Experiment IV

Meters

Purpose

To determine the resistance of a galvanometer whose full-scale current is known. To use that information, and the proper additional resistance as calculated from Ohm's law to convert the galvanometer first to a 100 mA fullscale ammeter and then to a 5 V full-scale voltmeter.

Equipment

Galvanometer with a full scale reading of 500 µA (0.5 mA), 2 decade resistance boxes, a 40 **Ù** slide wire rheostat, resistance wire, standard ammeter and voltmeter, switch, wires and power supply.

Note: Bring linear graph paper.

Theory

A galvanometer is an instrument for detecting small currents. It consists essentially of a coil of fine wire mounted so that it can rotate in the field of a permanent magnet. When current flows through the coil, the resulting magnetic force on the coil windings creates a torque on the coil that makes it rotate until equilibrium is established between the torque on the coil and that exerted by a restoring spring. The angle of rotation of the coil thus will depend on the current flowing through coil and a needle attached to coil can be calibrated to give the current. (In many designs, the angle of rotation of the coil is linearly proportional to the current, but for the galvanometer used in this lab you will note that this is not quite the case.)

A typical analog ammeter consists of a sensitive galvanometer with a low resistance called a shunt connected in parallel with it. The shunt allows currents to flow through the ammeter that would otherwise burn out the galvanometer. The shunt also allows the ammeter to have a low resistance so that it will have a small effect on the circuit whose current is to be measured. (To use an ammeter the circuit must be broken and the ammeter inserted between the break.)

A typical analog voltmeter consists of a sensitive galvanometer connected in series with a resistance known as a multiplier. Since a voltmeter is placed in parallel with the voltage to be measured, it should have a high resistance so that it does not appreciably alter the circuit being measured.

The range or full-scale reading of an ammeter or voltmeter can be changed by changing the shunt or multiplier resistor. From a knowledge of the full-scale galvanometer current I_g, the galvanometer resistance R_g, and the desired range of the meter, the needed shunt or multiplier resistance can be easily calculated by means of Ohm's law.

Procedure

Part I Determination of R_g.

To determine the internal resistance, R_g, of the galvanometer you will use the half-scale method. Wire the circuit as in Figure 4.1 using decade boxes for R_p and R_e.

Set the decade resistance boxes to their highest value, then turn on the power supply and adjust to 4 V. With the switch S open, gradually reduce R_e until the galvanometer reads full-scale current I_g = 0.5 mA. Now close the switch and gradually reduce R_p until the galvanometer reads exactly one-half of full scale or $I_g/2$ = 0.25 mA. Record R_p and R_e.

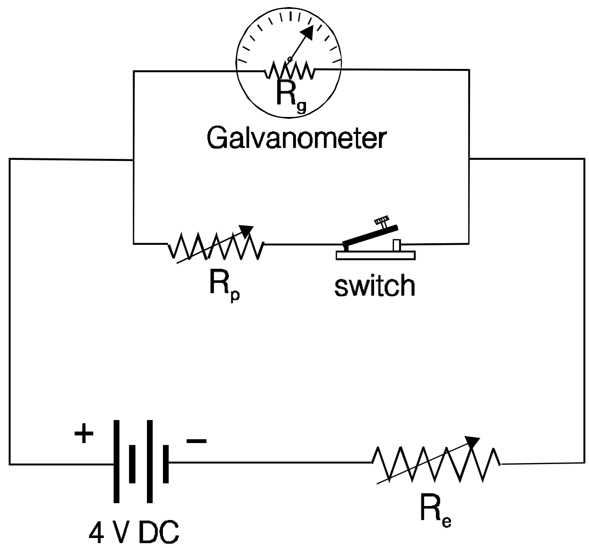


Figure 4.1 - Circuit to measure R_g.

Read the last page of this write-up on the half-scale method and use the result given there to calculate R_g from R_e and R_p. If you do not get a value for R_g between 200 and 400 **Ù**, repeat your work.

Part II Conversion of your galvanometer to an ammeter with a full scale reading of 100 mA.

In an ammeter the same voltage is across both the shunt resistor and the galvanometer. Use this fact and Ohm's law to calculate the value for a shunt resistor R_s that will make an ammeter with a full-scale reading of 100 mA.

Using resistance wire with linear resistance supplied by your instructor and cut a piece of wire long enough to give R_s plus a little extra to allow connections to be made at the galvanometer binding posts.

Wire your ammeter into the circuit shown in Figure 4.2. For your load resistor R_L set the decade box to 40 **Ù**.

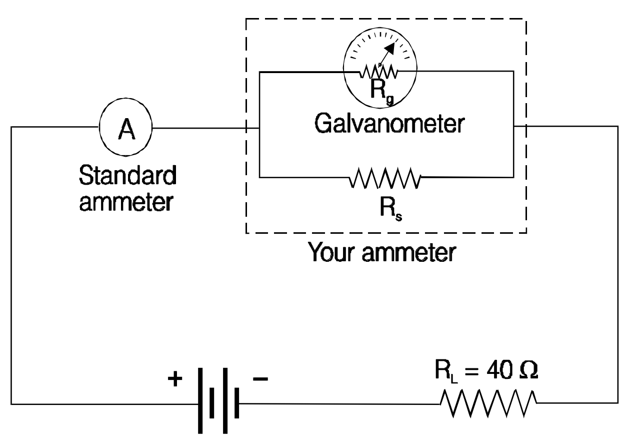


Figure 4.2 - Conversion of galvanometer to an ammeter.

Slowly vary the power supply voltage from zero to several volts so that your ammeter reads from zero to 100 mA. Make a calibration curve for your ammeter by plotting the readings of your ammeter versus the readings of the standard Ammeter.

Part III Conversion of your Galvanometer to a voltmeter with a full-scale reading of 5 V.

Use Ohm's law to calculate the value of the multiplier resistor that must be in series with your galvanometer resistance R_g to give full-scale deflection, I_g, when the voltage applied to the series combination is 5 V.

Wire the circuit as in Figure 4.3, using a decade box for the necessary multiplier resistance, R_m:

By varying the applied voltage V of the power supply, plot a calibration curve as in Part II of your voltmeter versus the standard voltmeter.

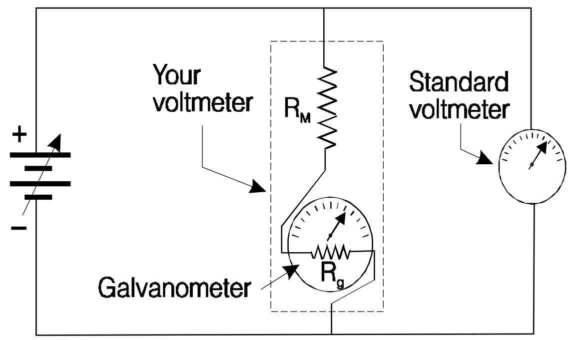


Figure 4.3 - Conversion from galvanometer to voltmeter.

Answer the following questions and include with your report:

1. What is the resistance for an ideal ammeter?

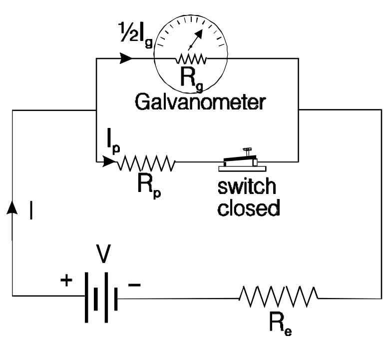
2. What would be the resistance of an ideal voltmeter?

3. Given an ammeter with a full-scale range of 1 Amp and an internal resistance of 100 **Ù**, what shunt resistance is needed to increase its range to 100 Amp?

Half scale method

First one has (see figure),

$I = I_g$ and $I_p = 0$



1. $V = I_gR_g + I_gR_e = I_g (R_g + R_e)$ (R_p out of circuit),
   With R_p in the circuit and current through meter = ½ I_g

2. $I = \frac{1}{2} I_g + I_p$

Since the meter and R_p have the same voltage on them,

$\frac{1}{2} I_g R_g = I_p R_p$ so $I_p = \frac{1}{2} I_g R_g/R_p$. Insertion of I_p into 2 then gives

3. $$I = \frac{1}{2} I_g + \frac{1}{2} I_g \frac{R_g}{R_p} = \frac{1}{2} I_g (1 + \frac{R_g}{R_p}) = \frac{1}{2} I_g (\frac{R_p + R_g}{R_p})$$

In parallel, R_g and R_p have an equivalent R given by

4. $$\frac{1}{R} = \frac{1}{R_g} + \frac{1}{R_p} = \frac{R_p + R_g}{R_g R_p} \quad \text{or} \quad R = \frac{R_g R_p}{R_p + R_g}$$

Now $V = I (R + R_e)$. Substitute I and R from 3 and 4 and equate result to result of 1 which also = V

$$\frac{1}{2} I_g (\frac{R_p + R_g}{R_p})(\frac{R_g R_p}{R_p + R_g} + R_e) = I_g (R_g + R_e)$$

$$\text{or} \quad (\frac{R_p + R_g}{R_p})(\frac{R_g R_p + R_e R_p + R_e R_g}{R_p + R_g}) = 2 (R_g + R_e)$$

$$R_g R_p + R_e R_p + R_e R_g = 2R_g R_p + 2R_e R_p$$

$$R_g R_p + R_e R_p = R_e R_g,$$

$$R_g (R_e - R_p) = R_e R_p \quad \text{or} \quad R_g = \frac{R_e R_p}{R_e - R_p}$$