* Effects of Meter Resistance

PHYSICS APPLIED
Correcting for meter resistance

It is important to know the sensitivity of a meter, for in many cases the resistance of the meter can seriously affect your results. Take the following Example.

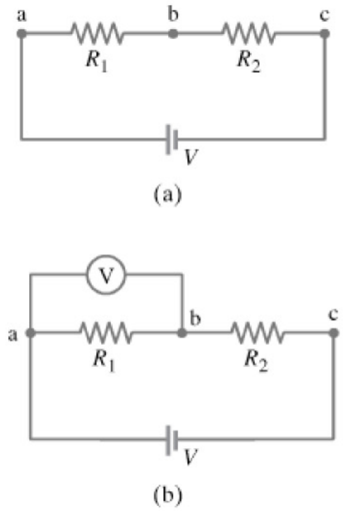

FIGURE 19–34 Example 19–15.

EXAMPLE 19–15 **Voltage reading versus true voltage.** Suppose you are testing an electronic circuit which has two resistors, R_1 and R_2, each 15 kΩ, connected in series as shown in Fig. 19–34a. The battery maintains 8.0 V across them and has negligible internal resistance. A voltmeter whose sensitivity is 10,000 Ω/V is put on the 5.0-V scale. What voltage does the meter read when connected across R_1, Fig. 19–34b, and what error is caused by the finite resistance of the meter?

APPROACH The meter acts as a resistor in parallel with R_1. We use parallel and series resistor analyses and Ohm's law to find currents and voltages.

SOLUTION On the 5.0-V scale, the voltmeter has an internal resistance of $(5.0\,\text{V})(10{,}000\,\Omega/\text{V}) = 50{,}000\,\Omega$. When connected across R_1, as in Fig. 19–34b, we have this $50\,\text{k}\Omega$ in parallel with $R_1 = 15\,\text{k}\Omega$. The net resistance R_{eq} of these two is given by

$$\frac{1}{R_{\text{eq}}} = \frac{1}{50\,\text{k}\Omega} + \frac{1}{15\,\text{k}\Omega} = \frac{13}{150\,\text{k}\Omega};$$

so $R_{\text{eq}} = 11.5\,\text{k}\Omega$. This $R_{\text{eq}} = 11.5\,\text{k}\Omega$ is in series with $R_2 = 15\,\text{k}\Omega$, so the total resistance of the circuit is now $26.5\,\text{k}\Omega$ (instead of the original $30\,\text{k}\Omega$). Hence the current from the battery is

$$I = \frac{8.0\,\text{V}}{26.5\,\text{k}\Omega} = 3.0 \times 10^{-4}\,\text{A} = 0.30\,\text{mA}.$$

Then the voltage drop across R_1, which is the same as that across the voltmeter, is $(3.0 \times 10^{-4}\,\text{A})(11.5 \times 10^3\,\Omega) = 3.5\,\text{V}$. [The voltage drop across R_2 is $(3.0 \times 10^{-4}\,\text{A})(15 \times 10^3\,\Omega) = 4.5\,\text{V}$, for a total of 8.0 V.] If we assume the meter is precise, it will read 3.5 V. In the original circuit, without the meter, $R_1 = R_2$ so the voltage across R_1 is half that of the battery, or 4.0 V. Thus the voltmeter, because of its internal resistance, gives a low reading. In this case it is off by 0.5 V, or more than 10%.

Example 19–15 illustrates how seriously a meter can affect a circuit and give a misleading reading. If the resistance of a voltmeter is much higher than the resistance of the circuit, however, it will have little effect and its readings can be trusted, at least to the manufactured precision of the meter, which for ordinary analog meters is typically 3% to 4% of full-scale deflection. An ammeter also can interfere with a circuit, but the effect is minimal if its resistance is much less than that of the circuit as a whole. For both voltmeters and ammeters, the more sensitive the galvanometer, the less effect it will have. A 50,000-Ω/V meter is far better than a 1000-Ω/V meter.

* Digital Meters

Digital meters (see Fig. 19–29b) are used in the same way as analog meters: they are inserted directly into the circuit, in series, to measure current (Fig. 19–33b), and connected "outside," in parallel with the circuit, to measure voltage (Fig. 19–33c).

The internal construction of digital meters, however, is different from that of analog meters in that digital meters do not use a galvanometer. The electronic circuitry and digital readout are more sensitive than the galvanometer and its needle that they replace, and have less effect on the circuit to be measured. When we measure dc voltages, the meter's resistance is very high, commonly on the order of 10 to 100 MΩ $(10^7\text{–}10^8\,\Omega)$. This internal resistance doesn't change significantly when different voltage scales are selected (as it does for analog