Revisiting Fizeau's Observations: Spectral study of Na source using Newton's rings

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Abstract

Conventional Newton's rings experiment is generally used in undergraduate laboratory to determine the average wavelength of Na doublet. A minor modification of this setup enables us to view simultaneously Newton's rings both in reflected as well as transmitted light. A movable glass plate with respect to the plano-convex lens allows us to observe the variation of contrast/visibility of these fringes and thus allows us to determine the separation of the Na yellow doublet.

1. Introduction

Newton's rings experiment is a classic example of fringes of equal thickness or Fizeau fringes[1,2]. This is generally used in undergraduate optics laboratory, as it enhances conceptual understanding of internal and external reflections and associated phase shifts. It also requires fair degree of experimental skill to perform this. Even in the literature [3,4,5,6] we find it being used for classroom demonstrations, for determination of wavelength of He-Ne laser etc. The apparatus can be rearranged by mounting the plano-convex lens and the glass plate vertically. This modification lends itself to observe the Newton's rings in the transmitted light. Moreover, if the glass plate is made movable, as was done in this work, this could also be used to estimate the Na doublet separation apart from being used to determine the average wavelength.

2. Theory of formation of Newton's rings

For a plane parallel glass plate of thickness, t, the path difference between two partially reflected light from top and the bottom surface of plate is given by [7]:

$$\delta=2\, n_f t \cos(\theta_t) \qquad (1)$$

wheren_f :Refractive index of glass plate, t:Thickness of glass plate, θ_t:Angle of refraction

If the glass plate is of varying thickness t, the optical path difference varies even without variation in the angle of incidence. Thus if the direction of the incident beam is fixed, say at normal incidence, a dark or bright fringe will be associated with a particular thickness for which λ satisfies the condition for destructive or constructive interference, respectively. For this reason, fringes produced by a plate of variable thickness are called Fringes of equal thickness or Fizeau fringes. For a monochromatic and collimated light, it is only the thickness variation which can result in path difference variation. Therefore, Fizeau fringes are contours of constant thickness.

When an air film, formed between the spherical surface of plano-convex lens and an optical flat is illuminated from a laser or sodium vapour lamp, equal thickness contours for a perfectly spherical surface are formed. These circular fringes are called Newton's rings. These fringes are formed around the point of contact. At the centre, thickness of the air film is zero and hence the path difference between the two reflected rays is zero due to propagation. But the central fringe is dark as a consequence of phase shift of π due to one external reflection.

3. Finding the Fine structure using Newton's rings

We know that the sodium lamp emits two wavelengths: 5890A and 5896A. These two wavelengths form two sets of Newton's rings with coincident centres. If we examine a few rings near the point of contact of lens and glass plate, the two sets of rings appear to coincide; but if they are traced to a sufficient distance from the centre, the misalignment becomes more and more apparent. Consequently, after some distance, the bright fringe of one set of rings will occupy the same position as the dark fringe of the other set, and they will mutually annihilate to a uniform intensity. If on the other hand, the glass plate is moved away from the lens, mutual annihilation would take place at the centre itself satisfying equation of the type (2) where d is the distance between the glass plate and plano-convex lens. Continuing the same line of reasoning, it is evident that perfect coincidence and perfect misalignment of the two systems of rings would recur alternately at regular intervals[8].

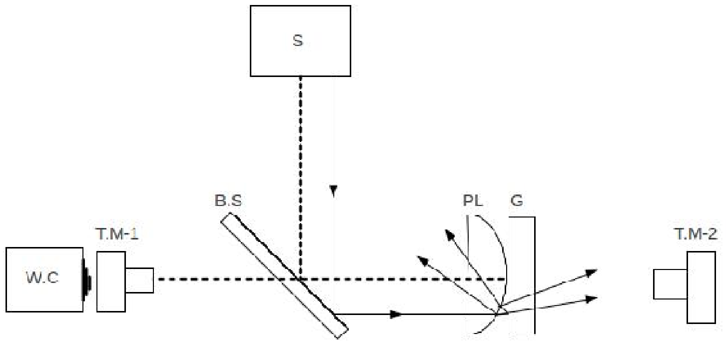
$$2d = m_1\lambda_1 = (m_2 + ½)\,\lambda_2 \qquad (2)$$

To observe this variation of contrast, the glass plate is made movable in a perpendicular direction with respect to plano-convex lens. When the glass plate is moved away, the higher order fringes appear at the centre. Due to finite coherence length of source, the contrast variation can be clearly seen as the glass plate is moved.

The separation of two wavelengths in the Na doubletthat is used to observe interference is related to the path difference, as in the case of Michelson interferometer[7]. If $\Delta\lambda$ is the separation between two spectral lines and λ is the average wavelength, then

$$\Delta\lambda = \frac{\lambda^2}{2\,\Delta d} \qquad (3)$$

whereΔd is the mirror movement required between two consecutive coincidences(bright fringe of λ_1 overlapping with bright fringe of λ_2) in a Michelson interferometer. This formula can be used in Newton's rings in the case where glassplate is moved with respect to the plano-convex lens. In this case, Δd represents distance through which the glass plate is moved from zero pathdifference(glass plate touching the plano-convex lens) position to the subsequent region of maximum contrast.



Fig(1) : Schematic diagram of Newton's rings with glass plate, G and plano-convex lens, PL mounted vertically and the Glass plate made movable. T.M-1 and T.M-2: Travelling microscopes, W.C: Webcam connected to travelling microscope, BS: Beam splitter, S: Light source

4. Experimental details and Results

4.1 Determination of average wavelength of Na

The average wavelength of Na light is easily determined by measuring the diameters of a few rings. A plot of radius-square and the ring number gives a straight line. By finding the slopeand knowing the radius of curvature,R, we can get the wavelength of Na light using the formula,

$$\lambda = \frac{r_{m+p}^2 - r_m^2}{pR} \qquad (4)$$

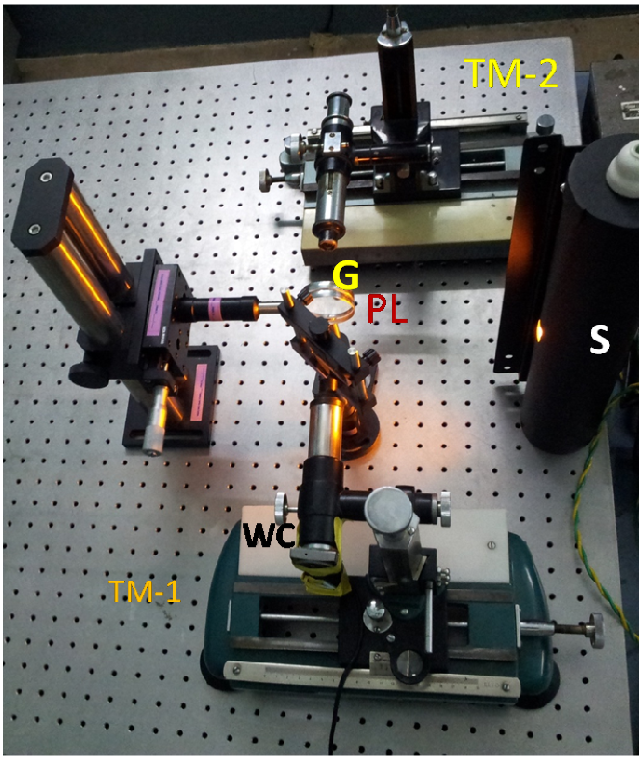
where, r_m and r_{m+p} are radii of the m^{th} ring and $(m+p)^{th}$ ring, R is Radius of curvature of the lens.

The conventional Newton's rings experiment was performed and the graph of ring no. m versus r_m^2 was plotted as shown in Fig(3). The slope of this graph is $(r_{m+p}^2 - r_m^2)/p$. Therefore the average wavelength of sodium source

= slope /radius of curvature (R)

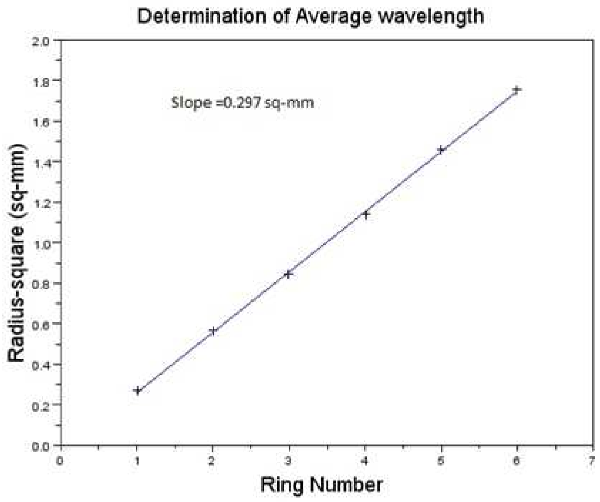
= 0.297×10^{-6} m^2 / 0.5 m

= 595nm



Fig(2): Photograph of experimental setup showing the vertical mounting of plano-convex lens, PL and glass plate, G

The expected value of average wavelength of Na is 589.3nm and the experimental value is accurate to about one percent. The average value is required to determine the separation of the Na doublet.



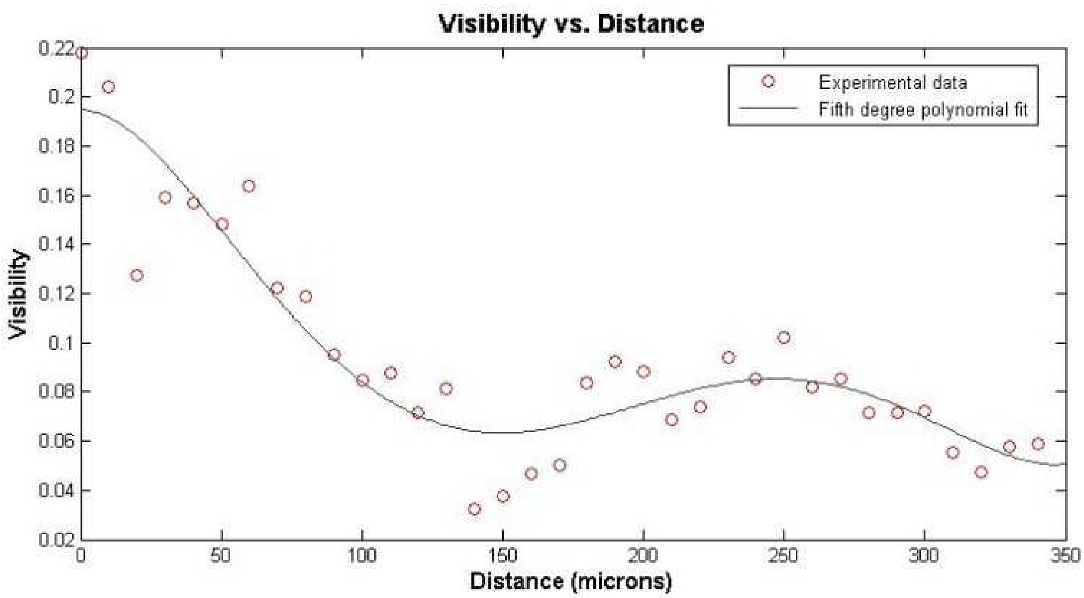
Fig(3) : Graph of ring no versus diameter-square to determine the average wavelength. The linear regression is used to get the best-fit straight line, with a correlation coefficient of 0.99

4.2 Estimation of Na doublet separation

The schematic diagram and the photograph of the experimental setup are shown in fig(1) and fig(2) respectively. The glass plate was mounted on a micrometer translation stage so that its distance can be varied in a controlled manner. Newton's rings in the reflected light were captured using a webcam (without the lens) attached to travelling microscope without the eyepiece. Newton's rings were captured for every 10μm distance. From the snapshot, the visibility of the fringes was calculated using ImageJsoftware (freely downloadable, image processing software developed by National Institutes of Health).Sample snapshots at different distances are provided in fig(5) to fig(9) which clearly show the contrast variation. Fig(10) & fig(11) show the Newton's rings in the reflected and transmitted light.Plot of distance versus visibility is shown in the fig(4). As expected, there is a periodic variation of contrast starting with its maximum value at zero path difference. From the graph, we get Δd = 250μm, which is the separation between two successive maxima in the graph.

$$\Delta\lambda = \frac{\lambda^2}{2\,\Delta d} = (595\text{nm})^2/2(250\mu\text{m}) = 7\ \text{A}$$

This shows that the separation of the Na doublet whose expected value is 6A, could be estimated to an accuracy of about 17 percent using this analysis.



Fig(4) : Plot of visibility as a function of distance of glass plate from the plano-convex lens.

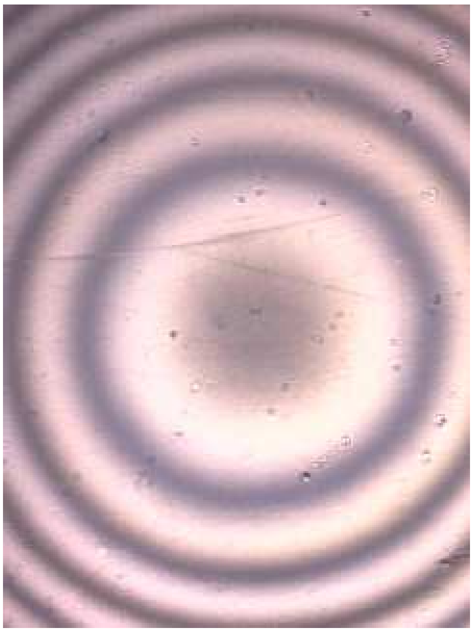


Fig. (5): Zero path difference

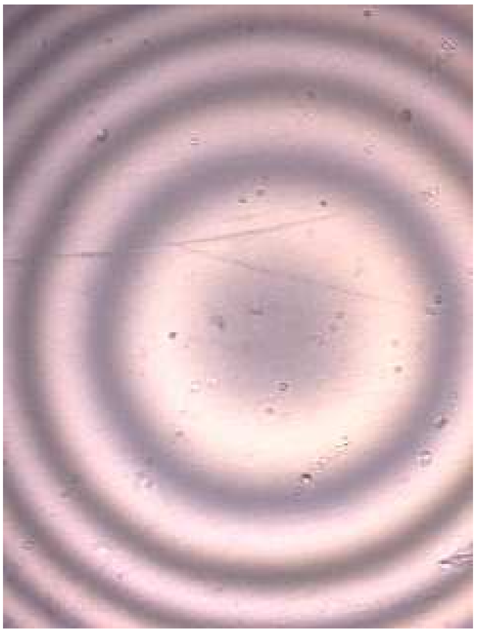


Fig. (6): Path difference = 50micron

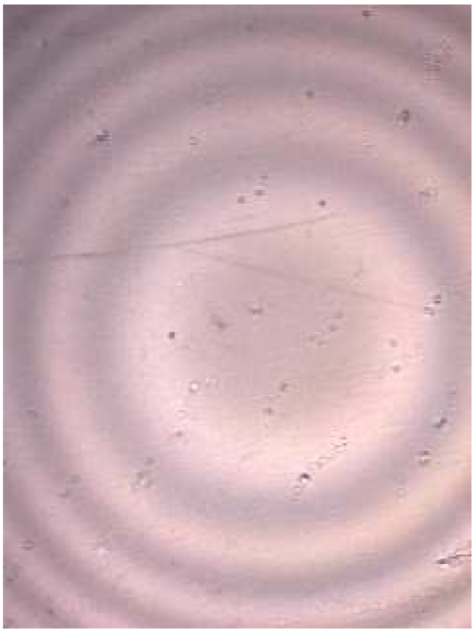


Fig. (7): Path difference=100 micron

Fig. (8): Path difference=150 micron

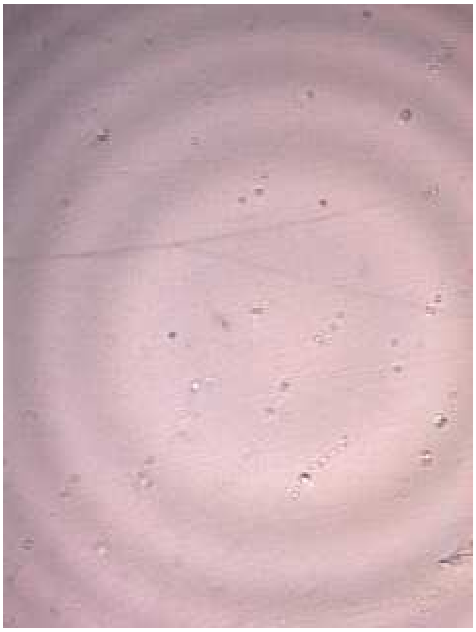


Fig.(9): Path difference=250 micron

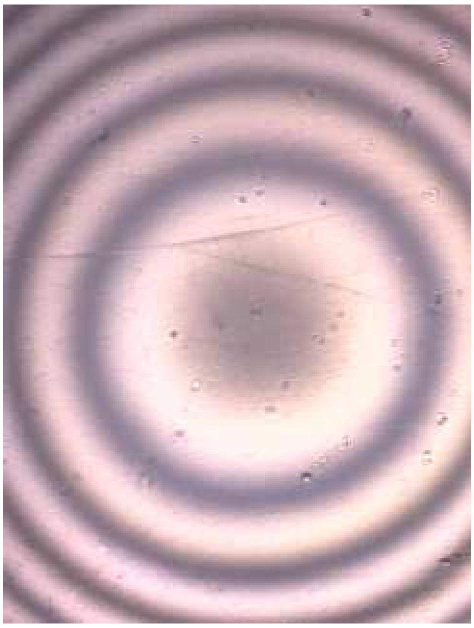


Fig. (10): Newton's rings: Reflected light

- **Central Dark Fringe**
- **High Contrast**

Fig. (11): Newton's rings: Transmitted light

- **Central Bright Fringe**
- **Low Contrast**

5. Conclusion

In this work, we have revisited Fizeau's observations by modifying the conventional Newton's rings setup. Both the glass plate and plano-convex lens are mounted vertically which enables us to view both the reflected and transmitted rings simultaneously, compare and contrast them with considerable ease. Moreover, the glass plate mounted on a micrometer translation stage, allows us to observe clearly the variation fringe contrast/visibility. From the graph of distance versus visibility, we were able to calculate the separation of Na doublet. This also enables us to make an estimate of coherence length of Na source by noting the distance to the first minimum in the graph.

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