CHAPTER 2

Direct-Current Meters

2-1 Instructional Objectives

The purpose of this chapter is to familiarize the reader with the d'Arsonval meter movement, how it may be used in ammeters, voltmeters, and ohmmeters, some of its limitations, as well as some of its applications. After completing Chapter 2 you should be able to

1. Describe and compare constructions of the two types of suspension used in the d'Arsonval meter movement.
2. Explain the principle of operation of the d'Arsonval meter movement.
3. Describe the purpose of shunts across a meter movement.
4. Describe the purpose of multipliers in series with a meter movement.
5. Define the term *sensitivity*.
6. Analyze a circuit in terms of voltmeter loading or ammeter insertion errors.
7. Describe the construction and operation of a basic ohmmeter.
8. Perform required calculations for multipliers or shunts to obtain specific meter ranges of voltage and current.
9. Apply the concepts related to error studied in Chapter 1 to the circuits of Chapter 2.

INTRODUCTION

The history of the basic meter movement used in direct-current (dc) measurements can be traced to Hans Oersted's discovery in 1820 of the relationship between current and magnetism. Over the next half-century, various types of devices that made use of Oersted's discovery were developed. In 1881 Jacques d'Arsonval patented the *moving-coil galvanometer*. The same basic construction developed by d'Arsonval is used in meter movements today.

This basic moving-coil system, generally referred to as a d'Arsonval meter movement or a permanent magnet moving-coil (PMMC) meter movement, is

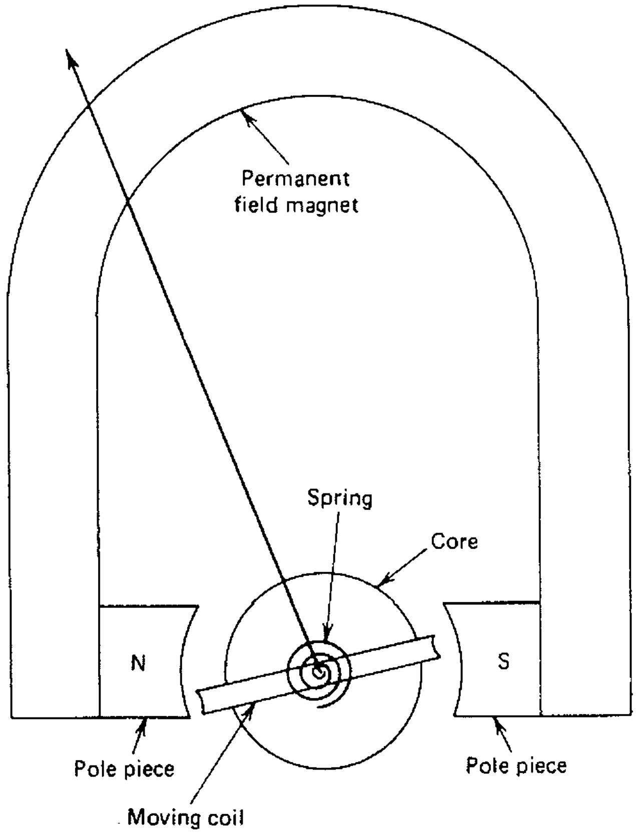

FIGURE 2-1 The d'Arsonval meter movement.

shown in Fig. 2-1. The moving-coil mechanism is generally set in a jewel and pivot suspension system to reduce friction. Another method of suspension is the "taut-band" suspension system which provides a more sensitive, but more expensive, meter movement. As a matter of comparison, a typical full-scale current for a jewel and pivot suspension system is 50 μA, whereas a full-scale current of 2 μA for a taut-band system is entirely practical.

2-3 THE D'ARSONVAL METER MOVEMENT

The **d'Arsonval meter movement** is in wide use even today. For this reason this chapter presents a detailed discussion of its construction and principle of operation. The typical commercial meter movement, shown in Fig. 2-2, operates on the basic principle of the dc motor. Figure 2-1 shows a horseshoe-shaped permanent magnet with soft iron pole pieces attached to it. Between the north–south pole pieces is a cylindrical-shaped soft iron core about which a coil of fine wire is wound. This fine wire is wound on a very light metal frame and mounted in a jewel setting so that it can rotate freely. A pointer attached to the moving coil deflects up scale as the moving coil rotates.

Current from a circuit in which measurements are being made with the meter passes through the windings of the moving coil. Current through the

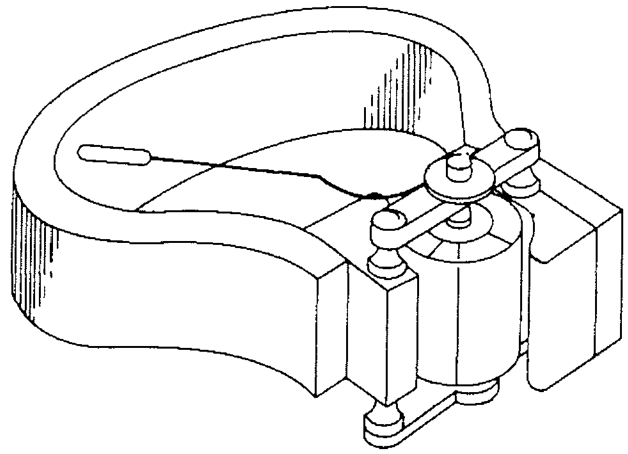

FIGURE 2-2 Cutaway view of the d'Arsonval meter movement. (Courtesy Weston Instruments, a Division of Sangamo Weston, Inc.)

coil causes it to behave as an electromagnet with its own north and south poles. The poles of the electromagnet interact with the poles of the permanent magnet, causing the coil to rotate. The pointer deflects up scale whenever current flows in the proper direction in the coil. For this reason, all dc meter movements show polarity markings.

It should be emphasized that the d'Arsonval meter movement is a *current* responding device. Regardless of the units (volts, ohms, etc.) for which the scale is calibrated, the moving coil responds to the amount of current through its windings.

D'ARSONVAL METER MOVEMENT USED IN A DC AMMETER

Since the windings of the moving coil shown in Fig. 2-2 are of very fine wire, the basic d'Arsonval meter movement has only limited usefulness without modification. One desirable modification is to increase the range of current that can be measured with the basic meter movement. This is done by placing a low resistance in *parallel* with the meter movement resistance, R_m. This low resistance is called a **shunt** (R_{sh}), and its function is to provide an alternate path for the total metered current I around the meter movement. The basic dc ammeter circuit is shown in Fig. 2-3. In most circuits I_{sh} is much greater than I_m, which flows in the movement itself. The resistance of the shunt is found by applying Ohm's law to Fig. 2-3

where

R_{sh} = resistance of the shunt

R_m = **internal resistance** of the meter movement (resistance of the moving coil)

I_{sh} = current through the shunt

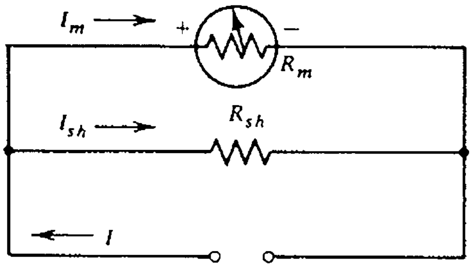

FIGURE 2-3 D'Arsonval meter movement used in an ammeter circuit.

I_m = full-scale deflection current of the meter movement
I = full-scale deflection current for the **ammeter**

The voltage drop across the meter movement is

$$V_m = I_m R_m$$

Since the shunt resistor is in parallel with the meter movement, the voltage drop across the shunt is equal to the voltage drop across the meter movement. That is,

$$V_{sh} = V_m$$

The current through the shunt is equal to the total current minus the current through the meter movement:

$$I_{sh} = I - I_m$$

Knowing the voltage across, and the current through, the shunt allows us to determine the shunt resistance as

$$R_{sh} = \frac{V_{sh}}{I_{sh}} = \frac{I_m R_m}{I_{sh}} = \frac{I_m}{I_{sh}} R_m = \frac{I_m}{I - I_m} \times R_m \ (\Omega) \qquad (2\text{-}1)$$

EXAMPLE 2-1

Calculate the value of the shunt resistance required to convert a 1-mA meter movement, with a 100-Ω internal resistance, into a 0- to 10-mA ammeter.

Solution

$$V_m = I_m R_m = 1 \text{ mA} \times 100 \ \Omega = 0.1 \text{ V}$$

$$V_{sh} = V_m = 0.1 \text{ V}$$

$$I_{sh} = I - I_m = 10 \text{ mA} - 1 \text{ mA} = 9 \text{ mA}$$

$$R_{sh} = \frac{V_{sh}}{I_{sh}} = \frac{0.1 \text{ V}}{9 \text{ mA}} = 11.11 \ \Omega \qquad (2\text{-}1)$$

The purpose of designing the shunt circuit is to allow us to measure a current I that is some number n times larger than I_m. The number n is called a multiplying factor and relates total current and meter current as

$$I = nI_m \tag{2-2}$$

Substituting this for I in Eq. 2-1 yields

$$R_{sh} = \frac{R_m I_m}{nI_m - I_m}$$

$$= \frac{R_m}{n-1}\ (\Omega) \tag{2-3}$$

Example 2-2 illustrates the use of Eqs. 2-2 and 2-3.

[EXA]MPLE 2-2

A 100-μA meter movement with an internal resistance of 800 Ω is used in a 0- to 100-mA ammeter. Find the value of the required shunt resistance.

[So]l[u]tion

The multiplication factor n is the ratio of 100 mA to 100 μA or

$$n = \frac{I}{I_m} = \frac{100\ \text{mA}}{100\ \mu\text{A}} = 1000 \tag{2-2}$$

Therefore,

$$R_{sh} = \frac{R_m}{n-1} = \frac{800\ \Omega}{1000-1} = \frac{800}{999} \approx 0.80\ \Omega$$

[2-]5 THE AYRTON SHUNT

The shunt resistance discussed in the previous sections works well enough on a single-range ammeter. However, on a multiple-range ammeter, the **Ayrton shunt**, or the universal shunt, is frequently a more suitable design. One advantage of the Ayrton shunt is that it eliminates the possibility of the meter movement being in the circuit without any shunt resistance. Another advantage is that it may be used with a wide range of meter movements. The Ayrton shunt circuit is shown in Fig. 2-4.

The individual resistance values of the shunts are calculated by starting with the most sensitive range and working toward the least sensitive range. In Fig. 2-4, the most sensitive range is the 1-A range. The shunt resistance is $R_{sh} = R_a + R_b + R_c$. On this range the shunt resistance is equal to R_{sh} and can be computed by Eq. 2-3 where

$$R_{sh} = \frac{R_m}{n-1}$$

The equations needed to compute the value of each shunt, R_a, R_b, and R_c, can be developed by observing Fig. 2-5. Since the resistance $R_b + R_c$ is in parallel with $R_m + R_a$, the voltage across each parallel branch should be equal and can be written as

$$V_{R_b+R_c} = V_{R_a+R_m}$$

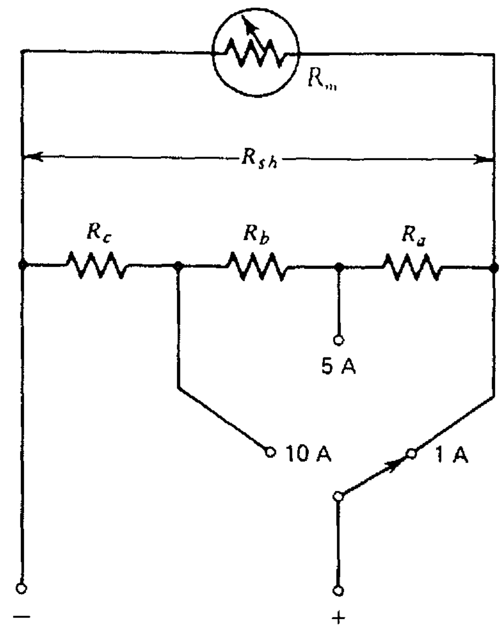

FIGURE 2-4 An ammeter using an Ayrton shunt.

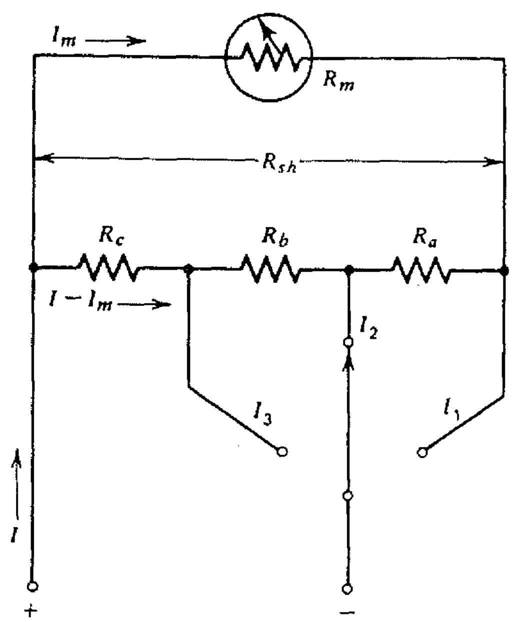

FIGURE 2-5 Computing resistance values for the Ayrton shunt.

In current and resistance terms we can write

$$(R_b + R_c)(I_2 - I_m) = I_m(R_a + R_m)$$

or

$$I_2(R_b + R_c) - I_m(R_b + R_c) = I_m[R_{sh} - (R_b + R_c) + R_m]$$

Multiplying through by I_m on the right yields

$$I_2(R_b + R_c) - I_m(R_b + R_c) = I_m R_{sh} - I_m(R_b + R_c) + I_m R_m$$

This can be rewritten as

$$R_b + R_c = \frac{I_m(R_{sh} + R_m)}{I_2} \ (\Omega) \qquad (2\text{-}4)$$

Having already found the total shunt resistance R_{sh}, we can now deterime R_a as

$$R_a = R_{sh} - (R_b + R_c) \ (\Omega) \qquad (2\text{-}5)$$

The current I is the maximum current for the range on which the ammeter is set. The resistor R_c can be determined from

$$R_c = \frac{I_m(R_{sh} + R_m)}{I_3} \qquad (2\text{-}6)$$

The only difference between Eq. 2-4 and Eq. 2-6 are the currents I_2 and I_3, which in each case is the maximum current for the range for which a shunt value is being computed.

The resistor R_b can now be computed as

$$R_b = (R_b + R_c) - R_c \ (\Omega) \qquad (2\text{-}7)$$

A‾MPLE 2-3 Compute the value of the shunt resistors for the circuit shown in Fig. 2-6.

lution The total shunt resistance R_{sh} is found from

$$R_{sh} = \frac{R_m}{n-1} = \frac{1\ \text{k}\Omega}{100-1} = \frac{1\ \text{k}\Omega}{99} = 10.1\ \Omega \qquad (2\text{-}2)$$

This is the shunt for the 10 mA range. When the meter is set on the 100-mA range, the resistors R_b and R_c provide the shunt. The total shunt resistance is found by the equation

$$R_b + R_c = \frac{I_m(R_{sh} + R_m)}{I_2} = \frac{(100\ \mu\text{A})(10.1\ \Omega + 1\ \text{k}\Omega)}{100\ \text{mA}} = 1.01\ \Omega \qquad (2\text{-}4)$$

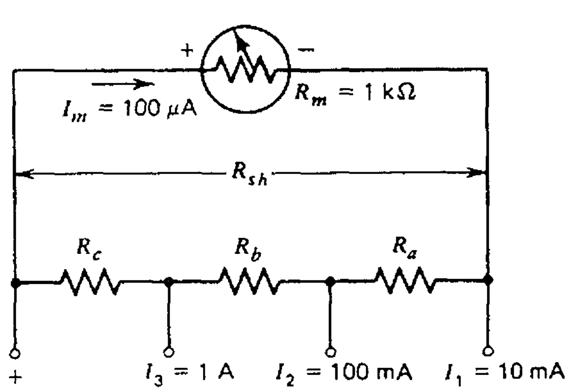

FIGURE 2-6 Ayrton shunt circuit.

The resistor R_c, which provides the shunt resistance on the 1-A range, can be found by the same equation; however, the current I will now be 1 A.

$$R_c = \frac{I_m(R_{sh} + R_m)}{I_3}$$

$$= \frac{(100\ \mu A)(10.1\ \Omega + 1\ k\Omega)}{1\ A} = 0.101\ \Omega \qquad (2\text{-}6)$$

The resistor R_b is found from Eq. 2-7 in which

$$R_b = (R_b + R_c) - R_c = 1.01\ \Omega - R_c = 1.01\ \Omega - 0.101\ \Omega = 0.909\ \Omega$$

The resistor R_a is found from

$$R_a = R_{sh} - (R_b + R_c)$$

$$= 10.1\ \Omega - (0.909\ \Omega + 0.101\ \Omega) = 9.09\ \Omega \qquad (2\text{-}5)$$

Check: $R_{sh} = R_a + R_b + R_c = 9.09\ \Omega - 0.909\ \Omega + 0.101\ \Omega = 10.1\ \Omega$

2-6 D'ARSONVAL METER MOVEMENT USED IN A DC VOLTMETER

The basic d'Arsonval meter movement can be converted to a dc **voltmeter** by connecting a **multiplier** R_s in *series* with the meter movement as shown in Fig. 2-7.

The purpose of the multiplier is to extend the voltage range of the meter and to limit current through the d'Arsonval meter movement to a maximum full-scale deflection current. To find the value of the multiplier resistor, we may first determine the **sensitivity**, *S*, of the meter movement. The sensitivity is found by taking the reciprocal of the full-scale deflection current, written as

$$\text{Sensitivity} = \frac{1}{I_{fs}}\ (\Omega/V) \qquad (2\text{-}8)$$

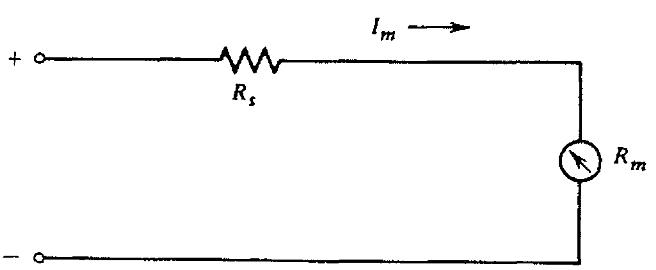

FIGURE 2-7 The d'Arsonval meter movement used in a dc voltmeter.

The units associated with sensitivity in Eq. 2-8 are ohms per volt, as may be seen from

$$\text{Sensitivity} = \frac{1}{\text{amperes}} = \frac{1}{\dfrac{\text{volt}}{\text{ohms}}} = \frac{\text{ohms}}{\text{volt}}$$

Voltage measurements are made by placing the voltmeter across the resistance of interest. This in effect places the total voltmeter resistance in parallel with the circuit resistance; therefore, it is desirable to make the voltmeter resistance much higher than the circuit resistance. Since different meter movements are used in various voltmeters and since the value of the multiplier is different for each range, total resistance is a difficult instrument rating to express. More meaningful information can be conveyed to the user via the sensitivity rating of the instrument. This rating, generally printed on the meter face, tells the resistance of the instrument for a *one*-volt range. To determine the total resistance that a voltmeter presents to a circuit, multiply the sensitivity by the range (see Example 2-5).

K MPLE 2-4

Calculate the sensitivity of 100-μA meter movement which is to be used as a dc voltmeter.

ol tion

The sensitivity is computed as

$$S = \frac{1}{I_{fs}} = \frac{1}{100\ \mu\text{A}} = 10\ \frac{\text{k}\Omega}{\text{V}}$$

The units of sensitivity express the value of the multiplier resistance for the 1-V range. To calculate the value of the multiplier for voltage ranges greater than 1 V, simply multiply the sensitivity by the range and subtract the internal resistance of the meter movement, or

$$R_s = S \times \text{Range} - \text{Internal Resistance} \qquad (2\text{-}9)$$

K MPLE 2-5

Calculate the value of the multiplier resistance on the 50-V range of a dc voltmeter that used a 500-μA meter movement with an internal resistance of 1 kΩ.

ol tion

The sensitivity of the 500-μA meter movement in Fig. 2-8 is

$$S = \frac{1}{I_{fs}} = \frac{1}{500\ \mu\text{A}} = 2\ \frac{\text{k}\Omega}{\text{V}} \qquad (2\text{-}8)$$

The value of the multiplier R_s is now calculated by multiplying the sensitivity by the range and subtracting the internal resistance of the meter movement.

$$R_s = S \times \text{Range} - R_m$$

$$= \frac{2\ \text{k}\Omega}{\text{V}} \times 50\ \text{V} - 1\ \text{k}\Omega = 100\ \text{k}\Omega - 1\ \text{k}\Omega = 99\ \text{k}\Omega \qquad (2\text{-}9)$$

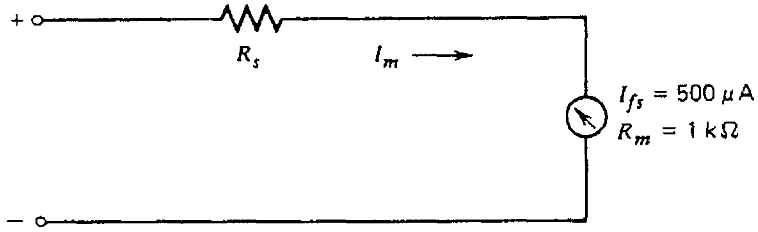

FIGURE 2-8 Basic dc voltmeter circuit.

By adding a rotary switch arrangement, we can use the same meter movement for ranges of dc voltage as shown in Example 2-6.

XAMPLE 2-6

Calculate the value of the multiplier resistances for the multiple-range dc voltmeter circuit shown in Fig. 2-9.

olution

The sensitivity of the meter movement is computed as

$$S = \frac{1}{I_{fs}} = \frac{1}{50\,\mu A} = 20\,\frac{k\Omega}{V} \qquad (2\text{-}8)$$

The value of the multiplier resistors can now be computed as follows.

(a) On the 3-V range,

$$R_{s1} = S \times \text{Range} - R_m$$
$$= \frac{20\ k\Omega}{V} \times 3\ V - 1\ k\Omega = 59\ k\Omega \qquad (2\text{-}9)$$

(b) On the 10-V range,

$$R_{s2} = S \times \text{Range} - R_m$$
$$= \frac{20\ k\Omega}{V} \times 10\ V - 1\ k\Omega = 199\ k\Omega \qquad (2\text{-}9)$$

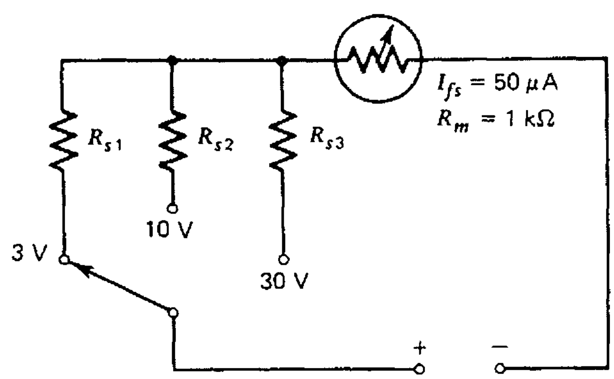

FIGURE 2-9 Multiple-range voltmeter circuit.

(c) On the 30-V range,

$$R_{s3} = S \times \text{Range} - R_m$$
$$= \frac{20\ \text{k}\Omega}{\text{V}} \times 30\ \text{V} - 1\ \text{k}\Omega = 599\ \text{k}\Omega \qquad (2\text{-}9)$$

A frequently used circuit for commercial multiple-range dc voltmeters is shown in Fig. 2-10. In this circuit the multiplier resistors are connected in series, and the range selector switches the appropriate amount of resistance into the circuit in series with the meter movement. The advantage of this circuit is that all multiplier resistors except the first (R_a) have standard resistance values and can be obtained commercially in precision tolerance.

(EXA)MPLE 2-7

Calculate the value of the multiplier resistors for the multiple-range dc voltmeter circuit shown in Fig. 2-10.

(So)lution

The sensitivity of the meter movement is computed as

$$S = \frac{1}{I_{fs}} = \frac{1}{50\ \mu\text{A}} = 20\ \text{k}\Omega/\text{V}$$

The value of the multiplier resistors can be computed as follows.

(a) On the 3-V range,

$$R_a = S \times \text{Range} - R_m = \frac{20\ \text{k}\Omega}{\text{V}} \times 3\ \text{V} - 1\ \text{k}\Omega$$
$$= 59\ \text{k}\Omega$$

(b) On the 10-V range,

$$R_b = S \times \text{Range} - (R_a + r_m) = \frac{20\ \text{k}\Omega}{\text{V}} \times 10\ \text{V} - 60\ \text{k}\Omega$$
$$= 140\ \text{k}\Omega$$

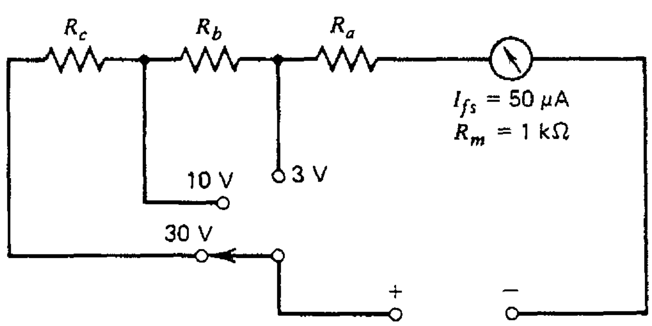

FIGURE 2-10 A commercial version of a multiple-range voltmeter.

(c) On the 30-V range,

$$R_c = S \times \text{Range} - (R_a + R_b + R_m) = \frac{20\ \text{k}\Omega}{\text{V}} \times 30\ \text{V} - 200\ \text{k}\Omega$$

$$= 400\ \text{k}\Omega$$

2-7 VOLTMETER LOADING EFFECTS

When a voltmeter is used to measure the voltage across a circuit component, the voltmeter circuit itself is in parallel with the circuit component. Since the parallel combination of two resistors is less than either resistor alone, the resistance seen by the source is less with the voltmeter connected than without. Therefore, the voltage across the component is less whenever *the voltmeter is connected*. The decrease in voltage may be negligible or it may be appreciable, depending on the *sensitivity* of the voltmeter being used. This effect is called *voltmeter loading*, and it is illustrated in the following examples. The resulting error is called a **loading error**.

EXAMPLE 2-8

Two different voltmeters are used to measure the voltage across resistor R_B in the circuit of Fig. 2-11. The meters are as follows.

Meter A: $S = 1\ \text{k}\Omega/\text{V}$, $R_m = 0.2\ \text{k}\Omega$, range $= 10\ \text{V}$

Meter B: $S = 20\ \text{k}\Omega/\text{V}$, $R_m = 1.5\ \text{k}\Omega$, range $= 10\ \text{V}$

Calculate

(a) Voltage across R_B without any meter connected across it.
(b) Voltage across R_B when meter A is used.
(c) Voltage across R_B when meter B is used.
(d) Error in voltmeter readings.

Solution

(a) The voltage across resistor R_B without either meter connected is found using the voltage divider equation:

$$V_{R_B} = E \frac{R_B}{R_A + R_B}$$

$$= 30\ \text{V} \times \frac{5\ \text{k}\Omega}{25\ \text{k}\Omega + 5\ \text{k}\Omega} = 5\ \text{V}$$

(b) Starting with meter A, the total resistance it presents to the circuit is

$$R_{T_A} = S \times \text{Range}$$

$$= \frac{1\ \text{k}\Omega}{\text{V}} \times 10\ \text{V} = 10\ \text{k}\Omega$$

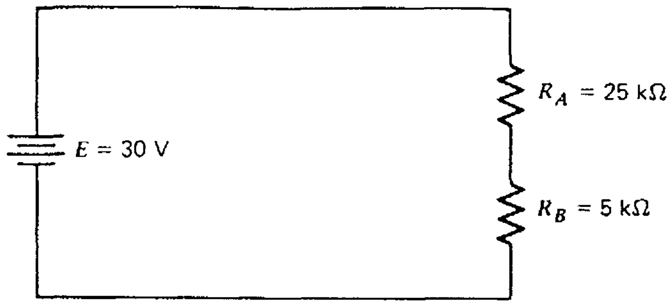

FIGURE 2-11 Circuit for Example 2-8 showing voltmeter loading.

The parallel combination of R_B and meter A is

$$R_{e1} = \frac{R_B \times R_{T_A}}{R_B + R_{T_A}}$$

$$= \frac{5\ \text{k}\Omega \times 10\ \text{k}\Omega}{5\ \text{k}\Omega + 10\ \text{k}\Omega} = 3.33\ \text{k}\Omega$$

Therefore, the voltage reading obtained with meter A, determined by the voltage divider equation, is

$$V_{R_B} = E \frac{R_{e1}}{R_{e1} + R_A}$$

$$= 30\ \text{V} \times \frac{3.33\ \text{k}\Omega}{3.33\ \text{k}\Omega + 25\ \text{k}\Omega}\ 3.53\ \text{V}$$

(c) The total resistance that meter B presents to the circuit is

$$R_{T_B} = S \times \text{Range}$$

$$= \frac{20\ \text{k}\Omega}{\text{V}} \times 10\ \text{V} = 200\ \text{k}\Omega$$

The parallel combination of R_B and meter B is

$$R_{e2} = \frac{R_B \times R_{T_B}}{R_B + R_{T_B}}$$

$$= \frac{5\ \text{k}\Omega \times 200\ \text{k}\Omega}{5\ \text{k}\Omega + 200\ \text{k}\Omega} = 4.88\ \text{k}\Omega$$

Therefore, the voltage reading obtained with meter B, determined by use of the voltage divider equation, is

$$V_{R_B} = E \frac{R_{e2}}{R_{e2} + R_A}$$

$$= 30\ \text{V} \times \frac{4.88\ \text{k}\Omega}{4.88\ \text{k}\Omega + 25\ \text{k}\Omega} = 4.9\ \text{V}$$

(d)

$$\text{Voltmeter } A \text{ error} = \frac{5\ \text{V} - 3.53\ \text{V}}{5\ \text{V}} \times 100\% = 29.4\%$$

$$\text{Voltmeter } B \text{ error} = \frac{5\ \text{V} - 4.9\ \text{V}}{5\ \text{V}} \times 100\% = 2\%$$

Note in Example 2-8 that, although the reading obtained with meter *B* is much closer to the correct value, the voltmeter still introduced a 2% error due to loading of the circuit by the voltmeter. It should be apparent that, in electronic circuits in which high values of resistance are generally used, commercial volt–ohm–milliammeters (VOM) still introduce some circuit loading. Such instruments generally have a sensitivity of at least 20 kΩ/V. Instruments with a lower sensitivity rating generally prove unsatisfactory for most electronics work.

When a VOM is used to make voltage measurements, circuit loading due to the voltmeter is also minimized by using the highest range possible, as shown in Example 2-9.

EXAMPLE 2-9

Find the voltage reading and the percentage of error of each reading obtained with a voltmeter on

(a) Its 3-V range.
(b) Its 10-V range.
(c) Its 30-V range.

The instrument has a 20-kΩ/V sensitivity and is connected across R_B in Fig. 2-12.

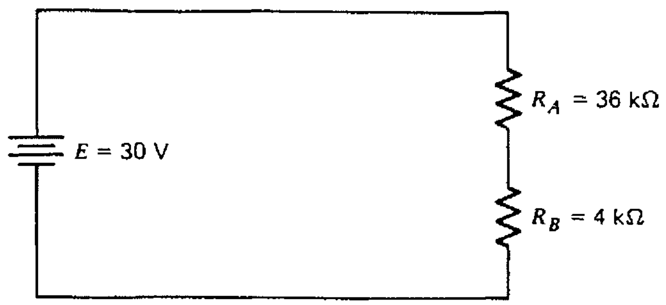

FIGURE 2-12 Circuit for Example 2-9 showing the effects of voltmeter loading on different ranges.

The voltage drop across R_B without the voltmeter connected is computed as

$$V_{R_B} = E\frac{R_B}{R_A + R_B}$$

$$= 30\ \text{V} \times \frac{4\ \text{k}\Omega}{36\ \text{k}\Omega + 4\ \text{k}\Omega} = 3\ \text{V}$$

(a) On the 3-V range,

$$R_T = S \times \text{Range}$$

$$= \frac{20\ \text{k}\Omega}{\text{V}} \times 3\ \text{V} = 60\ \text{k}\Omega$$

$$R_{eq1} = \frac{R_T R_B}{R_T + R_B} = \frac{60\ \text{k}\Omega \times 4\ \text{k}\Omega}{60\ \text{k}\Omega + 4\ \text{k}\Omega} = 3.75\ \text{k}\Omega$$

The voltmeter reading is

$$V_{R_B} = E\frac{R_{eq1}}{R_{eq1} + R_A}$$

$$= 30\ \text{V} \times \frac{3.75\ \text{k}\Omega}{3.75\ \text{k}\Omega + 36\ \text{k}\Omega} = 2.8\ \text{V}$$

The percentage of error on the 3-V range is

$$\text{Percent error} = \frac{3\ \text{V} - 2.8\ \text{V}}{3\ \text{V}} \times 100\% = 6.66\%$$

(b) On the 10-V range,

$$R_T = \frac{20\ \text{k}\Omega}{\text{V}} \times 10\ \text{V} = 200\ \text{k}\Omega$$

$$R_{eq2} = \frac{R_T R_B}{R_T + R_B} = \frac{200\ \text{k}\Omega \times 4\ \text{k}\Omega}{200\ \text{k}\Omega + 4\ \text{k}\Omega} = 3.92\ \text{k}\Omega$$

The voltmeter reading is

$$V_{R_B} = E\frac{R_{eq2}}{R_{eq2} + R_A}$$

$$= 30\ \text{V} \times \frac{3.92\ \text{k}\Omega}{3.92\ \text{k}\Omega + 36\ \text{k}\Omega} = 2.95\ \text{V}$$

The percentage of error on the 10-V range is

$$\text{Percent error} = \frac{3\text{ V} - 2.95\text{ V}}{3\text{ V}} \times 100\% = 1.66\%$$

(c) On the 30-V range,

$$R_T = \frac{20\text{ k}\Omega}{\text{V}} \times 30\text{ V} = 600\text{ k}\Omega$$

$$R_{\text{eq3}} = \frac{R_T R_B}{R_T + R_B} = \frac{600\text{ k}\Omega \times 4\text{ k}\Omega}{600\text{ k}\Omega + 4\text{ k}\Omega} = 3.97\text{ k}\Omega$$

The voltmeter reading is

$$V_{R_B} = E\frac{R_{\text{eq3}}}{R_{\text{eq3}} + R_A}$$

$$= 30\text{ V} \times \frac{3.97\text{ k}\Omega}{3.97\text{ k}\Omega + 36\text{ k}\Omega} = 2.98\text{ V}$$

The percentage of error on the 30-V range is

$$\text{Percent error} = \frac{3\text{ V} - 2.98\text{ V}}{3\text{ V}} \times 100\% = 0.66\%$$

We have learned the following from Example 2-9. The 30-V range introduces the least error because of loading. However, the voltage being measured causes only a 10% full-scale deflection, whereas on the 10-V range the applied voltage causes approximately one-third full-scale deflection with less than 2% error. The reading obtained on the 10-V range would be acceptable and less subject to gross error (Section 1-6). The percentage of error on the 10-V range is less than the average percentage of error for a mass-produced d'Arsonval meter movement.

We can experimentally determine whether the voltmeter is introducing appreciable error by changing to a higher range. If the voltmeter reading does *not* change, the meter is not loading the circuit appreciably. If loading is observed, select the range with the greatest deflection and yielding the most precise measurement (Section 1-6).

2-8 AMMETER INSERTION EFFECTS

A frequently overlooked source of error in measurements is the error caused by inserting an ammeter in a circuit to obtain a current reading. All ammeters contain some internal resistance, which may range from a low value for current meters capable of measuring in the ampere range to an appreciable value of 1 kΩ or greater for microammeters. Inserting an ammeter in a circuit always increases the resistance of the circuit and, therefore, always reduces the current in the circuit. The error caused by the meter depends on the relationship between the value of resistance in the original circuit and the value of resistance in the ammeter.

Consider the series circuit shown in Fig. 2-13 in which there is current through resistor R_1. The expected current, I_e, is the current *without* the ammeter in the circuit. Now, suppose we connect an ammeter in the circuit to measure the current as shown in Fig. 2-14. The amplitude of the current has now been reduced to I_m, as a result of the added meter resistance, R_m.

If we wish to obtain a relationship between I_e and I_m we can do so by using Thévenin's theorem. The circuit in Fig. 2-14 is in the form of a Thévenin equivalent circuit with a single-voltage source in series with a single resistor. With the output terminals X and Y shorted, the expected current flow is

$$I_e = \frac{E}{R_1} \tag{2-10}$$

Placing the meter in series with R_1 causes the current to be reduced to a value equal to

$$I_m = \frac{E}{R_1 + R_m} \tag{2-11}$$

Dividing Eq. 2-11 by Eq. 2-10 yields the following expression

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + R_m} \tag{2-12}$$

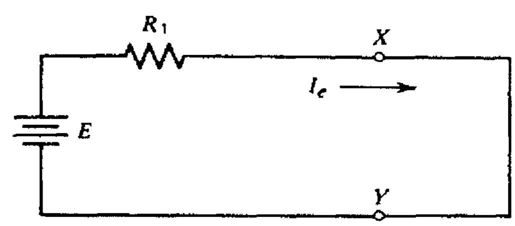

FIGURE 2-13 Expected current value in a series circuit.

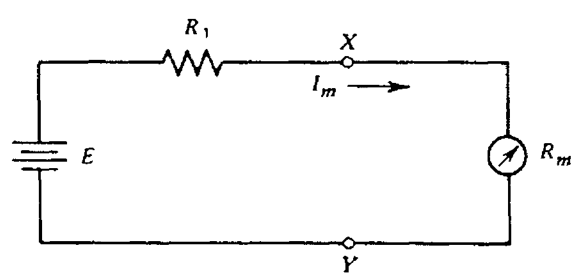

FIGURE 2-14 Series circuit with ammeter.

Equation 2-12 is quite useful in that it allows us to determine the error introduced into a circuit caused by ammeter insertion if we know the value of Thévenin's equivalent resistance and the resistance of the ammeter.

EXAMPLE 2-10

A current meter that has an internal resistance of 78 Ω is used to measure the current through resistor R_c in Fig. 2-15. Determine the percentage of error of the reading due to ammeter insertion.

Solution

The current meter will be connected into the circuit between points X and Y in the schematic in Fig. 2-16. When we look back into the circuit from terminals X and Y, we can express Thévenin's equivalent resistance as

$$R_{\mathrm{Th}} = R_c + \frac{R_a R_b}{R_a + R_b}$$

$$= 1\ \mathrm{k}\Omega + 0.5\ \mathrm{k}\Omega = 1.5\ \mathrm{k}\Omega$$

Therefore, the ratio of meter current to expected current is

$$\frac{I_m}{I_e} = \frac{R_1}{R_1 + r_m} = \frac{1.5\ \mathrm{k}\Omega}{1.5\ \mathrm{k}\Omega + 78\ \Omega} = 0.95 \qquad (2.12)$$

Solving for I_m yields

$$I_m = 0.95 I_e$$

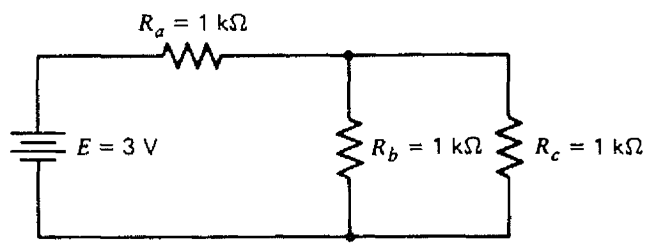

FIGURE 2-15 Series–parallel circuit for Example 2-10.

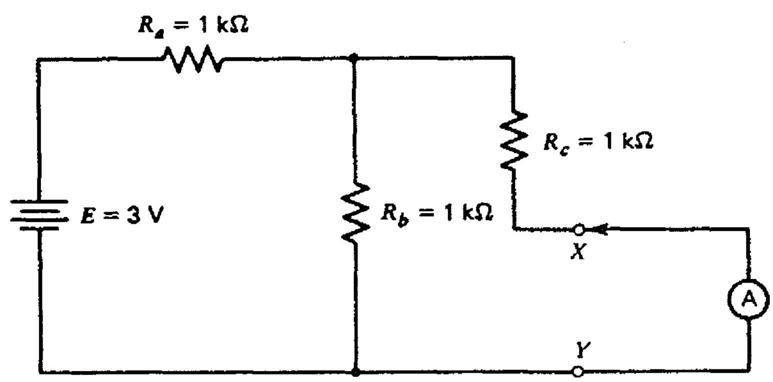

FIGURE 2-16 Circuit to demonstrate ammeter insertion.

The current through the meter is 95% of the expected current; therefore, the current meter has caused a 5% error as a result of its insertion. We can write an expression for the percentage of error attributable to ammeter insertion as

$$\text{Insertion error} = \left(1 - \frac{I_m}{I_e}\right) \times 100\% = 5.0\%$$

.9 THE OHMMETER

The basic d'Arsonval meter movement may also be used in conjunction with a battery and a resistor to construct a simple **ohmmeter** circuit such as that shown in Fig. 2-17. If points X and Y are connected, we have a simple series circuit with current through the meter movement caused by the voltage source, E. The amplitude of the current is limited by the resistors R_z and R_m. Notice in Fig. 2-17 that resistor R_z consists of a fixed portion and a variable portion. The reason for this will be discussed toward the end of this section. Connecting points X and Y is equivalent to shorting the test probes together on an ohmmeter to "zero" the instrument before using it. This is normal operating procedure with an ohmmeter. After points X and Y are connected, the variable part of resistor R_z is adjusted to obtain exactly full-scale deflection on the meter movement.

The amplitude of the current through the meter movement can be determined by applying Ohm's law as

$$I_{fs} = \frac{E}{R_z + R_m} \tag{2-13}$$

To determine the value of the unknown resistor we connect the unknown, R_x, between points X and Y in Fig. 2-17, as shown in Fig. 2-18. The circuit current is now expressed as

$$I = \frac{E}{R_z + R_m + R_x}$$

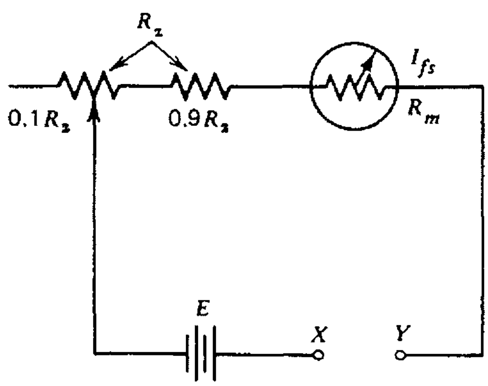

FIGURE 2-17 Basic ohmmeter circuit.

The current I is less than the full-scale current, I_{fs}, because of the additional resistance, R_x. The ratio of the current I to the full-scale deflection current I_{fs} is equal to the ratio of the circuit resistances and may be expressed as

$$\frac{I}{I_{fs}} = \frac{E/(R_z + R_m + R_x)}{E/(R_z + R_m)} = \frac{R_z + R_m}{R_z + R_m + R_x}$$

If we let P represent the ratio of the current I to the full-scale deflection current I_{fs}, we can say that

$$P = \frac{I}{I_{fs}} = \frac{R_z + R_m}{R_z + R_m + R_x} \qquad (2\text{-}14)$$

Equation 2-14 is very useful when marking off the scale on the meter face of the ohmmeter to indicate the value of a resistor being measured.

The following example illustrates the use of Eq. 2-14.

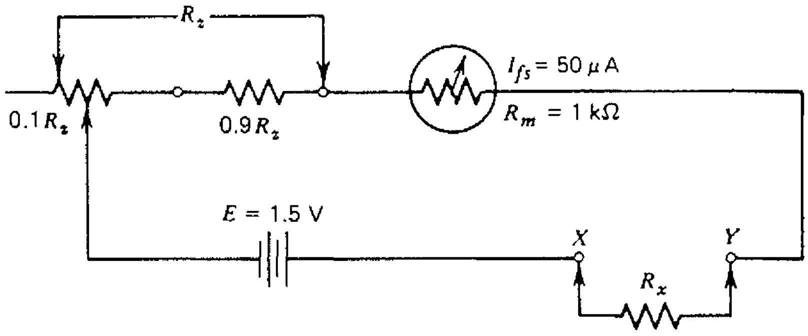

FIGURE 2-18 Basic ohmmeter circuit with unknown resistor R_x connected between probes.

EXAMPLE 2-11

A 1-mA full-scale deflection current meter movement is to be used in an ohmmeter circuit. The meter movement has an internal resistance, R_m, of 100 Ω, and a 3-V battery will be used in the circuit. Mark off the meter face for reading resistance.

Solution

The value of R_z, which will limit current to full-scale deflection current, is computed as

$$R_z = \frac{E}{I_{fs}} - R_m$$

$$R_z = \frac{3\text{ V}}{1\text{ mA}} - 100\ \Omega = 2.9\text{ k}\Omega$$

The value of R_x with 20% full-scale deflection is

$$R_x = \frac{R_z + R_m}{P} - (R_z + R_m)$$

$$= \frac{2.9\text{ k}\Omega + 0.1\text{ k}\Omega}{0.2} - (2.9\text{ k}\Omega + 0.1\text{ k}\Omega)$$

$$= \frac{3\ k\Omega}{0.2} - 3\ k\Omega = 12\ k\Omega$$

The value of R_x with 40% full-scale deflection is

$$R_x = \frac{R_z + R_m}{P} - (R_z + R_m)$$

$$= \frac{3\ k\Omega}{0.4} - 3\ k\Omega = 4.5\ k\Omega$$

The value of R_x with 50% full-scale deflection is

$$R_x = \frac{R_z + R_m}{P} - (R_z + R_m)$$

$$= \frac{3\ k\Omega}{0.5} - 3\ k\Omega = 3\ k\Omega$$

The value of R_x with 75% full-scale deflection is

$$R_x = \frac{R_z + R_m}{P} - (R_z + R_m)$$

$$= \frac{3\ k\Omega}{0.75} - 3\ k\Omega = 1\ k\Omega$$

The data are tabulated in Table 2-1. Using the data from Table 2-1, we can draw the ohmmeter scale shown in Fig. 2-19.

Two interesting and important facts may be seen from observing the ohmmeter scale in Fig. 2-19 and the data in Table 2-1. First, the ohmmeter scale is very nonlinear. This is due to the high internal resistance of an

TABLE 2-1
Scale of Ohmmeter in Example 2-11

P (%)	R_x (kΩ)	$R_z + R_m$ (kΩ)
20	12	3
40	4.5	3
50	3	3
75	1	3
100	0	3

ohmmeter. Second, at half-scale deflection, the value of R_x is equal to th value of the internal resistance of an ohmmeter. A variable resistor may b connected to the ohmmeter probes and then set to the value required fo half-scale deflection of the pointer. The variable resistor may then be remove and measured. Its value should equal the internal resistance of the ohmmeter

EXAMPLE 2-12 An ohmmeter uses a 1.5-V battery and a basic 50-μA movement. Calculat

(a) The value of R_z required.

(b) The value of R_x that would cause half-scale deflection in the circuit i Fig. 2-24.

Solution (a) The proper value of R_z is computed as

$$R_z = \frac{E}{I_{fs}} - R_m$$

$$= \frac{1.5\ \text{V}}{50\ \mu\text{A}} - 1\ \text{k}\Omega = 29\ \text{k}\Omega$$

(b) With midscale deflection, R_x is equal to the internal resistance of th ohmmeter; therefore

$$R_x = R_z + R_m = 30\ \text{k}\Omega$$

In Example 2-11 the value of resistance that corresponded to 20% full scale deflection was computed to be 12 kΩ. Suppose we connected a 97-k resistor to our ohmmeter circuit. The resulting current flow would be

$$I = \frac{E}{R_x + R_z + R^m} = \frac{3\ \text{V}}{100\ \text{k}\Omega} = 30\ \mu\text{A}$$

This amount of current would cause the pointer to deflect 3% of full scale. should be apparent that larger-value resistors would permit less deflectio Therefore, we can conclude that a 100-kΩ resistor would be about th maximum value of resistance that could be measured with any degree o accuracy with the particular ohmmeter circuit of Fig. 2-19.

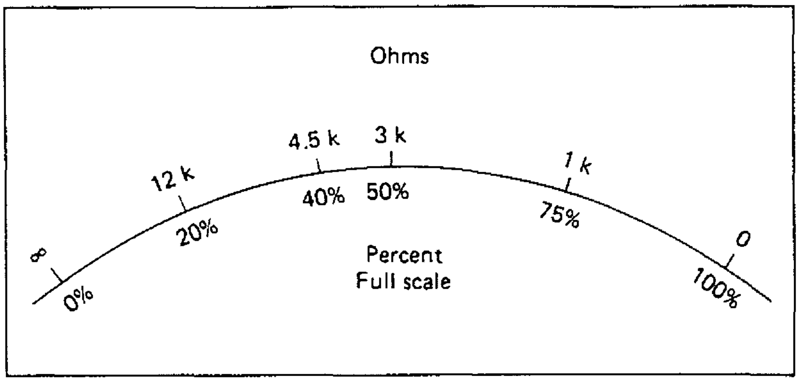

FIGURE 2-19 Ohmmeter scale showing nonlinear characteristics.

The variable portion of resistor R_z is frequently viewed as a means of compensating for battery aging. However, you should be aware of the consequences of this action. Consider the following calculations.

EXAMPLE 2-13

An ohmmeter is designed around a 1-mA meter movement and a 1.5-V cell. If the cell voltage decays to 1.3 V because of aging, calculate the resulting error at midrange on the ohmmeter scale.

Solution

The internal resistance of the ohmmeter is

$$R_{in} = \frac{E}{I} = \frac{1.5\text{ V}}{1\text{ mA}} = 1.5\text{ k}\Omega$$

Therefore, the ohmmeter scale should be marked as 1.5 kΩ at midrange. An external resistance of 1.5 kΩ would cause the pointer to deflect to midscale. When the cell voltage decays to 1.3 V and the ohmmeter is adjusted for full-scale deflection by reducing R_z, the total internal resistance of the ohmmeter is now

$$R_{in} = \frac{E}{I} = \frac{1.3\text{ V}}{1\text{ mA}} = 1.3\text{ k}\Omega$$

If a 1.3-kΩ resistor is now measured with the ohmmeter, we will expect less than midscale deflection. However, the pointer will deflect to midscale, which is marked as 1.5 kΩ. The aging of the cell has caused an incorrect reading. The percentage of error associated with the reading is

$$\text{Percent error} = \frac{1.5\text{ k}\Omega - 1.3\text{ k}\Omega}{1.5\text{ k}\Omega} \times 100\% = 13.3\%$$

To prevent the ohmmeter from being zeroed if the battery has aged considerably, the variable portion of R_z is usually limited to a maximum of 10% of the total value of R_z (see Figs. 2-17 and 2-20).

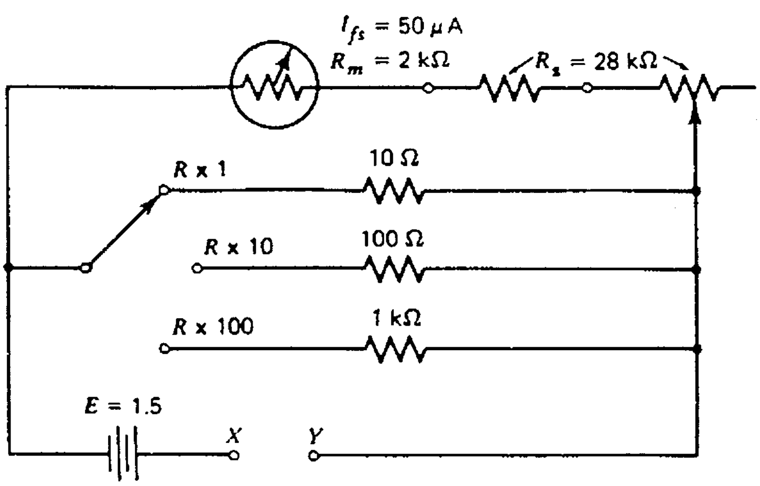

FIGURE 2-20 Multiple-range ohmmeter.

2-10 MULTIPLE-RANGE OHMMETERS

The ohmmeter circuit discussed in the previous section is not capable of measuring resistance over a wide range of values. Therefore, we need to extend our discussion of ohmmeters to include *multiple*-range ohmmeters.

One way to build a multiple-range ohmmeter is shown in Fig. 2-20. This instrument makes use of a basic 50-μA meter movement with an internal resistance of 2 kΩ. An additional resistance of 28 kΩ is provided by R_z, which includes a fixed resistance and the zeroing potentiometer. R_z is necessary to limit current through the meter movement to 50 μA when the test probes (not shown) connected to X and Y are shorted together. As may be seen, when the instrument is on the $R \times 1$ range, a 10-Ω resistor is in parallel with the meter movement. Therefore, the internal resistance of the ohmmeter on the $R \times 1$ range is 10 Ω in parallel with 30 kΩ, which is approximately 10 Ω. This means the pointer will deflect to midscale when a 10-Ω resistor is connected across X and Y.

When the instrument is set to the $R \times 10$ range, the total resistance of the ohmmeter is 100 Ω in parallel with 30 kΩ, which is now approximately 100 Ω. Therefore, the pointer deflects to midscale when a 100-Ω resistor is connected between the test probes. Midscale is marked as 10 Ω. Therefore, the value of the resistor is determined by multiplying the reading by the range multiplier of 10 producing a midscale value of 100 Ω ($R \times 10$).

When our ohmmeter is set on the $R \times 100$ range, the total resistance of the instrument is 1 kΩ in parallel with 30 kΩ, which is still approximately 1 kΩ. Therefore, the pointer deflects to midscale when we connect the test probes across a 1-kΩ resistor. This provides us a value for the midscale reading of 10 multiplied by 100, or 1 kΩ for our resistor.

EXAMPLE 2-14

(a) In Fig. 2-21 determine the current through the meter, I_m, when a 20-Ω resistor between terminals X and Y is measured on the $R \times 1$ range.
(b) Show that this same current flows through the meter movement when a 200-Ω resistor is measured on the $R \times 10$ range.
(c) Show that the same current flows when a 2 kΩ resistor is measured on the $R \times 100$ range.

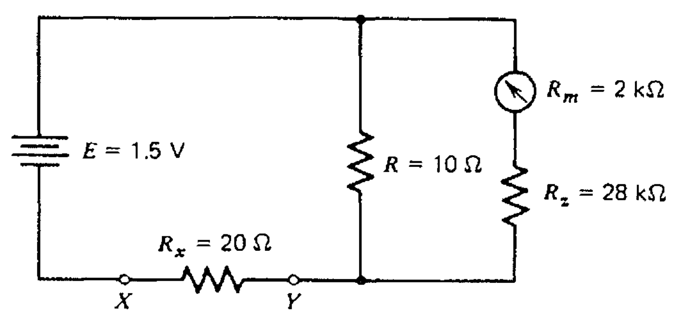

FIGURE 2-21 Circuit for Example 2-14 with ohmmeter on $R \times 1$ range.

(a) When the ohmmeter is set on the $R \times 1$ range, the circuit is as shown in Fig. 2-21. The voltage across the potential combination of resistance is computed as

$$V = 1.5\ \text{V} \times \frac{10\ \Omega}{10\ \Omega + 20\ \Omega} = 0.5\ \text{V}$$

The current through the meter movement is computed as

$$I_m = \frac{0.5\ \text{V}}{30\ \text{k}\Omega} = 16.6\ \mu\text{A}$$

(b) When the ohmmeter is set on the $R \times 10$ range, the circuit is as shown in Fig. 2-22. The voltage across the parallel combination of resistance is computed as

$$V = 1.5\ \text{V} \times \frac{100\ \Omega}{100\ \Omega + 200\ \Omega} = 0.5\ \text{V}$$

The current through the meter movement is computed as

$$I_m = \frac{0.5\ \text{V}}{30\ \text{k}\Omega} = 16.6\ \mu\text{A}$$

(c) When the ohmmeter is set on the $R \times 100$ range, the circuit is as shown in Fig. 2-23. The voltage across the parallel combination is computed as

$$V = 1.5 \times \frac{1\ \text{k}\Omega}{1\ \text{k}\Omega + 2\ \text{k}\Omega} = 0.5\ \text{V}$$

The current through the meter movement is computed as

$$I_m = \frac{0.5\ \text{V}}{30\ \text{k}\Omega} = 16.6\ \mu\text{A}$$

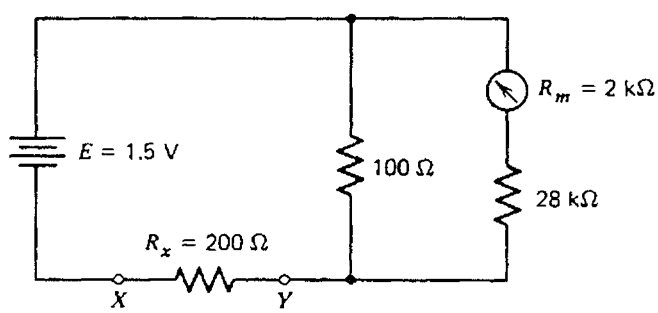

FIGURE 2-22 Ohmmeter on $R \times 10$ range.

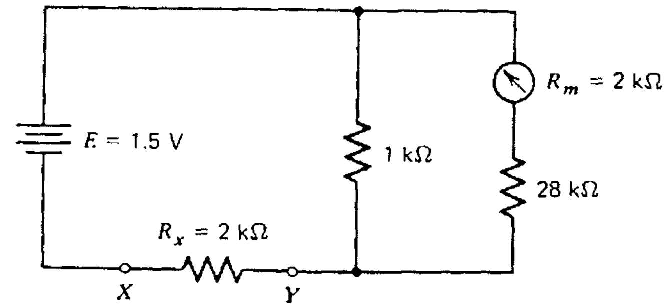

FIGURE 2-23 Ohmmeter on $R \times 100$ range.

As can be seen, the current through the meter movement is 16.6 μA in each situation in Example 2-14. This means the meter face is marked as 20 Ω at 33.2% of full-scale deflection.

When the ohmmeter is on the $R \times 1$ range, a reading of 20 Ω times the multiplier of 1 means the unknown resistor has a value of 20 Ω. When the ohmmeter is on the $R \times 10$ range, a reading of 20 Ω times the multiplier of 10 means the unknown resistor has a value of 200 Ω. Similarly, when the ohmmeter is on the $R \times 100$ range, a reading of 20 Ω times the multiplier of 100 means the unknown resistor has a value of 2 kΩ. The important thing to note is that a multiple-range ohmmeter may have a *single* scale for *all* ranges.

2-11 THE MULTIMETER

Thus far in Chapter 2 we have discussed the ammeter, the voltmeter, and the ohmmeter. All these instruments have one thing in common. Each uses the *same* basic current-sensitive d'Arsonval meter movement. Therefore, it might seem reasonable, given a proper switching arrangement, to combine the three circuits in a *single instrument*. The **multimeter** or volt–ohm–milliammeter (VOM) is such an instrument. It is a general-purpose test instrument that has the necessary circuitry to measure ac or dc voltage, direct current, or resistance.

A typical commercial VOM of laboratory quality is normally designed around a basic 50-μA meter movement. The Simpson, Model 260 (shown in Fig. 2-24), is a typical general-purpose VOM. The instrument uses a 50-μA meter movement and therefore has a sensitivity of 20 kΩ/V on the dc voltage ranges. It is capable of a wide range of measurements, as shown in Table 2-2.

TABLE 2-2
Simpson 260 Measurement Ranges

Direct current	0–50 μA, 0–1/10/100/500 mA, 0–10 A
Dc volts	0–250 mV, 0–2.6/10/50/250/1000/5000 V
Ac volts	0–2.5/100/50/250/1000/5000 V
Ohms	$R \times 1$, $R \times 100$, $R \times 10{,}000$

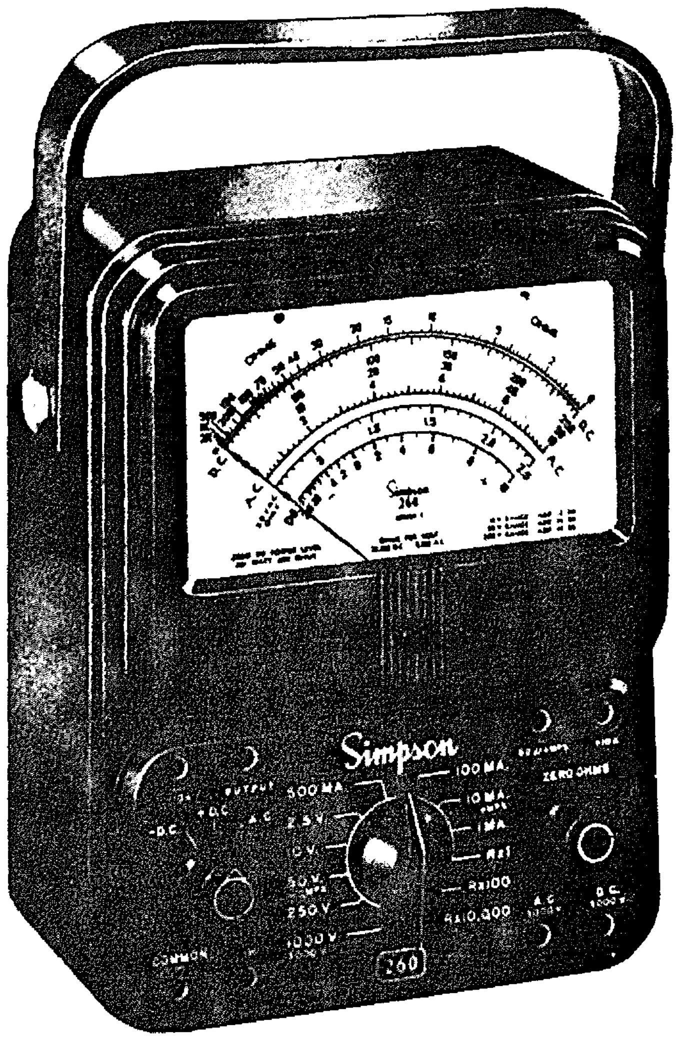

FIGURE 2-24 Typical laboratory-quality VOM (Simpson Model 260). (Courtesy Simpson Electric Company.)

which lists 22 ranges for measuring voltage, current, and resistance as well as additional ranges for measuring audio-frequency output voltage and sound level.

2 CALIBRATION OF DC INSTRUMENTS

Although the actual techniques for calibrating instruments using the d'Arsonval meter movement are covered in subsequent chapters, we introduce the topic here since we have just discussed dc instruments.

Calibration means to compare a given instrument against a *standard* instrument to determine its accuracy. A dc voltmeter may be calibrated by comparing it with one of the standards discussed in Section 1-5 or with a potentiometer as described in Section 4.3. The circuit shown in Fig. 2-25 may be used to calibrate a dc voltmeter, the test voltmeter reading, *V*, is compared to the voltage reading obtained with the standard instrument, *M*.

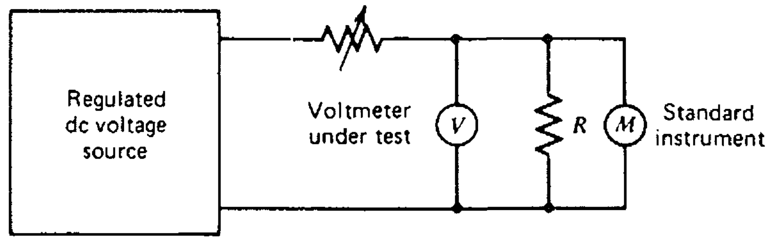

FIGURE 2-25 Calibration circuit for a dc voltmeter.

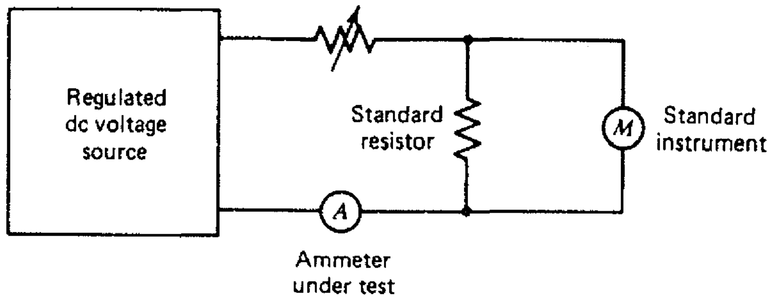

FIGURE 2-26 Calibration circuit for a dc ammeter.

A dc ammeter is usually calibrated by using a standard resistor R_s and either a standard voltmeter or a potentiometer *M*. The circuit shown in Fig. 2-26 may be used to calibrate an ammeter. The test ammeter reading, *A*, is compared to the calculated Ohm's law current from the voltage reading obtained across the known standard resistor using the standard voltmeter *M*.

The ohmmeter circuit designed around the d'Arsonval meter movement is usually considered to be an instrument of moderate accuracy. The accuracy of the instrument may be checked by measuring different values of standard resistance and noting the reading obtained. However, when precise resistance measurements are required, a comparison-type resistance measurement using a bridge is preferable (see Chapter 5 on bridges).

2-13 APPLICATIONS

The most fundamental applications of the instruments designed around the d'Arsonval meter movement are implied by the names of the instruments—voltmeter, ammeter, and ohmmeter. The purpose of this section is to point out some applications that may not be quite as obvious. These will show you the versatility of the instruments and help you to adapt them to your own needs.

2-13.1 Electrolytic Capacitor Leakage Tests

A current meter may be used to measure the leakage current of electrolytic capacitors. The leakage current depends on the voltage rating of the capacitor and its capacitance value. The test voltage applied to the capacitor should be near the dc-rated value for the capacitor. After the capacitor charges to the

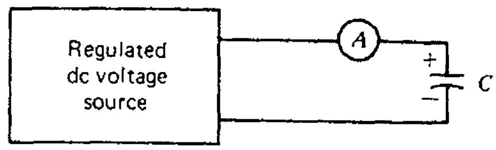

FIGURE 2-27 Circuit for determining leakage current for an electrolytic capacitor.

supply voltage, ideally the flow of current should stop; however, because of capacitor leakage, a small current continues to exist.

Because of the design of electrolytic capacitors, they tend to have a relatively high leakage current. As a rule of thumb, the *acceptable* leakage current for electrolytic capacitors when tested as in Fig. 2-27 is

1. Capactiors rated at 300 V or higher—0.5 mA.
2. Capacitors rated at 100 to 300 V—0.2 mA.
3. Capacitors rated at less than 100 V—0.1 mA.

2-13.2 Nonelectrolytic Capacitor Leakage Tests

A voltmeter may be used to check for leakage current across the plates of nonelectrolytic capacitors (paper, molded composition, mica, etc.). The leakage of a capacitor may be expressed in terms of its equivalent resistance. If we apply a dc voltage across a series circuit consisting of a capacitor suspected of being leaky, and a dc voltmeter, as shown in Fig. 2-28, the applied voltage will be divided across this voltage divider network according to the ratio of the resistance (after charging) in series with the input resistance of the voltage. Therefore, all the applied voltage will appear across the capacitor. If the capacitor is leaky, a voltage reading will be obtained on the voltmeter because of the flow of current. The equivalent resistance that the capacitor represents can be computed from

$$R = R_{\text{in}} \frac{E - V}{V} \ (\Omega) \qquad (2\text{-}15)$$

where

R = capacitor's equivalent resistance, Ω
R_{in} = input resistance of the voltmeter, Ω
E = applied dc voltage, volts
V = voltmeter reading, volts

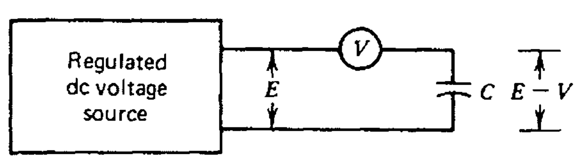

FIGURE 2-28 Circuit for determining leakage current of a nonelectrolytic capacitor.

The equivalent resistance R of a nonelectrolytic capacitor should be on the order of 100 MΩ or higher. Therefore, if an equivalent resistance value of less than, say 80 MΩ, is obtained, the capacitor should be suspect.

2-13.3 Using the Ohmmeter for Continuity Checks

An important application of the ohmmeter is to check *continuity* on such components as lamps or fuses when troubleshooting. An open filament on a lamp or a burned-out fuse, a switch contact, or a coil may appear acceptable upon visual inspections but may actually be faulty. A continuity check with an ohmmeter would indicate whether an "open" exists.

Continuity checks can also be made on test leads, oscilloscope probes, coaxial cables, multiconductor cables, ac cords, and many other devices. An ohmmeter check for continuity is made by setting the resistance switch to a suitable scale, and placing the test probes at two points between which continuity is being checked, as shown in Fig. 2-29. A full-scale reading on the ohmmeter indicates continuity.

2-13.4 Using the Ohmmeter to Check Semiconductor Diodes

The ohmmeter is frequently used to make quick checks on semiconductor diodes. The question of which (unmarked) terminal of a semiconductor diode is the anode and which is the cathode frequently comes up. The ohmmeter can be used to answer this question very easily. If the positive lead of the ohmmeter is connected to the anode (p material) of the diode and the common terminal of the ohmmeter is connected to the cathode (n material), the ohmmeter should indicate a relatively *low* value of *forward* (bias) resistance. If the ohmmeter leads are reversed, the ohmmeter should indicate a high value of *reverse* (bias) resistance. These measurements are shown in Fig. 2-30.

This test also distinguishes between a good and a defective diode. A good diode will have a high ratio of reverse to forward resistance, a defective diode a low ratio.

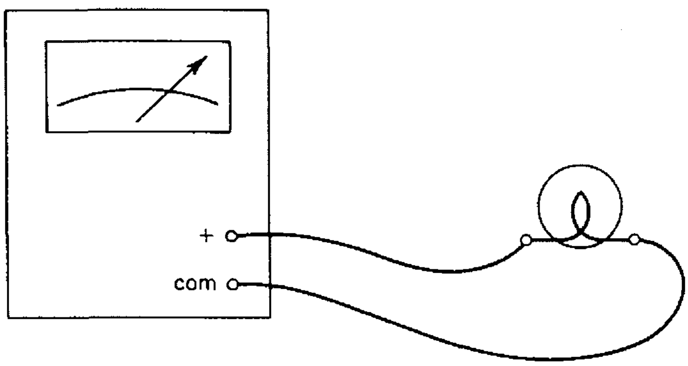

FIGURE 2-29 Continuity check on a lamp filament.

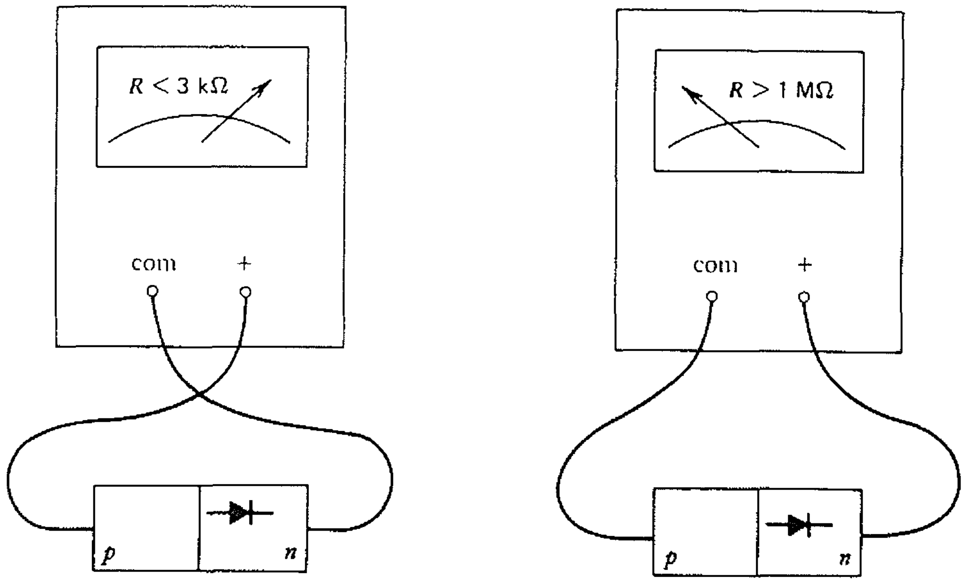

FIGURE 2-30 Checking a semiconductor diode for forward- and reverse-biased conditions.

SUMMARY

The basic d'Arsonval *meter movement* is a *current*-sensitive device capable of directly measuring only very small currents. Its usefulness as a measuring device is greatly increased with the proper external circuitry. Large currents can be measured by adding *shunts*. Voltages can be measured by adding *multipliers*. Resistance can be measured by adding a *battery* and a *resistance* network.

All ammeters and voltmeters introduce some error into any circuit under test because the meter *loads* the circuit—this is a common instrumentation problem. The effects of voltmeter loading may be reduced by using a voltmeter with a sensitivity rating of 20 kΩ/V or greater. Most laboratory-quality, commercial multimeters have sensitivity ratings of this value or higher.

GLOSSARY

Ammeter: An instrument for measuring current, using a basic movement and shunts.

Ayrton shunt: A shunt arrangement, also called a universal shunt, that prevents a meter movement from being used with no shunt.

d'Arsonval meter movement: A device consisting of a permanent horseshoe magnet and a movable electromagnetic coil that rotates about a magnetic core. A pointer is attached to the movable coil.

Internal resistance: The resistance within the meter movement caused mostly by the resistance of the fine wire used to wind the electromagnetic moving coil.

Loading error: The error (or disturbance to original conditions) caused by placing an ammeter in a circuit to obtain a measurement.

Multimeter: An instrument containing the proper circuitry in a single enclosure to obtain voltage, current, and resistance measurements. Usually designed around the d'Arsonval meter movement.

Multiplier: A resistor placed in series with a basic meter movement to extend the voltage range of a basic meter movement.

Ohmmeter: An instrument, designed around a basic meter movement, that is capable of measuring resistance.

Sensitivity: The reciprocal of the full-scale deflection current expressed in units of ohms per volt. A measure of the instrument indication (deflection) to a change in current.

Shunt: A resistor placed in parallel (shunt) with a basic meter movement to extend the current range of the basic meter movement.

Voltmeter: An instrument, using a basic meter movement and multipliers, that is capable of measuring voltage.

2-16 REVIEW QUESTIONS

The following review questions relate to the material in the chapter. Readers should answer these questions after study of the chapter to determine their comprehension of the material.

1. List two types of suspension system used with the d'Arsonval meter movement.
2. Describe briefly the principle of operation of d'Arsonval meter movements.
3. How can the basic d'Arsonval meter movement be used to measure high-amplitude currents?
4. How can the d'Arsonval meter movement be used to measure voltages?
5. How can the d'Arsonval meter movement be used to measure resistance?
6. What is meant by sensitivity? What are its units of measurement?
7. What effect, if any, does connecting a voltmeter across a resistor in a circuit have on the current through the resistor?
8. What effect, if any, does connecting an ammeter in series with a resistor in a circuit have on the current through the resistor?
9. What is the purpose of the zeroing resistor in an ohmmeter and does it always accomplish its intended purpose?

10. What is the significance of midscale deflection on any ohmmeter range?
11. How can a person check whether a voltmeter is introducing error through loading?

2.17 PROBLEMS

2-1 Calculate the voltage drop developed across a d'Arsonval meter movement having an internal resistance of 850 Ω and a full-scale deflection current of 100 μA.

2-2 Find the resistance of a multiplier required to convert a 200-μA meter movement into a 0- to 150-V dc voltmeter, if $R_m = 1$ kΩ.

2-3 Calculate the half-scale current of a meter movement that has a sensitivity of 20 kΩ/V.

2-4 Find the value of shunt resistance required to convert a 1-mA meter movement with an internal resistance of 105 Ω into a 0- to 150-mA meter current.

2-5 Which meter has a greater sensitivity: meter A having a range of 0 to 10 V and a multiplier resistor of 18 kΩ, or meter B with a range of 0 to 300 V and a 298-kΩ multiplier resistor? Both meter movements have an internal resistance of 2 kΩ.

2-6 Find the currents through meters A and B in the circuit of Fig. 2-31.

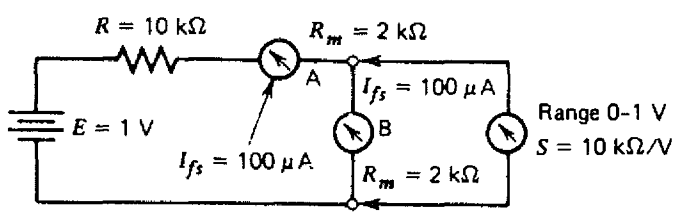

FIGURE 2-31 Circuit for Problem 2-6.

2-7 Calculate the value of the resistors R_1 through R_5 in the circuit of Fig. 2-32.

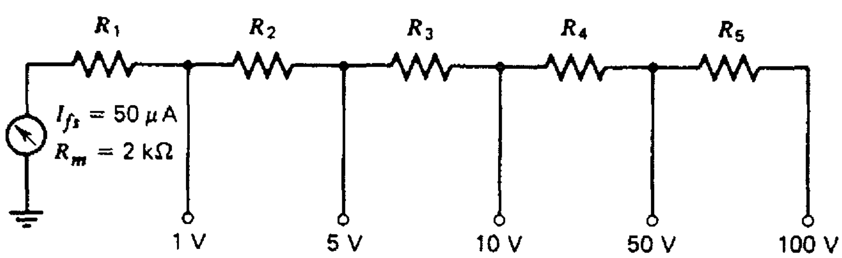

FIGURE 2-32 Circuit for Problem 2-7.

2-8 Calculate the value of the resistors R_1 through R_3 in the circuit of Fig. 2-33.

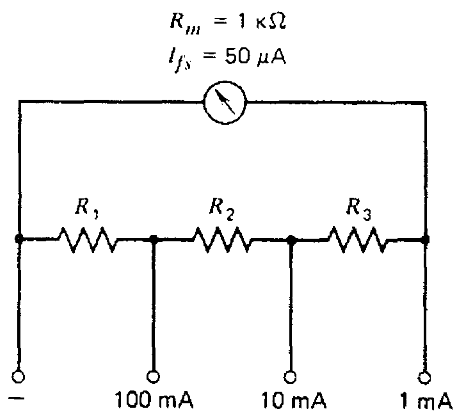

FIGURE 2-33 Circuit for Problem 2-8.

2-9 Calculate the value of the resistors R_1 through R_4 in the circuit of Fig. 2-34.

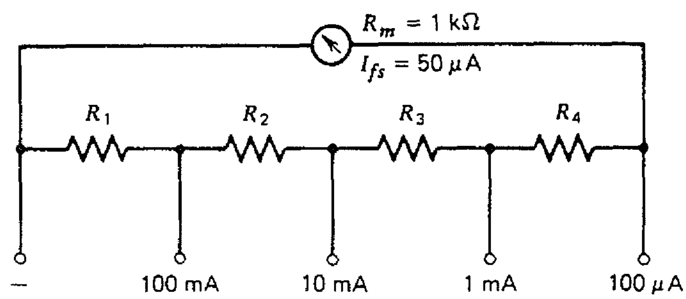

FIGURE 2-34 Circuit for Problem 2-9.

2-10 In the circuit of Fig. 2-35, what is the value of R_x if the meter reads half-scale?

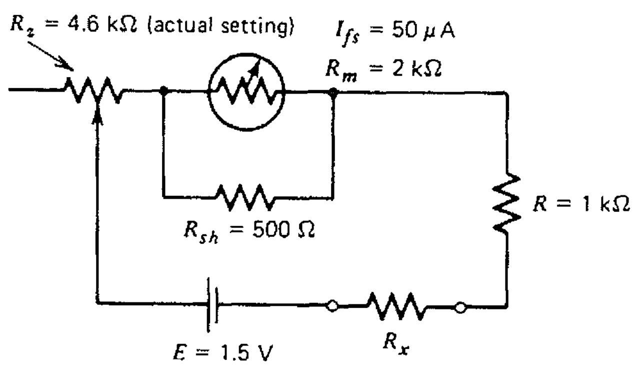

FIGURE 2-35 Circuit for Problem 2-10.

2-11 A voltage reading is to be taken across the 6-kΩ resistor in the circuit of Fig. 2-36. A voltmeter with a sensitivity of 10 kΩ/V is to be used. If the instrument has ranges of 1 V, 5 V, 10 V, and 100 V, what is the most sensitive range that may be used to obtain a reading having less than 3% error owing to voltmeter loading?

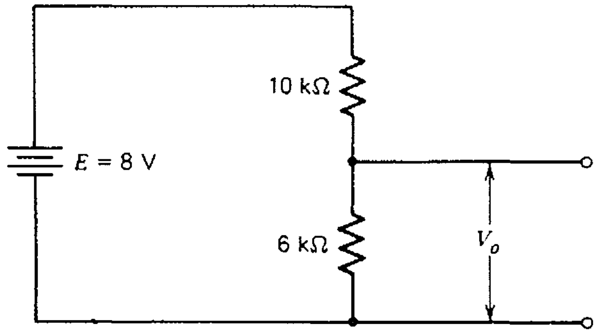

FIGURE 2-36 Circuit for Problem 2-11.

2-12 In the circuit of Fig. 2-37, voltmeter A having a sensitivity of 5 kΩ/V is connected to points X and Y and indicates 15 V on its 30-V range. Voltmeter B is then connected to points X and Y and indicates 16.13 V on its 50-V range. Find the sensitivity of voltmeter B.

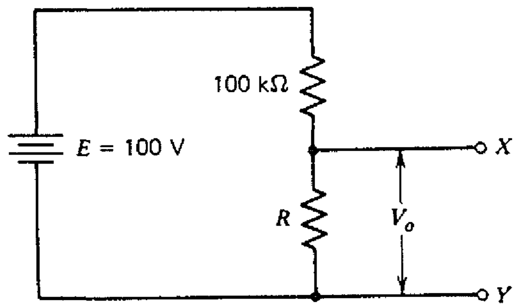

FIGURE 2-37 Circuit for Problem 2-12.

2-13 A voltage reading is to be taken across the 50-kΩ resistor in the circuit of Fig. 2-38. A voltmeter with a sensitivity of 20 kΩ/V and a guaranteed accuracy of ±2% at full scale is to be used on its 10-V range. What is the minimum voltmeter reading that could be expected?

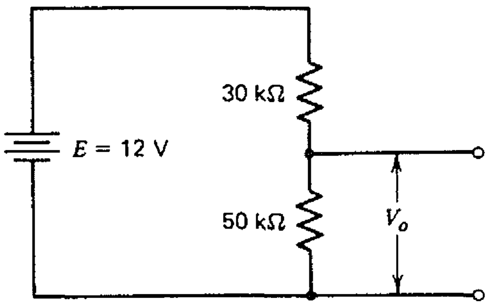

FIGURE 2-38 Circuit for Problem 2-13.

8 LABORATORY EXPERIMENTS

Experiments E3 and E4, which are found at the back of the text, deal specifically with the theory presented in Chapter 2. These experiments are intended to provide students with hands-on experience, which is essential for a thorough understanding of the concepts involved.

The experiments require no special equipment; therefore, the equipment should be found in almost any electronics laboratory. One comment might be in order—the resistance values for the shunts on the multimeter experiment are **standard** EIA commercial values for composition resistors. However, they may not be values that are ordinarily stocked in the laboratory. Because they are standard, they are easily purchased.

The contents of the laboratory report to be submitted by each student are listed at the end of each experimental procedure. The troubleshooting procedure is necessary only for problems requiring circuits or measurements.