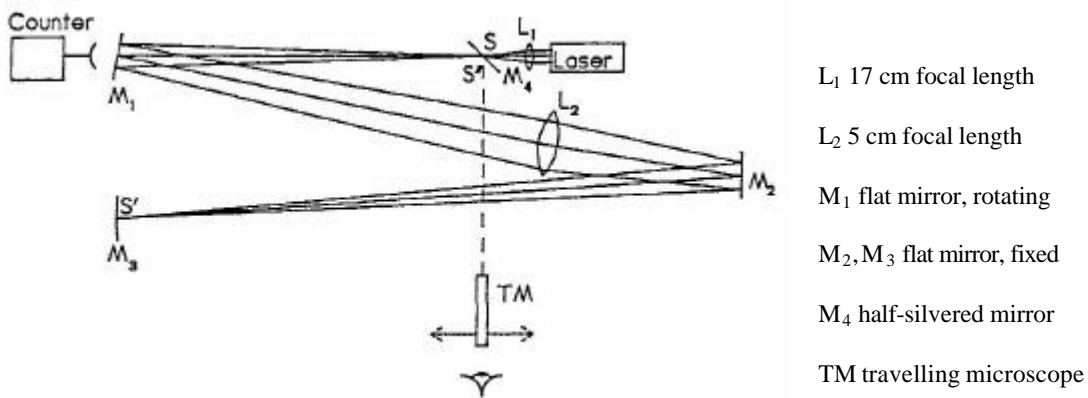


THE UNIVERSITY OF WATERLOO

Physics 360 - E1
THE SPEED OF LIGHT

References: Elementary optics books by Morgan, Jenkins and White and Sears

(A) The speed of light using a variation of the Michelson-Foucault method.



In an optimum arrangement the distance from the source (or object), S to the lens L_2 is $2f_2$. An image S' is formed at M_3 and the image distance L_2 to M_3 is then also $2f_2$. The distance from S to the rotating mirror M_1 should be approximately equal to f_2 for best results.

The light from M_3 is then directed back through the system to form an image S'' as shown. The telescope is used to locate S'' .

In your introduction show that the position of S'' is independent of the angular position of M_1 , as long as light can pass through the system. Object-image position relationships for plane mirrors and lenses are all that are required for a basis for this proof. Explain why the image of S'' moves when the rotating mirror is speeded up. Derive an expression for speed of light in terms of the speed of the rotating mirror and the distances involved.

SYSTEM ALIGNMENT: Assuming that the focal length of L_2 is 5.0m, arrange M_1 , M_3 and L_2 as shown to an accuracy of ± 5 cm. L_1 is already mounted on the laser.

Using the special key provided, adjust the angular position of M_1 to cause the beam to pass through the centre of L_2 , and reflect off the centre of M_2 and then M_3 . Now adjust the position of M_3 so that it reflects the beam directly back upon itself. You should be able to see the

two spots on L_2 as they come into coincidence. It is critically important that the returning beam is seen to enter the opening for the rotating mirror. The beam should now form image S'' . Insert the polarizer into the beam and adjust it to obtain a minimum intensity. DO NOT look through the microscope with M_1 stationary. Note that for an adequate photocell signal considerable laser light must pass M_1 when it is parallel to the beam. The photocell therefore needs to be carefully adjusted to realize an adequate output.

Start the mirror rotating at ~ 2 rotations/sec. Set up the travelling microscope to focus on M_1 . You should see a sharp bright spot flashing at 4Hz. Extra spots are due to reflections at the back surface of the beam splitter. If the spot is not adequate repeat the alignment.

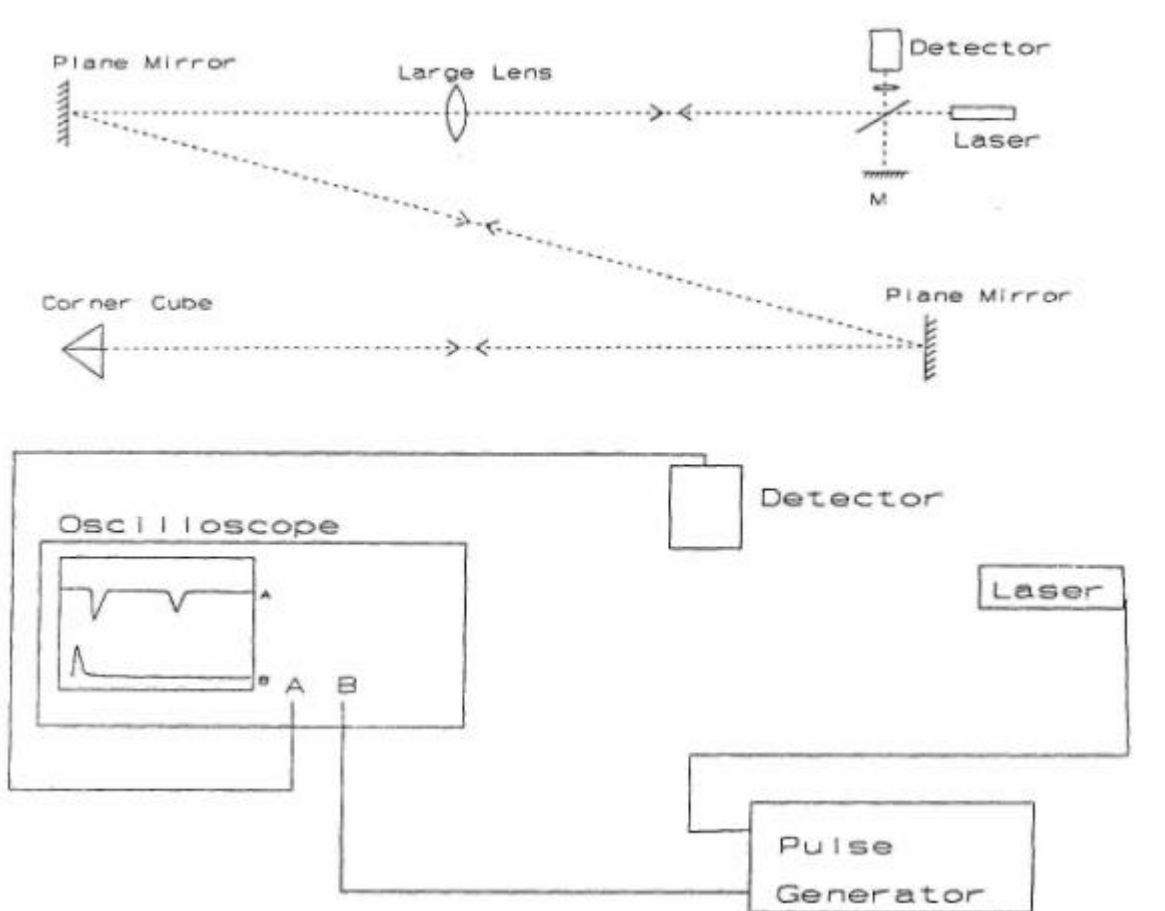
Note that the position of S'' changes with mirror speed. Make several graphs relating this displacement to the mirror speed. Use least squares fits and average the values of C obtained from the several graphs. Make significant and quantitative comments on sources of errors for this experiment. Specifically decide if it is the instrumental or experimenters errors which are most significant.

(B) The Speed of Light Using a Pulsed Laser

A red light emitting semiconductor laser which can have its output power modulated by an applied voltage is used to direct a beam of light along a long path by way of a lens, some plane mirrors and a retro-reflector (corner cube). The latter returns the beam to the source. An applied voltage pulse periodically cuts off the light. The returned beam is directed into a fast photodiode, along with the reference pulse, from a nearby mirror. The difference in arrival time of the (negative) pulses can be measured directly on a digital storage oscilloscope. The measured time interval and the known distances can be used to determine the speed of light.

OPTICS: The laser beam converges to a sharp focus about 30 cm in front of the laser. The large lens has a focal length of 5.0 m. It should therefore be placed at this distance from the focus of the laser. The beam, quite large at the lens will then remain well collimated and return to refocus at the original focus. The detector and small lens should be adjusted to pick up the returning beam, and the small mirror "M" should be adjusted to put sufficient reference beam into the detector.

ELECTRONICS: The pulse generator provides two outputs, one to modulate the laser, and another to trigger the oscilloscope. The A input should be set at maximum sensitivity, and connected to the detector. The B input is used to display the voltage pulse, and to trigger the sweep of the oscilloscope. Once good signal are obtained, the oscilloscope should be put into averaging mode to smooth out the pulses. A hard copy of the screen of the scope may be obtained if a plotter is connected.



EXPERIMENT: Measure all relevant distances. Note that the retro-reflector may be placed in the beam anywhere beyond the large lens. You should do measurements for several different distances. Give some thought to where you position the cursor; some places may be better than others.

RESULTS: Calculate the values for the speed of light using the measurements for the different path lengths. Assign experimental errors for each. Combine the results, weighting the different values according to standard methods (see Appendix). Quote your final average result and its absolute error.

APPENDIX

$$c_1 = \frac{\ell_1 \pm e_\ell}{t_1 \pm e_t} = \frac{\ell_1}{t_1} \pm \sqrt{(\%e_\ell)^2 + (\%e_t)^2} = c_1 \pm (\%e_1) = c_1 \pm e_1$$

where e_1 will only have one significant figure and c_1 is rounded off appropriately.

WEIGHTING: Each c value is weighted inversely as the square of the associated error. You can use the absolute error or the % error here since the resulting difference in - although important in some situations - is not significant here.

$$\therefore \bar{c} = \frac{\sum \frac{c_n}{e_n^2}}{\sum \frac{1}{e_n^2}}$$

As well, the error in the mean is given by:

$$e_{mean} = \sqrt{\frac{1}{\sum \frac{1}{e_n^2}}}$$

An example:

$$c_1 = 2.85 \pm 0.08, \quad c_2 = 3.05 \pm 0.06, \quad c_3 = 3.15 \pm 0.2$$

Then:

$$\bar{c} = \frac{\frac{2.85}{(0.08)^2} + \frac{3.05}{(0.06)^2} + \frac{3.15}{(0.2)^2}}{\frac{1}{(0.08)^2} + \frac{1}{(0.06)^2} + \frac{1}{(0.2)^2}} = 2.9874 \pm 0.0467$$

or finally with attention to significant figures.

$$\bar{c} = 2.99 \pm 0.05$$