PH203: Optics

Lecture #1 + Lecture #2

31.10.2018 + 01.11.2018

PH203: Modern Physics and Optics

Brief description of the Optics Course:

- Fermat's principle and applications in geometrical optics
- Introduction to Wave Optics, Interference due to division of wave front and division of amplitude
- Introduction to diffraction, Fresnel's and Fraunhoffer diffraction, Diffraction by single and double slits, Diffraction grating
- Introduction to polarization, Types of Polarization, Malus's and Brewster's Laws, Application of Polarization
- Spontaneous and stimulated Emissions, Population Inversion, Working principle of Laser and its application
- Principle of propagation of light in optical fiber, Acceptance angle, Types of optical fibers, Optical Fiber in communication

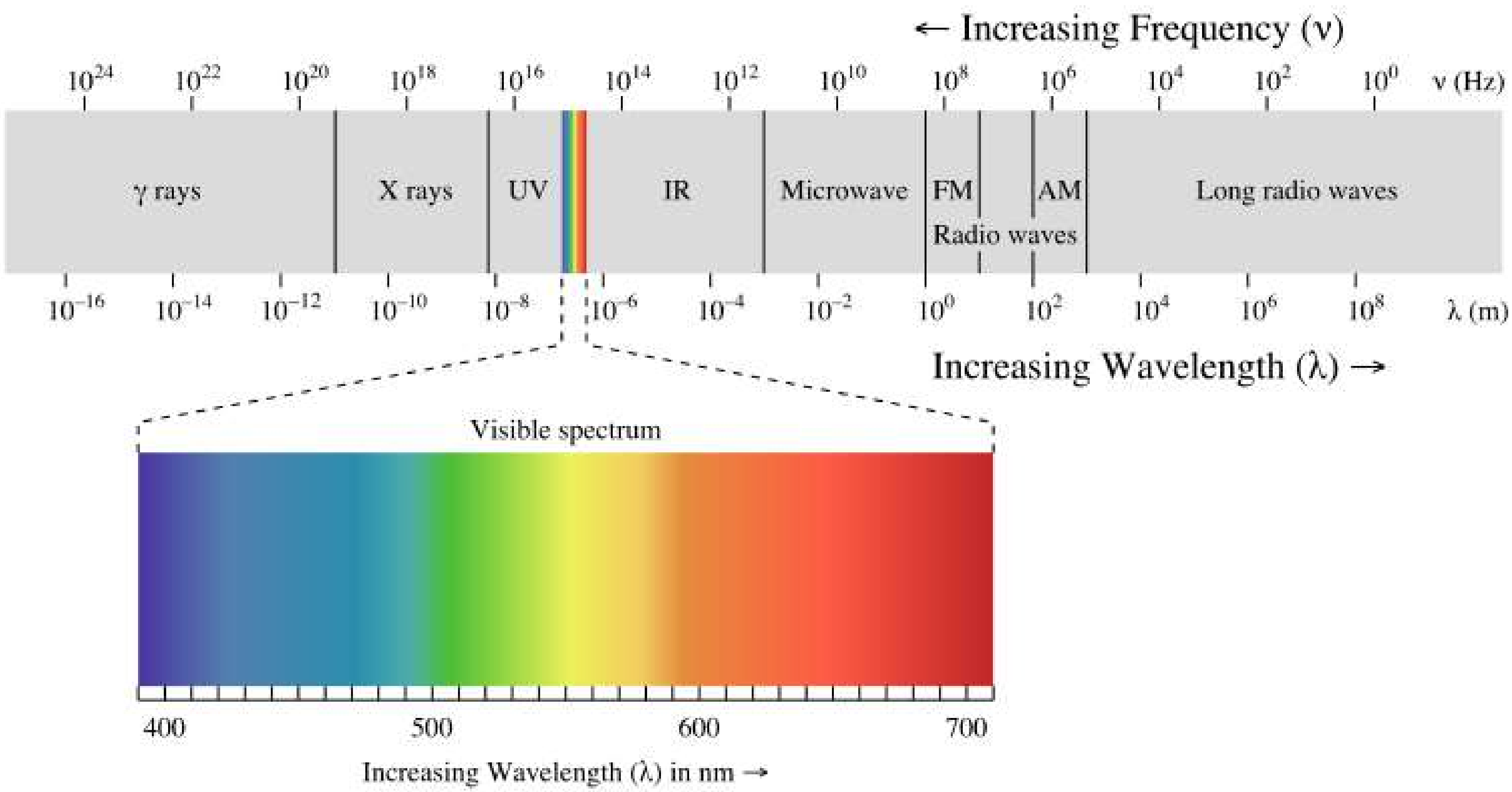
Text Book:

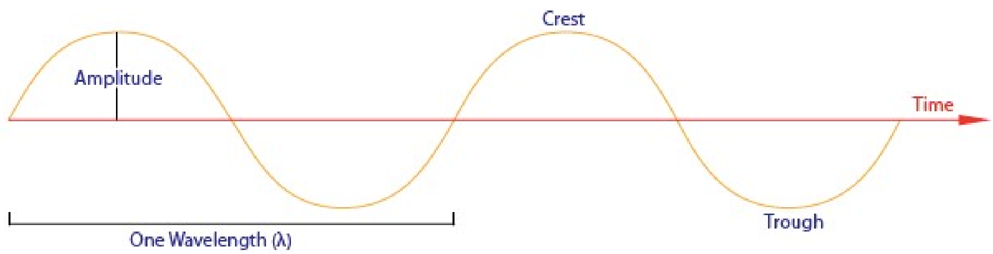
1. ***"Optics"*** by A. Ghatak, 6th Edition, McGraw-Hill Publication.

Reference Books:

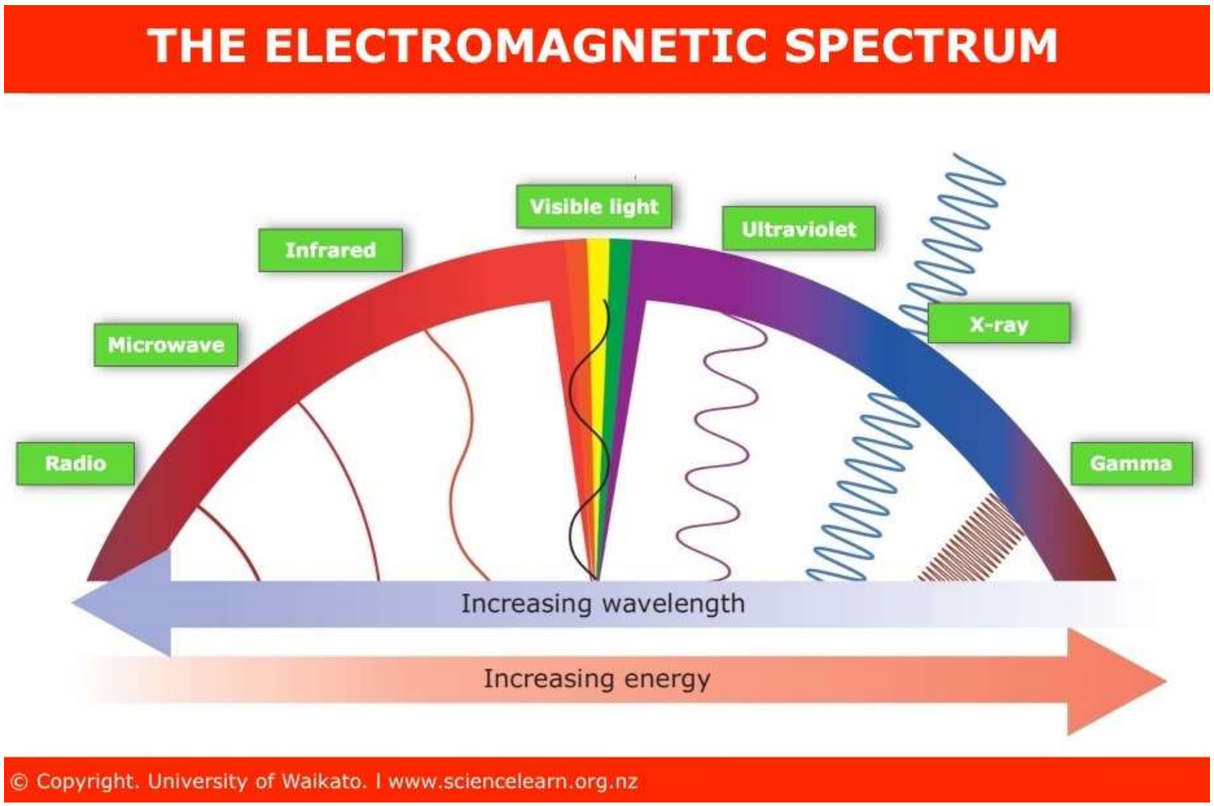
Fundamentals of Optics by Francis Jenkins & Harvey White, Tata-McGraw-Hill, 4th Edition.
Optics by Eugene Hecht

Electromagnetic spectrum





$$\lambda = \frac{c}{\nu} \quad \Rightarrow \quad \nu = \frac{c}{\lambda}$$



ω?

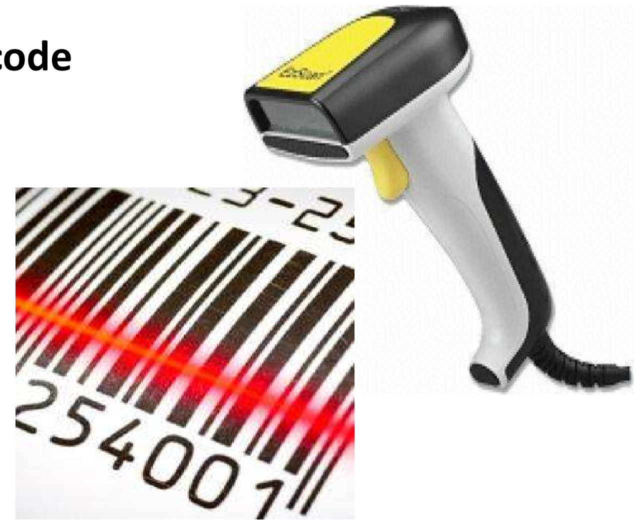
$$\omega = 2\pi\nu$$

Today Optical Technologies dominate our life style

Examples:

- **Credit cards with hologram for higher level of security**

- **Barcode**



- **YouTube**

- **The Internet**

More examples:

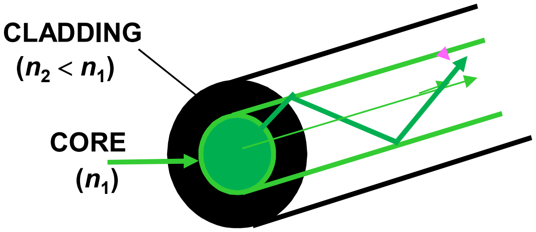
- **Smart Phones**

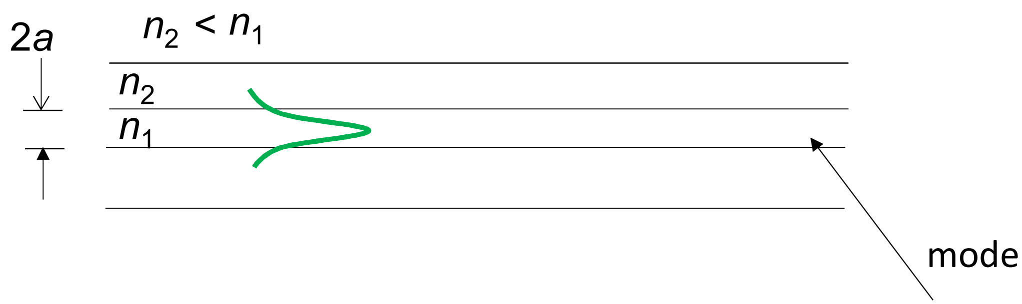
Almost 40% of it is optics!

- **Colour TV transmission & reception**

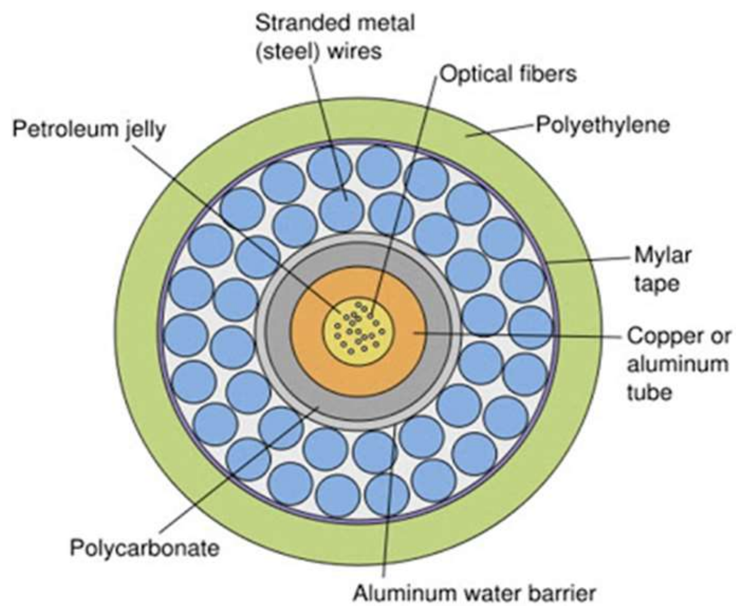
Fiber optics

TIR responsible for light guidance in a glass fiber:





Fiber optic cable



Artist's view of a Fiber cable on ocean bed

A sizeable amount of the installed fiber-optic links that carry Internet and telecommunication traffic around the globe is owned by Indian companies e.g.

- FLAG (65000 kms), world's largest private undersea fiber cable system that integrates with 190,000 km of fiber network – Reliance Communications

- Tata Communications cover > 20% of the world's Internet routes with 200,000 km of sub-sea and terrestrial optical fibers

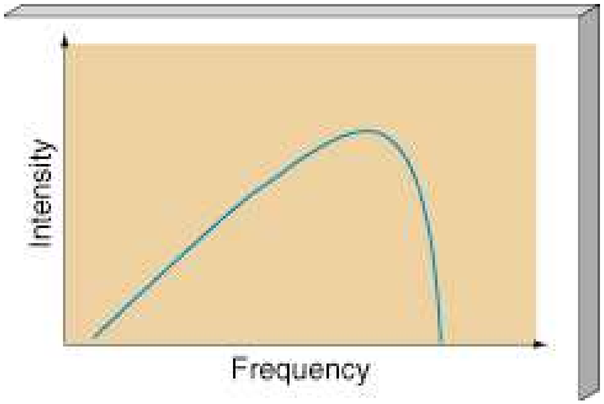
Millions of youngsters today “*use video-chat services without appreciating the century of work – quantum mechanics, the laser, the development of optical fiber networks – underpinning the simple-to-use technology. Without Einstein, without Charles Townes, without the theory of the laser and its instrumentation, we would not have these technologies*”

- John Dudley

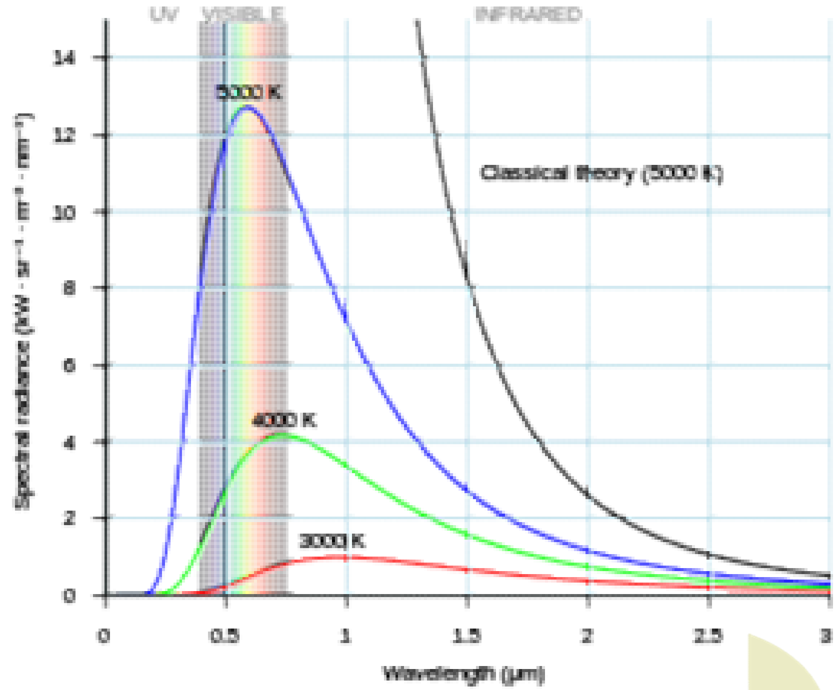
Interestingly, Quantum Physics was born out of **<u>three</u>** fundamental questions raised about light in the early years of 19^{th} Century

Blackbody spectrum:

Q1. Why is blackbody radiation spectrum (asymmetric) bell-shaped?

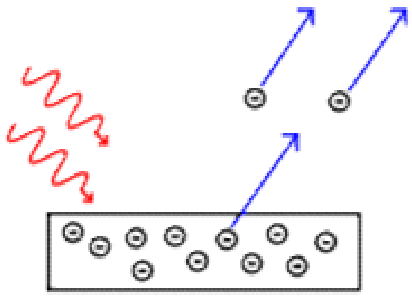


Planck's curve

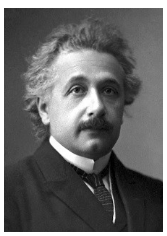


http://en.wikipedia.org/wiki/Black-body_radiation

Q2. Why is there a frequency threshold in PHOTOELECTRIC EFFECT?

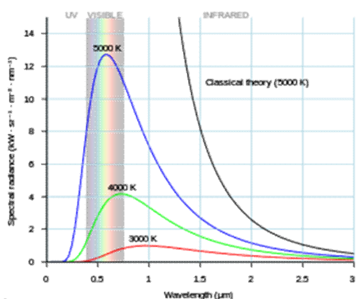


http://en.wikipedia.org/wiki/Photoelectric_effect



Could explain both in 1905

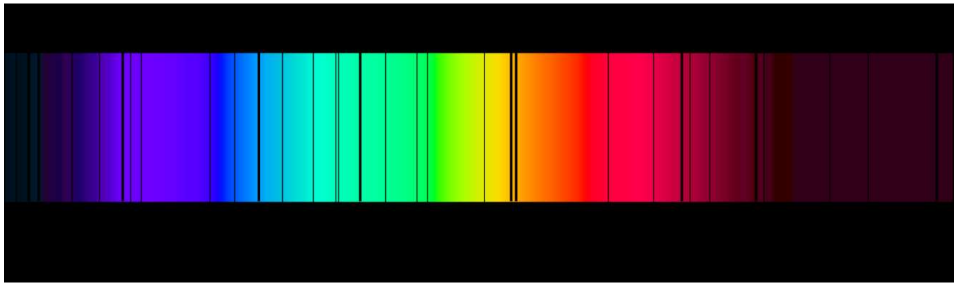
$\Downarrow$



Light behaves as particles and also as waves

Quantum Mechanics was born!

Q3. Why are there discrete lines in an absorption/emission spectrum?



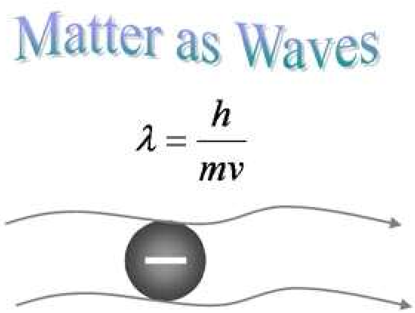
http://en.wikipedia.org/wiki/Niels_Bohr

In 1913

$$E_2 - E_1 = h\upsilon = h\frac{c}{\lambda}$$

In 1923

De Broglie: Electrons are waves



Note: v is for velocity and not for frequency as shown before.

Louis de Broglie

American Inst of Physics

$\Rightarrow$ Light and matter are waves and particles at the same time!

Erwin Schrödinger

In 1926

Schrödinger equation

$$i\hbar\frac{\partial\Psi}{\partial t} = \left[-\frac{\hbar^2}{2m}\nabla^2 + V\right]\Psi$$

In 1D:

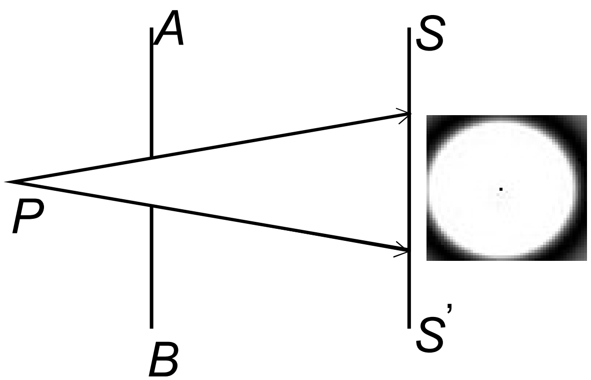
$$i\hbar\frac{\partial\Psi}{\partial t} = \left[-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial x^2} + V(x)\right]\Psi(x,t)$$

With $\Psi(x,t) = \psi(x)e^{-Et/\hbar}$

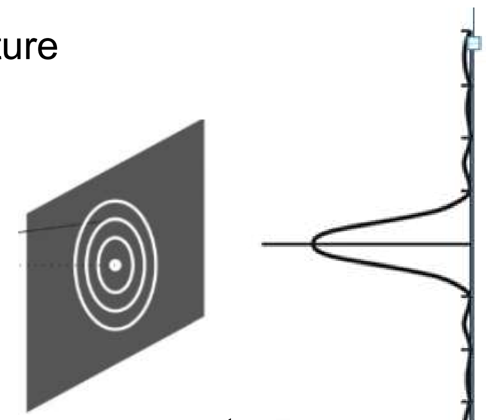
$$\frac{d^2\psi(x)}{dx^2} + \frac{2m}{\hbar^2}[E - V(x)]\psi(x)$$

Geometrical Optics?

- Concerned with propagation of rays



- Consider a circular aperture in front of a point source *P*
- For an adjustable diameter (2*a*) of aperture >> λ , (~ 1 cm) a well defined patch of light will appear on the screen SS$^/$ with clear boundary between illuminated and dark regions
- For increasingly <u>smaller</u> *a*, the pattern will cease to have a well defined boundary
- It will show a structure



- This is the phenomenon of diffraction
- In the limit $\lambda \rightarrow 0 \Rightarrow k \rightarrow \infty$ theoretically diffraction pattern will be absent even for very small values of *a*

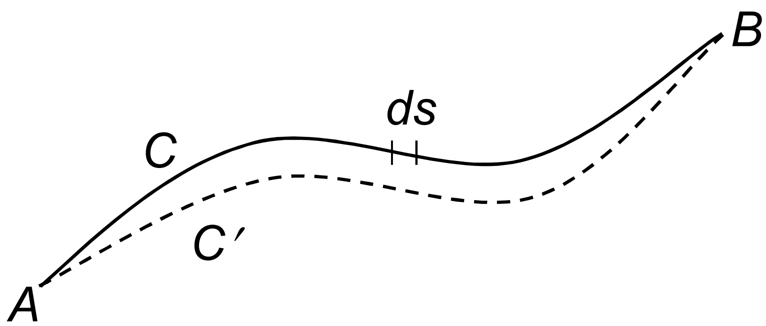
- Normal optical instruments and devices like lenses, mirrors, camera etc. whose typical dimensions are >>> λ, ray optics is sufficient to describe the underlying optics

Fermat's principle:

A geometrical ray corresponds to that path for which the time taken is an extremum compared to nearby paths

$\Rightarrow$ It is either a maximum or a minimum or stationary

Time taken to cover a geometrical path *ds* in a medium of position dependent r. i. *n*:



$$\Delta\tau = \frac{\text{distance}}{\text{velocity}} = \frac{ds}{c/n} = \frac{n\,ds}{c}$$

Total time taken to traverse the path AB along C:

$$\Rightarrow \quad \tau = \frac{1}{c}\sum_i n_i\, ds_i \quad \Rightarrow \quad \tau = \frac{1}{c}\int_{A \xrightarrow{C} B} n\, ds$$

Consider an adjacent path AC′B which takes time τ'

then $\tau \leq$ or $> \tau'$ for all nearby paths like AC′B $\Rightarrow \int_{A \xrightarrow{C} B} n\, ds$ is an extremum (since *c* is a const.)

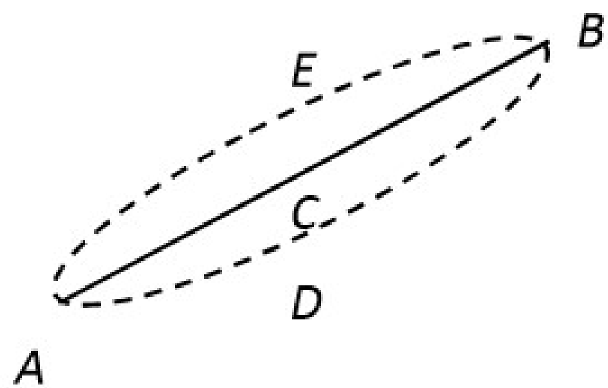
$\Rightarrow$ Light will take only the path for which

$$\Rightarrow \delta \int_{A \to B} n\, ds = 0$$ i.e. change in the value of the integral for an infinitesimal variation in the ray path is 0

Fermat principle:

"Actual ray path between two points is the one for which the optical path length is stationary with respect to variations of the path"

⇒ In a homogeneous medium, in which R.I. is a constant, rays connecting any two points in the medium will be a straight line, which is the shortest optical path !

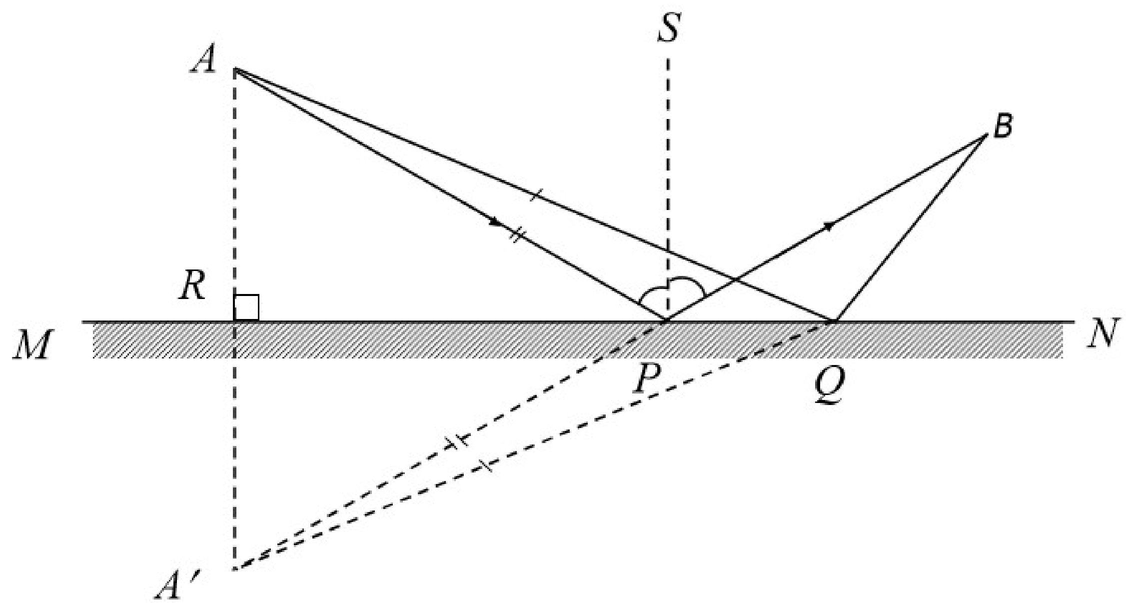


Any other nearby paths *ADB* or *AEB* will be longer!

Law of reflection:

Straight line connecting A and B is the shortest optical path

Let us assume we need to find the opt path between A and B via the mirror



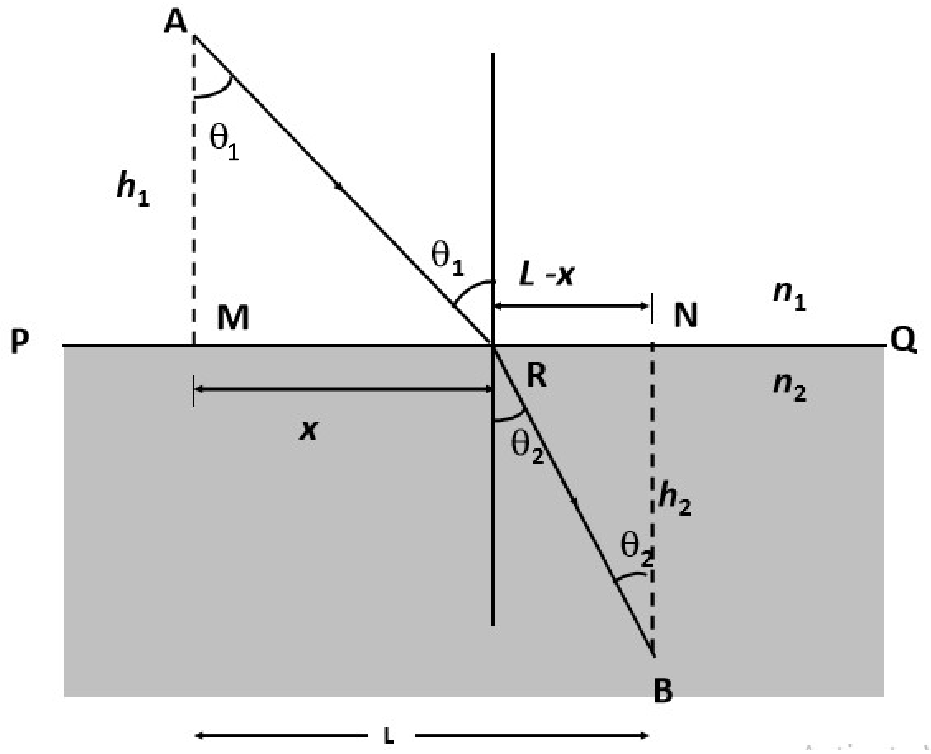
- drop AR perpendicular to MN
- Point $A^{/}$ is on the normal AR such that $AR = RA^{/}$
- AQB is a path adjacent to APB $\Rightarrow$ $AQ = A'Q$
- For APB to be a minimum, P must lie on the st line $A'B$

- A, A', P and B will lie on the same plane
- Draw normal PS, S should also lie on the same plane

From the figure
$$AR^2 + RP^2 = AP^2$$
$$RA^{/2} + RP^2 = PA^{/2}$$
$\Rightarrow AP = PA^{/}$

- $APR = A'PR \Rightarrow A'PR = BPN \Rightarrow APS = BPS$

Law of refraction:



- Let PQ separates the two media of r.i. n_1 and n_2
- Let AR intersects the interface at R
- It then proceeds along RB to B

- For minimum opt. path length incident & refracted rays and the normal at the point of incidence must lie in one plane
- Drop perpendiculars AM and BN on the interface PQ
- $AM = h_1$, $BN = h_2$ and $MR = x$ and $RN = MN - x = L - x$
- $\Rightarrow$ Optical path: • $L_{opt} = n_1 AR + n_2 RB$

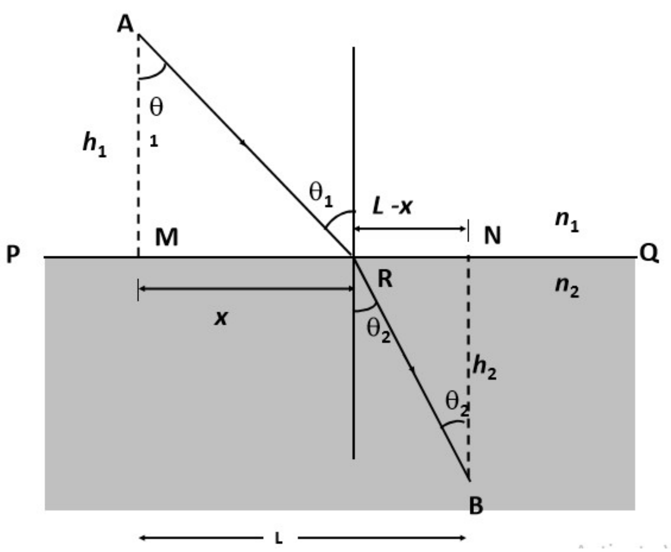
$$\Rightarrow L_{\text{opt}} = n_1\sqrt{h_1^2 + x^2} + n_2\sqrt{h_2^2 + (L-x)^2}$$

- $\Rightarrow$ For minimization of L_{opt}
- we must have $\dfrac{d L_{\text{opt}}}{d x} = 0$

Thus

$$\frac{1}{\cancel{2}}\frac{n_1.\cancel{2}x}{\sqrt{x^2+h_1^2}}-\frac{n_2.\cancel{2}(L-x)}{\cancel{2}\sqrt{(L-x)^2+h_2^2}}=0$$

Again

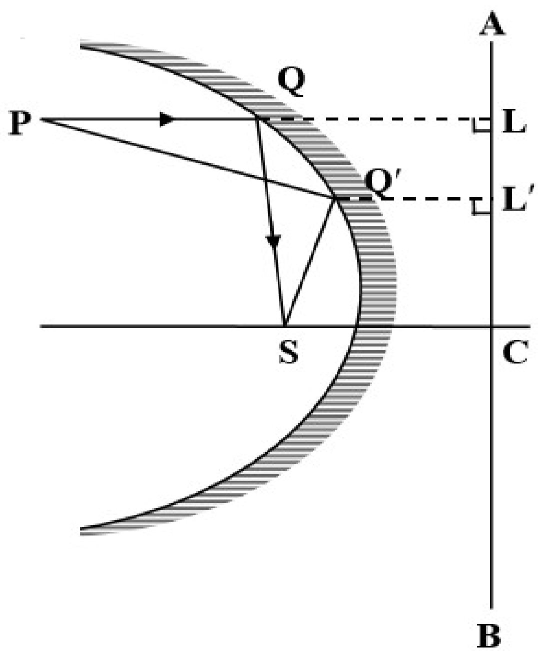


$$\sin\theta_1=\frac{x}{\sqrt{x^2+h_1^2}}$$

$$\sin\theta_2=\frac{(L-x)}{\sqrt{(L-x)^2+h_2^2}}$$

$$\Rightarrow n_1\sin\theta_1=n_2\sin\theta_2$$

From Fermat's principle, show that a set of rays parallel to the axis of a paraboloid mirror will pass through its focus



- Consider a ray that connects focus S to a point P via Q'
- By Fermat's principle, ray path will be one for which $PQ' + Q'S$ is a minimum
- Drop perpendicular $Q'L'$ on the directrix AB
- By definition $Q'S = Q'L'$

$$\therefore \quad PQ' + Q'S = PQ' + Q'L'$$

From Fermat's principle, $PQ' + Q'S$ should be a minimum

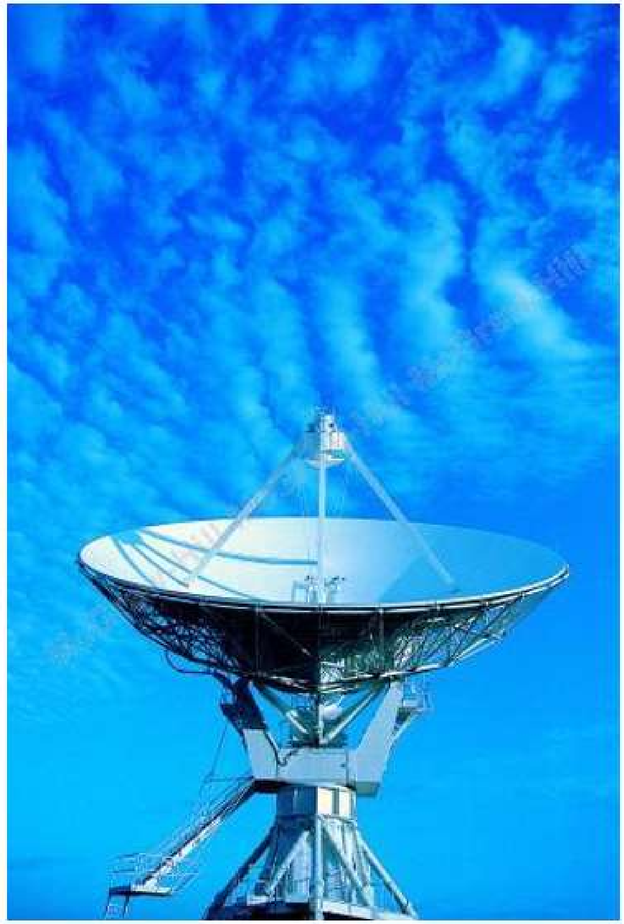
- Let L be foot of the perpendicular from P on AB, which intersects the mirror at Q

$\Rightarrow$ PQ is parallel to the axis

Thus for $PQ' + Q'L'$ to be a minimum, Q' must lie on PQL

Thus actual ray that connects P and S will be $PQ + QS$,

Thus all rays from the focus S that suffer reflection will be parallel to the axis



A paraboloidal satellite dish

One of the 30 paraboloidal dishes each of 45 meter diameter fully steerable Giant Metrewave Radio Telescope (GMRT) @ Pune