Nalanda Open University

B.SC Part-2

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Topic- Fabry-Perot Interferometer

Fabry-Perot Interferometer

Another commonplace division-of-amplitude interferometer is the Fabry-Per´ot interferometer, which uses a principle similar to that of the Michelson interferometer to produce interference fringes. The core of this device consists of two parallel flat glass plates, one movable, one fixed, the inner surfaces of which are coated with a partially reflective metallic layer (see Fig. 1).

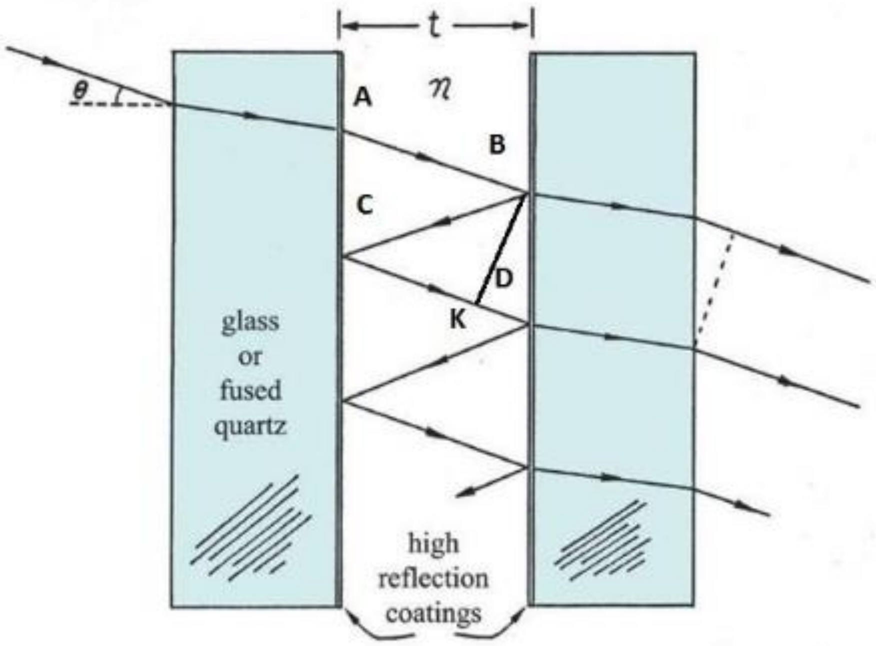

Figure 1 : The reflected and transmitted beams of light going through the two glass surfaces of a Fabry-Per´ot interferometer

Due to coating, a beam of light incident on the first plate at an angle θ to the horizontal produces a series of beams passing through to the other side, as each continuously gets either transmitted through the second plate to go on to the observer, or bounces back and forth between the inner surfaces until it does (it could also potentially come back out from the side the original beam entered the arrangement, but those rays are of no consequence to us).

Each of the beams arrives at the point of observation with a path difference of δ with the one before and after it: thus they reinforce each other and produce an interference pattern. Let the distance between the plates be t. From Fig. 7, the path difference δ between the rays exiting at B and D is exactly

$$\delta = BC + CK$$

In the diagram, the line BK is normal to CD. The angle between BC and CK is 2θ, and the triangle BCK is a right angle one. Hence we may write

$$CK = BC \cos 2\theta$$

Moreover, we can relate the hypotenuse BC to the distance between the plates via

$$BC \cos \theta = t$$

The path difference

$$\delta = BC + CK = BC(1 + \cos 2\theta) = 2BC\cos^2\theta = 2t\cos\theta$$

The condition for constructive interference is

$$n\lambda = 2t\cos\theta$$

where n is the fringe order, and λ is the wavelength. We can vary the separation between the glass plates and watch the fringes disappear in the centre of the field of view, thus allowing us to do almost exactly the same measurements as we could with a Michelson interferometer. The advantage of the Fabry-Per´ot is its high resolving power: it makes it a valuable tool in the study of the Zeeman Effect and the hyperfine structure of certain spectral lines.

One point has to be made concerning this device: since the interference only occurs for light incident on the plate as an angle θ, a perfectly parallel beam of light may not produce fringes: hence we must once again use an extended light source to remedy this problem.

Experiment with the Fabry-Perot Interferometer (1weight)

The chief advantage of the Fabry-Per´ot interferometer is its higher resolving power compared to that of the Michelson interferometer: as such, it is often used to investigate the fine structure of spectral lines. In this experiment we will study the spectral line of sodium, which is actually a doublet of two lines separated by a very small wavelength difference. We will be able to discern them and quantify the separation.

Set up the interferometer as described above, with the mirror A set all the way back. The first task is to make the adjustable mirror of unit E almost exactly parallel to mirror A: begin by employing an incandescent light bulb and, without the telescope, adjusting the calibration screws of mirror E to make the light bulb electrical arc aligned with its multiple reflections.

Once this is accomplished, the two mirrors are approximately parallel: now finer adjustments are needed. Replace the light bulb with the sodium lamp and observe the interference fringes (again without the telescope): the pattern is hard to discern, as the mirrors are likely still not perfectly aligned — there might be several underlying interference patterns. Focus on the ones in the background, and try to align them with each other by bringing the centre of the circular fringes to the centre of the field of view.

Insert the telescope tube, first without the magnifying piece, and make more adjustments to move the pattern to the centre. Next, insert the magnifying piece and focus on the pattern by adjusting the depth of insertion of the magnifying piece into the telescope tube; once you are in focus, complete the final adjustments center the pattern at the field of view of the telescope. If at any point of this procedure you feel you completely lost the pattern, go back to the light bulb. In the end, you should observe perfectly focused circular fringes, with the doublet clearly visible (to check if you got it right, try turning the micrometer screw - the fringes should come in and out of coincidence). The view should resemble Fig.

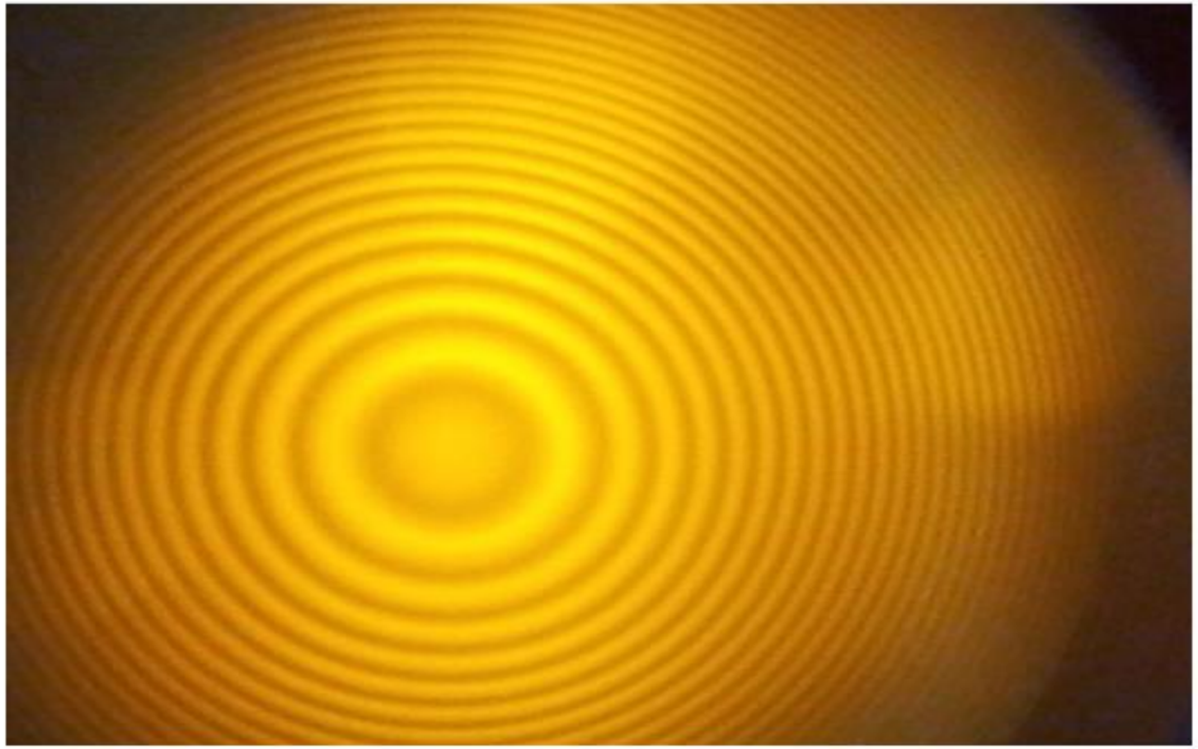

Figure : Circular fringes from a sodium light source as seen in the Fabry-Peròt interferometer.

If that is not the case, try starting from scratch: reset the adjustable mirror E to the very back, then start from the beginning with the light bulb.

After locating the circular fringes, proceed to calibrate the device just as you have done for the Michelson interferometer: count fringes passing the field of view and record the micrometer readings every 50 fringes (have the mirror carriage move toward you, as before).

With the calibration curve, use the interference pattern to determine the wavelength separation of the doublet.

Let the two wavelengths of the spectral lines in the doublet be λ_1 and λ_2, with $\lambda_2 < \lambda_1$. For certain path difference, the two interference patterns produced by the spectral lines may be interfering with each other (on top of with interfering with themselves to produce the fringes in the first place), moving in and out of complete coincidence with each other. The coincidence condition is $f\lambda_1 = g\lambda_2$ where f and g are some integers. The next time a coincidence will occur, as we increase the fringe order, is when the condition

$$(f + h)\lambda_1 = (g + h + 1)\lambda_2$$

is satisfied, where h is another integer. Subtracting the two, we obtain $h\lambda_1 = (h + 1)\lambda_2$, or, rearranging for the difference

$$\frac{\lambda_2}{h} = \lambda_1 - \lambda_2 \equiv \Delta\lambda$$

where $\Delta\lambda$ is the sought wavelength separation. Knowing the number of fringes h between positions of coincidence of the two wavelengths, along with the wavelength value of one of the lines in the doublet, λ_2, find the separation of the lines in the doublet.

Use the calibration curve: instead of patiently counting the fringes, let us note the micrometer readings of displacements — call it M — and convert it to actual mirror displacement d via the conversion factor, $d = f M$. Knowing the mirror displacement d, we use the basic result that $h\lambda_1 = 2d$, which gives

$$h = \frac{2d}{\lambda_1} \Rightarrow \Delta\lambda = \frac{\lambda_1 \lambda_2}{2d}$$

The product of the two wavelengths can be treated as their geometric mean squared, i.e. $\lambda_1\lambda_2 \approx \langle\lambda\rangle^2$ — where we take the value of the average sodium spectral line wavelength to be $\langle\lambda\rangle = 589.3$ nm. Hence our final expression for the wavelength difference is

$$\Delta\lambda = \frac{\bar{\lambda}^2}{2fM}$$