

NAME: \_\_\_\_\_



**DEPARTMENT OF PHYSICS**  
**UNIVERSITY OF CAPE TOWN**  
IYUNIVESITHI YASEKAPA • UNIVERSITEIT VAN KAAPSTAD

**COURSE I LABORATORY**  
**PRACTICALS - PART II**

This page intentionally blank

# **COURSE I PHYSICS LABORATORY PRACTICALS - PART II**

## **CONTENTS**

1. Multimeter & Simple Circuits.....	4
2. Ohmic & Non-Ohmic Circuit Elements .....	8
3. Introduction to the Oscilloscope .....	11
4. RC Circuit .....	14
5. LRC Resonance.....	17
6. Sodium Spectrum.....	22

# 1. Multimeter & Simple Circuits

*NOTE:*

*The deliverable for this practical is a completed worksheet to be handed in by 5:00 pm on the day of the practical.*

*In this practical, you need to become familiar with the operation of a multi-meter and gain experience in setting up simple circuits.*

## 1.1 Introduction

This experiment is designed as an introduction to the concepts that you need to understand simple electrical circuits: current, voltage, resistance, Ohm's Law, and series and parallel circuits.

You may well do this practical before you receive any university lectures on electric circuits, but this should not be a problem since you do not need any more theory what you will have learned at high school. In preparation for this practical you should remind yourself of the concepts of electric charge, current, potential difference and resistance.

## 1.2 Apparatus

You will be supplied with a circuit box, a power supply with variable voltage, a multi-meter and several wires.

### Circuit Box

The circuit box provided has 3 resistors, 2 light bulbs, a push-button (on/off switch) and a power supply input, as shown in Figure 1-1.

Using the supplied wires, one is able to connect the resistors and lamps in a number of circuits.

As an example, Figure 1-2 shows the two mounted bulbs connected in parallel with each other, and connected to the power supply.

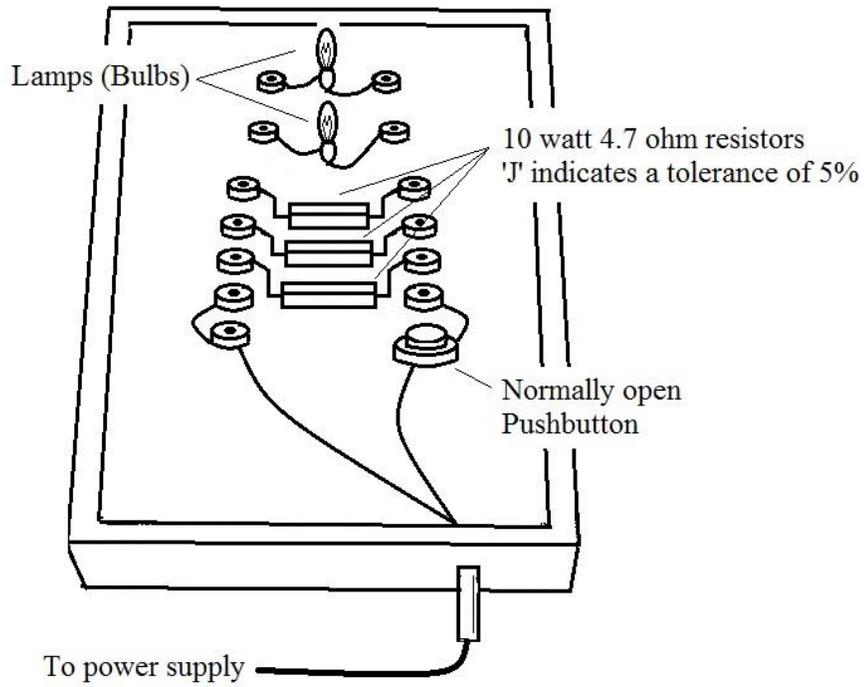


Figure 1-1: Circuit box

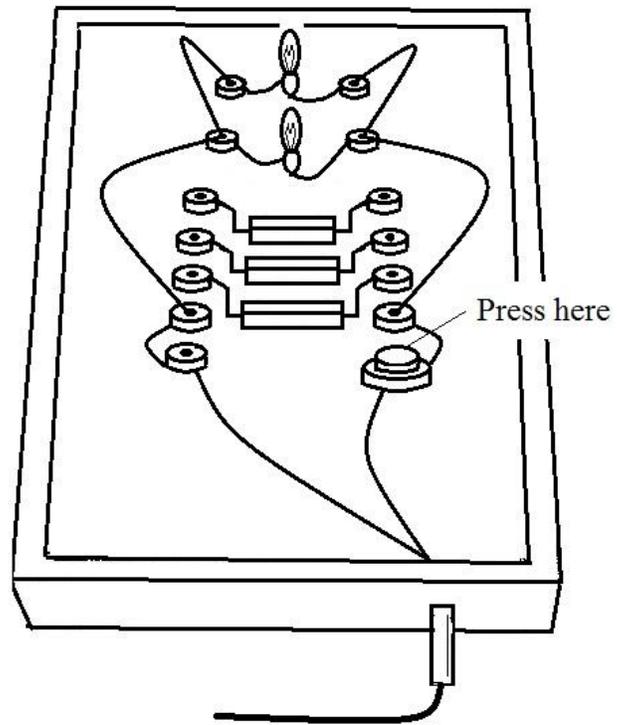


Figure 1-2: Two bulbs connected in parallel

### 1.3 Multi-meter Operation

In this practical you will use an ISO-TECH IDM67 digital multi-meter (DVM).

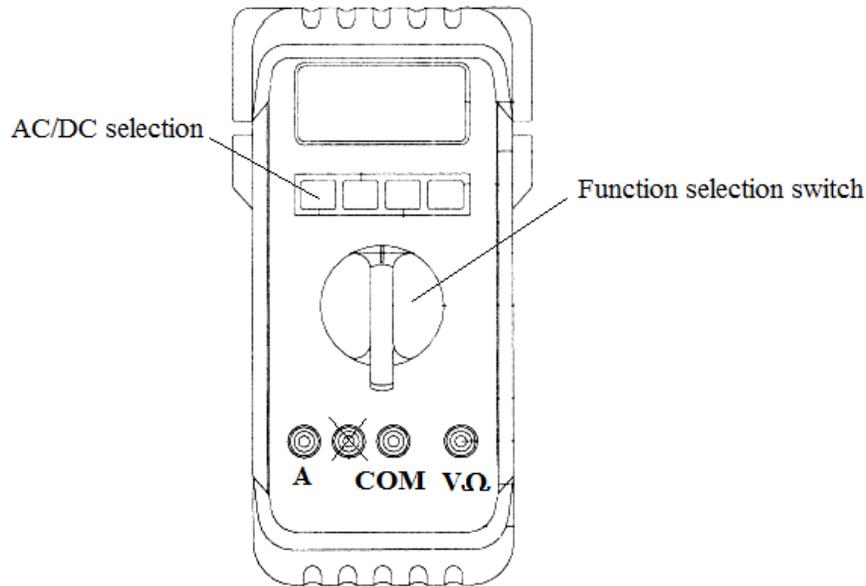


Figure 1-3: ISO-TECH IDM67 multi-meter controls

#### Measuring Potential Difference (Multi-meter as a voltmeter)

- For measuring the potential difference, put one lead in COM and another into V $\Omega$ .
- Set the function selection switch to  $V_{\text{---}}$ .

#### Measuring Resistance (Multi-meter as an ohmmeter)

- For measuring resistance, put one lead in COM and another into V $\Omega$ .
- Set the function selection switch to  $\Omega$ .

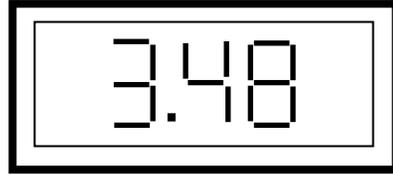
When measuring resistance, **THE EXTERNAL POWER SUPPLY MUST BE OFF.** The multi-meter has an internal battery that it uses to power the instrument when it is in  $\Omega$  mode.

#### Measuring Current (Multi-meter as an ammeter)

- For measuring the current, put one lead in COM and another into A.
- Set the function selection switch to  $A_{\text{---}}$ , and select DC using the blue AC/DC button.

### 1.4 Example of a TYPE B evaluation of uncertainty when using a digital multi-meter

Refer also to the *Laboratory Guide to Reporting and Measurement*. Assume that you have connected the multi-meter (set to read voltage) to the power supply and you see the following on the dial of the instrument:



The displayed reading is the best approximation of the voltage, in this case 3.48 V.

Consider that in this measurement there are two sources of uncertainty to be evaluated:

- 1) the uncertainty associated with the rating of the instrument,  $u(V_{rating})$  and
- 2) the uncertainty associated with reading the display,  $u(V_{read})$ .

There are various ways in which the manufacturer's rating of digital instruments are specified, but in this case we will use a simple method by which we consider that the typical rating of an instrument of this type is  $\pm 1\%$  of the reading displayed on the instrument.

So the standard uncertainty as a result of the rating,  $u(V_{rating}) = 3.48 \times \frac{1}{100} = 0.0348$  V.

To evaluate the uncertainty in the reading, consider that the lower and upper bounds of the value of the measurand are 3.475 V and 3.485 V, and that the evaluation of the uncertainty associated with the reading of a digital display may be modeled on a rectangular pdf, so

$$u(V_{read}) = \frac{(V_{upper} - V_{lower})}{2\sqrt{3}} = \frac{(3.485 - 3.475)}{2\sqrt{3}} = 0.0029 \text{ V.}$$

The standard uncertainties are combined:

$$u(V) = \sqrt{[u(V_{rating})]^2 + [u(V_{read})]^2}$$

$$u(V) = \sqrt{[0.0348]^2 + [0.0029]^2}$$

$$u(V) = 0.0349 \text{ V.}$$

Finally, the voltage can be quoted as  $V = (3.480 \pm 0.035)$  V with a 58% coverage probability.

## 2. Ohmic & Non-Ohmic Circuit Elements

*NOTE:*

*The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.*

*In this practical the focus is on a Type A evaluation of uncertainty and the calculation (propagation) of uncertainty.*

*No Type B evaluations of uncertainty are required, although you will be expected to discuss sources of uncertainty and draw up an uncertainty budget.*

### 2.1 Aim

The aim of this practical is to investigate the relationship - for two different circuit elements - between the potential difference  $V$ , across a circuit element, and the current  $I$  in that element. In each case a DC voltage is applied to the element it is required to determine the resistance  $R$  of the element over a range of applied voltages.

### 2.2 Theory

An electric current  $I$  is a flow of charge, and a direct current (DC) implies a flow in one direction only. The unit of electric current is the *ampere*, symbol A.

To initiate and maintain a current in a circuit element, an electrical potential difference, or *voltage*,  $V$ , has to be established across the ends of the circuit element. The electrical potential difference is measured in *volts*, symbol V, and the power source for such an electrical potential difference may be a battery or a ‘DC’ power supply working off the ‘AC mains’.

When a circuit element carries an electric current, the moving charge carriers interact with the constituent atoms of the material from which the circuit element is made, thus impeding (slowing down) the flow of the charge carriers through the material. This phenomenon is called *electrical resistance*. The unit of electrical resistance  $R$  is the *ohm* (volt/ampere), symbol  $\Omega$ .

The resistance of a circuit element can be determined by the following ratio:

$$R = \frac{V}{I} . \quad \text{Eq. 2-1}$$

As the potential difference  $V$  across a circuit element is varied, the current  $I$  will also vary.

There are two categories of circuit elements to be considered in this practical. They are:

- 1) **Linear or Ohmic elements**, where the ratio  $V/I$  is constant for all values of  $V$ , and the resistance obeys Ohm's Law, i.e.  $R = V/I = \text{constant}$ .

This is best verified by plotting values of  $V$  vs.  $I$ . The resultant graph will be a straight line through the origin and the slope of this line gives the resistance,  $R$ .

- 2) **Non-linear or non-Ohmic elements**, where the ratio  $V/I$  is not constant, and Ohm's Law does not hold.

Plots of  $V$  vs.  $I$  produce graphs of varying shapes. The resistance, however, is still calculated from the ratio  $V/I$  for whatever the particular values of  $V$  and  $I$  may be.

### 2.3 Apparatus and Method

The circuit elements to be investigated are: 1) a carbon resistor, and 2) a light bulb (lamp).

To measure the voltage and current, suitable analogue meters are provided. The power supply is connected to the circuit element via a rheostat (an adjustable resistor) which will allow you to vary the voltage across the circuit element in question.

The circuits are shown in Figure 2-1.

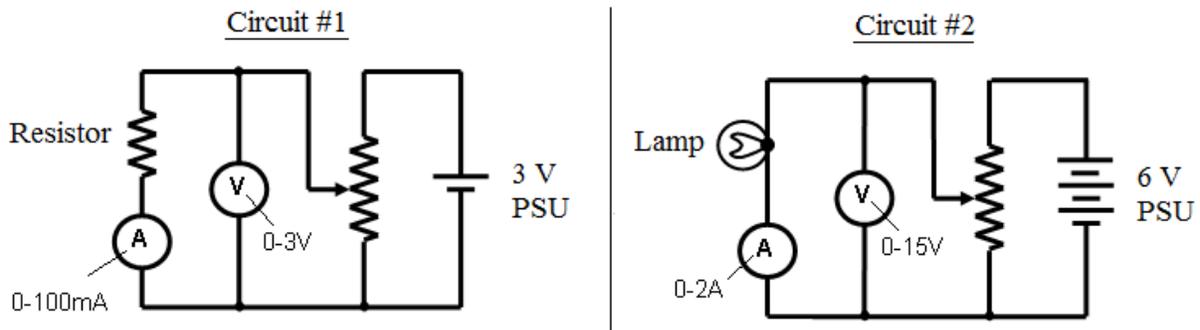


Figure 2-1: Circuits for Ohmic and non-Ohmic experiment

#### **IMPORTANT:**

**If you are not sure of the connections, have the circuit checked by a demonstrator before you turn on the power.**

## 2.4 Data and graphs

Tabulate 8 sets of readings of the voltage and current, at suitable intervals over the largest possible range, for each of the two circuits.

Plot, **BY HAND**, the graphs of  $V$  vs.  $I$  for each of the two circuit elements, i.e.,  $V$  on the  $y$ -axis and  $I$  on the  $x$ -axis.

## 2.5 Calculations

### Resistor

Use an EXCEL spread sheet on the computers in the lab to calculate, from your  $(I_i, V_i)$  data pairs, a set of values for  $R_i$ , for  $i = 1, 2, \dots, 8$ .

Use the equations in section **B3 TYPE A evaluation of uncertainty** in the *Laboratory Guide to Reporting and Measurement* to calculate the mean resistance,  $\bar{R}$ , the standard deviation  $\sigma$ , and the standard uncertainty  $u(R)$ . Print out your EXCEL workings and paste them into your lab book.

### Light Bulb

Determine, from your graph, the resistance  $R_V$  of the light bulb at a voltage between 0.5 V and 1.0 V, as well as at a voltage between 4.0 V and 5.0 V.

You do not have to determine the uncertainty associated with these two readings.

## 2.6 Discussion and conclusion

State which of these circuit elements are Ohmic and which are Non-Ohmic, giving reasons for your answers.

Quote the result of: 1) the resistance of the resistor, as well as 2) the two resistance values of the lamp at the two different applied voltages. If the resistance of the lamp changed, suggest why.

For the resistor the result must be quoted with the uncertainty (as is usually the case), while for the lamp, only the best approximations need be given.

Include an uncertainty budget and make recommendations as to how the experiment may be improved.

### 3. Introduction to the Oscilloscope

*NOTE:*

*The deliverable for this practical is a completed Oscilloscope worksheet to be handed in by 5:00 pm on the day of the practical.*

*In this practical, you need to become familiar with the operation of an oscilloscope.*

*Special emphasis is placed on Type B evaluations of the uncertainty associated with oscilloscope measurements, examples of which are in the **Laboratory Guide to Reporting and Measurement***

#### 3.1 Introduction

The oscilloscope is used in all fields of scientific research, so learning to use this instrument is an important part of a scientist's training.

Further, although the latest generation of oscilloscopes do not use cathode ray tubes (CRTs), as in the oscilloscopes that you will be using in this prac, the controls and functions of all oscilloscopes have remained basically the same. If you can use the oscilloscopes in the Course I laboratory, you can use any oscilloscope.

#### 3.2 Apparatus

##### The Oscilloscope

There are three main components that make up a CRT-type oscilloscope:

1. the electron gun, which produces an electron beam that gives off a spot of light as the electrons hit the screen (the spot of light leaves a 'trace' as the beam is deflected and made to 'move' across the screen);
2. the "y" deflector plates that are able to deflect the beam up and down on the screen as the voltage across these plates is varied;
3. the "x" deflector plates that are able to deflect the beam to the left and right as the voltage across these plates is varied.

In combination, these three main components in the oscilloscope are able to draw a "picture" of Voltage vs Time of an input signal on the screen. Take a careful look at the simple schematic diagram of an oscilloscope depicted in Figure 3-1 and make sure that you can identify the components.

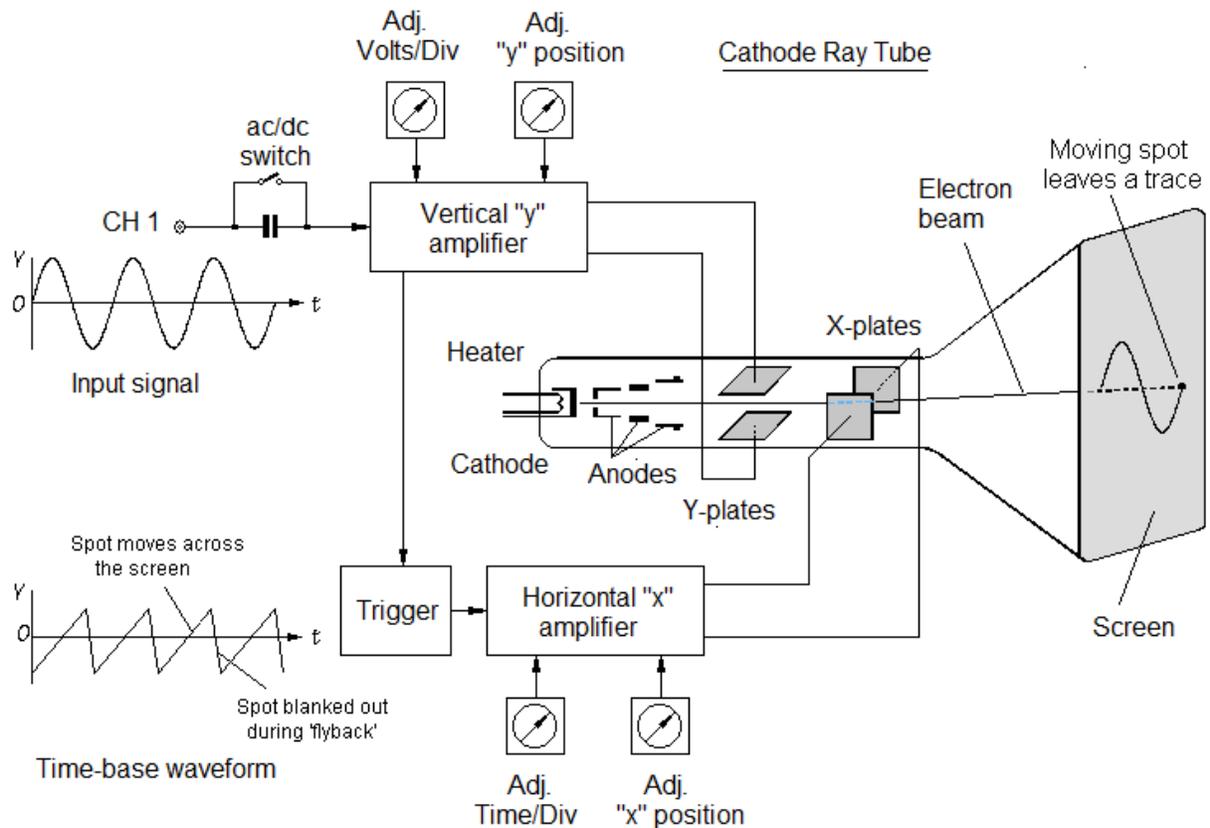


Figure 3-1: Simple schematic diagram of an oscilloscope

The first thing to note about the working of an oscilloscope is that the waveform of the time-base ( $x$ -axis) has a sawtooth shape. During the period that the voltage across the “ $x$ ” deflector plates is increasing, the beam is being deflected horizontally, and so the spot ‘sweeps’ across the screen from left to right. When the voltage across the “ $x$ ” plates decreases, back to its starting point, the beam is quickly deflected back to the left. The return time is called the ‘flyback’ time. During the flyback time the beam is blanked out, so you do not see the trace going back to its starting position.

### VOLT/DIV setting

The voltage of the input signal determines the voltage on the “ $y$ ” deflector plates, which will effectively move the spot up or down on the screen. When you adjust the VOLT/DIV setting on the oscilloscope, you are adjusting the amount of  $y$ -deflection thereby making the ‘picture’ on the screen bigger or smaller.

Changing this setting on the oscilloscope does not change the actual amplitude of the input signal coming from the signal generator.

### TIME/DIV setting

When you adjust the TIME/DIV calibration on the oscilloscope, you are adjusting the time that it takes for the spot to sweep across the screen from left to right. (The flyback time is set by the oscilloscope.) If you shorten this time it means that the sweep time is faster.

### TRIGGERING

Finally note that in order to see a steady picture on the screen, there has to be something that will synchronise the input signal on the  $y$ -axis with the sweep time on the  $x$ -axis; and this is done by the trigger circuitry.

The trigger setting will involve selecting the source signal with which the sweep must be synchronised, as well as the level at which it must synchronise.

### ISOTECH 622 manufacturer's rating

The oscilloscope used in Course 1 Lab is the dual-beam ISOTECH 622.

Note that the manufacturer's rating of the oscilloscope is 5% on the time ( $x$ -axis) scale and 3% on the voltage ( $y$ -axis) scale, with a 65% coverage probability, i.e., one standard uncertainty.

## 4. RC Circuit

*NOTE:*

*The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.*

*In this practical, you need to pay special attention to the way in which the equation in the method is linearised and the way in which the uncertainty associated with the measurement is calculated (propagated).*

*The method of least squares will be implemented in EXCEL.*

*This practical also requires that you use scientific notation carefully. Ensure that you are able to use the oscilloscope to measure both voltage and frequency.*

### 4.1 Aim

The aim of this practical is to measure the capacitance of a capacitor using an RC circuit.

### 4.2 Theory

In the circuit shown in Figure 4-1, a resistor and capacitor are connected in series and the signal generator provides a sinusoidal input of frequency  $f$ . The instantaneous current  $i(t)$  and peak current  $I_o$  are the same in all parts of the circuit at any time. The peak current can be determined by  $I_o = V_R/R$ , where  $V_R$  is the peak voltage across the resistor of resistance  $R$ .

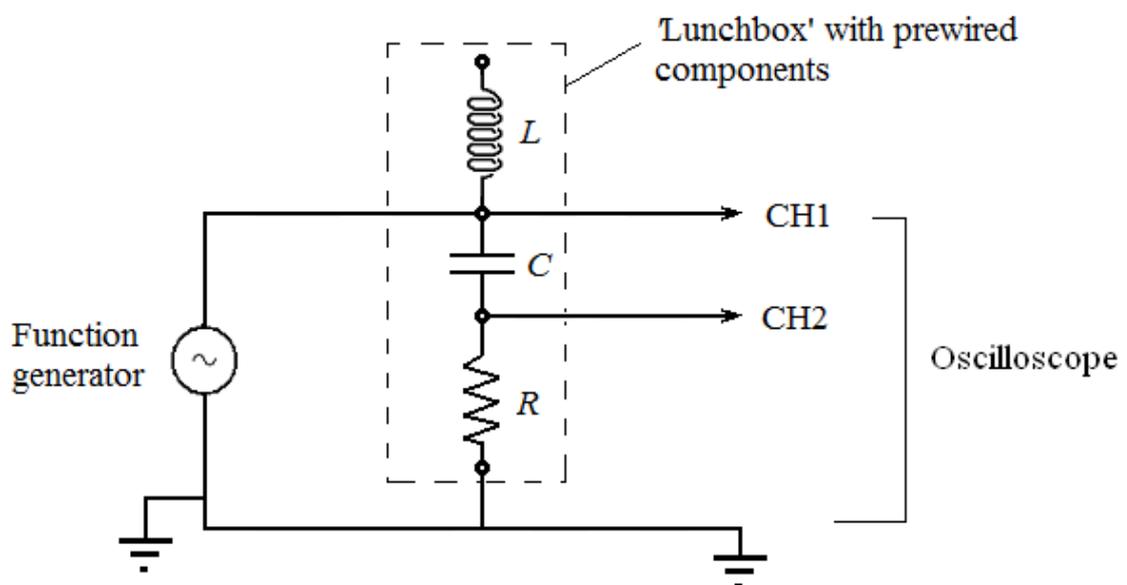


Figure 4-1: Circuit for RC experiment

The total circuit impedance  $Z$  of the resistor and the capacitor, which plays an analogous role to total resistance for an AC circuit containing resistors and capacitors, is given in the following equations:

$$Z = \sqrt{R^2 + \left(\frac{1}{\omega C}\right)^2}, \quad \text{Eq. 4-1}$$

where  $\omega = 2\pi f$ , and

$$I_0 = \frac{V_R}{R} = \frac{V_{in}}{\sqrt{(R)^2 + \left(\frac{1}{\omega C}\right)^2}} \quad \text{Eq. 4-2}$$

where  $V_{in}$  refers to the input peak voltage. Rearranging terms and squaring both sides gives

$$\left(\frac{V_{in}}{V_R}\right)^2 (R)^2 = (R)^2 + \left(\frac{1}{\omega C}\right)^2 \quad \text{Eq. 4-3}$$

Dividing throughout by  $R^2$  and substituting  $\omega = 2\pi f$ ,

$$\left(\frac{V_{in}}{V_R}\right)^2 = \left(\frac{1}{2\pi RC}\right)^2 \left(\frac{1}{f}\right)^2 + 1 \quad \text{Eq. 4-4}$$

Although it may take a moment or two of looking carefully at it, you should see that the above equation is in a linear form of

$$y = mx + c. \quad \text{Eq. 4-5}$$

### 4.3 Apparatus

The apparatus you will use is a ‘lunchbox’ which has three pre-wired components – a resistor, a capacitor, and an inductor - a signal (function) generator, an oscilloscope, a digital multi-meter, and interconnecting wires.

**IMPORTANT:** When doing this practical,

- make sure that you connect the ground (black) wire of the oscilloscope to the ground (black) wire of the signal generator,
- make sure you know what a “ground loop” is, and
- make sure you know the difference between  $V_{rms}$ ,  $V_{peak}$  and  $V_{peak-to-peak}$ .

#### 4.4 Method

Use one of the multi-meters in the laboratory to measure the resistance  $R \pm u(R)$  of the resistor in the 'lunchbox'. This requires that you do a **TYPE B evaluation** of the uncertainty in the measurement. Then build the circuit as shown in Figure 4-1.

**Set the amplitude** of the signal (function) generator to a peak voltage of about 4 V, i.e., a peak-to-peak voltage of about 8 V. (In this experiment the actual amplitude of the input voltage does not matter as long as it does not change for the duration of the experiment.)

**Adjust the frequency** of the signal (function) generator output to 8 different frequencies of your choice - over a range of around 2 kHz to 8 kHz - and at each chosen frequency use the dual beam oscilloscope to tabulate readings of:

1. the amplitude of  $V_{in \text{ peak-to-peak}}$ ,
2. the amplitude of  $V_{R \text{ peak-to-peak}}$ , and
3. the period,  $T$ , of either of the voltages (period is same for both).

Also record the frequency displayed on the function generator at each setting.

Using *EXCEL* on the laboratory computers, calculate the respective peak voltages as well as the frequencies  $f$  (from  $T$ ). Use the calculated values of  $V_{in \text{ peak}}$ ,  $V_{R \text{ peak}}$  and  $f$  to determine the values of the linearised data pairs as required by Eq. 4-4.

Plot an *EXCEL* graph of the linearised data pairs to confirm that the relationship between these values is indeed linear. Print out the graph and paste it in your lab book.

Implement the **E3 Method of least squares** as shown in the *Laboratory Guide to Reporting and Measurement*, using *EXCEL*, to determine  $m \pm u(m)$  and  $c \pm u(c)$  of the line of best fit of the linearised data. Print out the calculations and paste them in your lab book.

Use *LINEARFIT* to check the *EXCEL* result for  $m \pm u(m)$  and  $c \pm u(c)$ , and record the *LINEARFIT* result in your lab book.

Determine the capacitance of the capacitor, i.e.,  $C \pm u(C)$ .

#### 4.5 Conclusion

Quote the result of  $C \pm u(C)$  to the correct number of significant figures and decimal places and comment, *inter alia*, on;

- how well the intercept of your best-fit compares to the theoretical prediction, and
- the comparison between the frequencies calculated from the oscilloscope period readings with those displayed on the function generator.

Be sure to include a complete uncertainty budget.

## 5. LRC Resonance

*NOTE:*

*The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical.*

*In this practical, you need to pay special attention to the plotting and interpreting of the graph that shows the characteristic response of an LRC circuit when an alternating current (AC) signal of varying frequency is applied to the circuit.*

*By the end of this practical, you should be able to use the oscilloscope to measure both the voltage and period (to determine frequency) of a signal with confidence.*

### 5.1 Aim

The aim of this practical is to investigate the response of an *LRC* series circuit to a sinusoidal voltage, applied at various frequencies, and to determine the circuit's resonance frequency, and to determine the value of the inductance *L*.

### 5.2 Theory

As the name implies, the *LRC* series circuit contains an inductor *L*, a resistor *R* and a capacitor *C*, which are connected in series across an AC power supply (function generator).

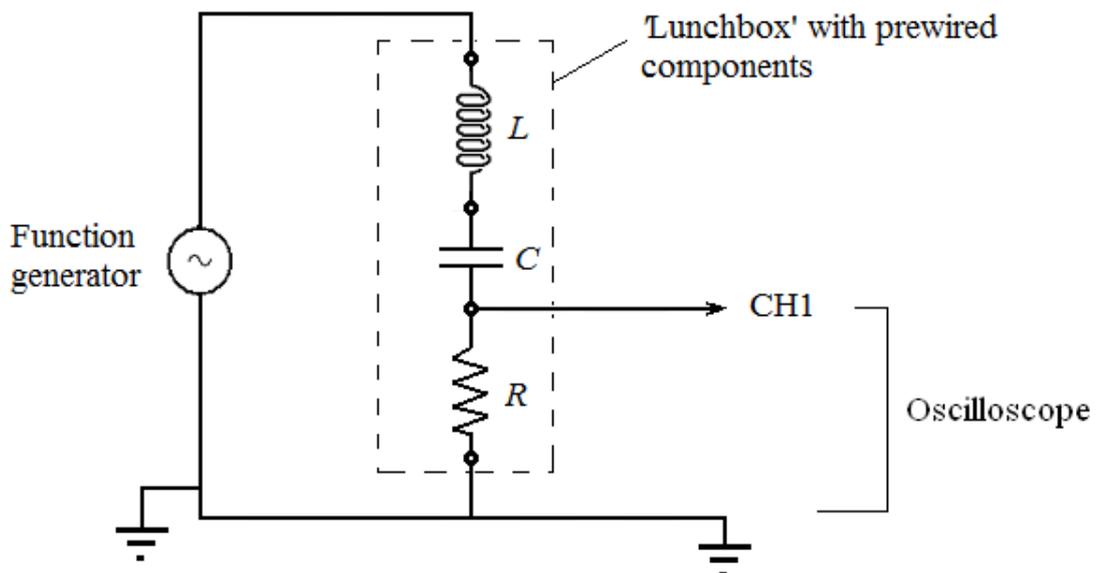


Figure 5-1: Circuit for LRC experiment

It can be shown that the instantaneous current in the circuit is given by

$$i(t) = I_o \sin(\omega t + \phi), \quad \text{Eq. 5-1}$$

where

$I_o$  is the amplitude (peak) of the alternating current,

$\omega$  is the angular frequency of applied signal ( $\omega = 2\pi f$ ), and

$\phi$  is the difference in phase between the applied voltage  $V(t)$  and the current  $i(t)$ .

The phase difference  $\phi$  occurs because the voltage across the capacitor and the voltage across the inductor are not in phase with the current in these components. The value of  $\phi$  in Eq. 5-1 is given by:

$$\tan \phi = \frac{\left( \omega L - \frac{1}{\omega C} \right)}{R}. \quad \text{Eq. 5-2}$$

The peak current  $I_o$  is related to the applied peak voltage  $V_o$  by:

$$I_o = \frac{V_o}{Z} = \frac{V_o}{\sqrt{R^2 + \left( \omega L - \frac{1}{\omega C} \right)^2}}. \quad \text{Eq. 5-3}$$

Since the peak current in the resistor is also  $I_o$ , by Ohm's Law,

$$I_o = \frac{V_R}{R} \quad \text{Eq. 5-4}$$

By equating Eq. 5-3 and Eq. 5-4, and re-arranging, we get

$$Z = \frac{V_o}{V_R} R \quad \text{Eq. 5-5}$$

If the applied peak voltage  $V_o$  remains constant, then the peak current  $I_o$  depends on the angular frequency  $\omega = 2\pi f$  of the applied signal. A typical plot of peak current  $I_o$  vs applied frequency  $f$  is shown in Figure 5-2.

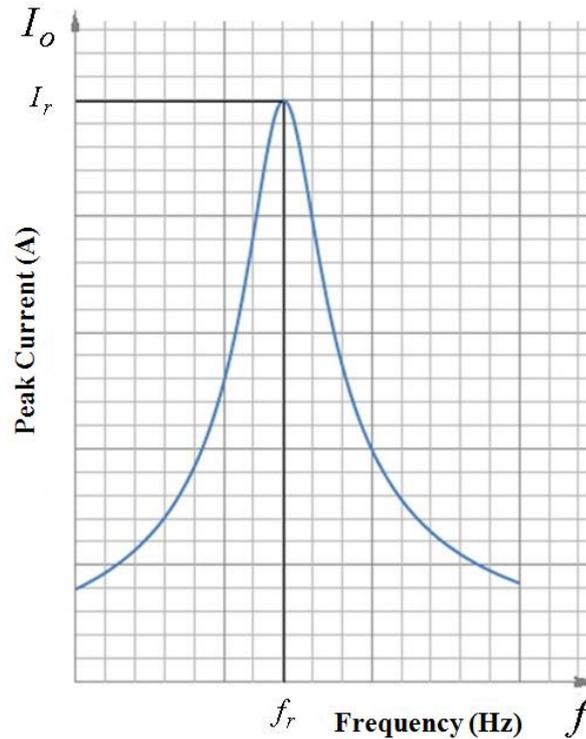


Figure 5-2: Typical plot of peak current vs. frequency

Note from Figure 5-2 that, at low frequencies, the peak current  $I_o$  is low; and that as the frequency is increased, the peak current rises to a maximum  $I_r$ , before falling off again.

The frequency  $f_r$  at which the peak current is a maximum is called the “resonance frequency”, and this occurs when

$$\left( \omega_r L - \frac{1}{\omega_r C} \right) = 0. \quad \text{Eq. 5-6}$$

So at resonance,  $\omega_r^2 = \frac{1}{LC}$  and the resonance frequency  $f_r$  is given by:

$$f_r = \frac{1}{2\pi\sqrt{LC}}. \quad \text{Eq. 5-7}$$

### 5.3 Apparatus

The apparatus you will use is a ‘lunchbox’ which has three pre-wired components – a resistor, a capacitor, and an inductor - a signal (function) generator, an oscilloscope, a digital multi-meter, and interconnecting wires.

**The value of the capacitor,  $C \pm u(C)$ , will be given to you by the laboratory staff.**

## 5.4 Method

Use one of the multi-meters in the laboratory to measure the resistance  $R \pm u(R)$  of the resistor in the ‘lunchbox’. This requires that you do a **TYPE B evaluation** of the uncertainty in the measurement. Then build the circuit as shown in Figure 5-1.

Select the sinusoidal output waveform on the signal (function) generator and set the amplitude (peak) of the signal from the signal generator to a voltage of about 3 V. i.e., a peak-to-peak voltage of about 6 V.

Now adjust the frequency of the signal (function) generator so as to “sweep” through a range of frequencies, starting around 1 kHz, and observe what happens to the voltage across the resistor  $V_R$  at the various frequencies. You should see that around a particular frequency there is a fairly sharp increase in the voltage across the resistor,  $V_R$ .

The frequency at which the voltage across the resistor is a maximum is the resonance frequency  $f_r$ . Record the reading displayed on the signal (function) generator when the resistor voltage  $V_R$  is a maximum. Use the oscilloscope to measure the period  $T_r \pm u(T_r)$  of the voltage at this setting (a TYPE B evaluation) and calculate the frequency  $f_r \pm u(f_r)$  from the measured period. Does the frequency displayed on the signal (function) generator fall within the interval given by the frequency measured by means of the oscilloscope?

Having established the value resonance frequency directly, the next step is to do so graphically. Decide the range of frequencies over which you will take readings to produce a plot like that shown in Figure 5-2. Record the different frequencies  $f$  and their associated peak-to-peak voltages,  $V_R$ , within your chosen range.

Make sure that you take more readings in the vicinity of the resonance frequency.

Using Eq. 5-4, calculate  $I_o$  for every recorded value of  $V_R$  and plot, **BY HAND**, a graph of  $I_o$  vs  $f$ . Determine the best estimate of the resonance frequency  $f_r$  from the graph.

Now, in order to determine the uncertainty associated with the resonance frequency  $f_r$ , consider that the graph you have plotted may have a shape “close enough” to be thought of as Gaussian and use the graphical method shown in **SECTION F** of the *Laboratory Guide to Reporting and Measurement* to determine the standard deviation  $\sigma$  of the distribution of the frequency readings around the mean value. From the standard deviation, calculate the standard uncertainty,  $u(f_r)$ . This is a TYPE A evaluation of uncertainty.

Having obtained  $f_r \pm u(f_r)$  by two methods, and having been given the value of the capacitor,  $C \pm u(C)$ , use Eq. 5-7 to calculate the value of the inductance  $L \pm u(L)$  of the coil. Note that the unit of inductance is the Henry, H.

## 5.4 Conclusion

Apart from quoting the result of  $L \pm u(L)$  to the correct number of significant figures and decimal places, comment, *inter alia*, on the validity of considering the graph you have plotted as being a Gaussian. What can you say about the symmetry of the graph?

As always, include a complete uncertainty budget and suggest ways to improve the results of the experiment.

## 6. Sodium Spectrum

*NOTE:*

*The deliverable for this practical is a full write-up to be handed in by 5:00 pm on the day of the practical. In this practical, the focus is on learning to use the spectrometer.*

*No uncertainty calculations are required.*

### 6.1 Aim

The aim of this practical is to study the emission spectrum of atomic sodium using a diffraction grating.

### 6.2 Introduction

Sodium has an atomic number of eleven. The sodium atom may therefore be pictured to consist of a positively charged nucleus surrounded by eleven electrons.

Using the electron orbital model, and according to the Pauli Principle, each orbital may be occupied by no more than two electrons.

When the sodium atom is in its ground state, two of the eleven electrons will occupy the  $1s$  orbital, another two the  $2s$  orbital, six the three  $2p$  orbitals, and the remaining electron will occupy the  $3s$  orbital. In this state then, the  $n = 1$  and  $n = 2$  shells are completely filled; here  $n$  refers to the principal quantum number and  $s$  and  $p$  refer to the angular momentum quantum number,  $l = 1$ ,  $l = 2$ .

However, these electrons can be relatively easily excited to a higher state and on de-exciting, the electron will emit a photon with a wavelength  $\lambda$  is determined by the energies of the orbitals between which the electron is undergoing transition, i.e.,

$$E_1 - E_2 = hc / \lambda. \quad \text{Eq. 6-1}$$

The energy level diagram of sodium, together with the allowed transitions, is shown in Figure 6-1 below.

## The sodium spectrum

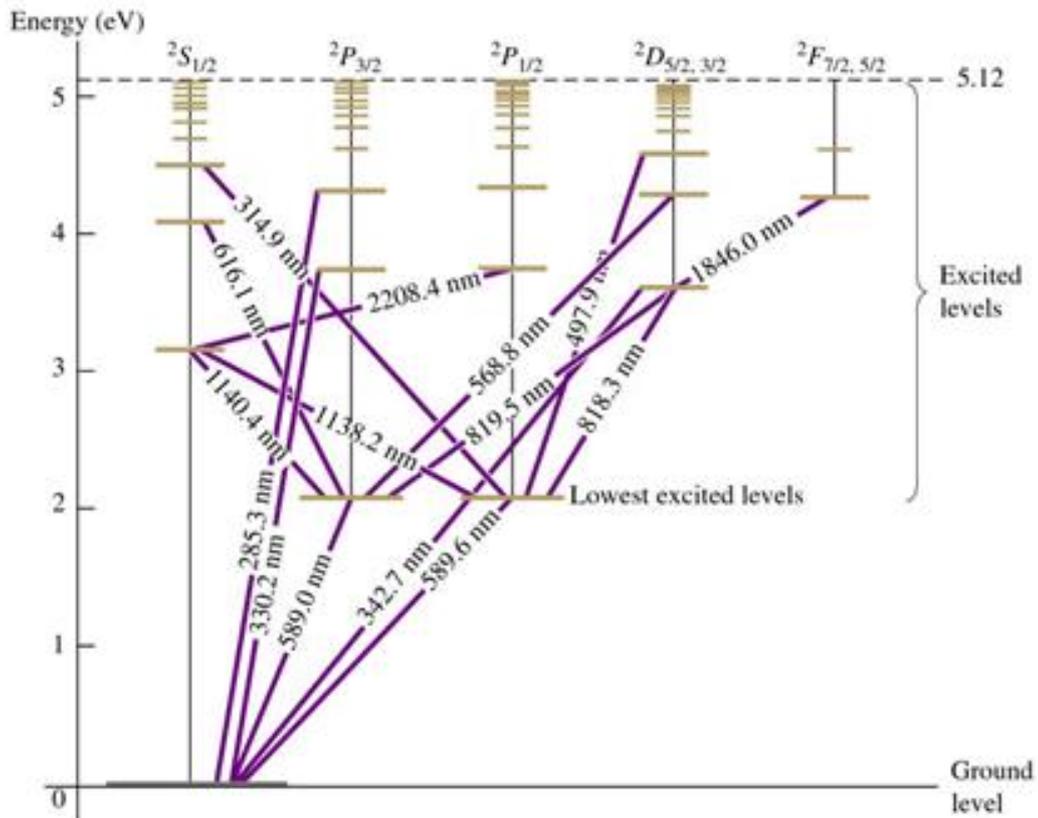


Figure 6-1: Energy level diagram of atomic sodium

The horizontal lines in Figure 6-1 indicate the energy levels of the orbitals in sodium.

Also indicated in the diagram are some of the allowed transitions, together with the wavelength of the associated photon.

## The sodium doublet

Sodium light is dominated by two characteristic **yellow-orange** wavelengths (589.0 nm & 589.6 nm), often referred to as a “doublet”, that are emitted when electrons make transitions between two very closely-spaced “lowest excited levels” to ground level.

The two lines in the “doublet” are so close together that they often seem blurred together as a single line.

### 6.3 Apparatus

#### Diffraction grating

A diffraction grating will be used to study the wavelengths of the photons emitted by the sodium spectrum. With a grating, the constructive interference of the omissions may be observed since the wavelength of the photon  $\lambda$  is related to the grating spacing  $d$  by the relationship

$$n\lambda = d\sin\theta_n, \quad \text{Eq. 6-2}$$

where  $n$  is the order of the spectrum, and  $\theta_n$  is the angle between the zero and  $n^{\text{th}}$  order spectral lines.

#### Spectrometer

The spectrometer is an instrument for the measurement of angles of deviation of light rays resulting from reflection, refraction or diffraction. The essential components of the spectrometer are shown in Figure 6-2 below.

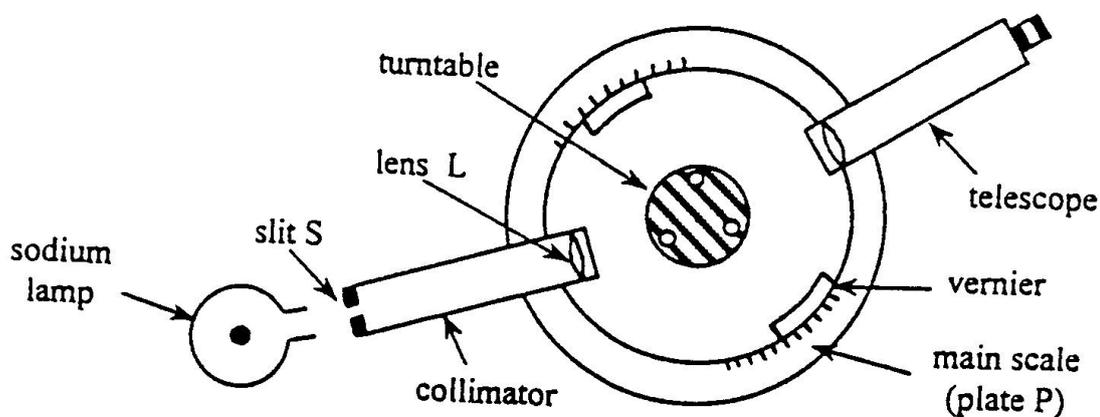


Figure 6-2: Essential components of a spectrometer

A circular horizontal plate  $P$ , which carries the main scale graduated in degrees, is mounted on a vertical column that also carries the telescope.

The collimator consists of a tube carrying a slit  $S$  of adjustable width and so mounted that it can be placed at the focal point of lens  $L$ . With  $S$  at the focal point of  $L$ , it is possible to regard slit  $S$  as an infinitely distant line-source of light because waves (light rays) that originate at  $S$  become plane waves (parallel rays) after passing through lens  $L$ .

### To determine the angle of diffraction

To determine the angle between the zero order and  $n^{\text{th}}$  order spectral lines, the difference between the “telescope left” reading and the “telescope right” reading in each spectral orders is calculated and that angle,  $2\theta_n$ , as shown in Figure 6-3, is halved to give  $\theta_n$ .

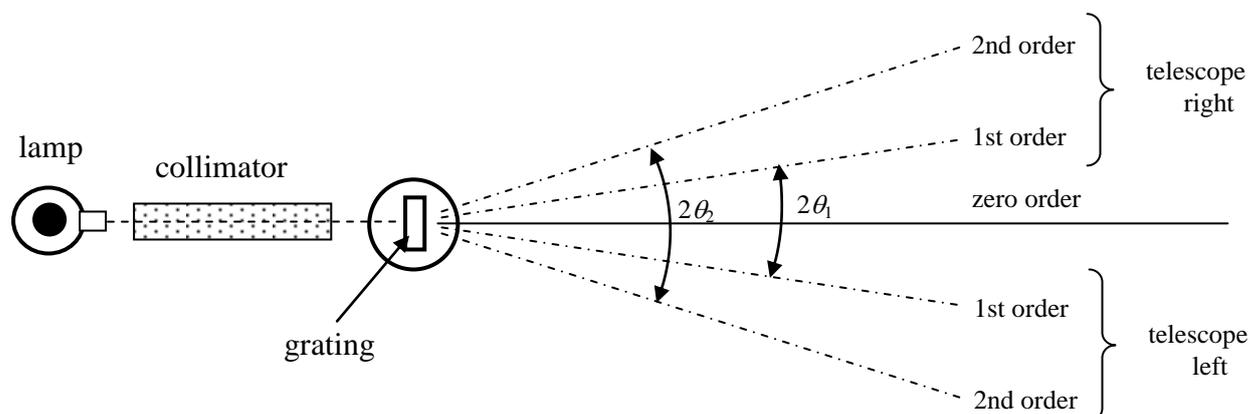


Figure 6-3: Method for obtaining the angle  $2\theta_n$

### Reading the Vernier scale

You can read the Vernier scale on either side of the turntable and because you will need to find angles relative to one another, it does not matter from which side you choose to take the readings; do whatever is most convenient.

Use the magnifying glass on the torch supplied to you to practice reading the scale by setting the apparatus to some random position and then getting everyone in the group to take the reading and see if you all agree.

Remember that angles can be divided into smaller units in the same way that time can be divided, i.e.,

$$1 \text{ hour} = 60 \text{ minutes; and } 1 \text{ minute} = 60 \text{ seconds.}$$

Just so,  $1 \text{ arc degree} = 60 \text{ arc minutes; and } 1 \text{ arc minute} = 60 \text{ arc seconds.}$

To read the Vernier scale one must first establish the smallest unit of the divisions of the main scale and then note that this is the same number of divisions on the Vernier scale.

If the smallest division on the main scale is 0.5 degrees, i.e., 30 arc minutes, then the Vernier scale will have a full scale of 30 arc minutes.

A video on how to read the Vernier scale will be shown in the laboratory and demonstrators are on hand to show you how to do it.

## 6.4 Method

### Diffraction grating

Obtain a diffraction grating from a demonstrator and record its number in your lab book.

Indicated on the diffraction grating is the number of lines per mm or lines per inch on the grating. Use this to calculate the spacing  $d$  between lines and quote this distance in metres.

Remember, 1 inch = 2.540 cm.

### Adjust the cross wires in the eyepiece and the telescope focus

With the spectrometer in normal lighting (on one of the laboratory benches), loosen the 'main scale and the telescope' setscrew and rotate the telescope so that you can look past the collimator at an object on the far side of the laboratory.

Now push and/or pull (or screw as the case may be), the eyepiece in and out until the cross wires in the telescope become visible and sharp.

Next, without changing the eyepiece setting, turn the telescope focus adjustment, which is on the side of the telescope, until you have focussed on the object at the far end of the laboratory. You should see the distant object in the cross wires clearly.

Do not change these settings for the duration of this experiment.

### Adjust the slit width and collimator focus

Still in normal lighting, align the telescope with the collimator and set the slit of the collimator to a width of about 0.5 mm. Check that the slit is vertical.

When you look through the telescope you will probably see a blurred bright line instead of a clear image of the slit. **Do not re-focus the telescope**, but adjust the draw tube of the collimator until the image of the slit can be seen clearly.

To achieve greater accuracy, make the collimator slit as narrow as possible while still remaining clearly visible.

The cross wires should be arranged at about  $45^\circ$  with respect to the slit, rather than parallel and perpendicular to it, and when taking readings the cross should be on the fixed side of the image of the slit, as shown in Figure 6-4.

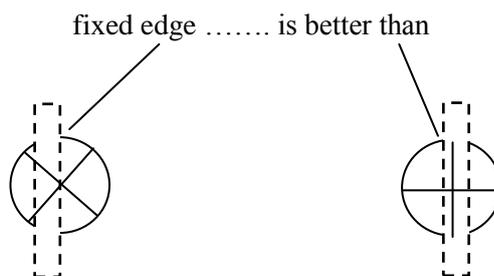


Figure 6-4: Alignment of cross wires

The slit is now set at the focal point of the lens and so the collimator now produces a beam of parallel light rays that go into the focussed telescope.

Adjust the Vernier position and the turntable position

Using the bottom set of adjustment screws, turn the ‘Vernier and turntable’ so that the sections of the Vernier scale that you can read are at right angles to the line of the collimator and telescope. This is done simply to make reading of the Vernier scale easier.

Take readings of the angles of diffraction

Direct the collimator slit at the sodium light source.

Set up the cowl provided to keep as much background light out as possible and place the grating in the centre of the turntable of the spectrometer so that it is perpendicular to the light beam from the collimator.

Look through the telescope - which should still be looking along the principle axis of the collimator - and you should see a bright yellow line, which is the zero order image produced by the grating

Record the position (reading on the Vernier scale) of this ‘zero order image’.

Loosen the clamping screw of the ‘main scale and the telescope’ and slowly rotate the telescope to the left or right until you see the first order spectrum.

Record the order in which you see the different colours, this will tell you which colour has deviated the least and which the most.

Record the angles at which you see the yellow, red, and green lines for the 1<sup>st</sup> and 2<sup>nd</sup> order on both the left and the right of the principle axis. You may also record the angles at which you see any other colours that may be of interest.

### **6.5 Calculate the wavelengths of spectral lines and identify the transitions**

Calculate the diffraction angles for the identified colours in the spectrum (as shown in Figure 6-3) and then use Eq. 6-2 to calculate the relevant wavelength of that colour.

Remember that  $d$  is the distance between the lines of the grating.

You do not need to evaluate the uncertainty in these measurements, but you do need to work with sufficient care to enable you to identify the transitions that you have observed on the energy level diagram of the sodium spectrum shown in Figure 6-1.

### **6.6 Conclusion**

State which spectral lines have been observed and identified. Comment on ways to improve the experiment.