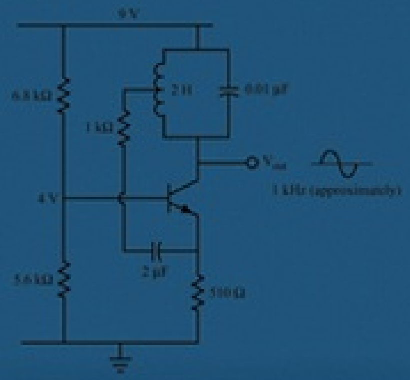


Earl Boysen + Harry Kybett

COMPLETE ELECTRONICS SELF-TEACHING GUIDE

with Projects

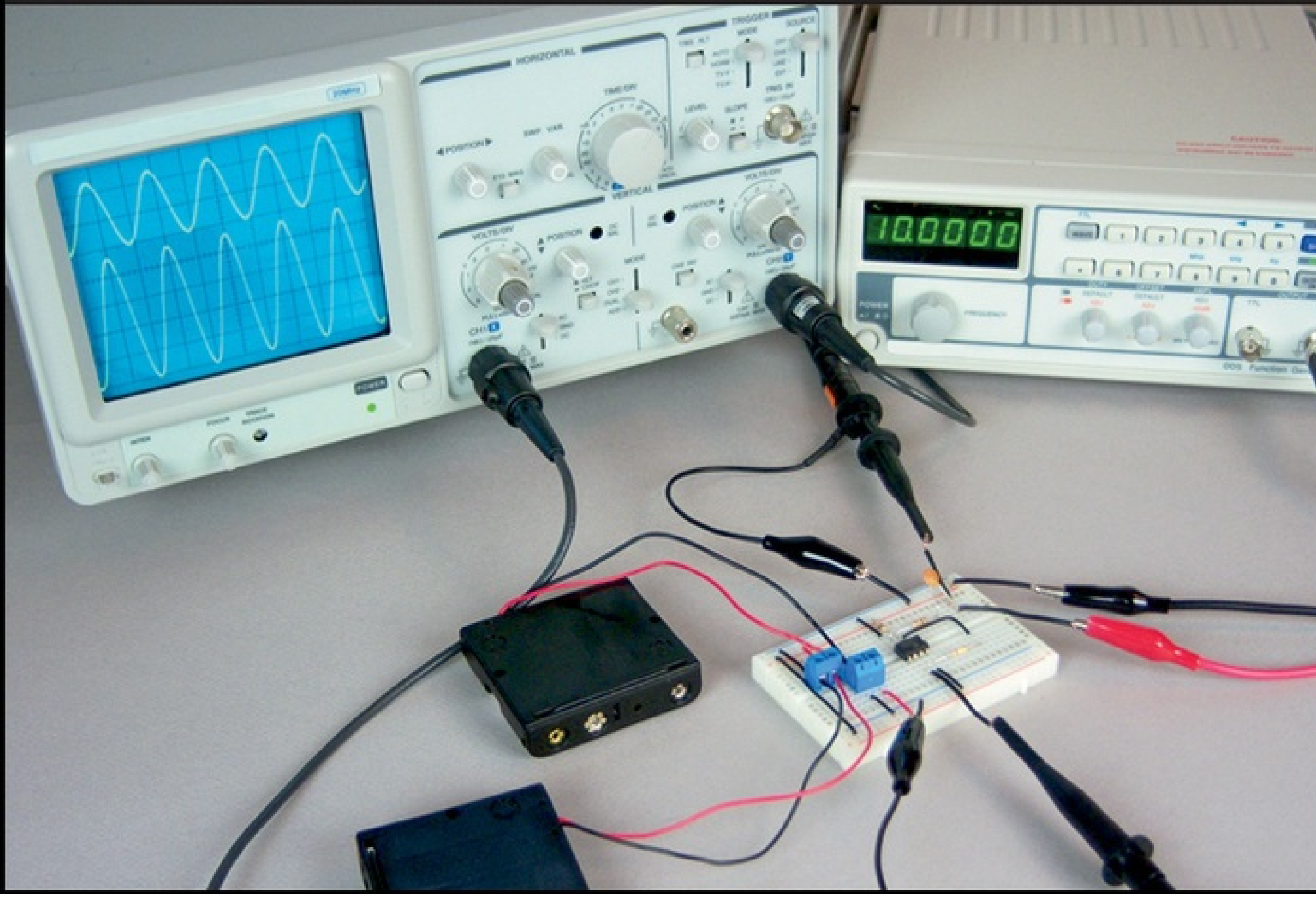


Table of Contents

Chapter 1

DC Review and Pre-Test

Electronics cannot be studied without first understanding the basics of electricity. This chapter is review and pre-test on those aspects of direct current (DC) that apply to electronics. By no means do 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 o 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, th source provides a potential difference to a circuit that enables a current to flow. An *electric current* a flow of electric charge. In the case of a battery, electrons are the electric charge, and they flow fro the terminal that has an excess number of electrons to the terminal that has a deficiency of electron This flow takes place in any complete circuit that is connected to battery terminals. It is th difference in the charge that creates the potential difference in the battery. The electrons try to balanc the difference.

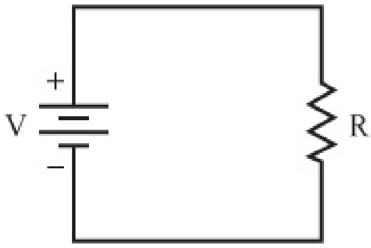
Because electrons have a negative charge, they actually flow from the negative terminal and retu to the positive terminal. This direction of flow is called *electron flow*. Most books, however, us current flow, which is in the opposite direction. It is referred to as *conventional current flow*, simply 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 a 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? ___________

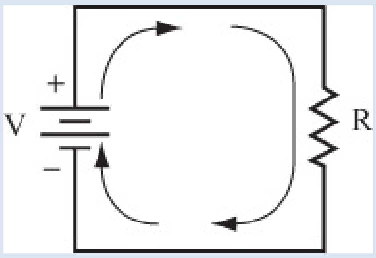
C. What does the potential difference cause? ___________

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 law to select the value of a resistor that gives you the correct current in a circuit. For a given voltag the current flowing through a circuit increases when using smaller resistor values and decreases whe using larger resistor values.

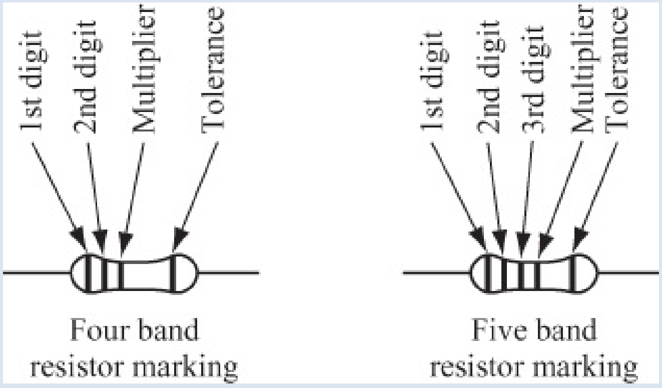
This resistor value works something like pipes that run water through a plumbing system. Fo example, to deliver the large water flow required by your water heater, you might use a 1-inc diameter pipe. To connect a bathroom sink to the water supply requires much smaller water flow an therefore, works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

Tolerance refers to how precise a stated resistor value is. When you buy *fixed resistors* (in contrast *variable resistors* that are used in some of the projects in this book), they have a particular resistanc value. Their tolerance tells you how close to that value their resistance will be. For example, a 1,00 ohm resistor with ± 5 percent tolerance could have a value of anywhere from 950 ohms to 1,05 ohms. A 1,000-ohm resistor with ± 1 percent tolerance (referred to as a *precision resistor*) could hav a value ranging anywhere from 990 ohms to 1,010 ohms. Although you are assured that the resistanc of a precision resistor will be close to its stated value, the resistor with ± 1 percent tolerance cos more to manufacture and, therefore, costs you more than twice as much as a resistor with ± 5 percen

Most electronic circuits are designed to work with resistors with ± 5 percent tolerance. The mo commonly used type of resistor with ± 5 percent tolerance is called a *carbon film resistor*. This ter refers to the manufacturing process in which a carbon film is deposited on an insulator. The thickne and width of the carbon film determines the resistance (the thicker the carbon film, the lower th 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 thickne and width of the metal film determines the resistance. These resistors are called *metal film resisto* 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, illustrated in the following figure. The four-band color code is used for most resistors. As shown the figure, by adding a fifth band, you get a five-band color code. Five-band color codes are used provide more precise values in precision resistors.



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

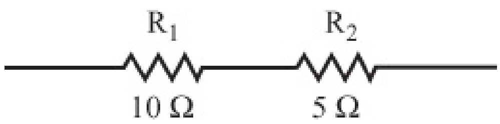
Color	Significant Digits	Multiplier	Tolerance
Black	0	1	
Brown	1	10	± 1 percent
Red	2	100	± 2 percent
Orange	3	1,000	
Yellow	4	10,000	
Green	5	100,000	
Blue	6	1,000,000	
Violet	7		
Gray	8		
White	9		
Gold		0.1	± 5 percent
Silver		0.01	± 10 percent

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

Answers

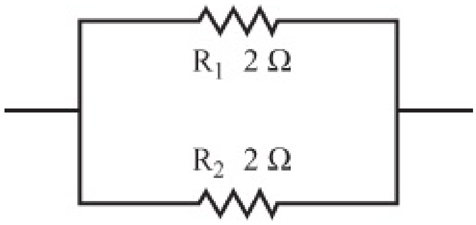
$$R_T = R_1 + R_2 = 10 \text{ ohms} + 5 \text{ ohms} = 15 \text{ ohms}$$

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? _____

Answers

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

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? _____

Answers

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

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 = _____

Answers

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 expressed in terms of watts.

Question

What is the formula for power? _____

Answers

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 ar 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 curre 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 resistance and power rating. Appendix D shows a table of standard resistance values for 0.25- ar 0.05-watt resistors. Quite often, when a certain resistance value is needed in a circuit, you must choo 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 circu 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 powe 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 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 mo 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 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, 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 simp 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

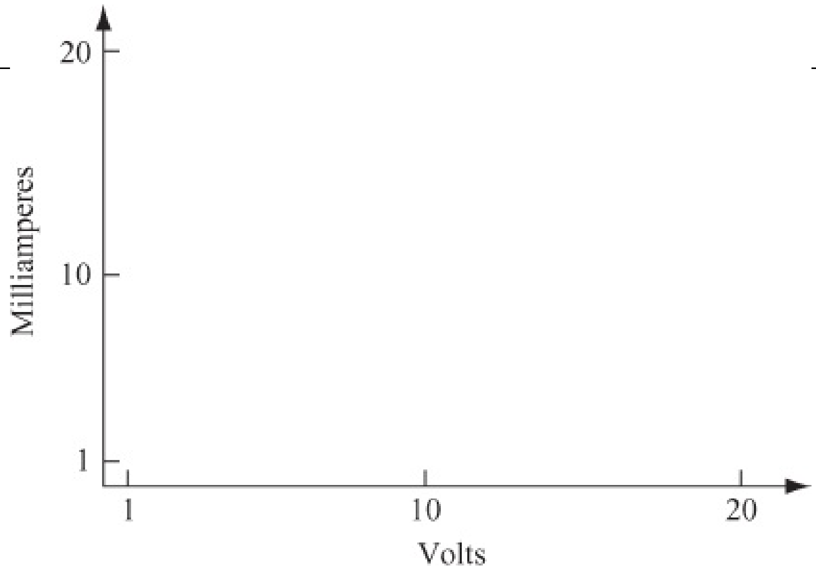
A. 10 mA

B. 1 mA

C. 20 mA

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

Figure 1.5



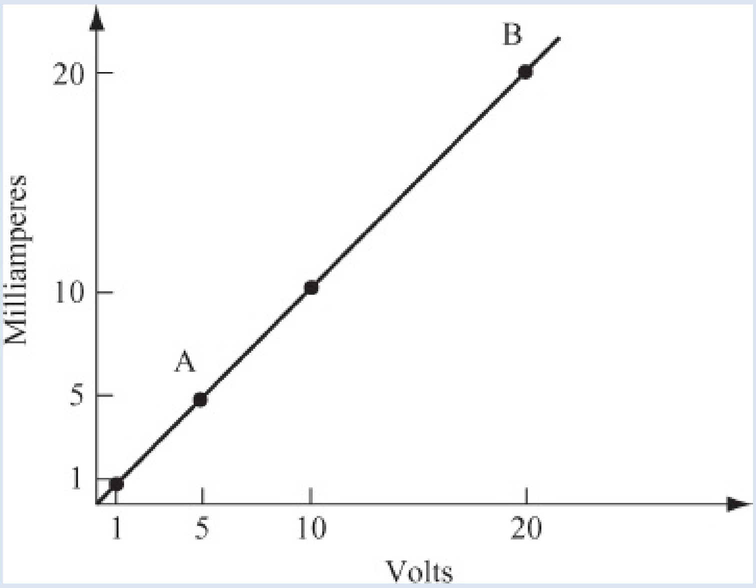
Question

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

Answers

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 ca 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:

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

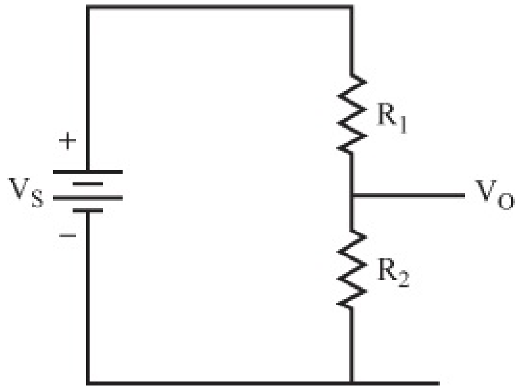
In other words, the slope of the line is equal to the resistance.

Later, you learn about V-I curves for other components. They have several uses, and often they ar 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 importa 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 tw resistors and the input voltage. V_0 is also the *voltage drop* across R_2.

Question

What is the formula for V_0? _____

Answers

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

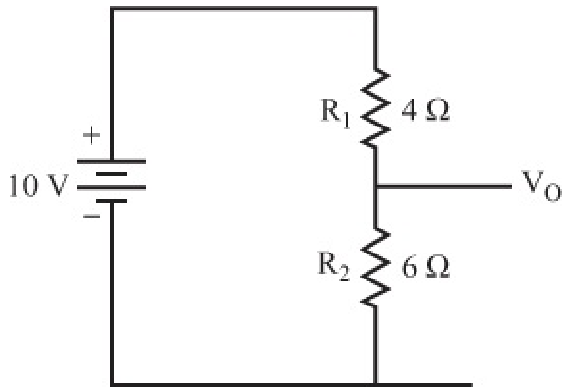
$R_1 + R_2 = R_T$, the total resistance of the circuit.

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



Answers

$$V_O = V_S \times \frac{R_2}{R_1+R_2}$$
$$= 10 \times \frac{6}{4+6}$$
$$= 10 \times \frac{6}{10}$$
$$= 6 \text{ volts}$$

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. Voltag dividers are often used to apply specific voltages to different components in a circuit. Use the voltag 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

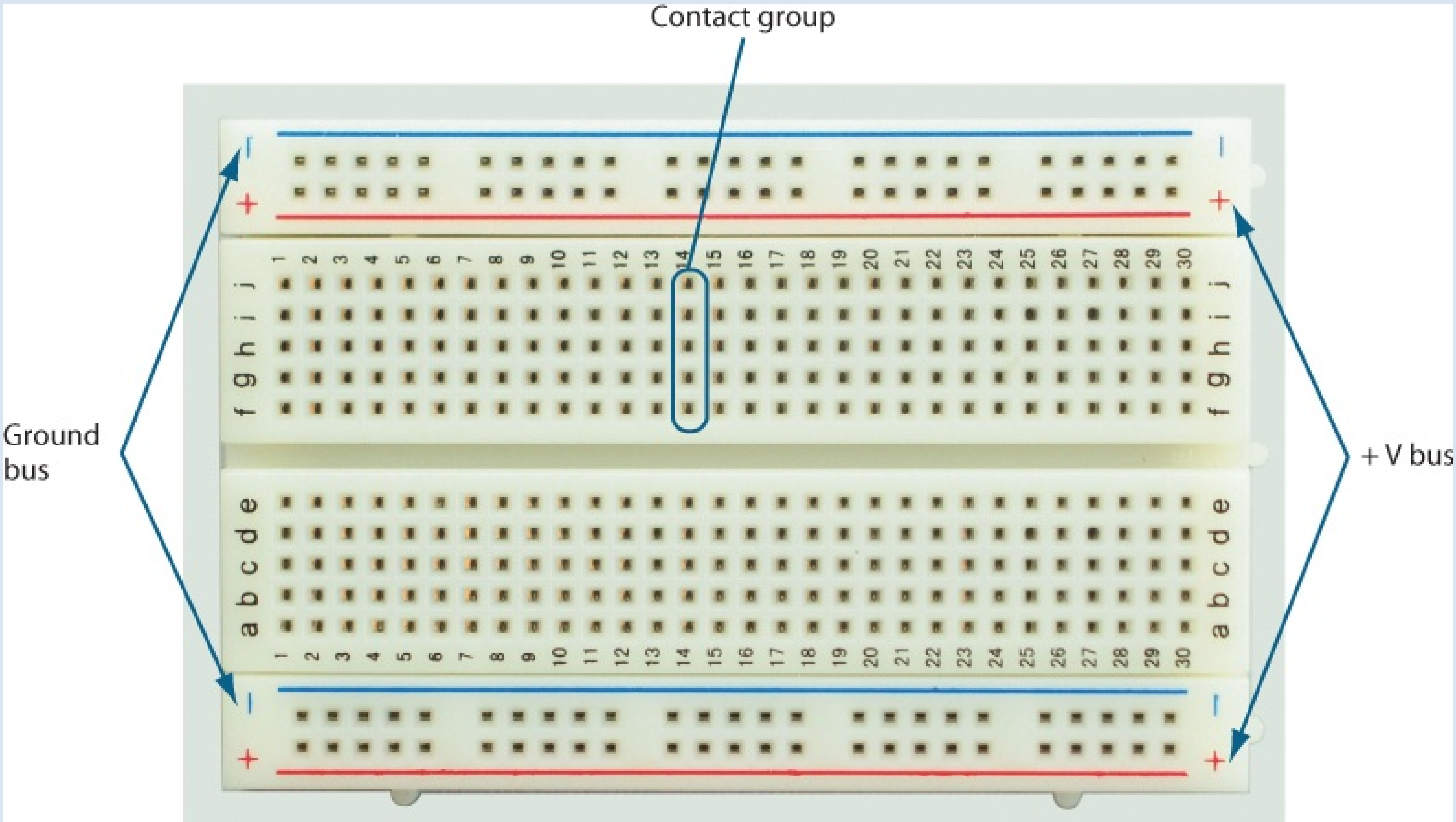
B. The sum is 28 volts.

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

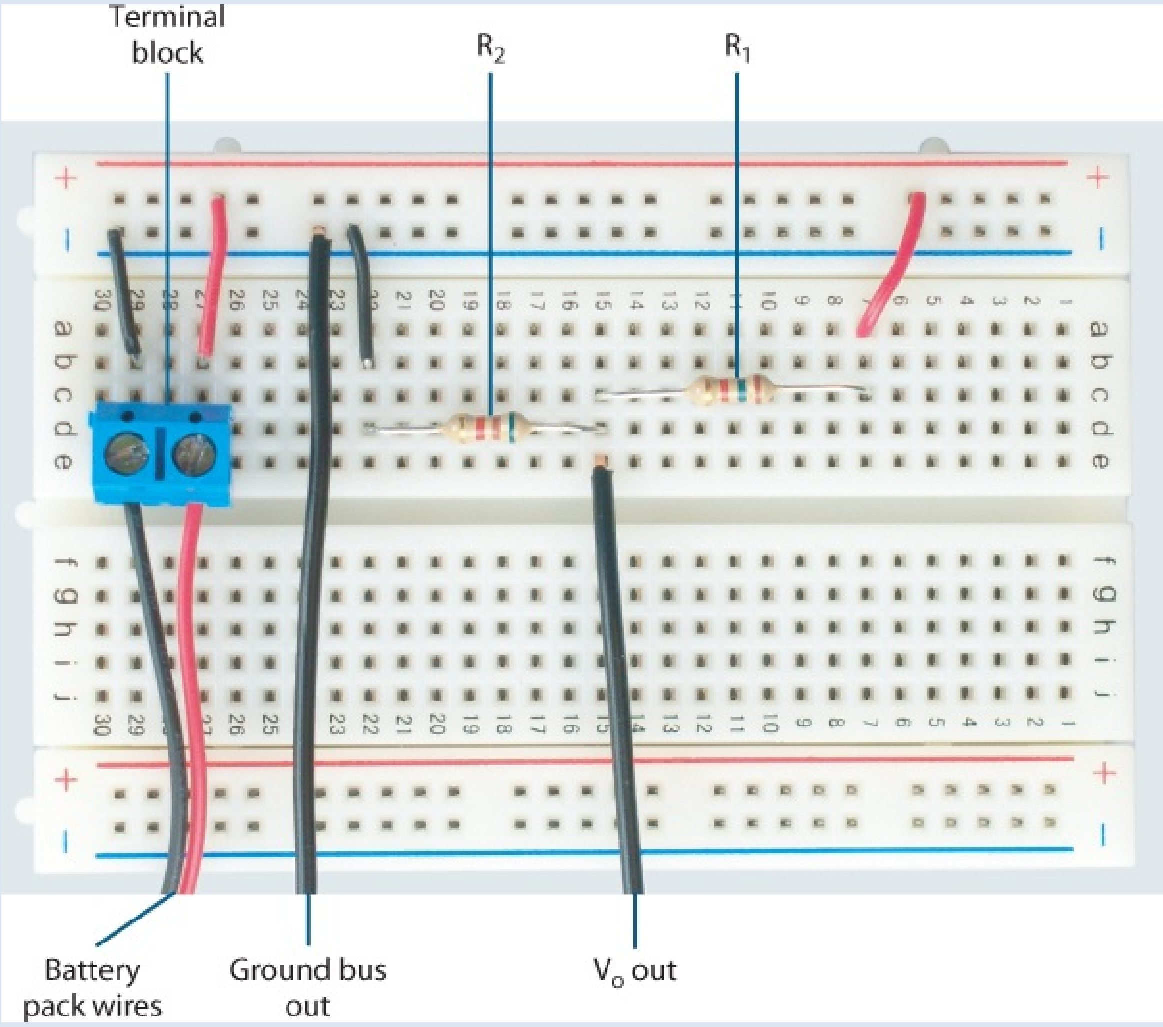
A convenient way to create a prototype of an electronic circuit to verify that it works is to build it on a *breadboard*. You can use breadboards to build the circuits used in the projects later in this book. As shown in the following figure, a breadboard is a sheet of plastic with several contact holes.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



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 pow supply and are referred to as the *ground bus*. The 1V buses and ground buses running along the to and bottom of the breadboard make it easy to connect any component in a circuit with a short piece wire called a *jumper wire*. Jumper wires are typically made of 22-gauge solid wire wi 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 inserted into a group of contact holes that is also connected by a jumper wire to the 1V bus. The oth end of R_1 is inserted into the same group of contact holes that contains one end of R_2. The other en of R_2 is inserted into a group of contact holes that is also connected by a jumper wire to the groun 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.



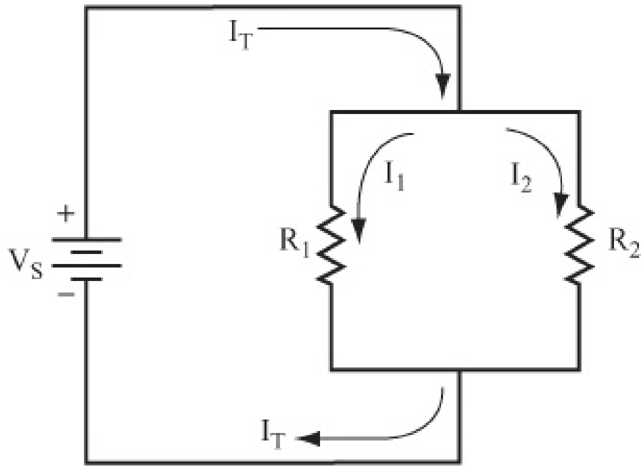
A *terminal block* is used to connect the battery pack to the breadboard because the wires supplie with battery packs (which are stranded wire) can't be inserted directly into breadboard contact hole The red wire from a battery pack is attached to the side of the terminal block that is inserted into group of contact holes, which is also connected by a jumper wire to the 1V bus. The black wire from battery pack is attached to the side of the terminal block that is inserted into a group of contact hole which is also connected by a jumper wire to the ground bus.

To connect the output voltage, Vo, to a multimeter or a downstream circuit, two addition connections are needed. One end of a jumper wire is inserted in the same group of contact holes th contain both R_1 and R_2 to supply Vo. One end of another jumper wire is inserted in a contact hole i the ground bus to provide an electrical contact to the negative side of the battery. When connectin test equipment to the breadboard, you should use a 20-gauge jumper wire because sometimes the 2 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 a 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).