CHAPTER 21: CIRCUITS, BIOELECTRICITY, AND DC INSTRUMENTS

21.1 RESISTORS IN SERIES AND PARALLEL

1. *(a) What is the resistance of ten $275\text{-}\Omega$ resistors connected in series? (b) In parallel?*

Solution (a) From the equation $R_s = R_1 + R_2 + R_3 + \ldots$ we know that resistors in series add:

$$R_s = R_1 + R_2 + R_3 + \ldots\ldots\ldots + R_{10} = (275\,\Omega)(10) = \underline{2.75\,\text{k}\Omega}$$

(b) From the equation $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots.$, we know that resistors in series add like:

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots\ldots\ldots + \frac{1}{R_{10}} = (10)\left(\frac{1}{275\,\Omega}\right) = 3.64\times10^{-2}/\Omega$$

So that $R_p = \left(\frac{1}{3.64\times10^{-2}}\right)\Omega = \underline{27.5\,\Omega}$

7. *Referring to the example combining series and parallel circuits and Figure 21.6, calculate I_3 in the following two different ways: (a) from the known values of I and I_2; (b) using Ohm's law for R_3. In both parts explicitly show how you follow the steps in the Problem-Solving Strategies for Series and Parallel Resistors.*

Solution ***Step 1:*** The circuit diagram is drawn in Figure 21.6.

Step 2: Find I_3.

Step 3: Resistors R_2 and R_3 are in parallel. Then, resistor R_1 is in series with the combination of R_2 and R_3.

Step 4:

(a) Looking at the point where the wire comes into the parallel combination of R_2 and R_3, we see that the current coming in I is equal to the current going out I_2 and I_3, so that $I = I_2 + I_3$, or $I_3 = -I_2 = 2.35\text{ A} - 1.61\text{ A} = \underline{0.74\text{ A}}$

(b) Using Ohm's law for R_3, and voltage for the combination of R_2 and R_3, found in Example 21.3, we can determine the current: $I_3 = \frac{V_p}{R_3} = \frac{9.65\text{ V}}{13.0\,\Omega} = \underline{0.742\text{ A}}$

Step 5: The result is reasonable because it is smaller than the incoming current, I, and both methods produce the same answer.

21.2 ELECTROMOTIVE FORCE: TERMINAL VOLTAGE

15. *Carbon-zinc dry cells (sometimes referred to as non-alkaline cells) have an emf of 1.54 V, and they are produced as single cells or in various combinations to form other voltages. (a) How many 1.54-V cells are needed to make the common 9-V battery used in many small electronic devices? (b) What is the actual emf of the approximately 9-V battery? (c) Discuss how internal resistance in the series connection of cells will affect the terminal voltage of this approximately 9-V battery.*

Solution (a) To determine the number simply divide the 9-V by the emf of each cell:

$$9\text{ V} \div 1.54\text{ V} = 5.84 \Rightarrow \underline{6}$$

(b) If six dry cells are put in series , the actual emf is $1.54\text{ V} \times 6 = \underline{9.24\text{ V}}$

(c) Internal resistance will decrease the terminal voltage because there will be voltage drops across the internal resistance that will not be useful in the operation of the 9-V battery.

30. ***Unreasonable Results*** *(a) What is the internal resistance of a 1.54-V dry cell that supplies 1.00 W of power to a* $15.0\text{-}\Omega$ *bulb? (b) What is unreasonable about this result? (c) Which assumptions are unreasonable or inconsistent?*

Solution (a) Using the equation $P = I^2 R$, we have $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{1.00\text{ W}}{15.0\,\Omega}} = 0.258\text{ A}$. So using Ohm's Law and $V = E - Ir$ we have

$$V = E - Ir = IR\text{, or: } r = \frac{E}{I} - R = \frac{1.54\text{ V}}{0.258\text{ A}} - 15.0\,\Omega = \underline{-9.04\,\Omega}$$

(b) You cannot have negative resistance.

(c) The voltage should be less than the emf of the battery; otherwise the internal resistance comes out negative. Therefore, the power delivered is too large for the given resistance, leading to a current that is too large.

21.3 KIRCHHOFF'S RULES

31. *Apply the loop rule to loop abcdefgha in Figure 21.25.*

Solution Using the loop rule for loop abcdefgha in Figure 21.25 gives:

$$\underline{-I_2R_3 + E_1 - I_2r_1 + I_3r_3 + I_3r_2 - E_2 = 0}$$

37. *Apply the loop rule to loop akledcba in Figure 21.52.*

Solution Using the loop rule to loop akledcba in Figure 21.52 gives:

$$\underline{E_2 - I_2r_2 - I_2R_2 + I_1R_5 + I_1r_1 - E_1 + I_1R_1 = 0}$$

21.4 DC VOLTMETERS AND AMMETERS

44. *Find the resistance that must be placed in series with a* $25.0\text{-}\Omega$ *galvanometer having a* $50.0\text{-}\mu\text{A}$ *sensitivity (the same as the one discussed in the text) to allow it to be used as a voltmeter with a 0.100-V full-scale reading.*

Solution We are given $r = 25.0\ \Omega$, $V = 0.200\ \text{V}$, and $I = 50.0\ \mu\text{A}$.

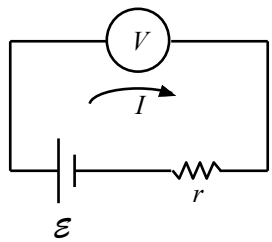
Since the resistors are in series, the total resistance for the voltmeter is found by using $R_s = R_1 + R_2 + R_3 + \ldots$. So, using Ohm's law we can find the resistance R:

$$R_{tot} = R + r = \frac{V}{I}, \text{so that } R = \frac{V}{I} - r = \frac{0.100\ \text{V}}{5.00 \times 10^{-5}\ \text{A}} - 25.0\ \Omega = 1975\ \Omega = \underline{1.98\ \text{k}\Omega}$$

50. *Suppose you measure the terminal voltage of a 1.585-V alkaline cell having an internal resistance of* $0.100\ \Omega$ *by placing a* $1.00\text{-k}\ \Omega$ *voltmeter across its terminals. (Figure 21.54.) (a) What current flows? (b) Find the terminal voltage. (c) To see how close the measured terminal voltage is to the emf, calculate their ratio.*

Solution

(a)



Going counterclockwise around the loop using the loop rule gives:

$$-E + Ir + IR = 0, \text{ or}$$

$$I = \frac{E}{R + r} = \frac{1.585\ \text{V}}{(1.00 \times 10^3\ \Omega) + 0.100\ \Omega} = 1.5848 \times 10^3\ \text{A} = \underline{1.58 \times 10^3\ \text{A}}$$

(b) The terminal voltage is given by the equation $V = E - Ir$:

$$V = E - Ir = 1.585\ \text{V} - (1.5848 \times 10^3\ \text{A})(0.100\ \Omega) = \underline{1.5848\ \text{V}}$$

Note: The answer is reported to 5 significant figures to see the difference.

(c) To calculate the ratio, divide the terminal voltage by the emf:

$$\frac{V}{E} = \frac{1.5848\ \text{V}}{1.585\ \text{V}} = \underline{0.99990}$$

21.5 NULL MEASUREMENTS

58. *Calculate the* emf_x *of a dry cell for which a potentiometer is balanced when* $R_x = 1.200\,\Omega$*, while an alkaline standard cell with an emf of 1.600 V requires* $R_s = 1.247\,\Omega$ *to balance the potentiometer.*

Solution We know $E_x = IR_x$ and $E_s = IR_s$, so that

$$\frac{E_x}{E_s} = \frac{I_x}{I_s} = \frac{R_x}{R_s}, \text{ or } E_x = E_s\left(\frac{R_x}{R_s}\right) = (1.600\text{ V})\left(\frac{1.200\,\Omega}{1.247\,\Omega}\right) = \underline{1.540\text{ V}}$$

21.6 DC CIRCUITS CONTAINING RESISTORS AND CAPACITORS

63. *The timing device in an automobile's intermittent wiper system is based on an* RC *time constant and utilizes a* $0.500\text{-}\mu\text{F}$ *capacitor and a variable resistor. Over what range must* R *be made to vary to achieve time constants from 2.00 to 15.0 s?*

Solution From the equation $\tau = RC$, we know that:

$$R = \frac{\tau}{C} = \frac{2.00\text{ s}}{5.00\times10^{-7}\text{ F}} = 4.00\times10^{6}\ \Omega \text{ and } R = \frac{\tau}{C} = \frac{15.0\text{ s}}{5.00\times10^{-7}\text{ F}} = 3.00\times10^{7}\ \Omega$$

Therefore, the range for R is: $\underline{4.00\times10^{6}\ \Omega - 3.00\times10^{7}\ \Omega} = \underline{4.00 \text{ to } 30.0\text{ M}\Omega}$

69. *A heart defibrillator being used on a patient has an* RC *time constant of 10.0 ms due to the resistance of the patient and the capacitance of the defibrillator. (a) If the defibrillator has an* $8.00\text{-}\mu\text{F}$ *capacitance, what is the resistance of the path through the patient? (You may neglect the capacitance of the patient and the resistance of the defibrillator.) (b) If the initial voltage is 12.0 kV, how long does it take to decline to* 6.00×10^{2} V *?*

Solution (a) Using the equation $\tau = RC$ we can calculate the resistance:

$$R = \frac{\tau}{C} = \frac{1.00\times10^{-2}\text{ s}}{8.00\times10^{-6}\text{ F}} = 1.25\times10^{3}\ \Omega = \underline{1.25\text{ k}\Omega}$$

(b) Using the equation $V = V_0 e^{-\tau/RC}$, we can calculate the time it takes for the voltage to drop from $12.0\text{ kV to }600\text{ V}$:

$$\tau = -RC\ \ln\left(\frac{V}{V_0}\right)$$

$$= -\left(1.25\times10^{3}\ \Omega\right)\left(8.00\times10^{-6}\text{ F}\right)\ln\left(\frac{600\text{ V}}{1.20\times10^{4}\text{ V}}\right) = 2.996\times10^{-2}\text{ s} = \underline{30.0\text{ ms}}$$

74. ***Integrated Concepts*** *If you wish to take a picture of a bullet traveling at 500 m/s, then a very brief flash of light produced by an RC discharge through a flash tube can limit blurring. Assuming 1.00 mm of motion during one RC constant is acceptable, and given that the flash is driven by a $600\text{-}\mu\text{F}$ capacitor, what is the resistance in the flash tube?*

Solution Using $c = \frac{x}{t}$ or $t = \frac{x}{v}$ and the equation for the time constant, we can write the time constant as $\tau = RC$, so getting these two times equal gives an expression from which we can solve for the required resistance:

$$\frac{x}{v} = RC, \text{or } R = \frac{x}{vC} = \frac{1.00\times10^{-3}\text{ m}}{(500\text{ m/s})(6.00\times10^{-4}\text{ F})} = \underline{3.33\times10^{-3}\ \Omega}$$