COURSE GUIDE

**PHY 492
LABORATORY PHYSICS III**

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NATIONAL OPEN UNIVERSITY OF NIGERIA

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INTRODUCTION

The key area in teaching and understanding physics is laboratory work which introduces students to both individual experiments and group investigations in first and second years in the university. A similar laboratory experience extends into third and fourth years as well as postgraduate studies with more advanced experiments. The purpose of laboratory physics is to instruct you in the use of instruments and techniques, and to develop your understanding of good experimental methods while illustrating and illuminating the content of course book.

It is in the laboratory that physics students learn to practice the activities of scientists - asking questions, performing procedures, collecting data, analysing data, answering questions, and thinking of new ideas or questions to go into.

The laboratory experiments described in this manual are an important part of your physics courses. Most of the experiments are designed to teach, re-enforce or illustrate important concepts or law which ordinarily has been taught or described in the course book. This is why before going for practical class the student is expected to have the basic ideas and terms on each particular experiment.

The experiments in general involve measurements, graphical representation of the data, and calculation of a final result. The student should bear in mind that equipment can malfunction and final results may differ from expected values by what may seem to be large amounts. This does not mean that the exercise is a failure. The success of an experiment lies rather in the degree to which a student having mastered the physical principles involved; understood the theory and operation of the instruments used, and realised the significance of the final conclusions.

WHAT YOU WILL LEARN IN THIS COURSE

This two credit units course, Laboratory Physics III, is purely practical in nature. There is 14 experiments numbered serially. The procedure in each of these experiments has been planned so that it is possible for the prepared student to perform the experiment in the scheduled laboratory period. It is assumed that your year one laboratory physics has well equipped you in the handling of error analysis.

EXPERIMENT 1: (a) Determination of magnification produced by a convex lens through the variation of the distance of the image from the lens (b) Determination of the focal length of the lens graphically

EXPERIMENT 2: Determination of the focal length of a concave lens using a concave mirror

EXPERIMENT 3: Determination of the focal length of a concave lens using a convex lens

EXPERIMENT 4: Measurement of D.C. voltages

EXPERIMENT 5: Measurement of the thickness of paper or tinfoil by means of interference fringes in an air wedge

EXPERIMENT 6: Boys' method for the radii of curvature of the surfaces of a convex lens and hence the refractive index of the lens

EXPERIMENT 7: Determination of the refractive index of a glass and liquid by real and   apparent depth method using a travelling microscope

EXPERIMENT 8: Determination of the characteristic of a junction diode

EXPERIMENT 9: Measurement of A.C. voltages

EXPERIMENT 10: Demonstration of the action of a junction diode as
(1) a half-wave rectifier (2) a full-wave rectifier

EXPERIMENT 11: Investigation of the properties of a series resonance circuit

EXPERIMENT 12: Investigation of the properties of a parallel resonance circuit

EXPERIMENT 13: Determination of the characteristics of an npn transistor in a common-emitter configuration

EXPERIMENT 14: Determination of the characteristics of an operational amplifier (OP-AMP) by measuring the voltage gains and bandwidths.

COURSE AIMS

The aim of this laboratory physics course is to further teach or reinforce you with an understanding of the importance of physical ideas by way of actual handling of equipment or apparatus as well as to allow you to know the methods and instrumentation of physical investigation.

COURSE OBJECTIVES

After studying this course, you should be able to:

• perform experiments that illustrate the optical behaviour of lenses
• describe some commonly used optical lab equipment
• perform basic measurements and recognise the associated limitations
• practice the process of verifying a mathematical model, including data collection data display, and data analysis (particularly graphical data analysis with curve fitting)
• practice the process of keeping an adequate lab notebook

- experience the process of "fiddling" with an experiment until it finally "works".

The intended outcomes of this course are: maintenance and continuous improvement of the national primary measurement standards for extreme ultraviolet radiation (EUV: wavelengths between 4 nm and 250 nm, i.e., from soft X rays to vacuum ultraviolet), development of techniques for fabricating and characterising EUV optical systems, and the development of a synchrotron-based, national primary standard for source-based

WORKING THROUGH THIS COURSE

Laboratory Physics III is a further laboratory work which has been running all through from year one. It is expected that the student should spend quality time preparing and conducting these experiments.

COURSE MATERIALS

You will be provided with the following materials:

1. Course Guide
2. Study Units
3. Textbooks and references
4. Assignment file
5. Presentation Schedule

STUDY UNITS

The following experiments are contained in this course:

EXPERIMENT 1: (a) Determination of magnification produced by a convex lens through the variation of the distance of the image from the lens (b) Determination of the focal length of the lens graphically

EXPERIMENT 2: Determination of the focal length of a concave lens using a concave mirror

EXPERIMENT 3: Determination of the focal length of a concave lens using a convex lens

EXPERIMENT 4: Measurement of D.C. voltages.

EXPERIMENT 5: Measurement of the thickness of paper or tinfoil by means of interference fringes in an air wedge.

EXPERIMENT 6: Boys' method for the radii of curvature of the surfaces of a convex lens and hence the refractive index of the lens.

EXPERIMENT 7:   Determination of the refractive index of a glass and liquid by real and   apparent depth method using a travelling microscope.
EXPERIMENT 8:   Determination of the characteristic of a junction diode.
EXPERIMENT 9:   Measurement of A.C. voltages.
EXPERIMENT 10: Demonstration of the action of a junction diode as (1) a half-wave rectifier (2) a full-wave rectifier.
EXPERIMENT 11: Investigation of the properties of a series resonance circuit.
EXPERIMENT 12: Investigation of the properties of a parallel resonance circuit.
EXPERIMENT 13: Determination of the characteristics of an npn transistor in a common-emitter configuration.
EXPERIMENT 14: Determination of the characteristics of an operational amplifier (OP-AMP) by measuring the voltage gains and bandwidths.

TEXTBOOKS AND REFERENCES

Some reference books, which you may find useful, are given below:

Armitage, A. (1992). Practical Physics in SI. (2nd ed.). Great Britain: Bath Press.

James Sinclair (1908). Third Year's Course in Practical Physics. London: George Bell and Sons.

Worsnot, B. L. and Flint, H. T. (1927). Advanced Practical Physics for Students. (2nd ed.). London: Methuen and Co. Ltd.

Squires, G. l. (2001). Practical Physics. (4th ed.). Cambridge: University Press.

ASSESSMENT

There are two components of assessment for this course. The Tutor-Marked Assignment (TMA), and the end of course examination.

TUTOR-MARKED ASSIGNMENT

The TMA is the continuous assessment component of your course is the number of experiments you were asked to perform by the instructor. It accounts for 30% of the total score. You will be given 14 experiments to perform. Ten of these must be performed before you are allowed to sit

for the end of course examination. The TMA's would be given to you by your facilitator and returned after they have been graded.

FINAL EXAMINATION AND GRADING

This examination concludes the assessment for the course. It constitutes 70% of the whole course. You will be informed of the time for the examination. It may or may not coincide with the university semester examination.

SUMMARY

This course is supposed to be the last of your laboratory physics at undergraduate level. At the end of this course, you should be able to:

- perform experiments that illustrate the optical behaviour of lenses
- describe some commonly used optical lab equipment
- perform basic measurements and recognise the associated limitations
- practice the process of verifying a mathematical model, including data collection, data display, and data analysis (particularly graphical data analysis with curve fitting)
- practice the process of keeping an adequate lab notebook
- experience the process of "fiddling" with an experiment until it finally "works".

GENERAL INFORMATION

1.   You are expected to carry out all the experiments but only ten (10) experiments will be assessed.
2.   It is expected that you plan your practical work before carrying out the experiment.
3.   The experiments may be carried out individually or in groups.
4.   In the event of being absent in any of the fixed practical period, try as much as possible to have another period fixed for you by the instructor.
5.   You should ensure that the result generated at the end of the experiment is endorsed by the instructor before leaving the laboratory.
6.   The practical work when completed should be submitted to the instructor within the number of days given to you by the instructor. Failure to submit your report at the appropriate day as required by the instructor attracts some loss of marks.
7.   Practical work report not submitted at all should be awarded zero (0) mark.

GUIDELINES FOR ASSESSING THE EXPERIMENTS

The areas of the practical work report to be assessed are as follows:

1.   Procedure or Method: This should be assessed based on observing how the student carryout the actual practical as well as the description of the method in the practical work.
2.   Observation and Measurements: This should be assessed based on the followings:

   a.   Relevant observation without assistance.
   b.   Readings recorded to reasonable accuracy.
   c.   Have good distribution of readings.
   d.   Present derived data to appropriate significant figures.
   e.   Form composite table with correct symbols and units correctly.

3.   Processing and Analysis of Data: This should include:

   a.   Choosing suitable graph for the data.
   b.   Choosing suitable scales on the graph for the data.
   c.   Plotting points correctly.
   d.   Drawing the best line of fit.
   e.   Calculate the slope correctly.
   f.   Stating the calculated slope with correct significant figure as well as the units.

    g.   Reading intercept on the graph correctly.
    h.   Make correct deduction from the graph.

4.   Results: This should be assessed under the following:

    a.   Obtain the physical relations of the results from the slope or intercept calculated.
    b.   Draw the conclusions consistent with the analysed data.
    c.   State appropriate precautionary measures taken during the experiment.
    d.   State appropriate sources of errors.
    e.   State useful comments.

5.   General Comments
    a.   Completion and submission of the practical work report on time.
    b.   Done the required number of experiments by the instructor.
    c.   Used good language in reporting the experiments.
    d.   Shown good moral behavior.

The marks awarded to each of the above vital assessment areas is left at the discretion of the course lecturer.

EXPERIMENT 1

(a)   Determination of Magnification produced by a Convex Lens through the Variation of the Distance of the Image from the Lens

(b)   Determination of the Focal Length of the Lens Graphically

Aim

(a)   To determine the magnification produced by a convex lens through the variation of the distance of the image from the lens.

(b)   To determine the focal length of a lens graphically.

Apparatus

Convex lens and holder: illuminated object consisting of three   vertical slits; 10mm, 15mm and 20mm in length, cut in stiff cardboard and illuminated by an electric light bulb placed close behind image screen of stiff white cardboard.

Method

First, find the appropriate focal length of the lens by the usual method of focusing the image of the window panes on a sheet of paper.

Put the lens at rather more than its focal distance from the illuminated object.

Adjust the position of the image screen until the images of the three object slits for the image of the illuminated scale appear most clearly in focus. Selecting the image whose size can be most conventionally and accurately measured (dividers are useful here) measure the size of the image.

Record the corresponding size of the object. Measure also the image and object distances from the lens.

Gradually increase the distance of the object from the lens and take further sets of readings.

Remember that in the experiment, as in nearly all other graphical problems in optics, one set of readings is in reality *two* sets, yielding two different points on the graph. Thus, $v, u, m,$ represent the image

distance; the object distance and the magnification, then $u, v, \frac{1}{m}$ are also values of image distance, object distance and magnification respectively. It is for this reason that a space for u has been allotted in the table of results.

Tabulate the readings as shown in the table below:

Distance of image from lens v/cm	Distance of object from lens u/cm	Size of image h/cm	Size of object h_0/cm	Magnification $\frac{h}{h_o} = m$

Plot a graph with values of m on the vertical axis and v on the horizontal axis.

Theory:
$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$
$$\therefore \qquad \frac{v}{u} + 1 = \frac{v}{f}$$

Putting $\quad \frac{v}{u} = m \quad$ we then have $m = \frac{v}{f} - 1$

        (1)

Thus, the graph of m against v is a straight line whose slope, obtained from two well-separated points on the graph, is numerically equal to $\frac{1}{f}$

It is interesting to note that this method of measuring f does not depend on the accuracy of any measurement involving the optical centre of the lens.

By writing $v + \varepsilon$ (where ε is an error in measurements, supposed constant) for, equation (1) above becomes
$$m = \frac{v + \varepsilon}{u} - 1$$
i.e. $\qquad m = \frac{v}{u} - \left(1 - \frac{\varepsilon}{f}\right)$

which still yields a straight line slope $\frac{1}{f}/cm$

Alternative methods of deducing the focal length from the graph are:

(a) To read off the value of v corresponding to $m = 1$. Half of this is the numerical value of f. This follows from the fact that $m = 1$ when $v = u = 2f$.

(b)   To measure the intercept made by the straight line graph on the v axis. When m $= 0$, $v = f$. Hence, this intercept is numerically equal to f.

It should be clear that both of these methods depend for their deduction of f on a particular value of v and they have not the advantage of calculation of f from the slope of the graph.

Errors and Accuracy

Besides the usual errors in reading the scale positions of object, image and lens, and also in judging the position of maximum sharpness of the image on the screen, there are also the errors of measuring the lengths of the small object and its image.

From the graph estimate, the likely error in f is from the difference between the slope of the chosen best straight line and the slopes of other possible straights lines drawn through the points.

EXPERIMENT 2

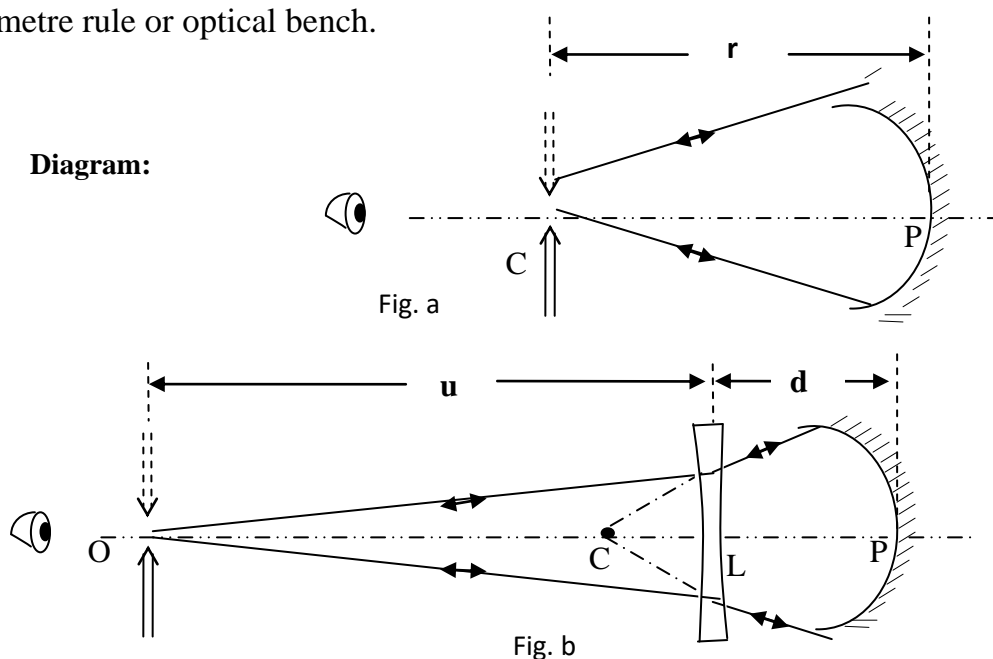## Determination of the Focal Length of a Concave Lens using a Concave Mirror

Aim

To determine the focal length of a concave lens using a concave mirror.

Apparatus

Concave lens and holder, concave mirror and holder, mounted pin, metre rule or optical bench.

Diagram:

Fig. a

Fig. b

Method:

Find the radius of curvature r *of* the concave minor by the simple method of finding the position of the mounted pin so that it coincides with its own image in the mirror as in figure a above.

Measure the distance CP of the pin from the mirror. Repeat the observations and obtain a mean value for r the first column in the table of results.

Insert the concave lens between the pin and the minor and quite close to the pin. Move the pin farther away from the lens until it again coincides with its own image as in fig. b above.

Measure the distance u of the pin from the lens and the distance d between the lens and the mirror.

Calculate the focal length f from the equation $\frac{1}{f} = \frac{1}{u} - \frac{1}{r-d}$

Moving the lens towards the mirror by about 2 cm each time, obtain several sets of readings of u and d.

Tabulate the readings as below:

CP/cm	u/cm	d/cm	$(r-d)/cm$	f/cm from
Mean (r/cm)				Mean (f/cm)

Experimental Details

When the lens L is increased between C and P, it is no use inserting it in such a position that its distance CL from C is greater than its focal length. Any difficulty in locating the position O where object and image coincide will probably be due to the fact that this distance CL is too great, hence the advisability of starting with the lens quite near C.

Theory and Calculation

Referring to the figure b, if rays from O finally return to O, then, after leaving the lens, they must strike the mirror normally. That is, the virtual image formed by the lens must be at the centre of curvature C of the mirror.

For the concave lens and with the usual notation,
$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$
But $v = -(r-d)$ since the image at C is virtual
 Hence,
$$\frac{1}{u} - \frac{1}{r-d} = \frac{1}{f}$$
From which f may be calculated.

Errors and Accuracy

Errors occur in reading the scale positions of the mirror, lens and pin
and in judging the position of no parallax.
From the variation in the values obtained for f *in* the final column of the
table, estimate the likely error in f and state your result accordingly.

EXPERIMENT 3

Determination of the Focal Length of a Concave Lens using a Convex Lens

Aim

The focal length of a concave lens using a convex lens.

Apparatus

Concave lens and holder, convex lens and holder, plane mirror, two mounted pins, metre rule or optical bench, illuminated object and screen.

Part A

This method can only be used if the convex lens is stronger than the concave lens.

Find the focal length f_1 of the convex lens by the plane mirror method of experiment 1.

Combine the two lenses together by placing them in the same lens holder and find the focal length of the convex combination by the same method.

Deduce the focal length f_2 of the concave lens from

$$\frac{1}{F} + \frac{1}{f_1} - \frac{1}{f_2}$$

Part B: Although this experiment may be performed using a mounted pin as the object and another to locate the image, it is much quicker to employ an illuminated object and screen.
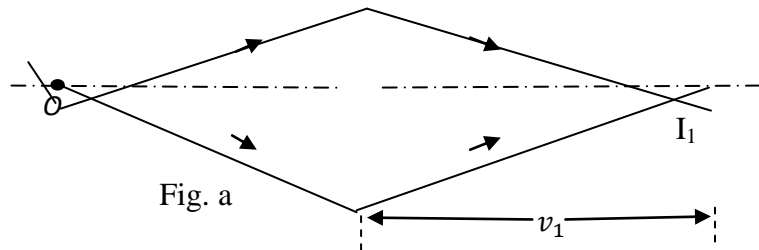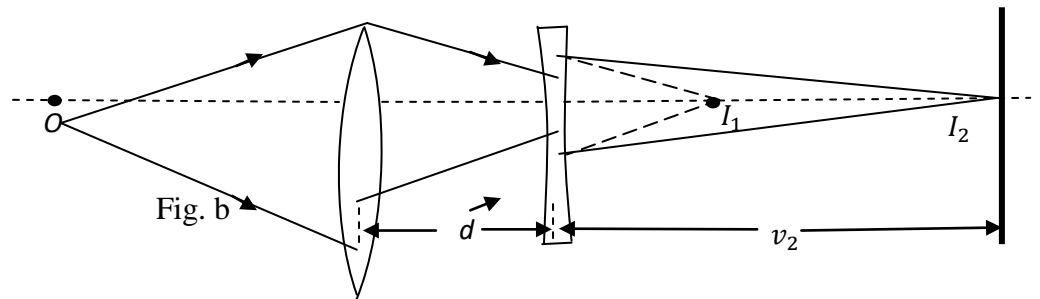
Diagram:

Fig. a

Fig. b

Method:

Place the screen about 40cm from the convex lens and adjust the position of the illuminated object O until a sharply focused image I_1 is seen on the screen (figure a). Measure the image distance v_1 from screen to lens.

Insert the concave lens between the convex lens and the screen and fairly near the screen. Move the screen farther away (as shown in figure b) until the image I_2 is again sharply focused on the screen. Measure the distance v_2 of the new image from the concave lens and also the distance d between the lenses.

Moving the illuminated object to a slightly different position each time obtain several further sets of readings for v_1, v_2 and d.

Tabulate the readings as shown in table below:

v_1/cm	v_2/cm	d/cm	$(v_1 - d)/cm$	Focal length of concave lens f/cm from $$\frac{1}{f} = \frac{1}{v_2} - \frac{1}{v_1 - d}$$
				Mean

Experimental Details

1. The second real image I_2 (i.e. after the insertion of the concave lens) will only be formed if the distance between the concave lens and the first position of the image I_1, is less than the focal length of the concave lens. If, therefore, the second real image I_2 cannot be located, the concave lens must be moved nearer to the first position of the image pin I_1
2. Adjust the distance d so that I_2 is sufficiently removed from I_1, to give reliable readings.

Theory and Calculation

For the concave lens and with usual notation
$$\frac{1}{f} = \frac{1}{u} - \frac{1}{v}$$
Now I_2 is the real image of the virtual object I_1 $\therefore u = -(v_1 - d)$
and $v = v_2$
$$\therefore \qquad \frac{1}{f} = \frac{1}{-(v_1-d)} + \frac{1}{v_2} \text{ or } \frac{1}{f} = \frac{1}{v_2} + \frac{1}{v_1-d}$$

Errors and Accuracy

Errors are due to reading the positions of the lenses and the screen and in judging the position of maximum sharpness of the image on the screen.

From the variations in the values obtained for f in the final column of the table, estimate the likely error in f and state your result accordingly.

Part C

Part B may be adapted to measure the focal length of the concave lens (diverging lens) directly.

If the concave lens (diverging lens) is placed at a distance from I_1 equal to its focal length, the rays of light after leaving the lens will be parallel to the principal axis. If, therefore, they fall normally on to a plane mirror they will be turned back and, after re-traversing their original paths, they will combine to form a real image coincident with the object at O.

Diagram:
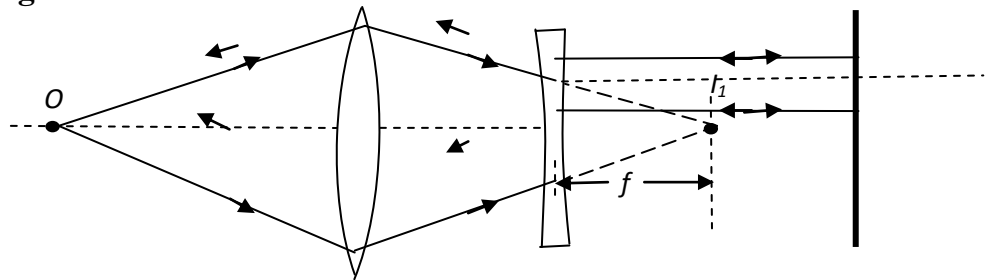
When this is obtained, the distance of the first image I_1 from the concave lens must be the focal length of the concave lens.

Moving the illuminated object to a slightly different position each time, obtain several measurements for f and take the mean.

Experimental Details

The plane mirror in the diagram is placed at a fairly large distance (exceeding f) from the concave lens so that the diagram may show clearly what is happening. In the actual experiment, the plane mirror may be placed immediately behind the concave lens and the two moved about together.
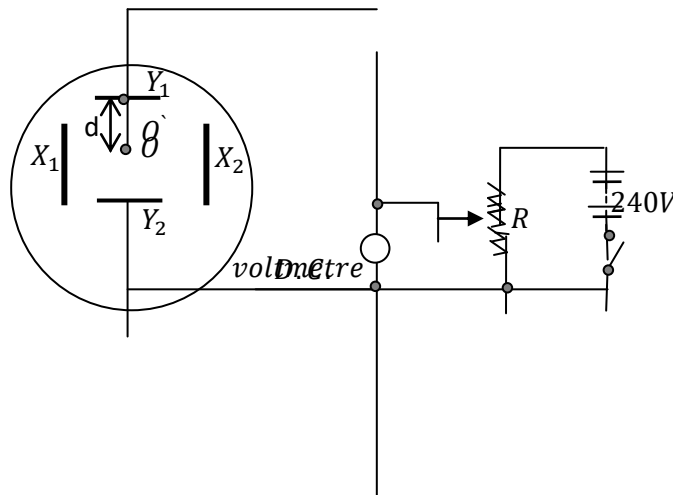
EXPERIMENT 4

Measurement of D.C. Voltages

Aim

To measure the D.C. voltage using cathode ray oscilloscope

Diagram

Method

Switch off cathode ray oscilloscope (C.R.O.) time-base to obtain a stationary spot of light on the screen. In this and all experiments where deflection of the C.R.O. spot is measured, turn down the brightness control until the actual movement of the measurement has arrived. Then turn the brightness up, make measurement and reduce the brightness.

For a given setting of the Y sensitivity control (the Y-amplifier), apply suitable D.C. voltage to the Y-plates by means of the above circuit (R being 20 - 50kΩ) and measure the corresponding deflection of the spot of light. Plot a graph with values of d/mm on the vertical axis against the corresponding values of applied voltage on the horizontal axis. The straight line observed confirms that the deflection is proportional to the potential difference applied. Calculate the slope of the graph. What is the physical significance of the slope in mm per volt (mmV^{-1})

Additional Experiment

Check the Y-sensitivity control indications by using small input voltages, a voltmeter of smaller range and the next highest Y-sensitivity setting

EXPERIMENT 5

**Measurement of the Thickness of Paper or Tinfoil by means of Interference Fringes in an Air Wedge**

Aim

To measure the thickness of paper or tinfoil by means of interference fringes in an air wedge

Apparatus

Glass block, microscope slide, thin glass plate, sodium burner or flame, travelling microscope, stand and clamp, convex lens and holder, methylated spirit and clean rag.

Diagram
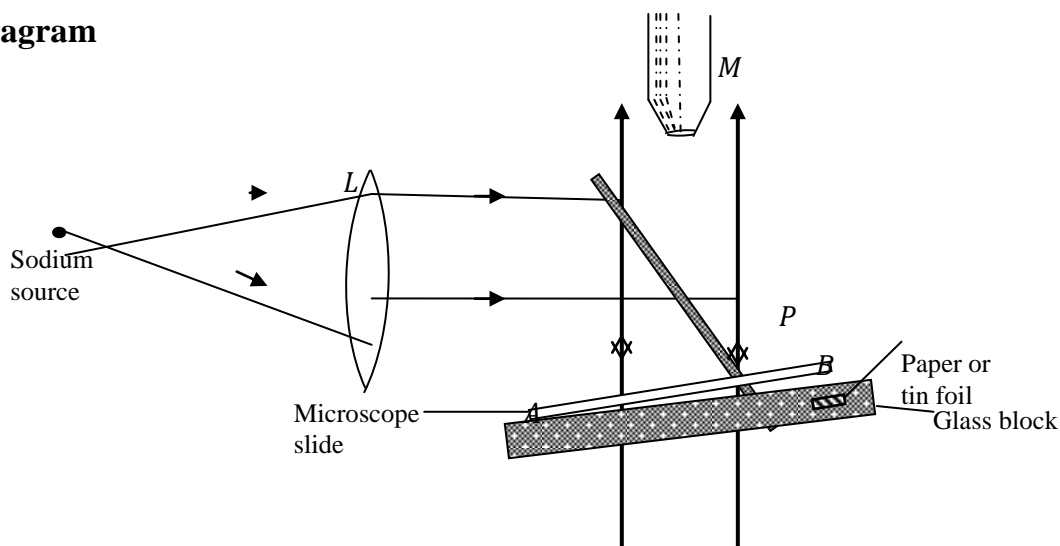
Method

First clean the glass block and microscope slide with methylated spirit and a clean rag. Make an air wedge as shown in the diagram by inserting the piece of paper or tinfoil under one end B of the microscope, slide the other end A resting on the glass block.

By means of the glass plate P held in a clamp at 45^0 to the horizontal, shine a parallel beam of monochromatic light, obtained by placing the sodium source at the focus of the convex lens L, vertically down on to air wedge.

Put the microscope M immediately above the reflecting plate and focus it on the air wedge when interference fringe should be seen. These should be straight fringes parallel to the line of contact between the slide and the glass block, and the position and tilt of the reflecting plate P should be adjusted until the fringes appear as bright and clear as possible.

Using the horizontal traverse of the microscope adjust the microscope so that its cross-hairs coincides with the centre of a bright (or dark) fringe near A. Read and record the vernier reading d_1.

Traverse the microscope across a counted number of fringes N and again read and record the vernier reading d_2. The fringe separation ω is thus $\frac{d_2 - d_1}{N}$

Still using the microscope, measure the length L of the air film from the common line of contact A to the inner edge of the paper or foil.

Theory and Calculation
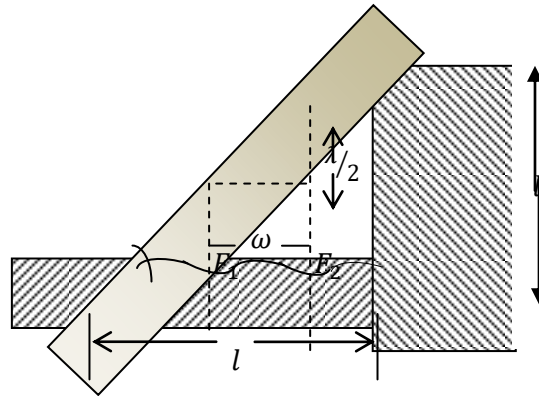
The generally exaggerated diagram above shows two adjacent fringes F_2 and F_1 separated by a distance ω. As the microscope moves from one fringe to the next, the thickness of the air film must increase by $\frac{1}{2}\lambda$ in order that the path difference (twice the thickness of the air film) between reinforcing (or interfering) coherent rays increase by λ .
From the geometry of the diagram

$$tan\alpha = \frac{\frac{1}{2}\lambda}{\omega} - \frac{t}{l}$$

where t is the thickness of the paper or tinfoil.

Hence, $t = \frac{\lambda l}{2\omega} = \frac{\lambda l N}{2(d_2 - d_1)}$

Convert the microscope readings for *l and* $d_2 - d_1$ to metres
take $\qquad\qquad\qquad \lambda_{sodium} = 5.89 \times 10^{-7} m$

Hence *t* in metres.

Further, if the image α of the air wedge is required, since α is small

$$\therefore tan\alpha = \alpha = \frac{\frac{1}{2}\lambda}{\omega} = \frac{\lambda l N}{2(d_2 - d_1)}$$

Errors and Accuracy

The errors involved are those of setting the cross-hairs on the centre of a bright (or dark) fringe and on the extreme ends of the distance L and in reading the vernier. The error may be estimated by setting the vernier on the same fringe (or end of *l)* several times and reading the vernier each time. Estimate this likely error ε. The error in both *l* and $d_2 - d_1$ is 2ε as both are different measurements.

From (1)   % error in *t* = %error in *l* + % error in $d_2 - d_1$
Evaluate this and state your result for *t* accordingly.

EXPERIMENT 6

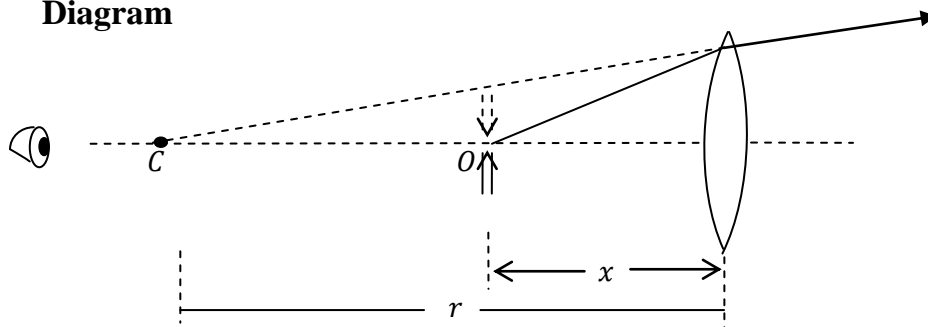**Boys' Method for the Radii of Curvature of the Surfaces of a Convex Lens and hence the Refractive Index of the Lens**

Aim

To determine the radii of curvature of the surfaces of a convex lens and hence the refractive index of the lens using Boy's method.

Apparatus

Convex lens and holder, mounted pin and plane mirror.

Diagram

Method

First find the focal length f of the lens by the plane mirror method of experiment 1.

Now place the lens in front of a dark background and the mounted object pin O in front of the lens.

Look from the object side of the lens towards the lens and, especially if the pin is moved backwards and forwards across the field of view, you will be able to discern two faint images. One of these, the stronger one will be erected and behind the lens. It is formed by reflection in the surface of the lens which is acting as a convex mirror. The other image, which may be either inverted or erect, is formed by light which has been internally reflected from the back surface of the lens acting as a concave mirror.

Move the object pin about until it coincides with its images by reflection in the second surface. In this position the image will be real, inverted and of the same size as the object.

Measure the distance x of the object pin from the lens.

Displacing the object pin each time take three or four determinations of x and calculate the mean value.

Calculate the radius of curvature *r* of this surface from the equation.

$$\frac{1}{x} + \frac{1}{r} = \frac{1}{f}$$

Turn the lens round and repeat to find the radius of curvatures of the other surface.

$$\frac{1}{f} = (n - 1)\left(\frac{1}{r} + \frac{1}{x}\right)$$

Experimental Details

When the experiment is first performed, it is often difficult to locate the required image formed by reflection in the back surface of the lens, so the following hints might prove useful.

1.   First guess the approximate radius of curvature of the back surface and place the object pin nearer to the lens than this.
2.   A paper flag on the object pin is often seen by reflection much more clearly than the pin itself. When the required image has been discerned, the final adjustment to coincidence may be made with the flag removed.
3.   Whitening the object pin with chalk is also useful.

Note: Floating the lens on a horizontal mercury surface greatly improves the reflecting power of the second surface of the lens and the image required is consequently much more easily found. On the other hand, vertical distances are more difficult to measure than horizontal ones and the method is not recommended.

Theoretical Calculation

Let O be position of the object pin when it coincides with its own image by reflection in the back surface. Rays of light, originally starting from O, must be striking normally, for some of this light is reflected back to

form an image coincident with the object. A lot of this light passes out through the lens and C, the centre of the back surface, is therefore the virtual image of the object O.

Hence in the lens equation $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$u = x$ (real and positive)
$v = r$ (virtual and negative)

Since f and u are known $v(r)$ may now be calculated.

Errors and Accuracy

Errors occur in measuring the distance x and the focal length f and in judging the position of parallax between object and image.
Estimate the % error δf in f.

The % error in r is unlikely to be less than the sum of these % errors in x and f.

Since n depends on r, x and f, the % error in n is unlikely to be less than the sum of the % errors in r, s and f .

EXPERIMENT 7

Determination of the Refractive Index of a Glass and Liquid by Real and Apparent Depth Method using a Travelling Microscope

Aim

To determine the refractive index of a glass and liquid by real and apparent depth method using a travelling microscope.
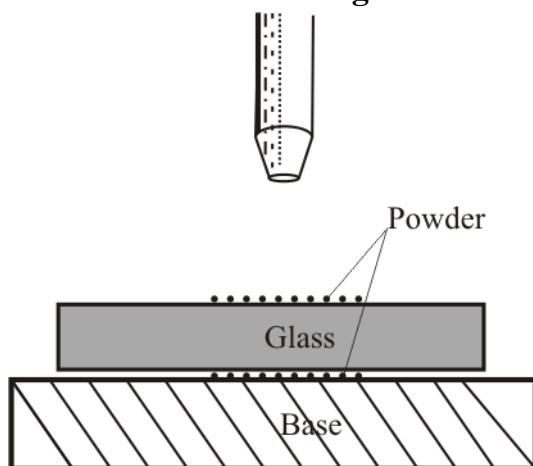
Apparatus

Travelling microscope, two slabs of glass, lucopodium powder, liquid (e.g. water) vessel with a plane base to hold the liquid and some fine sand.

Part A
To measure the refractive index of glass

Diagram

Method
Place one of the glass slabs on the bench to serve as a base and sprinkle some lycopodium on its upper surface.

Adjust the cross-hairs of the microscope so that they can be clearly seen without strain. Place the microscope vertically above the lycopodium powder and adjust the length of the instrument until the grains are in sharp focus with no parallax between their image and the cross-hairs. Read the vertical vernier scale of the microscope (d_1).

Place the second glass slab on top of the first one without removing the powder and raise the microscope slowly until the grains are again in focus. Read vernier (d_2).

Sprinkle some lycopodium on the upper surface of the second slab and raise the microscope again until these grains are clearly focused. Read the vernier (d_3).

Turn the upper glass slab on its side and repeat the measurement to obtain a second set of readings:

	Microscope readings			Real depth $d_3 - d_1$/mm	Apparent depth $d_3 - d_1$/mm	$\dfrac{Real\ depth}{Apparent\ depth}$
	d_1 /mm	d_2 /mm	d_3 /mm			
1st set						
2nd set						
						Mean………………

Part B
To measure the refractive index of water

Method

Sprinkle some grains of fine sand on the bottom of flat-bottomed vessel and focus the microscope on them. Read vernier scale (d_1)

Pour some water to a depth of about 10mm into the vessel. Raise the microscope until the grains of sand are again in focus. Read vernier scale (d_2)

Sprinkle lycopodium on the water surface. Raise microscope farther still until the lycopodium on the surface is in focus. Read vernier scale (d_3). Continue the experiment with increasing depths of water and tabulate the readings:

Microscope readings		Real depth	Apparent depth	$\dfrac{Real\ depth}{Apparent\ depth}$
d_2/mm	d_3/mm	$d_3 - d_1$/mm	$d_3 - d_1$/mm	= n
				Mean ………………

Experimental Details

1. For those who are unfamiliar with the use of the microscope, it is suggested that the instrument is first focused on the printed page of an open book placed approximately at the height of the grains of lycopodium which are presently to be focused. By this means, the observer becomes familiar with the very small range of travel of the instrument over which the object being focused can be seen.
2. When a travelling microscope is used, or any instrument which is moved by means of screw, the last movement of the screw should always be in the direction which moves the instrument forward through the nut of the screw.
3. It will be obvious that the underneath glass slab is merely a rigid base on which to rest the slab whose refractive index is being measured.
4. The actual thickness of the upper slab is measured by the difference between the two vertical positions of the microscope. This method is superior to the use of calipers or micrometer guage as it renders all necessary lengths difference measurements.
5. If the microscope is not provided with an eyepiece with which to read the vernier, use a short-focus convex lens.
6. Finally ground chalk can be used if lycopodium is not available.

Error and Accuracy

Any microscope reading is subject to error due to focusing and to error in reading the scale and vernier. The error may be estimated by focusing on the same object several times and reading the vernier each time. Estimate this likely error ε.

Both the real and apparent depths are different measurements and the total error in each is therefore 2ε. Both errors can be expressed as percentage. The % error in *n* is the sum of these % errors.

EXPERIMENT 8

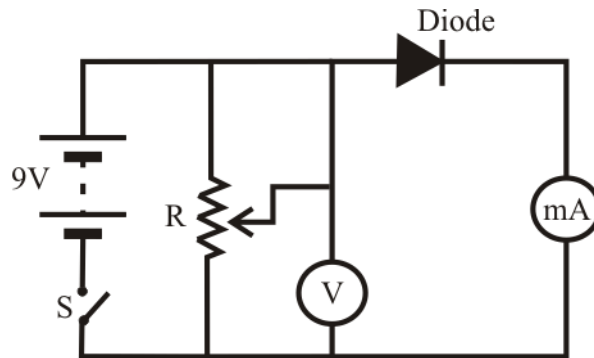## Determination of the Characteristic of a Junction Diode

Aim

To determine the forward and reverse bias characteristic of a junction diode.

Apparatus

Junction diode (e.g. Mullard OA70 or Mullard AAZ15), 9V dry battery, 2kΩ rheostat *R,* milliammeter 0-10 mA, circuit key.

Diagram

Method

Connect up the circuit as shown in the diagram above. Set the slider of the rheostat *R* so as to give minimum reading on the voltmeter, close S and proceed to measure the circuit in the circuit for increasing applied voltage.

When the current has reached 10mA, reduce the voltage applied to the diode circuit to zero by means of the rheostat and open S. Reverse the connections to the diode. Close S and take further observations as the reversed voltage is increased.

Tabulate the readings:

Forward Bias	Applied voltage *V/V*						
	Current *I/mA*						
Reverse Bias	Applied voltage *V/V*						
	Current *I/mA*						

Using the same graph, plot a graph of values of current on the vertical axis and the corresponding values of applied voltage on the horizontal axis.

Discussions

It will be found that very little current flows until the applied voltage rises above 0.2V after which the current increases rapidly. For reverse applied voltages, the current remains at zero. However, if very large reverse voltage are applied (of the order 20-100V) breakdown in the diode occurs and a small reverse current which increases sharply in value occurs (the Zener or avalanche effect). Identify the part of the graph that is forward bias and reverse bias respectively.
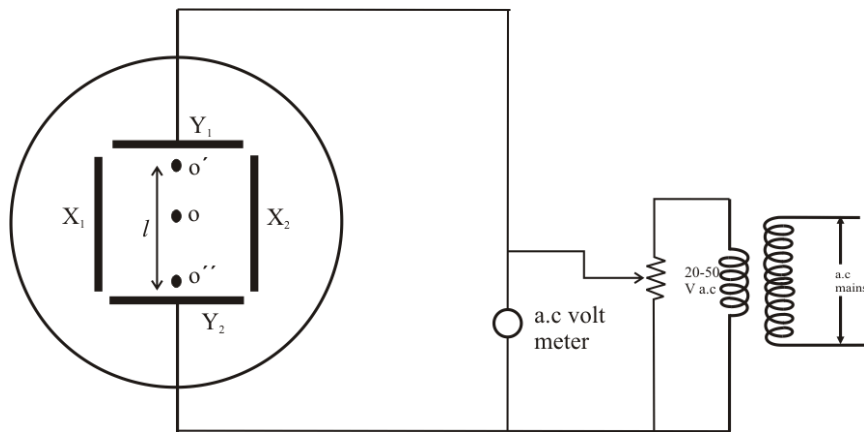
EXPERIMENT 9

Measurement of A.C. Voltages

Aim

To measure A.C. voltages using Cathode Ray Oscilloscope.

Apparatus

Cathode Ray Oscilloscope (CRO), stepdown transformer, A.C. voltmeter, variable resistor.

Diagram

Method

Switch off the CRO time-base to obtain a stationary spot of light on the screen.

For a given setting of the Y-sensitivity control, apply suitable A.C. voltages to the Y-plates by means of the above circuit (R being 2.5kΩ) and measure the length l of the vertical line 0'0" which is traced out by the spot of light.

Plot a graph with values of l (mm) on the vertical axis against the corresponding values of applied voltages on the horizontal.
Two points to note

1.   The deflection 00' or 00" corresponds to the peak value of the applied voltage, whereas

2.   The A.C. voltmeter measures the rms value of the applied
        voltage.

From the graph, calculate the deflection sensitivity as the slope in mm
per rms volt, which provided the A.C. supply is truly sinusoidal should
be $2\sqrt{2}$ times the result obtained in the previous experiment with D.C.
voltages.

EXPERIMENT 10

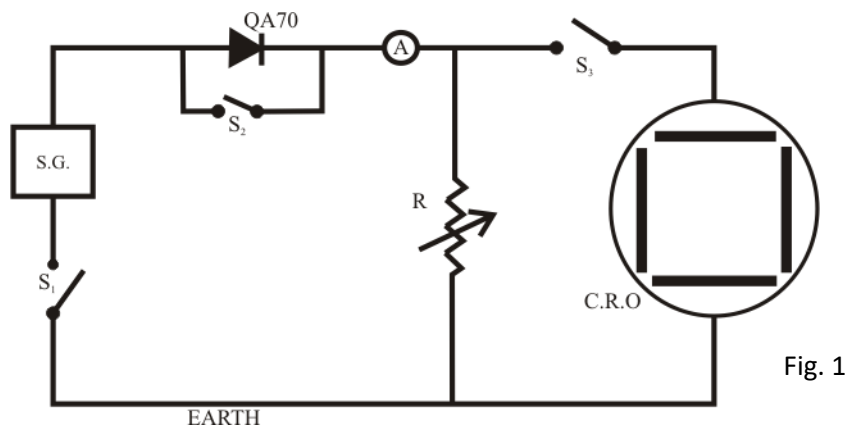**Demonstration of the action of a Junction Diode as (1) a Half-Wave Rectifier (2) a Full-Wave Rectifier**

Aim

To demonstrate the action of a junction diode as (1) a half-wave rectifier (2) a full-wave rectifier.

Apparatus

Four junction diodes, signal generator, D.C. milliammeter A, 1kΩ rheostat R, cathode ray oscilloscope CRO, three circuit keys.

Diagram

Fig. 1

Part A:

Demonstration of half-wave rectification

Method

Connect up one junction diode into the circuit as shown in the figure above.

Set the signal generator to give an output voltage of about 1 V at a frequency of 100 Hz. With S2 and S3 open, close S1 and observe that though the milliammeter A is vibrating (at the frequency of the A.C. input, 100Hz) it nevertheless indicates that a small steady direct current is passing through the circuit and that rectification has been effected.

This is because the junction diode being a one-way device, only allows current to pass through it for a half of each cycle.

Close S2 thus enabling current to by-pass the diode in either direction. The milliammeter shows no steady deflection, merely a 100Hz vibration of the tip of the pointer about the zero of the scale.

Part B

Demonstration of the rectifying action with the CRO.

Method

1.   Select a low speed for the CRO time-base suitable for viewing 100Hz oscillations. With S1, S2 and S3 all closed; observe the forum of the alternating current in the circuit as demonstrated by the waveform of the voltage developed across R (which can of course be varied) figure 2(I).

2.   Now open S2 and examine the new form of the voltage across R and hence the new form of the current in the circuit figure 2 (II). This is half-wave rectification.

3.   Keeping S2 open, connect in turn capacitances of 1, 2, 4 and $8\mu F$ in parallel with R and examine the effect on the shape of the CRO trace. It will be found that this capacitor C, called a reservoir capacitor, exerts a profound effect on the voltage across R, converting it from the half-wave unidirectional pulsations of figure 2 (II) to the pattern of figure 2 (III). This is because when the capacitor has been charged during the half-cycle when the diode is conducting. Its charge and therefore its pd only slowly decay at a rate dependent upon the time-constant CR. Before much charge has leaked away the diode is once again allowing current through and the charge on the capacitor is thus replenished.
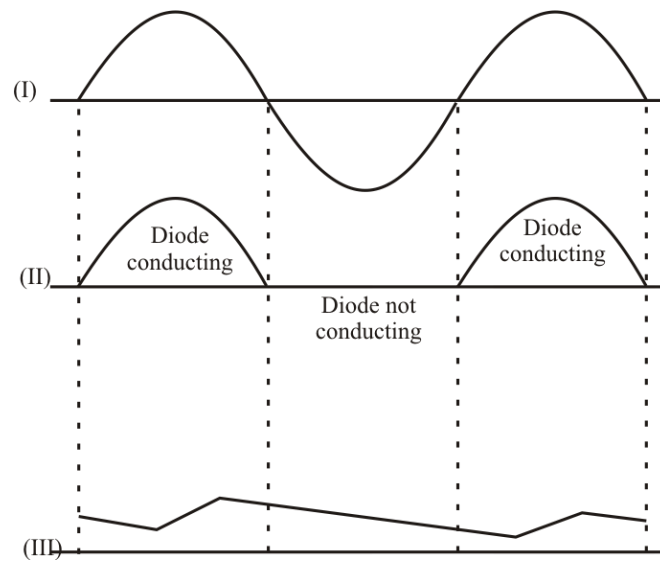
(I)

(II)

Diode
conducting

Diode
conducting

Diode not
conducting

Fig. 2

(III)

EXPERIMENT 11

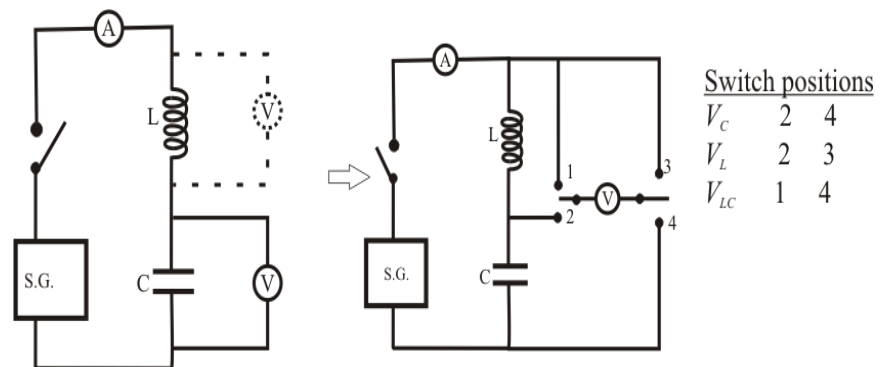## Investigation of the Properties of a Series Resonance Circuit

Aim

To investigate the properties of a series resonance circuit.

Apparatus

Signal generator, high resistance A.C. voltmeter of 0-100V, A.C. ammeter (0-0.1A), a $1\mu F$ capacitor, an inductor of about 30mH.

Diagram

Switch positions
V_C	2	4
V_L	2	3
V_{LC}	1	4

Method

Connect up the circuit as shown in the diagram above. Before switching on the signal generator adjust its output to 2V and do not alter this setting throughout the experiment. Select the lowest available frequency, f, switch on the record the values of the current I in the circuit and the voltage V_c across the capacitor, C.

Transfer the voltmeter to the dotted position shown in the circuit diagram so that the voltage, V_L across the inductance, L is measured. Finally, connect the voltmeter across the points marked X and Y in the diagram so that the voltage V_{LC} across L and C in series is measured. Increase the frequency and measure the values of I, V_C, V_L and V_{LC} through a suitable frequency range of 100-5000Hz. Calculate the value of Z_{LC} in each case using $Z_{LC} = \frac{V_{LC}}{I}$

Tabulate your readings.

Plot a graph of I, V_C, V_L, V_{LC} and Z_{LC} against frequency in each case. Determine the resonant frequencies in each case.

Experimental Details

1.   A slight modification to the circuit employing two single-pole two-way switches will enable the voltages V_C, V_L and V_{LC} to be obtained without the necessity of changing the connections of the voltmeter leads.
2.   It will be found that each graph exhibits a pronounced maximum or minimum value which occurs either at or very near to an important frequency f, called the resonance frequency. In order to determine this resonance frequency as accurately as possible, many readings of I, V_C, V_L and V_{LC} should be taken in the neighbourhood of the resonance frequency once the first graph of I against f has indicated the approximate value of f_r.
3.   The maximum values of V_C, and V_L which will be found to be nearly equal, will be in excess of the applied voltage. This is unexpected and a remarkable feature of the series resonance circuit. It should be remembered and allowed for in selecting the appropriate voltage range for the voltmeter when approaching the resonance frequency.

Theory

The resonance frequency f_r is given by $f_r = \dfrac{1}{2\pi\sqrt{(LC)}}$ and should be tested by inserting the values for L and C in the above formula and comparing the calculated value for f_r with the experimentally obtained value.

The ratio $\dfrac{V_C max.}{applied\ voltage}\left(or\ \dfrac{V_L max.}{applied\ voltage}\right)$ is called the circuit magnification, Q.

Although V_C and V_L are in antiphase with each other at any frequency (V_C lagging on the current I by 90°, V_L leading the current by 90°), it is only at the resonance frequency that they are equal as well as in antiphase. It is this fact that explains the shape of the curves showing the variation of V_{LC} and Z_{LC} with frequency. The reason that the minimum value of V_{LC} is not zero is accounted for by the fact that the coil inevitably has some resistance and cannot be considered to be a pure inductance.

By inserting series resistance of (i) 100Ω (ii) 200Ω into the circuit, investigate the effect on the resonance curves in the above experiment.

EXPERIMENT 12

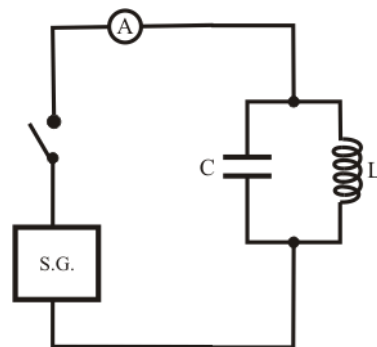**Investigation of the Properties of a Parallel Resonance Circuit**

Aim

To Investigate the properties of a parallel resonance circuit.

Apparatus

Signal generator, A.C. ammetre 0-0.1A, and inductor of about 30mH, a 1μF capacitor.

Diagram

Method

Connect up the circuit as shown in the diagram above. Before switching on the signal generator, adjust its output voltage to 5V and do not alter the setting throughout the experiment.

Select a frequency of 100Hz, switch on and record the value I of the currents in the circuit. Increase the frequency in suitable steps up to 5 kHz, keeping the output voltage of the signal generator constant, and record the values of L. Tabulate your readings. Plot of a graph I on the vertical axis and frequency on the horizontal axis.

Theory

The graph is found to show the exact opposite of what is obtained for the series resonance circuit whereas the current in the series circuit exhibited a maximum at the resonance frequency, the current in a parallel resonance circuit passes through a minimum value at a particular frequency, f_r of the parallel resonance also known as the

resonance frequency. To a close approximation, the resonance frequency f_r of the parallel resonance circuit is given by the same equation as for a series resonance circuit, namely $f_r = \dfrac{1}{2\pi\sqrt{(LC)}}$. This relationship should be tested by inserting the values for L and V in the above equation and comparing the calculated vlalue for f_r with the value obtained from the graph. The exact equation for the resonance frequency of a paralled resonance circuit is $f_r = \dfrac{1}{2\pi}\sqrt{\left(\dfrac{1}{LC} - \dfrac{R^2}{L^2}\right)}$ where R is the resistance of the coil whose inductance is L. In practice, R is usually so small that the term $\dfrac{R^2}{L^2}$ can be neglected in comparison with the term $\dfrac{1}{LC}$ and the simple formula $f_r = \dfrac{1}{2\pi\sqrt{(LC)}}$ gives the resonance frequency to a high degree of approximation.

EXPERIMENT 13

**Determination of the Characteristics of an npn Transistor in a Common-emitter Configuration**

Aim

To determine the characteristics of an npn transistor in a common-remitter configuration.

Apparatus

npn transistor (BC 108 or equivalent), two rheostats of range $0 – 10k\Omega$, two 9V dry batteries, fixed resistor of $2.2k\Omega$, multimeter or milliammeter of range $0 – 50mA$, microammeter of $0 - 100\mu A$, high resistance voltmeter of $0 – 10V$ and two keys.

Diagram
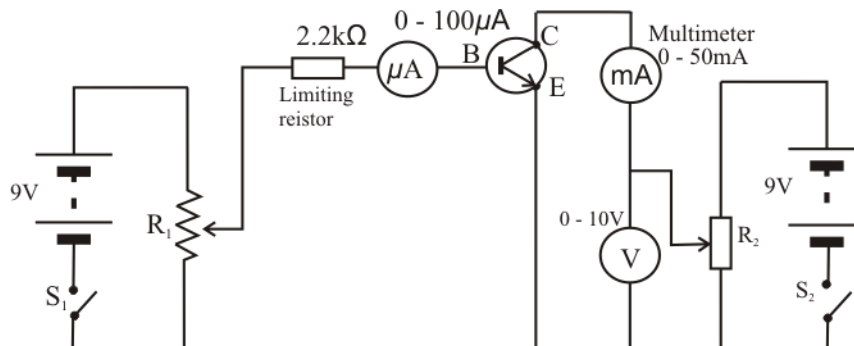
Method

Connect up the circuit as shown above in the diagram.

Part A: Collector Characteristics

Close S_1 and by means of the rheostat R_1, adjust the value of I_b to a low value of about $20\mu A$ and keep it constant. Close S_2 and by means of the second rheostat R_2, reduce the V_{ce} to zero. Observe and record the values of I_c as V_{ce} is increased from zero up to 1V in steps of 0.1 V (it is in the early stages of the experiment when I_c is increasing very rapidly that a multimeter serves better than a milliammeter) and then by steps of 1 V up to a maximum value taking care to ensure that I_b remains constant throughout at $20\mu A$.

Repeat the procedure and measurements for I_b = 40, 60, 80 and 100μA.
Tabulate your readings as shown below:

I_b = 20μA	V_{ce}/V						
	I_c/mA						
I_b = 40μA	V_{ce}/V						
	I_c/mA						
I_b = . . .	V_{ce}/V						
	I_c/mA						

Plot graphs of I_c against V_{ce} labeling each curve with the appropriate constant base current.

Calculation

Draw a line through the characteristics for a particular value of
V_{ce} say at 5 V and calculate the ratio

$$\frac{change\ in\ collector\ current,\ \Delta I_c}{change\ in\ base\ current,\ \Delta I_b} = current\ gain$$

The current gain of the transistor describes how a small change in the base current produces a much larger change in collector current at a particular value of collector-emitter potential difference. A newer term for the current gain (β) is the small signal forward current transfer ratio for which the symbol is h_{fe} in which the subscript f denotes 'forward' and e a common-emitter circuit.

Calculate also for a particular curve beyond the knee, the ratio
$$\frac{change\ in\ collector\ voltage,\ \Delta V_{ce}}{change\ in\ collector\ current,\ \Delta I_c}$$
$$= output\ resistance\ for\ a\ particular\ base\ current$$

Part B: Transfer Characteristics

The transfer characteristics exhibit the variation of collector current I_c with base current I_b while the collector voltage is kept constant. It can be plotted quite easily from the collector characteristics but much better to plot it from the data gained from a separate experiment. Select a suitable collector voltage beyond the knee of the collector cures, say 5 V and keep it constant by means of R_2. By suitable adjustment of R_1, increase

the base current I_b in suitable steps from zero to about $100\mu A$ and take the corresponding readings from the collector current, I_c.

Tabulate your readings as below.

$V_{ce} = \ldots$	$I_b/\mu A$				
V	I_c mA				

Calculation: Calculate the ratio

$$\frac{change\ in\ collector\ current,\ \ \Delta I_c}{change\ in\ base\ current,\ \ \Delta I_b}$$

The ratio h_{fe} *is* the small signal forward current transfer ratio or current gain.

EXPERIMENT 14

Determination of the Characteristics of an Operational Amplifier (OP-AMP) by Measuring the Voltage Gains and Bandwidths
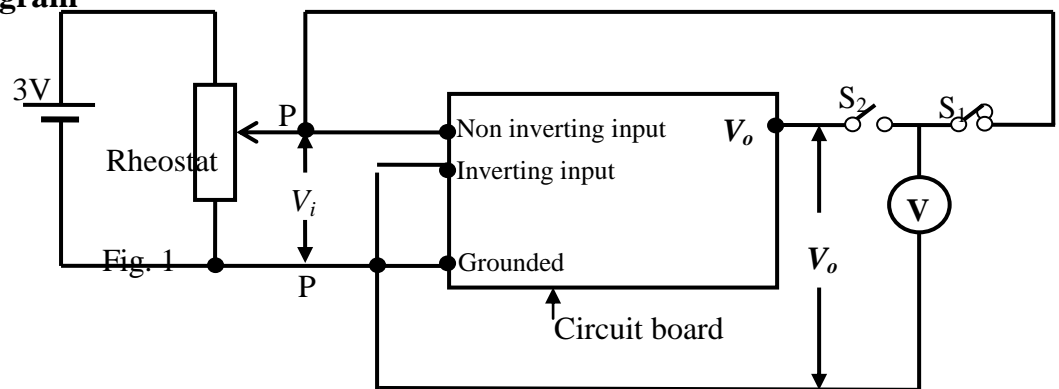
Aim

To determine the characteristics of an operational amplifier by measuring the voltage gains and bandwidths.

Apparatus

OP-AMP 741 IC with socket, signal generator, circuit board, rheostat, 2.2kΩ resistor, 22kΩ resistor, 3 V (two 1.5V) dry cell battery, connecting wires.

Diagram

Fig. 1

Method

Part A: (a) Set up the circuit as shown in the diagram. (b) Close S_1 and open S_2. Adjust rheostat until digital multimeter reads $V_i = 0.1$ V. Record V_i. Open S_1 and close S_2. Record digital multimeter reading V_o. (c) Repeat step (b) with V_i increasing in steps until $V_i = 1.2$ V. (d) Tabulate the readings. Plot a graph of V_o against V_i. Calculate the voltage gain from the graph.

Part B: (a) Remove the rheostat and 3 V battery from terminal PQ and replace it with a signal generator. (b) Set the digital multimeter knob to alternating current. Adjust the frequency f of the signal generator to 1 kHz. (c) Open S_2 and close S_1. Adjust input voltage V_i of signal generator so that the digital multimeter reads

between 0.10 V and 0.15 V. Record V_i and f. (d) Open S_1 and close S_2. Record the output voltage V_o. (e) Repeat steps (b), (c) and (d) by increasing the frequency f of the generator in steps until 30kHz. Tabulate the readings as f, V_i, V_o and $A = V_o/ V_i$. Plot a graph of A and f. From the graph, estimate the gain and bandwidth of frequency response of the inverting amplifier.

Theory: OP-AMP is used to detect the difference in the potential of two signals connected respectively to the two inputs, i.e. $(V_2 - V_1)$, which is multiplied by a factor A and will produce a voltage $A(V_2-V_1)$ as the output. Ideally, OP-AMPs have very high gain, very high input impedance and very low output impedance. OP-AMP is represented as shown in figure 2a.
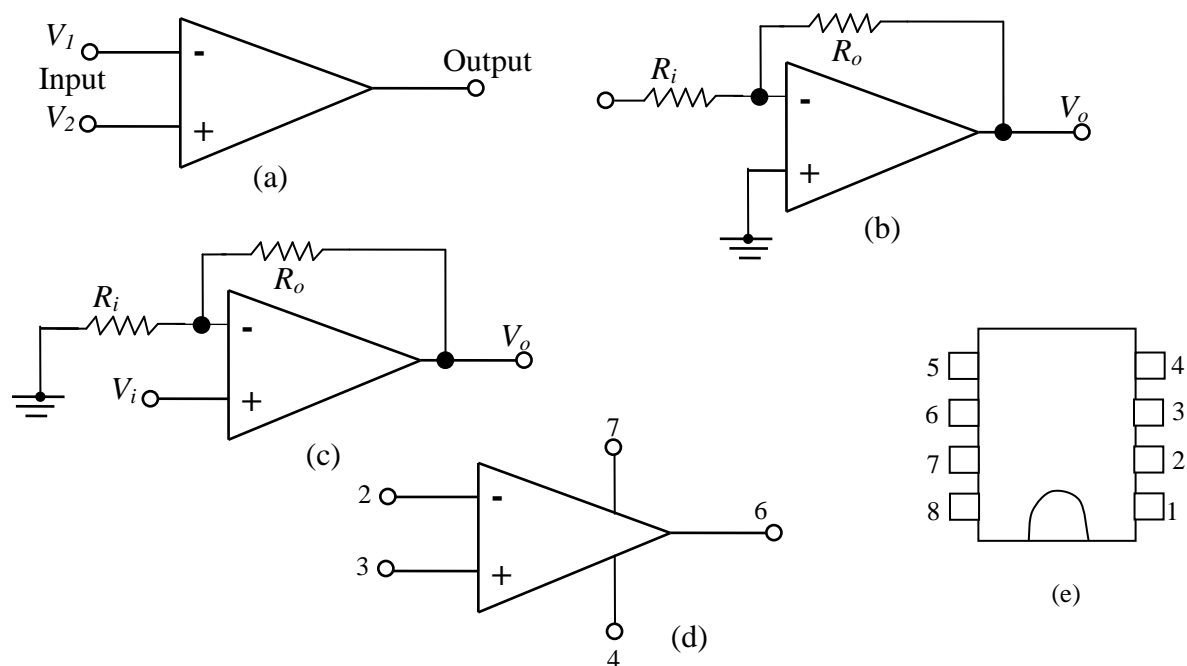

Fig. 2: OP-AMP Circuit Symbol and Pins

The symbol (+) stands for non-inverting input while (-) represents the inverting input. Inverting input implies that the output will be negative if the potential at the inverting input is greater than the potential at the non-inverting input and vice versa. Thus sign (+) and (-) does not mean that (+) input is more positive than (-) input.

Normally, OP-AMP is used with the negative feedback. There are two kinds of amplifiers with negative feedback, i. e. inverting amplifier and non-inverting amplifier. In the case of

inverting amplifier (fig. 2b), the non-inverting input is grounded and output voltage is given by $V_o = -\left(\frac{R_o}{R_i}\right) V_i$. Note that the resistor, R_o joins the output to the inverting input and this setup is called negative feedback. The equation relating to the gain is given by

$$\text{Gain } A = \frac{V_o}{V_i} = \frac{R_o}{R_i}$$

In the non-inverting amplifier (fig. 2c) the output voltage is given by

$$V_o = \left(1 + \frac{R_o}{R_i}\right) V_i \text{ and the gain } A \text{ } as \text{ } 1 + \frac{R_o}{R_i}$$

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