**OPTICS**

**Lesson 1**

Let us start with two important questions:

* **Why should an engineer study optics?**
* **What should be our approach?**

Let us take the first question:

There are two important word ‘*Engineer’* and ‘*Optics*’

Who is an Engineer?

* An **Engineer** applies scientific knowledge to solve technical problem or he/she fabricates devices which are useful to the society at large.

What is optics?

* **Optics**: studies relating to the behavior and properties of light including its interaction with matter and the construction of instrument that use or detect it.

Before we go to the engineering and optics there are two very important points about light:

1. The energy from sun is coming in the form of light which is processed by plants (Photosynthesis) and we survive
2. All our physical communications are because of light.

But these are not enough reasons for an engineer to study optics. It is because an engineer has to produce things and solve everyday problems and challenges.

*Some practical examples:*

1. One summer I was in Jodhpur for few months and I visited a farm ‘*Kansara* ‘. This farm produces roller bearings which are then exported to Germany. The German company needs very high precision roller bearings (say of the order of the fraction of mm). So they had designed an instrument which can measure the length of the roller bearings very precisely. I was quite amazed to see that an instrument which does this job very efficiently using a light beam (laser beam) to separate out the pieces which does not meet the required specifications of length. But what bothered me was that the instrument was bought from Germany and not from India. But Indian engineers could have easily done it. So it is the idea which is important and in order to get these ideas we need to study the basics of optics (or any science), remember them and apply them. So, just learning for examination will not help anyone.
2. The second example I would like to give is of an experiment which is there in our first year Physics Lab: *‘To find the slit width using single slit diffraction experiment’* in which you find the slit width of the order of few hundred micron but the same has many industrial application like to find the crack in a wheel.

**Why should an Electronics Engineer read optics?**

A quite popular subject: [**Optoelectronics**](http://en.wikipedia.org/wiki/Optoelectronics) which deals with the large number of phenomena and devices connected with optics and electronics for example *Led*, *Lasers*, *Photodiodes,Photo voltaic devices* etc. This subject includes analytical study of optics and sound knowledge of fabricating the electronic devices.

But the most important application is Mobile Phone and internet which is possible through [Fiber Optic Communication](http://inventors.about.com/library/weekly/aa980407.htm). Today the entire world is connected through extensive optical network such as the under sea fiber optic cable [SEA-ME-WE3](http://en.wikipedia.org/wiki/SEA-ME-WE_3) which is an undersea ***WDM*** (wavelength division multiplexing) cable network starting from *Norway to Singapore*. Our country connects this cable at Mumbai and Cochin

**Why should a Computer Science Engineer read optics?**

[Quantum information](http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=12555) is a new emerging field where physical information is held in a state of a quantum system, a subject partly emerged from *quantum optics* and partly from theoretical *computer science*. So bringing photons into use for information transfer and computation .

[Optical Computing](http://mitpress.mit.edu/catalog/item/default.asp?ttype=2&tid=9271) where photons takes place the place of electrons will probably be our future computer industry which will be very fast. Optical transistors, Optical Gates are new upcoming chips that will replace the electrical ones.

[Holographic Data Storage](http://www.signallake.com/innovation/ashley.pdf) HVD disks can store 200 times more data than single DVD.

There are many other important areas like [Computer Vision](http://en.wikipedia.org/wiki/Computer_vision) for surveillance videos etc. where knowledge of optics is very important for computer engineers.

**Now! what should be *our approach*?**

Read the basics first; Solve good examples; Do good experiments; Design Projects - only then it will be clear how the concepts are used. Also watch videos related to optics on YouTube.

**Branches of Optics**

On the basis of behavior of light and its interaction with matter, study of optics could be broadly classified into three main branches.

1. **Geometric Optics:** Study of light as rays.
2. **Physical Optics:**  Study of light as waves
3. **Quantum Optics:** Study of light as massless particles -photons with energy

**Geometrical Optics**

Light travelling through straight line, like sunlight coming through a hole in the room. Large objects cast sharp shadows. The object with which light is interacting is far larger in dimension than the wavelength of light. (So there is no diffraction effect. It is not the case for sound wave or (water waves).

**How does it interact with the matter?**

1. **Law of Reflection** – By Euclid around 300 BC, explains the nature of reflected rays.
2. **Law of Refraction** – By Snell in 1621, It explains how a light ray changes direction when it passes a planar boundary from one material to another – for example a pencil half submerged in the glass of water appears to be bent

**Applications:** All type mirrors and optical devices as telescopes, microscopes, lenses, mirrors etc.

**Physical Optics**

It is the wave Optics

Three Basic concepts of physical optics are Interference, Diffraction and Polarization

**Applications** of wave optics are:

[*Holograms*](http://en.wikipedia.org/wiki/Holography), [*Interferometer*](http://en.wikipedia.org/wiki/Interferometer), thin film interferometer, coating for high reflection and antireflection,[*gratings*](http://en.wikipedia.org/wiki/Diffraction_grating), [*polarizers*](http://en.wikipedia.org/wiki/Polarizers), [*Quarter wave plates*](http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/quarwv.html)*,* laser beam divergence in the near and far field

**Quantum Optics**

It is the field of Quantum Physics that deals specifically with the **interaction of photons with matter.**

According to the findings of quantum optics EM - radiation is both a wave and a particle that is wave particle duality. The overall behavior of these particles is determined by the probability of the particle being at a given location at a given time.

**Applications:** Photodiode, Lasers etc.

**QED**[(quantum electrodynamics)](http://en.wikipedia.org/wiki/Quantum_electrodynamics) : A kind of Mathematical description mostly developed by Feynman; he interpreted Quantum optics in the form of creation and annihilation of photons described by field operations.

**History**

**Why history of science is important?**

History of Science is different from just ‘History’ It tells us how the theories evolved. It is the **history of ideas**. It gives us an added insight into sciences and develops a scientific outlook. It motivates us to seek further and deeper knowledge in science. It also helps us to understand the latest theories very deeply.

**Pre Newtonian Era/Ancient history (Ist ERA)**

(Till 11th century AD)

* **Euclid**(Greek Mathematician300 B.C) OPTICA – Light travels in straight line and described the laws of reflection.
* **Ibn –Al – Haytham** also known as **Alhazen** – Published seven volume treatise on Optics. Light consists of rays which originates in the object and not in the eye, a view contrary to Euclid and Ptolmey.

**Newtonian Era (IInd ERA)**

(15 Century AD)

Two major developments in this era

1. Corpuscular nature of light

* Pierre Gassendi (1592-1655) – Proposed Corpuscular theory
* Descartes (1596-1650)

Developed laws of refraction independently

* Snell (1580 -1626)
* Newton (1643 – 1727) – strong proponent of Corpuscular theory of light

He wrote two books related to optics: Hypothesis of light(1675) and OPTICKS (1704). They described Reflection as a result of elastic collision. And Refraction as a result of attraction of light particles by the denser medium which increases the speed of light so the light refracts and bends.

1. Fabrication of Optical Devises

Newton – First reflecting Telescope

Galileo – 1609 Refracting Telescope

Compound Microscope

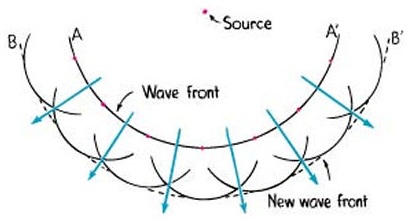
1595 First Microscope in Holland

**Post Newtonian Era (IIIrd ERA)**

Huygens Wave theory

**Wave theory**

Electromagnetic Wave theory

* Robert Hooke (1660) published ‘Wave theory of light’(1690)
* Christiane Huygens (1678) published ‘Treatise on light’(contemporary of Newton)
  + - Light emitted in all directions as wave in a medium called ether
    - It was assumed that they slowed down upon entering a denser medium.
    - He demonstrated how waves might interfere to form a wave front propagating in a straight line.
    - Various points of an arbitrary surface, as they are reached by a wave front become the sources of secondary wavelet. The geometrical envelope of these wavelets at any given time is called wave front at that time.
    - This explains the [laws of reflection and refraction](http://micro.magnet.fsu.edu/primer/java/reflection/huygens/index.html) by wave theory
    - Huygens proposals remained in a dump for almost a century because of great faith in Newton’s writings.

Double Split Experiment: Thomas Young

This experiment seriously challenged the corpuscular theory of light as it cannot be explained by the Corpuscular theory of light. (Why?)

This is one of 10 most beautiful experiments in physics.

The experiment proposed that different colours were caused by different wavelengths of light and thus calculated wavelength of all seven colours.

Young and Fresnel were the first to state that ***light waves were transverse*** and explained polarization.

Fresnel

He worked his own wave theory of light and presented it to ‘Academic des science. He did experiment with diffraction of light. His famous relation known as [**Fresnel relation**](galileo.phys.virginia.edu/classes/531.cas8m.fall05/l6.pd) which relates parallel and perpendicular component of - field after reflection and refraction from a surface.

It almost overturned the Newton’s Corpuscular theory but one last step needed to be solved, i.e. speed of light inside the medium is less than that outside/vacuum.

Leon Foucault (1850)

He measured accurately the speed of light in air and in the material and found that the speed of light decreases in the material. This was the complete defeat of corpuscular theory.

**Electromagnetic Waves**

Faraday (1845)

He observed angle of polarization ([Faraday rotation](http://www.pas.rochester.edu/~advlab/reports/padmaraju_faraday.pdf)) of a light beam as it passed through a polarizing material and noticed that it could be altered by magnetic field.

He proposed light as a high frequency electromagnetic vibration

Maxwell (1873)

Maxwell was inspired by Faraday’s work.

Laws of electricity and magnetism can be described by 4 partial differential equations known as Maxwell equations.

From the above equations he derived the form of self-propagating electromagnetic waves which would travel through space at constant speed. This was very close to measured speed of light.

He concluded that light was a form of E M radiation. His prediction came true when Hertz observed electromagnetic wave as radio wave from a spark gap.

[**Michelson and Morley Experiment**](http://galileoandeinstein.physics.virginia.edu/lectures/michelson.html)

Light which is travelling from Sun needs a material medium to travel and in the same context luminiferous ether was proposed.

He designed an interferometer to detect the presence of ether but the results were negative. So, it was proved that there is no ether. So electromagnetic waves (EM) waves do not need any material medium to travel.

**Quantum Optics**

Max Planck

Difficulties in the wave theory seemed to show up in the situation that involved interaction of light with matter.

In 1899, at the very dawn of twentieth century, Max Planck announced in a meeting of German Physical Society that he was able to derive correct black body spectrum by assuming the atoms emitted light in discrete energy chunks rather than in a continuous manner. Thus Quanta and Quantum Mechanics were born. According to Planck the energy E of an electromagnetic radiation is proportional to the frequency νof the radiation

, Planck’s const.

Einstein

He explained the photoelectric effect making use of the fact that light consists of light quanta whose energy is related to frequency by Planck’s equation

Neil’s Bohr

He incorporated the quantum of radiation in his explanation of the emission and absorption process of the hydrogen atom, proving the physical basis for understanding the hydrogen spectrum.

Crompton (1922)

He explained the scattering of X- rays from electrons as particle like collision between light quanta and electrons in which both energy and momentum were conserved.

Gilbert Lewis

He suggested the name of photon for the quanta of light.

**Wave Particle Duality**

(Re-appearance of the wave property)

Lewis De Broglie

He explained that the subatomic particles are endowed with wave properties.

That is a particle has an associated wavelength. And is Planck’s constant

Thus the wave particle duality came fill circles.Light behaves like waves in its propagation in the phenomena of interferences, diffraction and polarization; however it exhibits particle like behavior when it exchanges energy with matter as in Compton and Photoelectric effect.

Similarly electron also behaves as particles as well as like waves in the diffraction produced by electron microscope

Feynman

QED (Quantum Electrodynamics) : A mathematical formulation of light and its interaction with matter developed by Feynman.