Q-Switching Methods:-

Active Q-Switching

In active Q-switching, the Q-switch is an externally controlled variable attenuator.

This may be a mechanical device such as shutter, chopper wheel (or) spinning mirror placed inside the cavity (or) it may be a modulator (or) an electro-optic device. The pulse repetition rate can be externally controlled.

Passive Q-Switching:-

In passive Q-switching, the Q-switch is a saturable absorber, a material whose transmission increases when the intensity of light exceeds some threshold.

The material may be an ion-doped crystal like Cr-YAG which is used for Q-switching of Nd-YAG lasers, a bleachable dye (or) a passive semiconductor device.

The pulse repetition rate can be indirectly controlled, Direct control of the repetition rate can be achieved by using a pulsed pump source as well as passive Q-switching.

Applications:-

Q-Switched lasers are used in applications which demand high laser intensities in nano-second pulses.

They can also be used for measurement purposes, such as for distance measurements by measuring the time it takes for the pulse to get to some target and the reflected light to get back to the sender.

Q-Switched lasers are used to remove tattoos.

The amplitude modulation (AM) acts as a weak shutter to the light bouncing between the mirrors of the cavity, attenuating the light when it is closed, and letting it through when it is open. Then a single pulse of light will bounce back and forth in the cavity. Then the modulation does not have to be large. Then it will be a mode-locked laser.

Active mode locking can be acheived with an electro-optic modulator (or) integrated-optic modulator (or) a semi conductor electro absorption modulator.

Passive Mode Locking :-

Passive mode locking methode do not use an external signal, but on placing some element into the laser cavity which causes self-modulation of the light.

The most common type of device which will do this is a saturable absorber.

When a saturable absorbere are placed in laser cavity, As the light in the cavity oscillates, this process. repeats, leading to the amplification of low intensity light. After many round-trips, this leads to a train of pulses and mode locking of the laser.

Saturable absorbers are commonly liquid organic dyes, but they can also be made from doped crystals and semi conductors.

Mode Locking applications :-

1). Mode locked lasers are used in photo chemistry. This method is particularly useful in bio chemistry. where it is used to analyze details of protein folding and function.

2) Nuclear fusion

3) Non linear optics and for the generation of Tetrahertz radiation.

... modes, then they ... the same relative phase

$$\delta_n = \delta$$

This Laser is then said to be a mode-locked Laser.

The angular frequency of the n^{th} mode is

$$\omega_n = \omega - n\Delta\omega$$

$$\therefore E(t) = A \sum_{N=0}^{N-1} \exp\left(i\{(\omega - n\Delta\omega)t + \delta\}\right)$$

$$E(t) = A \exp(i(\omega t + \delta)) \sum_{N=0}^{N-1} \exp(-int\Delta\omega)$$

$$E(t) = A \exp(i(\omega t + \delta)) \sum_{N=0}^{N-1} \exp(-in\phi)$$

$$(\because \phi = t\Delta\omega)$$

$$E(t) = A \exp\{(i(\omega t + \delta))\} \left\{\frac{e^{-Ni\phi} - 1}{e^{-i\phi} - 1}\right\}$$

The Intensity is given by the square of the amplitude

$$I = A^2 \left\{\frac{e^{-Ni\phi} - 1}{e^{-i\phi} - 1}\right\}^2$$

$$I = A^2 \frac{\sin^2(N\phi/2)}{\sin^2 \phi/2}$$

Is the expression for Intensity for modes Locked in phase

$$I = N^2 A^2$$

The output of a mode-Locked Laser is N times the Power of the same Laser with modes unlocked.

Mode Locking Methods

Methods for producing mode locking in a Laser may be classified as either active Mode Locking (or) Passive Mode Locking.

Active Mode Locking

Active Mode locking methods involve using an external signal to induce a modulation of the intra-Cavity light

Factor :- Let W(t) be the energy stored in a Cavity at time 't'. The energy will gradually decay with time due to various losses (scattering, absorption, diffraction etc).

The reduction energy is proportional to W(t) and the time Interval dt

$$-dW(t) \propto W(t)\,dt$$
$$-dW(t) = A\,W(t)\,dt$$

where 'A' is a Constant.

Integrating we get

$$W(t) = W_0 \exp(-At)$$

The decay time $\tau_c = \frac{1}{A}$ $\left(\because A = \frac{1}{\tau_c}\right)$ —(1)

$$W(t) = W_0 \exp\left(-\frac{t}{\tau_c}\right)$$

From the definition of the quality factor

$$-\frac{dW(t)}{dt} = \frac{\omega \times W(t)}{Q}$$

$$W(t) = W_0 \exp\left(-\frac{\omega t}{Q}\right) \quad \text{—(2)}$$

Comparing equations (1) and (2) we have

$$\tau_c = \frac{Q}{\omega}$$

(or) $Q = 2\pi \nu \tau_c$ $\quad (\because \omega = 2\pi\nu)$

Where 'Q' is a dimensionless quantity.

Mode Locking (Expression for the Intensity ...)

$$E(t) = A \sum_{N=0}^{N-1} \exp\left(i(\omega_n t + \delta_n)\right)$$

$\omega_n = \omega - \Delta\omega$

N – total number of modes

ω_n – angular frequency of the n^{th} mode

δ_n – relative phase

The total Intensity is found by adding the Intensities of the modes.

When the modes are uncoupled, the Intensity is

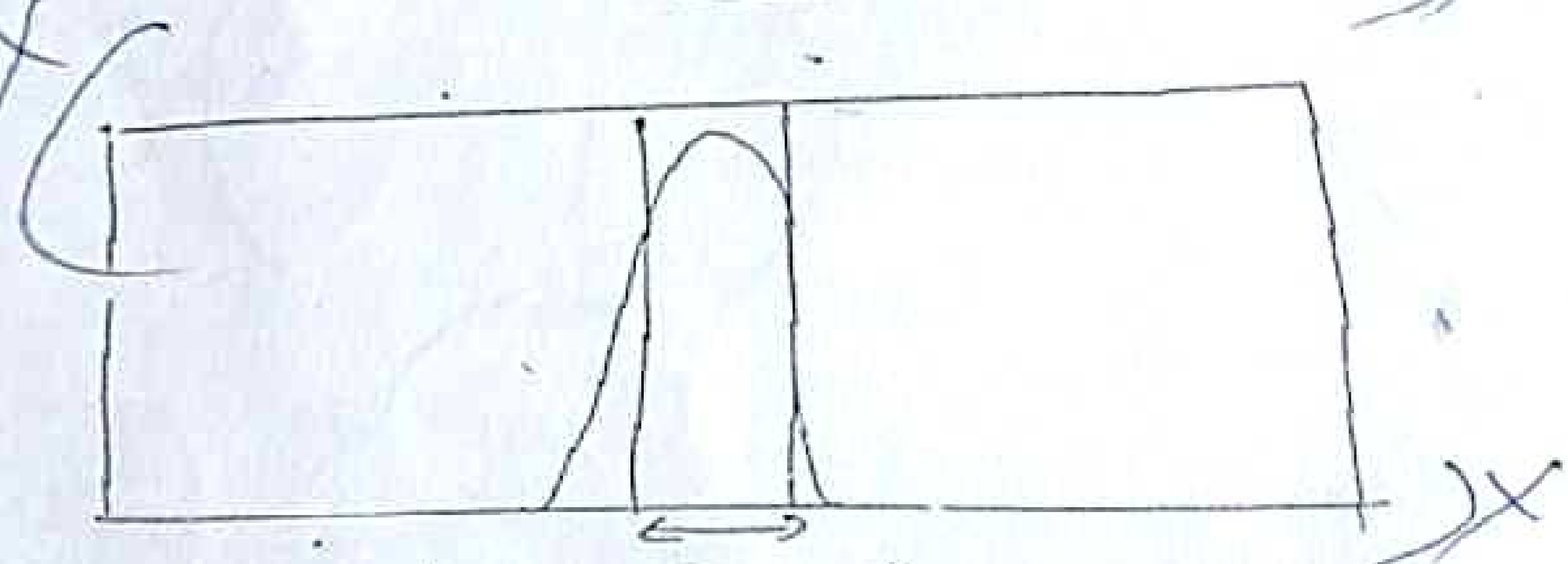
$$\boxed{I = NA^2}$$

(passes) through the
amplifying medium (5) Since the population inversion has been built up to a large value, the power of the laser beam grows very quickly (6) When the shutter is suddenly opened, a huge light pulse gets generated and this technique is referred to as Q-Switching.
For generating another pulse, the medium would again need to be pumped while the shutter is kept closed and the process repeated again.

When the shutter is kept closed and suddenly opened, the Q of the cavity is suddenly increased from a very small value to a large value and hence the name Q-Switching.

Q-Switching produces very high intensity pulses but the pulse durations are typically in the nanosecond.

Q-Switched pulse emitted from a neodymium YAG Laser.
The Energy pulse is 850 milli joules
and pulse width is about 6 nanoseconds.
The pulse frequency is 10 Hertz, i.e. the laser emits 10 pulses per second.



Energy pulse ~850 mJ
Pulse width ~6 ns
repetation rate ~10 Hz

Uses: Using this phenomenon, it is possible to generate extremely high power pulses for use in various applications such as cutting, drilling (or) in nuclear fusion experiments.

The Locking of phase among the various frequencies is achieved by various techniques such as putting a time-varying loss element inside the cavity loss Special components called Saturable absorbers. which transmit low when incident intensity is low and transmit high when the incident intensity is high.

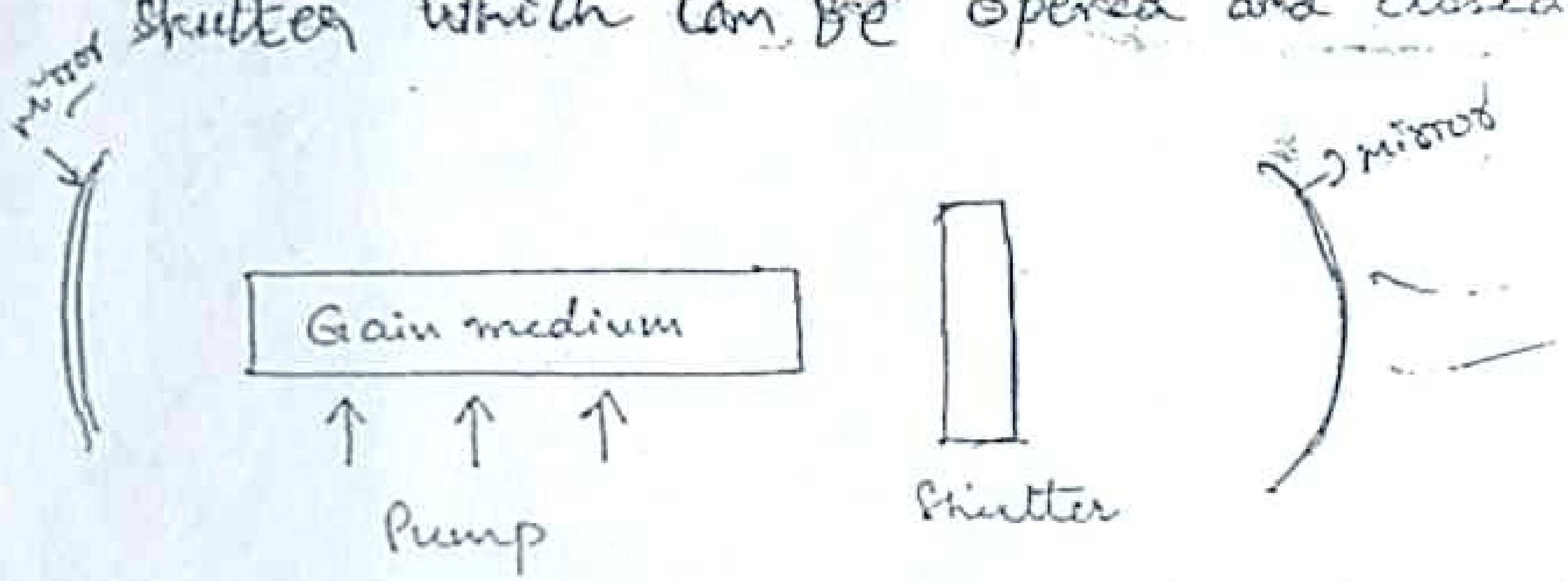
Q-Switching :-

Q-Switching some times known as giant pulse formation

It is a technique by which a Laser can be made to produce a pulsed out put beam,

The technique allows the production of light with extremely high (giga watt) Peak power.

Imagine a Laser Cavity with in which we have placed a Shutter which can be opened and closed.



Let us assume that the Shutter is closed (does not trans.) and we start to pump the amplifying medium. (2) Since the Shutter is closed, (3) there is no feed back from the mirror and the Laser beam does not build up. (3) Since the pump is taking the atoms from the ground state and depositing them in to the excited state and there is no stimulated emission the population Inversion continues to build up (4) when the inversion is built to a reasonably high value and the Shutter is opened, then the spontaneous emission is able to reflect from the

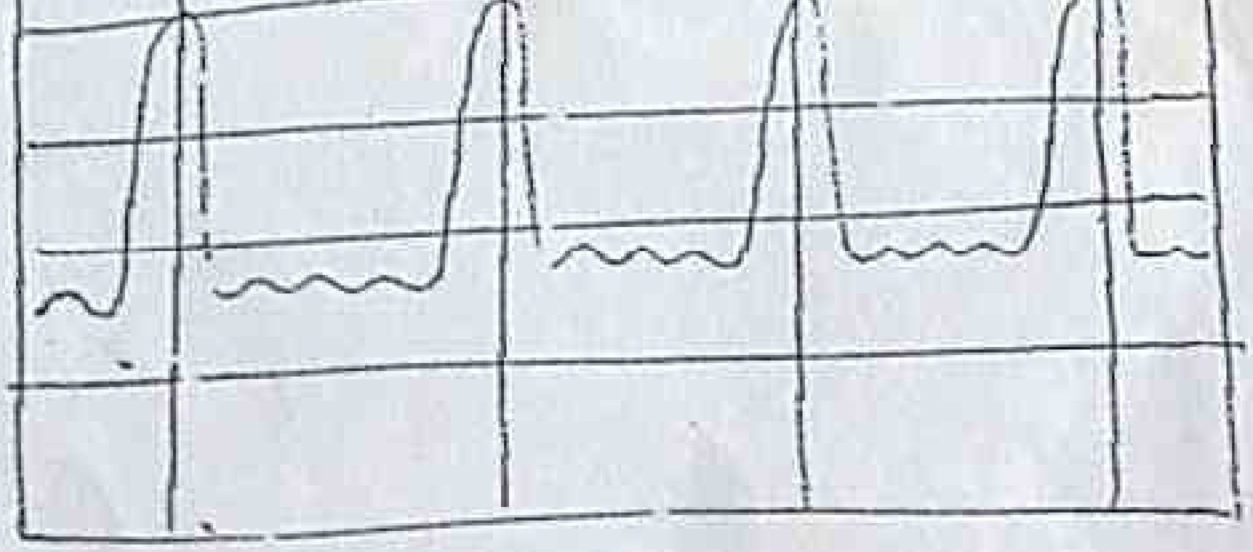
Mode locking :-

Mode locking is a technique in Optics by which a Laser can be made to produce pulses of light of extremly short duration on the order of Picoseconds (10^{-12}s) (or) femto seconds (10^{-15}s)

The basis of the technique is to induce fixed phase relationship between the modes of the Laser Cavity. The Laser is then said to be phase-locked (or) mode locked. Interference between these modes causes the Laser light to be produced as a train of pulses.

The waves will have their crests and troughs coinciding to give a very large out put, and at other times the crests and troughs will not be overlapping, thus giving a much smaller Intensity. In such a case the out put from the laser would be a repetative series of pulses of light. and such a pulse train is called "mode locked pulse train" and this phenomenon is called "mode locking".

In case of Lasers, if we can lock the phases of each of the oscillating modes, that is bring them all in phase at any time and maintain this phase relation ship, just like in the case of beats.



[Out put mode-locked pulse train coming out of a Laser]

Quality factor :- 302 Nov. + C

E. Vamsi Krishna
No : 31

Q factor is a dimensionless parameter

A laser is an Oscillator, its resonator Cavity is characterized by the Quality factor 'Q'.

Q is 2π times the ratio of the Energy stored in the resonator to the Energy loss per cycle.

$$Q = 2\pi \frac{\text{Energy stored in the resonator}}{\text{Energy lost in cycle}}$$

The Q is done in the Case of an electronic Oscillator. In the Case of Lasers 'Q' is very high and 'Q' stands for quality of the Cavity.

A system with low Q-factor $(Q < \frac{1}{2})$

It is said to be Over damped

Such a system does not Oscillate at all

Imp

A system with high Q-factor $(Q > \frac{1}{2})$

It is said to be under damped

Underdamped system combine Oscillation at a Specific frequency with a decay of the amplitude of the Signal.

A system with an intermediate Q-factor $(Q = \frac{1}{2})$

It is said to be Critically damped

The Output does not Oscillate.

uality factor :- 302 Unit-C

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COLLISION BROADENING:-

The atoms in a gas frequently collide with each other and with the walls of the containing vessel. This interrupts the process of light emission and can shorten the effective life time of the excited state.

If the mean time between collision $\tau_{collision}$ is shorter than the radiative life time, then we need to replace τ by $\tau_{collision}$ in equation

$$\Delta\omega_{life\,time} = \frac{1}{\tau}$$

This give rise to additional line broadening.

A simple analysis based on the Kinetic Theory of gases gives the following result for $\tau_{collision}$

$$\tau_{collision} \sim \frac{1}{\sigma_s P}\left(\frac{\pi m K_B T}{8}\right)^{1/2}$$

where σ_s is the collision cross-section

P is the pressure

It is apparent that $\tau^{-1}_{collision}$ and $\Delta\omega$ are proportional to P.

Collision broadening is therefore also called pressure Broadening.

The Lorentzian line shape function is given by

$$g_{(\omega)}(\omega) = \frac{\tau_0}{\pi} \frac{1}{1+(\omega-\omega_0)^2\tau_0^2}$$

The FWHM is $\Delta\omega_c = \frac{2}{\tau_0}$

The broadening caused by Doppler mechanism can be determined by considering the light emitted by an atom moving with velocity component V_x towards the observer.

If the transition frequency in the rest frame of the atom is ω_0, the observed frequency will be Doppler shifted to

$$\omega = \omega_0\left(1 + \frac{V_x}{c}\right) \quad \text{— (1)}$$

The number of atoms with velocity between V_x and $V_x + dV_x$ is given by Maxwell-Boltzmann distribution

$$N(V_x) = N_0\left(\frac{2K_BT}{\pi m}\right)^{1/2} \exp\left(\frac{-mV_x^2}{2K_BT}\right) \quad \text{— (2)}$$

where T is the temperature

N_0 is the total number of atoms

M is their mass

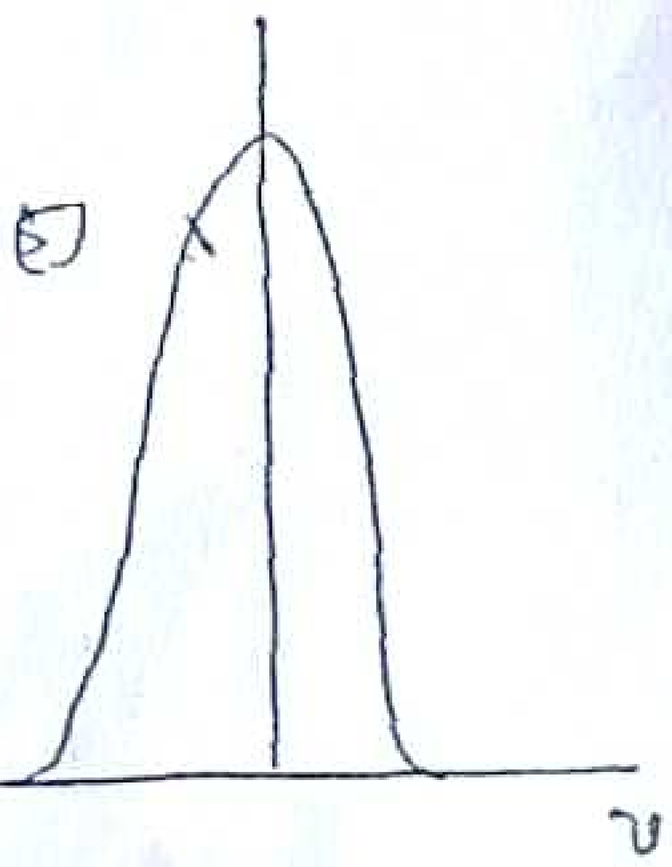
By coupling equations (1) and (2) we find the Normalized Gaussian line shape function

$$g_{(\omega)}(\omega) = \frac{c}{\omega_0}\sqrt{\frac{m}{2\pi K_BT}} \exp\left(\frac{-mc^2(\omega-\omega_0)^2}{2K_BT\,\omega_0^2}\right) \quad \text{— (3)}$$

FWHM is given by

$$\Delta\omega_{Doppler} = 2\omega_0\left(\frac{(2\ln 2)K_BT}{mc^2}\right)^{1/2} \quad \text{— (4)}$$

$$\Delta\omega = \frac{4\pi}{\lambda}\left(\frac{(2\ln 2)K_BT}{m}\right)^{1/2} \quad \text{— (5)}$$

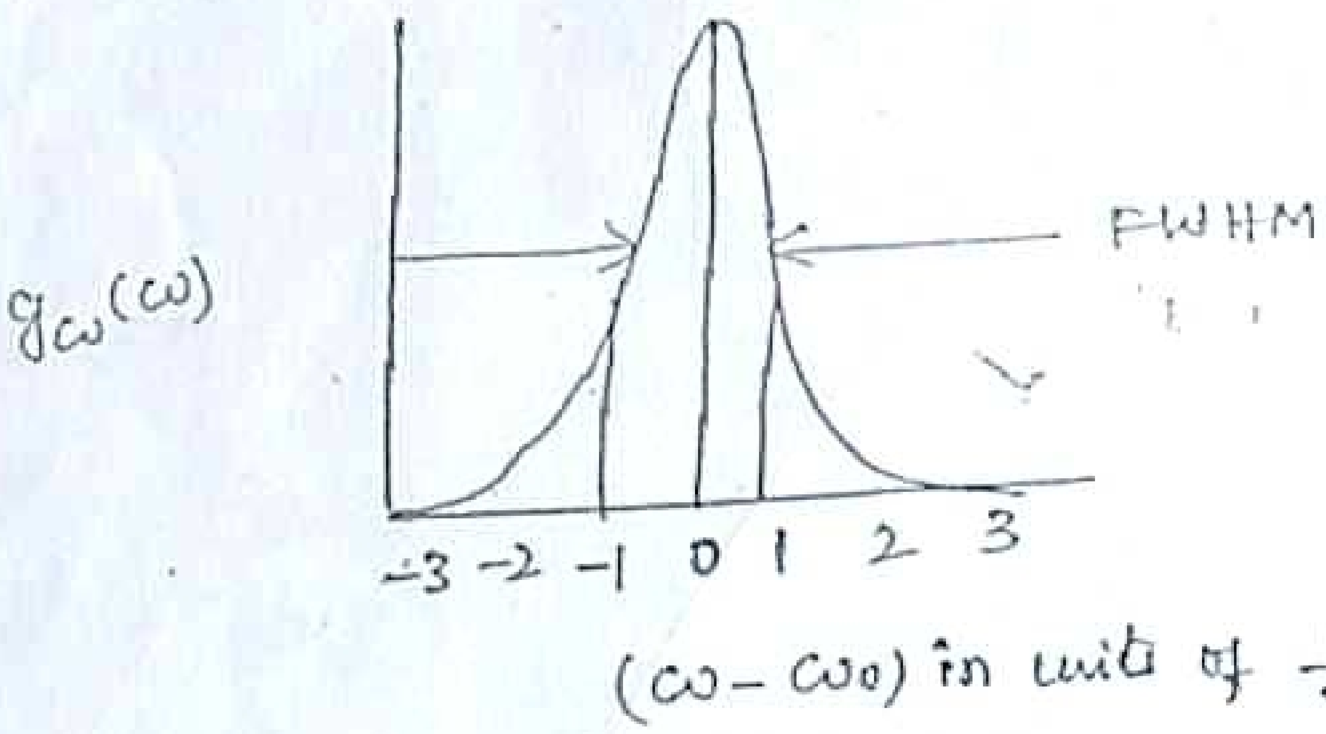


Gaussian line shape

The detailed form of the life time broadening be deduced by taking the Fourier transformation of a burst of light that decays exponentially with time const. τ.

This gives the following spectral line shape function

$$g_{\omega}(\omega) = \frac{\Delta\omega}{2\pi} \frac{1}{(\omega-\omega_0)^2+\left(\frac{\Delta\omega}{2}\right)^2}$$



The function peaks at the line centre ω_0 and has a FWHM of $\frac{1}{\tau}$

The FWHM is given by $\Delta\omega_{\text{life time}} = \frac{1}{\tau}$

The spectrum described by Eqn is called a Lorentzian line shape.

DOPPLER BROADENING:-

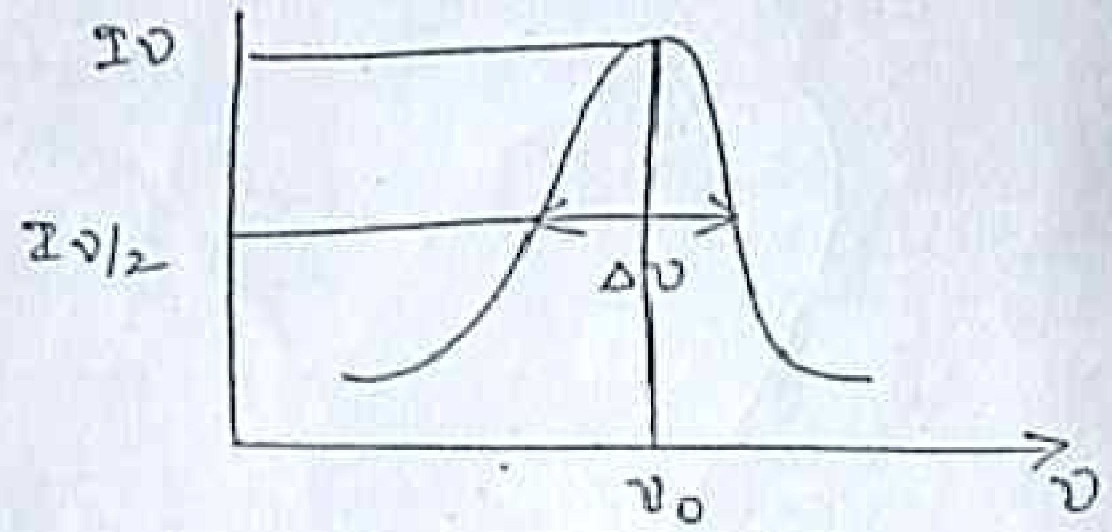
Doppler broadening originates from the random motion of the atoms in the gas. The random Thermal motion of the atoms gives rise to Doppler shifts in the observed frequency which causes line broadening.

$$\int_{-\infty}^{\infty} g(\omega)\,d\omega = \frac{2K\pi}{\gamma} = 1$$

$$\text{(or)} \quad K = \frac{\gamma}{2\pi}$$

Hence
$$g_L(\omega) = \frac{\gamma}{2\pi} \frac{1}{(\omega-\omega_0)^2 + \frac{\gamma^2}{4}} \quad —(3)$$

The line shape of such a distribution is known as Lorent line shape:-



(Lorentzian line shape)

The maximum value $g_L(\omega)$ at $\omega = \omega_0$ is

$$g_L(\omega) = \frac{\gamma}{2\pi} \frac{1}{\frac{\gamma^2}{4}} = \frac{4}{2\pi\gamma} = \frac{2}{\pi\gamma} \quad —(4)$$

The Full width at half maximum Intensity $\Delta\omega^{FWHM}$ is obtained by setting eq'n (4) equal to half the value of $g_L(\omega)$

$$g_L(\omega) = \frac{1}{2}\left(\frac{2}{\pi\gamma}\right) = \frac{1}{\pi\gamma}$$

we can obtain the FWHM emission line width as

$$\Delta\omega^{FWHM} = \gamma = \frac{1}{\tau} = 2\pi\Delta\nu_c$$

where $\Delta\nu_c$ denotes the classical line width.

...al Broadening:- (Emission broadening) (Natural Broadening)

This type of broadening occurs when every atom of the ...me species making the same transition produces an Identical ...e shape and width. Such a situation leads to the Lorentzian ...e shape function and is refered to as homogeneous broadening.

Let us Consider an electron performing simple harmonic ...otion with characteristic angular frequency ω_0 and γ is the damping factor resulting from radiation. Then the Oscillator has a life time $\tau = \frac{1}{\gamma}$

The frequency spectrum of such an Oscillator is

$$E(\omega) = -\frac{E_0}{2\pi} \frac{1}{i\left[(\omega-\omega_0) + \frac{\gamma}{2}\right]} \quad -(1)$$

The Intensity distribution per unit frequency $I(\omega)$ is proportional to $|E(\omega)|^2$

$$I(\omega) \propto |E(\omega)|^2$$

$$I(\omega) = \left(\frac{E_0}{2\pi}\right)^2 \frac{1}{(\omega-\omega_0)^2 + \frac{\gamma^2}{4}}$$

The line shape function is

$$g(\omega) = \frac{K}{(\omega-\omega_0)^2 + \frac{\gamma^2}{4}} \quad -(2)$$

where $K = \left(\frac{E_0}{2\pi}\right)^2$ is a Constant.

Equation (2) has been Normalized

$$\int_{-\infty}^{\infty} g(\omega)\,d\omega = 1 \quad -(3)$$

$$\int_{-\infty}^{\infty} g(\omega)\,d\omega = \frac{4K}{\gamma^2} \int_{-\infty}^{\infty} \frac{d\omega}{\frac{4}{\gamma^2}(\omega-\omega_0)^2 + 1} = 1$$

$$\int_{-\infty}^{\infty} g(\omega)\,d\omega = \frac{2K}{\gamma}\left[\tan^{-1}\frac{2(\omega-\omega_0)}{\gamma}\right]_{-\infty}^{\infty} = 1$$

For small values of γ

$$\left[\tan^{-1}\frac{2(\omega-\omega_0)}{\gamma}\right]_{-\infty}^{\infty} = \pi$$