Name ______________________ Section ____________ Date ____________

Laboratory 31

Voltmeters and Ammeters

PRELABORATORY ASSIGNMENT

Read carefully the entire description of the laboratory and answer the following questions based on the material contained in the reading assignment. Turn in the completed prelaboratory assignment at the beginning of the laboratory period prior to the performance of the laboratory.

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, or (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), or (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 or (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 or (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 voltmeter of 20.0 V full scale? Show your work.

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

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

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

Laboratory 31

Voltmeters and Ammeters

OBJECTIVES

A galvanometer is a device used to detect the presence of electrical current. In this laboratory, measurements made with several circuits containing a galvanometer will be used to accomplish the following objectives:

1. Determination of the internal resistance of the galvanometer R_g
2. Determination of the current sensitivity of the galvanometer K
3. Transformation of the galvanometer into a voltmeter of given full-scale deflection by placing the appropriate value of resistance in series with the galvanometer
4. Transformation of the galvanometer into an ammeter of given full-scale deflection by placing the appropriate value of resistance in parallel with the galvanometer
5. Comparison of the accuracy of the voltmeter and ammeter constructed from the galvanometer with a standard voltmeter and a standard ammeter

EQUIPMENT LIST

1. Direct-current power supply (capable of at least 3 V)
2. Galvanometer (D'Arsonal type zero centered, available from Central Scientific, Sargent-Welch and other supply companies)
3. Resistance box (variable in steps of 10 Ω between 2500 Ω and 3500 Ω)
4. A resistor of approximately 330 Ω (This should be either a 1% resistor or else a resistance meter should be provided for the class so that the value of this resistor can be accurately measured.)
5. Direct-current voltmeter (range of 0–3.00 V, preferably digital readout)
6. Direct current ammeter (range of 0–1.00 A, preferably digital readout)
7. Spool of #28 copper wire (one for the class)
8. Assorted leads

THEORY—GALVANOMETER CHARACTERISTICS

The D'Arsonal-type galvanometers used in this experiment are based on the fact that a wire coil located in the presence of a magnetic field will experience 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. Since 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." This constant is simply the amount of current needed to deflect the galvanometer one scale division, and it is expressed in units of A/div. The values of R_g and K for the galvanometers used in the experiment are taken to be unknown. They will be determined experimentally by a series of measurements with known values of resistance in series and parallel with the galvanometer as described in the following procedure.

EXPERIMENTAL PROCEDURE TO DETERMINE R_g AND K

1. As shown in Figure 31.1 connect the galvanometer, power supply, and the decade resistance box in series, and then connect the voltmeter in parallel with the power supply. 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 Table 1.

2. A resistor connected in parallel with a device is referred to as a shunt resistor because it diverts part of the current that was originally going through the device. Use a composition resistor whose value is approximately 330 Ω as a shunt resistor. Using the ohmmeter, measure an accurate value for this shunt resistor R_s and record it in Data Table 1. Leaving the power supply voltage set exactly as above, connect the shunt resistor in parallel with the galvanometer as shown in Figure 31.2. The deflection of the galvanometer will now be less than full scale.

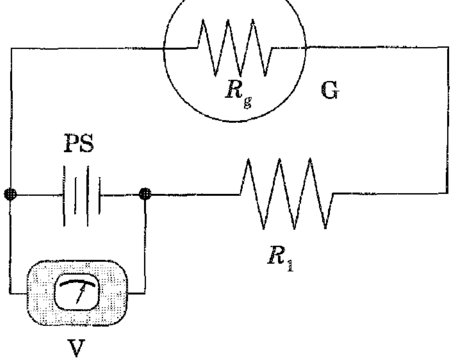

Figure 31.1 Original Circuit.

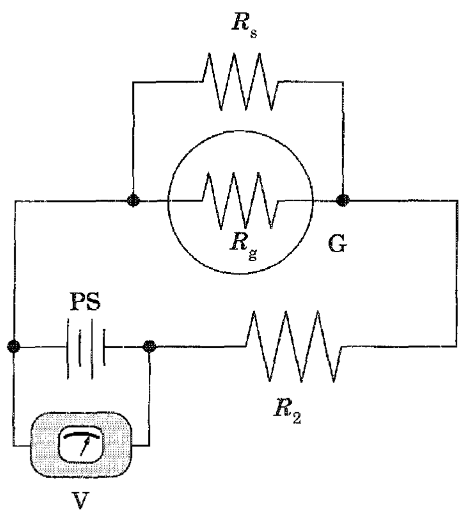

Figure 31.2 Original Circuit plus shunt.

3. Still leaving the power supply voltage set, adjust the value of the resistance box from its present value 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 very large abrupt decrease in the value of the resistance box could divert enough current through the galvanometer to cause permanent damage to the galvanometer.

Record the value of the resistance box setting that gives a full scale deflection as R_2 in Data Table 1.

4. Turn the power supply to zero and remove the shunt resistor. The circuit is again like Figure 31.1; 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 Table 1.

5. Repeat steps 2 and 3 above, inserting the same shunt resistor R_s of 330 Ω. Determine the value of R_2 needed to produce a full-scale deflection with the shunt resistor in place and record it in Data 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 Ω and repeat steps 1, 2, and 3, recording the values of V and R_2 in Data Table 1.

CALCULATION OF R_g AND K

1. By applying Ohm's law to the circuits in Figure 31.1 and Figure 31.2, 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

$$R_g = \frac{R_s}{R_2}(R_1 - R_2) \qquad (1)$$

Using equation 1, calculate the three values of R_g determined by the three trials in Data Table 1. Also, calculate the mean $\overline{R}_g$ and standard error α_{R_g} for these measurements. Record all calculated values in 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 31.1 leads to the following:

$$I = KN = \frac{V}{R_1 + R_g} \quad \text{or} \quad K = \frac{V}{N(R_1 + R_g)} \qquad (2)$$

Using equation 2, determine K (the galvanometer current sensitivity) from the values of V and R_1 in Data Table 1 and the calculated values of R_g in 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 Calculations Table 1.

THEORY—CONVERSION OF THE GALVANOMETER INTO A VOLTMETER

The galvanometer deflects full scale for a value of current given by $I_g = KN$. The voltage V_g across the galvanometer terminals that produces a full-scale deflection is given by $V_g = I_g R_g = KNR_g$. 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 31.3 illustrates this idea. If a voltage of V_{FS} between terminals 1 and 2 in Figure 31.3 results in a current in the galvanometer equal to KN, then the series combination of R_V and the galvanometer act as a voltmeter with a full-scale voltage V_{FS}. In other words, the deflection of the galvanometer will be proportional to the voltage between terminals

1 and 2, with the galvanometer showing full-scale deflection when the voltage between terminals 1 and 2 is equal to V_{FS}. In equation form this is

$$I = KN = \frac{V_{FS}}{R_V + R_g} \quad (3)$$

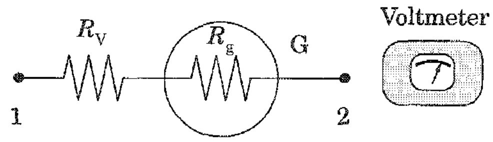

Figure 31.3 Combination of Galvanometer and Series Resistor form a Voltmeter.

Solving equation 3 for R_V leads to the following expression:

$$R_V = \frac{V_{FS}}{KN} - R_g \quad (4)$$

Equation 4 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}. For example, if a galvanometer has $K = 2.00 \times 10^{-4}$ A/div, $R_g = 100\ \Omega$, and $N = 5$, equation 4 can be used to find the value of R_V needed to make a voltmeter that measures a maximum voltage of 25.0 V ($V_{FS} = 25.0$ V). Placing those values in equation 4 and solving, gives $R_V = 24{,}900\ \Omega$. Therefore, a 24,900-Ω resistor in series with the galvanometer will produce between terminals 1 and 2 in Figure 31.3, a voltmeter that reads 25.0 V at full scale. Also note that since there are 5 divisions on the galvanometer scale, the scale marks 1, 2, 3, 4, and 5 stand for 5, 10, 15, 20, and 25 V.

As a final word on the theory of voltmeters, note that when a voltmeter is used to measure the voltage in a circuit, it must necessarily alter the original circuit because of the current in the voltmeter. If the current in the voltmeter is a minimum, then the alteration of the original circuit is held to a minimum. Since a voltmeter is always placed in a circuit in parallel it follows that the larger the resistance of the voltmeter, the less current it draws, and the more accurate is the voltmeter. In fact, the ideal voltmeter would have an infinite resistance.

EXPERIMENTAL PROCEDURE—GALVANOMETER INTO A VOLTMETER

1. Using equation 4, 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 Calculations Table 1. Record this value of R_V in Data Table 2.
2. Connect one side of the galvanometer to one side of the resistance box set to the value of R_V. Connect one end of a second lead to the other side of the galvanometer. Connect one end of a third lead to the other side of the resistance box. Between the loose ends of the second and third leads is a voltmeter that reads 5.00 V at full scale. This voltmeter will be referred to as the experimental voltmeter.
3. Compare the experimental voltmeter with the standard voltmeter by connecting them in parallel across the output of the power supply as shown in Figure 31.4.

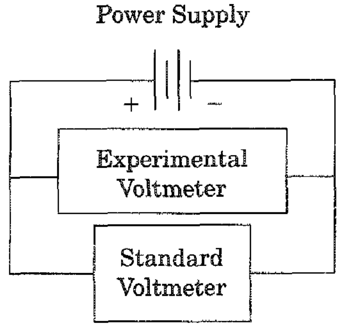

Figure 31.4 Experimental and standard voltmeter in parallel with power supply.

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 Table 2.

4. Following steps 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 Table 2.
5. Following the same procedure, construct a voltmeter that reads 15.0 V at 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 Table 2.
6. Calculate the percentage error of the experimental voltmeter readings compared to the standard voltmeter and record the results in Calculations Table 2.

THEORY—CONVERSION OF THE GALVANOMETER INTO AN AMMETER

As previously described, a galvanometer deflects full scale when the current is $I_g = KN$. If it is desired to measure a current larger 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 31.5. 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 $I = I_g + I_A$. Since R_g and R_A are in parallel, they have the same voltage across them, or in equation form, $I_gR_g = I_AR_A$. Combining the two previous equations leads to

$$IR_A = I_g(R_A + R_g) \tag{5}$$

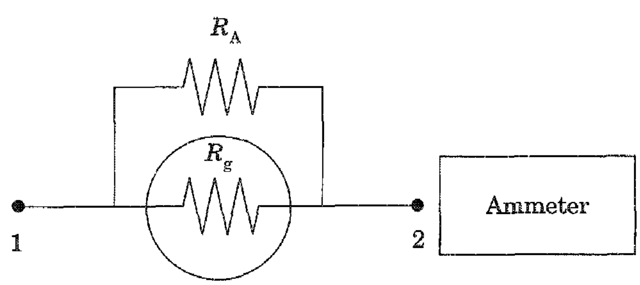

Figure 31.5 Galvanometer and shunt resistor in parallel form an Ammeter.

In order for the combination in Figure 31.5 to act as an ammeter of a given full-scale deflection I_{FS}, it is necessary that $I = I_{FS}$ when $I_g = KN$. Making these assumptions in the above equation gives

$$I_{FS}R_A = KN(R_A + R_g) \tag{6}$$

Solving equation 6 for R_A leads to the following equation:

$$R_A = \frac{KNR_g}{I_{FS}} - KN \tag{7}$$

Equation 7 can be used to calculate the value of the resistor R_A needed to cause the parallel combination shown in Figure 31.5 to be an ammeter whose full-scale current is 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.

PROCEDURE—GALVANOMETER INTO AN AMMETER

1. Using equation 7, calculate the value of R_A needed to turn your galvanometer into an ammeter that reads 1.00 A at full scale. For values of R_g and K, use the mean value in Calculations Table 1. Record the value of R_A in Data 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 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 it away a few centimeters on each end of the wire. Attach the wire between the posts of the galvanometer in such a way 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 at full scale. Refer to it as the experimental ammeter.

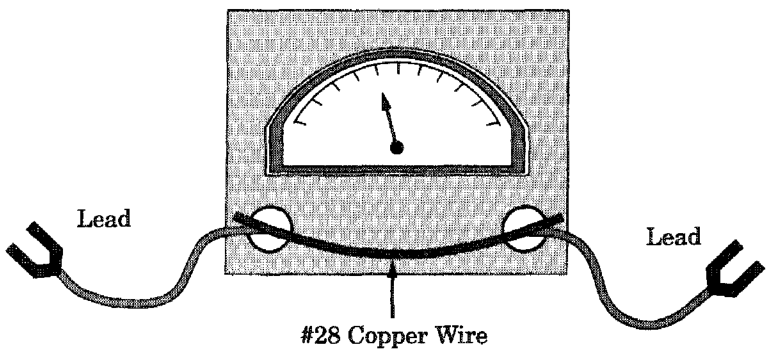

Figure 31.6 Galvanometer with #28 copper wire shunt resistor.

3. 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 Table 3. Continue this process, comparing the experimental ammeter to the standard ammeter at 0.400, 0.600, 0.800, and 1.000 A.

4. Calculate the percentage errors of the experimental ammeter readings compared to the standard ammeter and record the results in Calculations Table 3.

Name ________________ Section ________ Date ________

Laboratory 31

Voltmeters and Ammeters

LABORATORY REPORT

Data Table 1

R_1 (Ω)	V (volts)	R_2 (Ω)

$N =$ ________

$R_s =$ ________

Calculations Table 1

R_g (Ω)	$\overline{R_g}$ (Ω)	α_{R_g}	K (A/div)	$\overline{K}$ (A/div)	α_K

SAMPLE CALCULATIONS

Data Table 2

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

Calculations Table 2

Percentage Error of Experimental Voltmeter Versus % Full Scale Reading

Type	20% FS	40% FS	60% FS	80% FS	100% FS
5-V Meter					
10-V Meter					
15-V Meter					

Data Table 3

I_{FS} = 1.00 A		R_A = ________ Ω		Length R_A = ________ cm	
Experimental I	0.200 A	0.400 A	0.600 A	0.800 A	1.000 A
Standard I					

Calculations Table 3

Percentage Error of Experimental Ammeter Versus % Full Scale Reading

Type	20% FS	40% FS	60% FS	80% FS	100% FS
1-A Meter					

QUESTIONS

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

2. Are the absolute differences between each of the three experimental voltmeters and the standard voltmeter approximately of the same order of magnitude?

3. Are the percentage errors of the three experimental voltmeters approximately constant?

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

5. Presumably a change in the value of R_V would cause better agreement of the 5-V experimental voltmeter with the standard voltmeter. Would R_V need to be a larger or smaller resistance and why?

6. Are the absolute differences between the experimental ammeter readings and the standard ammeter readings approximately of the same order of magnitude?

7. Are the percentage errors of the experimental ammeter approximately constant?

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

9. 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 and why?

10. It is stated in the laboratory instructions that the same voltage V is applied to both circuits in Figures 31.1 and 31.2 and the galvanometer deflects full scale in both cases. Thus, the galvanometer current is $I_g = KN$ for both circuits. In Figure 31.2 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.