SECOND YEAR LABORATORY

EXPERIMENTS WITH AN OPTICAL MICHELSON INTERFEROMETER

1 Aims

To understand the principle of operation and how to use a Michelson interferometer. To understand the formation of beats in fringe visibility produced by a doublet. To understand, at the atomic level, why some lines are doublets.

2 Objectives

To use the Michelson interferometer to:

1. Determine the reduction factor of the mechanical lever mechanism.
2. Measure the wavelength of the mercury blue line to an accuracy of a few percent.
3. Measure the splitting of the yellow doublet in mercury and of the sodium D lines.

3 Introduction

Michelson interferometers have been used in some of the most famous experiments in physics – ranging from Michelson and Morley's experiment that attempted to detect the presence of the aether in 1887 through to the detection of gravitational waves that led to the award of the Nobel physics prize in 2017.

4 Theory

A schematic representation of a Michelson interferometer is shown in Fig. 1.

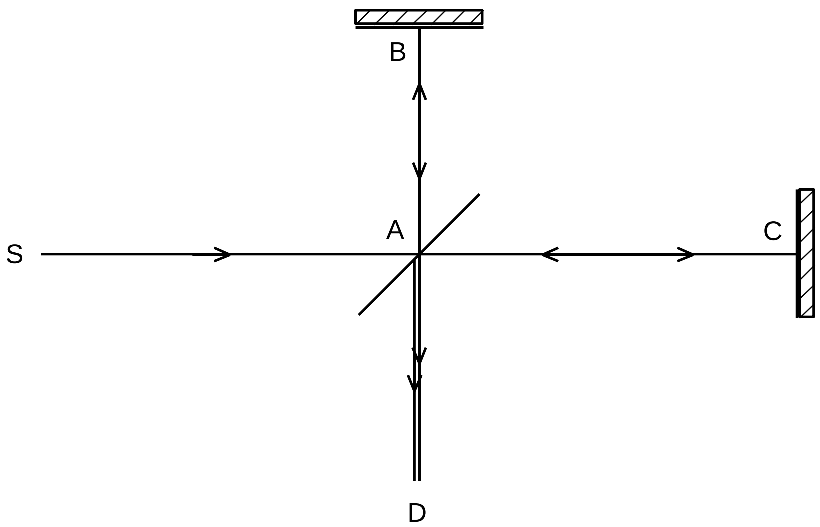

Figure. 1. Schematic representation of a Michelson interferometer.

Light enters the interferometer from the source (S) and is then split into two by the beam splitter (A). The optical path lengths in the two arms of the interferometer after the beam splitter are d_1 (AB) and d_2 (AC). SABAD and SACAD represent the two on-axis paths for light rays.

Exercises: Show that for on-axis monochromatic light of frequency v the intensity at D is given by

$$I(\Delta) = \frac{I}{2}\left(1 + \cos\frac{2\pi v}{c}\Delta\right)$$

where $\Delta = 2(d_2 - d_1)$.

Also, show that if the source has a spectral frequency distribution given by $I(v)\mathrm{d}v$,

$$I(\Delta) = \mathrm{Const} + \frac{1}{2}\int_0^\infty I(v)\cos\frac{2\pi v}{c}\Delta \mathrm{d}v\,. \qquad (1)$$

How should this be modified for OFF-axis rays?

5 Setting up the Interferometer

If the mirrors of the interferometer need cleaning, inform a demonstrator. You must not try and do this yourself.

Adjustments must be made to set the planes of the two mirrors perpendicular to one another.

Place the ground glass on the lamp and the green (Wratten 74) filter on the interferometer, and switch on the mercury lamp. On looking into the lower of the two viewing apertures, three images of the pointer will in general be visible (**Error! Reference source not found.**) at D.

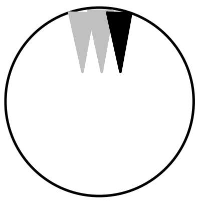

Figure 2. Images of the pointer.

Adjust the two screws on the right-hand mirror (C) so as to bring the two right-hand images into coincidence. Fringes should be visible, and by careful adjustment of the screws (only very small adjustments are needed), they can be expanded so that only a few fringes are visible in the field of view.

6 Experiments

a) Calibrate mirror motion: use green filter, and take 546.1 nm as the wavelength of the green mercury line. Find the movement of the micrometer screw necessary for the far mirror (B) to traverse a convenient number of fringes past the fixed marker in the field of view. Guidance on counting fringes is provided in the next section. Do this at a number of positions along the micrometer scale. Thus establish a relation between micrometer movement and mirror displacement (account for any lack of linearity).

b) Measure the wavelength of the blue and yellow mercury lines: use the appropriate filter, and count a sufficient number of fringes n to ensure good accuracy (1% is possible!) in the determination of wavelength. Using the calibration established in (a), and the relation $2t = n\lambda$, where t is the distance moved by the mirror. Calculate λ for the two wavelengths, and compare with tabulated values.

c) Measure the separation of the two components of the mercury yellow line: the visibility of the fringes due to these lines will fluctuate between a maximum and zero, as the patterns get in and out of step. Use this fact to calculate the wavelength separation of the lines.

   You can also use Eq. 1 to calculate the expected $I(\Delta)$.
   (Hint: set $I(\nu)=I_0(\delta(\nu-\nu_1)+\delta(\nu-\nu_2))$, where ν_1 and ν_2 are the frequencies of the two components of the doublet and I_0 is a constant).

d) Estimate the splitting of the sodium D line. What quantum mechanical effects give rise to this splitting?

7 Counting fringes

You can either choose to count the fringes by eye or using a camera such as the supplied USB webcam. You should consider the advantages and disadvantages of each approach. An example image of fringes obtained using the webcam is shown Fig. 3.

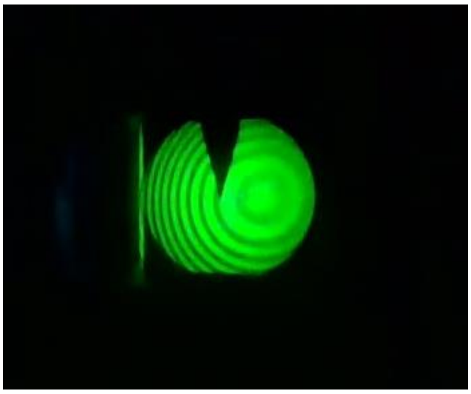

Figure 3. Example image obtained using a USB webcam. The image has been cropped.

If you choose to use the webcam, you should first adjust the interferometer so that fringes are visible by eye. Then connect the camera to a USB port on the computer. Use the native Windows camera app for viewing and recording images (or videos). Note that the focus of the webcam will need to be manually adjusted to get the best visibility of the fringes. This is achieved by twisting the lens of the webcam in the appropriate direction. You should keep making small changes to get the sharpest possible image. The webcam can then be held in position using the retort and clamp stand.

In the Windows camera application, click on the '>' symbol at the top of the screen to switch to 'Pro' mode. This allows access to a brightness control which can be accessed by clicking on the brightness icon at the top and then adjusted by using the controls on the right to improve the contrast of the fringes.

It is possible to record either photographs or videos from the webcam. Recording videos mean that you can carefully turn the micrometer screw wheel to move through a number of fringes. The fringe count can then be checked (or re-checked) by replaying the video. Make sure you that you label all images or videos with a sensible filename and document each one in your lab notes. At the end of each lab day you should transfer all files to your personal Onedrive (or alternative cloud storage) making sure that both partners have access to a copy of all files. If your programming skills have developed sufficiently then you may wish to consider using software to analyse videos and extract the number of fringes but you are not expected to do this.

8 Experiment for three-week experiment

e) Find white light fringes: the condition for obtaining white light fringes is that the path difference between the two arms of the interferometer is zero ± 5 fringes. To obtain this, adjust the controls so that the centre of the (generally) circular fringes is in the field of view. Turn the micrometer so that the fringes move towards the centre of the pattern. Eventually the pattern will expand so that only one circular fringe is visible. Now tilt the right-hand mirror so that the field is crossed by about 10 fringes which should be nearly straight. Switch on the white light (leave the mercury lamp on), and continue moving the micrometer slowly in the same direction as before, until a group of bright, high-contrast fringes appears in the field. Switch off the mercury lamp, and this group of fringes will remain visible in white light. Note the micrometer reading, then check on the reproducibility of this. Do not use any filter in this part of the experiment. What can you deduce from the number of white light fringes that you observe? What intensity response do you expect if the frequency distribution is Gaussian (use Eq. 1)?

f) Use the number of fringes which can be seen through the three filters to estimate the width of the pass band of the filters.

9 Bibliography

E. Hecht, *Optics*, 5th edition (Pearson, 2017). Library link (includes online version).

H. D. Young and R. Freedman, *University Physics*, 15th edition (Pearson, 2019).
Library link (includes online version).

The lab technician has copies of other textbooks which may be useful for this experiment. These can be borrowed for use during lab sessions.

Last revised by Dr. Paul Walmsley, September 2022