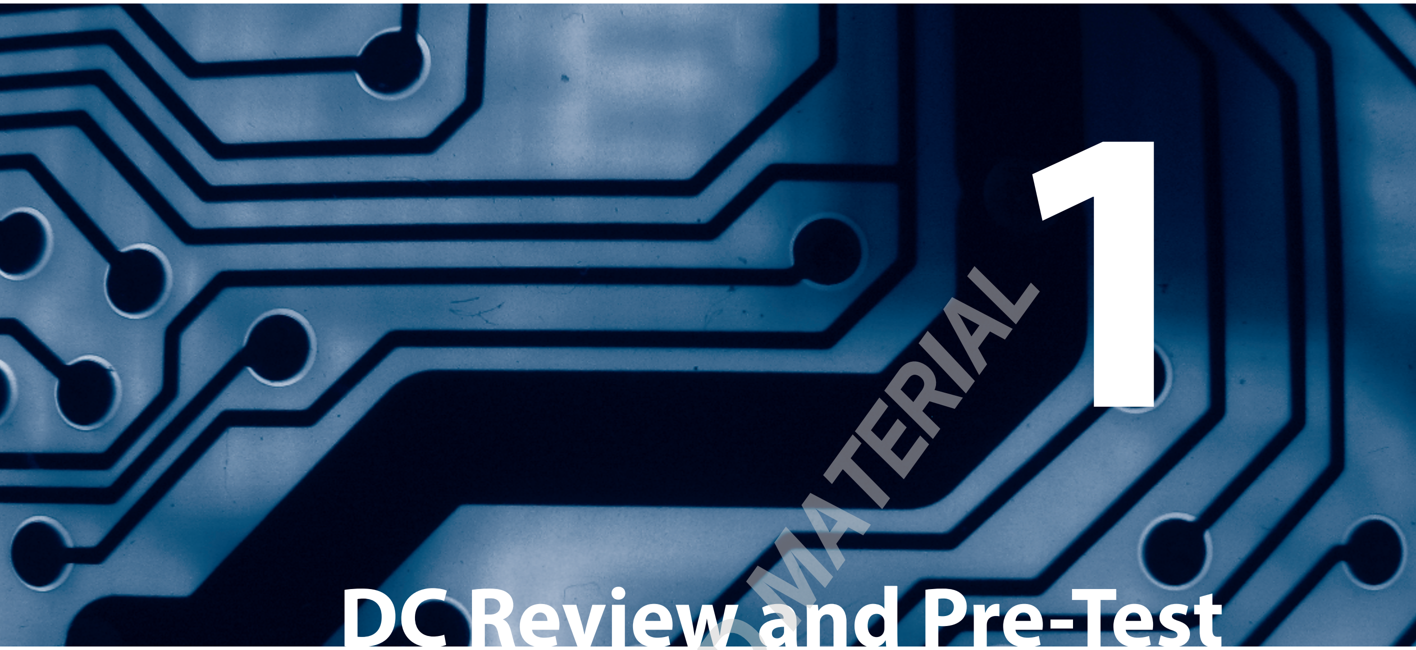


1 DC Review and Pre-Test

Electronics cannot be studied without first understanding the basics of electricity. This chapter is a review and pre-test on those aspects of direct current (DC) that apply to electronics. By no means does it cover the whole DC theory, but merely those topics that are essential to simple electronics.

This chapter reviews the following:

- Current flow
- Potential or voltage difference
- Ohm's law
- Resistors in series and parallel

- Power
- Small currents
- Resistance graphs
- Kirchhoff's Voltage Law
- Kirchhoff's Current Law
- Voltage and current dividers
- Switches
- Capacitor charging and discharging
- Capacitors in series and parallel

CURRENT FLOW

1 Electrical and electronic devices work because of an electric current.

QUESTION

What is an electric current? ____

____

ANSWER

An *electric current* is a flow of electric charge. The electric charge usually consists of negatively charged electrons. However, in semiconductors, there are also positive charge carriers called *holes*.

2 There are several methods that can be used to generate an electric current.

QUESTION

Write at least three ways an electron flow (or current) can be generated. ____________

____

____

____

ANSWER

The following is a list of the most common ways to generate current:

- *Magnetically*—This includes the induction of electrons in a wire rotating within a magnetic field. An example of this would be generators turned by water, wind, or steam, or the fan belt in a car.
- *Chemically*—This involves the electrochemical generation of electrons by reactions between chemicals and electrodes (as in batteries).
- *Photovoltaic generation of electrons*—This occurs when light strikes semiconductor crystals (as in solar cells).

Less common methods to generate an electric current include the following:

- *Thermal generation*—This uses temperature differences between thermocouple junctions. Thermal generation is used in generators on spacecrafts that are fueled by radioactive material.
- *Electrochemical reaction*—This occurs between hydrogen, oxygen, and electrodes (fuel cells).
- *Piezoelectrical*—This involves mechanical deformation of piezoelectric substances. For example, piezoelectric material in the heels of shoes power LEDs that light up when you walk.

3 Most of the simple examples in this book contain a battery as the voltage source. As such, the source provides a potential difference to a circuit that enables a current to flow. An *electric current* is a flow of electric charge. In the case of a battery, electrons are the electric charge, and they flow from the terminal that has an excess number of electrons to the terminal that has a deficiency of electrons. This flow takes place in any complete circuit that is connected to battery terminals. It is this difference in the charge that creates the potential difference in the battery. The electrons try to balance the difference.

Because electrons have a negative charge, they actually flow from the negative terminal and return to the positive terminal. This direction of flow is called *electron flow*. Most books, however, use current flow, which is in the opposite direction. It is referred to as *conventional current flow*, or simply current flow. In this book, the term conventional current flow is used in all circuits.

Later in this book, you see that many semiconductor devices have a symbol that contains an arrowhead pointing in the direction of conventional current flow.

QUESTIONS

A. Draw arrows to show the current flow in Figure 1.1. The symbol for the battery shows its polarity.

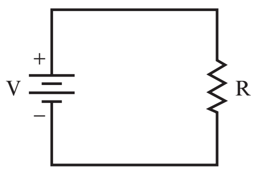


FIGURE 1.1

B. What indicates that a potential difference is present? ______________________________

____

C. What does the potential difference cause? ______________________________

____

D. What will happen if the battery is reversed? ______________________________

____

ANSWERS

A. See Figure 1.2.

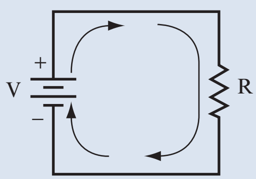


FIGURE 1.2

B. The battery symbol indicates that a difference of potential (also called *voltage*) is being supplied to the circuit.

C. Voltage causes current to flow if there is a complete circuit present, as shown in Figure 1.1.

D. The current flows in the opposite direction.

OHM'S LAW

4 Ohm's law states the fundamental relationship between voltage, current, and resistance.

QUESTION

What is the algebraic formula for Ohm's law? ______________________________

____

ANSWER

$V = I \times R$

This is the most basic equation in electricity, and you should know it well. Some electronics books state Ohm's law as $E = IR$. E and V are both symbols for voltage. This book uses V to indicate voltage. When V is used after a number in equations and circuit diagrams, it represents volts, the unit of measurement of voltage. Also, in this formula, resistance is the opposition to current flow. Larger resistance results in smaller current for any given voltage.

5 Use Ohm's law to find the answers in this problem.

QUESTIONS

What is the voltage for each combination of resistance and current values?

A. R = 20 ohms, I = 0.5 amperes

V = ____

B. R = 560 ohms, I = 0.02 amperes

V = ____

C. R = 1,000 ohms, I = 0.01 amperes

V = ____

D. R = 20 ohms I = 1.5 amperes

V = ____

ANSWERS

A. 10 volts

B. 11.2 volts

C. 10 volts

D. 30 volts

6 You can rearrange Ohm's law to calculate current values.

QUESTIONS

What is the current for each combination of voltage and resistance values?

A. V = 1 volt, R = 2 ohms

I = ____________________

B. V = 2 volts, R = 10 ohms

I = ____________________

C. V = 10 volts, R = 3 ohms

I = ____________________

D. V = 120 volts, R = 100 ohms

I = ____________________

ANSWERS

A. 0.5 amperes

B. 0.2 amperes

C. 3.3 amperes

D. 1.2 amperes

7 You can rearrange Ohm's law to calculate resistance values.

QUESTIONS

What is the resistance for each combination of voltage and current values?

A. V = 1 volt, I = 1 ampere

R = ______________________________

B. V = 2 volts, I = 0.5 ampere

R = ______________________________

C. V = 10 volts, I = 3 amperes

R = ______________________________

D. V = 50 volts, I = 20 amperes

R = ______________________________

ANSWERS

A. 1 ohm

B. 4 ohms

C. 3.3 ohms

D. 2.5 ohms

8 Work through these examples. In each case, two factors are given and you must find the third.

QUESTIONS

What are the missing values?

A. 12 volts and 10 ohms. Find the current. ______________________________

____

B. 24 volts and 8 amperes. Find the resistance. ______________________________

____

C. 5 amperes and 75 ohms. Find the voltage. ______________________________

____

ANSWERS

A. 1.2 amperes

B. 3 ohms

C. 375 volts

INSIDE THE RESISTOR

Resistors are used to control the current that flows through a portion of a circuit. You can use Ohm's law to select the value of a resistor that gives you the correct current in a circuit. For a given voltage, the current flowing through a circuit increases when using smaller resistor values and decreases when using larger resistor values.

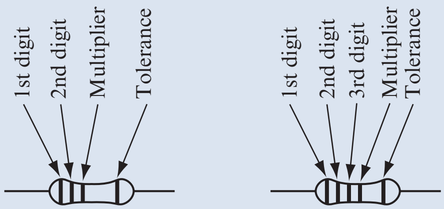
This resistor value works something like pipes that run water through a plumbing system. For example, to deliver the large water flow required by your water heater, you might use a 1-inch diameter pipe. To connect a bathroom sink to the water supply requires much smaller water flow and, therefore, works with a 1/2-inch pipe. In the same way, smaller resistor values (meaning less resistance) increase current flow, whereas larger resistor values (meaning more resistance) decrease the flow.

Tolerance refers to how precise a stated resistor value is. When you buy *fixed resistors* (in contrast to *variable resistors* that are used in some of the projects in this book), they have a particular resistance value. Their tolerance tells you how close to that value their resistance will be. For example, a 1,000-ohm resistor with ± 5 percent tolerance could have a value of anywhere from 950 ohms to 1,050 ohms. A 1,000-ohm resistor with ± 1 percent tolerance (referred to as a *precision resistor*) could have a value ranging anywhere from 990 ohms to 1,010 ohms. Although you are assured that the resistance of a precision resistor will be close to its stated value, the resistor with ± 1 percent tolerance costs more to manufacture and, therefore, costs you more than twice as much as a resistor with ± 5 percent.

Most electronic circuits are designed to work with resistors with ± 5 percent tolerance. The most commonly used type of resistor with ± 5 percent tolerance is called a *carbon film resistor*. This term refers to the manufacturing process in which a carbon film is deposited on an insulator. The thickness and width of the carbon film determines the resistance (the thicker the carbon film, the lower the resistance). Carbon film resistors work well in all the projects in this book.

On the other hand, precision resistors contain a metal film deposited on an insulator. The thickness and width of the metal film determines the resistance. These resistors are called *metal film resistors* and are used in circuits for precision devices such as test instruments.

Resistors are marked with four or five color bands to show the value and tolerance of the resistor, as illustrated in the following figure. The four-band color code is used for most resistors. As shown in the figure, by adding a fifth band, you get a five-band color code. Five-band color codes are used to provide more precise values in precision resistors.



Four band resistor marking

Five band resistor marking

The following table shows the value of each color used in the bands:

Color	Significant Digits	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1 percent
Red	2	100	± 2 percent
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7		
Gray	8		
White	9		
Gold		0.1	± 5 percent
Silver		0.01	± 10 percent

Continued

(continued)

By studying this table, you can see how this code works. For example, if a resistor is marked with orange, blue, brown, and gold bands, its nominal resistance value is 360 ohms with a tolerance of ± 5 percent. If a resistor is marked with red, orange, violet, black, and brown, its nominal resistance value is 237 ohms with a tolerance of ± 1 percent.

RESISTORS IN SERIES

9 You can connect resistors in series. Figure 1.3 shows two resistors in series.

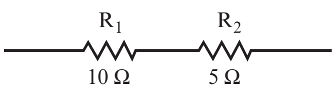


FIGURE 1.3

QUESTION

What is their total resistance? ______________________________

____

ANSWER

$R_T = R_1 + R_2 = 10 \text{ ohms} + 5 \text{ ohms} = 15 \text{ ohms}$

The total resistance is often called the *equivalent series resistance* and is denoted as R_{eq}.

RESISTORS IN PARALLEL

10 You can connect resistors in parallel, as shown in Figure 1.4.

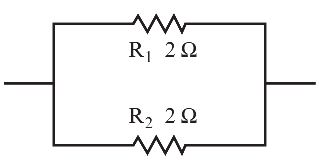


FIGURE 1.4

QUESTION

What is the total resistance here? ______________________________

____

ANSWER

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{2} + \frac{1}{2} = 1\text{; thus } R_T = 1\text{ ohm}$$

R_T is often called the *equivalent parallel resistance*.

11 The simple formula from problem 10 can be extended to include as many resistors as wanted.

QUESTION

What is the formula for three resistors in parallel? ______________________________

____

ANSWER

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

You often see this formula in the following form:

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

12 In the following exercises, two resistors are connected in parallel.

QUESTIONS

What is the total or equivalent resistance?

A. $R_1 = 1$ ohm, $R_2 = 1$ ohm

$R_T =$ ________________________________

B. $R_1 = 1{,}000$ ohms, $R_2 = 500$ ohms

$R_T =$ ________________________________

C. $R_1 = 3{,}600$ ohms, $R_2 = 1{,}800$ ohms

$R_T =$ ________________________________

ANSWER

A. 0.5 ohms

B. 333 ohms

C. 1,200 ohms

R_T is always smaller than the smallest of the resistors in parallel.

POWER

13 When current flows through a resistor, it dissipates power, usually in the form of heat. Power is expressed in terms of watts.

QUESTION

What is the formula for power? ________________________________

____

ANSWER

There are three formulas for calculating power:

$$P = VI \text{ or } P = I^2R \text{ or } P = \frac{V^2}{R}$$

14 The first formula shown in problem 13 allows power to be calculated when only the voltage and current are known.

QUESTIONS

What is the power dissipated by a resistor for the following voltage and current values?

A. V = 10 volts, I = 3 amperes

P = ____________________

B. V = 100 volts, I = 5 amperes

P = ____________________

C. V = 120 volts, I = 10 amperes

P = ____________________

ANSWERS

A. 30 watts.

B. 500 watts, or 0.5 kW. (The abbreviation kW indicates kilowatts.)

C. 1,200 watts, or 1.2 kW.

15 The second formula shown in problem 13 allows power to be calculated when only the current and resistance are known.

QUESTIONS

What is the power dissipated by a resistor given the following resistance and current values?

A. R = 20 ohm, I = 0.5 ampere

P = ____________________

B. R = 560 ohms, I = 0.02 ampere

P = ____________________

C. V = 1 volt, R = 2 ohms

P = ____________________

D. V = 2 volt, R = 10 ohms

P = ____________________

ANSWERS

A. 5 watts

B. 0.224 watts

C. 0.5 watts

D. 0.4 watts

16 Resistors used in electronics generally are manufactured in standard values with regard to resistance and power rating. Appendix D shows a table of standard resistance values for 0.25- and 0.05-watt resistors. Quite often, when a certain resistance value is needed in a circuit, you must choose the closest standard value. This is the case in several examples in this book.

You must also choose a resistor with the power rating in mind. Never place a resistor in a circuit that requires that resistor to dissipate more power than its rating specifies.

QUESTIONS

If standard power ratings for carbon film resistors are 1/8, 1/4, 1/2, 1, and 2 watts, what power ratings should be selected for the resistors that were used for the calculations in problem 15?

A. For 5 watts ____________________

B. For 0.224 watts ____________________

C. For 0.5 watts ____________________

D. For 0.4 watts ____________________

ANSWERS

A. 5 watt (or greater)

B. 1/4 watt (or greater)

C. 1/2 watt (or greater)

D. 1/2 watt (or greater)

Most electronics circuits use low-power carbon film resistors. For higher-power levels (such as the 5-watt requirement in question A), other types of resistors are available.

SMALL CURRENTS

17 Although currents much larger than 1 ampere are used in heavy industrial equipment, in most electronic circuits, only fractions of an ampere are required.

QUESTIONS

A. What is the meaning of the term *milliampere*? ______________________

____

B. What does the term *microampere* mean? ______________________

____

ANSWERS

A. A milliampere is one-thousandth of an ampere (that is, 1/1000 or 0.001 amperes). It is abbreviated mA.

B. A microampere is one-millionth of an ampere (that is, 1/1,000,000 or 0.000001 amperes). It is abbreviated μA.

18 In electronics, the values of resistance normally encountered are quite high. Often, thousands of ohms and occasionally even millions of ohms are used.

QUESTIONS

A. What does kΩ mean when it refers to a resistor? ______________________

____

B. What does MΩ mean when it refers to a resistor? ______________________

____

ANSWERS

A. Kilohm (k = kilo, Ω = ohm). The resistance value is thousands of ohms. Thus, 1 kΩ = 1,000 ohms, 2 kΩ = 2,000 ohms, and 5.6 kΩ = 5,600 ohms.

B. Megohm (M = mega, Ω = ohm). The resistance value is millions of ohms. Thus, 1 MΩ = 1,000,000 ohms, and 2.2 MΩ = 2,200,000 ohms.

19 The following exercise is typical of many performed in transistor circuits. In this example, 6 volts is applied across a resistor, and 5 mA of current is required to flow through the resistor.

QUESTIONS

What value of resistance must be used and what power will it dissipate?

R = ______________________ P = ______________________

ANSWERS

$$R = \frac{V}{I} = \frac{6 \text{ volts}}{5 \text{ mA}} = \frac{6}{0.005} = 1200 \text{ ohms} = 1.2\,\text{k}\Omega$$

$$P = V \times I = 6 \times 0.005 = 0.030 \text{ watts} = 30\,\text{mW}$$

20 Now, try these two simple examples.

QUESTIONS

What is the missing value?

A. 50 volts and 10 mA. Find the resistance. ______________________

B. 1 volt and 1 MΩ. Find the current. ______________________

ANSWERS

A. 5 kΩ

B. 1 μA

THE GRAPH OF RESISTANCE

21 The voltage drop across a resistor and the current flowing through it can be plotted on a simple graph. This graph is called a *V-I curve*.

Consider a simple circuit in which a battery is connected across a 1 kΩ resistor.

QUESTIONS

A. Find the current flowing if a 10-volt battery is used. ______________________

____

B. Find the current when a 1-volt battery is used. ______________________

____

C. Now find the current when a 20-volt battery is used. ______________________

____

ANSWERS

A. 10 mA

B. 1 mA

C. 20 mA

22 Plot the points of battery voltage and current flow from problem 21 on the graph shown in Figure 1.5, and connect them together.

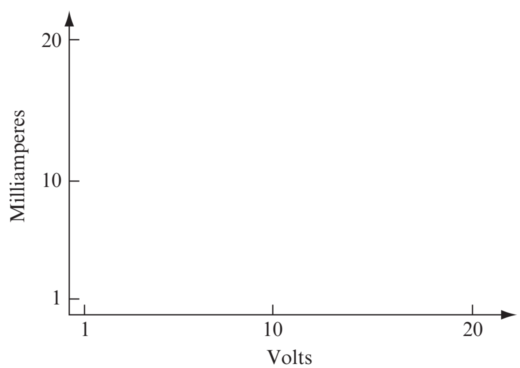


FIGURE 1.5

QUESTION

What would the slope of this line be equal to? ______________________

____

ANSWER

You should have drawn a straight line, as in the graph shown in Figure 1.6.

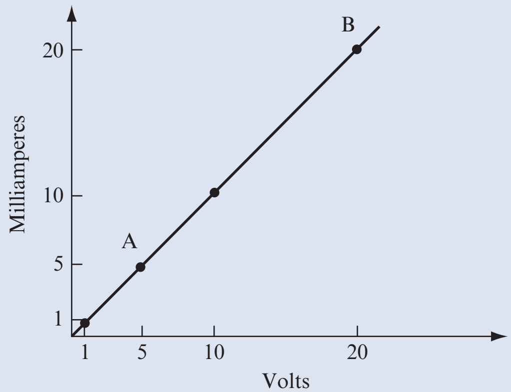


FIGURE 1.6

Sometimes you need to calculate the slope of the line on a graph. To do this, pick two points and call them A and B.

- For point A, let V = 5 volts and I = 5 mA
- For point B, let V = 20 volts and I = 20 mA

The slope can be calculated with the following formula:

$$\text{Slope} = \frac{V_B - V_A}{I_B - I_A} = \frac{20 \text{ volts} - 5 \text{ volts}}{20 \text{ mA} - 5 \text{ mA}} = \frac{15 \text{ volts}}{15 \text{ mA}} = \frac{15 \text{ volts}}{0.015 \text{ ampere}} = 1 \text{ k}\,\Omega$$

In other words, the slope of the line is equal to the resistance.

Later, you learn about V-I curves for other components. They have several uses, and often they are not straight lines.

THE VOLTAGE DIVIDER

23 The circuit shown in Figure 1.7 is called a *voltage divider*. It is the basis for many important theoretical and practical ideas you encounter throughout the entire field of electronics.

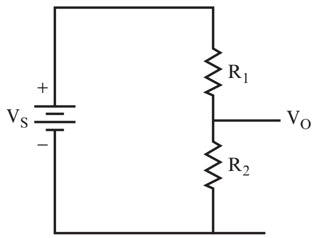


FIGURE 1.7

The object of this circuit is to create an output voltage (V_0) that you can control based upon the two resistors and the input voltage. V_0 is also the *voltage drop* across R_2.

QUESTION

What is the formula for V_0? ______________________________

____

ANSWER

$$V_o = V_S \times \frac{R_2}{R_1 + R_2}$$

$R_1 + R_2 = R_T$, the total resistance of the circuit.

24 A simple example can demonstrate the use of this formula.

QUESTION

For the circuit shown in Figure 1.8, what is V_0? ______________________________

____

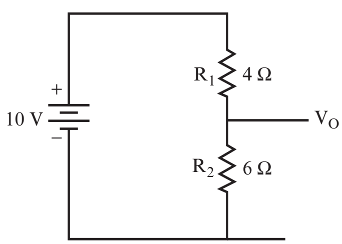


FIGURE 1.8

ANSWER

$$V_O = V_S \times \frac{R_2}{R_1 + R_2}$$

$$= 10 \times \frac{6}{4+6}$$

$$= 10 \times \frac{6}{10}$$

$$= 6 \text{ volts}$$

25 Now, try these problems.

QUESTIONS

What is the output voltage for each combination of supply voltage and resistance?

A. V_S = 1 volt, R_1 = 1 ohm, R_2 = 1 ohm

V_0 = ____________________

B. V_S = 6 volts, R_1 = 4 ohms, R_2 = 2 ohms

V_0 = ____________________

C. V_S = 10 volts, R_1 = 3.3. kΩ, R_2 = 5.6 kΩ

V_0 = ____________________

D. V_S = 28 volts, R_1 = 22 kΩ, R_2 = 6.2 kΩ

V_0 = ____________________

ANSWERS

A. 0.5 volts

B. 2 volts

C. 6.3 volts

D. 6.16 volts

26 The output voltage from the voltage divider is always less than the applied voltage. Voltage dividers are often used to apply specific voltages to different components in a circuit. Use the voltage divider equation to answer the following questions.

QUESTIONS

A. What is the voltage drop across the 22 kΩ resistor for question D of problem 25? ____

____

B. What total voltage do you get if you add this voltage drop to the voltage drop across the 6.2 kΩ resistor? ______________________________

____

ANSWERS

A. 21.84 volts

B. The sum is 28 volts.

The voltages across the two resistors add up to the supply voltage. This is an example of *Kirchhoff's Voltage Law (KVL)*, which simply means that the voltage supplied to a circuit must equal the sum of the voltage drops in the circuit. In this book, KVL is often used without actual reference to the law.

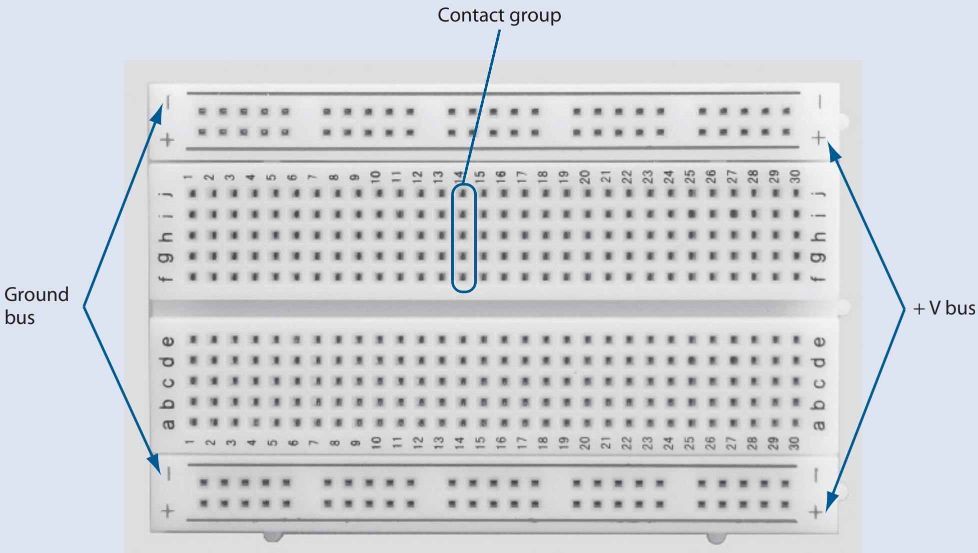
Also the voltage drop across a resistor is proportional to the resistor's value. Therefore, if one resistor has a greater value than another in a series circuit, the voltage drop across the higher-value resistor is greater.

USING BREADBOARDS

A convenient way to create a prototype of an electronic circuit to verify that it works is to build it on a *breadboard*. You can use breadboards to build the circuits used in the projects later in this book. As shown in the following figure, a breadboard is a sheet of plastic with several contact holes. You use these holes to connect electronic components in a circuit. After you verify that a circuit works with this method, you can then create a permanent circuit using soldered connections.

Continued

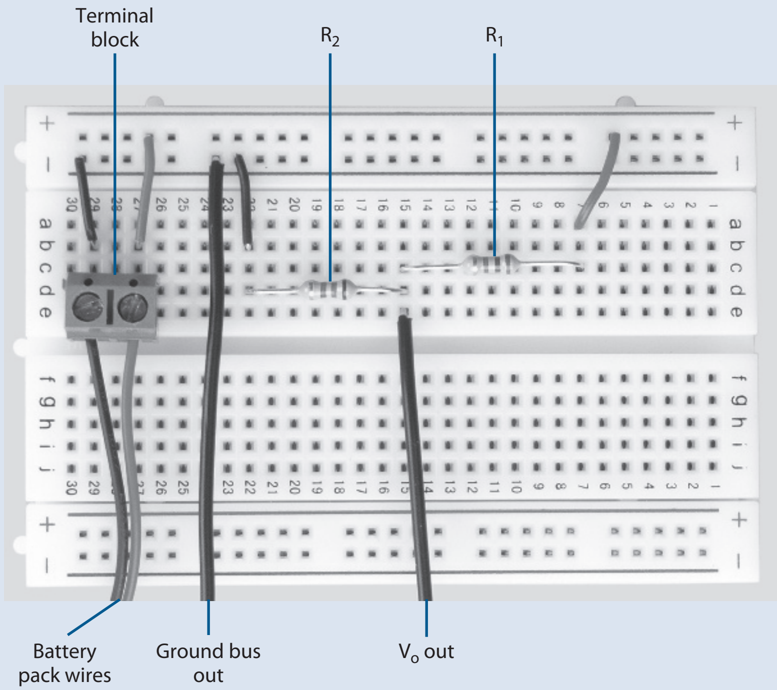
(continued)



Breadboards contain metal strips arranged in a pattern under the contact holes, which are used to connect groups of contacts together. Each group of five contact holes in a vertical line (such as the group circled in the figure) is connected by these metal strips. Any components plugged into one of these five contact holes are, therefore, electrically connected.

Each row of contact holes marked by a "+" or "–" are connected by these metal strips. The rows marked "+" are connected to the positive terminal of the battery or power supply and are referred to as the +V bus. The rows marked "–" are connected to the negative terminal of the battery or power supply and are referred to as the *ground bus*. The +V buses and ground buses running along the top and bottom of the breadboard make it easy to connect any component in a circuit with a short piece of wire called a jumper wire. Jumper wires are typically made of 22-gauge solid wire with approximately 1/4 inch of insulation stripped off each end.

The following figure shows a voltage divider circuit assembled on a breadboard. One end of R_1 is inserted into a group of contact holes that is also connected by a jumper wire to the +V bus. The other end of R_1 is inserted into the same group of contact holes that contains one end of R_2. The other end of R_2 is inserted into a group of contact holes that is also connected by a jumper wire to the ground bus. In this example, a 1.5 kΩ resistor was used for R_1, and a 5.1 kΩ resistor was used for R_2.



A *terminal block* is used to connect the battery pack to the breadboard because the wires supplied with battery packs (which are stranded wire) can't be inserted directly into breadboard contact holes. The red wire from a battery pack is attached to the side of the terminal block that is inserted into a group of contact holes, which is also connected by a jumper wire to the +V bus. The black wire from a battery pack is attached to the side of the terminal block that is inserted into a group of contact holes, which is also connected by a jumper wire to the ground bus.

To connect the output voltage, V_o, to a multimeter or a downstream circuit, two additional connections are needed. One end of a jumper wire is inserted in the same group of contact holes that contain both R_1 and R_2 to supply V_o. One end of another jumper wire is inserted in a contact hole in the ground bus to provide an electrical contact to the negative side of the battery. When connecting test equipment to the breadboard, you should use a 20-gauge jumper wire because sometimes the 22-gauge wire is pulled out of the board when attaching test probes.

THE CURRENT DIVIDER

27 In the circuit shown in Figure 1.9, the current splits or divides between the two resistors that are connected in parallel.

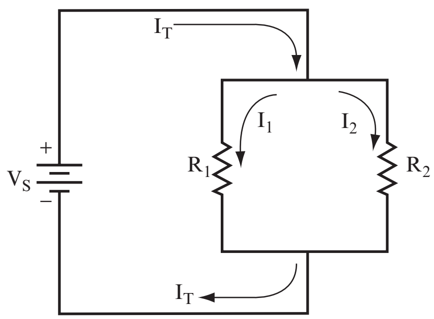


FIGURE 1.9

I_T splits into the individual currents I_1 and I_2, and then these recombine to form I_T.

QUESTIONS

Which of the following relationships are valid for this circuit?

A. $V_S = R_1 I_1$

B. $V_S = R_2 I_2$

C. $R_1 I_1 = R_2 I_2$

D. $I_1/I_2 = R_2/R_1$

ANSWERS

All of them are valid.

28 When solving current divider problems, follow these steps:

1. Set up the ratio of the resistors and currents:

   $I_1/I_2 = R_2/R_1$

2. Rearrange the ratio to give I_2 in terms of I_1:

$$I_2 = I_1 \times \frac{R_1}{R_2}$$

3. From the fact that $I_T = I_1 + I_2$, express I_T in terms of I_1 only.
4. Now, find I_1.
5. Now, find the remaining current (I_2).

QUESTION

The values of two resistors in parallel and the total current flowing through the circuit are shown in Figure 1.10. What is the current through each individual resistor?

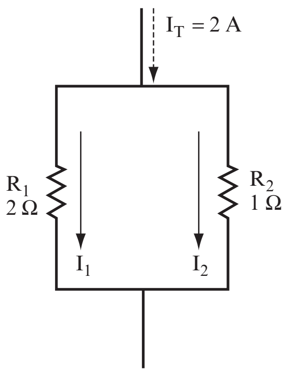


FIGURE 1.10

ANSWER

Work through the steps as shown here:

1. $I_1/I_2 = R_2/R_1 = 1/2$
2. $I_2 = 2I_1$
3. $I_T = I_1 + I_2 = I_1 + 2I_1 = 3I_1$
4. $I_1 = I_T/3 = 2/3$ ampere
5. $I_2 = 2I_1 = 4/3$ amperes

29 Now, try these problems. In each case, the total current and the two resistors are given. Find I_1 and I_2.

QUESTIONS

A. $I_T = 30$ mA, $R_1 = 12$ kΩ, $R_2 = 6$ kΩ ______

B. $I_T = 133$ mA, $R_1 = 1$ kΩ, $R_2 = 3$ kΩ ______

C. What current do you get if you add I_1 and I_2? ______

ANSWERS

A. $I_1 = 10$ mA, $I_2 = 20$ mA

B. $I_1 = 100$ mA, $I_2 = 33$ mA

C. They add back together to give you the total current supplied to the parallel circuit.

Question C is actually a demonstration of *Kirchhoff's Current Law (KCL)*. Simply stated, this law says that the total current entering a junction in a circuit must equal the sum of the currents leaving that junction. This law is also used on numerous occasions in later chapters. KVL and KCL together form the basis for many techniques and methods of analysis that are used in the application of circuit analysis.

Also, the current through a resistor is inversely proportional to the resistor's value. Therefore, if one resistor is larger than another in a parallel circuit, the current flowing through the higher value resistor is the smaller of the two. Check your results for this problem to verify this.

30 You can also use the following equation to calculate the current flowing through a resistor in a two-branch parallel circuit:

$$I_1 = \frac{(I_T)(R_2)}{(R_1+R_2)}$$

QUESTION

Write the equation for the current I_2. ____________________

____

Check the answers for the previous problem using these equations.

ANSWER

$$I_2 = \frac{(I_T)(R_2)}{(R_1 + R_2)}$$

The current through one branch of a two-branch circuit is equal to the total current times the resistance of the opposite branch, divided by the sum of the resistances of both branches. This is an easy formula to remember.

USING THE MULTIMETER

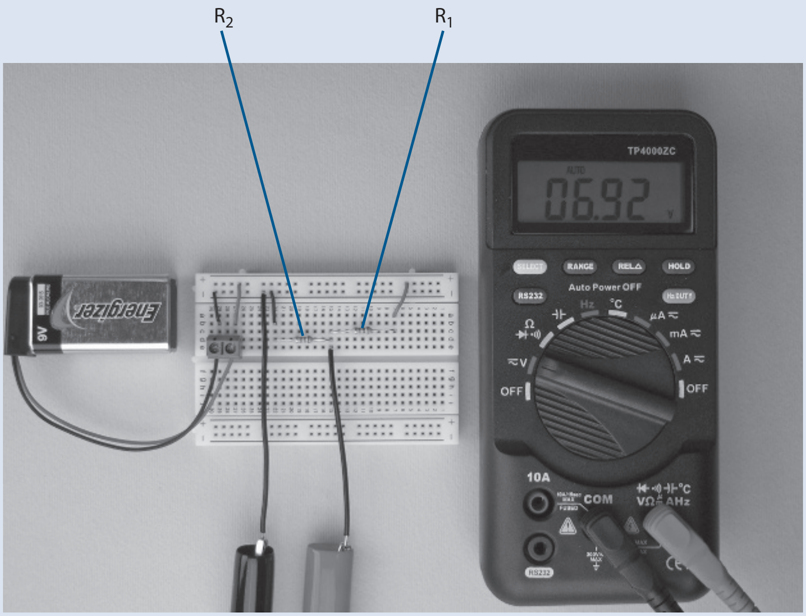
A *multimeter* is a must-have testing device for anyone's electronics toolkit. A multimeter is aptly named because it can be used to measure multiple parameters. Using a multimeter, you can measure current, voltage, and resistance by setting the rotary switch on the multimeter to the parameter you want to measure, and connecting each mulitmeter probe to a wire in a circuit. The following figure shows a multimeter connected to a voltage divider circuit to measure voltage. Following are the details of how you take each of these measurements.

VOLTAGE

To measure the voltage in the circuit shown in the figure, at the connection between R_1 and R_2, use jumper wire to connect the red probe of a multimeter to the row of contact holes containing leads from both R_1 and R_2. Use another jumper wire to connect the black probe of the multimeter to the ground bus. Set the rotary switch on the multimeter to measure voltage, and it returns the results.

Continued

(continued)

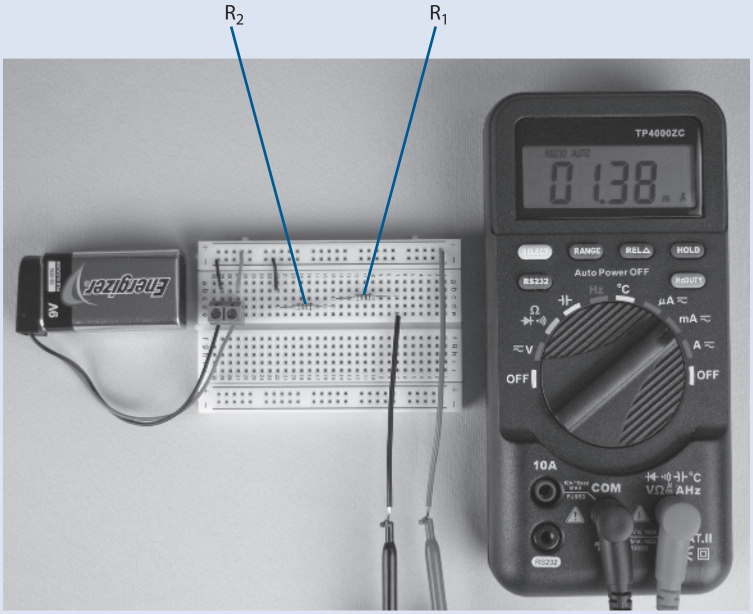


NOTE The circuit used in a multimeter to measure voltage places a large-value resistor in parallel with R_2 so that the test itself does not cause any measurable drop in the current passing through the circuit.

TIP Whenever you perform tests on a circuit, attach alligator clips or test clips with plastic covers to the ends of the probes. This aids the probes in grabbing the jumper wires with little chance that they'll cause a short.

CURRENT

The following figure shows how you connect a multimeter to a voltage divider circuit to measure current. Connect a multimeter in series with components in the circuit, and set the rotary switch to the appropriate ampere range, depending upon the magnitude of the expected current. To connect the multimeter in series with R_1 and R_2, use a jumper wire to connect the +V bus to the red lead of a multimeter, and another jumper wire to connect the black lead of the multimeter to R_1. These connections force the current flowing through the circuit to flow through the multimeter.



NOTE The circuit used in a multimeter to measure current passes the current through a low-value resistor so that the test itself does not cause any measurable drop in the current.

RESISTANCE

You typically use the resistance setting on a multimeter to check the resistance of individual components. For example, in measuring the resistance of R_2 before assembling the circuit shown in the previous figure, the result was 5.0 kΩ, slightly off the nominal 5.1 kΩ stated value.

You can also use a multimeter to measure the resistance of a component in a circuit. A multimeter measures resistance by applying a small current through the components being tested, and measuring the voltage drop. Therefore, to prevent false readings, you should disconnect the battery pack or power supply from the circuit before using the multimeter.

SWITCHES

31 A *mechanical switch* is a device that completes or breaks a circuit. The most familiar use is that of applying power to turn a device on or off. A switch can also permit a signal to pass from one place to another, prevent its passage, or route a signal to one of several places.

In this book, you work with two types of switches. The first is the simple on-off switch, also called a *single pole single throw* switch. The second is the *single pole double throw* switch. Figure 1.11 shows the circuit symbols for each.

FIGURE 1.11

Keep in mind the following two important facts about switches:

- A closed (or ON) switch has the total circuit current flowing through it. There is no voltage drop across its terminals.
- An open (or OFF) switch has no current flowing through it. The full circuit voltage appears between its terminals.

The circuit shown in Figure 1.12 includes a closed switch.

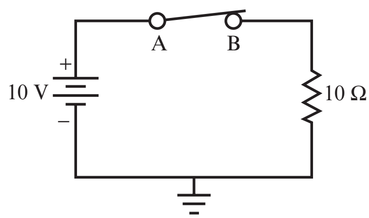


FIGURE 1.12

QUESTIONS

A. What is the current flowing through the switch? ______________________

____

B. What is the voltage at point A and point B with respect to ground? ______________

____

C. What is the voltage drop across the switch? ______________________________

____

ANSWERS

A. $\frac{10 \text{ volts}}{10 \text{ ohms}} = 1 \text{ ampere}$

B. $V_A = V_B = 10$ volts

C. 0 V (There is no voltage drop because both terminals are at the same voltage.)

32 The circuit shown in Figure 1.13 includes an open switch.

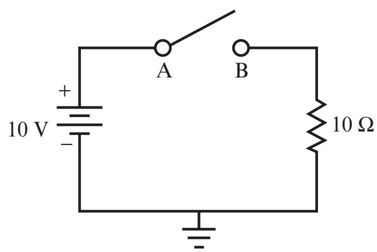


FIGURE 1.13

QUESTIONS

A. What is the voltage at point A and point B? ______________________________

____

B. How much current is flowing through the switch? __________________________

____

C. What is the voltage drop across the switch? ______________________________

____

ANSWERS

A. $V_A = 10$ volts; $V_B = 0$ volts.

B. No current is flowing because the switch is open.

C. 10 volts. If the switch is open, point A is the same voltage as the positive battery terminal, and point B is the same voltage as the negative battery terminal.

33 The circuit shown in Figure 1.14 includes a single pole double throw switch. The position of the switch determines whether lamp A or lamp B is lit.

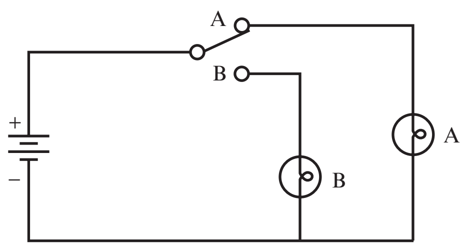


FIGURE 1.14

QUESTIONS

A. In the position shown, which lamp is lit? ______________________

____

B. Can both lamps be lit simultaneously? ______________________

____

ANSWERS

A. Lamp A.

B. No, one or the other must be off.

CAPACITORS IN A DC CIRCUIT

34 Capacitors are used extensively in electronics. They are used in both alternating current (AC) and DC circuits. Their main use in DC electronics is to become charged, hold the charge, and, at a specific time, release the charge.

The capacitor shown in Figure 1.15 charges when the switch is closed.

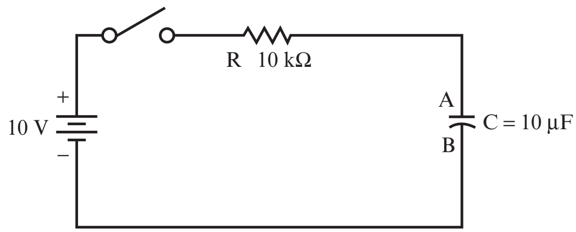


FIGURE 1.15

QUESTION

To what final voltage will the capacitor charge? ______________________

____

ANSWER

It will charge up to 10 volts. It will charge up to the voltage that would appear across an open circuit located at the same place where the capacitor is located.

35 How long does it take to reach this voltage? This is an important question with many practical applications. To find the answer you must know the *time constant* (τ) (Greek letter tau) of the circuit.

QUESTIONS

A. What is the formula for the time constant of this type of circuit? ______________________

____

B. What is the time constant for the circuit shown in Figure 1.15? ____________

C. How long does it take the capacitor to reach 10 volts? ____________

D. To what voltage level does it charge in one time constant? ____________

ANSWERS

A. $\tau = R \times C$.

B. $\tau = 10\ k\Omega \times 10\ \mu F = 10{,}000\ \Omega \times 0.00001\ F = 0.1$ seconds. (Convert resistance values to ohms and capacitance values to farads for this calculation.)

C. Approximately 5 time constants, or about 0.5 seconds.

D. 63 percent of the final voltage, or about 6.3 volts.

36 The capacitor does not begin charging until the switch is closed. When a capacitor is uncharged or discharged, it has the same voltage on both plates.

QUESTIONS

A. What is the voltage on plate A and plate B of the capacitor in Figure 1.15 before the switch is closed? ____________

B. When the switch is closed, what happens to the voltage on plate A? ____________

C. What happens to the voltage on plate B? ____________

D. What is the voltage on plate A after one time constant? ____________

ANSWERS

A. Both will be at 0 volts if the capacitor is totally discharged.

B. It will rise toward 10 volts.

C. It will stay at 0 volts.

D. About 6.3 volts.

37 The *capacitor charging graph* in Figure 1.16 shows how many time constants a voltage must be applied to a capacitor before it reaches a given percentage of the applied voltage.

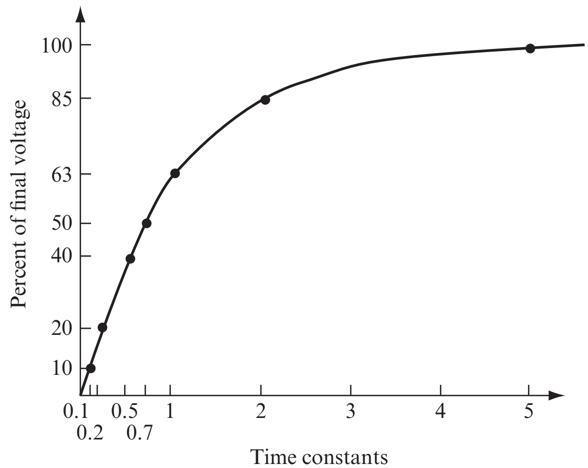


FIGURE 1.16

QUESTIONS

A. What is this type of curve called? ______________________________

____

B. What is it used for? ______________________________

____

ANSWERS

A. It is called an *exponential* curve.

B. It is used to calculate how far a capacitor has charged in a given time.

38 In the following examples, a resistor and a capacitor are in series. Calculate the time constant, how long it takes the capacitor to fully charge, and the voltage level after one time constant if a 10-volt battery is used.

QUESTIONS

A. R = 1 kΩ, C = 1,000 μF ______________________________

____

B. R = 330 kΩ, C = 0.05 μF ______________________________

____

ANSWERS

A. τ = 1 second; charge time = 5 seconds; V_C = 6.3 volts.

B. τ = 16.5 ms; charge time = 82.5 ms; V_C = 6.3 volts. (The abbreviation "ms" indicates milliseconds.)

39 The circuit shown in Figure 1.17 uses a double pole switch to create a discharge path for the capacitor.

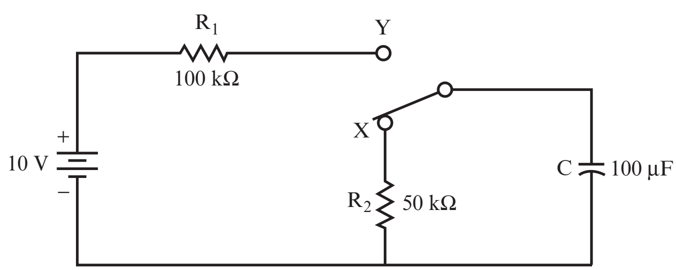


FIGURE 1.17

QUESTIONS

A. With the switch in position X, what is the voltage on each plate of the capacitor? ___

B. When the switch is moved to position Y, the capacitor begins to charge. What is its charging time constant? ___

C. How long does it take to fully charge the capacitor? ___

ANSWERS

A. 0 volts

B. $\tau = R \times C = (100\ k\Omega)\ (100\ \mu F) = 10$ secs

C. Approximately 50 seconds

40 Suppose that the switch shown in Figure 1.17 is moved back to position X after the capacitor is fully charged.

QUESTIONS

A. What is the discharge time constant of the capacitor? ___

B. How long does it take to fully discharge the capacitor? ___

ANSWERS

A. $\tau = R \times C = (50\ k\Omega)\ (100\ \mu F) = 5$ seconds (discharging through the 50 kΩ resistor)

B. Approximately 25 seconds

Continued

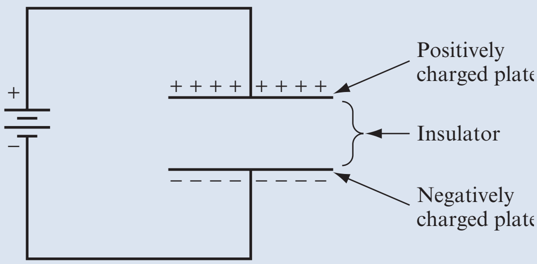
(continued)

ANSWERS

The circuit powering a camera flash is an example of a capacitor's capability to store a charge and then discharge upon demand. While you wait for the flash unit to charge, the camera uses its battery to charge a capacitor. When the capacitor is charged, it holds that charge until you click the Shutter button, causing the capacitor to discharge, which powers the flash.

INSIDE THE CAPACITOR

Capacitors store an electrical charge on conductive plates that are separated by an insulating material, as shown in the following figure. One of the most common types of capacitor is a *ceramic capacitor*, which has values ranging from a few μF up to approximately 47 μF. The name for a ceramic capacitor comes from the use of a ceramic material to provide insulation between the metal plates.



Another common type of capacitor is an electrolytic capacitor, available with capacitance values ranging from 0.1 μF to several thousand μF. The name electrolytic comes from the use of an electrolytic fluid, which, because it is conductive, acts as one of the "plates," whereas the other plate is made of metal. The insulating material is an oxide on the surface of the metal.

Unlike ceramic capacitors, many electrolytic capacitors are polarized, which means that you must insert the lead marked with a "+" in the circuit closest to the positive voltage source. The symbol for a capacitor indicates the direction in which you insert polarized capacitors in a circuit. The curved side of the capacitor symbol indicates the negative side of the capacitor, whereas the straight side of the symbol indicates the positive side of the capacitor. You can see this orientation later in this chapter in Figure 1.22.

Units of capacitance are stated in pF (picofarad), μF (microfarad), and F (farad). One μF equals 1,000,000 pF and one F equals 1,000,000 μF. Many capacitors are marked with their capacitance value, such as 220 pF. However, you'll often find capacitors that use a different numerical code, such as 224. The first two numbers in this code are the first and second significant digits of the capacitance value. The third number is the multiplier, and the units are pF. Therefore, a capacitor marked with 221 has a value of 220 pF, whereas a capacitor with a marking of 224 has a value of 220,000 pF. (You can simplify this to 0.22 μF.)

41 Capacitors can be connected in parallel, as shown in Figure 1.18.

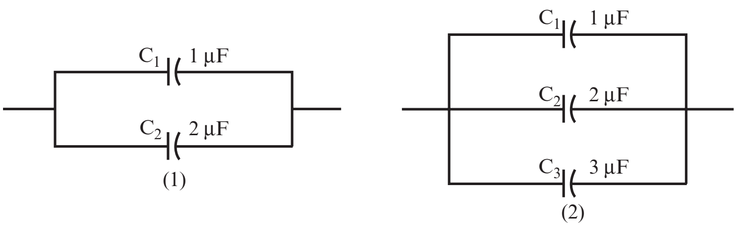


FIGURE 1.18

QUESTIONS

A. What is the formula for the total capacitance? ______________________________

____

B. What is the total capacitance in circuit 1? ______________________________

____

C. What is the total capacitance in circuit 2? ______________________________

____

ANSWERS

A. $C_T = C_1 + C_2 + C_3 + \ldots + C_N$

B. $C_T = 1 + 2 = 3\ \mu F$

C. $C_T = 1 + 2 + 3 = 6\ \mu F$

In other words, the total capacitance is found by simple addition of the capacitor values.

42 Capacitors can be placed in series, as shown in Figure 1.19.

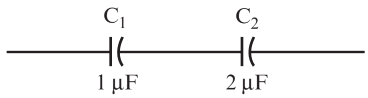


FIGURE 1.19

QUESTIONS

A. What is the formula for the total capacitance? ______

B. In Figure 1.19, what is the total capacitance? ______

ANSWERS

A. $\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_N}$

B. $\frac{1}{C_T} = \frac{1}{1} + \frac{1}{2} = 1 + \frac{1}{2} = \frac{3}{2}$; thus $C_T = \frac{2}{3}$

43 In each of these examples, the capacitors are placed in series. Find the total capacitance.

QUESTIONS

A. $C_1 = 10$ µF, $C_2 = 5$ µF ______

B. $C_1 = 220$ µF, $C_2 = 330$ µF, $C_3 = 470$ µF ______

C. $C_1 = 0.33$ µF, $C_2 = 0.47$ µF, $C_3 = 0.68$ µF ______

ANSWERS

A. 3.3 μF

B. 103.06 μF

C. 0.15 μF

SUMMARY

The few simple principles reviewed in this chapter are those you need to begin the study of electronics. Following is a summary of these principles:

- The basic electrical circuit consists of a source (voltage), a load (resistance), and a path (conductor or wire).
- The voltage represents a charge difference.
- If the circuit is a complete circuit, then electrons flow, which is called current flow. The resistance offers opposition to current flow.
- The relationship between V, I, and R is given by Ohm's law:

  $$V = I \times R$$

- Resistance could be a combination of resistors in series, in which case you add the values of the individual resistors together to get the total resistance.

  $$R_T = R_1 + R_2 + \cdots + R_N$$

- Resistance can be a combination of resistors in parallel, in which case you find the total by using the following formula:

  $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N} \quad \text{or} \quad R_T = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}+\cdots+\frac{1}{R_N}}$$

- You can find the power delivered by a source by using the following formula:

  $$P = VI$$

- You can find the power dissipated by a resistance by using the following formula:

  $$P = I^2R \quad \text{or} \quad P = \frac{V^2}{R}$$

- If you know the total applied voltage, V_S, you can find the voltage across one resistor in a series string of resistors by using the following voltage divider formula:

  $$V_1 = \frac{V_S R_1}{R_T}$$

- You can find the current through one resistor in a two resistor parallel circuit with the total current known by using the current divider formula:

  $$I_1 = \frac{I_T R_2}{(R_1 + R_2)}$$

- Kirchhoff's Voltage Law (KVL) relates the voltage drops in a series circuit to the total applied voltage.

  $$V_S = V_1 + V_2 + \cdots + V_N$$

- Kirchhoff's Current Law (KCL) relates the currents at a junction in a circuit by saying that the sum of the input currents equals the sum of the output currents. For a simple parallel circuit, this becomes the following, where I_T is the input current:

  $$I_T = I_1 + I_2 + \cdots + I_N$$

- A switch in a circuit is the control device that directs the flow of current or, in many cases, allows that current to flow.
- Capacitors are used to store electric charge in a circuit. They also allow current or voltage to change at a controlled pace. The circuit time constant is found by using the following formula:

  $$\tau = R \times C$$

- At one time constant in an RC circuit, the values for current and voltage have reached 63 percent of their final values. At five time constants, they have reached their final values.
- Capacitors in parallel are added to find the total capacitance.

$$C_T = C_1 + C_2 + \cdots + C_N$$

- Capacitors in series are treated the same as resistors in parallel to find a total capacitance.

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_N} \quad \text{or} \quad C_T = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots + \frac{1}{C_N}}$$

DC PRE-TEST

The following problems and questions test your understanding of the basic principles presented in this chapter. You need a separate sheet of paper for your calculations. Compare your answers with the answers provided following the test. You can work many of the problems in more than one way.

Questions 1–5 use the circuit shown in Figure 1.20. Find the unknown values indicated using the values given.

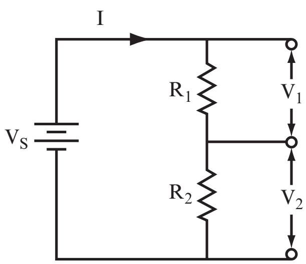


FIGURE 1.20

1. $R_1 = 12$ ohms, $R_2 = 36$ ohms, $V_S = 24$ volts

$R_T =$ ____________________, $I =$ ____________________

2. $R_1 = 1\ \text{k}\Omega$, $R_2 = 3\ \text{k}\Omega$, $I = 5$ mA

$V_1 =$ ______________, $V_2 =$ ______________, $V_S =$ ______________

3. $R_1 = 12\ k\Omega$, $R_2 = 8\ k\Omega$, $V_S = 24$ volts

$V_1 =$ ______________________, $V_2 =$ ______________________

4. $V_S = 36$ V, $I = 250$ mA, $V_1 = 6$ volts

$R_2 =$ ____

5. Now, go back to problem 1. Find the power dissipated by each resistor and the total power delivered by the source.

$P_1 =$ ________________, $P_2 =$ ______________, $P_T =$ ______________

Questions 6–8 use the circuit shown in Figure 1.21. Again, find the unknowns using the given values.

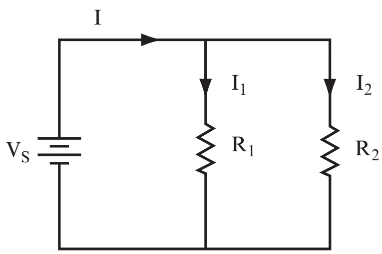


FIGURE 1.21

6. $R_1 = 6\ k\Omega$, $R_2 = 12\ k\Omega$, $V_S = 20$ volts

$R_T =$ ______________________, $I =$ ______________________

7. $I = 2$ A, $R_1 = 10$ ohms, $R_2 = 30$ ohms

$I_1 =$ ______________________, $I_2 =$ ______________________

8. $V_S = 12$ volts, $I = 300$ mA, $R_1 = 50$ ohms

$R_2 =$ ______________________, $P_1 =$ ______________________

9. What is the maximum current that a 220- ohm resistor can safely have if its power rating is 1/4 watt?

$I_{MAX} =$ ____

10. In a series RC circuit the resistance is 1 kΩ, the applied voltage is 3 volts, and the time constant should be 60 μsec.

A. What is the required value of C?

$C =$ ____

B. What is the voltage across the capacitor 60 μsec after the switch is closed?

V_C = ______________________________

C. At what time will the capacitor be fully charged?

T = ______________________________

11. In the circuit shown in Figure 1.22, when the switch is at position 1, the time constant should be 4.8 ms.

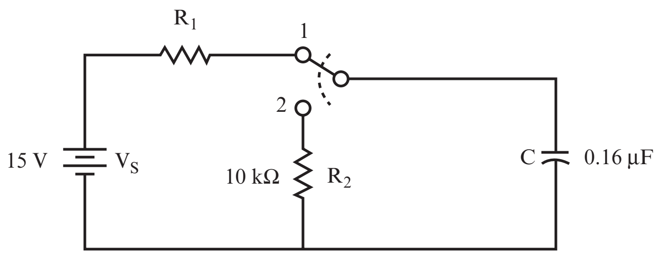


FIGURE 1.22

A. What should be the value of resistor R_1?

R_1 = ______________________________

B. What will be the voltage on the capacitor when it is fully charged, and how long will it take to reach this voltage?

V_C = ______________, T = ______________

C. After the capacitor is fully charged, the switch is thrown to position 2. What is the discharge time constant, and how long will it take to completely discharge the capacitor?

τ = ______________, T = ______________

12. Three capacitors are available with the following values:

$C_1 = 8\ \mu F$; $C_2 = 4\ \mu F$; $C_3 = 12\ \mu F$.

A. What is C_T if all three are connected in parallel?

C_T = ______________________________

B. What is C_T if they are connected in series?

C_T = ______________________________

C. What is C_T if C_1 is in series with the parallel combination of C_2 and C_3?

C_T = ______________________________

ANSWERS TO DC PRE-TEST

If your answers do not agree with those provided here, review the problems indicated in parentheses before you go to Chapter 2, "The Diode." If you still feel uncertain about these concepts, go to a website such as `www.BuildingGadgets.com` and work through DC tutorials listed there.

It is assumed that Ohm's law is well known, so problem 4 will not be referenced.

1.	R_T = 48 ohms, I = 0.5 ampere	(problem 9)
2.	V_1 = 5 volts, V_2 = 15 volts, V_S = 20 volts	(problems 23 and 26)
3.	V_1 = 14.4 volts, V_2 = 9.6 volts	(problems 23 and 26)
4.	R_2 = 120 ohms	(problems 9 and 23)
5.	P_1 = 3 watts, P_2 = 9 watts, P_T = 12 watts	(problems 9 and 13)
6.	R_T = 4 kΩ, I = 5 mA	(problem 10)
7.	I_1 = 1.5 amperes, I_2 = 0.5 ampere	(problems 28 and 29)
8.	R_2 = 200 ohms, P_1 = 2.88 watts	(problems 10 and 13)
9.	I_{MAX} = 33.7 mA	(problems 13, 15, and 16)
10A.	C = 0.06 μF	(problems 34 and 35)
10B.	V_C = 1.9 volts	(problem 35)
10C.	T = 300 μsec	(problems 34–38)
11A.	R_1 = 30 kΩ	(problems 33, 39, and 40)
11B.	V_C = 15 V, T = 24 ms	(problem 35)
11C.	τ = 1.6 ms, T = 8.0 ms	(problems 39–40)
12A.	C_T = 24 μF	(problems 41 and 42)
12B.	C_T = 2.18 μF	(problem 42)
12C.	C_T = 5.33 μF	(problems 42–43)