FABRY-PEROT INTERFEROMETER

Objectives:

I. **Alignment of Fabry-Perot Interferometer to observe concentric circular fringes**
II. **Measurement of the wavelength of a diode Laser**
III. **Determination of difference in wavelengths of sodium doublet**

Introduction

The Fabry-Perot interferometer uses the phenomenon of multiple beam interference that arises when light shines through a cavity bounded by two reflective parallel surfaces. Each time the light encounters one of the surfaces, a portion of it is transmitted out, and the remaining part is reflected back. The net effect is to break a single beam into multiple beams which interfere with each other. If the additional optical path length of the reflected beam (due to multiple reflections) is an integral multiple of the light's wavelength, then the reflected beams will interfere constructively. More is the number of reflections inside the cavity, sharper is the interference maximum. Using Fabry-Perot (FP) interferometer as a spectroscopic tool, concepts of finesse and free spectral range can be understood.

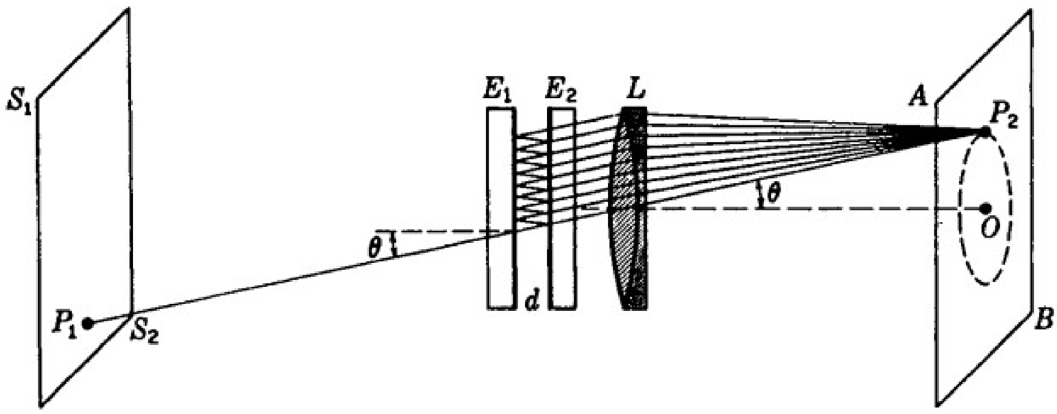

Fig. 1: Schematics of a Fabry-Perot Interferometer

Principle of Working

The basic principle of working of the Fabry-Perot interferometer is schematically explained in the adjacent figure. Two partial mirrors **E₁** and **E₂** are aligned parallel to one another at a distance d, forming a reflective cavity. The cavity is irradiated by a monochromatic light of wavelength λ from a broad source S_1S_2 (in our case, a laser followed by a beam expander). In Fig.1 a ray from the point P_1 on the source is incident at an angle θ, producing multiple reflections take inside the cavity. Part of the light is transmitted each time the light reaches the second reflecting surface. All such transmitted parallel rays can be brought together using another lens L (or by eye) at point P_2 on the screen AB at the same angle θ. (In our case we can see the patterns by directly projecting on a diffusing screen). The conditions for maxima or minima depend on the path difference between them. Let n be the refractive index of the medium in the cavity (in this case it is air). Then the optical path difference between two neighbouring rays is:

$$\Delta = 2nd\cos\theta \quad \ldots\ldots \qquad (1)$$

Then the phase difference is given by $\delta = (\frac{2\pi}{\lambda})\Delta \ldots \ \ldots \qquad (2)$

The calculation of path difference is shown in Fig. 2 for a general cavity where α and β are the angles of incidence and refraction, respectively. For the case of air as a medium between the mirrors, α≈β. In our notation, α≈β = θ.

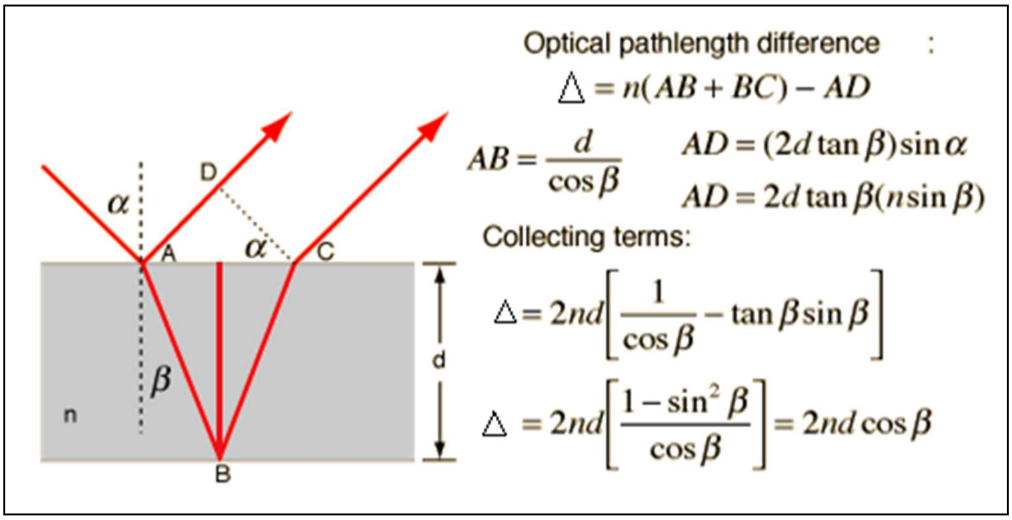

Fig 2. Calculation of path difference

Thus, the resultant transmitted light intensity I_T is:

$$I_T = I_0 \frac{1}{1+\frac{4R}{(1-R)^2}\sin^2\frac{\delta}{2}} \quad \ldots \qquad \ldots \qquad (3)$$

where, I_0 is the incident intensity, R is the reflectivity of the mirrors. It can be noticed that I_T varies with δ.

I_T is maximum when $\Delta = m\lambda$ ($m = 0, 1, 2\ldots$) or $\delta = 2m\pi$ ... ... (4)

and minimum when $\Delta = (2m+1)\lambda/2$ ($m = 0, 1, 2\ldots$) or $\delta = (2m+1)\pi$ ... (5)

The complete interference pattern appears as a set of concentric rings. The sharpness of the rings depends on a parameter called coefficient of finesse, F, defined as $F = \frac{4R}{(1-R)^2}$.

Determination of wavelength (λ): Using the relations 1 and 4 (or 5) wavelength of the incident light can be determined accurately. Since in the present set up, the medium between the mirrors is air, so n = 1. Let the initial separation between the mirrors is d_1. If one counts the number of fringes (say maxima) appearing or disappearing at the centre ($\theta \approx 0$) by varying the distance between the mirrors to d_2, then λ can be determined as follows:

$2d_1 = m_1 \lambda$, $2d_2 = m_2 \lambda$, $m_2 - m_1$ = Number of maxima counted

$$\boldsymbol{\lambda = \frac{2(d_2 - d_1)}{m_2 - m_1}} \quad \ldots \quad \ldots \quad (6)$$

Determination of difference in wavelengths of sodium doublet (Δλ):

The Fabry-Perot interferometer can be used for measurement of the wavelength separation of sodium D-lines. The yellow sodium doublet consists of two wavelengths whose values are very close to each other, i.e. 589.0 and 589.6 nm. Therefore, during the process of moving the interferometer's movable mirror, the interference fringes produced by the two yellow lines will appear periodically clear and blurry (due to splitting). For a given separation (2d) of the mirrors, maxima of the two wavelengths coincide to give a clear fringe pattern and satisfy the following relation:

$$2d = m_1 \lambda_1 = m_2 \lambda_2 \quad \ldots \quad \ldots \quad (7)$$

where m_1 and m_2 are respective orders of maxima for λ_1 and λ_2. Due to difference in wavelength, when the mirror is moved the corresponding fringes will not move equally and the pattern will be blurry. On further movement the pattern becomes clear again where the (m_1+m)th order of the longer wavelength coincides with (m_2+m+1)th order of the shorter wavelength. If d_1 is the distance moved between two clear fringe patterns, then Eq. (7) can be written as (assuming $\lambda_1 > \lambda_2$)

$$2(d+d_1) = (m_1 + m)\lambda_1 = (m_2+m+1)\lambda_2 \quad \ldots \quad \ldots \quad (8)$$

If λ is the average of λ_1 and λ_2 (so that $\lambda_1\lambda_2$ can be approximated as λ^2), then the difference of the two wavelengths, Δλ, can be expressed as:

$$\boldsymbol{\Delta\lambda} = \frac{\boldsymbol{\lambda^2}}{\boldsymbol{2d_1}} \qquad \ldots \qquad \ldots \qquad (9)$$

Experimental Setup:

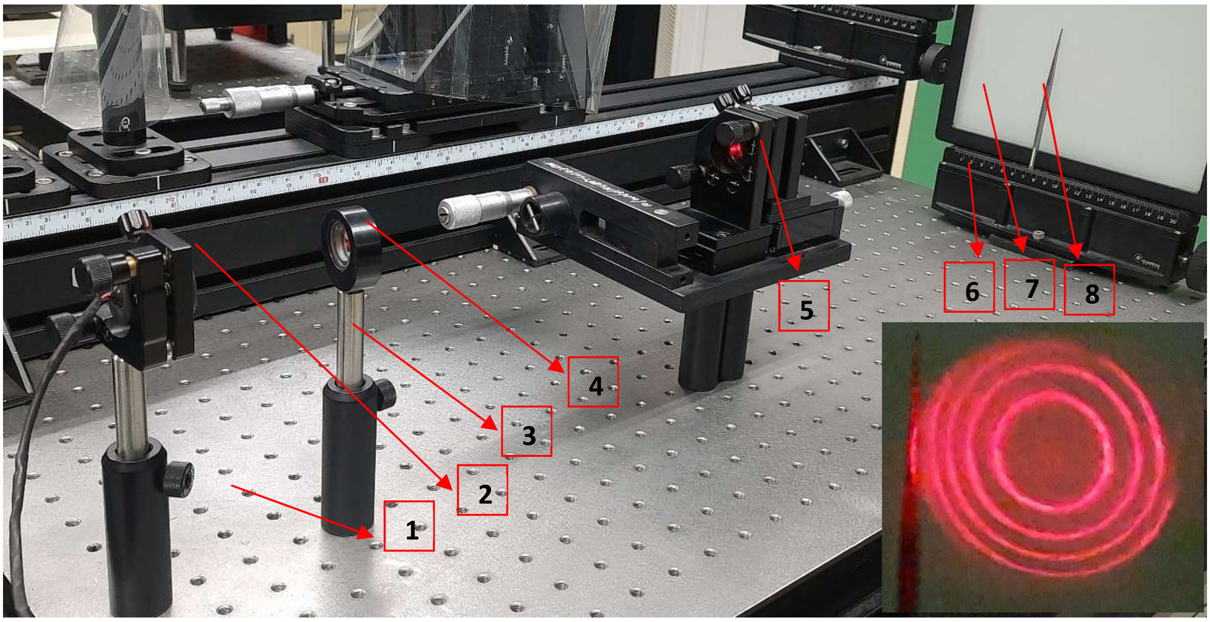

Fig 3. Fabry-Perot interferometer set up with fringes (shown in inset) as viewed in dark

(I) Different parts of the experimental set up are numbered in Fig.3 and described below:

1. Optical Breadboard
2. Laser diode (633 nm, 1mW)
3. Optical post and post holder
4. Achromatic lens (beam expander)
5. Fabry-Perot interferometer with kinematic adjustment (expanded view shown in Fig. 4)
6. Linear translation stage
7. Diffusing screen
8. Pointer

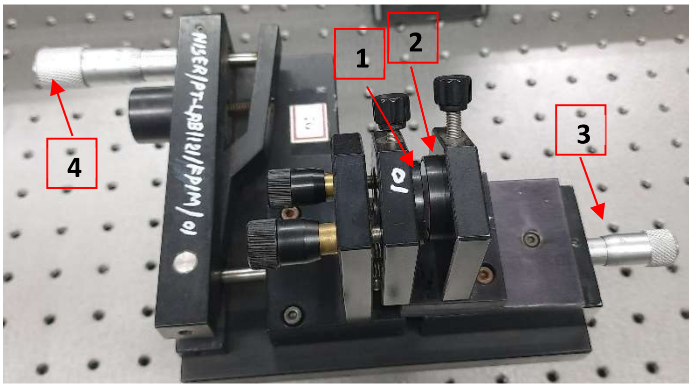

Fig 4. Fabry-Perot interferometer with adjustment screws

(II) Different parts of the interferometer as numbered in Fig. 4:

1. Movable mirror with mount and two adjustment screws on the rear side
2. Fixed mirror with mount

3. Coarse movement screw

4. Fine movement screw

Procedure

Warning: Never look into the direct laser beam.

I. Alignment of Fabry-Perot Interferometer to observe concentric circular fringes

1) The optical rail is already mounted on an optical breadboard for better stability and avoid vibration issues.

2) Mount and lock the diode laser on the optical rail towards one end.

2) Mount the Fabry-Perot interferometer towards the middle of the optical rail (about 40 cm from laser). It has one fixed and one movable mirror as shown in Fig. 3.

3) Adjust the three screws behind the movable mirror to make sure that the two mirrors are visibly parallel to each other approximately. Using the micrometer screw adjust the initial distance between the mirrors to about 2mm.

Take sufficient precautions such that the two mirrors never touch each other, otherwise the surfaces will be damaged permanently.

4) Mount the diffusion screen at the other extreme end.

5) Switch on the diode laser and adjust it such that the beam passes through the centre of the two mirrors. Adjust the two black screws (for movement in x and y directions) behind the movable mirror to let the multiple reflected beams coincide on the screen. It means both the mirrors are now nearly parallel.

6) Place the lens in front of the laser to expand the beam to create a broad source. Adjust the position of the lens so that the entire reflection cavity is illuminated. With all the components perfectly set, the observer can find a series of very intense, concentric circular interference rings on the screen.

Note: Reflections from the static surfaces may cause additional interference patterns in the background of the main fringe pattern. These patterns are static in nature with respect to the mirror movement and have no impact on the measurements made using the main interference pattern.

II. Measurement of the Wavelength of a diode Laser

1) Setup the Fabry Perot interferometer as described above to observe clear circular fringes at the centre of the ground glass screen. You may use an additional aperture on the laser head so as to see only the centre of the fringe pattern. This might make the counting of the fringes easier.

2) Determine the least count of the coarse and fine micrometer screw attached to the movable mirror. Please note that the lever ratio is 0.03: 1 for the fine micrometer screw, i.e. the mirror is actually displaced by 0.03mm for a 1mm change on the fine micrometer screw. This ratio is best applicable in a limited range from 24mm downwards on the fine screw. So it is advisable to start your reading around 24mm and move the screw downwards while counting fringes. Let the initial reading of the fine micrometer be d_1.

3) Turn the fine micrometer slowly and count the number of fringes that appear (or disappear) at the centre of the screen. Record the micrometer reading d_2 after every count 50 fringes.

CAUTION: The micrometer screw is extremely sensitive. So move it very slowly to avoid collapse of many fringes while counting, which will lead to error.

4) Acquire enough data and fill up the observation table. Using Eq. 6, calculate λ in each case and find the mean λ.

III. Determination of difference in wavelengths of sodium doublet

1) Replace the laser with a sodium lamp and following the procedure (I) adjust the set up to get a concentric fringe pattern. You may see two sets of concentric fringes already due to the sodium doublet as shown in Fig. 5.

2) Carefully move the mirror to see a distinct pattern where both sets of fringes coincide and record the micrometer reading. Move the mirror further (the pattern becomes split) till you see a distinct pattern again and record the reading.

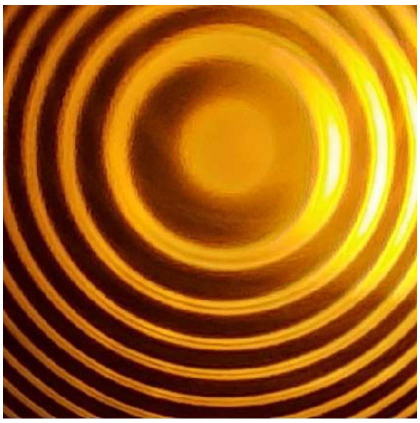

Fig. 5: Two sets of concentric fringes

3) Find the difference of the two positions ($2d_1$).

4) Repeat the above step 5 times and determine average $\Delta\lambda$.

Observations:

Least count of coarse micrometer = …. Least count of fine micrometer = ...

Table 1: Initial position of fine micrometer, d_1 = ...

Sl. No.	No. of fringes appeared/disappeared **m_2-m_1**	No. of divisions rotated on micrometer	**d_2 (cm)**	**$d_2 - d_1$ (cm)**	**λ (nm)**	**Mean λ (nm)**
1	50					
2	100					
3	150					
..	..					

Table 2:

Sl. No.	**$2d_1$**	**$\Delta\lambda$**	**Avg. $\Delta\lambda$**

Results and discussions:

λ_{mean} = ….

Actual value of λ = 633 nm

Precautions:

1. Do not touch or contact in any way either the front or back surfaces of the mirror pieces. Doing so will permanently damage the mirror coatings.
2. Avoid eye exposure to the direct laser beam.
3. Move the micrometer screw very slowly.

Reference:

1. Supplier manual

2. Fundamentals of Optics, Jenkins & White