

NORTHWESTERN UNIVERSITY TECHNOLOGICAL INSTITUTE

ECE 270

Experiment #2
**DC ELECTRICAL MEASUREMENTS
PRELAB**

1. Using an 65mV, 5mA d'Arsonval meter, design an ammeter with a full-scale current reading of 50mA. Show a schematic of this ammeter and specify all resistor values.
2. Using an 50mV, 5mA d'Arsonval meter to make an ohmmeter as shown in Figure 6, what percentage of full-scale deflection would occur if an unknown resistance $R_x = 5.6k\Omega$ is measured. Let $E = 1.5V$.

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INTRODUCTION

An important consideration in the measurement of any quantity is the error introduced from the loading of the measuring instrument upon the applied system. This section of the laboratory deals with the operating basis and the proper use of ammeters, voltmeters and ohmmeters. An ammeter is placed in series with the current to be measured and will ideally have zero internal impedance. Alternatively, a voltmeter is placed in parallel to the circuit and should have a large input impedance (ideally infinite).

CURRENT MEASUREMENTS

The most common design for current measuring instruments is the d'Arsonval meter whose operation is based upon a Lorentz Force deflecting a pointer along a scale. A permanent magnet produces a magnetic field and the unknown current is passed perpendicular to it through a coil with a pointer attached, as shown in Figure 1.

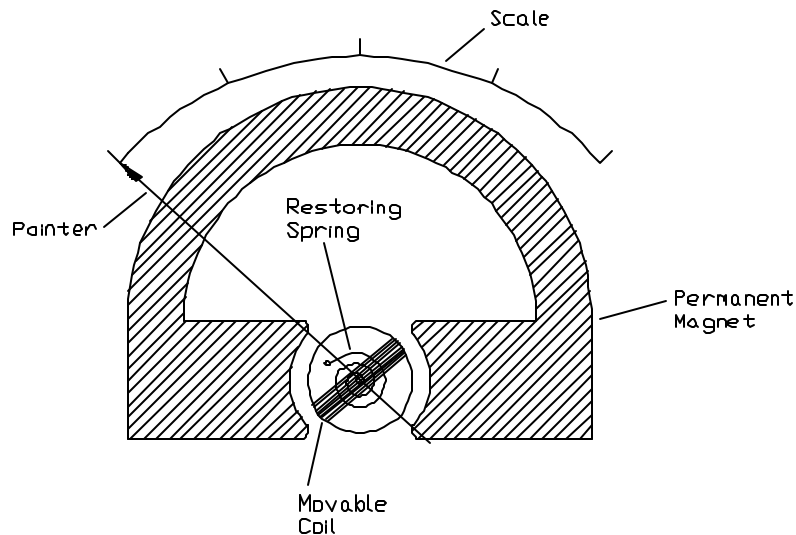


Figure 1

A force on each length, l , of the conductor is impressed upon the coil ($F = qv \times B = IlB$) and a mechanical torque directly proportional to the current I is exerted to the pointer. Equating the torque to the force exerted to the coil by the springs (with spring constant K), the amount of meter deflection is given by:

$$\theta = \frac{nAB}{K} I$$

A = Area of the coil
 n = number of turns of the coil

An ideal d'Arsonval meter would have no resistance, however real meters have a resistance R_m which is due to the coil. A more accurate representation of the meter then consists of an ideal meter with a series resistance R_m . In many cases, a d'Arsonval meter will have specified limits such as: 50mV, 1mA meter. In this case $R_m = 50\Omega$ and a voltage of 50mV across the meter or a current of 1mA through it would cause full-scale deflection.

Figure 2 shows a circuit which may be used to change the current required for full-scale deflection of the d'Arsonval meter to increase the useful range of the meter.

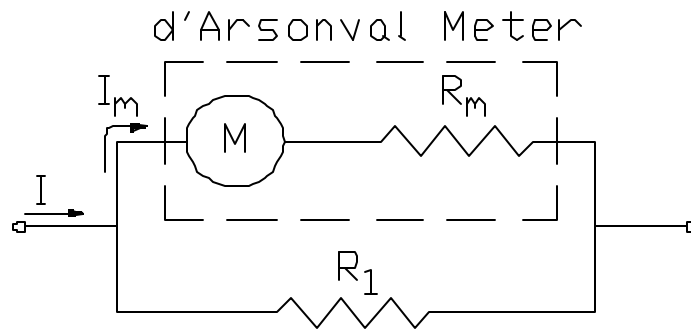


Figure 2

The metered value of current is I_m and simple circuit analysis reveals the current to be determined is:

$$I = I_m \left(1 + \frac{R_m}{R_1} \right)$$

Note that the equivalent resistance of the ammeter (including this shunt resistance R_1) is now $(R_m \parallel R_1)$ or:

$$R'_m = \frac{R_m R_1}{R_m + R_1}$$

If the ammeter shown in Figure 2 is used to measure the current in a circuit having a total resistance of R , then unless $R'_m \ll R$, the ammeter of Figure 2 will load the circuit and the current indicated by the ammeter is much less than the true current. However, if both these resistances are known, corrections can be made to obtain the true current.

VOLTAGE MEASUREMENTS

One circuit configuration for voltage measurement is shown in Figure 3. Since the deflection of the d'Arsonval meter is also proportional to voltage $V_m = R_m I_m$, placement of a resistance R_s in series with the ammeter results in a measured voltage $V = I_m(R_m + R_1)$. Commonly the sensitivity of a voltmeter is specified in terms of the ratio of its internal resistance, $R_m + R_1$, to the full-scale voltage in units of ohms per volt.

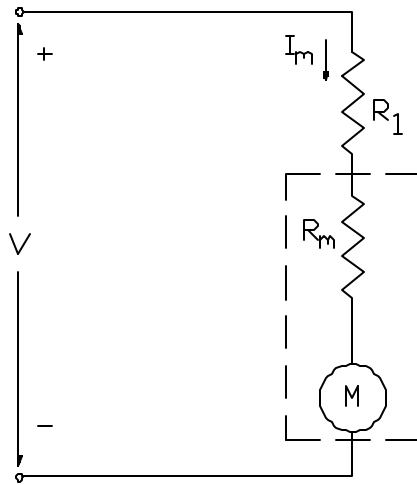
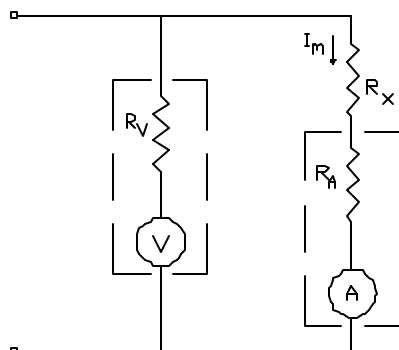


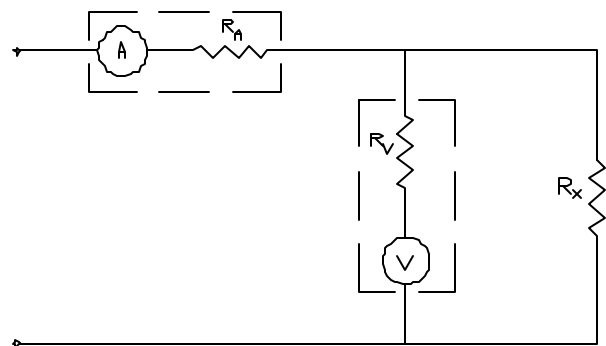
Figure 3

RESISTANCE MEASUREMENTS

Resistance measurement of an element in a "live" circuit may be attained by simultaneously measuring voltage and current and then applying Ohm's law. Two arrangements for this are shown in Figure 4.



(a)



(b)

Figure 4

Using Kirchoff's laws, the unknown resistance R in Figure 4a is:

$$R = \frac{V}{A} - R_A$$

and in Figure 4b:

$$R = \frac{V}{A} \frac{1}{1 - \frac{V}{A} \left[\frac{1}{R_V} \right]}$$

Thus the first circuit is most useful when $R_A \gg R$ and the second circuit when $R_V \gg R$. Where R_A and R_V are for the ammeter and voltmeter configurations and are analogous to R_m and $(R_m + R_1)$ respectively.

Normally the element to be measured is not "live" and the resistance measurement requires the use of an external battery within the voltmeter. This is true of any commercial ohmmeter and consequently applying the leads to a live circuit element can cause damage to the meter. A typical ohmmeter circuit is shown in Figure 5. The variable resistance R_1 adjusts the meter reading to full-scale when the test leads are first shorted together. This is usually called 'zero ohms' on the instrument and the above procedure compensates for changes in battery voltage. With the test leads connected to the unknown resistance R, the use of Ohm's law around the current loop yields the above relation between it and the measured current on the ammeter:

$$I = \frac{I_{FS}}{1 + \frac{R}{R_T}}$$

where R_S is the battery's source resistance and $R_T = (R_S + R_1 // R_m)$ is the total series resistance of the ohmmeter. Thus the ohms scale will be nonlinear with a zero reading indicating an open circuit, or infinite ohms.

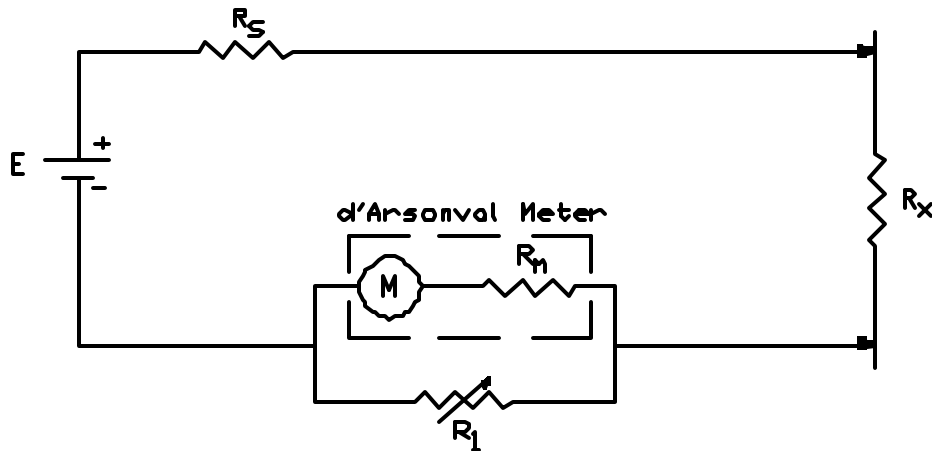


Figure 5

Finally, note that the above procedures for current and voltage measurements are valid only for direct current analysis. More sophisticated circuitry is necessary for alternating current measurements.

PROCEDURE:

(1) Each lab group is supplied with a milliammeter, whose internal resistance will be given, and a commercial VOM. Before using the milliammeter, the mechanical zero must be set by turning the screw located beneath the scale. This adjustment varies the tension in the suspension spring controlling the meter movement. Using the voltage supply set at 2.0 volt, place the ammeter in series with the following resistors and record the measured current:

2k Ω
1k Ω
680 Ω
560 Ω
430 Ω

Next use the VOM to measure the actual resistance for each of the resistors above. Calculate what the current through each resistor should be using its actual resistance and a supply of 2.0 volts. Compare the currents measured with the milliammeter to those calculated from the actual resistance values. Determine the accuracy of the milliammeter from the above data assuming an accuracy of 1% for the VOM. Observe that the internal resistance of the milliammeter is much less than the series resistance R of the circuit, thus adding negligible error to the current readings.

(2) Design a voltmeter with a full-scale reading of 10V. Calculate the sensitivity of the meter in ohms per volt. Connect this voltmeter directly across the output terminals of the voltage supply and place the VOM to serve as a voltmeter in parallel with this. **WARNING: BE SURE THE VOM IS READING DC VOLTS BEFORE ATTACHING TO THE CIRCUIT.** Again determine the error between the VOM readings and your voltmeter as determined from $V = I_m(R_m + R_s)$. How does the accuracy of the milliammeter and the voltmeter constructed from it compare. Explain.

(3) Construct the ohmmeter of Figure 6 and measure five unknown resistances ' R_x ' ranging from 1k Ω to 10k Ω . A battery and a variable resistor will be supplied and an appropriate voltmeter must be constructed. Check the resistance values with your ohmmeter and the VOM and note whether the resistors are within their tolerances specified by the color codes upon them. Finally, observe that the accuracy of the ohmmeters depends upon the tolerance of R_1 and the accuracy of the milliammeter within the circuit.

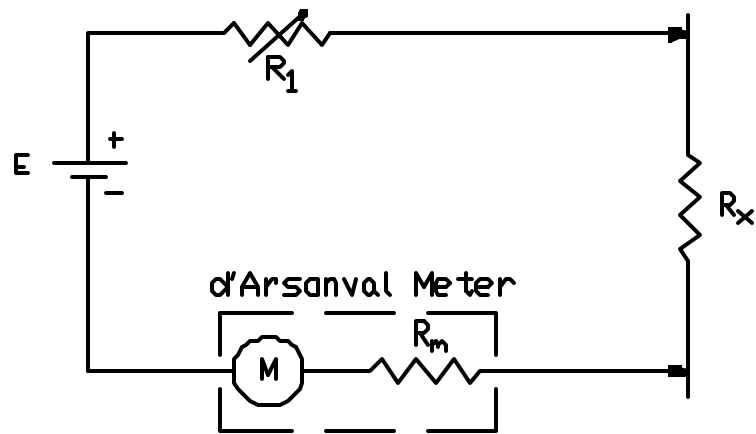


Figure 6

where:

R_x = unknown resistance

R_1 = variable resistance adjusted for full-scale reading of the meter when the probes are shorted together

R_m = internal resistance of the meter

I_1 = current reading with the probes shorted together

I_2 = current reading with the unknown resistor (R_x) connected

DIGITAL MULTIMETER

VOLTAGE MEASUREMENTS

The digital voltmeter measures voltage by sampling the voltage several times and calculating the average value of the samples. By sampling we mean, at regular intervals the voltage is measured for only an instant of time. The value of this single measurement is then stored in memory. This process is repeated N number of times over a specified period of time. The average value of these N measurements is then calculated and displayed on the meter. Each individual measurement is referred to as a sample. N can range from just a few samples to several thousand samples depending upon the accuracy of the meter.

It may seem odd that the meter takes so many samples and then displays their average value. Why not display the value of each individual measurement? There are three primary reasons for not doing this:

1. noise on the measured signal
2. variations in the measuring device
3. constantly changing measurements

The first two factors above affect the accuracy of the measurement. The time function of a DC voltage signal is shown in Figure 7. V_0 is a real constant.

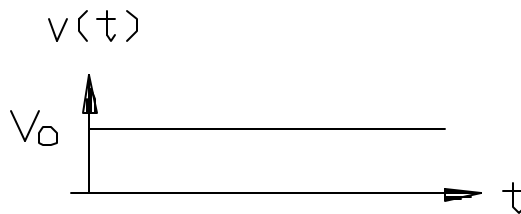


Figure 7

However, in physical systems the actual waveform would appear as shown in Figure 8.

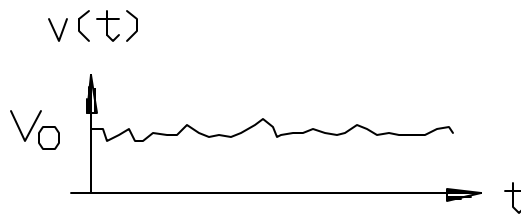


Figure 8

The slight variations of the signal around V_0 are due to noise added to the signal. Noise is an undesired voltage signal which gets added to the desired signal. The noise can come from a variety of sources including thermal noise generated by the device being measured and voltages caused by electromagnetic waves present in the area where the measurement is being taken.

Variations in the measuring device can also occur. The nature of the electronics that make up the meter actually causes very small, but random variations in the result of each sample. These variations result in small errors in the measurements.

In averaging the measurements it is assumed that the average error over time is zero. For example, suppose the following waveform is measured using a digital voltmeter, and the samples are taken as shown.

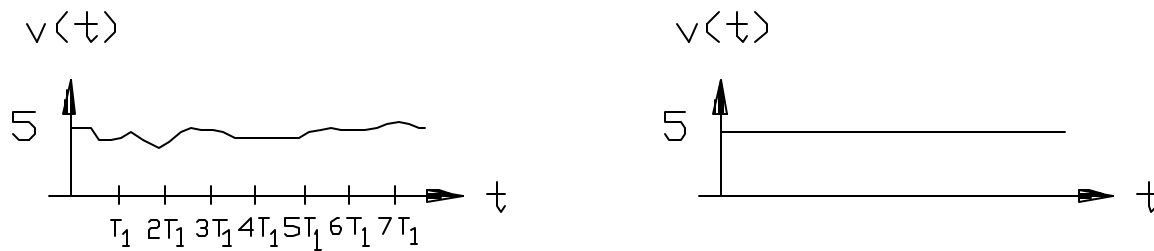


Figure 9

$V(T_1) = 4.95 \text{ V}$	$V(5T_1) = 4.90 \text{ V}$
$V(2T_1) = 4.87 \text{ V}$	$V(6T_1) = 5.05 \text{ V}$
$V(3T_1) = 5.10 \text{ V}$	$V(7T_1) = 5.20 \text{ V}$
$V(4T_1) = 4.95 \text{ V}$	

$$\text{Average} = 5.003 \text{ V (5.00 V)}$$

5.00 V would be displayed on the meter. Note that none of the samples equaled 5.00 V. Therefore, the accuracy of measuring the desired signal has been improved.

The third reason for averaging is to improve the readability of the meter. If the readout changed with every sample it would be difficult to read. Also, the user would not know which measurement to accept as the correct result.

Concerning loading, the digital voltmeter has two advantages over the analog meter. First, the loading does not change with the voltage range. It is constant. The second is that the input resistance is much higher ($10\text{M}\Omega$) than in the analog meter. This resistance is high enough so that the loading effect can be ignored for many practical circuits.

CURRENT MEASUREMENT

The digital meter measures current by internally converting the measured current to a directly proportional voltage. This voltage is measured as above. The current is then calculated from the measured voltage and displayed.

To measure the current in a branch of a circuit, that branch has to be opened, or broken. The meter is then inserted into the break in the circuit to close the circuit again. See the example in Figure 10 to measure the current through R_2 .

The ammeter is represented by the boxed portion of Figure 10b. Note that it has an internal resistance R_i . R_i reduces the current in R_2 . The ammeter does read the actual current in R_2 with R_i present. When R_i is known, the current that would be flowing in R_2 if R_i were not present can be calculated. For the Fluke 75 and 77 meters, R_2 is about 5.

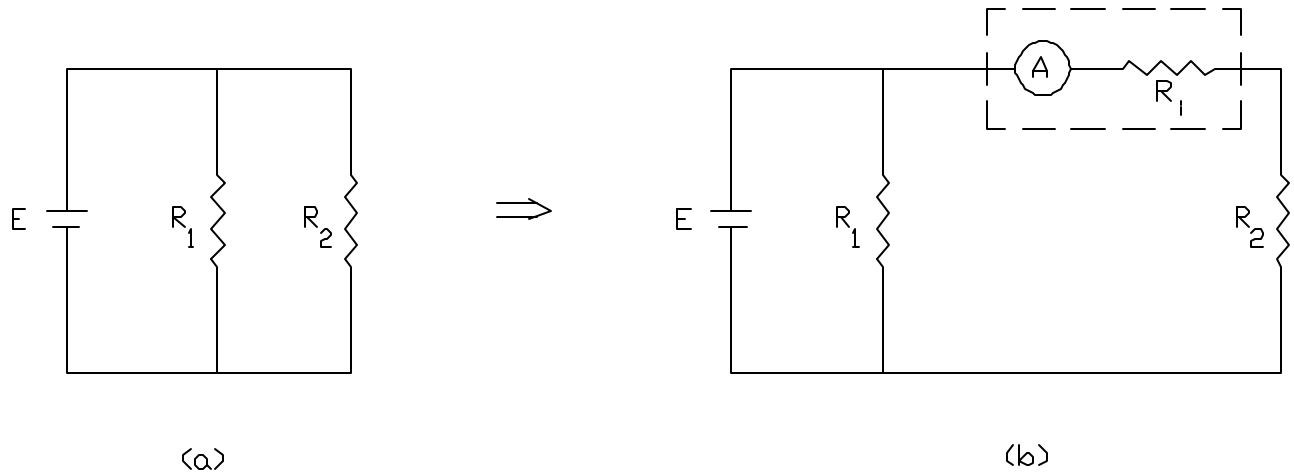


Figure 10

RESISTANCE MEASUREMENTS

The digital meter makes resistance measurements by placing a voltage source (battery) in series with the resistance to be measured and an internal resistor (See Figure 11).

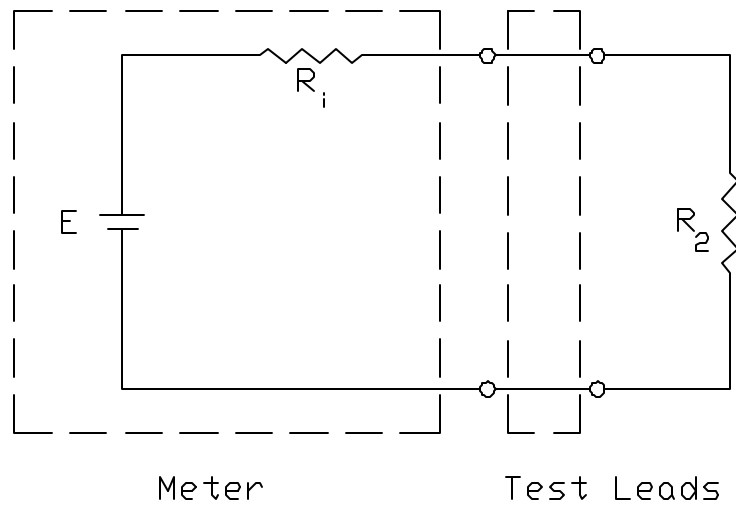


Figure 11

The voltage across R_i is:

$$V_i = E \frac{R_i}{R_i + R_2}$$

Therefore,

$$R_2 = R_i \left[\frac{E}{V_i} - 1 \right]$$

Since R_i and E are known internally to the meter, R_2 is measured by measuring V_i as above and then calculating R_2 using the formula. The calculated value is then displayed on the meter.