Electron mikroscope

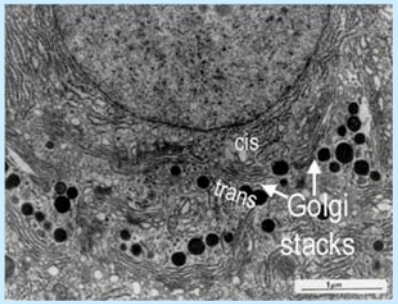


Semi-thin section of a spinach leaf in the light microscope.

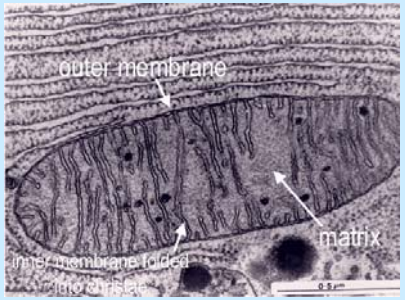


TEM micrograph: ultra-thin section of a spinach cell (chloroplast).

TEM



An electron micrograph showing golgi stacks

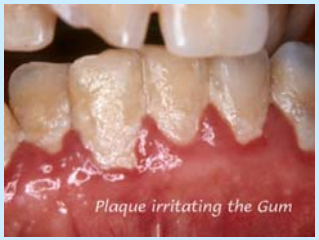


An electron micrograph showing mitochondrium

SEM

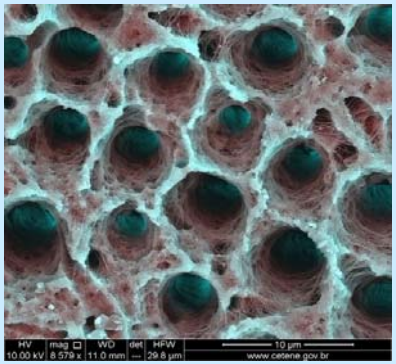
Brush your teeth often because this is what the surface of a tooth with a form of plaque looks like.

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.

Optics of the eye

$$D = \frac{n'-n}{R}$$

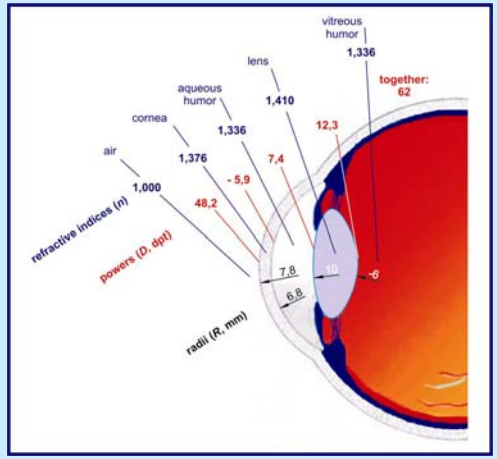
D : power (dpt)

n : refr. index of the 1. medium

n' : refr. index of the 2. medium

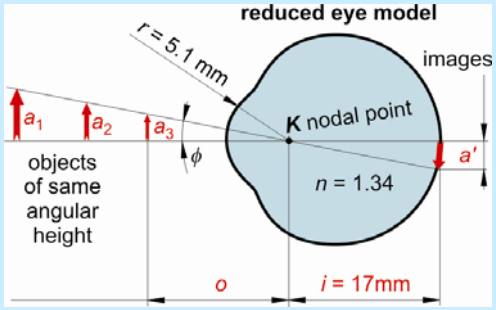
R : radius (m)
+ convex
– concave

Power of the human eye



Optics of the eye

Image formation of the reduced eye



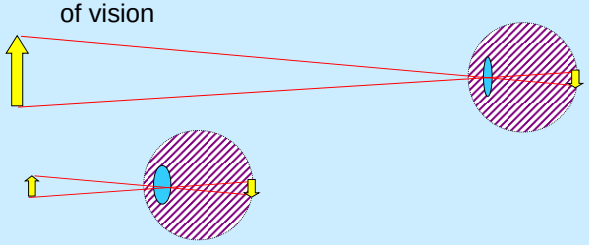
Power of the eye: sum of the powers of all refractive surfaces of the eye
unit: 1 dpt = 1/m, D_{eye} = 59 – 72 dpt

The image:
- real
- diminished
- inverted

Accomodation power

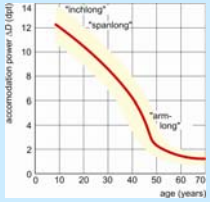
far point of vision

near point of vision



$$D_r = \frac{n'}{i} + \frac{n}{o_r}$$

$$D_p = \frac{n'}{i} + \frac{n}{o_p}$$

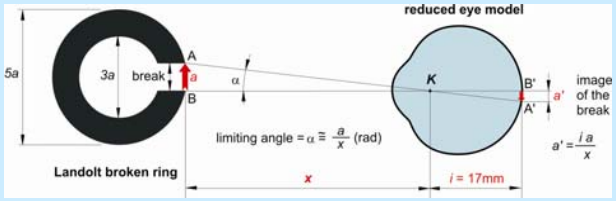


Accomodation power: the difference of the largest and the smallest power of the eye

$$\Delta D = D_p - D_r = \frac{1}{o_p} - \frac{1}{o_r}$$

Near point

Far point



Limiting angle of view (α):

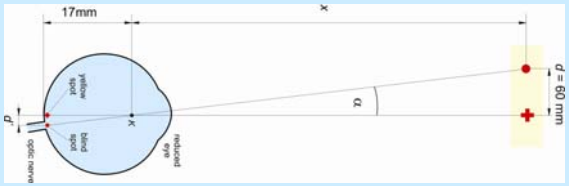
the smallest angular view of separated points A and B that can be just distinguished

Resolution of the eye or visual acuity (visus):

$$\text{visus} = \frac{1(')}{\alpha(')} \cdot 100\%$$

normal limiting angle (1')

individual limiting angle



Measurement of the distance of the blind spot from the yellow spot

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.