EXPERIMENT 2

Measurement of the Speed of Light

Introduction

Basically the measurement of the speed of light "*c*" involves determining the distance d and time t, where $c = d/t$. Since c is very large, early attempts were inaccurate or required inconveniently long distances. With an optical system involving a high-speed rotating mirror and some electronic timing apparatus, we can easily measure c in the lab. The arrangement of the optical components is shown in Figure 1.

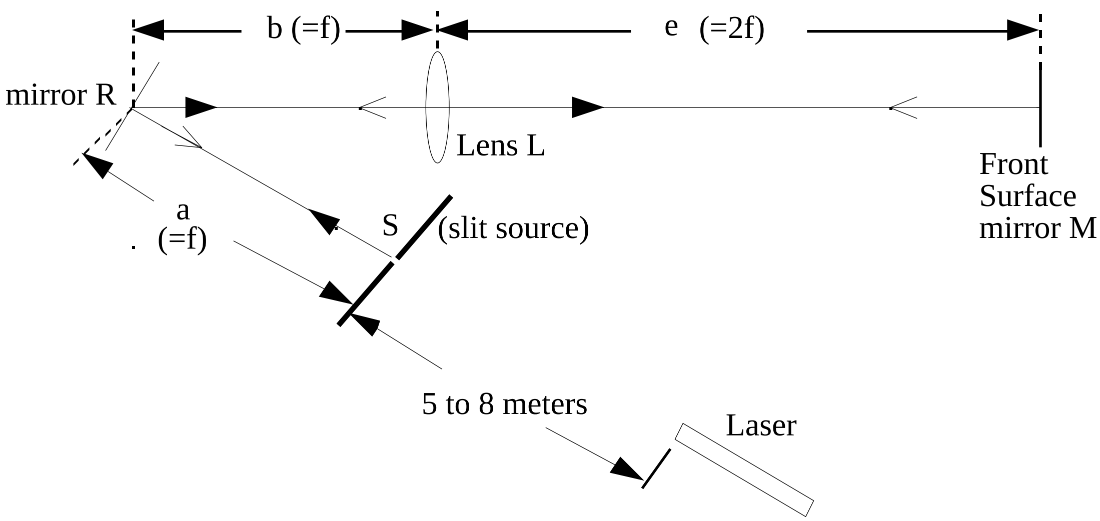

Figure 1

Stationary Mirror

A beam of light from slit S is deflected by mirror R through lens L and reaches the front surface mirror M. The beam then **retraces** its path and returns to slit S. If an image of the slit is formed at M, then a new image will be reformed at S by the returning beam. To obtain an image at S, the positions of mirrors R and M must be consistent with the simple lens equation

$$\frac{1}{(a+b)} + \frac{1}{e} = \frac{1}{f} \tag{1}$$

where f is the focal length of lens L. For simplicity, we choose $a = b = f$ so that e becomes $2f$ (verify this). This value is also chosen to obtain favorable light intensity when the beam returns to S. Refer to Appendix 1 of this lab for an alternate set-up.

Rotating Mirror

Consider the situation that occurs when the mirror R is rotating. The light beam bounces off R, goes to mirror M, and then returns to R. During this time, the rotating mirror has turned through a small angle θ causing the returning beam to deviate by an angle 2θ from that of the starting beam at slit S (see Figure 2). If a glass plate is placed (at 45°) in the path of the light beam as shown in Figure 3, the return beam is redirected to form an image of the slit on a ground glass screen.

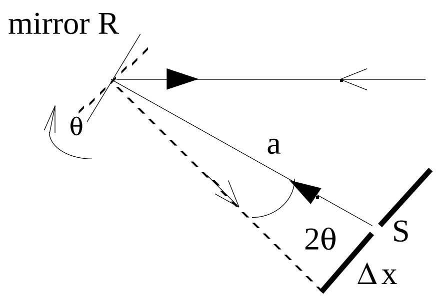

Figure 2

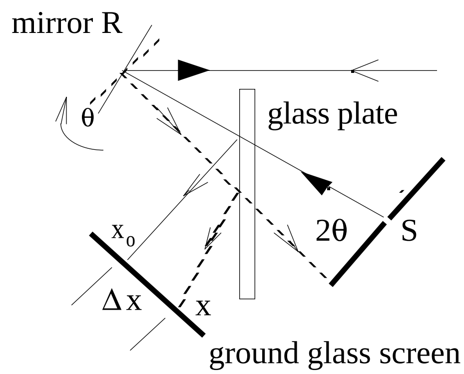

Figure 3

If x_0 is the position of the image on the glass screen for a stationary mirror, and x is the position of the image for the rotating mirror, the shift Δx is related to the angle of deviation by

$$\Delta x = x - x_0 = 2\theta a . \quad (2)$$

If the mirror is rotating at a rate of N revolutions per second, the angle θ as a function of the time t during which the mirror has rotated is given by

$$\theta = \omega t = 2\pi N t . \quad (3)$$

Finally, the time t for light to bounce off R and return is related to the distance traveled d and the speed of light c by

$$t = d/c . \quad (4)$$

Procedure and Analysis

Caution: Do not view the laser light through the Filer eyepiece for the stationary mirror.

Align the optical components as accurately as possible for the stationary mirror. Use a piece of thin paper (or tissue) to locate and trace the laser beam. If your set-up is correct, a sharp image of the slit should occur at the distant mirror M and at the location of the Filer eyepiece. Note the number of images present at mirror M, and just in front of the eyepiece (using the paper screen). Since laser light may damage your eyes, do not observe and measure x_0 via the eyepiece!

Making sure the key for the rotating mirror is removed, slowly turn on the variac for the rotating mirror and observe the frequency counter. The frequency counter is connected to a photodiode (inside the mirror housing) which detects a flash of light reflected off the rotating mirror. Since the rotating mirror has two reflecting sides, the frequency f_c measured by the counter is double the rotation rate N of the mirror. Adjust the sensitivity of the frequency counter and note whether there is an effect on the number of counts. Does the background room light affect the counts?

Measure the position x of the leftmost image (observed via the eyepiece) for various speeds of the rotating mirror between 50 and 600 rev/sec. Graphically determine c by deriving a relation between the variables x and N. For comparison, since 1986, c is defined as 2.99792458×10^8 m/sec. What do you obtain for the value of x_0?

Note: Before starting the experiment, consider the following points:

(1) Do not touch or use tissue on the front surface mirrors R and M since the reflective coating will become damaged.

(2) For the stationary case, a key is used to rotate mirror R such that it directs the light beam through the center of lens L and onto to mirror M.

(3) The returning beam from M must retrace the original beam. Adjust mirror M so the beams coincide as they pass through lens L. Only half of the original beam should be blocked with paper while trying to match the return beam. A simpler method is to cover lens L with a paper mask containing a hole at the center. The original and return beams must both pass through the hole for proper alignment.

(4) The ground glass screen inside the Filer eyepiece is located approximately in line with the micrometer. Also, watch out that the micrometer scale reads backwards from 10mm to 0mm!

Questions

1. Suppose that the rotating mirror R turns by an angle θ during the traversal of the light beam. Using a suitable diagram, explain why the returning beam is deflected by an angle 2θ compared to the path it would take if the mirror was stationary.

2. Why is it important to use front surface mirrors for M and R rather than ordinary mirrors?

3. The use of lens L with a long focal length requires long distances in the lab room. How would using a smaller focal length lens affect the accuracy of the experiment?

4. How many images of the slit are observed at the ground glass screen? At the far mirror M? Explain.

5. Since the laser generates a collimated (parallel) beam of light, discuss if a slit is even necessary to do the experiment?

APPENDIX 1

It is important to set up the apparatus so that the image of the slit on the screen, *S* in Figure 1, is as bright as possible. To accomplish this as much light as possible must be reflected back to the rotating mirror *R* from the mirror *M*.

Using ray optics, it is possible to examine the path of the light passing through a given optical arrangement. For example, for the arrangement in Figure 1, all the light leaving the rotating mirror *R* and passing through the lens *L* will return to *R* by way of *L*. Therefore the intensity of the light depends on how much of the light striking *R* is directed to the lens *L*. It is instructive to compare a second optical arrangement, Figure 4, with the one you have been given.

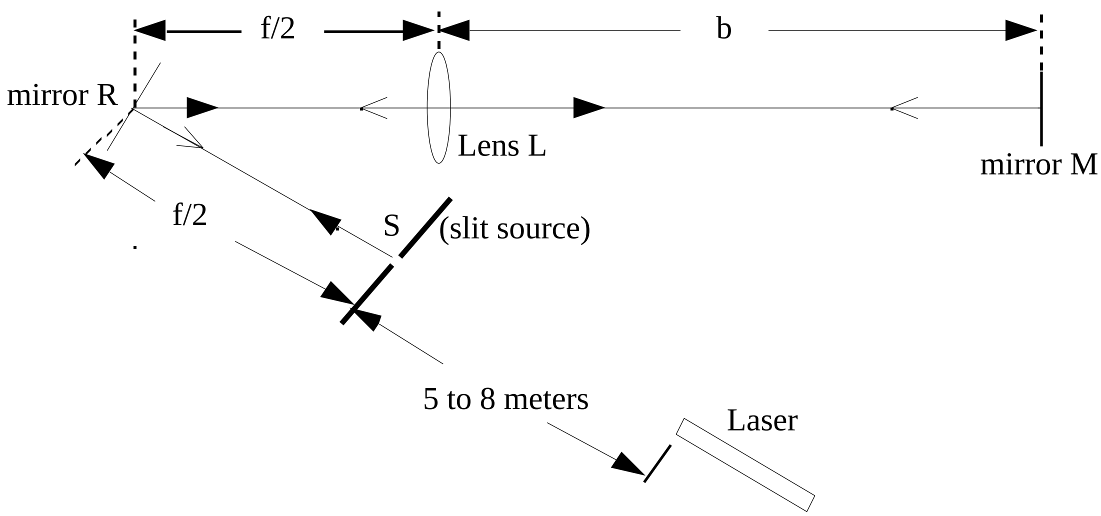

Figure 4

The apparatus can be aligned so that the light reflecting off the rotating mirror strikes *M* and returns to *S*. However, with the arrangement of Figure 4, any movement of the mirror *R* will cause movement in the position of the image at *S*. Thus, as the mirror rotates, the image will move across the field of view. In the setup of Figure 1, the image at *M* moves as the mirror rotates but the image at *S* remains stationary.