AL- Mustaqpal University
Science College
Dep. Medical physics

Medical physics
Third Stage

Lec 9

Exponential law of absorption

م . م علي سـلمان حمادي

Exponential law of absorption

Lambert's law:

The intensity of light decreases exponentially in function of the distance ***x*** .

The intensity (**I**) of the transmitted radiation through a thickness (**x**) of homogeneous material, is described by the experimental equation of exponential absorption (Lambert Law): $\mathbf{I} = \mathbf{I}_0 \exp(-\mathbf{ax})$

$\mathbf{I}_0$ = Intensity of incoming radiation.

a = Absorption coefficient of the material

Absorption of electromagnetic Radiation

We saw that the process of **photon absorption** by the atom is a process of raising the atom (electron) from a lower energy level into a higher energy level (excited state), by an amount of energy which is equivalent to the energy of the absorbed photon.

Our discussion involved a **microscopic system** in which one photon interacts with one atom.

In a **macroscopic system**, when electromagnetic radiation passes through matter, part of it is transmitted, and part is absorbed by the atoms.

The **intensity (I)** of the transmitted radiation through a thickness (x) of homogeneous material, is described by the experimental equation of exponential absorption (**Lambert Law**):

$$\mathbf{I=I_0 exp(-\alpha x)}$$

$\mathbf{I_0}$ = Intensity of incoming radiation.

α = Absorption coefficient of the material.

The thicker the material (bigger x), the lower the intensity after the material (the transmitted beam).

The **transmission (T)** of this material is described by the relation between the transmitted intensity (I) to the incident intensity (I_0):

$$\mathbf{T = I/I_0}$$

From the last two equations we get the Transmission:

$$\mathbf{T = \exp(-\alpha x)}$$

It is common to use units of **centimeter** (10^{-2} [m]), to measure the width of the material (x), so **the units of the absorption coefficient (α) are:**

$$\mathbf{[cm^{-1}] = [1/cm]}.$$

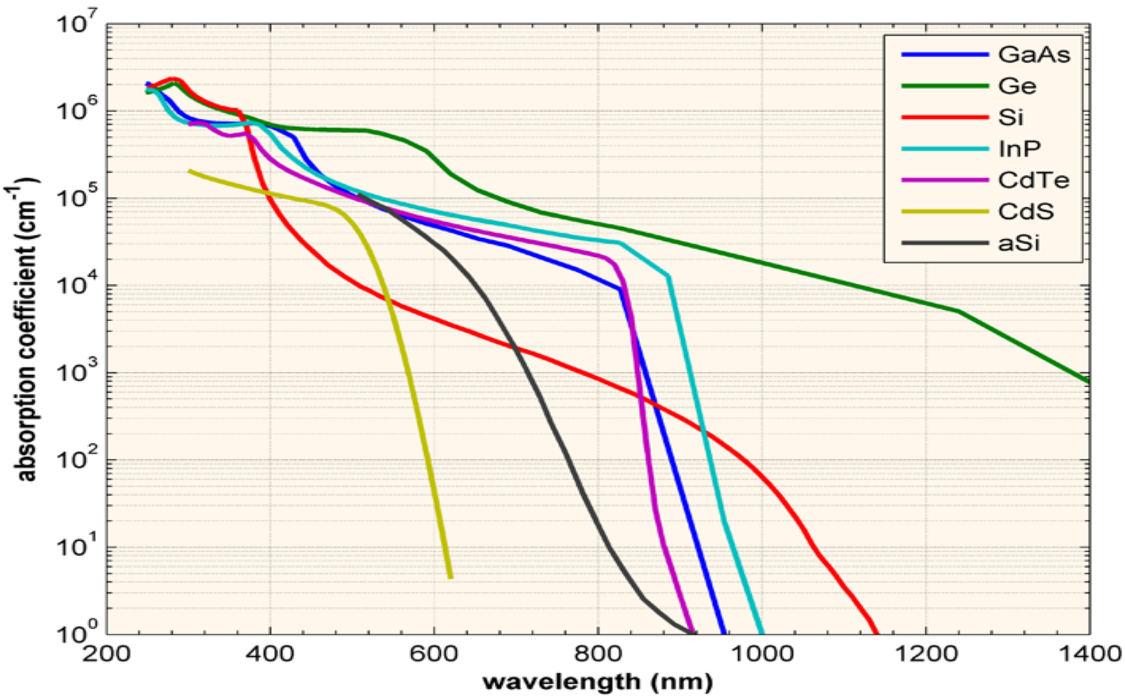
Every material is transparent differently to different wavelengths, so **the absorption coefficient (α) is a function of the wavelength: α(λ)**. This fact is very important (as we shall see) to understand the interaction of electromagnetic radiation with matter, in the variety of applications of the laser.

Absorption Coefficient

Overview

1. Different semiconductor materials have different absorption coefficients.
2. Materials with higher absorption coefficients more readily absorb photons, which excite electrons into the conduction band.
3. Knowing the absorption coefficients of materials aids engineers in determining which material to use in their solar cell designs.

The absorption coefficient determines how far into a material light of a particular wavelength can penetrate before it is absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength. The absorption coefficient depends on the material and also on the wavelength of light which is being absorbed. Semiconductor materials have a sharp edge in their absorption coefficient, since light which has energy below the band gap does not have sufficient energy to excite an electron into the conduction band from the valence band. Consequently, this light is not absorbed. The absorption coefficient for several semiconductor materials is shown below.



The absorption coefficient, α, in a variety of semiconductor materials at 300K as a function of the vacuum wavelength of light.

The above graph shows that even for those photons which have an energy above the band gap, the absorption coefficient is not constant, but still depends strongly on wavelength. The probability of absorbing a photon depends on the likelihood of having a photon and an electron interact in such a way as to move from one energy band to another. For photons which have an energy very close to that of the band gap, the absorption is relatively low since only those electrons directly at the valence band edge can interact with the photon to cause absorption. As the photon energy increases, not just the electrons already having energy close to that of the band gap can interact with the photon. Therefore, a larger number of electrons can interact with the photon and result in the photon being absorbed.

The absorption coefficient, α, is related to the extinction coefficient, k, by the following formula:

$\alpha=4\pi k / \lambda$

where λ is the wavelength. If λ is in nm, multiply by 10^{-7} to get the absorption coefficient in the units of cm^{-1}

Discussion

1. Lambert's law describes intensity decrease as a function of:

A) Time

B) Distance

C) Energy

D) Temperature

E) Pressure

Ans: B

2. Formula for Lambert's law:

A) I=I0+a/x

B) I=I0exp(-ax)

C) I=I0-x/a

D) I=I0+ax

E) I=I0/ax

Ans: B

3. In $I=I0\exp(-ax)$, I0 is:

A) Transmitted intensity

B) Absorption coefficient

C) Incident intensity

D) Transmission factor

E) Reflection index

Ans: C

4. Symbol for absorption coefficient:

A) β

B) α

C) γ

D) δ

E) κ

Ans: B

5. Unit of absorption coefficient:

A) cm

B) cm^2

C) cm^{-1}

D) W/cm^2

E) m^{-2}

Ans: C

6. Transmission T is defined as:

A) T = I0/I

B) T = I/I0

C) T = I0+I

D) T = I0-I

E) T = I0×I

Ans: B

7. Transmission formula with α, x:

A) $T = \exp(-\alpha x)$

B) $T = \exp(\alpha x)$

C) $T = 1-\exp(-\alpha x)$

D) $T = \alpha x$

E) $T = I0/I$

Ans: A

8. Thicker material means:

A) More transmission

B) Less transmission

C) Same transmission

D) Zero reflection

E) Constant I

Ans: B

9. Absorption coefficient depends on:

A) Mass

B) Wavelength

C) Voltage

D) Temperature

E) Density

Ans: B

10. In microscopic view, photon absorption excites:
A) Proton
B) Nucleus
C) Electron
D) Neutron
E) Atom core
Ans: C

11. Photon absorption promotes electron to:

A) Ground state

B) Lower band

C) Excited state

D) Empty space

E) Hole state

Ans: C

12. Macroscopic absorption involves:

A) Single atom

B) One photon

C) Many atoms

D) Proton transfer

E) Only nuclei

Ans: C

13. Transparent material has:

A) High α

B) Zero α

C) Low α

D) Negative α

E) Infinite α

Ans: C

14. Semiconductor absorption edge relates to:

A) Band gap

B) Temperature

C) Thickness

D) Current

E) Reflection

Ans: A

15. Below band gap energy, light is:

A) Absorbed

B) Reflected

C) Not absorbed

D) Amplified

E) Emitted

Ans: C

16. For photons just above band gap, absorption is:
A) High
B) Low
C) Zero
D) Infinite
E) Constant
Ans: B

17. Absorption probability increases with:

A) Lower energy

B) Higher energy

C) Smaller α

D) Shorter x

E) No photons

Ans: B

18. α is related to extinction coefficient k by:

A) $\alpha = \lambda/4\pi k$

B) $\alpha = 4\pi k/\lambda$

C) $\alpha = \lambda/\pi k$

D) $\alpha = k/\lambda$

E) $\alpha = 4\lambda/k$

Ans: B

19. If λ is in nm, multiply by:

A) 10^{-2}

B) 10^{-3}

C) 10^{-6}

D) 10^{-7}

E) 10^{-9}

Ans: D

20. Absorption coefficient helps in designing:
A) Capacitors
B) Solar cells
C) Resistors
D) Motors
E) Inductors
Ans: B

21. Strong absorbers have:

A) High α

B) Low α

C) Zero α

D) Negative α

E) Constant α

Ans: A

22. Poorly absorbed light makes material:

A) Opaque

B) Transparent

C) Reflective

D) Black

E) Amplifying

Ans: B

23. α unit in SI is:

A) m^2

B) m^{-1}

C) s^{-1}

D) J/m^2

E) N/m

Ans: B

24. As thickness increases, T:

A) Increases

B) Decreases

C) Constant

D) Oscillates

E) Doubles

Ans: B

25. In Lambert’s law, exponential decrease is due to:

A) Reflection

B) Refraction

C) Absorption

D) Scattering

E) Emission

Ans: C