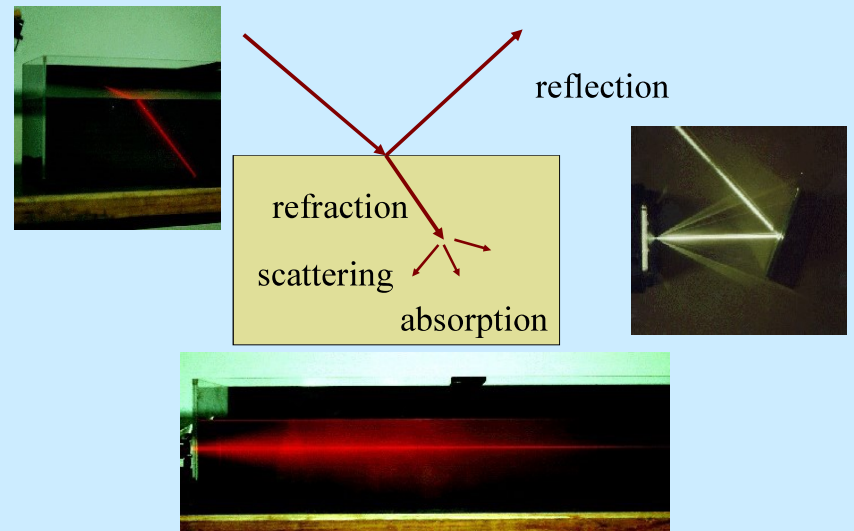


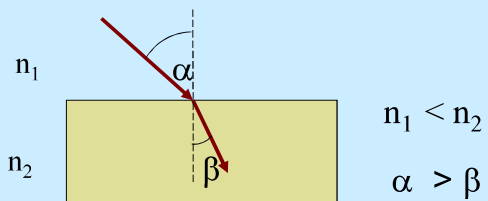
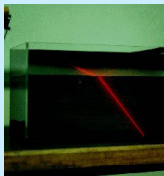
# Interaction of light with matter 1.

## Interaction of light with matter



## Refraction of light

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

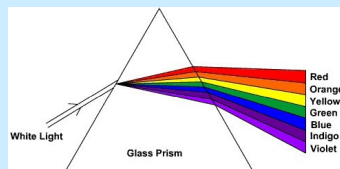


Snell's Law

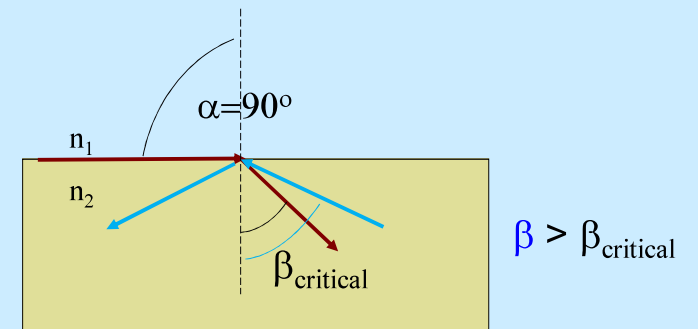
$$\frac{\sin \alpha}{\sin \beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1} = n_{21}$$

The index of refraction

Dispersion of light



## Critical angle – total internal reflection



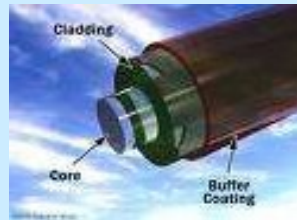
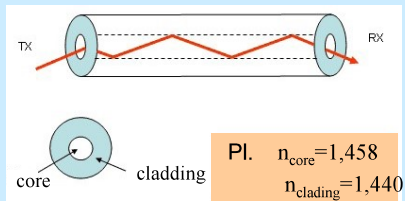
## Medical application

Determination of concentration – refractometry

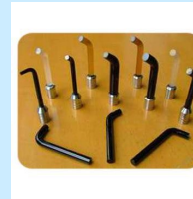
Concentration of solutions is proportional  
with their index of refraction .



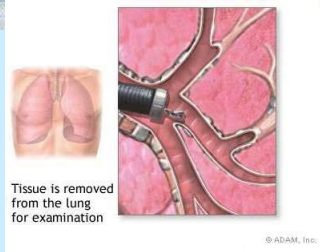
Optical fibers



## Application in dentistry



## Other medical applications

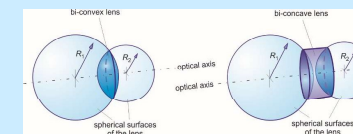


**Bronchoscopy**

**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*

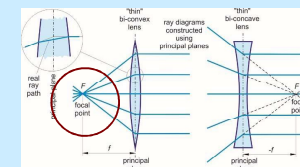
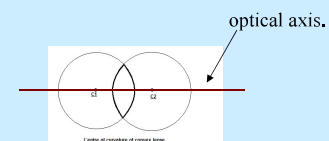
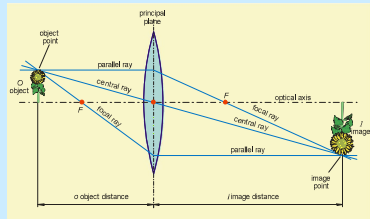


Image formation occurs, when light rays emerging from one point converge at another point.

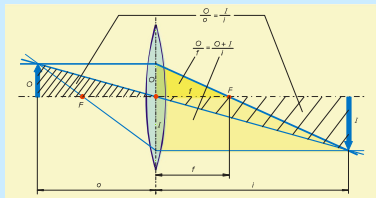
Image construction by principal rays



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

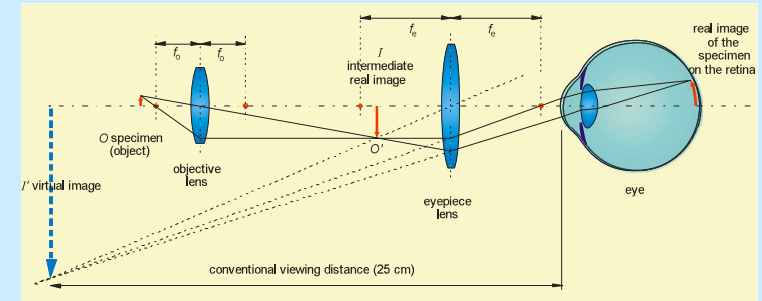
$$D = \frac{1}{f} = \frac{1}{o} + \frac{1}{i} = (n-1) \left( \frac{1}{R_1} + \frac{1}{R_2} \right)$$

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**

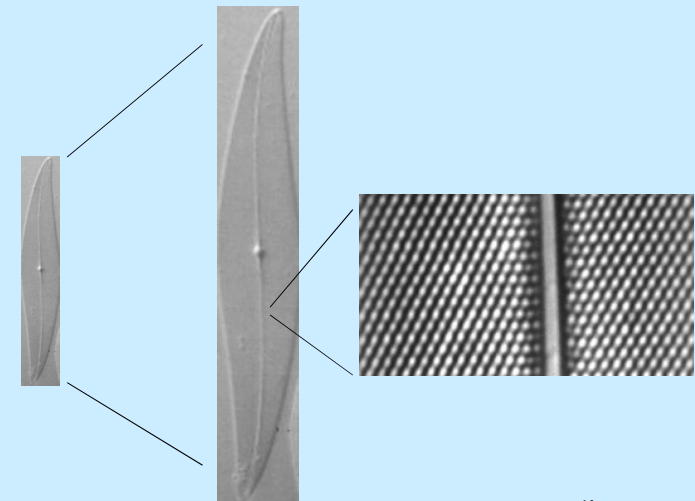


The image is **magnified**  
**reversed**  
**virtual**

Magnification vs Resolution



Magnification vs Resolution

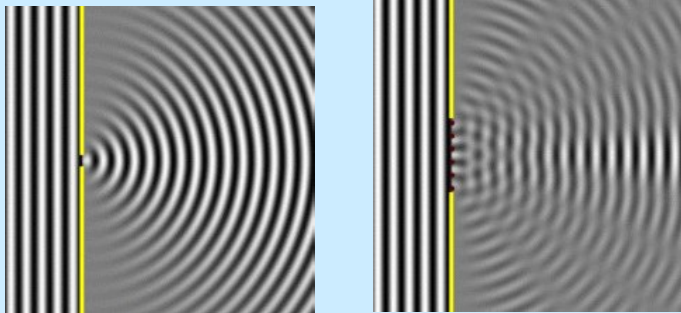


diatome

## Limited resolution of microscopy

### Wave nature of light

#### Huygens-principle



## Young experiment

Where are the bright areas?

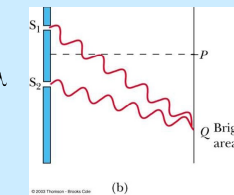
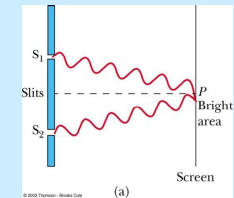
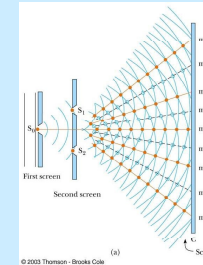
Constructive interference

If the distances from the slits

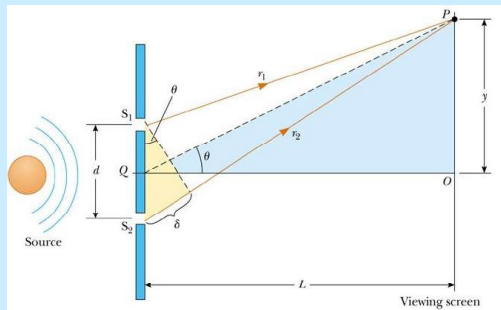
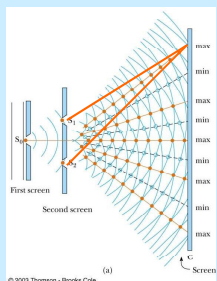
- are equal

or

- their difference is equal  $n \cdot \lambda$



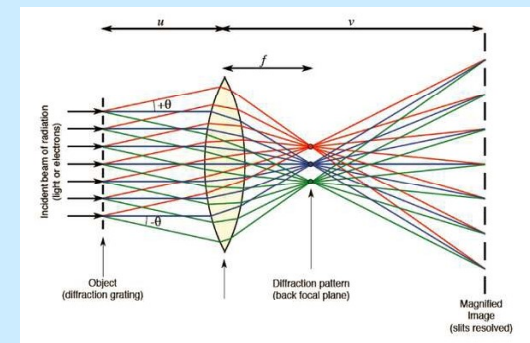
## Young experiment



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

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

## Diffraction pattern in the microscope



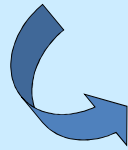
$$d = 0,61 \frac{\lambda}{n \sin \Theta}$$

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.

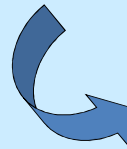
To decrease the limit of resolution – shorter wavelength – ¿matter wave?

## Electron microscope

$$\lambda = h / mv$$



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



U : 10 – 100 kV

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

## Limit of resolution

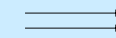
Light microscope

Electron microscope

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

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

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



$$d = \lambda / NA$$

NA ~ 2

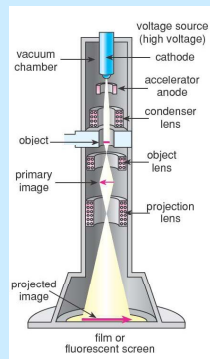
NA ~ 10<sup>-3</sup>

Limit of resolution ~ **200 nm**

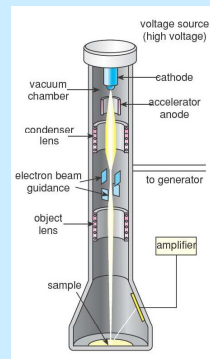
Limit of resolution ~ **0,2 - 0,5 nm**

## Structure of electron microscopes

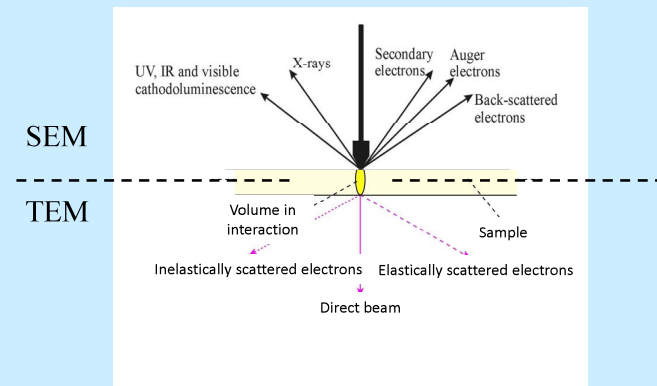
Transmission electron microscope  
TEM



Scanning electron microscope  
SEM

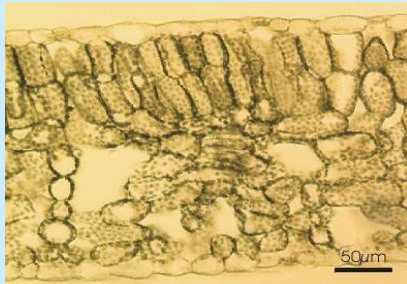


## Interactions of electron beam

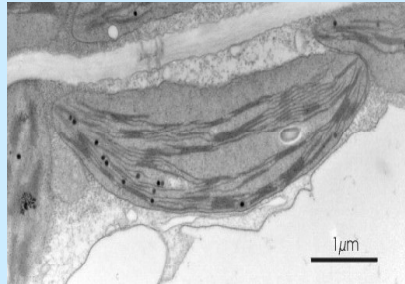




## Light microscope vs Electron microscope

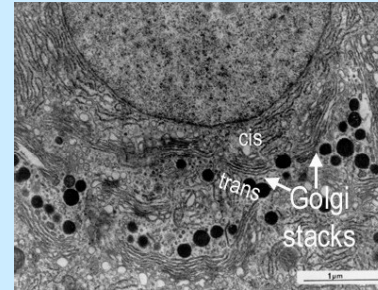


Semi-thin section of a spinach leaf in the light microscope.

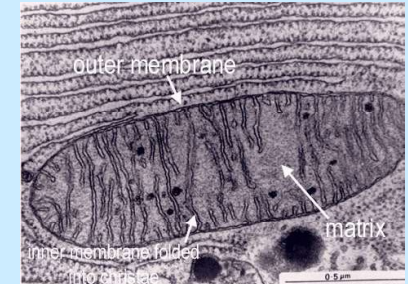


TEM micrograph: ultra-thin section of a spinach cell (chloroplast).

## 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

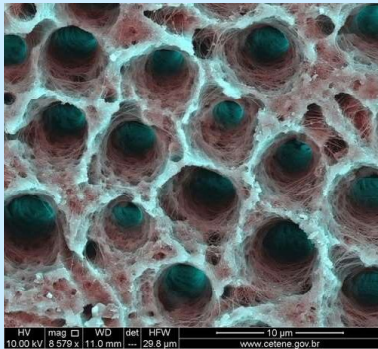


Scanning Electron Microscope image of bacteria in dental plaque magnified 30000 times !



Photograph © Mr. Steve Gschmeissner

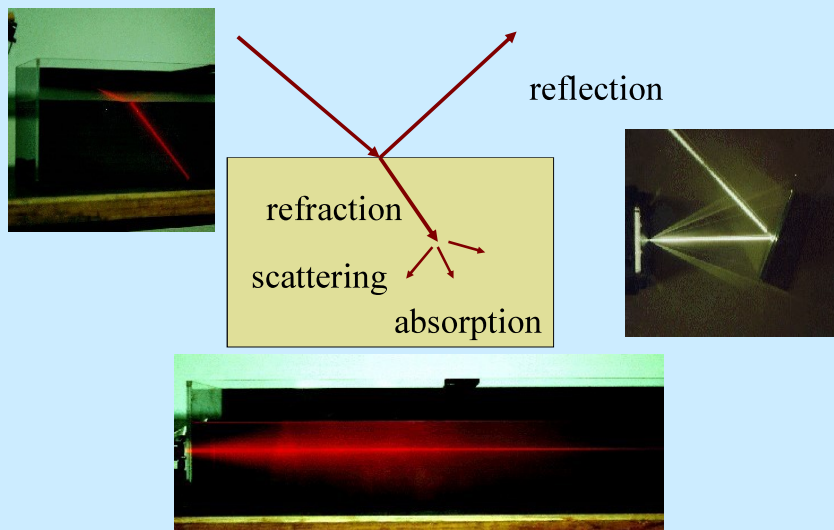
## SEM



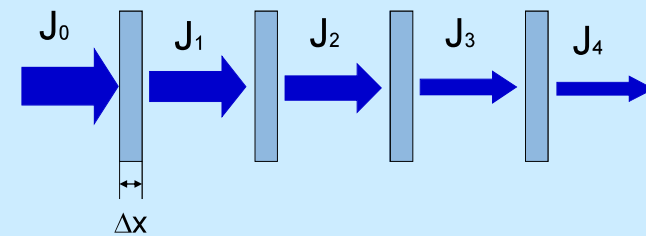
Dentin is found in teeth and comprises tiny channels called dentinal tubules. This image shows those tubules.

## Interaction of light with matter 2.

### Interaction of light with matter

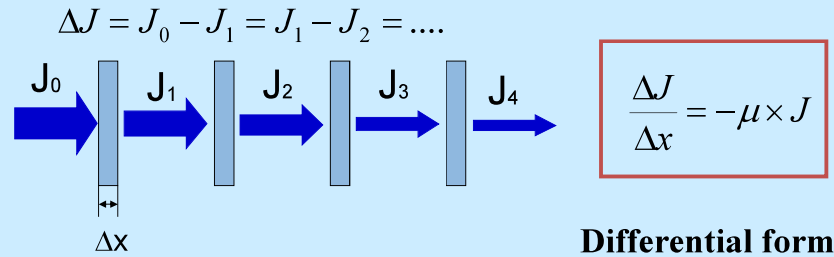


### Absorption



Intensity of radiation is attenuated when passing through material

## Law of attenuation



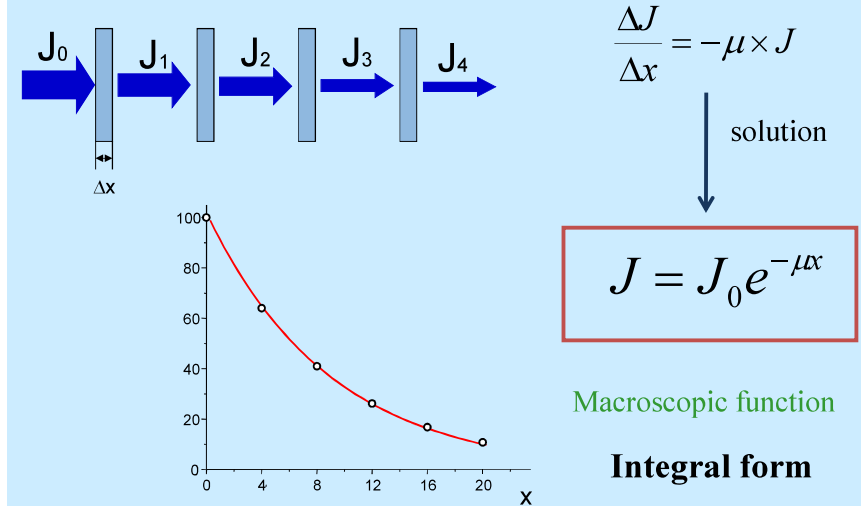
$J$  : incident intensity [ $\text{W}/\text{m}^2$ ]

$\Delta J$  : change of intensity after passing through  $\Delta x$  thickness

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

The decrease is proportional to the thickness of absorber  $\Delta x$  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 [ $\text{W}/\text{m}^2$ ]

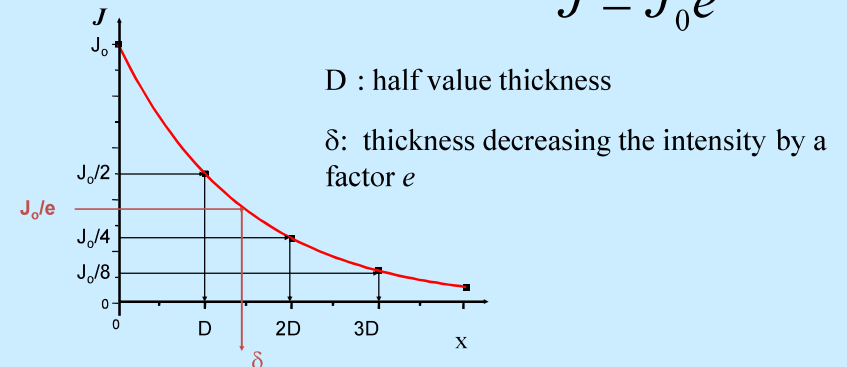
$J$  : intensity after passing through  $x$  thickness

$\mu$ : 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  $\delta$  depend on photon energy, quality (atomic number) of absorber, density of absorber



## Definition of attenuation coefficient

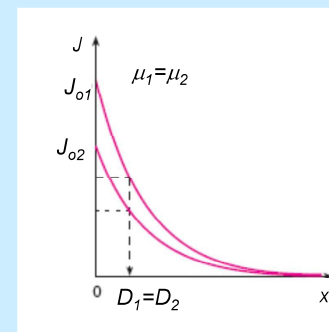
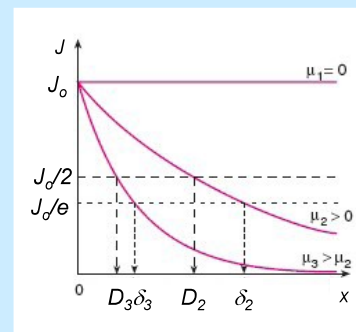
$$J = J_0 e^{-\mu x}$$

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

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

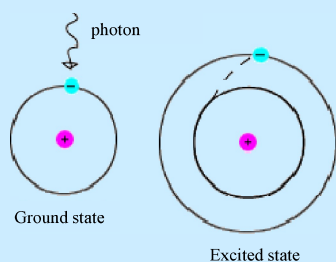
If  $x = \delta \longrightarrow J_0 / e = J_0 e^{-\mu \delta}$

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



## Mechanism of light absorption

Repetition: structure of atom

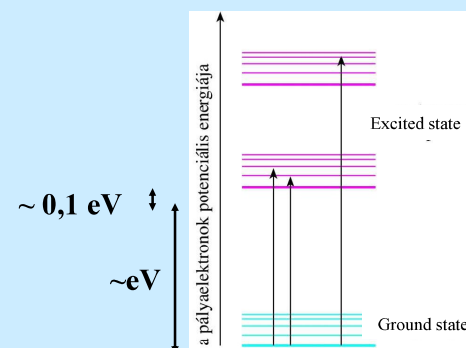


$$hf = \Delta E = E_{n+1} - E_n$$

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

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.