JAMIN INTERFEROMETER (2014)

The Jamin interferometer is used to measure the refractive index of a gas. Developed in 1856 by the French physicist Jules Jamin.

Experiments

Part 1	Measuring the refractive index (μ) for AIR
Part 2	Measuring μ for GLASS
Part 3	Measuring μ for AIR using White Light

Do part 1 and see a Demonstrator before starting part 2.

Part 3 should only be done if you have time and INTEREST

ADJUSTMENT **If you think the instrument is out of adjustment because you cannot see fringes, see a Demonstrator.**

Description of the instrument:

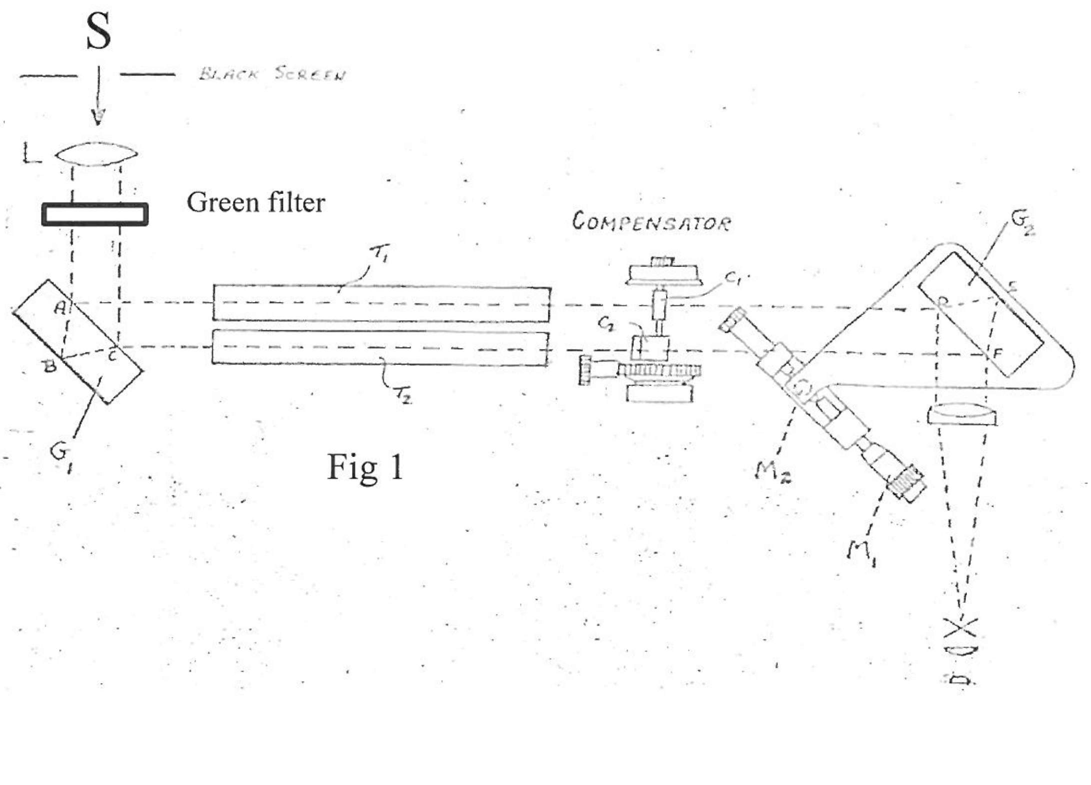


Fig 1

S is an extended dual light source set at a right angle to the interferometer. The dual light source consists of a mercury lamp and a tungsten lamp which can be individually switched or both lamps can be operated at the same time.

G_1 and G_2 are two exactly similar parallel- sided glass slabs silvered on their rear surfaces

A light beam from S is amplitude divided at the front surface of G_1 and the component beams are recombined at the front surface of G_2.

The slabs are mounted so that the light is incident at roughly 45°.
G_2 may be rotated by small amounts about both vertical and horizontal axes.

T_1 and T_2 are equal-length glass tubes which may be evacuated or filled with the gas for which the refractive index is required.

C_1 and C_2 are the so-called "compensator plates". These are exactly similar slabs of glass each of which may be rotated about a horizontal axis to insert any desired thickness of glass in each beam. A telescope is used for viewing.

General theory: Monochromatic light:

First consider only a single beam from the light source (Fig. 1) incident on G_1. This beam is divided at G_1 into two beams of nearly equal intensity. One beam traverses tube T_1 and the other T_2.A similar process at G_2 means that the two beams are superimposed again.
Now consider all possible beams from the source S for the case where G_2 and G_1 are parallel. Here the path lengths of all the beam pairs differ by exactly the same amount. So the beam pairs will all constructively or destructively interfere to the same extent so the whole field of view of the telescope is therefore of uniform brightness. (This is true no matter what the relative positions of the compensator plates).

However, generally G_1 and G_2 are not exactly parallel and so the various beam pairs will have path differences which change continuously over the field of view. The result of this is that there is a series of bright and dark fringes across the field of view. These fringes are straight because when G_1 and G_2 and not parallel they effectively form a 'wedge'.

THE JAMIN INTERFEROMETER : PART 1

Object: To measure the refractive index of air.

Theory: The two glass tubes are of equal length. Let this length be ℓ and assume that both tubes are initially evacuated.

Then the change in the optical path length of one beam when a gas of refractive index μ is admitted to one tube is ℓ

$$m = \frac{\ell(\mu - 1)}{\lambda} \qquad (1)$$

where λ is the wavelength of the light used, and m is the number of fringes.

The rate of change of fringe order with pressure is then given by

$$\frac{dm}{dP} = \frac{\ell}{\lambda}\frac{d\mu}{dP} \qquad (2)$$

The refractive index of a gas depends almost entirely on the density, and not on the pressure and temperature separately. Thus if μ is the refractive index of a gas at temperature T and pressure P we can write

$$(\mu - 1) = (\mu_o - 1)\cdot\frac{P}{T}\cdot\frac{T_o}{P_o}$$

where μ_o is the refractive index of the gas at N.T.P. ($T_o = 273$ K and P_o =760 mm Hg =760 torr =1000mbar)

Thus $$\frac{d\mu}{dP} = \frac{(\mu_o - 1)}{T}\cdot\frac{T_o}{P_o}$$

and, substituting in equation (2) above and rearranging,

$$(\mu_o - 1) = \frac{dm}{dP}\cdot\frac{\lambda}{\ell}\cdot\frac{P_o}{T_o}.\mathrm{T} \qquad (3)$$

Reference: Jenkins and White '-'Fundamentals of Optics"

Supplied data: The wavelength of mercury green light is 5461A

Procedure

(1) Open valve 'B'

(2) Switch on the ROTARY pump. The gauge should indicate that the glass tube is being evacuated.
It should take only a short time for the Gauge to read 'ZERO' pressure.

(3) Close valve 'B'

(4) Switch off the Rotary Pump.

(5) Now if valve "B" is opened very SLOWLY the fringes will be. seen to move across the field of view.
(If you cannot see fringes then carry out the adjustment in appendix A Or ask a demonstrator)

(6) Increase the pressure in steps (closing valve "B" to read the pressure each time) recording the appropriate values of 'm' for each value of 'P'.

(7) Record the temperature and the tube length. Then from a directly obtained mean value of 'dm / dP' or a graphical mean, calculate the Refractive Index of Air at N.T.P.

(If you have not got access to a Barometer, you may assume that the Atmospheric Pressure is 760 Torr).

THE JAMIN INTERFEROMETER: PART 2

Object: To determine the refractive index of the glass of the compensator plates.

Theory:

If **both compensator plates** are rotated in the same sense through the same angle i, then the optical path difference will be changed and so the fringe order observed at the cross-wire of the telescope will change by m, say.
Then, measurement of m for a known value of i yields the refractive index of the compensator plates. For the derivation of the expression for μ in terms of i and m it is convenient to consider the case where one plate is normal to the incident beam (Fig. 2).
The ray AB would travel along the path ABXZEF if a perpendicular plate was interposed at X.
However, if an inclined plate is interposed, the ray travels along ABXYCD

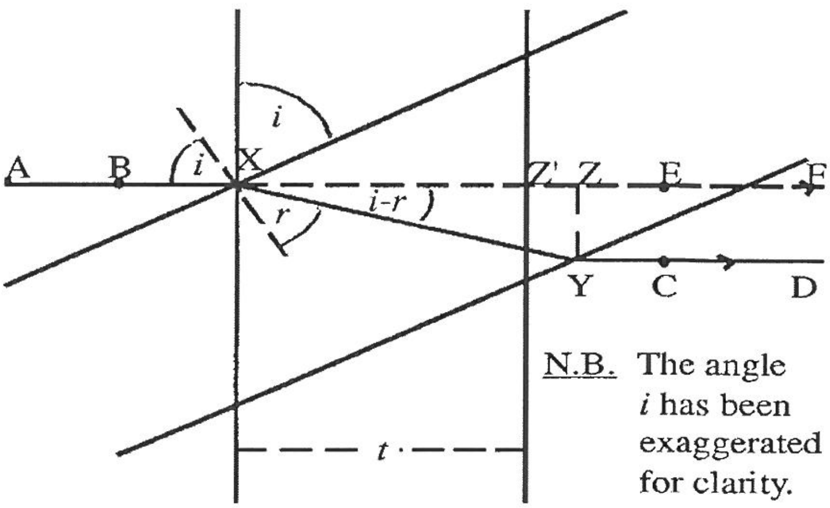


Fig 2

The optical path difference between the two emergent waves

$$= \mu XY - \mu t - Z'Z$$

$$= \mu(XY - t) - (XZ - t)$$

$$= \left(\frac{t}{\cos r} - t\right) - \frac{t}{\cos r} \cdot \cos(i - r) + t$$

$$= \left[\mu\left(\frac{1}{\sqrt{1 - \frac{\sin^2 i}{\mu^2}}}\right) - \sqrt{1 - \sin^2 i} - \frac{\sin^2 i}{\mu\sqrt{1 - \frac{\sin^2 i}{\mu^2}}} + 1\right]$$

$$= \frac{ti^2}{2}\left(1 - \frac{1}{\mu}\right)\text{:} \quad \underline{\text{if i is small}}$$

If **both plates are rotated** so that the one previously inclined ' , is now perpendicular to the beam and the other is now inclined at an angle of radian measure, i, the change in optical path difference between the rays in the two different cases.

$$= ti^2\left(1 - \frac{1}{\mu}\right)$$

and if m fringes pass the cross wires while this is being do

$$m\lambda = ti^2\left(1 - \frac{1}{\mu}\right)$$

$$\therefore \mu = \frac{1}{1 - \frac{m\lambda}{ti^2}}$$

Supplied Data **The thickness of the compensator plates, t, is 8.02. 10^{-3}m.**

THE JAMIN INTERFEROMETER : PART 3 (OPTIONAL)

Object: To measure the refractive index of air by making use of white light fringes.

Object: If the fringe order changes by a number m when the pressure in one of the tubes changes from zero to atmospheric pressure then equation (1) gives

$$\mu_o = 1 + \frac{m\lambda}{\ell}$$

where ℓ is the length of the tube.

In this method m is measured in two stages. The zero-order fringe with white light is made use of to translate the change in the optical path difference $(\mu - 1)\ell$ into an equivalent rotation, θ say, of the compensator plates. Then m is found by rotating the compensator plates through the same angle θ while using monochromatic light.

White light fringes: To understand what happens in this case consider the behaviour of the interferometer with G_1 and G_2 slightly off parallel as being similar to two-beam interference in a transparent wedge-shaped film. Consider light to be incident normally on such a film (Fig. 3).

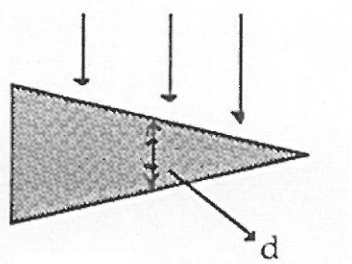


Fig 3

Part of the light is reflected at the upper surface and part at the lower. These beams leave the film with phase difference $2\pi\left(\frac{2d}{\lambda}\right)$ As d varies continuously across the film, monochromatic light will produce a series of straight bright and dark fringes across the length of the wedge. The condition for the reflected intensity maxima is $2d=(n+\frac{1}{2})\lambda$

Of the continuous range of wavelengths in white light first consider only two, say λ_1 and λ_2, for simplification.The fringe patterns due to these will be in step at the wedge apex where d = 0 and the fringe order n = 0. However, away from the apex for any particular value of d, the value of n will be different for the two values of λ i.e. the fringe patterns get out of step.

Now, considering all the wavelengths of white light it is clear that

(1) the zero-order fringe is in the same position for all wavelengths,

(2) for a few orders beside the zero-order the fringes will be coloured - the sides of the fringes toward the apex will be blue (the shorter wavelength) and the sides away from the centre will be red, (the longer wavelength), and (3) farther away from the zero-order (or d = 0) position, the maxima for various orders and different wavelengths overlap to give white continum where no fringes are visible.

N. B. In fact. Only a few coloured fringes are observed. Also, the smaller the angle of the wedge the more widely spaced will be the coloured fringes. The key point is that coloured fringes will only be observed, in any interferometer, very close to the situation where the path difference of the two interfering beams is zero.

Now returning to the Jamin interferometer, the zero-path-difference situation can be obtained by varying the inclination of the compensator plates, C_1 and C_2. The zero-order fringe is made use of as a reference point.

N.B. A very useful rule for interferometer adjustment:

When starting to adjust any interferometer to obtain fringes, one should simplify things as much as possible by starting with monochromatic light. Never start with white light. The reason for this should be obvious from the discussion above.

THE JAMIN INTERFEROMETER : PART 3 PROCEDURE

(1) Adjust the interferometer for green light as in appendix A.

(2) In order to obtain *white light* fringes the zero-path-difference situation must be located. Replace the mercury lamp with the white light and remove the green filter.

If the $G_1 - G_2$ wedge and the compensator plates are as in *Fig. 6,* then it turns out that the *path difference is **decreased** by rotating* the compensator plates together (i.e. keeping i = constant, Fig. 5) in the ***clockwise sense***. If the wedge is as in Fig. 7 then **anti-clockwise** rotation is needed.

(3) Check which of Figs. 6 or 7 describe the set-up you have and then very slowly rotate the compensator plates together (keeping i constant and = 3° to 10°) in the appropriate sense until a few coloured fringes come into the field of view of the telescope.

Note the angular reading, θ_1, say, on the front dial and record this setting of the compensator plates.

(4) Start the backing pump and evacuate one of the tubes (T_1). The coloured fringes will disappear.

(5) Think about which sense of rotation of the compensator planes (keeping i fixed) will counteract this decrease in the optical path length of the beam through the evacuated tube and very slowly rotate the plates together until the coloured fringes are again located. (In fact, when tube T is evacuated, the required sense of rotation is the same as that in (3), used to find θ_1).

Note this angular reading, θ_2 say.

(6) Now using mercury green light count the number of fringes which cross the field of view as the compensator plates are rotated (keeping I constant) from the θ_2 setting back to the θ_1 setting

(7) Measure the length, ℓ, of the evacuated tube and circulate the refractive index of air.

APPENDIX A

Adjustment to find fringes with mercury green light

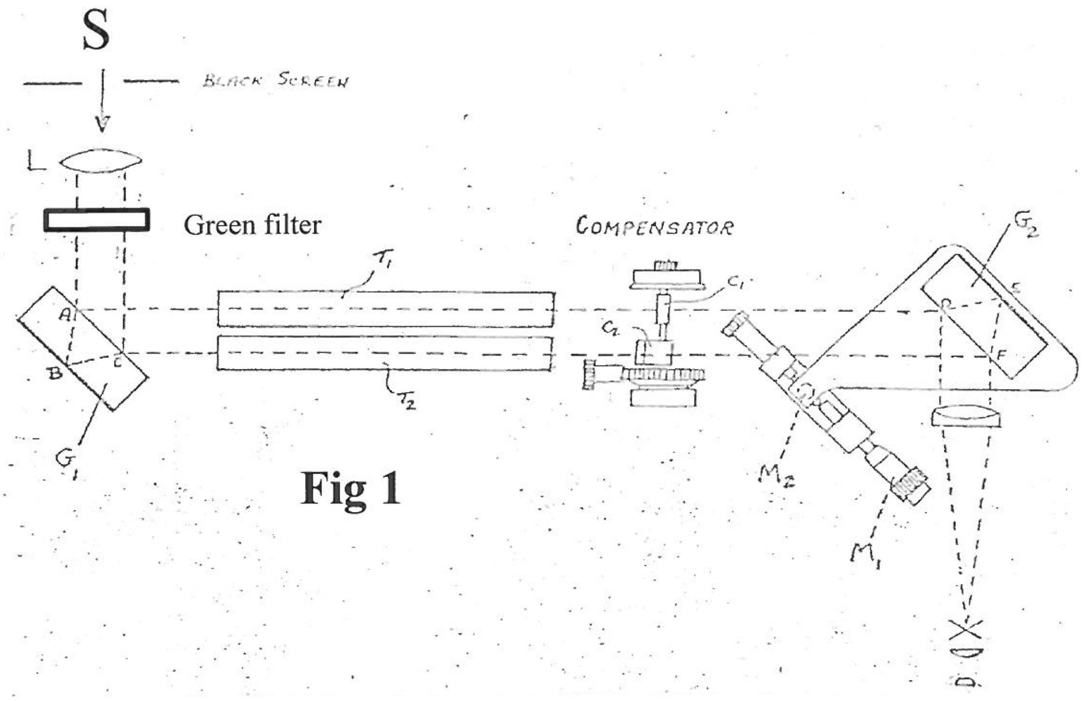


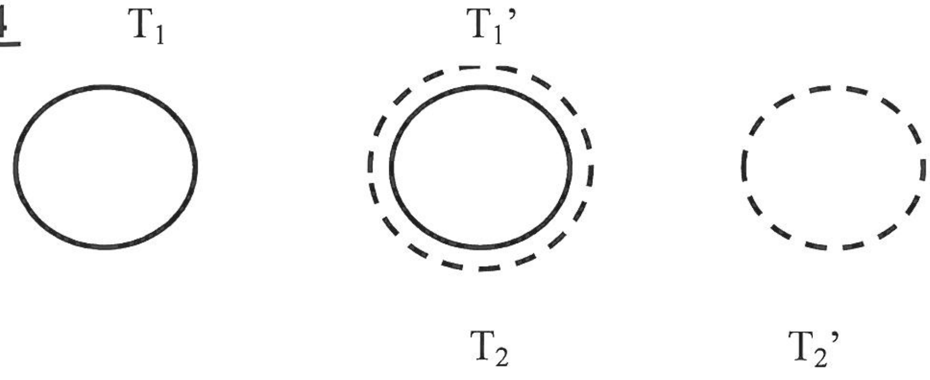
Fig 1

The optical bench should lie along a line which is normal to the direction of the Two glass tubes of the interferometer. When this condition is satisfied the light reflected from the front and back faces of G_1 will travel along and parallel to the tubes.

The alignment of the light path may be checked by holding a piece of white paper before and after the tubes. Note that the light beam through one tube will be much more intense than the other, since the back face of G_1 is silvered while the front is not. The weaker beam will be reflected from the back of G_2 and the stronger beam from the front, so the intensities of the beams leaving G_2 are therefore nearly equal. If the orientation of G_2 is suitable the beams reflected from it will travel parallel to and through the telescope.

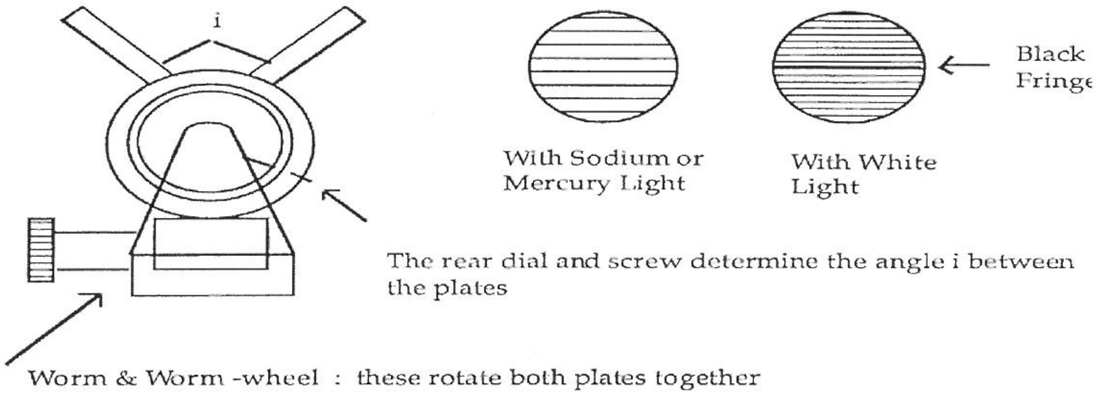
To achieve this situation, unscrew the telescope using the long vertical bolt underneath it and look straight along the channel into which the telescope normally sits and, by adjusting screws M_1 and M_2 (which respectively adjust the rotation and tilt of G_2; see Fig 1), arrange that you are also looking straight along the centre one of the three images of the tubes.(this one is in fact two images superimposed. See Fig 4.)

Fig 4



Fringes will only be seen if the path difference between the two superimposed beams is not too great.

Fig 5



Use the worm-wheel screw (see Fig. 5) to set the compensator plate nearest to you, C_2 ,in the vertical plane. Then unlock the fixing screw underneath C_1 and vary its position slowly until fringes are seen in the centre image tube.
Fringes should be seen when C_1 is a few degrees (~ 0° to 10°) to one side of C_2; the side depending on whether the tilt of G_2 is such that the wedge formed By G_1 and G_2 is as shown in fig 6(i) or as in fig 7 (i).
The respective positions of the compensator plates at which fringes should be found, are shown in figs 6(ii) and 7 (ii). (the reasons for these settings can be understood by tracing the paths of the two beams and finding when the paths are approximately equal, but this is quite complicated and need not be done.)

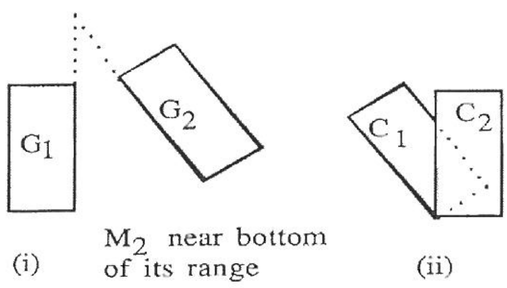


Fig. 6

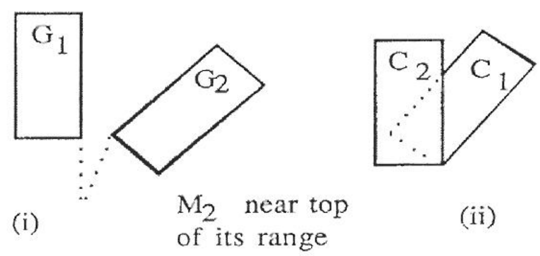


Fig. 7

The front face of G_2 may be made parallel to the face of G_1 by adjusting the rotation of M_1 (Fig. 1).When this is achieved straight horizontal fringes should be observed (Fig. 5)
Ajustment of the tilt screw, M_2 , will change the separation of the fringes.
Any change in the path difference between the two beams (e.g. by movement of the compensator plates, or changing the tilt of G_2, or by changing the refractive index of the material in either path) will be accompanied by a passage of the fringes up or down the field of view.
Now replace the telescope. (if it is necessary, adjustment of the 4 little levelling screws will bring the fringes into the centre of the telescope field of view.