Chapter 10

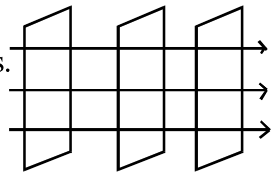
WAVE OPTICS

- Who proposed wave theory of light - Christian Hygens
- What is wave theory - A luminous body is a source of disturbance and the distarbance is propagated in the form of wave and energy in disributed in all directons
- Difference between wave front and Ray -

  Wave front is a surface in which particles of the medium vibrate in the same Phase (same amplitude) and are displaced at the same time

  Any line Perpendicular to the wave front is a ray along which energy Propagates.

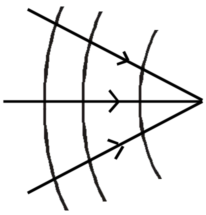
What are Different wave fronts



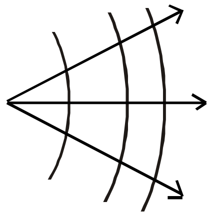
I Plane wave front - The surface perpendicular to the parallel Rays. Produced by a far distant source.

II Spherical wave fronts - Produced by point source.

a) Converging wave fronts. The surfaces perpendicular to the converging rays

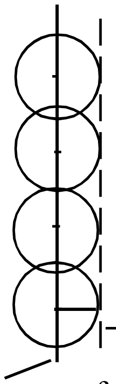


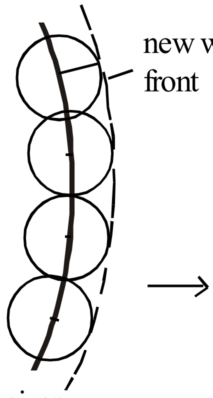
b) Diverging wave fronts - The surface perpendicular to the divering rays.



- Write Hygens Principle of wave front
  1) Light is propagated in to the form of wave
  2) Each portion of a wave front move perpendicular to it self and at the speed of light.
  3) In a medium set of straight lines which are perpendicular to the wave fronts are called rays of light along which energy propagates.
  4) Every point on a wave front can be regarded as the origin of secondary wave front
- How to construct a wave front if the position of earlier wave front is known.

Consider a number of points on the given wave front, Draw number of spheres of radius ct, with these points as centres. Draw envelop to all these spheres. The envelop will give wave front after the time t. (c- velocity of light)





- Explain Law of Reflection on the basis of wave theory

F - Incidenting wave front

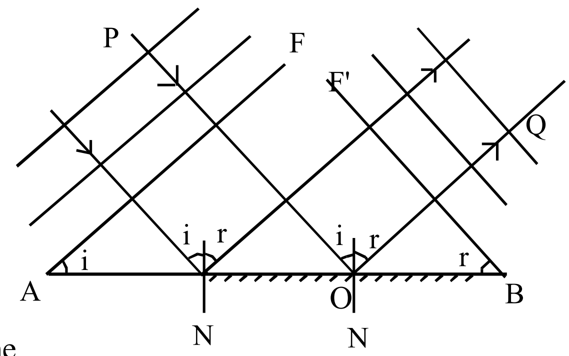
F' - Reflected wave front

Po - incident Ray,

oQ - Reflected ray

i - angle of incidence,

r - angle of reflection



Total time taken by F to move to F' along the

ray POQ is, $t = \frac{PO}{v} + \frac{OQ}{v}$ where 'v' velocity of light in the medium

From the figure PO=OA Sin i, OQ=OBSin r = (AB-OA) Sin r

$$t = \frac{OA\ Sin\ i}{v} + \frac{AB\ Sin\ r}{v} - \frac{OA\ Sin\ r}{v}$$

$$t = \frac{AB\ Sin\ r}{v} + \frac{OA(Sin\ i - Sin\ r)}{v}$$

This time should be same for all rays, The condition for this is

$$(Sin\ i - Sin\ r) = 0$$

$$\angle i = \angle r$$

- Explain law of refraction on the basis of wave theory

F - incidenting wave front

F' - Refracted wave fornt

PO - Incident Ray

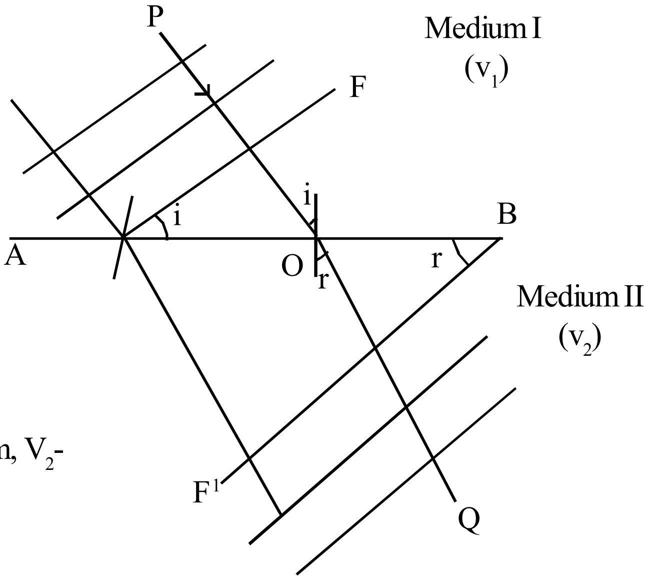
OQ - Refracted Ray

i - angle of incidence,

r - angle of refraction

Total time taken by F to move'

F' along the ray POQ is



$$t = \frac{PO}{v_1} + \frac{OQ}{v_2}$$

where v_1 velocity of light in the 1st medium, V_2- Velocity of light in the II medium

$$t = \frac{OA \text{ Sin } i}{v_1} + \frac{(AB - OA)\text{Sin } r}{v_2}$$

$$\frac{AB \text{ Sin } r}{v_2} + OA(\frac{\text{Sin } i}{v_1} - \frac{\text{Sin } r}{v_2}$$

This time should be the same for all the rays. The condition for this

$$\frac{\text{Sin } i}{v_1} - \frac{\text{Sin } r}{v_2} = 0$$

$$\frac{\text{Sin } i}{\text{Sin } r} = \frac{v_1}{v_2} = \frac{\frac{c}{v_2}}{\frac{c}{v_1}} = \frac{n_2}{n_1} = n_{21}$$, Snells Law of refraction.

- Explain coherent light sources - write the examples.

  Two light sources which emit light waves having same Frequency, Amplitude and Zero / Constant phase differance.

  Eg : Youngs double slit - Light coming from two parallel and close slits on an opaque screen illuminated by a narrow slit which is brightened by a light source.

  Lloyd's Mirror : A light source and its mirror image

- What is interference - The effect produced in a region of space by the superposition of two or more identical waves.

  These are two types,

Constructive interferance - The resultant displacement (Amplitude) of two identical waves after Super position is maximum.

A - Amplitude of electric field vector of each wave,

Resultant Displacement = A+A

Intensity $I = (2A)^2$

Note:- Electric field vector is used to represent monochromatic (single frequency) light.

Destructive Interference - The resultant displacement (Amplitude) of two identical waves after super position is zero(min). Resultant displacement = A-A $\therefore$ Intensity = 0

- What is the interference pattern - Alternative maximum intensity and minimum intensity.
- What is sustained interference write the condition for it.

The interference pattern in which the positions of maximum and minimum intensities do not change with time.

Conditions :

1) The sources of light must be coherant
2) The sources must be narrow and close to each other
3) They should emit light continously
4) The Screen must be comparately at large distance from the coherant sources.

- Write the conditions for constructive interference and disctructive interference

For constructive interferance

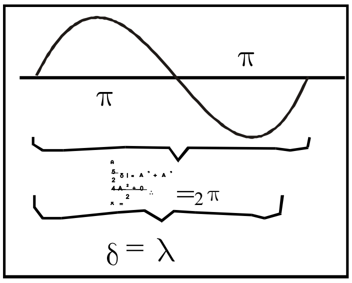
Phase differance between two waves, $\theta = 2n\pi$, where n = 0, 1, 2, 3, ...

Path differance between two waves, $\delta = n\lambda$ where n=0, 1, 2, 3.....

For destructive interferance,

Phase difference, $\theta = (2n+1)\pi$ where n = 0, 1, 2, 3, ...

Path difference, $\delta = (2n+1)\lambda/2$



- Relation between Path differance and Phase differance

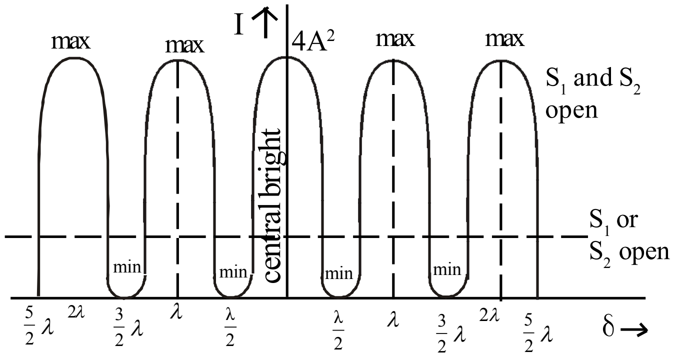
Phase differance, $\theta = 2\pi = \lambda = \delta$, Path difference

For unit wavelength, phase differance $\theta = 2\pi/\lambda$

For Path differance δ, Phase differance $\theta = 2\pi/\lambda \cdot \delta$

- Draw variation of intensity (I) of light due to double slit.

Intensity of light due to double slit is in between 0 (min) and 4 times (max) the contribution of single slit



A - Amplitude of light wave from each slit

Intensity of light due to double slit : $I \propto A^2 + A^2$

$= 2A^2$

For costructive interferance

the resultatnt amplitude = A+A

Intensity of light due to constructive interferance, $I \propto (2A^2) = 4A^2$

For destructive interferance the resultant amplitude = A - A

Intensity of light due to destructive interfarance = 0

Hence average intensity of light after interfarance $= \dfrac{4A^2 + 0}{2} = 2A^2$

So interferance is the redistribution of energy keeping total energy is constant i.e. energy is conserved.

- Relation between the width of a slit (w) and intensity of light

$I \propto W$

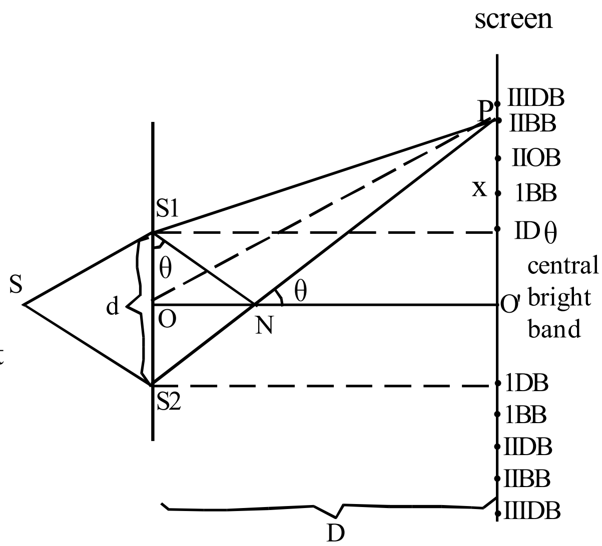
- The amplitude of lihgt waves from two slits are in the ratio 2:1.

What is the ratio of their width?

$I_1 : I_2 = A_1^2 : A_2^2 = W_1 : W_2$

$\therefore W_1 : W_2 = 4 : 1$

- Write the expression for path differance and band width of interfarance



S_1S_2 - double slit, S - narow slit arranged on the perpendicular bisector of S_1S_2

S_1S_2=d, distance between the slits, OO' = D - Distance of the screen from the double slit

P - a point on the screen OP = x

Pathdifferance between two rays proceeding from S_1 and S_2 on arrving at the poit P is

$$\delta = S_2P - S_1P = S_2N$$

from $\triangle S_1NS_2$, $\sin\theta = \dfrac{S_2N}{d}$

from $\Delta OO'P$ $\sin\theta = \dfrac{x}{OP} \sim \dfrac{x}{OO'} = \dfrac{x}{D}$ ($\because$ x is very small)

$$\frac{S_2N}{d} = \frac{x}{D}$$

Path difference $\delta = \dfrac{xd}{D}$

For constructive interfarance , $\delta = \dfrac{xd}{D} = n\lambda$ where n=0, 1, 2, 3 , ...

when n=0, δ =0,All rays from S_1 and S_2 joined together at O' formed central bright band.

when n = 1, $\dfrac{x_1 d}{D} = \lambda$ $\therefore x_1 = \dfrac{\lambda D}{d}$, distance of First Bright Band from central bright band.

when n = 2, $\dfrac{x_2 d}{D} = 2\lambda$ $\therefore x_2 = \dfrac{2\lambda D}{d}$, Distance of 2nd BB from central BB.

When n=3, $\dfrac{X_3 d}{D} = 3\lambda \therefore x_3 = \dfrac{3\lambda D}{d}$, Distance of 3rd BB from central BB.

.... etc.

Distance between two adjacent Bright $\beta = x_2 - x_1 = \dfrac{\lambda D}{d}$ called Bandwidth

For distructive interference, $\delta = (2n+1)\dfrac{\lambda}{2}$ where n=0, 1, 2, 3, ...

when n=0, $\frac{x_1 d}{D} = \frac{\lambda}{2}$, $\therefore x_1 = \frac{1}{2}\frac{\lambda D}{d}$, distance of 1st DB from CBB (lies in between CBB and IBB)

when n = 1, $\frac{x_2 d}{D} = \frac{3}{2}\lambda$ $\therefore x_2 = \frac{3}{2}\frac{\lambda D}{d}$, Distance of 2nd DB from CBB. (lies in between IBB and IIBB)

when n = 2, $\frac{x_3 d}{D} = \frac{5}{2}\lambda$ $\therefore x_2 = \frac{5}{2}\frac{\lambda D}{d}$, Distance of 3rd DB from CBB. (lies in between IIBB and IIIBB)

.... etc.

Distance between two adjacent dark Bands called Band width (fringe width)

$$\beta = x_2 - x_1 = \frac{\lambda D}{d}$$

- Calculate width of CBB - it is the distance between I[st] DB on either side of CBB

$$\beta = \frac{1}{2}\frac{\lambda D}{d} + \frac{1}{2}\frac{\lambda D}{d} = \frac{\lambda D}{d}$$

- When we immerse the Youngs double slit apparatus (Demonstration of interference of light) in a liguid of refractive index n -

What will be the fringe width?

In air, $\beta = \frac{\lambda D}{d}$

In a liquid, $\beta = \frac{\lambda ' D}{d}$ (only wavelength changes)

But, $\frac{\lambda}{\lambda '} = \frac{c}{v} = \frac{n}{n_{air}}$ (using $\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$)

$\lambda ' = \frac{\lambda}{n}$, since $n_{air}=1$

$\beta' = \frac{\lambda}{n}\frac{D}{d}$, $\beta ' = \frac{\beta}{n}$, decreases,

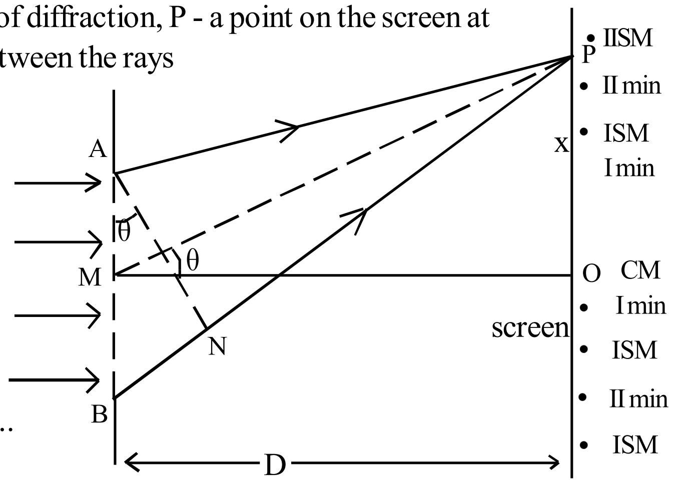
- In young's double slit experiment slits are 0.2mm apart and screen is 1.5m away. It is observed that the distance between CBB and fourth bright Band is 1.8cm. Calculate the wave length of light used.

$$4\beta = 1.8x10^{-2}m$$
$$4\lambda D/d = 1.8x10^{-2}m$$

$$\lambda = \frac{1.8x10^{-2}x0.2x10^{-2}}{4x1.5} = 0.6x10^{-6}m$$

- What is difraction of light - The phenomenon of bending of light around an opaque obstacle.
  Who explained difraction of light.
  Fresnal explained difraction on the basis of wave theory.

- Explain difraction of light at narrow slit
  AB - narrow slit of width a, θ - angle of diffraction, P - a point on the screen at a distance x from o. Path differance between the rays coming from top and bottom of the slit on arrving at the point P is
  δ =BP-AP=BN=a sinθ



$$\delta = a\theta = \frac{xa}{D} \quad (\theta \text{ is small})$$

Condition for difraction aθ =nλ

$$\therefore \theta = \frac{n\lambda}{a} \quad \text{where } n = 0, 1, 2, 3, ...$$

$\triangle MOP,\ \sin\theta = \frac{x}{D}$

$\triangle ABN,\ \sin\theta = \frac{BN}{a}$

$BN = \frac{xa}{D}$

I When n = 0, θ =0. All the rays coming from AB joined together at O.
This gives max intensity at O called <u>central maximum</u> (CM)

II The point P becomes dark (minima), Pathe difference, $Q\theta = \pm n\lambda$

When $\theta = \pm\frac{n\lambda}{a}$ where n = 1, 2, 3, ... called Ist, IInd, IIIrd.... minima (M) are formed on either side of the central max.

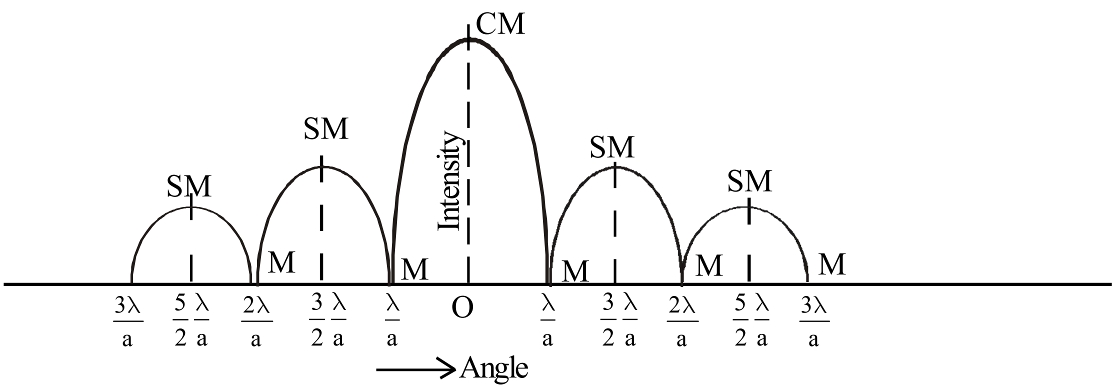
III The point P becomes less intense max (secondary max)

Path difference, $a\theta = (2n+1)\frac{\lambda}{2}$

Then $\theta = \frac{(2n+1)}{2}\frac{\lambda}{a}$, n = 1, 2, 3, ... called Ist, IInd, IIIrd.....

Secondary Max (SM) are formed on eiher side central max, but in between two minima.

- Draw variation of intensity of light with angle of difraction due to a narrow slit.



Note : As n increases intensity decreases.

- Calculate the width of diffraction minimum.

For nth minimum, $a\theta_n = \frac{x_n a}{D} = n\lambda$

$$x_n = \frac{n\lambda D}{a}, \text{ Distance of nth minimum from central maximum.}$$

Distance of (n+1)th minimum, $x_{(n+1)} = (n+1)\frac{\lambda D}{a}$

$\therefore$ Width of minimum, $x_{n+1} - x_n = \beta$

$$\therefore \beta = \frac{\lambda D}{a}$$

- Calculate the width of diffraction SM

for nth SM, $a\theta_n = \frac{x_n a}{D} = \frac{(2n+1)}{2}\lambda$

$$x_n = \frac{(2n+1)}{2}\frac{\lambda D}{a}, \text{ distance of nth SM from central maximum.}$$

Distance of (n-1)th minimum, $x_{(n-1)} = \frac{[2(n-1)+1]}{2}\frac{\lambda D}{a}$

$\therefore$ Width of SM, $\beta = x_n - x_{n-1}$

$$\beta = \frac{\lambda D}{a}$$

- Calculate the witdth of Central Max.

It is the distance between Ist minimum on either side of central maximum

$\therefore$ Width of central max, $\beta' = 2x_1$, where $x_1 = \frac{\lambda D}{a}$

$$= 2\frac{\lambda D}{a} = 2\beta$$

- What is the condition for complete polarisation of reflected ray?

Angle between reflected ray and refracted rays is 90

- State and explain Brewsters law

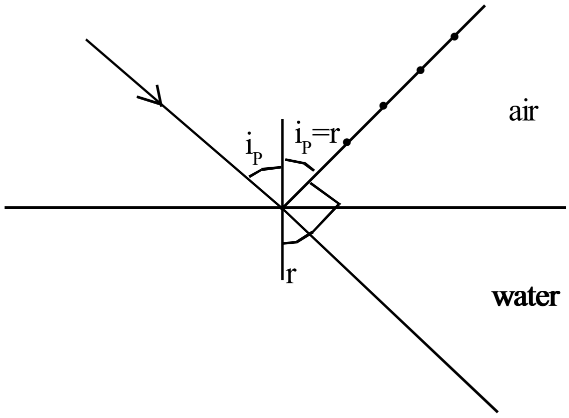
Tan of angle of incidence coresponding to complete polarisation is equal to refractive index of medium.

$i_p + 90 + r = 180$

$r = 90 - i_p$

By Snell's law,

$$n_{wa} = \frac{\text{Sin } i_P}{\text{Sin } r} = \frac{\text{Sin } i_P}{\text{Sin } (90 - i_P)}$$



$$n_{wa} = \frac{\text{Sin } i_P}{\text{Cos } i_P} = \text{Tan } i_p$$

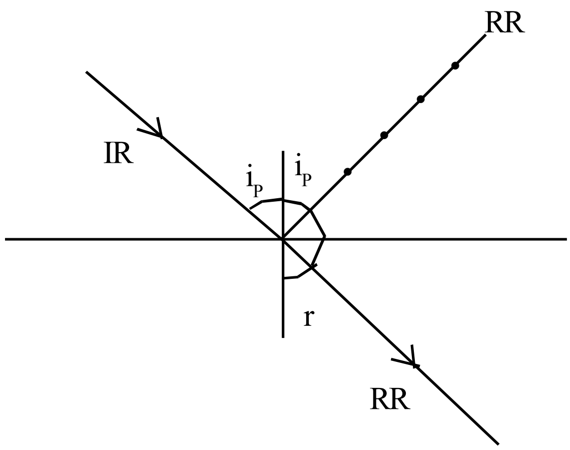
In general, $n = \text{Tan } i_p$

- What is Polarisation of light : Oscillation of Electric field vector (rep. of light) in transverse plane.
- Unpolarised light - $\vec{E}$ and $\vec{B}$ vibrate in infinity direction.
- Can sound wave get polarised?

No.

- Angle of incidence is equal to polarising angle. (i_p) Show that RR and RR' are mutually perpendiculer.

$$n = \text{Tan } i_p = \frac{\text{Sin } i_P}{\text{Cos } i_P} = \frac{\text{Sin } i_P}{\text{Sin } r}$$



$\text{Cos } i_p = \text{Sin } r$

$\text{Sin } (90-i_p) = \text{Sin } r$

$90-i_p = r$

$i_p + r = 90$

Angle between RR and RR is 90.

- Which property of light reveals light in Transverse in wave nature Polarisation
- What is polar oid write examples.

A synthetic substance in which the intensity of light is reduced to half

eg: Tourmaline crystal, Nicol Prism, Sugar Solution.

- Critical angle of glass is 40^0 calculate the Polarising angle. (Polarising Angle - Angle of incidence at which the reflected ray of completely polarised.)

$$n = \frac{1}{\text{Sin } c}, \quad n = \text{Tan } i_P$$

$$i_P = \text{Tan}^{-1}\left(\frac{1}{\text{Sin } c}\right)$$

$$= \text{Tan}^{-1}\left(\frac{1}{\text{Sin } 40}\right) = 56^0$$

- What is Doppler effect of light

The apparent change in frequency of light due to relative motion of the source and observer

Apparant frequency, $\nu' = \nu\left(\frac{c - v_o}{c - v_s}\right)$, where ν - actual frequency light

v_o - speed of observer
v_s - speed of source
c - velocity of light.

Case

1) Source is at rest observer move towards the source

$$\nu' = \nu\left(1 + \frac{v_o}{c}\right) \text{ increases}$$

2) Observer at rest source moves towards the observer

$$\nu' = \nu\left(1 + \frac{v_s}{c}\right) \text{ increases}$$

3) Source is at rest, observer receds from the source

$$\nu' = \nu\left(1 - \frac{v_o}{c}\right) \text{ decreases}$$

4) Observer at rest,source receds from the observer

$$\nu' = \nu\left(1 - \frac{v_s}{c}\right) \text{ decreases}$$

5) Source and observer approach each other.

$$\nu' = \nu\left(\frac{c + v_o}{c - v_s}\right) \text{ increases}$$