

Lab 2: DC Measurements

OBJECTIVES

- Understand the galvanometer and its limitations.
- Use circuit laws to build a suitable ammeter and voltmeter from the galvanometer.
- Understand the loading effect meters have on a circuit.

MATERIALS

- The lab assignment (this document).
- Your lab parts.
- Pre-lab questions including Multisim.
- Decade resistor box.
- Read section 3.5 in the textbook.

INTRODUCTION

The moving coil *galvanometer* (also known as a d'Arsonval meter) shown in Fig. 1, contains a pivoted coil of fine wire through which a current passes. The magnetic interaction between the magnetic field set up by this current and the magnetic field of a permanent magnet housed in the meter casing results in movement of the coil against a hair-spring (torsion spring). The resulting displacement is shown by the meter needle against a scale.

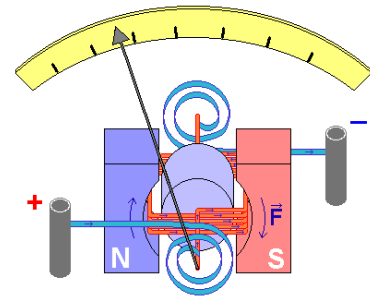


Figure 1 – D'Arsonval galvanometer (from Wikipedia).

The current that causes *full-scale deflection* (needle deflects to the maximum extent of the meter) is labeled on the galvanometer. Meter movements are usually rated by current and resistance. For our meters, this full-scale current is 1.0 mA and the meter resistance is approximately 50 Ω .

The current through the meter is proportional to the deflection. If the meter deflects 40% of the full-scale (or to 0.4 on the meter), the measured current is value of 40% of 1.0 mA, i.e., 0.4 mA. The galvanometer also has an internal resistance. If the resistance is known, the galvanometer can be used to measure voltage by utilizing Ohm's law. The full-scale voltage is found by multiplying the full-scale current by the meter resistance. If the full-scale voltage is 10 mV and the needle deflects to 0.2, the measured voltage is 2 mV.

Ammeter

The galvanometer, by itself, is not a very effective ammeter because its range is small (the full-scale current is only 1.0 mA). It also has a relatively high meter resistance, which changes the circuit it is measuring. Both problems can be mitigated with a *shunt resistor*. The shunt is a small resistor placed in parallel with the galvanometer. Because its resistance is much lower than that of the galvanometer, most current passes through the shunt and we don't overshoot the full-scale current of the galvanometer. (Going beyond the full-scale value of the galvanometer may damage the device.)

An improved ammeter that can be made with the galvanometer and a shunt resistor as shown in Fig. 2. The current to be measured is I . We design the ammeter by choosing the desired current range and then

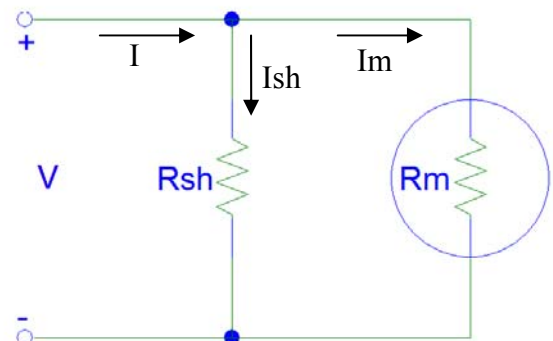


Figure 2 – Ammeter made from galvanometer and shunt resistor.

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determining which shunt resistance is necessary to achieve this maximum I . The development of the equation for the ammeter relies on the following two equations:

$$I = I_m + I_{sh} \qquad V = R_m I_m = R_{sh} I_{sh}$$

The first equation is an application of KCL. The second equation comes from the fact that the voltage across parallel elements is the same. The maximum current we can measure, I , occurs when the meter current, I_m , is full-scale.

$$R_m I_{m(fs)} = R_{sh} I_{sh} = R_{sh} (I - I_{m(fs)})$$

Solving for the shunt resistance:

$$R_{sh} = \frac{R_m I_{m(fs)}}{I - I_{m(fs)}} = \frac{R_m}{\frac{I}{I_{m(fs)}} - 1}$$

This equation is the ammeter equation, which provides the necessary shunt resistance for a meter of range I . The full-scale current is known to be 1.0 mA, but the galvanometer resistance must be measured.

For example, suppose a 0.1 mA, 20 Ω galvanometer is to be converted to an ammeter with a range of 0 to 10 mA. Here, $I = 10$ mA, $I_{m(fs)} = 0.1$ mA, and $R_m = 20$ Ω . The value of R_{sh} is calculated as follows:

$$R_{sh} = \frac{20 \Omega}{\frac{10 \text{ mA}}{0.1 \text{ mA}} - 1} = 0.202 \Omega$$

Voltmeter

The galvanometer, by itself, is not also not a very effective voltmeter because its resistance is too low to approximate the infinite resistance of an ideal voltmeter. The small range is also inhibitive. We can make a better voltmeter by adding a large resistance in series with the galvanometer. This resistor is called a *multiplier resistor*. The voltmeter constructed from the galvanometer and a multiplier resistor is shown in Fig. 3. Using Ohm's law results in the following equation:

$$V = I_m (R_{mult} + R_m)$$

Since the voltmeter is a series circuit, the current that passes through it is limited to the full-scale galvanometer current. We extend this range by increasing the resistance. Solving for the multiplier resistance and substituting the full-scale current, we get an equation for the maximum voltage that can be obtained.

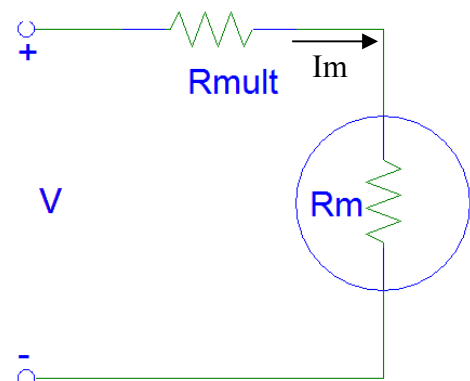


Figure 3 – Voltmeter made from galvanometer and multiplier resistor.

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$$R_{mult} = \frac{V}{I_{m(fs)}} - R_m$$

This is the voltmeter equation. It provides the multiplier resistance necessary to create a voltmeter capable of measuring up to a voltage V . As with the ammeter, the galvanometer resistance, R_m , needs to be determined.

To measure a voltage, the terminals of the circuit in Fig. 3 may be connected in parallel with the element to be measured, just as we would with the digital multimeter. The deflection of the needle corresponds to a fraction of the full-scale value, $V = I_m R_m$.

Ohmmeter

The ohmmeter shown in the below figure is **not** a precision instrument, but it is useful for the rapid measurement of resistance. It consists of a meter, a series resistor, and a series dc voltage source, as shown in Fig. 4. The unknown resistor (R_x) to be measured is connected to the ohmmeter circuit as shown. The series resistance R_s is chosen such that when terminals a and b are short-circuited ($R_x = 0$), the meter deflects full-scale. When these terminals are open-circuited ($R_x = \infty$), the meter shows no deflection. Therefore, a finite nonzero value of R_x will give a fraction of full-scale deflection. Thus, the meter scale can be calibrated to “read” the resistance R_x . A small variable resistor R_v is included in the ohmmeter circuit to permit zeroing of the ohmmeter when the a and b terminals are short-circuited. Due to aging of the battery and an increase in its internal resistance, the voltage available at its terminals decreases with time and is offset by reducing the resistance R_v . Because the meter deflection is proportional to the coil current I ,

$$deflection \propto I = \frac{V_s}{R_x + (R_s + R_v + R_m)},$$

where \propto indicates “is proportional to.”

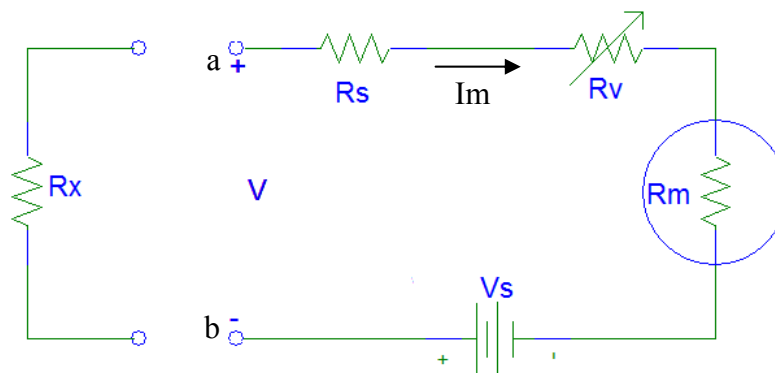


Figure 4 – Imprecise ohmmeter made from galvanometer, series resistor, variable resistor, and a dc voltage source.

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PRE-LAB AND QUESTIONS

1. If the galvanometer has a resistance of $2\text{ k}\Omega$, what shunt resistor would we need to build an ammeter capable of measuring up to 25 mA ? For this problem, assume the full-scale galvanometer current, $I_{m(fs)} = 1.0\text{ mA}$.
2. What is the total ammeter resistance for the above problem?
3. Using the same galvanometer, what multiplier resistance would we need to build a voltmeter with voltmeter resistance of $50\text{ k}\Omega$?
4. What is the range of this voltmeter?
5. Build the circuit of Fig. 5 in Multisim. Measure the three branch currents using the Multisim multimeter with ammeter resistance set to $1\text{ n}\Omega$, and then with the meter resistance equal to your result from part 2. Email the screen capture to your TA **BEFORE** your lab.
6. Based on the information from part 5, what would the galvanometer read when measuring the current in R_3 ? (Hint: the ratio of the current through R_3 to the ammeter max current of 25 mA is equal to the ratio of the galvanometer current to galvanometer full-scale current of 1 mA)

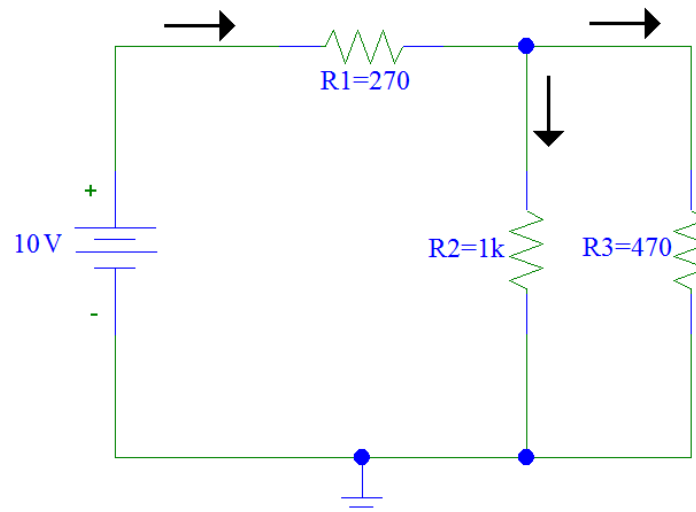


Figure 5 – Circuit for prelab questions 5 and 6. Three branch currents are shown.

LAB PROCEDURE AND QUESTIONS

Measuring Galvanometer Resistance

- In order to design an ammeter or voltmeter from the galvanometer, we must first know its resistance. This will be achieved by substituting current and voltage measurements of the galvanometer into Ohm's law.
- Our measurement will be less prone to errors if the voltage and current that we use are large because the precision of the multimeter is limited. A shunt resistor is again useful here, because we can feed a large current without damaging the galvanometer.
- Build the circuit in Fig. 6. This is the circuit that will be used to determine galvanometer resistance.

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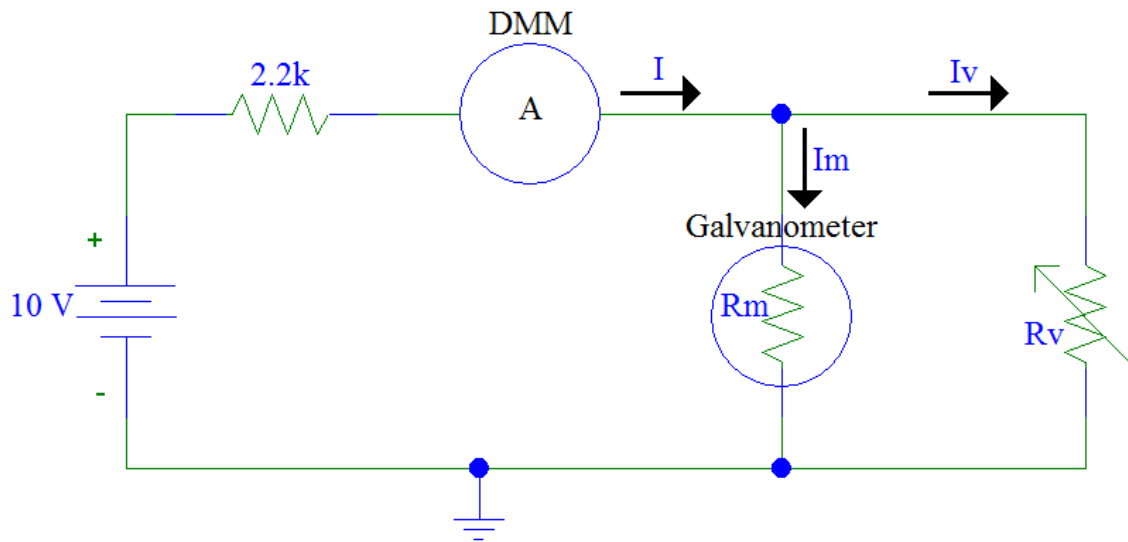


Figure 6: Galvanometer resistance measuring circuit.

- The voltage across R_m and R_v is the same because they are in parallel. We can derive an equation for meter resistance:

$$V = R_m I_m = R_v I_v$$

$$R_m = \frac{R_v I_v}{I_m} = \frac{R_v (I - I_m)}{I_m}$$

- The resistor R_v is a variable resistor. We will use the decade resistor box. Begin with R_v at 0. Slowly increase the resistor until the galvanometer reads exactly 1.0 mA (full-scale deflection). Note this value. CAUTION: Do not overshoot full-scale deflection by increasing R_v too quickly.
- We can now solve for meter resistance. R_v is the value set on the decade resistance box, I is the current measured by the DMM ammeter (labeled A in Fig. 6), and I_m is the full-scale galvanometer current 1.0 mA.
- After disconnecting your circuit from the galvanometer, use a DMM to measure the galvanometer resistance, R_m . Note this value.

Ammeter Constructions and Testing

- Design an ammeter having a range of 0-100 mA. Build the ammeter (circuit in Fig. 2), using the resistance box for R_{sh} .
- Build the circuit in Fig. 5 and measure all three branch currents with your constructed ammeter.
- Measure the branch currents with the DMM.
- Explain any differences between the two measurements.

Voltmeter Constructions and Testing

- Design a voltmeter having a range of 0-10 V. Build the voltmeter (circuit in Fig. 3), using the resistance box for R_{mult} .
- Build the circuit in Fig. 7. For $R = 330 \Omega$, 2.2 k Ω , and 18 k Ω , measure the voltage V_R with your constructed voltmeter.

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- Measure the voltage in these three cases with the DMM.
- Compute the percent error between the values obtained with your voltmeter and with the DMM. Explain the trend.

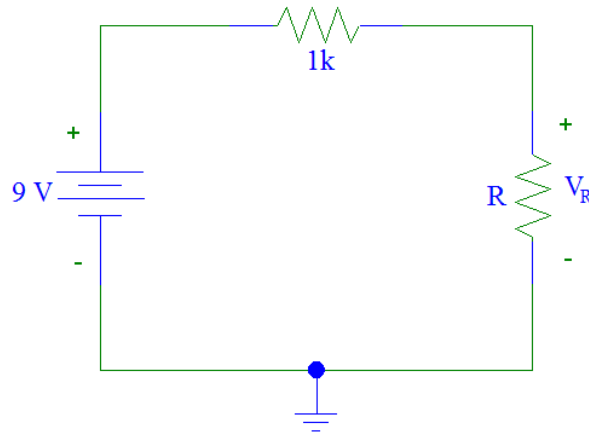


Figure 7 – Circuit for the voltmeter.