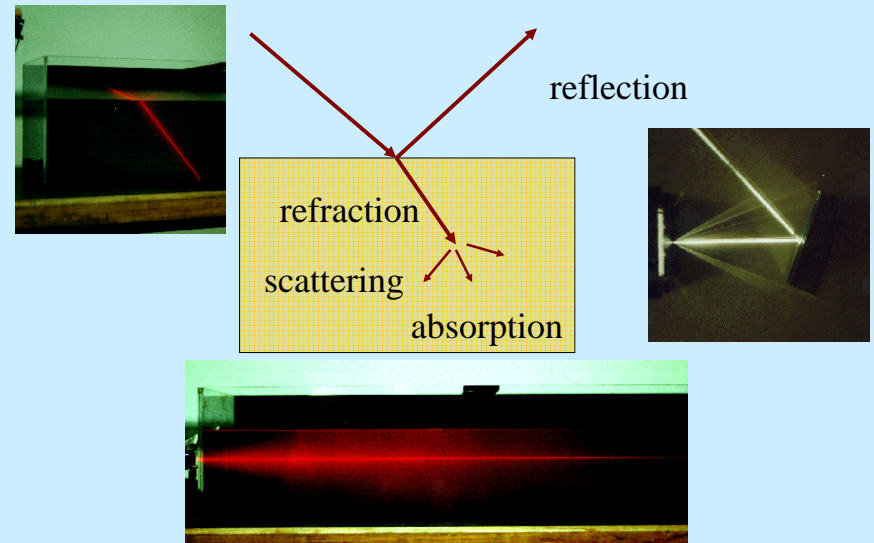


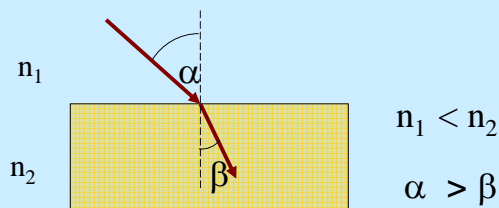
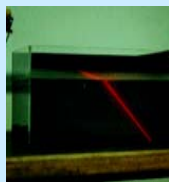
Interaction of light with matter 1.

Interaction of light with matter



Refraction of light

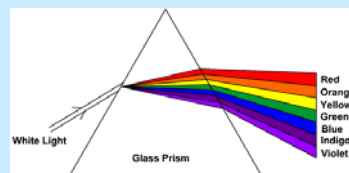
Fermat's Principle: Light follows the path of least time



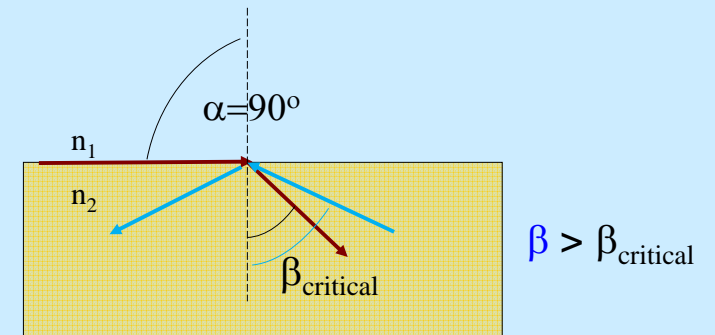
Snell's Law

$$\frac{\sin \alpha}{\sin \beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21} \quad \text{The index of refraction}$$

Dispersion of light



Critical angle – total internal reflection



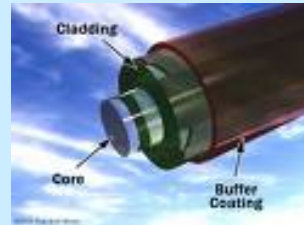
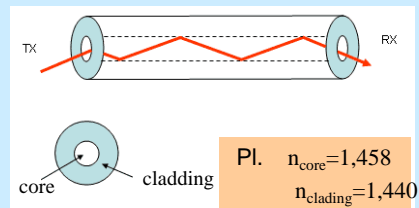
Medical application

Determination of concentration – refractometry

Concentration of solutions is proportional
with their index of refraction .



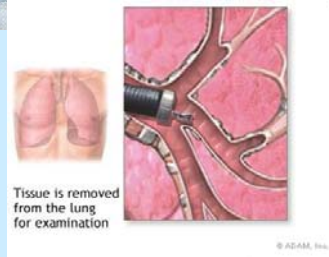
Optical fibers



Application in dentistry



Other medical applications

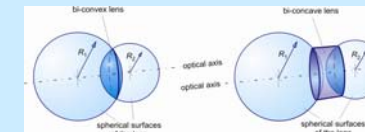


Colonoscopy

Bronchoscopy

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

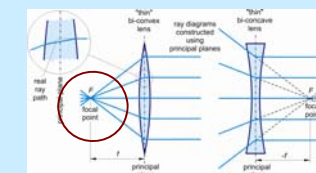
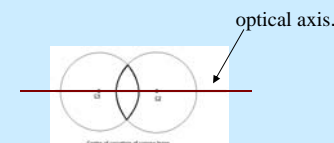
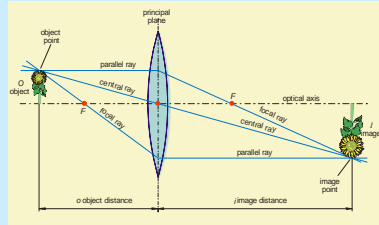


Image formation occurs, when light rays emerging from one point converge at another point.

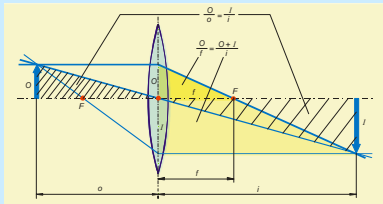
Image construction by principal rays



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

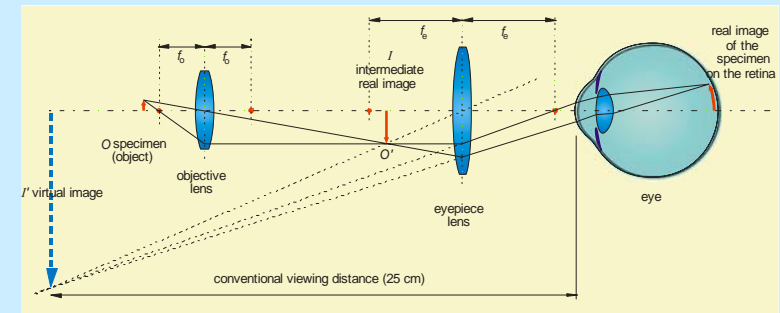
$$D = \frac{1}{f} = \frac{1}{o} + \frac{1}{i} = (n-1) \left(\frac{1}{R_1} + \frac{1}{R_2} \right)$$

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

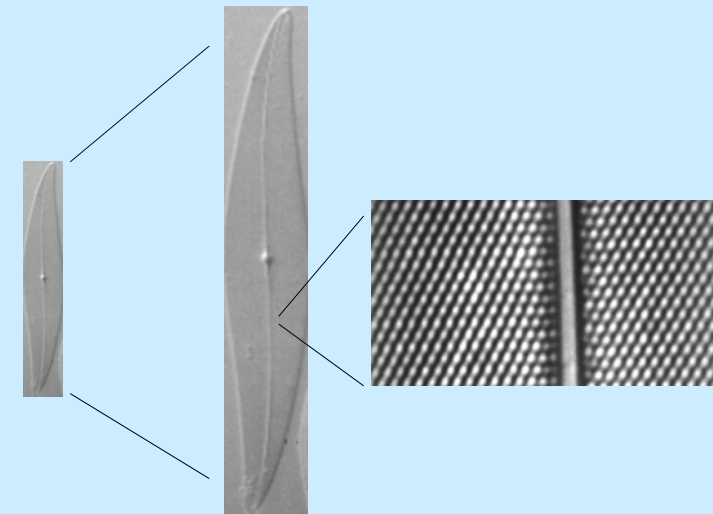


The image is magnified
reversed
virtual

Magnification vs Resolution



Magnification vs Resolution

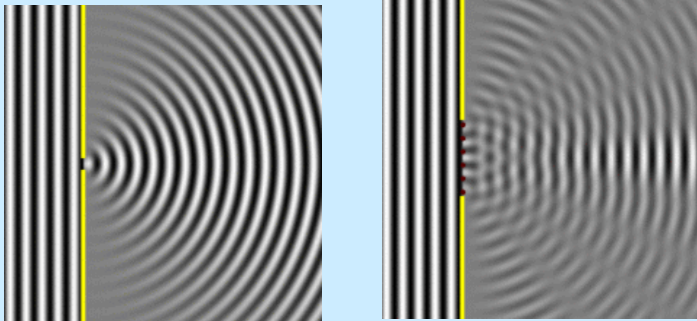


diatome

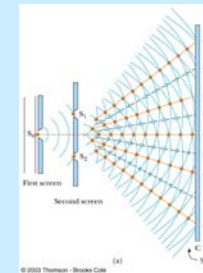
Limited resolution of microscopy

Wave nature of light

Huygens-principle



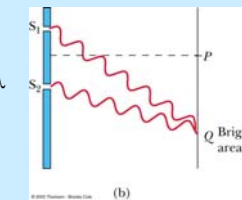
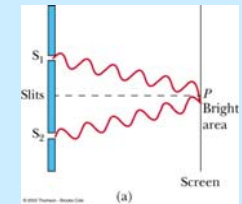
Young experiment



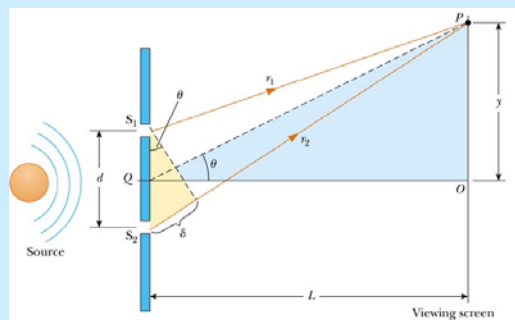
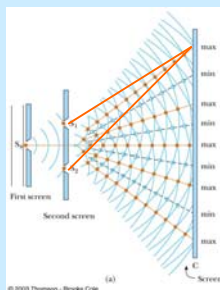
Where are the bright areas?

Constructive interference

If the distances from the slits
- are equal
or
- their difference is equal $n \cdot \lambda$



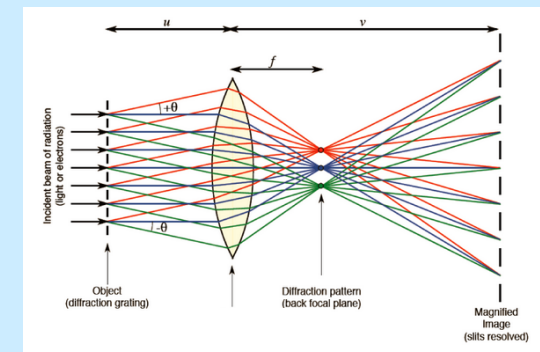
Young experiment



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

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

Diffraction pattern in the microscope



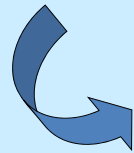
$$d = 0,61 \frac{\lambda}{n \sin \Theta}$$

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?

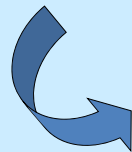
Electron microscope

$$\lambda = h / mv$$



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

U : 10 – 100 kV



$\lambda \sim 2 \text{ pm}$

Limit of resolution

Light microscope

$$\lambda \sim 400 \text{ nm}$$

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

$$NA \sim 2$$

Limit of resolution $\sim 200 \text{ nm}$

Electron microscope

$$\lambda \sim 2 \text{ pm}$$

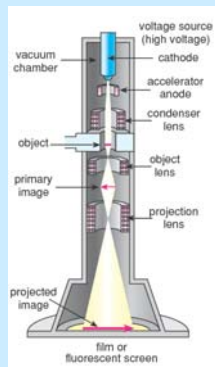
$$d = \lambda / NA$$

$$NA \sim 10^{-3}$$

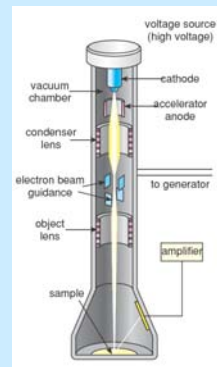
Limit of resolution $\sim 0,2 - 0,5 \text{ nm}$

Structure of electron microscopes

Transmission electron microscope
TEM



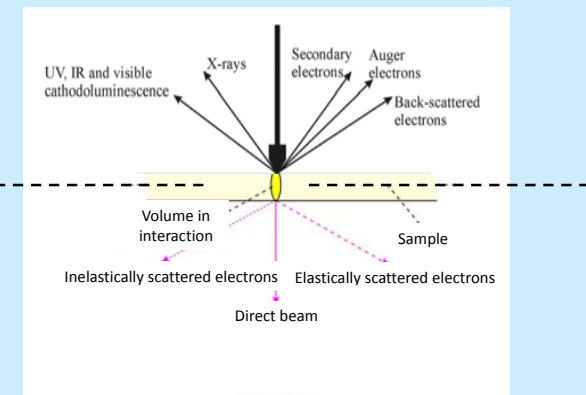
Scanning electron microscope
SEM



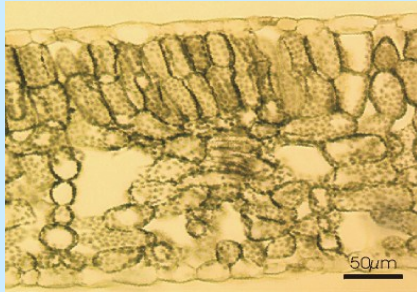
Interactions of electron beam

SEM

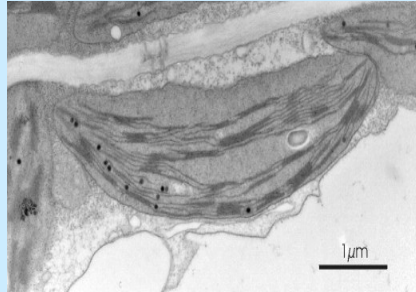
TEM



Light microscope vs Electron microscope

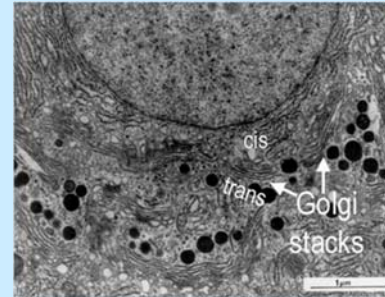


Semi-thin section of a spinach leaf in the light microscope.

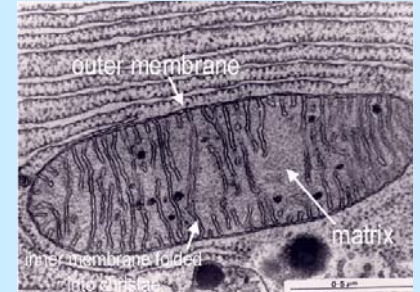


TEM micrograph: ultra-thin section of a spinach cell (chloroplast).

TEM

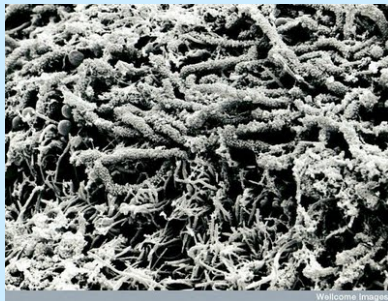


An electron micrograph showing golgi stacks



An electron micrograph showing mitochondrion

SEM



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

SEM

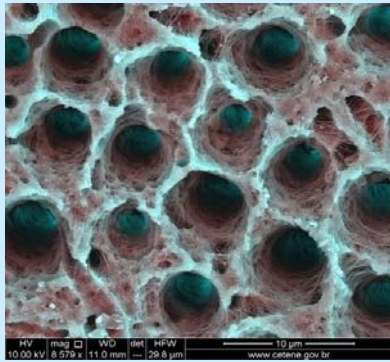


Scanning Electron Microscope image of bacteria in dental plaque magnified 30000 times !



Photograph © Mr. Steve Gschmeissner

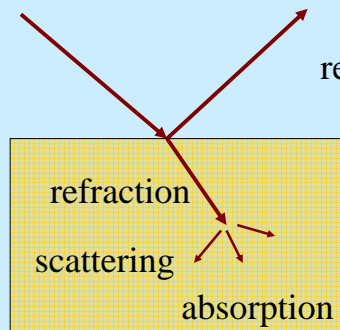
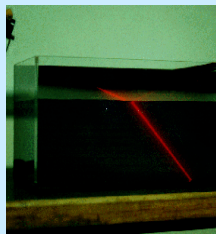
SEM



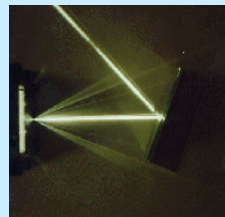
Dentin is found in teeth and comprises tiny channels called dentinal tubules. This image shows those tubules.

Interaction of light with matter 2.

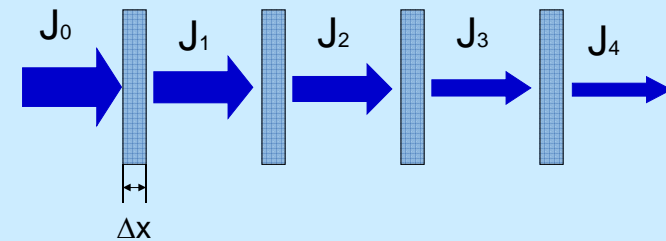
Interaction of light with matter



reflection

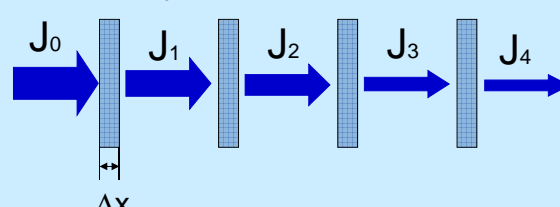


Absorption



Intensity of radiation is attenuated when passing through material

Law of attenuation

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


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

Differential form

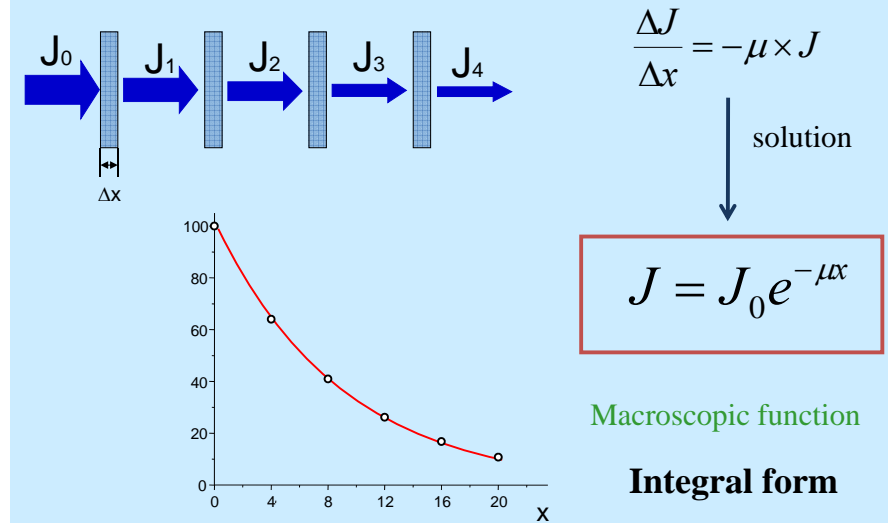
J : incident intensity [W/m^2]

ΔJ : change of intensity after passing through Δx thickness

μ : attenuation coefficient [$1/\text{m}$]

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

Law of attenuation



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]

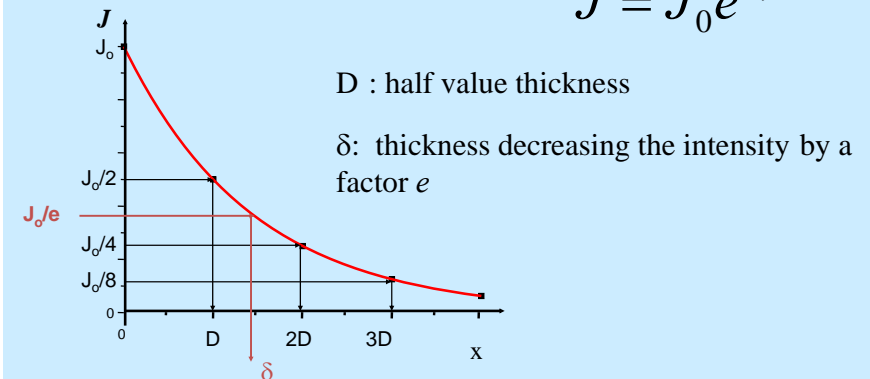
J : intensity after passing through x thickness

μ : attenuation coefficient [$1/\text{m}$]

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

Graphical representation

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



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

Definition of attenuation coefficient

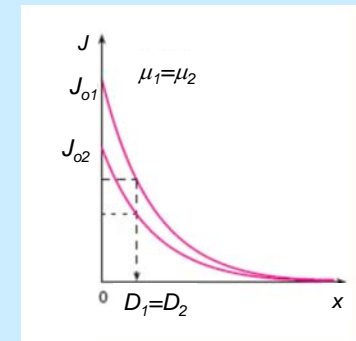
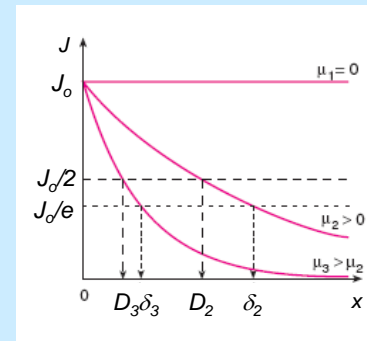
$$J = J_0 e^{-\mu x}$$

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

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

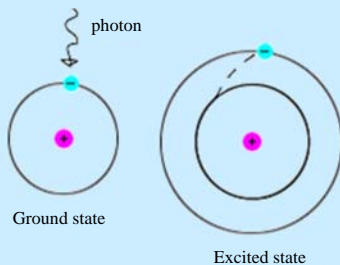
If $x = \delta \longrightarrow J_0 / e = J_0 e^{-\mu \delta}$

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



Mechanism of light absorption

Repetition: structure of atom

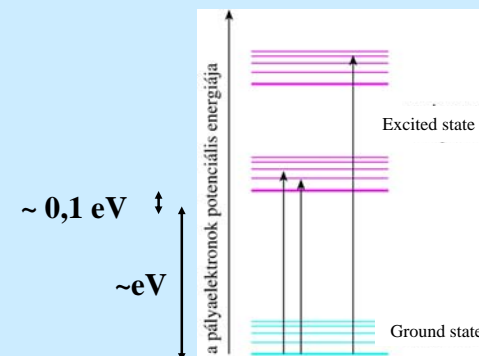


$$hf = \Delta E = E_{n+1} - E_n$$

$$E_{\text{VIS}} = 1.6 - 3.1 \text{ eV}$$

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.