Experiment # 1

Basics of Electricity

Introduction

This is an introductory laboratory session. No written report is required; but some quantitative measurements will be made and recorded in Data Tables.

Objectives of the Experiment

The purpose of this experiment is to introduce electricity and the necessary laboratory instruments. We shall talk about all the relevant topics, one by one, and familiarize ourselves with the instruments and their use in the laboratory.

Introduction to Electricity

Safety

One is afraid of working with *electricity* for fear of electrical hazards. Rest assured, the voltages and currents used, will be very much below the level of concern. We shall normally be using 5 volts or less. In one or two instances, the voltage may be as high as 20 volts. But such a voltage is still harmless and no precautionary measures will be required.

Electricity

Electricity is flow of electrons. Electrons are picked up from valence orbits of suitable atoms and *stored* in a *source* (such as a battery). These electrons possess high electrical potential energy. We may say that they are in a combat-ready state. When allowed to move out (switched on), electrons rush outward from the source and travel over a designated path (connecting wires). The path takes the electrons to some electrical device (such as a flashlight bulb). They do work in the device and return to the source, exhausted (i.e. in a state of zero electrical potential energy). The source reenergizes these electrons and sends them back to the device. This continues as long as the *circuit* remains switched on. All electrons always return to the source. No electron is ever lost! The complete arrangement is called an *electrical circuit*. The electrical circuit of a flashlight bulb is shown in Fig (1) on the next page.

Parameters of Electricity: (1) Voltage, V & (2) current, I

Electricity has two parameters: (i) Voltage (ii) Current.

(1) *Voltage* is the electrical potential energy of electrons per unit charge (joules per coulomb or J/C), at which they are stored in a given source. The unit is *volt.* We write V for it and the same represents it in an equation.

(2) *Current* represents the rate of flow of electrons in the circuit. The unit is *ampere* and we write A for it. It is a rather large unit and one often uses milliamperes (mA) or microamperes (μA). These are respectively 10^{-3} and 10^{-6} of an ampere. In an equation, current is represented by the letter I . Thus:

$$I = \Delta Q / \Delta t \quad \text{(A)} \qquad \text{..........(1)}$$

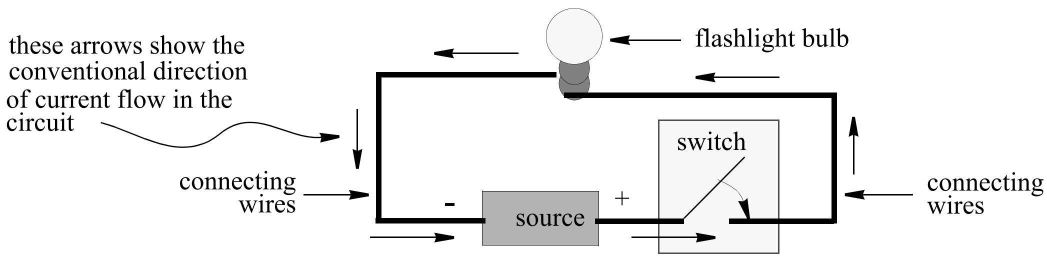


Fig (1) An Electrical Circuit

Sources of electricity have two terminals: one for electrons to travel outward (the negative terminal) and the other for them to return (the positive terminal). The terminology for conventional electricity, for some reasons, is opposite of the above. Conventional electricity travels outward from the positive terminal and returns via the negative terminal. This may seem unscientific but since the performance of a circuit is not affected by the direction of flow of current, we shall follow the crowd and use the conventional direction of flow of electricity.

Types of Electricity: DC & AC

A source of electricity can cause electrons to flow in two very different modes. These are: (a) unidirectional mode (b) bidirectional mode.

For unidirectional electricity, current flows in one direction only. Thus if we set up a hypothetical monitoring station somewhere along the circuit (as shown in Fig 2a) and monitor the electrons that pass by our field of view, we shall find that (1) they always flow in the same direction (2) their rate of flow remains constant at *all* times! A graph of *number of electrons vs. time* will yield a straight line parallel to the x-axis (the time axis). Such an electricity is called DC electricity where DC stands for *Direct Current* and such a graph is called a *waveform*.

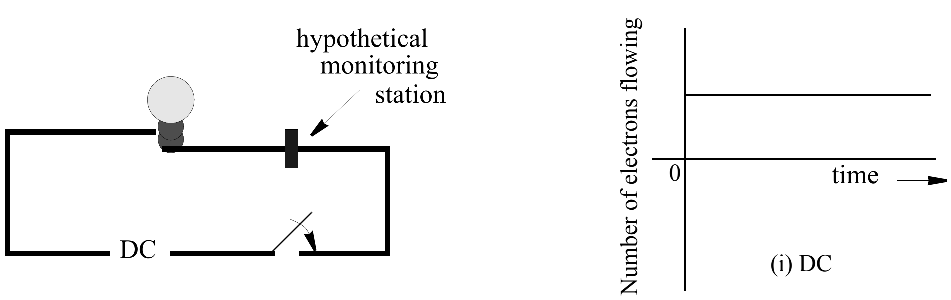


Fig (2a) A current Monitoring Station

In case of the bidirectional electricity, our observations at the hypothetical monitoring station will be somewhat as follows. At some instant of time, we shall find that no electrons are flowing, even though the circuit is *on*. A number of electrons will then be found to flow in one direction (say to the left). This number will grow from zero and acquire a maximum value. While still flowing to the left, the number will then begin to decrease and will become zero. The next thing we know is that electrons begin flowing in the opposite direction (i.e. to the right). The number grows from zero to maximum and then (while still flowing to the right) decreases down to zero. Electrons are then found to flow toward left and the story is repeated again and again. This is shown in Fig. (2b).

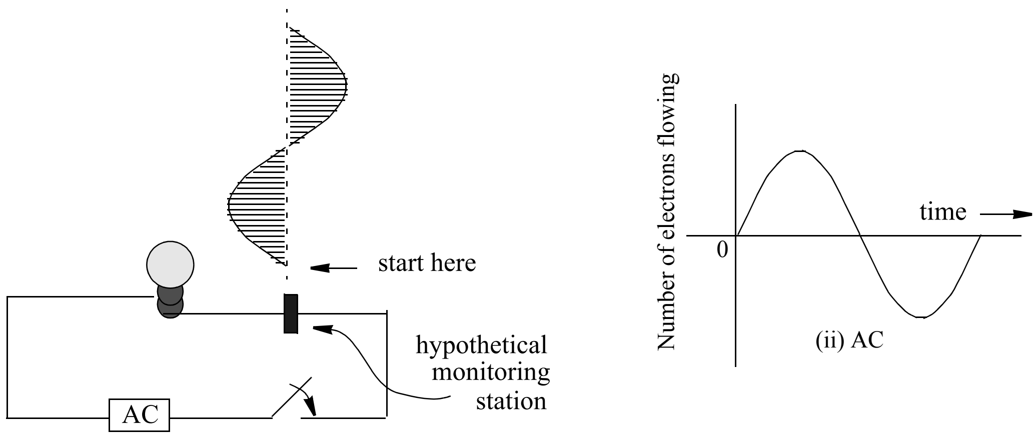


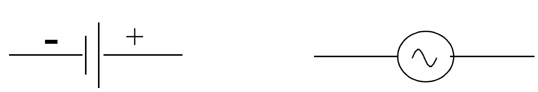
Fig (2b) A current Monitoring Station

One set of left-right motion of electrons is one *cycle*. The number of cycles that a source generates in one second is called its *frequency*, f. The MKS unit of frequency is *Hertz*. We write Hz for it. One Hz is *one cycle per second*. *Thousands of cycles per second* is represented by *kilo Hertz* or "kHz"; similarly, *millions of cycles per second* will be *Mega Hertz* or MHz. The time that a source takes to complete one cycle is called its *time period*, T. It is well known that $T = 1/f$ or that $f = 1/T$.

A graph of the intensity of flow i.e. *number of electrons flowing vs. time* is found to be a sine wave. The two directions of flow in a cycle are represented by the positive and negative halves of the sine waveform. Such an electricity is called *AC* electricity where *AC* stands for *Alternating Current*. Every source of AC electricity has a fixed frequency at which it operates.

It is interesting to note that the intensity of light, emitted by a light bulb operating on AC electricity will not be uniform. The household electricity is AC. Its frequency is 60 Hz. The intensity of light emitted from our table lamps is not uniform and the lamps do get switched off 120 times in each second.The rate at which intensity fluctuates, however, is much faster than the *persistence of vision* of our eyes. The result is that we are totally blind to these effects.

The electrical symbols for DC and AC sources of electricity are shown in Fig (3).



(a) A DC Source (b) An AC Source

Fig (3) Circuit Symbols for DC and AC Sources

Components of Electricity: R, C, & L

All materials and substances are divided into two groups, on the basis of their attitude (or policy) toward electricity. Substances with favorable attitudes conduct electricity and are called *conductors*. Substances with unfavorable attitudes do not conduct electricity and are called non-conductors or *insulators.*

A conductor allows electrons to flow through the body of the conductor thereby *conducting* electricity. But the flow is not smooth. Factors inside the conductor lead to a friction-like effect, known as electrical resistance. This resistance impedes the motion of electrons through the conductor and converts electrical energy into thermal energy. A good conductor will have relatively small resistance. Connecting wires are made of such conductors; their electrical resistances are negligibly small and are assumed to be zero.

Resistance of a conductor is a very useful property. It is made use of in electrical lighting and heating systems. A device based on the resistance of a conductor is called a *Resistor*. Resistance of a resistor depends on the shape and size of the conductor, and for a given shape and size, depends on the material of the conductor and hence varies from conductor to conductor. We write R for the resistance of a resistor. The unit is *ohm* and the symbol is Ω. An ohm is a rather small unit; we use larger units like kilo-ohms $k\Omega$ or mega-ohms $M\Omega$. These are respectively 10^{+3} and 10^{+6} ohms. The symbol of a resistor for a circuit diagram is shown in Fig (4a).

The electrical behavior of a resistor R, when connected to a source of voltage, V, is called its $V-I$ characteristics and is given by the *Ohm's Law*. The behavior is found to be independent of the type of electricity. Thus a resistor behaves identically in DC and AC circuits. Ohm's law states:

$$V = RI \qquad \text{..........(2)}$$

A resistance always causes loss of magnitude of electricity. Resistors are used to control the magnitudes of voltages and/or currents in different parts of circuits.

An insulator does not conduct electricity but its polar atoms and molecules get polarized when the insulator is suitably connected to a source of electricity. One of the ways in which this can be done, is to take a rectangular block of an insulator material and attach a pair of (thin) metal plates to one pair of (opposite) sides of the block. The metal plates are connected to a source of electricity. Such an arrangement is called a *parallel plate capacitor*, or just *capacitor.* A capacitor is said to have capacitance. The magnitude of capacitance depends on the shape and size of the insulator block; and for a given shape and size, the capacitance depends on the material of the insulator and hence varies from insulator to insulator. We write C for the capacitance of a capacitor. The unit is *farad* or F. A farad is a rather large unit; we use smaller units like microfarad (μF), nanofarad (nF) or picofarad (pF). These are respectively 10^{-6}, 10^{-9} and 10^{-12} of a farad. The symbol of a capacitor for a circuit diagram is shown in Fig (4b).

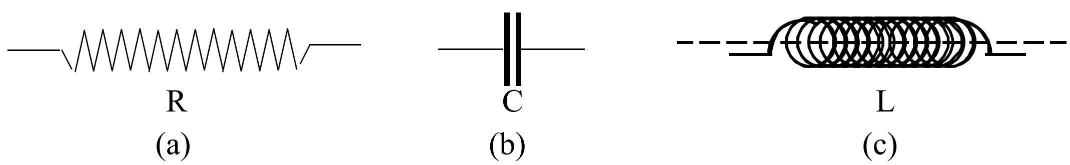


Fig (4) Electrical Circuit Symbols for (a) Resistor (b) Capacitor, and (c) Inductor

The electrical behavior of a capacitor, contrary to that of a resistor, is radically different for the two types of electricity. In a DC circuit, a capacitor stops the flow of electrons; as such no current flows in the circuit. The metallic plates end up accumulating some charge Q , the magnitude of which is given by the formula:

$$Q = CV \qquad \text{.........(3)}$$

In an AC circuit, the property of polarization leads to *pseudo conduction*. Current exists in all parts of the circuit including the connecting wires but there is no current flow *through* the insulator material itself. The capacitor is said to have *reactance*, *capacitive reactance* to be ex act. It is written as χ_C. It is found to have the units of resistance and is, therefore, expressed in ohms. The behavior of a capacitor in an AC circuit (its $V - I$ characteristics) is given by the following formula which is regarded as Ohm's law for capacitors in an AC circuit:

$$V_C = \chi_C I_C \qquad \text{.........(4)}$$

Here the subscript C refers to *capacitor.*

A conductor interacts with (affects or gets affected by) magnetic fields. Such an interaction does not take place in a DC circuit. In an AC circuit, however, things are quite different. An AC fed conductor, when *suitably* placed in a magnetic field, generates its own AC electricity with a polarity opposite to that of the original AC electricity. This interaction is called *Electromagnetic Induction*. The voltage generated in the conductor is usually less than the source voltage. This leads to a partial cancellation of voltages and the net voltage is less than the source voltage. This loss of the source voltage is analogous to that caused by a resistance. It should be pointed out however, that unlike resistance, electrical energy is *not* converted into thermal energy.

One way of getting such an effect is to take the conductor in the form of a wire and wrap it around a piece of tubular material, so as to make a coil. The tubular material itself may be hollow or solid and may even be removed after the coil is made. Such an arrangement is called an *inductor*. An inductor is said to have *inductance*. Sometimes an iron core is used to enhance or control the effect.The magnitude of inductance depends on the shape and size of the inductor.; and for a given inductor the inductance depends on the permeability, μ of the material *inside* the conductor and varies from material to material. We write L for inductance. The unit of inductance is *Henry* or H. It is also a rather large unit and we often use smaller units like millihenry (mH) or microhenry (μH) which are respectively $1\times10^{-3} H$ and $1\times10^{-6} H$. The symbol of an inductor for a circuit diagram is shown in Fig (4c).

The electromagnetic property, inductance, remains dormant (inactive) in a DC circuit. Since an inductor is basically a conductor, it will be found to have some resistance R, when placed in a DC or AC circuit. This resistance is sometime referred to as *ohmic* resistance and may be expressed as R_L. In an AC circuit, the property *inductance* acts as a resistance (as explained above). It is called AC resistance or (inductive) *reactance*: χ_L ; in ohms. Thus an inductor will have only one resistance (R_L), in a DC circuit and two resistances (R_L and χ_L) in an AC circuit. We define an ideal inductor as one that will not have any ohmic resistance R. The behavior of an ideal inductor in an AC circuit (its $V-I$characteristics) is given by the following formula (which may be regarded as Ohm's law for inductors in an AC circuit):

$$V_L = \chi_L I_L \qquad \text{.........(5)}$$

where the subscript L refers to "inductor".

To sum up:

There are only three passive components of electricity: R, C and L. These have been described at some length in this section and will be discussed in greater detail in forthcoming experiments. Each component has two terminals; one for the current to enter and the other for it to leave. These may be treated as the *left* and the *right hands* for passing electricity. A component may *receive* electricity from one hand (left or right) and *dispatch* it by the other. Either hand is good enough for receiving electricity or for dispatching it to the next component.

Important warning #1:

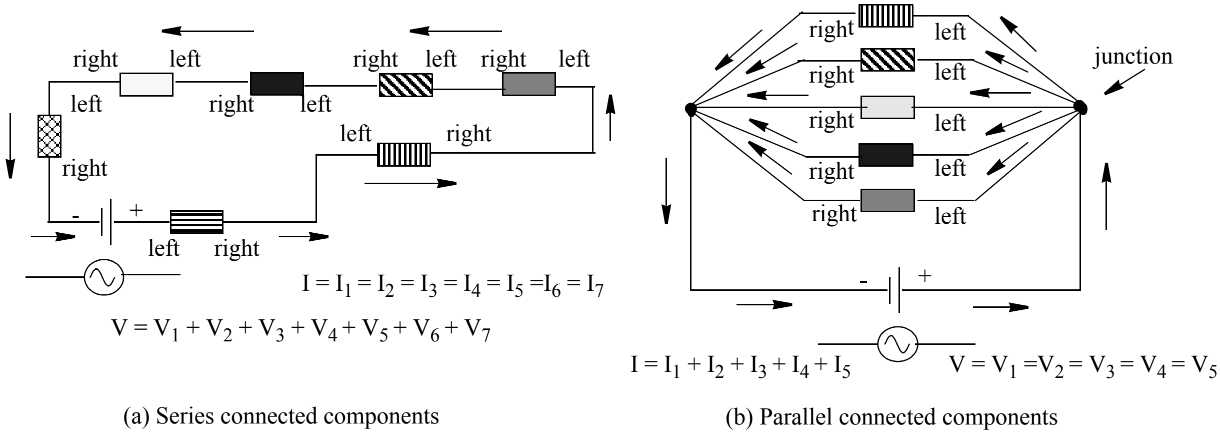
Some components in the laboratory may be found to have red and black terminals. This gives us a false impression that red is for receiving while black is passing it on. This is completely untrue! The black terminal is as good a receiving terminal as the red and vice versa. Similarly red and black connecting wires create the same false impression. Be careful.

Important warning #2:

Sources and meters (to be discussed later), on the other hand, have specific receiving and dispatching terminals. These are respectively the black and the red terminals. These must be used as such. Failure to use proper terminals may damage them or may result in incorrect data for the experiment.

Types of Electrical Circuits: Series & Parallel

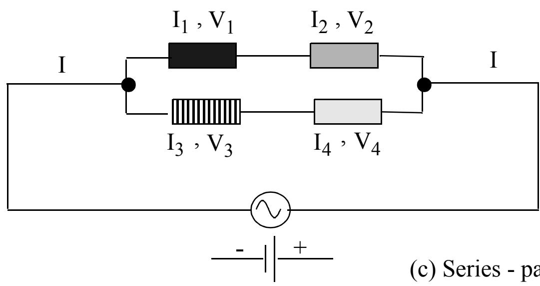
The components, described in the last section, may be connected together either in *series* or in p*arallel*. In a *series* arrangement, the components are connected successively, one after the other; like the links in a chain. Suppose electricity is being received by the front-most component by its left hand. Then its right hand will be connected to the left hand of the second component and the right hand of the second will be connected by the left hand of the third and so on. In a *parallel* arrangement, on the other hand, left hands of all components will be held together and to the source.All the right hands will also be held together in a similar manner.Electricity (electrical current) will be received by all components simultaneously and be dispatched by all of them simultaneously. Some sample arrangements are shown in Fig (5a). It is also possible to connect some components in series and combine it with others connected in parallel. Such an arrangement is called a *series-parallel* circuit. One such circuit is shown in Fig (5b).



(a) Series connected components (b) Parallel connected components

Fig (5a) Examples of Series and Parallel Circuits

It is very important to note and remember that all components connected in series, share a *common* current but each has its own characteristic voltage; the sum of all individual voltages equals the source voltage. Those connected together in parallel, share a *common* voltage but each has its own characteristic current; the sum of all individual currents equals the source current.



$$I_1 = I_2 \quad \text{and} \quad I_3 = I_4$$

$$I = I_1 + I_3 = I_2 + I_4 = I_1 + I_4 = I_2 + I_3$$

$$V = V_1 + V_2 \quad \text{and} \quad V = V_3 + V_4$$

(c) Series - parallel connected components

Fig (5b)An Example of a Series-Parallel Circuits

Meters: Voltmeter, Ammeter, Ohmmeter, & Multimeter

Measurements in electricity are limited to measuring the two parameters: voltage and current. The instrument that measures voltage is called a Voltmeter (as you would have guessed); the instrument that measures current is not called currentmeter (as you would have thought). It is called an Ammeter which stems from Ampere + meter. Because the property *resistance* of conductors is very important, a special meter called *Ohmmeter,* has been designed for its measurement. An ohmmeter measures only *ohmic* resistances and does not measure the AC resistances of capacitors and inductors

Modern technology has permitted the development of digital meters of very high quality. Most such meters combine all functions (measurements of voltages, currents and resistances) in one instrument. Such a meter is called a *Multimeter.* A multimeter, however, can be used to measure only one thing at one time. Thus if we need measure, both voltage and current in a circuit simultaneously, we will require two multimeters.

Following is the protocol for the use of *multimeters:*

(1) Do not switch on the meter yet.

(2) Is the meter to be used as a voltmeter or as an ammeter? Look for voltage/current selection. Correct selection must be made.

(3) Is the source voltage DC or AC? Look for DC/AC selection. Correct selection must be made.

(4) If the multimeter is to be used for voltage measurements, it *must be connected in parallel* with the component or the source. The *in* terminal of the voltmeter (red socket) must be connected to the *in* (receiving) terminal of the component or the *outward* terminal of the source. The *outward* terminal of a DC source is always the red socket. The *outward* terminal of an AC source is usually marked *live.* If no such marking is found, any terminal can be used as the *out* terminal. As for the component, one must *chase* the direction of flow of electricity in the circuit to locate the *in (receiving)* terminal. Fig (6) shows the *in* terminals of components in circuits. You must remember that when current comes *out* of a component (or device); it *does not* become negative. It is still positive and it will now enter another component (or device).

The *out* terminal of the voltmeter must be connected to the *out* terminal of the component or the *inward* terminal of the source. The *out* terminal of the voltmeter is always a black socket. The *inward* terminal of a DC source is also a black socket. The *inward* terminal of an AC source is usually marked *common* or *ground*. If no such marking is found, the un-used terminal will be used as the *inward* terminal.

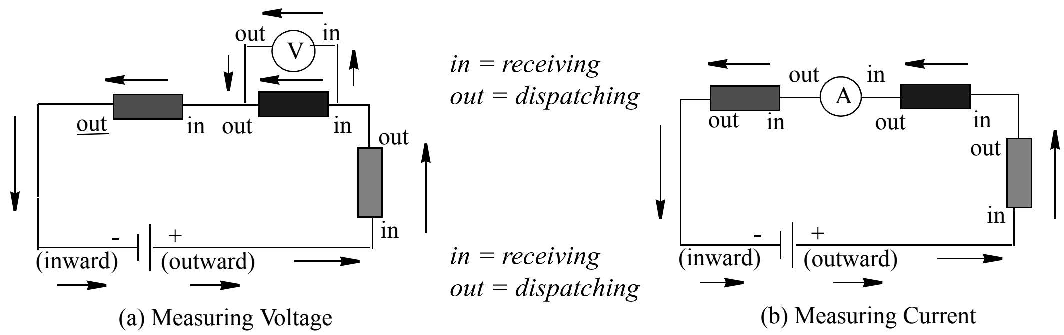


Fig (6a) Using Meters

(5) If the multimeter is to be used as an ammeter, it *must be connected in series* with the component. *Never attempt to measure the current of a source of electricity.* Such an act will burn the meter! In a multimeter, the *in* terminal of the ammeter is not the same as that of the voltmeter. You must look for the correct terminal of the multimeter for current measurements.

The *in* terminal of the meter must be connected to the *out* terminal of the component. The *out* terminal of an ammeter is always a black socket. It must be connected to the *in* terminal of the next component or to the *inward* terminal of the source (black socket). Remember the ammeter can be hooked up before or after the component whose current is to be measured. In fact it can be placed anywhere in a (series) string of components and batteries in between two junctions.

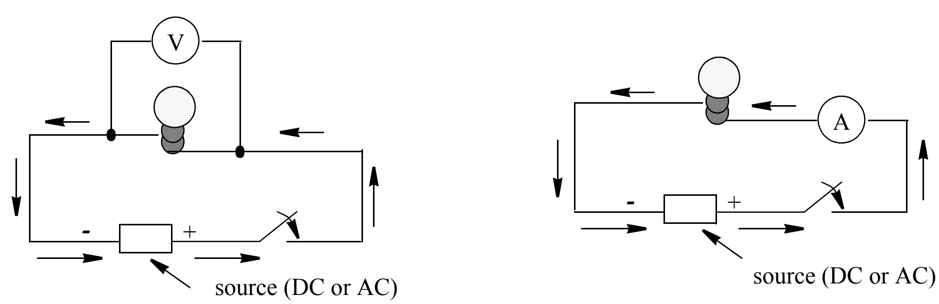


Fig (6b) Measuring the Voltage and Current for a Flashlight Bulb

(6) If the meter is to be used as an ohmmeter, the resistor must be taken **out** of the circuit. Select the appropriate range of resistance on the meter. There are no *in* or *out* rules for resistance measurements. Connect any one terminal of the meter to any one terminal of the resistor, followed by connecting the other terminal of the meter to the other terminal of the resistor.

(7) Select a suitable range of voltage or current or resistance on the meter. This will, in most cases, be given to you by the instructor.

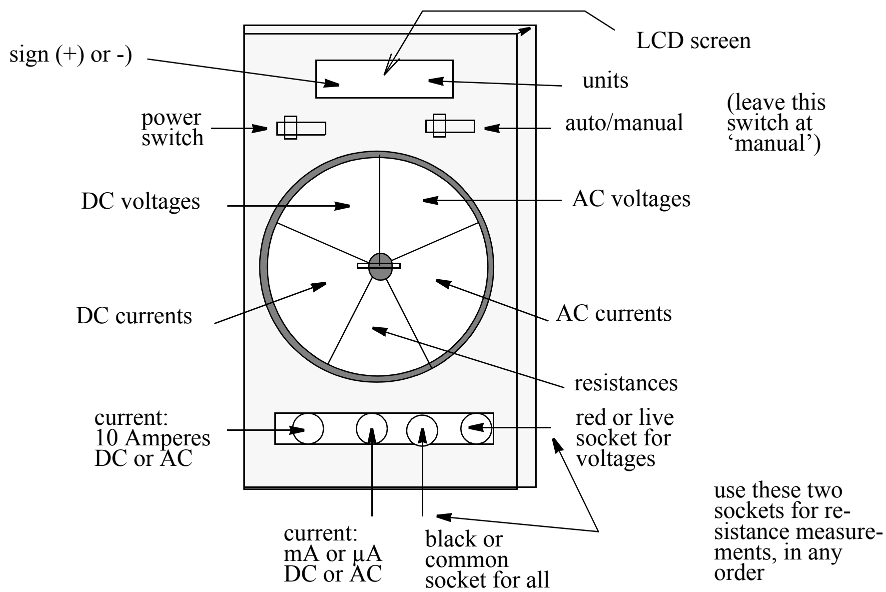


Fig (7) The Small Multimeter

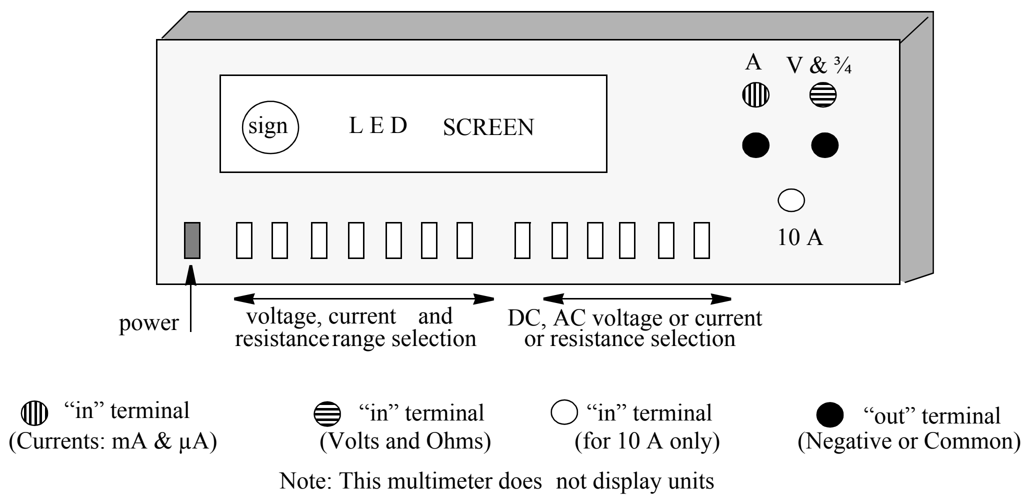


Fig (8) The Large Multimeter

(8) After the multimeter is set to: (1) correct type of electricity (DC or AC) (2) correct function (voltage, current or resistance) (3) correct range of values; you may switch on the meter and read and record the value shown on the screen. Record the sign (+ or -) of the voltage or current. Some meters also display the unit of voltage or current (as for example µA, k¾). This must be included in the recorded value.

Note: The meters shown in Figs: 7 & 8 were being used in the nineties. The one shown in Fig (7) has been replaced by a much improved version which is larger and wider and has a 4.5 digit display. We have 2 of the new ones for each table. The ones shown in Fig (8) are still in perfect condition but have been shelved because of the availability of a much superior multimeter.

The Function Generator & the Oscilloscope

The Function Generator.

The purpose of a function generator is to generate AC electricity at different frequencies. AC electricity may be of several different forms. The most common of these is the *sine wave* AC. It is this type of AC electricity that we use in homes and industries. Other types of AC waveforms are *square, rectangular (pulse), triangular, saw-tooth* etc. The function generator described here generates not only *sine-wave* AC but *rectangular (pulse)* and *triangular AC* electricity as well. These are used for scientific purposes and for digital electronics.

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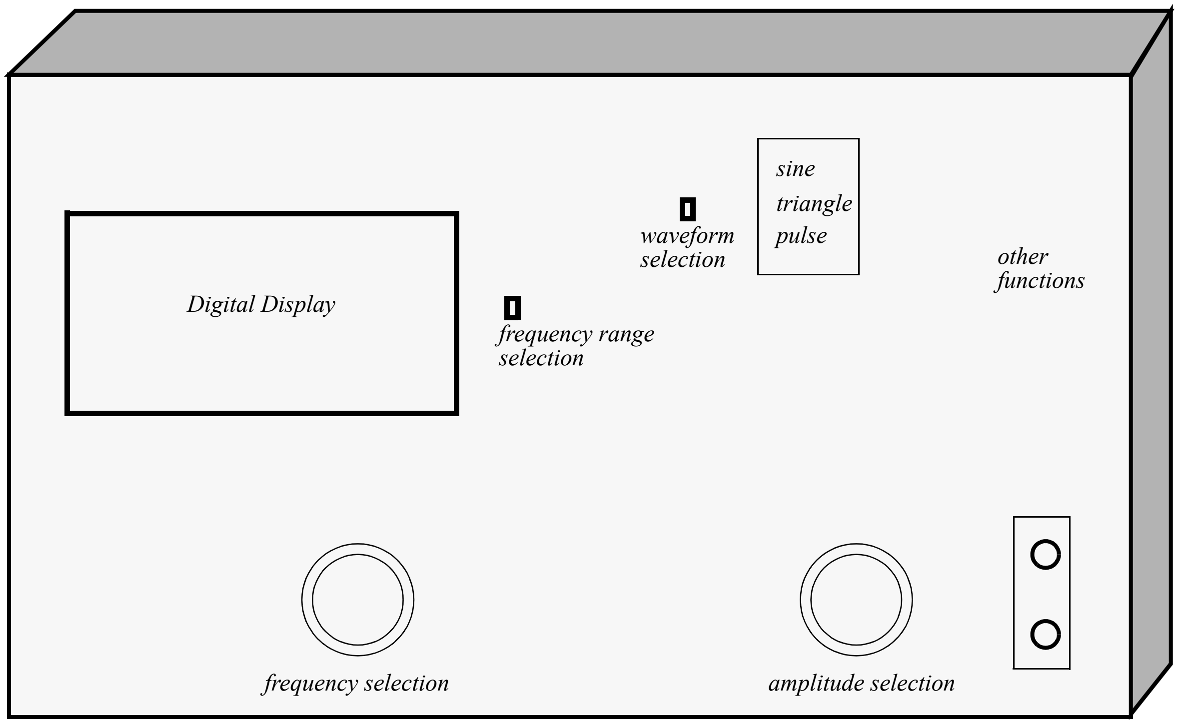


Fig (9) The Digital Function Generator

The essentials of the digital (state of the art) function generator are shown in Fig (9). The generator can generate AC electricity from $0.01\ Hz$ to $1\times10^5\ Hz$ (one Hz is one cycle per second); in three different waveform modes: the *sine wave* mode, the *triangular wave* mode and the *rectangular wave (pulse)* mode. The output is highly stabilized both, in amplitude and frequency. It comes with a built-in power amplifier and has a maximum output of 9 volts. Frequency is continuously variable through a single frequency-selection knob. The generator, however, does break up the range into 3 groups but that is for convenience only.

The function generator is used as a source of AC electricity. The *outward* terminal is the *live* (red) terminal while the *inward* terminal is the *common* (black) terminal.

The older models, used in the nineties, have been shelved. Those were of the analog type and one needed to check every frequency with the help of an oscilloscope. Advances in technology have led to the availability of accurate and precise digital generators, that we use now.

<u>*The Oscilloscope.*</u>

It is a device that plots graphs. The x-axis parameter is “time” while the y-axis parameter is “voltage”. Technically speaking one would define an oscilloscope as a “device that displays waveforms” graphically on a screen. This screen is a cathode ray tube. It has a grid that is 10 divisions long and 8 divisions wide. In the central horizontal and the central vertical lines, each division is further subdivided into 5 subdivisions. As one can easily read up to one-half of a subdivision, correct readings up to one-tenth of a division can be taken. The x-axis is “time” axis while the y-axis is “voltage” axis. A display is held on the screen in suspension by the process of synchronization. The oscilloscope is shown in Fig (10).

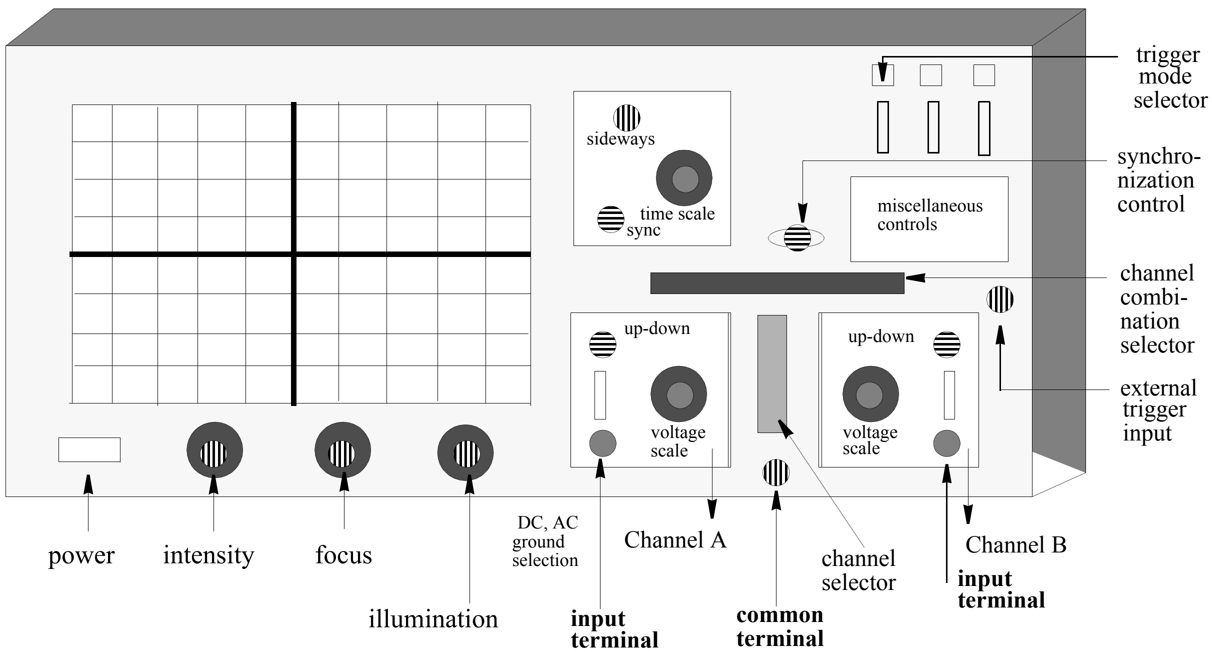


Fig (10) The Oscilloscope

The x-axis control is called “Time Base”. It is shown in the diagram as the upper box immediately to the right of the screen. It has three control knobs. We shall be using two of these controls and make sure that the third one is always in the switched-off position. One is the time control knob (center-right) to select the time scale for the x-axis and the other (top left) is the shift control knob to move the display (on the screen) sideways. The time control knob selects time on a circular scale which is calibrated in seconds, milliseconds and microseconds. The third control knob (bottom left) is for uncalibrated time. We shall always keep it switched off and shall always use the calibrated time.

The y-axis control is called “Vertical Amplifier”. It is shown in the diagram as the lower box immediately to the right of the screen. We shall use two of its controls. One is to select the voltage scale for the y-axis and the other is to shift the display up or down. The voltage control knob is a set of two concentric knobs. The outer knob selects voltage on a circular scale which is calibrated in volts and millivolts. The inner knob is for uncalibrated voltage. We shall always keep it switched off and shall always use the calibrated voltage. The oscilloscope shown, has two identical voltage amplifiers. This means that it is a two-channel oscilloscope; which, in turn, means that we can see two waveforms at one time. Because there is only one time base, the two waveforms may have different voltage scales but they must have the same time scale.

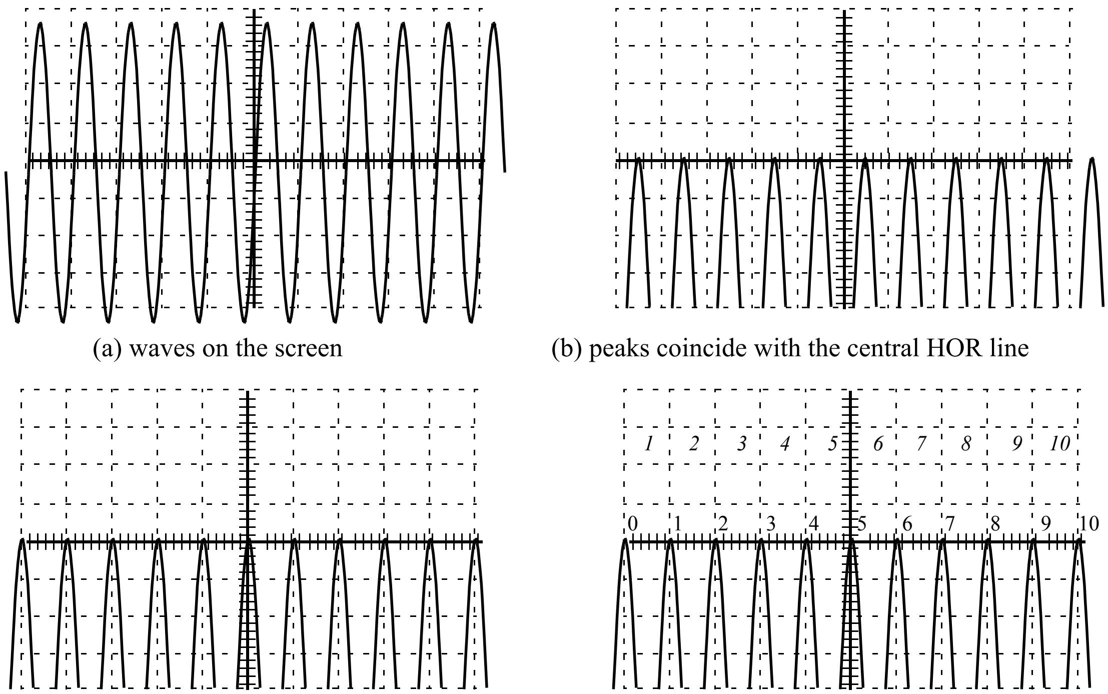
Even though an oscilloscope appears to be a complicated instrument, its use is not difficult at all. We shall use it for the following purposes: (1) peak-to-peak voltage measurement (2) measurement of the time period of a wave, and (3) measurement of the frequency of an Ac voltage.

To measure voltage amplitude:

1) select channel "A" and connect the oscilloscope *across* the component, just as you would connect a voltmeter.
2) Select any setting of the time base. It is un-important. In fact a time-base setting that would permit large number of waves on the screen is welcome.
3) Select a "volt /div" setting of the vertical amplifier that would allow largest display of waves. without going out of screen. Let this setting be called V.
4) Using the up-down control of the vertical amplifier, adjust the display such that the lower edge of display coincides with the lowest horizontal grid line.
5) Read the maximum *height* of the waves displayed along the central *vertical* line, estimated to one decimal pace; e.g. 7.7 divisions. Let the number of divisions be called d.
6) Multiply V by d. The product is the peak-to-peak voltage across the component.

To measure time period:

1) Select channel "A" and connect the oscilloscope to the source of AC supply of an unknown frequency in the manner you would connect a voltmeter to a source.
2) Select any convenient setting of the volt /div, on the voltage amplifier. The amplitude of the voltage is un-important.
3) Select a value of the time base setting such that the number of waves in the display is between 10 and 20; as shown in Fig (11a). Smaller number of waves will lead to larger error of reading while larger number will be difficult to count. These waves should cover more than 9 (but less than 10) divisions on the x-axis. Record the value of "time/div" in milli-second (mS) or "micro-second" (μS). Call it t.
4) To count the number horizontal divisions occupied by the waves, move the display down by using the up/down control of the vertical amplifier such that all the peaks lie on the central horizontal line; as shown in Fig (11b). This is because each division on this line is further sub-divided into 5 parts and one can read the number of divisions to one decimal place.
5) Next move the display sideways by using the sideways control knob of the time-base; such that the left-most peak coincides with the left-most vertical line; as shown in Fig (11c). We are now ready to count the number of waves. Count the number of peaks, starting with the left-most peak which will be counted as zeroth peak; as shown in Fig (11d). Let the number of peaks be n.
6) Determine the number of divisions occupied by the n waves, horizontally, to one decimal place. Call the number of divisions d.



(a) waves on the screen

(b) peaks coincide with the central HOR line

(c) left-most peak coincides with the left-most vertical line of the grid

(d) counting # of peaks "n" & the # of divisions "d" (10 peaks, 10 divisions in this diagram)

Fig (11) Determining the Time Period 'T' and the Frequency 'f'

7) The total time of n waves is the product of t and d.

8) Compute the time period T as:

$$T = \frac{t \times d}{n} \text{ sec} \qquad \text{..........(6)}$$

To determine frequency:

1) Carry out steps 1 through 6 of the previous section.

2) Compute frequency f as:

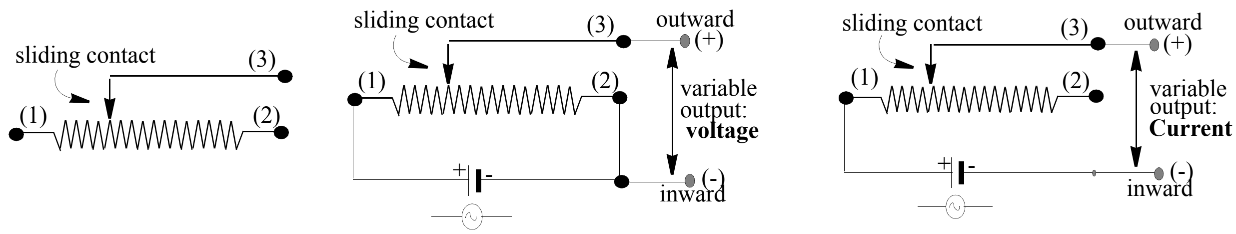
$$f = \frac{n}{t \times d} \text{ Hz} \qquad \text{..........(7)}$$

Voltage and Current Control Systems

The Voltage Divider Circuit.

The (output) voltage of a source is always fixed. One often needs smaller voltages for specific purposes. One example is a "dimmer" switch that we often use in our homes. Loudness, brightness and other control knobs in audio, video equipment also produce voltages smaller than the source voltage. A device that allows us to vary the source voltage is called a voltage control device or a "voltage divider". We shall need such a device in several experiments.

A simple way of setting up (assembling) a voltage divider circuit in the laboratory, is to use a "rheostat". A rheostat is basically a large resistor (in size, not in magnitude), made of resistance wire. It is wound over a ceramic former. The two ends of this wire are called terminals (1) and (2). A movable arm (called “sliding contact”) is provided. It slides over the said resistance wire, picks up the voltage (or current) at the contact point and delivers it at terminal (3). Such an arrangement (schematic) is shown in Fig (12a). Terminals (1) and (2) of the rheostat are connected respectively to the outward (“+” or live) and the inward (“-” or common) terminals of a (DC or AC) source. Terminals (3) and (2) are the new terminals of the voltage divider network; as shown in Fig (12b).The output voltage is continuously variable from minimum (zero) to maximum (source voltage). When the sliding contact is near terminal (1), resistance is minimum and the output voltage is maximum; when it is near terminal (2), the resistance is maximum and the output voltage is minimum.



(a) A Rheostat, Schematic **(b) A Voltage Divider Network** **(c) A Current Divider Network**

Fig (12) Rheostat and Voltage & Current Divider Networks

The Current Divider Circuit.

A current divider circuit allows one to draw continuously variable current in the manner a voltage divider permits one to draw continuously variable voltage. A current divider is also a rheostat based network. It is, in fact identical to a voltage divider network except that the terminal (2) of the rheostat is not connected to the inward (“-” or common) terminal of the source. In fact, terminal (2) is not used at all. A current divider circuit is shown in Fig (12c).

One should be familiar with these simple networks and be able to set up one of these whenever needed for an experiment.

Resistance & Capacitance Substitution Boxes

In an experiment one may need to use several different resistances or several different capacitances. It would be quite bothersome to disconnect one and connect another, several times in an experiment. Resistance and Capacitance Substitution Boxes are designed to facilitate quick and simple replacements (substitution) of resistances and capacitances.

One type of a resistance box is shown in Fig (13a). It has 4 x 7 = 28 switches. All switches are shown in the “off” position. A required resistance value may be engaged (brought in the circuit) simply by switching on the switches that together add up to the desired value. The “off” and “on” positions are also shown in the same diagram. This resistance box permits the selection of a resistance value anywhere from one ohm to ten million ohms.

One type of a capacitance box is shown in Fig (13b). It has 4 x 5 = 20 switches, similar to those used in the resistance box. One can engage the required capacitance value by switching on the switches that together will add up to the desired value. The range of capacitance values that may be selected here is from 100 pF to 10 μF.

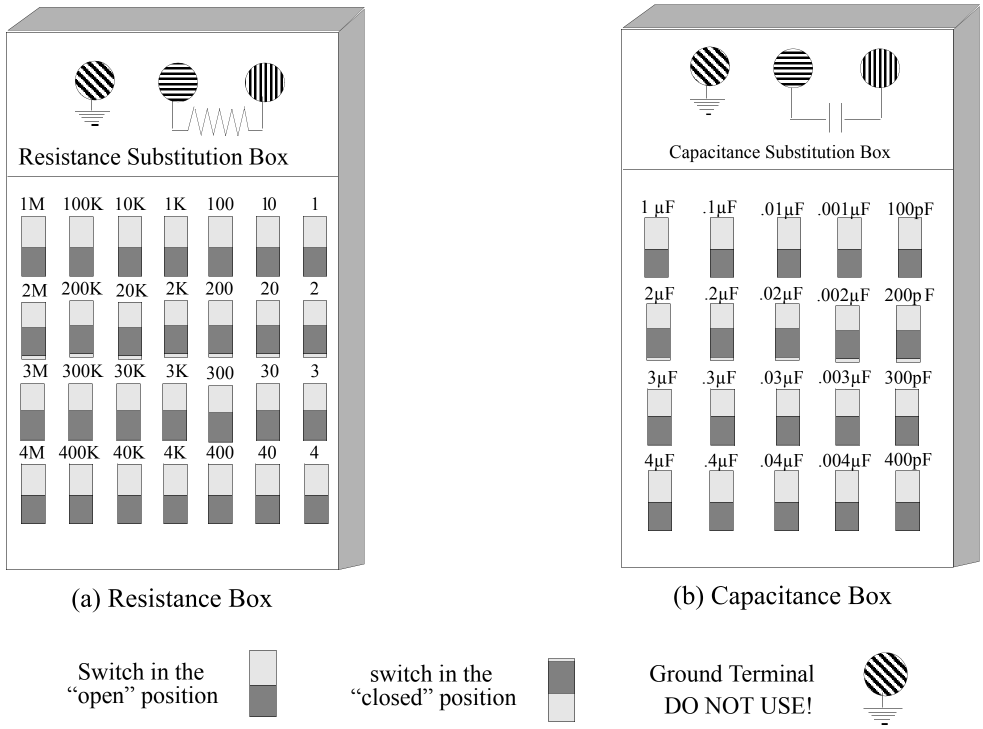


Fig (13) Resistance and Capacitance Substitution Boxes

The "ground" terminal should not be used. It is designed to save the outer metallic box from becoming an electrical hazard. In view of the voltages and currents to be used in experiments in this course, the use of this terminal is entirely un-necessary. Of the other two terminals, any one will serve as the "in" terminal for the electricity to enter; the other will automatically become the "out" terminal.

Things To Do

(1) Switch on the oscilloscope and familiarize yourself with the "intensity", "focus" and the "screen illumination" control knobs. Also see the "time base" and the "vertical amplifier" sections and the relevant control knobs in each section. Make sure that the "variable time" and the "variable volt" knobs are turned off. To switch these off, these should be turned clockwise gently until a faint "click" is heard.

(2) Connect a flashlight bulb to a DC source. Connect an oscilloscope and a voltmeter (set to 20 V, DC) across the bulb. Study the waveform of the DC supply and determine its voltage using the vertical amplifier of the oscilloscope. Read the voltage shown on the voltmeter. Compare the two voltages.

(3) Connect the flashlight bulb to an AC source. Set the voltmeter to 20 V, AC. Repeat step (2) above. An AC voltmeter reads RMS voltages while the oscilloscope shows peak-to-peak voltage. Check if your data verifies:

$$V_{p-p} = (2\sqrt{2})(V_{rms})$$

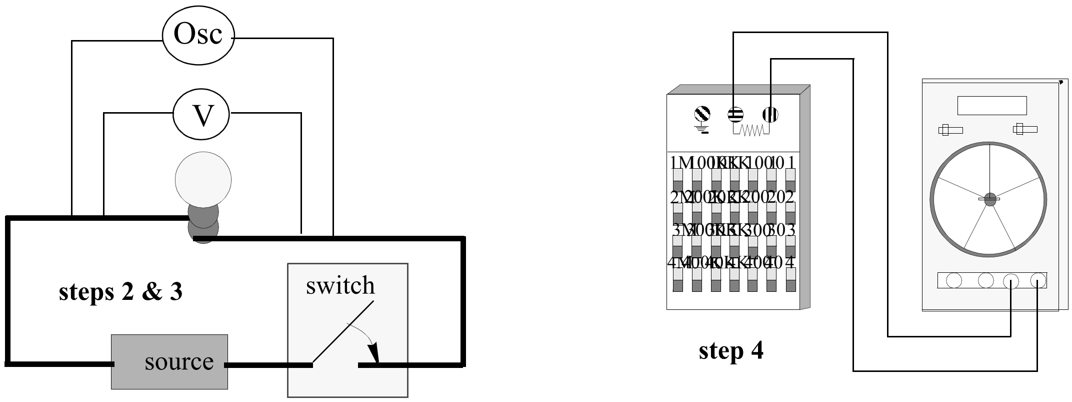


Fig (14) Step #s (2), (3) and (4)

(4) Set the following 10 resistance values on a resistance box: 110 Ω, 250 Ω, 1100 Ω, 2500 Ω, 15 $k\Omega$, 68 $k\Omega$, 270 $k\Omega$, 560 $k\Omega$, 1.2 $M\Omega$ and 10.875 $M\Omega$. Measure the value of each resistance using the small multimeter as ohmmeter. Set the ohmmeter to a suitable range for each measurement. Compare the measured values with the selected ones and write your remarks.

(5) Set up a voltage divider circuit and connect the flashlight bulb to it. Connect a voltmeter (small multimeter: set to 20 V, DC) in parallel and an ammeter (large multimeter: set to 100 mA, DC), in series. Set the sliding contact of the rheostat to 10 different positions (selected arbitrarily, covering the full range of sliding). For each position read and record the voltage and current values and enter in your data sheet. Comment on: (1) the range through which the voltage changed (2) the range through which the current changed (3) the intensity variation of the flashlight bulb.

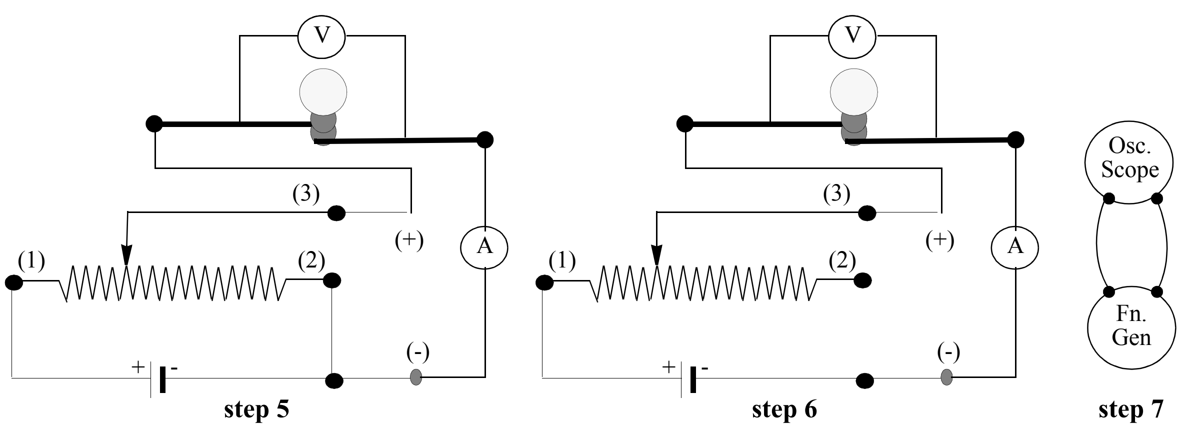


Fig (15) Steps (5), (6) and (7)

(6) Set up a current divider circuit and repeat step (5).

(7) Connect the output of the function generator to the oscilloscope. Set the function generator to 20 kHz of some convenient amplitude. Measure this frequency on the oscilloscope. Compare the selected and the measured values of the frequency and comment on the calibration of the function generator.

Data & Data Tables

Name.................................... **Date**..............................

Instructor.............................. **Lab Section**....................

Partner.......................... **Table #**..........................

(A) DC and AC Sources; using a flashlight bulb.

Draw a circuit diagram here:

Table 1: DC and AC Sources of Electricity

Type of supply	Vertical Amplifier setting: V/Div	Number of divisions on y-axis	Voltage across the bulb (volts)		Waveform as seen on the oscilloscope (arbitrary scale)
	V	d	$V \times d$	voltmeter	
DC					volts / time
AC				$V_{RMS} =$	volts / time
			$(2\sqrt{2})V_{rms} =$ $V_{p-p} = (2\sqrt{2})V_{rms}$		

(B) Measuring Resistances; using an ohmmeter.

Draw a circuit diagram here:

Table 2: Using Ohmmeter

Resistance Box Setting: R_{box} ($\Omega / k\Omega / M\Omega$)	Ohmmeter set to: (Range) ($\Omega / k\Omega / M\Omega$)	Ohmmeter Reading: R_{meter} ($\Omega / k\Omega / M\Omega$)	Difference Between R_{box} and R_{meter} (negligible / appreciable)
110 Ω	200 Ω		
250 Ω	2000 Ω		
1100 Ω	2000 Ω		
2500 Ω	20 $k\Omega$		
15 $k\Omega$	20 $k\Omega$		
68 $k\Omega$	200 $k\Omega$		
270 $k\Omega$	2000 $k\Omega$		
560 $k\Omega$	2000 $k\Omega$		
1.2 $M\Omega$	20 $M\Omega$		
10.875 $M\Omega$	20 $M\Omega$		

(C) Controlling Voltages and Currents; using a rheostat.

Draw a circuit diagram here for voltage control circuit:

Draw a circuit diagram here for current control circuit:

Table 3: Voltage & Current Control Circuits

Voltage Control Circuit			Current Control Circuit		
Arbitrary Position of the Sliding Contact #	Voltage **Across** the Flashlight Bulb (volts)	Current through the Flashlight Bulb (A or mA)	Arbitrary Position of the Sliding Contact #	Voltage **Across** the Flashlight Bulb (volts)	Current through the Flashlight Bulb (A or mA)
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		

(D) Measuring Frequency; using an oscilloscope.

Draw a circuit diagram here:

(a) Range selection push button on the
function generator set to 10 kHz

(b) The dial on the function generator set to: 2.0

(c) The Time Base of the oscilloscope set to: $t =$ 0.1 mS.

(d) Number of peaks counted: $n =$

(e) Number of HOR scale divisions counted to: $d =$

(f) Frequency: $n / (t \text{ x } d) =$

(g) Percent deviation from the value set on the
function generator: %