References

1-FUNDAMENTALS OF OPTICS, **Francis A. Jenkins**
University of California, Berkeley
2-اساسيات البصريات ترجمة عبد الفتاح الشاذلي –جامعة عين شمس

Optics is divided into three groups

Quantum optics
- Atomic orbits
- Probability densities
- Energy levels
- Quanta
- Lasers

Wave optics
- Interference
- Diffraction
- Electromagnetic character
- Polarization
- Double refraction

Geometrical optics is including:
- Rectilinear propagation
- Finite speed
- Reflection
- Refraction
- Dispersion

Syllabus

Chapter One (The Nature and Propagation of Light),
Wave front and rays, Huygens principles. Index of refraction,
The electromagnetic Spectrum,
Color dispersion
Problems

Chapter Two (Reflection and Refraction
1) Reduced distance -Optics path Reflection and refraction at plane surface, Fermat's principle
2) The laws of reflection and refraction.
3) **Refraction by a prism**
4) Minimum deviation
5) Plane –parallel plate
Ray treatment of reflection and refraction,
6) The principle of Reversibility,
Problems

Lect. 1

The Nature and Propagation of Light

(1-1)The Nature of Light

Light is a transverse electromagnetic wave.

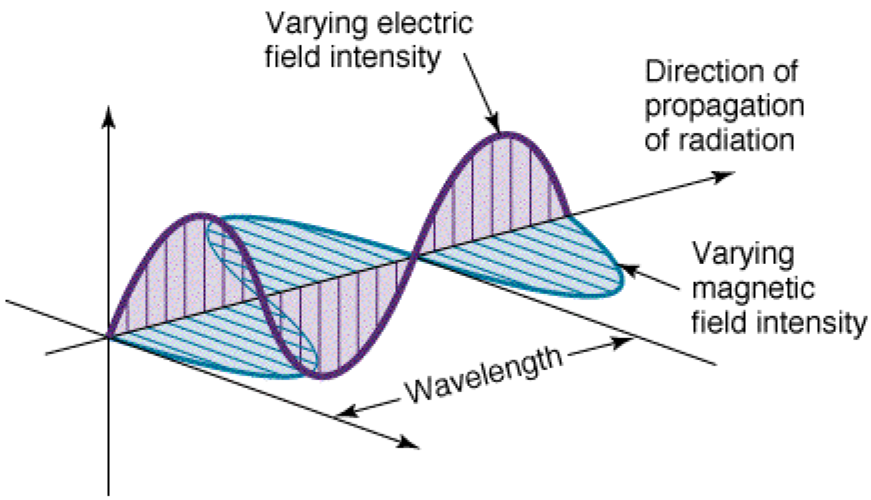


Figure (1): An Electromagnetic Wave is an alternating oscillations of the Electric (E) and Magnetic (B) fields,

1- 2) Wave front and Rays

A **wave front** is a surface passing through the points of a wave that have the same phase and amplitude.

There are two types of optical waves:

1) In a *plane wave* all rays are parallel to each other, and one can track just a single ray.
2) In *spherical wave* rays are along the radial directions and are divergent.

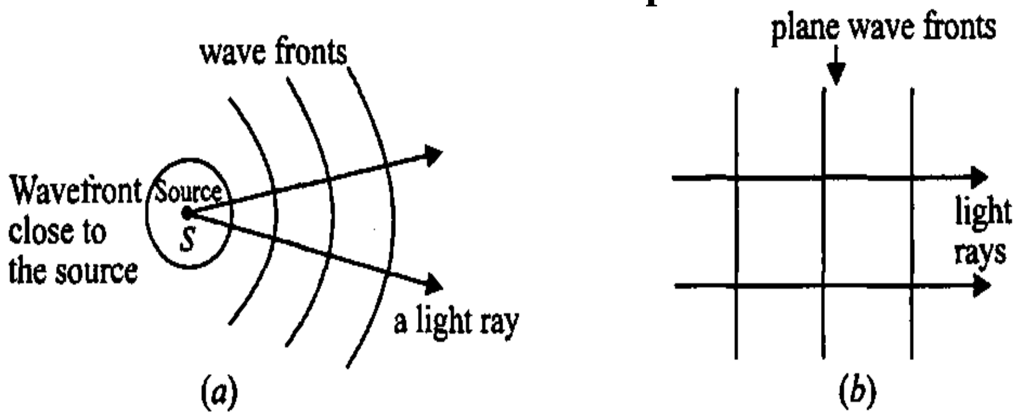


Figure (2): types of wave

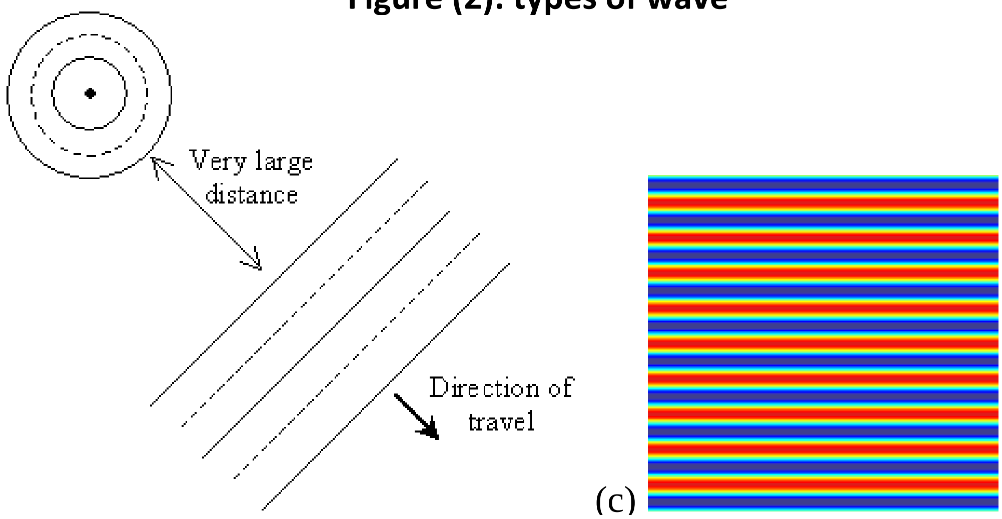
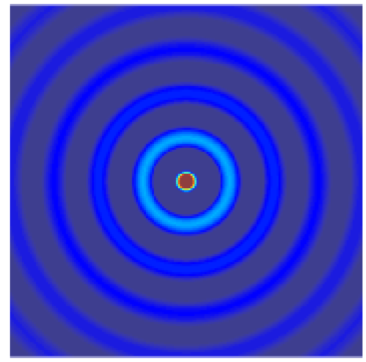


Figure 3: wove front shape (a) spherical and (b) planar, (c) difference between them after very large distance

In optics it is sufficient to track just the rays, if one is interested in phenomena over distances larger than a wavelength of light. This is **approximation of geometrical optics**



Point source emits spherical waves.

Far from the source, segment of spherical surface looks like plane and we speak about rays . EM waves from distant stars is very planar !

<u>Ray</u>

A ray is a thin beam of light that travels in a straight line.

(1-2) THE RECTILINEAR PROPAGATION OF LIGHT

The rectilinear propagation of light is the technical terminology applied to the principle that "light travels in straight lines." The fact that objects can be made to cast fairly sharp shadows may be considered a good demonstration of this principle.

Another illustration is found in the pinhole camera. In this simple and inexpensive device the image of a stationary object is formed on a photographic film or plate by light passing through a small opening, as diagramed in Fig. 3

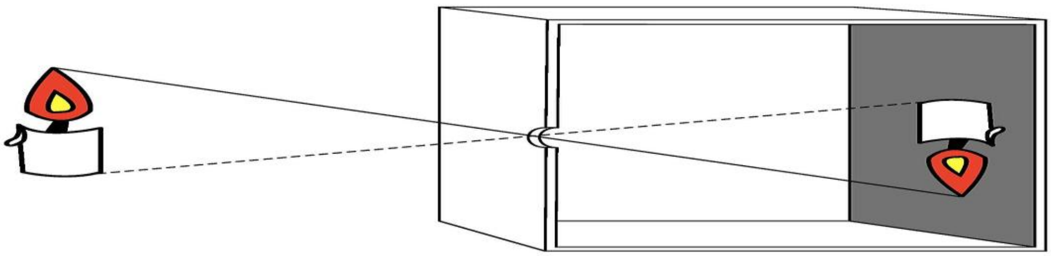


Figure 3: A demonstration experiment illustrating the principle that light rays travel in straight lines.

$c = 2.99792458 \times 10^8$ m/s .

Speed of light in vacuum is a fundamental physical constant

The EM wave travels in vacuum at a constant speed

$V = c = 3 \times 10^8$ m/s

$f\lambda = c$ (1)

(1-3) Photon

The particle-like nature of light is modeled with photons. A photon has no mass and no charge.

Particle Properties of Light

A beam of light Particle Properties of Light is modeled as a stream of photons, each carrying a well-defined energy that is dependent upon the wavelength of the light. The energy of a given photon can be calculated by: $E = \hbar f$.

$\hbar$ is called *the Planck's constant* and is another fundamental constant of nature.

Light presents itself a sequence of particle (photons) which have energy proprtional to the frequency

Photon energy (E) = hc/λ (2)

where E is in joules

h = Planck's constant = 6.625 10^{-34} J·s
c = Speed of light = 2.998 × 108 m/s
λ = Wavelength of the light (Units of length such as nm, Å ,etc.)

Since $f_{blue} > f_{red}$, blue photons carry more energy than red photons!

Example (2) :
Photons in a yellow light have a wavelength of 550 nm. (The symbol nm is defined as a
Nanometer = 10^{-9} m.) What is the energy of this photon?

Solution:
Photon energy (E) = hc/λ = $6.6*10^{-34}$ j. s$*3*10^{8}$ m/s/$550*10^{-9}$ m

E= **joule**

(1-4) the four important theories of light

Different theories on the nature of light have been proposed. The important theories are as follows:

- Newton's Corpuscular Theory
- Huygens' Wave Theory
- Maxwell's Electromagnetic Theory
- Planck's Quantum Theory

1- Newton's Corpuscular Theory

Newton's corpuscular theory of light is based on the following points
1. Light consists of very tiny particles known as "corpuscular".
2. These corpuscles on emission from the source of light travel in straight line with high velocity
3. When these particles enter the eyes, they produce image of the object or sensation of vision.
4. Corpuscles of different colors have different sizes.

2- Huygens' Wave Theory

- The wave theory says that every point on the wavefront is taken as a source of secondary spherical wavelets.

Each point on the wavefront radiates spherical waves which interfere to preserve it during propagation(see fig

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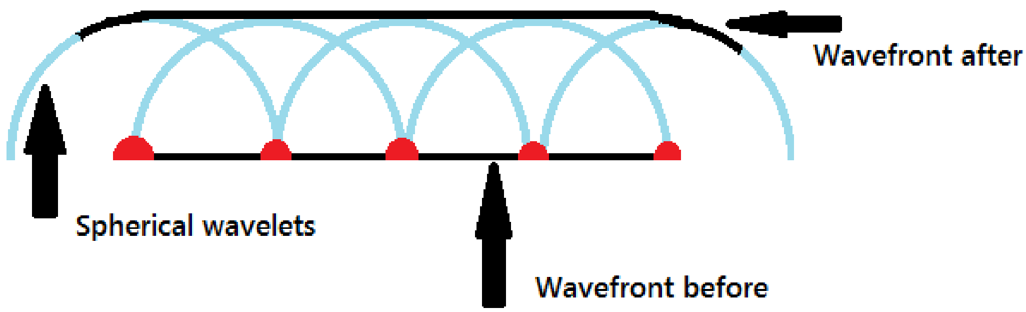


To brief of Huygens' wave theory of light
1. Each point in a source of light sends out waves in all directions in hypothetical medium called "ETHER".
2. Light is a form of energy
3. Light travels in the form of waves.
4. A medium is necessary for the propagation of waves & the whole space is filled with an imaginary medium called Ether
5. Light waves have very short wave length

3) Maxwell's Electromagnetic Theory

Maxwell’s wave equation showed that the speed of the waves, labeled c, is determined by a combination of constants in the laws of electrostatics and magnetostatics—in modern notation: $c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$ where ε_0, the permittivity of free space, has an experimentally determined value of 8.85×10^{-12} square coulomb per newton square metre, and μ_0, the magnetic permeability of free space, has a value of 1.26×10^{-6} newton square seconds per square coulombs

4) Planck's Quantum Theory

Two major postulates of this theory are:-

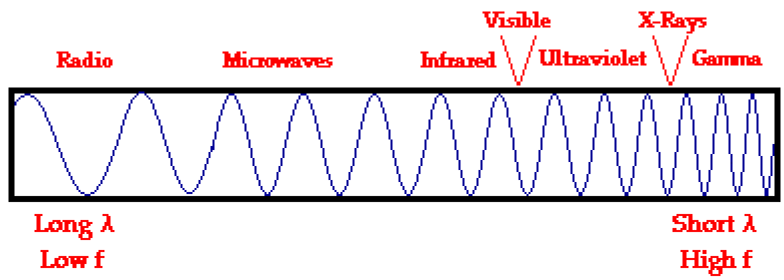
The amount of energy of energy associated with a quantum(or photon) of radiation is proportional to the frequency of radiation.

=> E = hv , where v is frequency of radiation and h is called Planck's constant (= 6.625 × 10^ -34 J.s).theory is put forward to explain phenomenon's like Black Body radiation, Photoelectric effect, etc.

(1-5) Electromagnetic spectrum

Distribution of light in frequency (wavelength) is EM spectrum. EM radiation is classified into types according to the frequency of the wavelength.

$E=hf=h\, c/\lambda$



The diagram below depicts the electromagnetic spectrum and its various regions.

If the EM wave has wavelength in the **visible** range **400 nm <** $\boldsymbol{\lambda}$**< 700 nm**

Our eyes interpret EM waves with different wavelengths in the visible range as different colors.

In order of long wavelength to short wavelength: red, orange, yellow, green, blue, indigo, violet

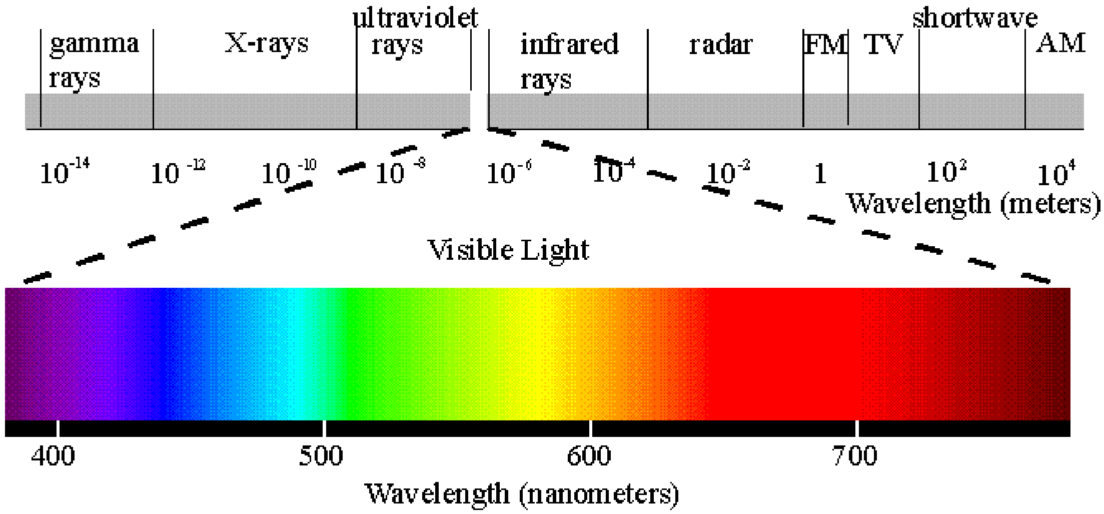
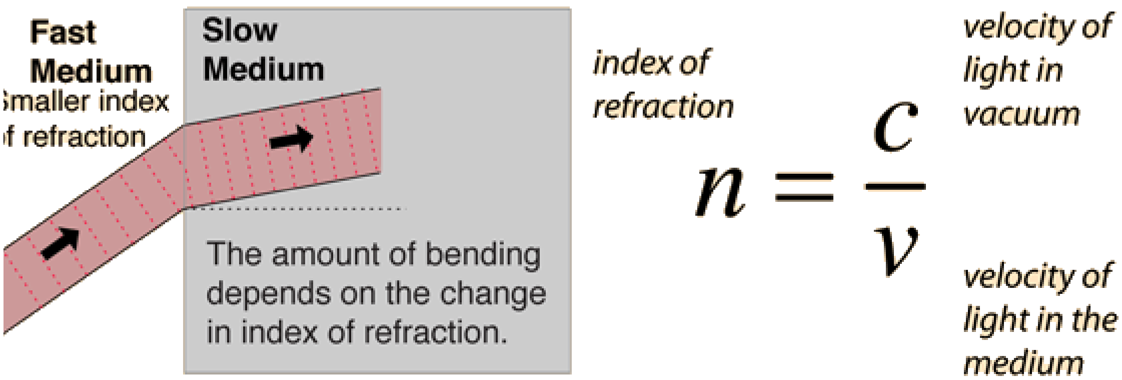


Table (1-1) : represented the wavelength and frequency ranges of the divisions of the electromagnetic spectrum.

Category	Range of Wavelengths (nm)	Range of Frequencies (Hz)
gamma rays	<1	$>3\times10^{17}$ $>3\times10^{17}$
X-rays	1–10	3×10^{16} –3×10^{17}
ultraviolet light	10–400	$7,5\times10^{14}$ –3×10
visible light	400–700	$4,3\times10^{14}$ –$7,5\times10^{14}$
Infrared	700–10^{5}	3×10^{12} –$4,3\times10^{14}$
microwave	10^{5} –10^{8}	3×10^{9} –3×10^{12}
radio waves	$>10^{8}$	$<3\times10^{9}$

(1-6) THE REFRACTIVE INDEX

The index of refraction, or refractive index, of any optical medium is defined as the ratio between the speed of light in a vacuum and the speed of light in the medium:



$$n = \frac{c}{v}$$

Table (1-1) :shows different refractive index with various materials.

Material	**n**	**Material**	**n**
Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

Example (1): The speed of light in an unknown medium is measured to be 2.76 x 10^8 m/s. What is the index of refraction of the medium?

Solution:

The index is found to be

$n = c/v$ = (3.00 x 108 m/s)/(2.76 x 108 m/s) = 1.09.

(1-7) Optical path

In a medium of constant refractive index, *n*, the optical path length OPL for a path of physical length *d* ,to define a quantity called the *optical path.* The path *d* of a ray of light in any medium is given by the product *velocity* times *time:*

$$d = vt$$

Since by definition $n = clv$, which gives $v = c/n$, we can write the product *nd* is called the *optical path* Δ:

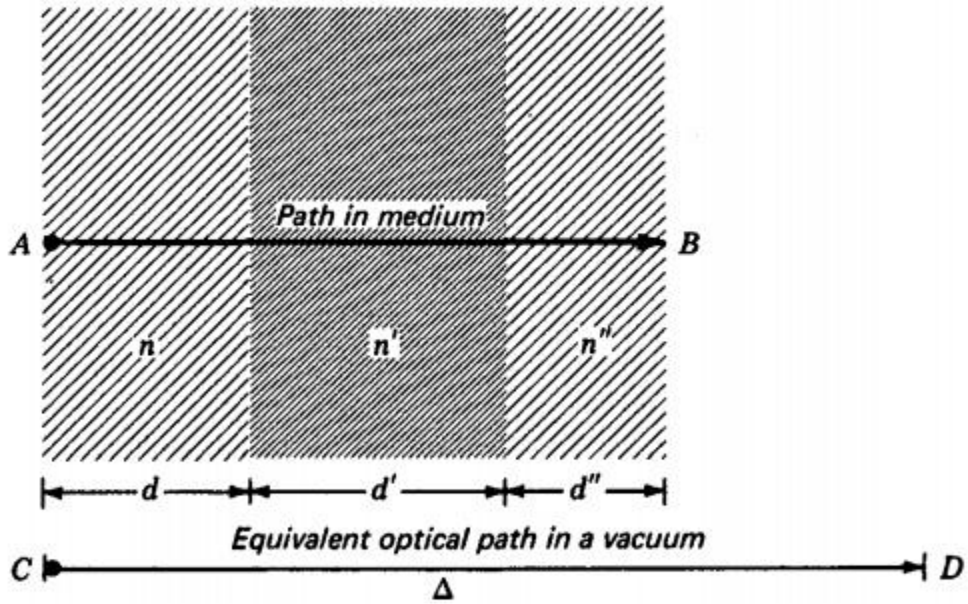
$$nd = ct$$

$$\Delta = n\,d$$

The optical path represents the distance light travels in a vacuum in the same time it travels a distance *d* in the medium. If a light ray travels through a series of optical media of thickness *d, d', d"* ... and refractive indices *n, n',* *n''*, ... , the total optical path is just the sum of the separate values:

.If the refractive index varies along the path, the OPL is given by

$$Opt= n_1d_1+n_2d_2$$



Problems chapter one

From (FUNDAMENTALS OF OPTICS, **Francis A. Jenkins)**

1.4 If the refractive index for a piece of optical glass is 1.5250, calculate the speed of light in the glass. *Ans.* 1.9659 x 108 *m/s*

1.5 Calculate the difference between the speed of light in kilometers per second in a vacuum and the speed of light in air if the refractive index of air is 1.0002340. Use velocity values to seven significant figures.
1.6 If the moon's distance from the earth is 3.840 x 105 km, how long will it take microwaves to travel from the earth to the moon and back again?

1.7 How long does it take light from the sun to reach the earth? Assume the earth's distance from the sun to be 1.50 X 10^8 km. *Ans.* 500 s, or 8 min 20 s

1.8 A beam of light passes through a block of glass 10.0 cm thick, then through water for a distance of 30.5 cm, and finally through another block of glass 5.0 cm thick. If the refractive index of both pieces of glass is 1.5250 and of water is 1.3330, find the total optical path.

1.9 A water tank is 62.0 cm long inside and has glass ends which are each 2.50 cm thick. If the refractive index of water is 1.3330 and of glass is 1.6240, find the overall optical path.

1.10 A beam of light passes through 285.60 cm of water of index 1.3330, then through 15.40 cm of glass of index 1.6360, and finally through 174.20 cm of oil of index 1.3870.
Find to three significant figures *(a)* each of the separate optical paths and *(b)* the total optical path. *Ans. (a)* 380.7, 25.19, and 241.6 cm, *(b)* 647 cm

1.11 A ray of light in air is incident on the polished surface of a block of glass at an angle of 10°. *(a)* If the refractive index of the glass is 1.5258, find the angle of refraction to four significant figures. *(b)* Assuming the sines of the angles in Snell's law can be Replaced by the angles themselves, what would be the angle of refraction? *(c)* Find the percentage error.

1.12 Find the answers to Prob. 1.11, if the angle of incidence is 45.0° and the refractive index is 1.4265.
1.13 A ray of light in air is incident at an angle of 54.0° on the smooth surface of a piece of glass. *(a)* If the refractive index is 1.5152, find the angle of refraction to four significant figures. *(b)* Find the angle of refraction graphically. (See Fig. P1.13).
Ans. (a) 32.272°, (b) 32.3°