Experiment 321: The Rayleigh Refractometer

Aims

The principal object of this experiment is to determine the refractive index μ of dry air and to compare this with a tabulated value in a given reference. The basis of the experiment is an instrument known as the Rayleigh Refractometer, a description of which can be found in Ref. 1. With care it is possible to determine the quantity $(\mu - 1)$ to an accuracy better than $\pm 1\%$ with this instrument.

The refractive index is wavelength dependent. This effect may be just detectable with the instrument as set up, and so a subsidiary investigation concerns the magnitude of this dispersion.

References

1. Born and Wolf , "Principles of Optics", Pergamon
2. Squires, "Practical Physics", McGraw-Hill.
3. Worsnop and Flint, "Advanced Practical Physics for Students", Methuen
4. CRC, "Handbook of Chemistry and Physics", CRC-Press

Experimental Set-up

As Ref. 1 will show, this experiment involves the development and observation of interference fringes, although the equipment used is somewhat different from that described. The experimental arrangement is shown in Fig. 1.

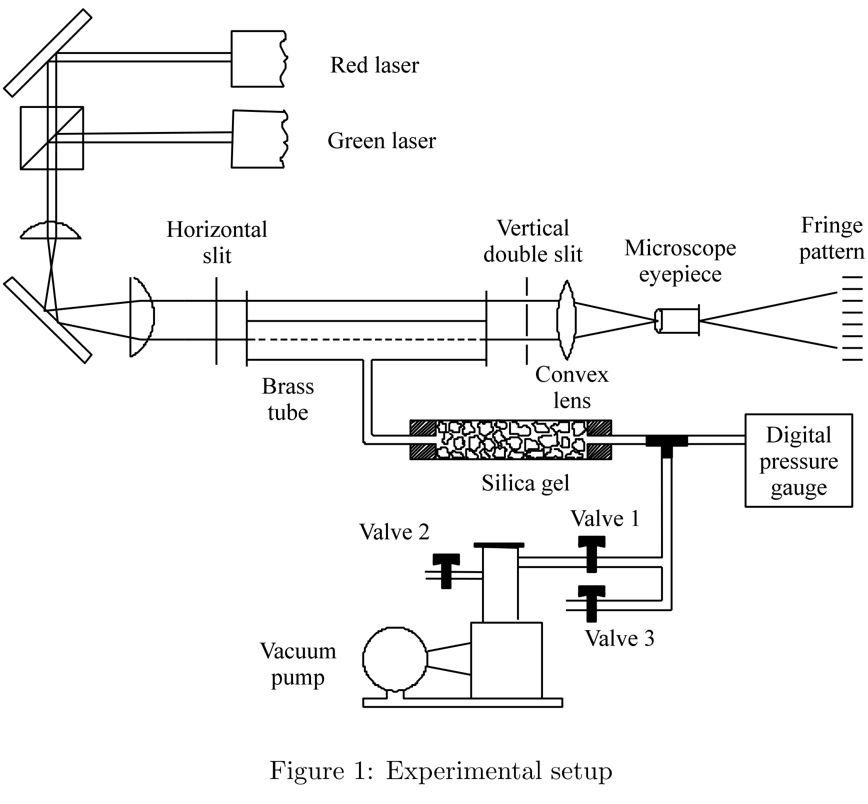

Figure 1: Experimental setup

The equipment is set up so that the laser used can be either a red helium-neon ($\lambda = 632.8\,\mathrm{nm}$) or a green helium neon laser ($\lambda = 543.365\,\mathrm{nm}$). The experiment should be performed first with one laser and then with the other. In each case a horizontally collimated beam of light from the laser is directed at a rectangular brass tube in such a way that half of the beam passes along the inside of the tube and half along the outside of the tube. The two beams thus produced then illuminate one aperture each of a broad double slit. Two-slit Fraunhofer interference fringes are formed and these are focussed onto an eyepiece which projects a magnified interference pattern onto the wall.

The tube is then evacuated using a vacuum pump (see Fig. 1). When dry air is slowly readmitted, the number of fringes which move across a convenient reference point is determined as a function of the change in air pressure in the tube.

The refractive index $\mu(P,T)$ of a gas at pressure P and temperature T (in kelvin) is given by:

$$\mu(P,T) - 1 = \gamma \frac{P}{T} \tag{1}$$

where γ is a constant of proportionality depending on the chemical composition of the gas and the wavelength of light. For this experiment γ is given by:

$$\gamma = \frac{n\lambda}{L}\frac{T_a}{\Delta P} \tag{2}$$

where n is the number of fringes moved, λ is the wavelength of the laser light, L is the length of the brass tube, T_a is the ambient room temperature (in kelvin) and ΔP is the change in pressure producing the movement of fringes.

Questions

These are to be answered as part of the write-up.

1. Use the ideal gas law, $PV = NkT$, to demonstrate that equation (1) is consistent with the assumption that $\mu - 1$ is proportional to the number of atoms per unit volume.
2. Derive equation (2).

To get a higher accuracy for γ, measure n to a fraction of a fringe. As with most optical experiments, the operator must be patient and methodical to obtain satisfactory results. To obtain good fringes it is important to note:

(a) The light passing through the tube should be parallel for optimum results, and the lens and eyepiece should lie on the optical axis.

(b) The two beams can be conveniently located and observed at any point by inserting a piece of paper into the path of the beam.

(c) Good fringes will be obtained only when the interfering beams are of comparable intensity and all light from the source except that passing through the double slits is excluded.

The change in pressure ΔP can be measured using the digital gauge attached to the apparatus. Alternatively, you might like to assume that when the tube is evacuated by the vacuum pump, the pressure inside the tube is negligible in comparison with atmospheric pressure, in which case $\Delta P = P_a$, where P_a is the ambient room pressure and can be measured using the laboratory barometer.

Procedure

(1) Check that the diffraction pattern observed is indeed that due to Fraunhofer diffraction at a double slit system by observing the change in the fringes as a piece of card is used to obscure one of the slits. Due to chromatic abberation in the lenses, the correct position of the microscope objective for the 'red' laser and the 'green' laser is different. Move the lens to obtain the best fringes.

(2) Examine the vacuum pump system and make sure you know the correct sequence for operating the pump before you switch it on. Test the system for leaks. Any leaks present should be cured.

Note: When the pump is stopped, Valve 2 must be opened to admit air and prevent oil being driven into the apparatus.

(3) With a vacuum established, measure the pressure. Slowly readmit air into the tube by manipulating Valve 3, while counting the movement of the fringes to within a quarter of a fringe. Close the valve and take a pressure reading after each 10 fringes have passed. This way, obtain the pressure as a function of the number of fringes passed, which should be a straight line. Use regression (Matlab) to obtain the slope of the line. As the room temperature changes quite rapidly, the change in pressure and the ambient room temperature should be noted for every experiment.

(4) Determine the quantity γ for both wavelengths available. By careful consideration of the errors in each determination decide whether any difference in the measured values is significant. Use equation (1) to compare your results with those given in Ref. 4. When you do this comparison, make sure you compare values at the same temperature and the same pressure!

List of Equipment

1. Helium-Neon (Red) Laser ($\lambda = 632.8\,\text{nm}$)
2. Frequency doubled YAG (Green) Laser ($\lambda = 532\,\text{nm}$)
3. Two Al mirrors
4. Dichroic beam splitter
5. $10\times$ Beam expander
6. Horizontal slit
7. Brass Tube
8. Double Slit
9. Convex Lens
10. Microscope Eyepiece
11. Vacuum Pump System
12. Glass Tube containing Drying Agent ($CaCl_2$)
13. Digital pressure gauge

R. Leonhardt

M.D. Hoogerland

This version: May 4, 2016.