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Light Amplification and Oscillation

When active medium is in inverted state, a photon of appropriate energy can stimulate the emission of a cascade of photons. This is a process of amplification. The initial photon may be looked upon as the input signal, the active medium as the quantum optical amplifier and the emerging light as the amplified output.

The degree of amplification is measured as gain, which is the increase in the intensity when the light beam passes through the active medium.

This Gain is expressed as:

$$G = \frac{1}{I}\frac{dI}{dx}$$

The Gain may be defined as

The amount of stimulated emission which a photon can generate as it travels the given distance.

If a gain is 4%, it means a single photon produces four photons per each centimeter it travels in the medium.

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Unfortunately the laser materials have very low gain. It means that the photon has to travel a long length of laser material for producing large amplification.

For example
If we have a material, whose gain is 0.001 per centimeter and if we wish to achieve a light amplification 1000 times, it is calculated that the light has to travel about 69 m in the medium. Such a long distance is obviously not practical.

One of the methods of making the light to pass through the long distance of laser material is by keeping mirrors on both sides of a short laser rod or tube. The light bounces back and forth between the mirrors and makes many passes through medium increasing the effective distance of travel by many times.

Such an arrangement of mirror is called Optical Resonator.

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close cavity is used as an oscillator in which standing wave may be produced. However in close cavity 'at light frequency' the close cavity can't sustain the standing wave since the dimensions of cavity should be in order of the wavelength It is difficult to fabricate such microcavity.

The Two American Scientists Townes and Schawlow showed that instead of a close cavity an open cavity may be used at light frequency in the form of two parallel mirrors to serve the purpose. This open cavity for generating light oscillations is called optical resonator.

"In case of laser, feedback is produced by placing the active medium between a pair of mirrors facing each other."

LASER Resonator

Laser feedback is obtained by placing active medium between a pair of mirrors facing each other. The role of input signal is played by chance photons spontaneously emitted along optic axis of laser rod or tube. The photons trigger many stimulated emissions in their wake and the photons at the end are reflected back into the medium by the mirror. The photons reserve reverse their direction reflected back into the medium by the mirror. The photons reserve their direction and travel through the medium till they reach the mirror at the other end.

Substantial amplifications occurs as the light beam is reflected several times at the mirrors and travel through the active medium gaining strength in each passage.

In the case of mirror the pair of mirrors and constitutes optical cavity. This structure is an open resonator if sides are open.

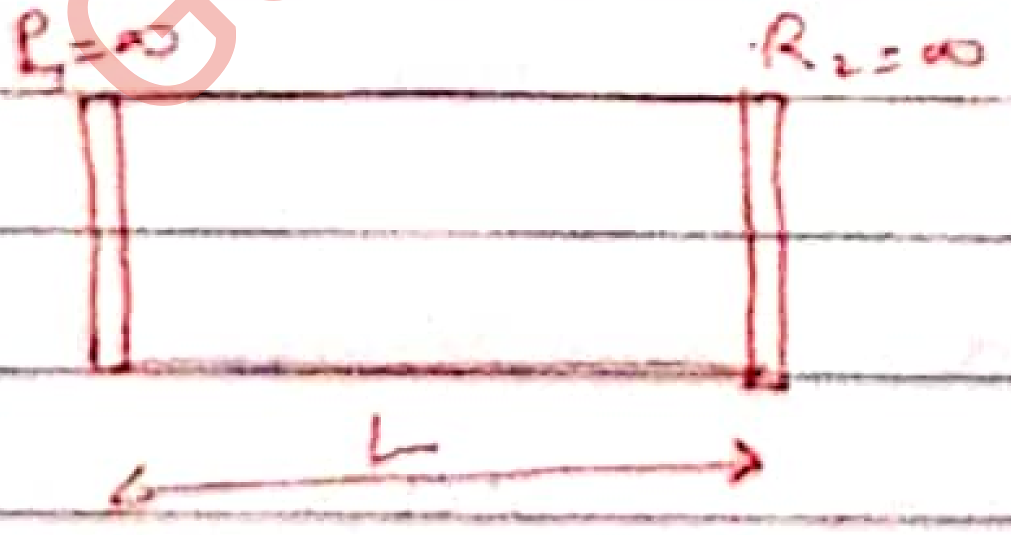
All the resonators used in the lasers may group into two categories

Stable resonator
The beam of light strictly remains within the cavity

Unstable Resonator
The ray of light after reflecting from the mirror diverges infinitely away from the axis of the mirror

There are different configurations of resonators which are widely used. Some of the commonly used resonators are

Fabray Perot Resonator:-
Febry-Perot Resonator consists of two plane mirrors aligned parallel to each other as:



The oscillations take place with two parallel mirrors acting as nodes. Thus the optical path length travelled by the wave between the two consecutive reflections

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at the same end mirror should be an integral multiple of the wavelength. λ.

If 'L' be the length of the cavity,

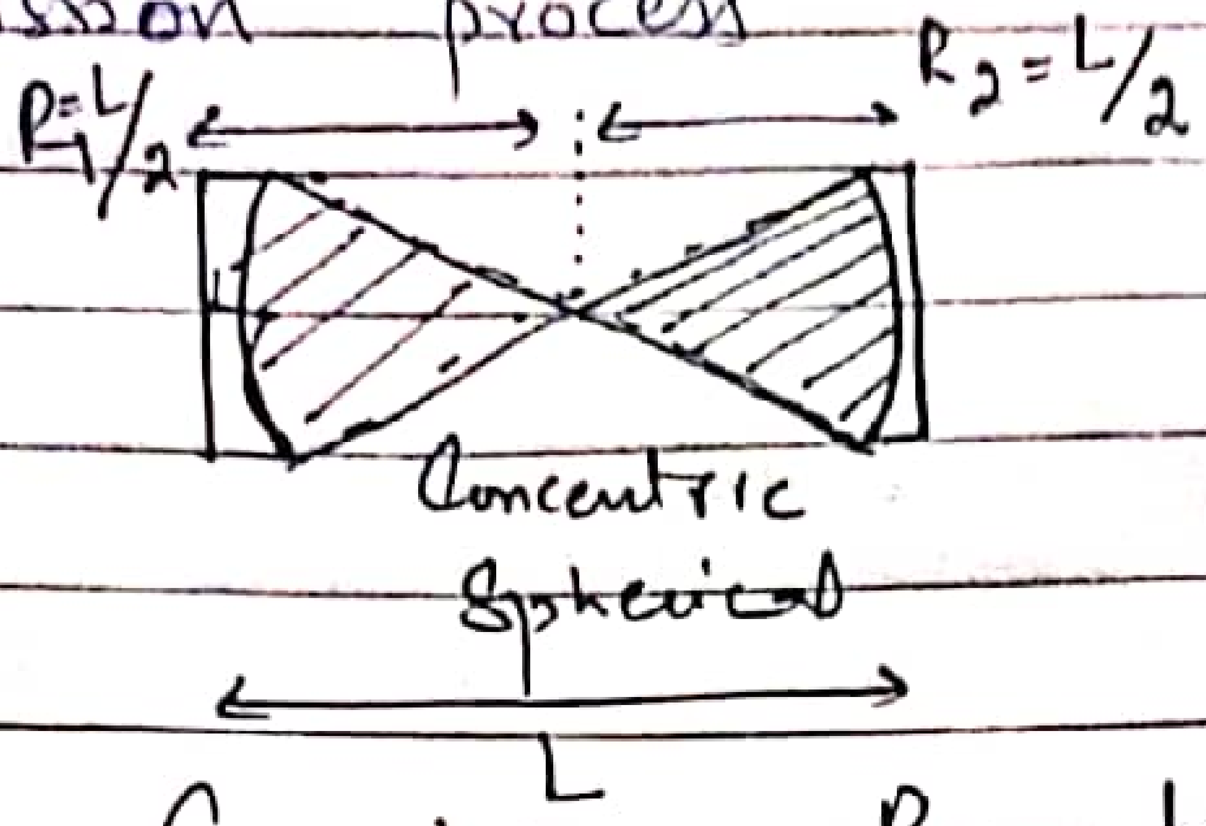
$$L = \frac{n\lambda}{2\mu}$$

And the frequency difference between it is

$$\Delta\nu = c/2\mu L$$

Concentric or Spherical Resonator:-

It consists of two spherical mirrors of the same radius of curvature R placed at a distance of length L facing each other such that the centres of curvature C_1 and C_2 of the mirror coincide. Thus the distance between the end mirrors is '2R'. This configuration offer of the resonator can be used can be used for oscillation of the wave of wavelength very much close to L/2. However the such accuracy is difficult to attain. This configuration offers a very limited use of volume of the active medium due to its small beam diameter, which in turn yields a less efficient stimulated emission process

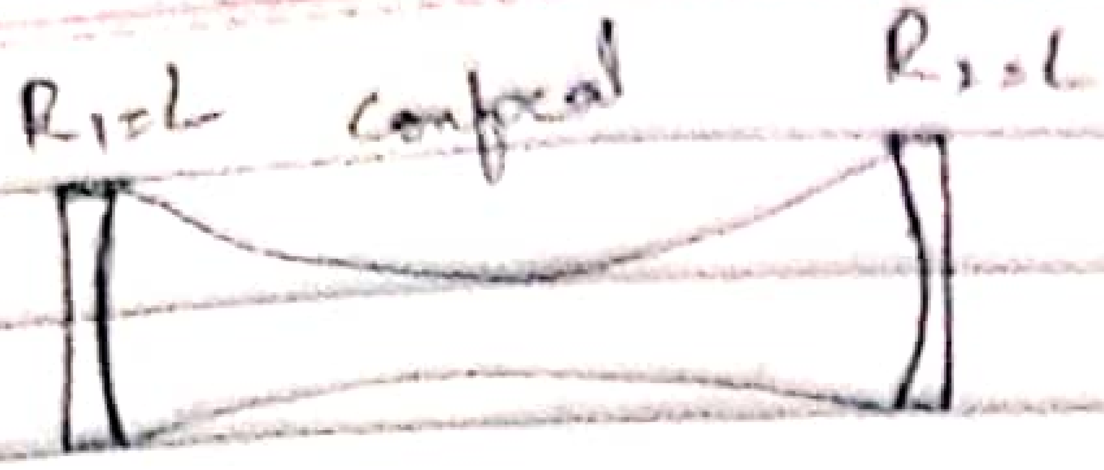


Concentric Resonator

Confocal Resonator:-

It consists of Two Spherical mirror M_1 and M_2 of same radius of curvature R placed at a distance L such that the foci of Two mirrors coincide. Hence the centre of curvature of M_1 lies on the surface of mirror M_2 and vice versa.
Thus, the distance between end mirrors is $L = R$

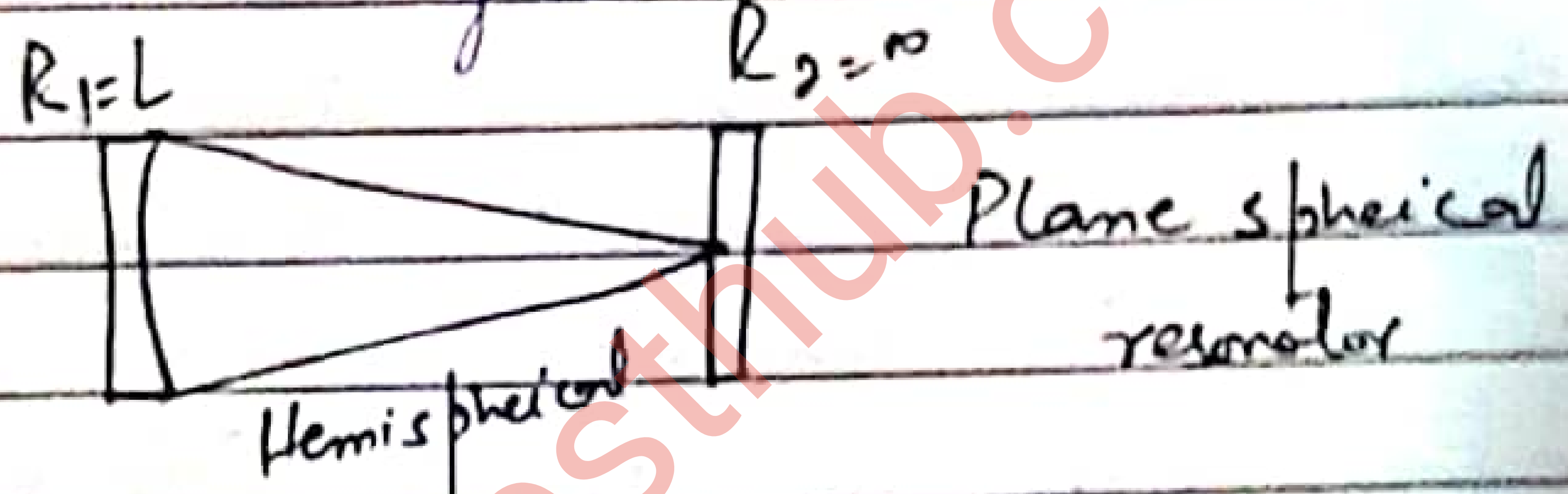
This configuration of mirror is an excellent choice when frequency alignments are required. However, in this configuration it is very difficult to obtain the configuration of the modes and hence resonant frequency.



Configuration of confocal Resonator

Combination of Plane and Spherical Resonator.

The typical plane and spherical combination of resonator is shown in Figure



The typical plane and spherical combination of resonator.

The radius of curvature of the spherical mirror in the configuration is usually larger than the cavity length. If the radius of curvature of the spherical mirror is equal to the length of the cavity, the beam takes conical shape inside the active medium; consequently the gain is unequal b/w two sides of cavity. The gain may be equal inside the cavity, if a gain medium placed near to spherical mirror.