Voltmeters and Ammeters

OBJECTIVES

- ❑ Determine the internal resistance R_g and current sensitivity K of a galvanometer.
- ❑ Construct a voltmeter and an ammeter by placing the appropriate values of resistance in series and parallel with the galvanometer.
- ❑ Compare the accuracy of the constructed voltmeter and ammeter with a standard voltmeter and a standard ammeter.

EQUIPMENT LIST

- Power supply (0–20 V direct current), galvanometer (D'Arsonal type, zero centered)
- Resistance box (variable in steps of 10 Ω between 2500 Ω and 3500 Ω)
- A resistor of about 330 Ω (either a 1% resistor or provide a resistance meter)
- Digital voltmeter (0–20 V direct current), digital ammeter (0–1.00 A direct current)
- Spool of #28 copper wire (one for the class), assorted leads

THEORY

Galvanometer Characteristics

The **D'Arsonal galvanometers** used in this laboratory are based upon the fact that a wire coil in the presence of a magnetic field experiences a torque when there is a current in the coil. This torque is exerted against a spring, and the deflection of a pointer attached to the coil is proportional to the current in the galvanometer.

Because the coil has a fixed resistance R_g, the deflection of the pointer will also be proportional to the voltage across the terminals of the galvanometer. Therefore, a galvanometer can be calibrated to serve as either a **voltmeter** or an **ammeter.**

A galvanometer is characterized by its resistance R_g and a constant K called the current sensitivity. K is the amount of current needed to deflect the galvanometer one scale division. It is expressed in units of A/div. Both R_g and K are taken to be unknown for the galvanometers used in the laboratory. We will determine them by a series of measurements described in a later section.

Conversion of the Galvanometer into a Voltmeter

The galvanometer deflects full scale for a value of current given by $I_g = KN$ where N is the number of scale divisions. The voltage V_g across the galvanometer terminals that produces a full-scale deflection is given by $V_g = I_g R_g = KN R_g$. If it is desired to measure a larger voltage than V_g, it is necessary to place a resistor R_V in series with the galvanometer so that most of the voltage is across R_V and the rest across the galvanometer. Figure 31-1 illustrates this idea.

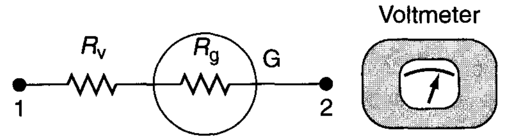

Figure 31-1 Combination of galvanometer and series resistor forms a voltmeter.

If a voltage of V_{FS} between terminals 1 and 2 in Figure 31-1 results in a current in the galvanometer equal to KN, then the series combination of R_V and the galvanometer acts as a voltmeter of full-scale voltage V_{FS}. In equation form this is

$$I = KN = \frac{V_{FS}}{R_V + R_g} \qquad \text{(Eq. 1)}$$

Solving Equation 1 for R_V leads to the following expression:

$$R_V = \frac{V_{FS}}{KN} - R_g \qquad \text{(Eq. 2)}$$

Equation 2 can be used to solve for the value of R_V needed to turn a galvanometer of given K, N, and R_g into a voltmeter of full-scale voltage V_{FS}.

Because a voltmeter must be connected into a circuit in parallel, it will alter the original circuit as little as possible when it has as high a resistance as possible. The ideal voltmeter, therefore, has infinite resistance.

Conversion of the Galvanometer into an Ammeter

The galvanometer deflects full scale when the current is $I_g = KN$. If it is desired to measure a larger current than I_g, it is necessary to place a small shunt resistance R_A in parallel with the galvanometer to divert part of the current away from the galvanometer as shown in Figure 31-2. The current I comes in at terminal 1 and divides at the junction. The current in the galvanometer is I_g, and I_A is the current in the shunt resistor where $I = I_g + I_A$. Because R_g and R_A are in parallel, they have the same voltage across them or in equation form, $I_g\, R_g = I_A\, R_A$. Combining the two previous equations and assuming $I = I_{FS}$ when $I_g = KN$ gives

$$R_A = \frac{KNR_g}{I_{FS} - KN} \qquad \text{(Eq. 3)}$$

Equation 3 can be used to calculate the value of the resistor R_A needed to cause the parallel combination shown in Figure 31-2 to be an ammeter with a full-scale current of I_{FS}.

Because an ammeter must be connected into a circuit in series, it will alter the original circuit as little as possible when it has as low a resistance as possible. The ideal ammeter therefore has zero resistance.

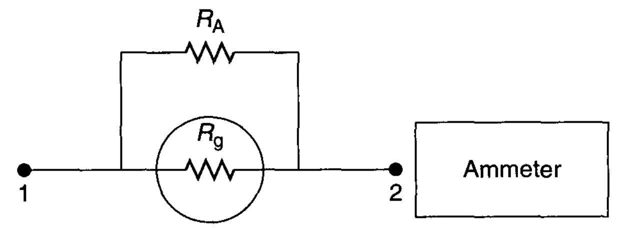

Figure 31-2 Galvanometer and shunt resistor in parallel form an ammeter.

EXPERIMENTAL PROCEDURE

Determine R_g and K

1. Connect the galvanometer, power supply, and decade resistance box in series, and then connect the voltmeter in parallel with the power supply as shown in Figure 31-3. Set the resistance box R_1 to a value of 2500 Ω and adjust the power supply voltage carefully until the galvanometer deflects full scale. Record the voltmeter reading as V and the number of large divisions into which the scale is divided as N in Data and Calculations Table 1.
2. A resistor in parallel with a device is called a shunt resistor because it diverts part of the current that was originally going through the device. Use a composition resistor with a value of approximately 330 Ω as a shunt resistor. Use the ohmmeter to measure an accurate value for the shunt resistor R_s and record it in Data and Calculations Table 1. With the power supply voltage set exactly as above, connect R_s in parallel with the galvanometer (Figure 31-4). The deflection of the galvanometer will now be less than full scale.
3. Leave the power supply voltage set and adjust the value of the resistance box to a somewhat lower *value needed to cause the galvanometer to again deflect full scale. Make small adjustments and watch* carefully so that the galvanometer does not deflect beyond full scale. A large abrupt decrease in the value of the resistance box could divert enough current through the galvanometer to damage it. Record the value of the resistance box setting that gives a full-scale deflection as R_2 in Data and Calculations Table 1.

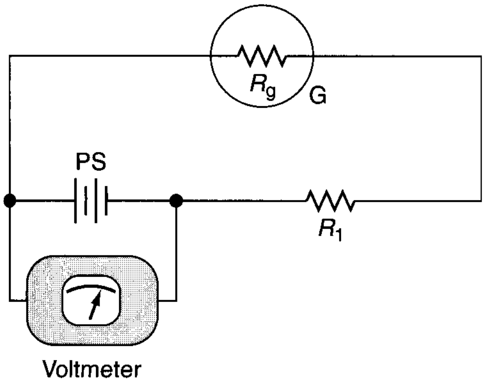

Figure 31-3 Original circuit.

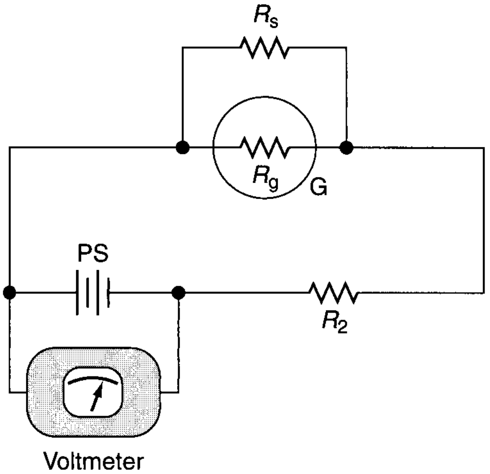

Figure 31-4 Original circuit plus shunt.

4. Turn the power supply to zero and remove the shunt resistor. The circuit is again like Figure 31-3; but now select a value of 3000 Ω for R_1, the resistance box, and repeat the procedure described in Step 1. Record the value of V needed to produce a full-scale deflection for this resistance in Data and Calculations Table 1.
5. Repeat Steps 2 and 3 above, inserting the same shunt resistor R_s. Determine the value of R_2 needed to produce a full-scale deflection with the shunt resistor in place, and record it in Data and Calculations Table 1.
6. Turn the power supply to zero and remove the shunt resistor. Set the resistance box to a value of $R_1 = 3500\,\Omega$ and repeat Steps 1, 2, and 3, recording the values of V and R_2 in Data and Calculations Table 1.

Galvanometer into a Voltmeter

1. Complete the Calculations section of this laboratory to determine the values of K and R_g.
2. Calculate the value of R_V needed to turn your galvanometer into a voltmeter that reads full-scale deflection for 5.00 V ($V_{FS} = 5.00$ V). In this calculation use the mean values of K and R_g from Data and Calculations Table 1. Record this value of R_V in Data and Calculations Table 2.
3. Connect one side of the galvanometer to one side of the resistance box set to the value of R_V. Between the other terminals of the galvanometer and the resistance box is what we will call the **experimental voltmeter** that reads 5.00 V full scale.
4. Compare the experimental voltmeter with the standard voltmeter by connecting them in parallel across the output of the power supply as shown in Figure 31-5. Turn the power supply up slowly until the experimental voltmeter reads exactly 1.00 V and record the value read by the standard voltmeter at this point. Make this same comparison at 2.00, 3.00, 4.00, and 5.00 V as read on the experimental voltmeter and record all results in Data and Calculations Table 2.
5. Following the steps in 1 through 3, calculate the value of R_V needed to make a voltmeter of 10.0 V full-scale deflection. Construct such a voltmeter and compare it to the standard voltmeter at 2.00, 4.00, 6.00, 8.00, and 10.00 V. Record all the results in Data and Calculations Table 2.
6. Following the same procedure, construct a voltmeter that reads 15.0 V full scale and compare it with the standard voltmeter at 3.00, 6.00, 9.00, 12.0, and 15.0 V. Record the results in Data and Calculations Table 2.
7. Calculate the percentage error of the experimental voltmeter readings compared to the standard voltmeter and record the results in Data and Calculations Table 2.

Galvanometer into an Ammeter

1. Calculate the value of R_A needed to turn your galvanometer into an ammeter that reads 1.00 A full scale. For values of R_g and K use the mean value in Data and Calculations Table 1. Record the value of R_A in Data and Calculations Table 3.
2. Number 28 copper wire has a resistance of 0.00213 Ω/cm. Calculate the length of #28 copper wire needed to have a resistance equal to R_A. Record that value in Data and Calculations Table 3.
3. Cut a piece of #28 copper wire a few centimeters longer than the length calculated in Step 2. If the wire being used has an insulating coating, cut away a few centimeters on each end of the wire. Attach the

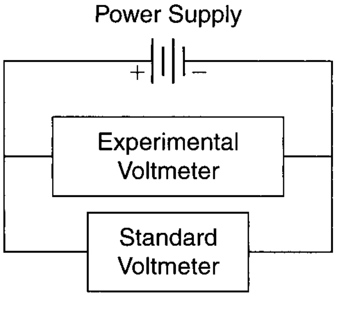

Figure 31-5 Experimental and standard voltmeter in parallel with power supply.

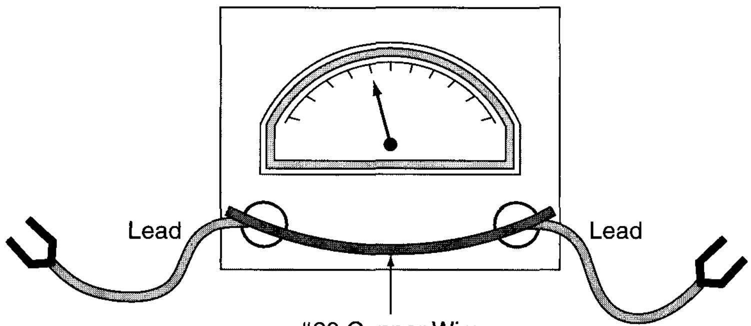

Figure 31-6 Galvanometer with #28 copper wire shunt resistor.

wire between the posts of the galvanometer so that the length of wire between where one end touches one post and the other end touches the other post is equal to the length calculated in Step 2. At the same time that the wire is attached between the posts, attach a short lead to each galvanometer post as shown in Figure 31-6. The two loose ends of the two leads are now an ammeter that reads 1.00 A full scale. Refer to it as the experimental ammeter.

4. After making sure that the power supply is turned completely to zero, place the experimental ammeter in series with a standard ammeter and with the power supply. Very slowly turn the supply up until the experimental ammeter reads 0.200 A. Record the reading of the standard ammeter in Data and Calculations Table 3. Continue this process, comparing the experimental ammeter to the standard ammeter at 0.400, 0.600, 0.800, and 1.000 A.
5. Calculate the percentage errors of the experimental ammeter readings compared to the standard ammeter readings and record the results in Data and Calculations Table 3.

CALCULATIONS

R_g and K

1. By applying Ohm's Law to the circuits in Figure 31-3 and Figure 31-4 when the applied voltage V is the same and the galvanometer is at full-scale deflection in both cases, it can be shown that the resistance of the galvanometer R_g is given by

$$R_g = \frac{R_s}{R_2}(R_1 - R_2) \qquad \text{(Eq. 4)}$$

Calculate the three values of R_g determined by the three trials in Data and Calculations Table 1. Also calculate the mean $\overline{R}_g$ and standard error α_{R_g} for these measurements. Record all calculated values in Data and Calculations Table 1.

2. The constant K is defined as the current needed to produce a deflection of one scale division, and the deflection in the above procedure was N scale divisions. Ohm's Law applied to the circuit of Figure 31-3 leads to the following:

$$K = \frac{V}{N(R_1 + R_g)} \qquad \text{(Eq. 5)}$$

Determine K the galvanometer current sensitivity from the values of V and R_1 in Data and Calculations Table 1 and the calculated values of R_g in Data and Calculations Table 1. For each calculation of K, use the value of R_g determined from the V and R_1 being used to calculate K. Also calculate the mean $\overline{K}$ and standard error α_K for the three values of K. Record all calculated quantities in Data and Calculations Table 1.

Name Section Date

LABORATORY 31 *Voltmeters and Ammeters*

PRE-LABORATORY ASSIGNMENT

1. Describe the principle on which the operation of a D'Arsonal type galvanometer is based.

2. A galvanometer has (a) a meter deflection proportional to the current in the galvanometer (b) a meter deflection proportional to the voltage across the galvanometer (c) a fixed resistance (d) all of the above are true.

3. The galvanometer constant K is (a) the current for full-scale deflection (units A) (b) the current for deflection of one scale division (units A/div) (c) the total current times the number of scale divisions (units A/div) (d) the reciprocal of the galvanometer resistance R_g (units 1/A).

4. In the procedure for determination of R_g and K when the shunt resistor R_S is placed in parallel with the galvanometer, what happens to galvanometer deflection, and why does it happen?

5. To construct a voltmeter of a given full-scale deflection from a galvanometer, the appropriate resistance must be placed in (a) series (b) parallel with the galvanometer.

6. To construct an ammeter of a given full-scale deflection from a galvanometer, the appropriate resistance must be placed in (a) series (b) parallel with the galvanometer.

7. A galvanometer has $R_g = 150\,\Omega$ and $K = 0.750 \times 10^{-4}$ A/div. The galvanometer has five divisions for a full-scale reading (i.e., $N = 5$). What value of resistance is needed, and how must it be connected to the galvanometer to form a full-scale voltmeter of 20.0 V? Show your work.

8. To form the galvanometer of Question 7 into an ammeter of 2.50 A full scale, what value of resistance is needed, and how must it be connected? Show your work.

9. To measure voltage, a voltmeter is placed in a circuit in (a) series (b) parallel. The resistance of an ideal voltmeter is ________________.

10. To measure the current, an ammeter is placed in a circuit in (a) series (b) parallel. The resistance of an ideal ammeter is ________________.

Name | Section | Date

Lab Partners

LABORATORY 31 *Voltmeters and Ammeters*

LABORATORY REPORT

Data and Calculations Table 1

R_1 (Ω)	V (V)	R_2 (Ω)	R_g (Ω)	K (A/div)	$\overline{R}_g$ (Ω)	α_{R_g} (Ω)	$\overline{K}$ (A/div)	α_K (A/div)
$N =$				$R_s =$				Ω

Data and Calculations Table 2

$V_{FS} = 5.00$ V $R_V =$ Ω	Experimental	1.00 V	2.00 V	3.00 V	4.00 V	5.00 V
	Standard	V	V	V	V	V
	% Error					
$V_{FS} = 10.00$ V $R_V =$ Ω	Experimental	2.00 V	4.00 V	6.00 V	8.00 V	10.0 V
	Standard	V	V	V	V	V
	% Error					
$V_{FS} = 15.00$ V $R_V =$ Ω	Experimental	3.00 V	6.00 V	9.00 V	12.0 V	15.0 V
	Standard	V	V	V	V	V
	% Error					

Data and Calculations Table 3

$I_{FS} = 1.00$ A		$R_A =$ Ω		*Length* $R_A =$ cm	
Experimental	0.200 A	0.400 A	0.600 A	0.800 A	1.000 A
Standard	A	A	A	A	A
% Error					

SAMPLE CALCULATIONS

1. $R_g = (R_s/R_2)(R_1 - R_2) =$
2. $K = (V)/(N(R_1 + R_g)) =$
3. $R_V = (V_{FS}/KN) - R_g =$
4. $R_A = (KN\ R_g)/(I_{FS} - KN) =$
5. Length of wire =
6. % Error =

QUESTIONS

1. Considering the standard error of your measurements, comment on the precision of your measurements of R_g and K. Express the standard error as a percentage of the mean.

2. Consider the 5 V experimental voltmeter. Does it tend to read too high or too low compared to the standard voltmeter?

3. Presumably a different value of R_V would give better agreement between the 5 V experimental voltmeter and the standard voltmeter. Would R_V need to be a larger or smaller resistance? Explain your answer.

4. Does the experimental ammeter tend to read too high or too low?

5. Presumably by a change in the value of R_A, the experimental voltmeter could be made to show better agreement with the standard ammeter. Does R_A need to be a larger or smaller resistance to accomplish this? Explain your answer.

EXTRA CREDIT QUESTION. It is stated in the laboratory instructions that the same voltage V is applied to both circuits in Figure 31-3 and Figure 31-4, and that the galvanometer deflects full scale in both cases. Thus the galvanometer current is $I_g = KN$ for both circuits. In Figure 31-4 let the current in R_s be called I_s. From the application of Ohm's Law to these circuits, derive the expression given as Equation 1 for R_g.