جامعة الموصل

كلية التربية للعلوم الصرفة

قسم الفيزياء

البصريات Optics

المرحلة الثانية

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First lecture (1)

Introduction to the optics

1.1 What is Optics

Optics: Is the branch of physics that studies the behavior and properties of light, Optics usually describes the behavior of visible, ultraviolet, and infrared light. Because light is an electromagnetic wave, other forms of electromagnetic radiation such as X-rays, microwaves, and radio waves exhibit similar properties.

Optics can be classified into three different fields: -

1- **Geometrical optics:** Describes the propagation of light in terms of "rays" which travel in straight lines, and whose paths are governed by the laws of reflection and refraction at interfaces between different media.

2- **Physical optics:** In physical optics, light is considered to propagate as a wave. This model predicts phenomena such as in interference and diffraction

3- **Quantum optics (Modern o ptics):** Is a branch of atomic, molecular, and optical physics dealing with how individual quanta of light, known as photons, interact with atoms and molecules. It includes the study of the particle-like properties of photons.

1.2 The nature of light

Light: Is a transverse, electromagnetic wave that can be seen by the human. Below are some properties of light: **-**

1. The light travels in straight lines.
2. The speed of light in a free space (vacuum) is constant and equal to ***3 X 10⁸*** m/sec.

$c = \lambda f$ where c is the velocity of light, λ is the wavelength of light and f is the frequency of light.

$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ where, ε_0 is the electrical permittivity of the vacuum and μ_0 is the magnetic permeability of the vacuum.

3. The light requires no medium to travel through, it can be traveled in free space because it is a transvers wave,

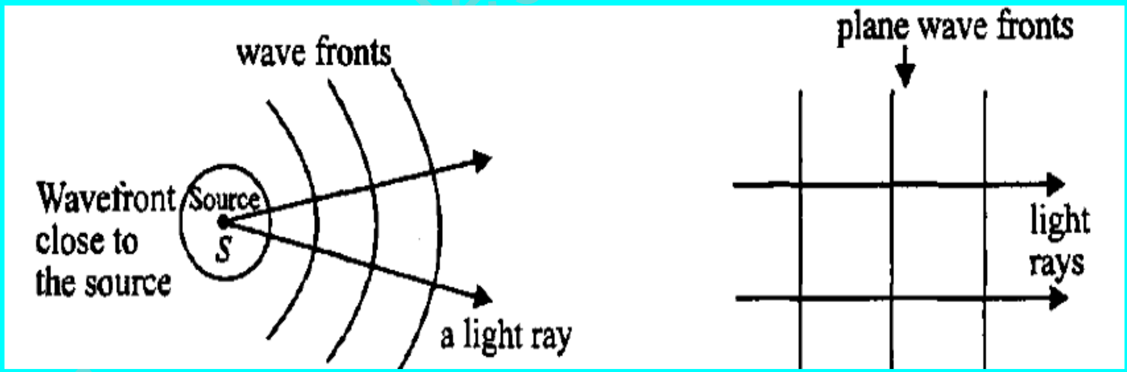
4. The light behaves as a **waves** according to wave theory in several phenomena like, refraction, reflection, interference, diffraction and polarization. On the other hand, light behaves as a stream of the **partials** called photons in other phenomena like, photoelectric effect, black body radiation, emission and absorption and others. This behavior called the duality of wave-particle of light.
5. The light reflects in a smooth surface.
6. The light refracts in a boundary between surface transmitted medium.
7. The light diffracts near a sharp edges and tine holes and interferes under certain conditions and can be polarized.
8.

1.3 Wave-front and Rays.

Wave-front: Is a surface passing through the points of a wave that have the same phase and amplitude.

Ray: Is a thin beam of light that travels in a straight line.

Optics is the study of electromagnetic waves that can be approximated using rays. The rays, corresponding to the direction of wave motion, are straight lines perpendicular to the wave.



1.4 Huygens Principle's

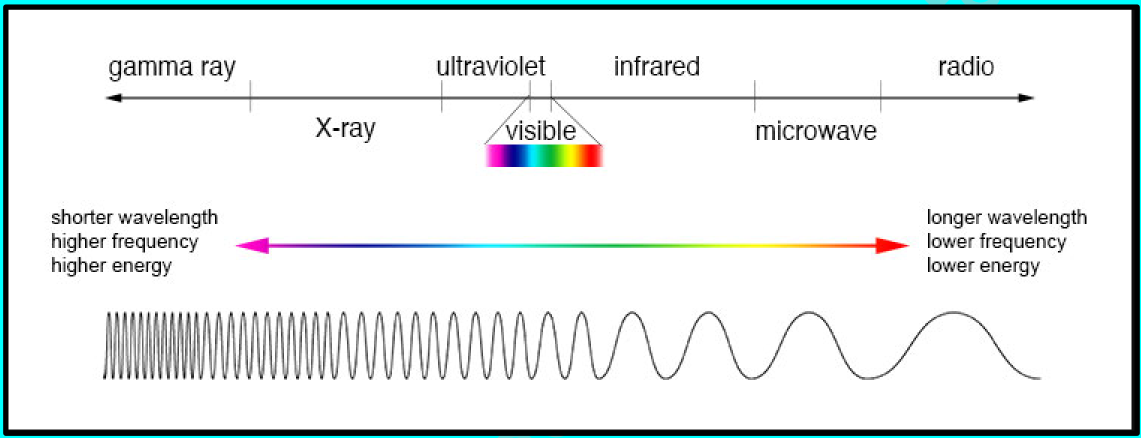
Every point on a wavefront may be consider as a source of the small secondary wavelets which spread out in the forward direction at the speed of light.

Second lecture (2)

Electromagnetic waves

1.5 Electromagnetic (EM) spectrum

The electromagnetic (EM) spectrum is the range of all types of EM radiation. Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation. The EM consist of many types of radiations, beginning at the low-frequency (long-wavelength) end of the spectrum these are**: radio waves, microwaves, infrared, visible light, ultraviolet, X-rays, and gamma rays** at the high-frequency (short wavelength) end



It is important to remember that the various kinds of electromagnetic radiation differ only in their **wavelength** and **frequency**. They are alike in all other respects and have same velocity (which is the **velocity** of light 3×10^8 m/sec).

$$c = \lambda f$$

Light, Electromagnetic Spectrum, Table 1 Regions of the electromagnetic spectrum

Wavelength range (nm)	Frequency range (s^{-1})	Description
<0.1 nm	10^{20}–10^{23}	Gamma rays
0.1–10 nm	10^{17}–10^{20}	X-rays
10–400 nm	10^{15}–10^{17}	Ultraviolet
400–700 nm	10^{14}–10^{15}	Visible
700 nm to 1 mm	10^{11}–10^{14}	Infrared
1 mm to 1 cm	10^{10}–10^{11}	Microwaves
1 cm to 100 km	10^{3}–10^{10}	Radio waves

Table : Metric, International System of Units (SI) Prefixes

Prefix	Unit Abbreviation	Meaning	Example
Tear	T	1,000,000,000,000	1 (Tm) = 10^{12} m
Giga	G	1,000,000,000	(Gm) = 10^{9} m
Mega	M	1,000,000	(Mm) = 10^{6} m
Kilo	k	1,000	(km) = 10^{3} m
Meter	m	1	1 meter (m)
Centi	cm	1/100	(cm) = 10^{-2} m
Milli	mm	1/1,000	(mm) = 10^{-3} m
Micro	µm	1/1,000,000	(µm) =10^{-6}m
Nano	nm	1/1,000,000,000	(nm) = 10^{-9}m
Angstrom	A^0	1/10,000,000,000	(A^0) = 10^{-10} m
Pico	pm	1/1,000,000,000,000	(pm) =10^{-12} m

Example 1. What is the frequency of orange light (λ =620 nm)?

Solution// $\boldsymbol{c = \lambda f \;\Rightarrow f = \frac{c}{\lambda} \;\Rightarrow c = \frac{3\,x\,10^8\ m/s}{620\,x\,10^{-9}}}$ = 576.5 x 10^{12} Hz

= 576.5 THz

Example 2. Determine the wavelength of the microwave radiation emitted by a microwave oven (f = 2.45x10^9 Hz).

Solution//

$\boldsymbol{f = \frac{c}{\lambda} \;\Rightarrow \lambda = \frac{c}{f} \;\Rightarrow \lambda = \frac{3\,x\,10^8\ m/s}{2.45\,x\,10^9\ Hz}}$ = 0.122 m = 1.22 cm

Example 3.

a- Determine the frequency of electromagnetic radiation which has a wavelength of 1.6 km.

b- What part of the electromagnetic spectrum does this fall within?

Solution//

$$a- \quad f = \frac{c}{\lambda} = \frac{3 \; x \; 10^{8} \; m/s}{1.6 \; x \; 10^{3} \; m} = 1.9x10^{5} \; Hz$$

b- Radio wave spectrum

1.6 The wave-particle duality of Light

In 1807, Thomas Young asserted that light has the properties of a wave in an experiment called Young's Interference Experiment. This Young's interference experiment showed that lights (waves) passing through two slits (double-slit) add together or cancel each other and then interference fringes appear. This phenomenon cannot be explained unless light is considered as a wave.

Albert Einstein in 1905 succeeded in explaining the photoelectric effect which had been unexplainable if one only considers light as a wave. Einstein asserted that light is a particle (called **Photon**) containing energy corresponding to their wavelength.

"Light is not only a wave but also a particle" in many phenomena behaves as a sequences of waves such as (Reflection, Refraction, Diffraction, Interference, Scattering and Polarization). However, in others phenomena, light behaves as steam of partials called

"photons" such as (Optical absorption, Optical emission, black body radiation, Compton effect, Photo electric effect,

The amount of energy carried by a photon is directly proportional to the photon's frequency and inversely proportional to its wavelength. To calculate a photon's energy, we use the following equations:

$$E = h\,f$$

Where **E** is the photon's energy [joules]. ***h*** is the **Planck constant**: 6.626 x 10^{-34} [m^2 * kg * s^{-1}], and f is the frequency [Hertz].

Or: $E = \frac{h\,c}{\lambda}$

Third lecture (3)

Practice Problems

Practice Problems

1. A photon has a frequency (*f*) of 2.68 x 10^{6} Hz. Calculate its energy.
   Ans: E = 1.78 x 10^{-27} J

2. Calculate the energy (E) and wavelength (λ) of a photon of light with a frequency (*f*)
   of 6.165 x 10^{14} Hz. *Ans: E = 4.1 x 10^{-19} J* *λ = 4.87 x 10^{-7} m*

3. Calculate the frequency and the energy of blue light that has a wavelength of 400 nm
   (h = 6.62 x 10^{-34} J-s). *Ans: f = 7.5 x 10^{14} Hz* *E = 4.97 x 10^{-19} J*

4. Calculate the wavelength and energy of light that has a frequency of 1.5 x 10^{15} Hz.
   Ans: λ = 2.0 x 10^{-7} m *E = 9.95 x 10^{-19} J*

5. A photon of light has a wavelength of 0.050 cm. Calculate its energy.
   Ans: E = 3.98 x 10^{-22} J

6. Calculate the number of photons having a wavelength of 10.0 μm required to produce 1.0 kJ of energy. *Ans: 5.0 x 10^{22} photons*

7. Calculate the total energy in 1.5 x 10^{13} photons of gamma radiation having λ = 3.0 x 10^{-12} m.
   Ans: 1.0 J

8. Calculate the energy and frequency of red light having a wavelength of 6.80 x 10^{-5} cm.
   Ans: E = 2.92 x 10^{-19} J *ν = 4.4 x 10^{14} Hz*

9. The wavelength of green light from a traffic signal is centered at 5.20 x 10^{-5} cm. Calculate the frequency.
   Ans: λ = 5.77 x 10^{14} Hz.

10. Calculate the frequency of light that has a wavelength of 4.25×10^{-9}m. Identify the type of electromagnetic radiation.

Ans: $f = 7.1 \times 10^{16}$ Hz.UV radiation

Equations and constants:

$E = hf$ and $E = hc/\lambda$ — E = energy of one photon with a frequency of f

$c = \lambda f$ $c/\lambda = f$ — c = speed of light = 3.0×10^{8} m/s

h = Planck's constant = 6.63×10^{-34} J-s

λ = wavelength in meters

f = frequency in Hz (waves/s or 1/s or s^{-1})

Fourth lecture (4)
Index of Refraction

1.7 Refractive index

Refractive Index (Index of Refraction) is defined as the ratio between the speed of light in a vacuum and its speed in a particular medium. The vacuum has a refractive index of 1. The formula for refractive index is.

$$n = \frac{C_o}{C_m}$$

- **n** is the refractive index.
- C_o is the velocity of light in a vacuum (3×10^8 m/s).
- C_m is the velocity of light in a material.

the value of n is usually greater than 1, where always c ≥ v.

in free space or vacuum and even the air n= 1, v = c so:

$$n = \frac{C_o}{C_o} = 1$$

1-The velocity of light in a free space (vacuum) is about 3×10^8 m/s

2- the velocity of light in a material substance is less than the velocity of light in the vacuum, because the electrical filed of the light wave interacts with the electrical filed of the molecules and atoms of the material.

3-the frequency of light **does not change** when light pass through the medium

4- Refractive index is the ratio of tow velocities, so it has no unit.

$$n = \frac{C_o}{C_m} = \frac{f\lambda_o}{f\lambda_m} = \frac{\lambda_o}{\lambda_m}$$

Refractive index (n) of different medium

medium	index of refraction n
vacuum	1.00 exactly
air	1.0003
water	1.33
oil	1.46
glass	1.50
diamond	2.41

1.8 Optical Path

When the light travels a distance (d) in the medium of the refractive index (n), the optical path (OP) is the product of (*n x d*)

$$[OP] = n_1 d_1 + n_2 d_2 + \cdots = \sum_{i=1}^{\infty} n_i d_i$$

Example: Find the optical path of the light in the 500 m of water ?

Solution: [OP] = *n x d = 1.33 x 500 = 665 m*

Example:
What is the velocity of light has a wavelength (λ = 500 nm) in the glass which has (n= 1.5) ?

Solution:

n=1.5 , C_o = 3 x 10^8 m/s , C_m =?

$\boldsymbol{n = \frac{C_o}{C_m}}$ ⟹ $\boldsymbol{C_m = \frac{C_o}{n}}$ ⟹ v= $\frac{\mathbf{3\ x\ 108\ m/sc}}{\mathbf{1.5}}$ = 2 x 10^8 m/s

Example: Light with wavelength in a vacuum of 500 nm, what is the wavelength of the light in glass (**n = 1.5**)?

Fifth lecture (5)

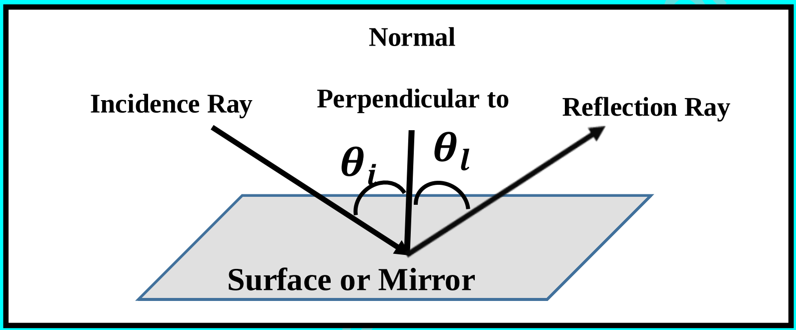
Law of Reflection

When a ray of light approaches a smooth polished surface and the light ray bounces back, it is called the **reflection of light.**

(Law of Reflection). The **angle of reflection** (the angle between reflected ray and the normal to the reflecting surface or the mirror) equals the **angle of incidence** (angle between incident ray and the normal). Also that the incident ray, reflected ray and the normal to the reflecting surface at the point of incidence lie in the same plane (see the figure below).

Angle of incidence (θ_i) = Angle of reflection (θ_l)

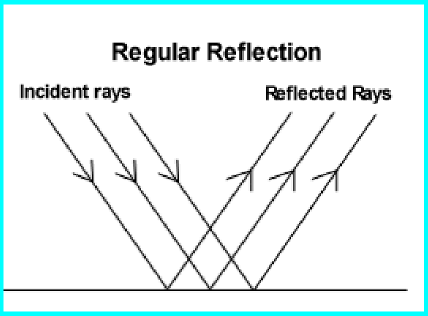
or $\theta_i = \theta_l$



2.1.1 Types of reflection

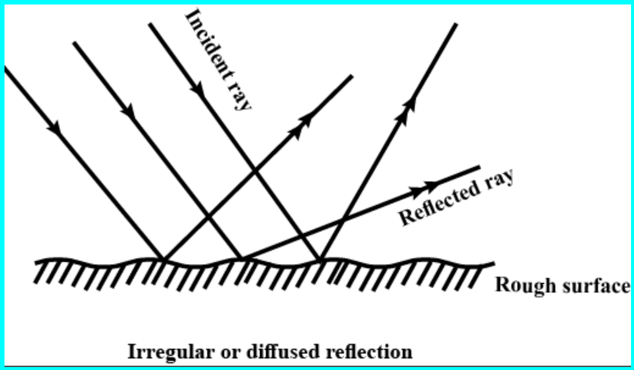
1- **Regular** reflection is also known as **specular** reflection.

It is the mirror-like reflection of light rays. In this case, the light rays are reflected from a smooth, shiny, or polished surface like that of a mirror, and are reflected by a definite angle. Here, the incident ray and reflected ray makes the same angle with the normal. The formation of an image is due to regular reflection.



2- **Diffused** reflection.

Diffused / Irregular reflection is a non-mirror type of reflection of light. In this reflection, the rays of light hit an irregular object with a rough surface and are reflected back from the object and scattered in all directions. In this case, the incident ray and the reflected ray don't make the same angles with the normal. This is because the angle of incidence and the angle of reflection are different.

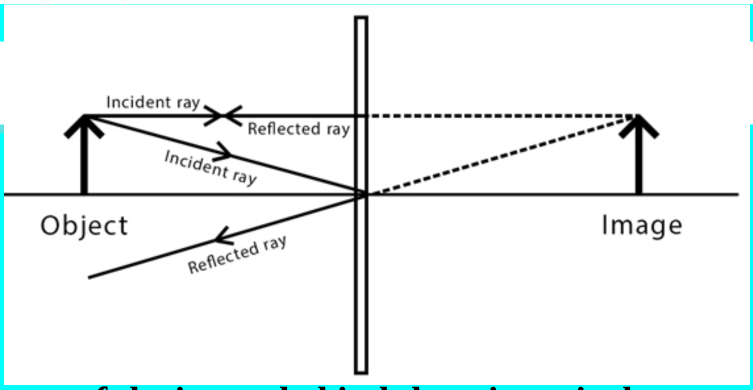


2.1.2 Reflection in the plane (Flat) Mirror

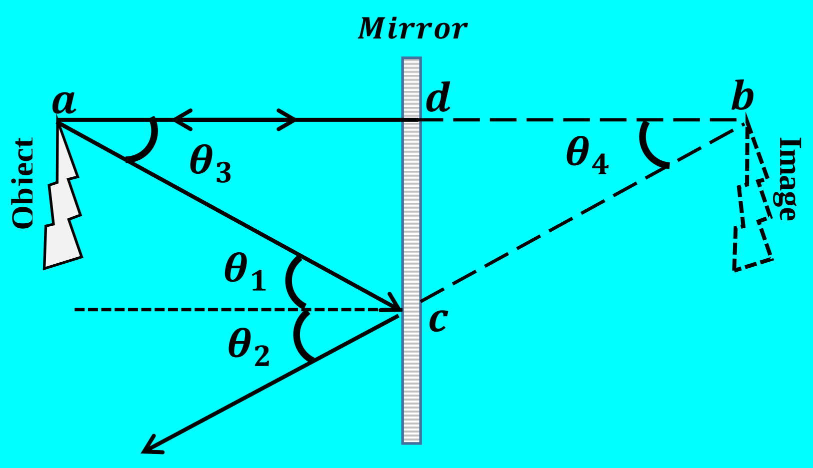
A mirror with a flat or planar reflective surface is called a plane mirror. The reflected angle is always equal to the incident angle for all the light rays, which strike the plane mirror. The angle that occupies within the incident ray and the normal is called the angle of incidence. The normal is said to be an imaginary line that is perpendicular to the surface.

Characteristics of the image formed by a plane mirror: -

1) The image formed is erect
2) The image is virtual (*because the image formed by the extended of the ray*)
3) The image is laterally inverted. *The right side appear to be left, and the left side appeared to be right.*
4) **The size of the image is equal to the size of the object.**
5) **The distance of the image behind the mirror is the same as the distance of an object from the mirror.**



<u>Prove</u>// The distance of the image behind the mirror is the same as the distance of an object from the mirror?



<θ1 = <θ2
(Law of reflection)

<θ1 = <θ3
(Alternate angles)

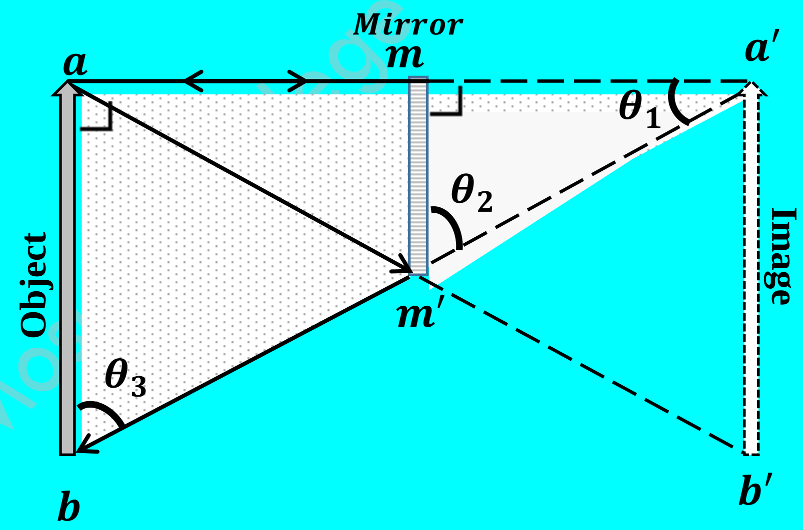
So, <θ2 = <θ3

<θ2 = <θ4
(Corresponding Angles)

So, <θ3 = <θ4

So Δ ***abc*** is isosceles triangle, therefor the normal *cd* is divided the bases *ab* into two equal parts ***ad* =*db*** (***ad*** (object distance)= ***db*** (image distance)

<u>Prove</u>// The minimum length of a plane mirror required to see the full image of an object must be ½ the length of that object ?



Δ ma/m/ ***and*** **Δ aa/b** ***are similar,***

Because they have three identical triangles, where θ_1 is common angle, <θ2 = <θ3 (Corresponding Angles) and the third angle is right for both (90^0).

So $\frac{\overrightarrow{aa'}}{\overrightarrow{am}} = \frac{\overrightarrow{ab}}{\overrightarrow{mm'}}$ **But,** $\overrightarrow{am} = \frac{1}{2}\overrightarrow{aa'}$

So $\frac{\overrightarrow{aa'}}{\frac{1}{2}\overrightarrow{aa'}} = \frac{\overrightarrow{ab}}{\overrightarrow{mm'}}$ then $\frac{\overrightarrow{ab}}{\overrightarrow{mm'}} = 2$ So, $\overrightarrow{mm'} = \frac{1}{2}\overrightarrow{ab}$

System with two plane mirrors with angle (θ) between them.

The number of images can be calculated by:

$$No.of\ images = \frac{360^o}{\theta} - 1$$

In case θ = o^0 (zero degree)

$$No.of\ images = \frac{360^o}{0^0} - 1 = \infty - 1 = \infty$$

In case θ = 90^0

$$No.of\ images = \frac{360^o}{90^o} - 1 = 4 - 1 = 3$$

In case θ = 180^0

$$No.of\ images = \frac{360^o}{180^o} - 1 = 2 - 1 = 1$$