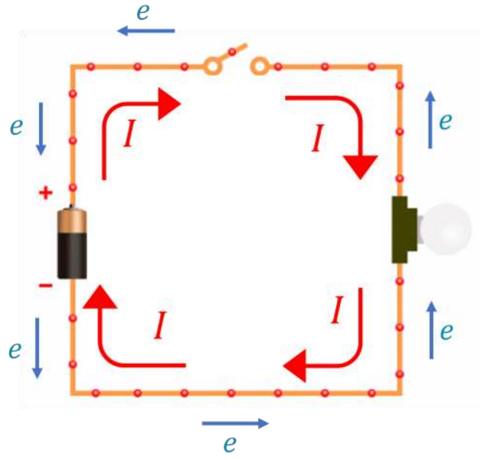
# EOT T2 10A

## UNIT 1

DON’T STUDY ONLY FROM HAIKAL

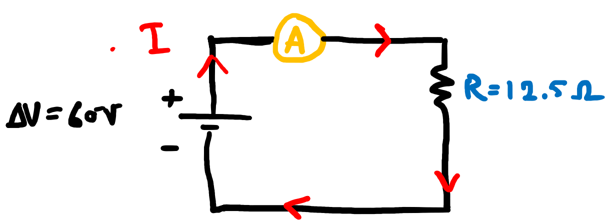
| | | |
|---|---|---|
| 1. Identify the direction of conventional current as the direction of motion of positive charges or opposite to the flow of electrons.<br>2. Define an electric circuit and describe the flow of charges through it. | Student Book (Figure 1)<br>Q8, Q9, Q20 | 90<br>95, 100 |

- **electric current:** the flow of **negative** charged particles (**electrons**) in a conductor.
- Electrons (the electric current) flow from the negative terminal to the positive terminal
- **Conventional current:** the direction in which **positive charges (protons)** move.
- protons (the conventional current) flow from the positive terminal to the negative terminal

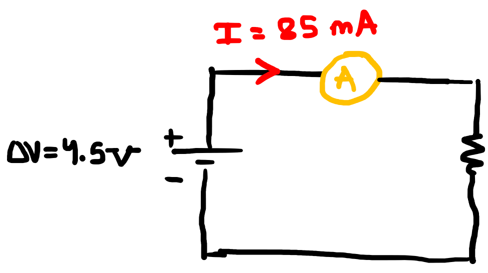



**PRACTICE Problems** ADDITIONAL PRACTICE

8. Draw a circuit diagram to include a 60.0-V battery, an ammeter, and a resistance of 12.5 Ω in series. Draw arrows on your diagram to indicate the direction of the current.

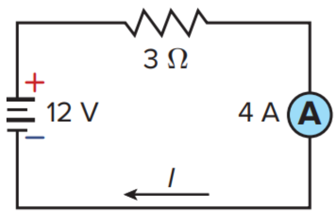



9. Draw a circuit diagram showing a 4.5-V battery, a resistor, and an ammeter that reads 85 mA. Show the direction of the current using conventional rules, and indicate the positive terminal of the battery.



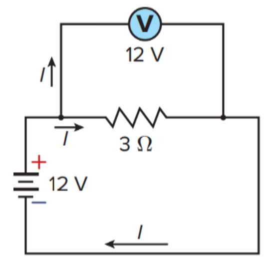

20. Draw a schematic diagram of a circuit that contains a battery and a lightbulb. Make sure the lightbulb will light in this circuit.

| | | | |
|---|---|---|---|
| 2 | 1. Identify the correct placements of ammeters and voltmeters in electric circuits.<br>2. Draw schematic circuit diagrams with different components along with ammeters and voltmeters correctly connected to measure current and voltage.<br>3. Identify what ammeters and voltmeters measure and how they are connected. | Student Book (Figure 5)<br>Q8-Q12, Q20, Q23, Q47, Q48, Q73 | 94-95, 100, 120-122<br>95, 122 |




**Series**

**Ammeters** measure current and are always connected in series




**parallel**

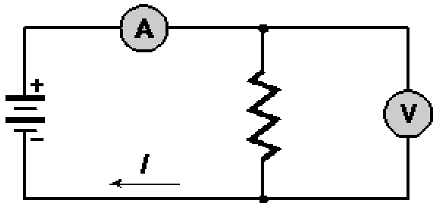
**voltmeters** measure voltage (potential difference) and are always connected in parallel

## PRACTICE Problems

ADDITIONAL PRACTICE

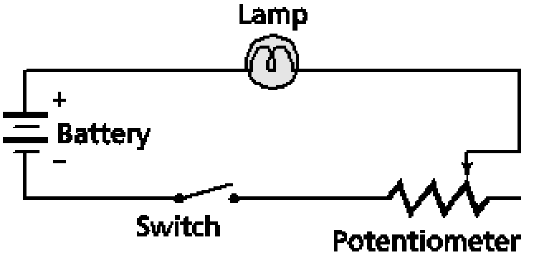
10. Add a voltmeter to measure the potential difference across the resistors in the previous two problems. Label the voltmeters

**Both circuits will take the form:**

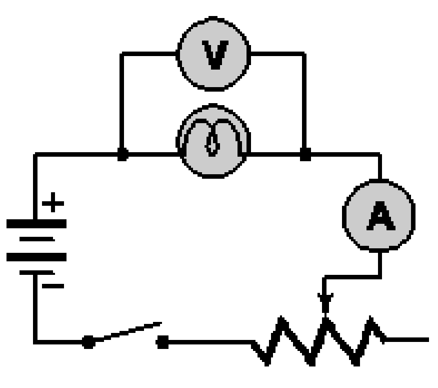



**Labels: 60.0 V for Practice Problem 8 and 4.5 V for Practice Problem 9.**

11. Draw a circuit using a battery, a lamp, a potentiometer to adjust the lamp's brightness, and an on-off switch




12. CHALLENGE Repeat the previous problem, adding an ammeter and a voltmeter across the lamp.

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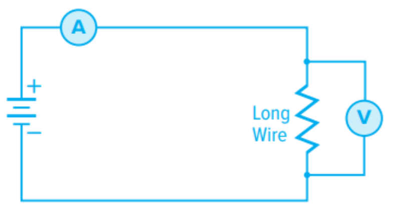
23. You want to measure the resistance of a long piece of wire. Show how you would construct a circuit with a battery, a voltmeter, an ammeter, and the wire to be tested to make the measurement. Specify what you would measure and how you would compute the resistance




Measure the current through the wire and the potential difference across it. Divide the potential difference by the current to obtain the wire resistance.

| | | | |
|---|---|---|---|
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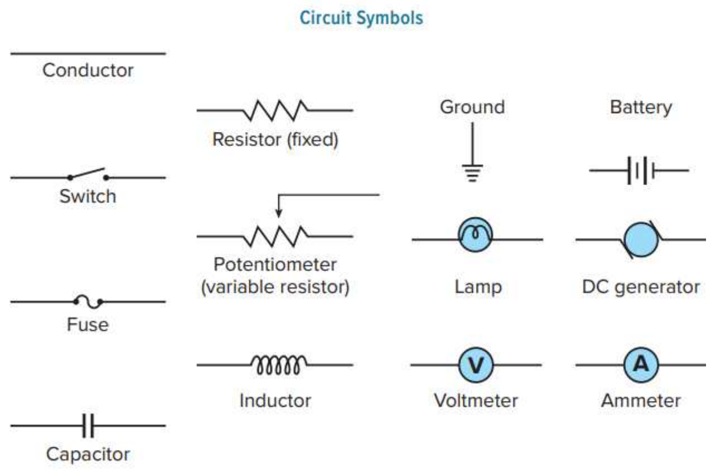
## Ammeters

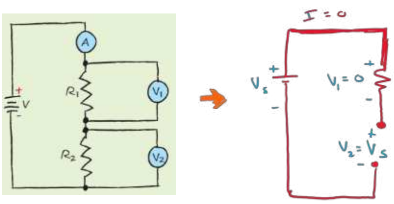
an ammeter is a device that is used to measure the current in any branch or part of a circuit. If, for example, you wanted to measure the current through a resistor, you would place an ammeter in series with the resistor. This would require opening the current path and inserting an ammeter.
Ideally, the use of an ammeter should not change the current in the circuit.
Because the current would decrease if the ammeter increased the resistance in the circuit, the resistance of an ammeter is designed to be as low as possible.




**PRACTICE Problems** ADDITIONAL PRACTICE

47. The circuit shown in Example Problem 4 is producing these symptoms: the ammeter reads 0 A, ΔV1 reads 0 V, and ΔV2 reads 45 V. What has happened?

**Since the ammeter reads 0A, this means the circuit is open. Since V1 reads 0 V , this means that R1 is still connected but no current passes in it, hence no voltage is dropped on it, since V2 has the same voltage of the battery, this means R2 was disconnected , the voltage across open terminals equals the voltage of the source.**

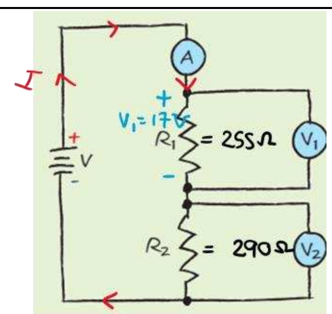



73. A voltmeter connected across bulb 2 measures 3.8 V, and a voltmeter connected across bulb 3 measures 4.2 V. What is the potential difference across the battery?

Solved in later pages

48. Suppose the circuit shown in Example Problem 4 has these values: R1 = 255 Ω, R2 = 290 Ω, and ΔV1 = 17 V. No other information is available.

a. What is the current in the circuit?
b. What is the potential difference across the battery?
c. What is the total power used in the circuit, and what is the power used in each resistor?
d. Does the sum of the power used in each resistor in the circuit equal the total power used in the circuit? Explain.




apply ohm's law to $R_1$ to find I

ⓐ $I = \frac{V_1}{R_1} = \frac{17}{255} = 0.067\ A$

ⓑ we can find it by either

$I = \frac{V_s}{R_{eq}} \rightarrow V_s = I R_{eq}$

or find $V_2$ then add $V_1$ and $V_2$

$V_2 = I R_2$

$R_{eq} = R_1 + R_2 = 255 + 290 = 545\ \Omega$

$V_s = I R_{eq} = 0.067 \times 545 = 36.5\ V$

or

$V_2 = I R_2 = 0.067 \times 290 = 19.43\ V$.

$V_s = V_1 + V_2 = 17 + 19.43 = 36.43\ V$

c. $P_s = I V_s = 0.067 \times 36.5 = 2.45\ W$

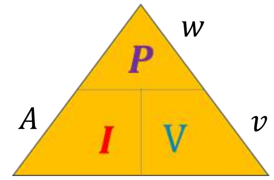
$P_1 = I V_1 = 0.067 \times 17 = 1.14\ W$

$P_2 = I V_2 = 0.067 \times 19.43 = 1.3$

the total power delivered by the battery is equal to the sum of consumed power in the loads

| 3 | 1. Apply the relationship between power, current and potential difference to solve numerical problems.<br>2. Rephrase the equation of power in terms of potential difference and resistance using Ohm's law: Power is equal to potential difference squared divided by the resistance. | Student Book<br>Q26-Q30, Q36, Q41 | 102<br>103, 105 |
|---|---|---|---|

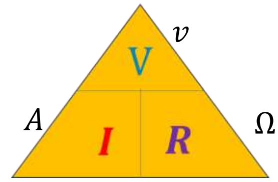
**power** $(P)(W)$




**Power** $(P)(W)$**:** the rate of energy consumption in electric devices (how many joules of energy is consumed for every second of operating)

$$P = I \times V$$

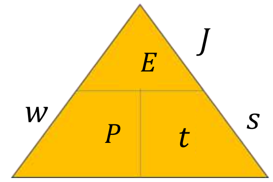
Combining with ohms law:




$$P = I^2R \qquad P = \frac{V^2}{R}$$

NOTE: $\Delta V$ same as $V$

**Energy** $(E)(J)$




- **Energy:** the power delivered multiplied by the operation time.
- If there are no losses, all the electrical energy is converted to other types of energy in electrical devices.

$$E = P \times t$$

**PRACTICE Problems** ADDITIONAL PRACTICE

26. A 15-Ω electric heater operates on a 120-V outlet.

a. What is the current through the heater?

$$I = \frac{V}{R} = \frac{120\ \text{V}}{15\ \Omega} = 8.0\ \text{A}$$

b. How much energy is used by the heater in 30.0 s?

$$E = I^2Rt = (8.0\ \text{A})^2(15\ \Omega)(30.0\ \text{s})$$
$$= 2.9\times10^4\ \text{J}$$

a. How much thermal energy is liberated in this time?

$2.9\times10^4$ J, because all electric energy is transformed to thermal energy.

27. A 39-Ω resistor is connected across a 45-V battery.

a. What is the current in the circuit?

$$I = \frac{V}{R} = \frac{45\ \text{V}}{39\ \Omega} = 1.2\ \text{A}$$

b. How much energy is used by the resistor in 5.0 min?

$$E = \frac{V^2}{R}t$$
$$= \frac{(45\ \text{V})^2}{(39\ \Omega)}(5.0\ \text{min})(60\ \text{s/min})$$
$$= 1.6\times10^4\ \text{J}$$

| | | | |
|---|---|---|---|
| 3 | 1. Apply the relationship between power, current and potential difference to solve numerical problems.<br>2. Rephrase the equation of power in terms of potential difference and resistance using Ohm's law: Power is equal to potential difference squared divided by the resistance. | Student Book | 102 |
| | | Q26-Q30, Q36, Q41 | 103, 105 |

## PRACTICE Problems

ADDITIONAL PRACTICE

28. A 100.0-W lightbulb is 22 percent efficient. This means that 22 percent of the electrical energy is transformed to radiant energy.

a. How many joules does the lightbulb transform into radiant energy each minute it is in operation?

$1\,min \times \frac{60\,s}{1\,min} = 60\,s$

$E = Pt = 100 \times 60 = 6000\,J$

$RE = 6000 \times \frac{22}{100} = 1320\,J$

$TE = 6000 \times \frac{78}{100} = 4680\,J$

a. How many joules of thermal energy does the lightbulb output each minute?

29. The resistance of an electric stove element at operating temperature is 11 Ω.

a. If 220 V are applied across it, what is the current through the stove element?

b. How much energy does the element transform to thermal energy in 30.0 s?

$Q = mc\Delta T$, $c = 4181\,J/kg \cdot K$

a. $I = \frac{\Delta V}{R} = \frac{220}{11} = 20\,A$

b. $E = P \times t = (I\Delta V) \times t = 20 \times 220 \times 30 = 132000\,J$

30. CHALLENGE A 120-V water heater takes 2.2 h to heat a given volume of water to a certain temperature. How long would a 240-V unit operating with the same current take to accomplish the same task

$$E = IVt = I(2V)\left(\frac{t}{2}\right)$$

**For a given amount of energy, doubling the voltage will divide the time by 2.**

$$t = \frac{2.2\ \text{h}}{2} = 1.1\ \text{h}$$

36. Resistance A hair dryer operating from 120 V has two settings, hot and warm. In which setting is the resistance likely to be smaller? Why?

**Hot draws more power,**
**P = IV, so the fixed voltage current is larger.**

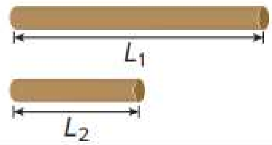
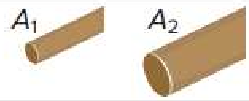
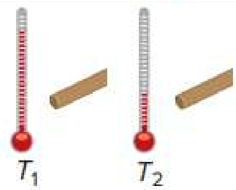
**Because I = V/R, the resistance is smaller**

41. Critical Thinking When demand for electric power is high, power companies sometimes reduce the voltage, thereby producing a "brown-out." What is being saved?

**Power, not energy; most devices will have to run longer.**

| 4 | Explain the factors (like length, cross-sectional area, temperature, and material of the conductor) that affect the resistance of a conductor. | Student Book (Table 1) | 96-97 |
|---|---|---|---|

## Table 1 Changing Resistance

| Factor | How Resistance Changes | Example |
|---|---|---|
| Length | Resistance increases as length increases. |  $R_{L1} > R_{L2}$ |
| Cross-sectional area | Resistance increases as the cross-sectional area decreases. |  $R_{A1} > R_{A2}$ |
| Temperature | Resistance usually increases as temperature increases. |  $R_{T1} > R_{T2}$ |
| Material | Keeping length, cross-sectional area, and temperature constant, resistance varies with the material used. | silver, copper, gold, aluminum, iron, platinum<br>*R* increases → |

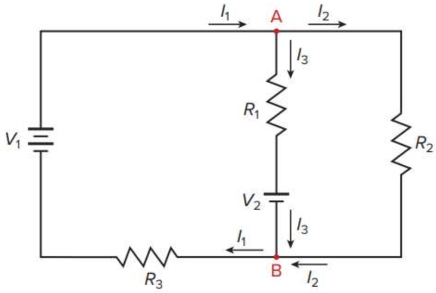
| 5 | 1. Explain how charge and energy are conserved in an electric circuit.<br>2. State Kirchhoff's junction rule and relate it to the conservation of charge. | Student Book<br>Q46, Q60, Q61, Q64 | 106-107, 115-116<br>108, 116 |
|---|---|---|---|

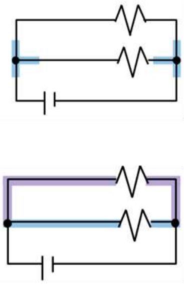
## Kirchhoff's rules

### The junction rule

The junction rule describes currents and is based on the **law of conservation of charge**.

**"the sum of currents entering a junction is equal to the sum of currents leaving that junction"**



**Junction**: Intersection of three or more pathways in a circuit.

**Branch**: A path connecting two junctions.

**PRACTICE Problems** ADDITIONAL PRACTICE

46.CHALLENGE Calculate the potential differences across three resistors, 12-Ω, 15-Ω, and 5-Ω, that are connected in series with a 75-V battery. Verify that the sum of their potential differences equals the potential difference across the battery.

① $R_{eq} = R_1 + R_2 + R_3 = 12 + 15 + 5 = 32\ \Omega$

② $I_{eq} = \frac{V_s}{R_{eq}} = \frac{75}{32} = 2.34\ A$

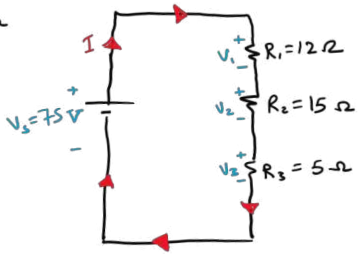
③ $V_1 = IR_1 = 2.34 \times 12 = 28.08\ V$

$V_2 = IR_2 = 2.34 \times 15 = 35.1\ V$

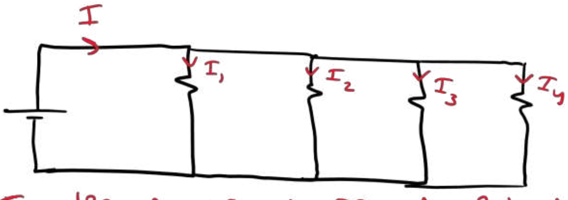
$V_3 = IR_3 = 2.34 \times 5 = 11.7\ V$

$V_1 + V_2 + V_3 = 74.88\ V \approx 75\ V$

which is the same as the potential difference of the battery




60. Total Current A parallel circuit has four branch currents: 120 mA, 250 mA, 380 mA, and 2.1 A. How much current passes through the power source?




$I = 120\ mA + 250\ mA + 380\ mA + 2.1\ mA$

$I = 752.1\ mA$

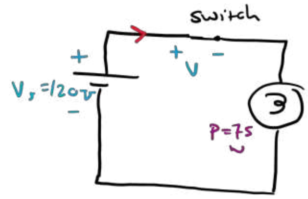
| | | | |
|---|---|---|---|
| 5 | 1. Explain how charge and energy are conserved in an electric circuit.<br>2. State Kirchhoff's junction rule and relate it to the conservation of charge. | Student Book | 106-107, 115-116 |
| | | Q46, Q60, Q61, Q64 | 108, 116 |

## PRACTICE Problems — ADDITIONAL PRACTICE

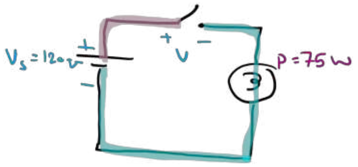
61. A series circuit has four resistors. The current through one resistor is 810 mA. What current passes through the power source?

Since its a series connection the current is the same every where so the current that passes through the battery is also 810 A

64. Junction Rule Explain how Kirchhoff's junction rule relates to the law of conservation of charge.




when the switch is closed, it's just a piece of wire so the Voltage drop on it is zero (doesn't consume energy)




when the switch is open it has the same Voltage as the battery.

| | | | |
|---|---|---|---|
| 6 | Define superconductors and demonstrate their importance. | Student Book | 102 |

**Superconductor**

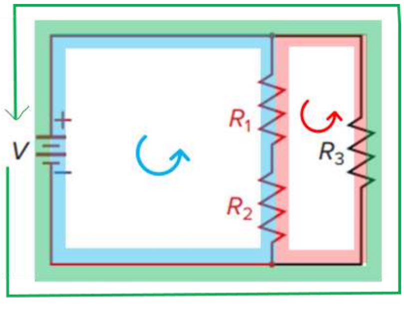
- A superconductor is a material with zero resistance. There is no restriction of current in superconductors, so there is no potential difference (ΔV) across a superconducting wire. Because the rate of energy transformation in a conductor is given by the product IΔV, a superconductor can conduct electricity without thermal energy transformations. At present, almost all superconductors must be kept at temperatures below 100 K. The practical uses of superconductors today include MRI magnets. Someday superconducting cables may efficiently carry electrical power to cities from distant power plants

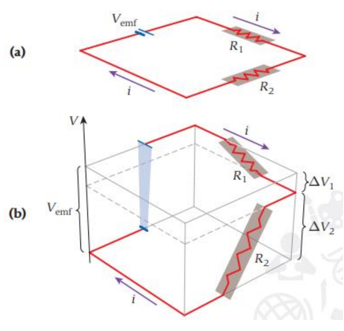
| | | | |
|---|---|---|---|
| 7 | State Kirchhoff's loop rule and relate it to the conservation of energy. | student Book | 115 |
| | | Q63, Q64 | 116 |

### The loop rule

The loop rule is based on the **law of conservation of energy**

**"The sum of increases in electric potential around a loop in an electric circuit equals the sum of decreases in electric potential around that loop."**




Electric potential increases by 9 V as the charge travels through the battery, if the electric potential drops by 5 V as this charge travels through resistor 1.
What will be the change in potential as the charge travels through resistor 2?

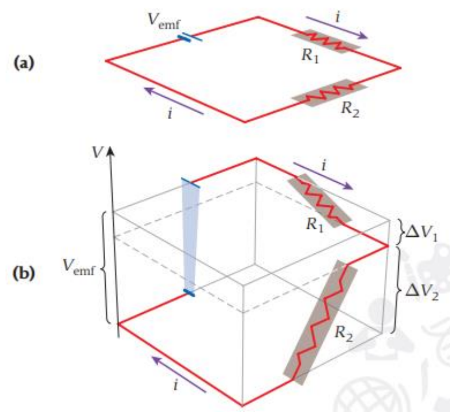
Because the increases in electric potential around a loop must equal the decreases in electric potential around that loop, the drop in electric potential across resistor 2 must be 9 V – 5 V = 4 V.

| | | | |
|---|---|---|---|
| 7 | State Kirchhoff's loop rule and relate it to the conservation of energy. | student Book | 115 |
| | | Q63, Q64 | 116 |

**PRACTICE Problems** ADDITIONAL PRACTICE

63 Compare Kirchhoff's loop rule to walking around in a loop on the side of a hill.

The increase in voltage is the same as climbing the hill , the voltage dropped on loads is the same as doing down the hill , the gravitational potential energy gained by climbing the hill is equal to the potential energy consumed and turned to kinetic energy while going down the hill




| | | | |
|---|---|---|---|
| 8 | Define a short circuit and describe its effects. | Student Book | 117 |

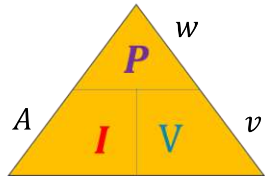
In an electric circuit, circuit breakers and fuses prevent circuit overloads that can occur when too many appliances are turned on at the same time or when a short circuit occurs in one appliance. A short circuit occurs when a circuit with very low resistance is formed. When appliances are connected in parallel, each additional appliance placed in operation reduces the equivalent resistance in the circuit and increases the current through the wires. This additional current might produce enough thermal energy to melt the wiring's insulation, cause a short circuit, or even begin a fire.

| | | | |
|---|---|---|---|
| 9 | 1. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV).<br>2. Identify the appropriate current rating of a fuse in a circuit.<br>Identify a fuse, a circuit breaker, and a ground-fault interrupter<br>3. Explain how fuses, circuit breakers and ground-fault interrupters protect electric circuits and make them safe to operate. | Student Book | 92, 118-119 |
| | | Q1-Q7, Q49, Q75 | 93, 111, 122 |

**power** $(P)(W)$

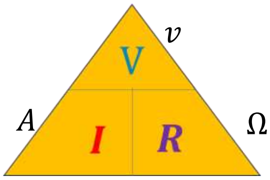
**Power** $(P)(W)$**:** the rate of energy consumption in electric devices (how many joules of energy is consumed for every second of operating)

$$P = I \times V$$




Combining with ohms law:

$$P = I^2R \qquad P = \frac{V^2}{R}$$

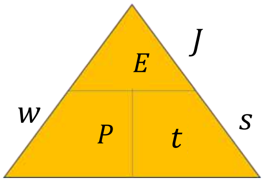



NOTE: $\Delta V$ same as $V$

<u>Energy $(E)(J)$</u>

- **Energy:** the power delivered multiplied by the operation time.
- If there are no losses, all the electrical energy is converted to other types of energy in electrical devices.

$$E = P \times t$$



| 9 | 1. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV).<br>2. Identify the appropriate current rating of a fuse in a circuit.<br>Identify a fuse, a circuit breaker, and a ground-fault interrupter<br>3. Explain how fuses, circuit breakers and ground-fault interrupters protect electric circuits and make them safe to operate. | Student Book<br>Q1-Q7, Q49, Q75 | 92, 118-119<br>93, 111, 122 |
|---|---|---|---|

A fuse is a short piece of metal that acts as a safety device by melting and stopping the current when too large a current passes through it. Engineers design fuses to melt before other elements in a circuit are damaged.

A ground-fault interrupter (GFI) is a device that contains an electronic circuit that detects small current differences between the two wires in the cord connected to an appliance. An extra current path, such as one through water, could cause this difference. The GFI stops the current when it detects such differences. This often protects a person from electrocution.

A circuit breaker, is an automatic switch that acts as a safety device by stopping the current if the current gets too large and exceeds a threshold value.

## PRACTICE Problems — ADDITIONAL PRACTICE

1. A car battery causes a current through a lamp and produces 12 V across it as shown in Figure 4. What is the power used by the lamp?

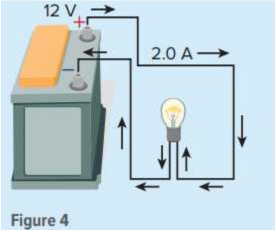


Figure 4

$P = I \times \Delta V$

$P = 2 \times 12$

$P = 24$ W

2. What is the current through a 75-W lightbulb that is connected to a 125-V outlet?

$$P = IV$$

$$I = \frac{P}{V} = \frac{75\text{ W}}{125\text{ V}} = 0.60\text{ A}$$

3. The current through a lightbulb connected across the terminals of a 125-V outlet is 0.50 A. At what rate does the bulb transform electrical energy to light? (Assume 100 percent efficiency.)

$P = I \times \Delta V =$

$0.5 \times 125 = 62.5$ W

4. The current through the starter motor of a car is 210 A. If the battery maintains 12 V across the motor, how much electrical energy is delivered to the starter in 10.0 s?

$E = P \times t$

$= I \times \Delta V \times t$

$= 210 \times 12 \times 10 = 25200$ J

5. A 75-V generator supplies 3.0 kW of power. How much current can the generator deliver?

$$I = \frac{P}{\Delta V} = \frac{3 \times 10^3}{75} = 40\text{ A}$$

| 9 | 1. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV).<br>2. Identify the appropriate current rating of a fuse in a circuit.<br>Identify a fuse, a circuit breaker, and a ground-fault interrupter<br>3. Explain how fuses, circuit breakers and ground-fault interrupters protect electric circuits and make them safe to operate. | Student Book<br>Q1-Q7, Q49, Q75 | 92, 118-119<br>93, 111, 122 |
|---|---|---|---|

## PRACTICE Problems

ADDITIONAL PRACTICE

6. A flashlight bulb is rated at 0.90 W. If the lightbulb produces a potential drop of 3.0 V, how much current goes through it?

$I = \frac{P}{\Delta V} = \frac{0.9}{3} = 0.3$ A

7. CHALLENGE A circuit is changed so the potential difference across a motor doubles and the current through the lightbulb triples. How does this change the motor's power?

$P = 3I \times 2\Delta V$

$P_{new} = 6 P_{old}$

49. Holiday lights often are connected in series and use special lamps that short out when the voltage across a lamp increases to the line voltage. Explain why. Also explain why these light sets might blow their fuses after many bulbs have failed.

**In a normal lightbulb lights, if one of the lightbulbs burn, the circuit becomes open and current stopps moving , so all lightbulbs stop working**
**In these special holiday lights , if one light bulb burns , it shorts out (tuns into an empty piece of wire), so the current keeps moving and the other light bulbs still work.**
**But if many light bulbs burn, and turn to only wire with no resistance, the equivalent resistance of the circuit decreases , which draws larger current from the socket , if the current is very large it burns the fuse (safety device) and opens the circuit to protect from fires**

75. Describe three common safety devices associated with household wiring.

A fuse is a short piece of metal that acts as a safety device by melting and stopping the current when too large a current passes through it. Engineers design fuses to melt before other elements in a circuit are damaged.

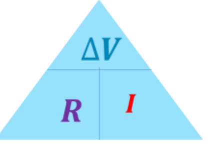
A ground-fault interrupter (GFI) is a device that contains an electronic circuit that detects small current differences between the two wires in the cord connected to an appliance. An extra current path, such as one through water, could cause this difference. The GFI stops the current when it detects such differences. This often protects a person from electrocution.

A circuit breaker, is an automatic switch that acts as a safety device by stopping the current if the current gets too large and exceeds a threshold value.

# paper questions

| | | | |
|---|---|---|---|
| 16 | 1. Define resistance and identify its SI unit as ohms (Ω)<br>2. Define a resistor as a device designed to have a specific resistance.<br>3. Sate Ohm's law and apply it to simple circuits (ΔV=RI).<br>4. Deriving resistance from the electrical (voltage - current) curve.<br>5. Identify devices which obey Ohm's law.<br>6. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV). | Student Book<br>Q1-Q7, Q13-Q18, Q21-Q25 | 92-99<br>93, 99, 100 |

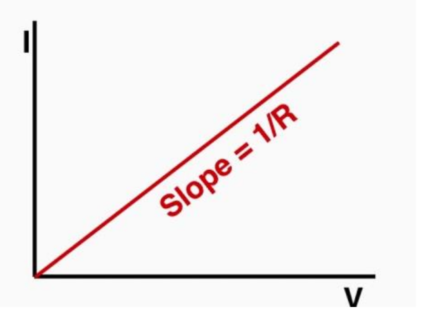
## Resistance (R) $(\Omega)$ and ohm's law




- **Resistance (R)** $(\Omega)$ : The measure of how strongly an object or a material impedes current.

$$R = \frac{\Delta V}{I}$$

- This is called **ohms law**, where:
  - $R$: resistance, measured in ohms $(\Omega)$, where $1\Omega = 1\ \text{v/A}$
  - $\Delta V$: the electric potential difference (voltage) measured in volts $(V)$
  - $I$: conventional current measured in Amperes $(A)$




- If the relationship between the voltage applied and the current is linear , the material is called **ohmic**
  **A device having constant resistance independent of the potential difference obeys Ohm's law.**
- **The slope in a v-I curve is equal to 1 over the resistance**

## Resistors

- **Resistor:** a component designed to have a specific resistance.
- may be made of carbon, semiconductors, or wires that are long and thin.
- Used to limit the flow of current and protect the wires and circuit from melting or burning

**PRACTICE Problems** — **ADDITIONAL PRACTICE**

13. An automobile panel lamp with a resistance of 33 Ω is placed across the battery shown in Figure 10. What is the current through the circuit?

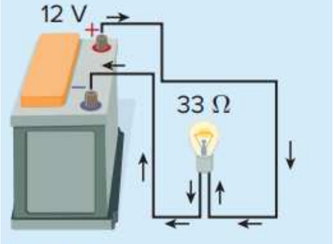



Figure 10

$$I = \frac{V}{R} = \frac{12\ \text{V}}{33\ \Omega} = 0.36\ \text{A}$$

14. A sensor uses 2.0×10−4 A of current when it is operated by the battery shown in Figure 11. What is the resistance of the sensor circuit?

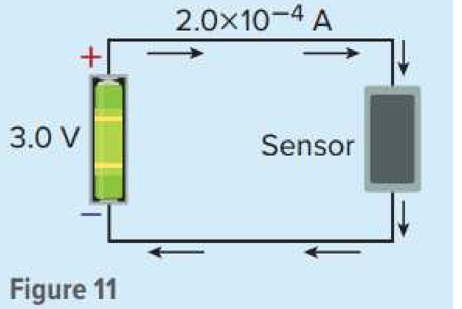



Figure 11

$$R = \frac{V}{I} = \frac{3.0\ \text{V}}{2.0\times10^{-4}\ \text{A}} = 1.5\times10^{4}\ \Omega$$

# paper questions

| | | | |
|---|---|---|---|
| 16 | 1. Define resistance and identify its SI unit as ohms (Ω)<br>2. Define a resistor as a device designed to have a specific resistance.<br>3. Sate Ohm's law and apply it to simple circuits (ΔV=RI).<br>4. Deriving resistance from the electrical (voltage - current) curve.<br>5. Identify devices which obey Ohm's law.<br>6. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV). | Student Book | 92-99 |
| | | Q1-Q7, Q13-Q18, Q21-Q25 | 93, 99, 100 |

## PRACTICE Problems

ADDITIONAL PRACTICE

15. A motor with the operating resistance of 32 Ω is connected to a voltage source as shown in Figure 12. What is the voltage of the source?

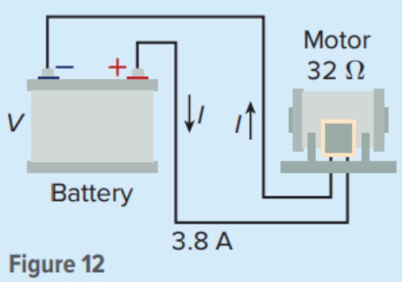



Figure 12

$$V = IR = (3.8\ \text{A})(32\ \Omega) = 1.2{\times}10^2\ \text{V}$$

16. A lamp draws a current of 0.50 A when it is connected to a 120-V source.

a. What is the resistance of the lamp?

$$R = \frac{V}{I} = \frac{120\ \text{V}}{0.50\ \text{A}} = 2.4\times10^2\ \Omega$$

b. What is the power consumption of the lamp?

$$P = IV = (0.50\ \text{A})(120\ \text{V}) = 6.0{\times}10^1\ \text{W}$$

17. A 75-W lamp is connected to 125 V.

a. What is the current through the lamp?

$$I = \frac{P}{V} = \frac{75\ \text{W}}{125\ \text{V}} = 0.60\ \text{A}$$

a. b. What is the resistance of the lamp?

$$R = \frac{V}{I} = \frac{125\ \text{V}}{0.60\ \text{A}} = 2.1\times10^2\ \Omega$$

18. A resistor is added to the lamp in the previous problem to reduce the current to half its original value. What is the potential difference across the lamp?

The new value of the current is

$$\frac{0.60\ \text{A}}{2} = 0.30\ \text{A}$$

$$V = IR = (0.30\ \text{A})(2.1\times10^2\ \Omega) = 6.3{\times}10^1\ \text{V}$$

a. How much resistance was added to the circuit?

The total resistance of the circuit is now

$$R_{total} = \frac{V}{I} = \frac{125\ \text{V}}{0.30\ \text{A}} = 4.2\times10^2\ \Omega$$

Therefore,

$$R_{res} = R_{total} - R_{lamp} = 4.2{\times}10^2\ \Omega - 2.1{\times}10^2\ \Omega = 2.1{\times}10^2\ \Omega$$

b. At what rate does the lamp transform electrical energy into radiant and thermal energy?

$$P = IV = (0.30\ \text{A})(6.3{\times}10^1\ \text{V}) = 19\ \text{W}$$

21. Joe states that because R = ΔV \ I , if he increases the voltage, the resistance will increase. Is Joe correct? Explain.

**No; resistance depends on the device. When V increases, so will I.**

22. A circuit has 12 Ω of resistance and is connected to a 12-V battery. Determine the change in power if the resistance decreases to 9.0 Ω.

① $P_1 = \frac{V^2}{R_1} = \frac{(12)^2}{12} = 12\ \text{W}$

② $P_2 = \frac{V^2}{R_2} = \frac{(12)^2}{9} = 16\ \text{W}$

$\Delta P = P_2 - P_1 = 16 - 12 = 4\ \text{W}$

power increased by 4 watts

## paper questions

| | | | |
|---|---|---|---|
| 16 | 1. Define resistance and identify its SI unit as ohms (Ω)<br>2. Define a resistor as a device designed to have a specific resistance.<br>3. Sate Ohm's law and apply it to simple circuits (ΔV=RI).<br>4. Deriving resistance from the electrical (voltage - current) curve.<br>5. Identify devices which obey Ohm's law.<br>6. Relate the electric power or rate of energy transfer to current and potential difference (P=IΔV). | Student Book | 92-99 |
| | | Q1-Q7, Q13-Q18, Q21-Q25 | 93, 99, 100 |

**PRACTICE Problems** ADDITIONAL PRACTICE

24. Energy A circuit transforms $2.2\times 10^3$ J of energy when it is operated for 3.0 min. Determine the amount of energy it will transform when it is operated for 1 h.

$2.2\times10^3$ J → 3 min

X ← 60 min

$\frac{3X}{3} = \frac{60\times 2.2\times10^3}{3}$

$X = 44000$ J

$= 4.4\times10^4$ J

25. **Critical Thinking** We sometimes say that power is "dissipated" in a resistor. To dissipate is to spread out or disperse. In what sense is something being dispersed when charge flows through a resistor?

***The potential energy of the charges decreases as they flow through the resistor. This potential energy is converted to thermal energy, and the thermal energy spreads out or dissipates in the surrounding environment.***

# paper questions

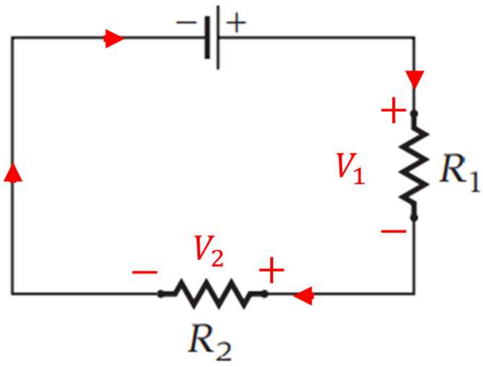
| | | | |
|---|---|---|---|
| 17 | 1. Define a resistor as a device designed to have a specific resistance.<br>2. Link the state of skin moisture in the human body to the amount of body resistance, and the effect of the intensity of the current passing through the human body. | Student Book | 96-98 |
| | | Q13-Q16, Q25 | 99-100 |

**HEALTH Connection** The human body acts as a variable resistor. Dry skin's resistance is high enough to keep currents that are produced by small and moderate voltages low. If skin becomes wet, however, its resistance is lowered, and an electric current can rise to dangerous levels. A current as low as 1 mA can be felt as a mild shock, while currents of 15 mA can cause loss of muscle control, and currents of 100 mA can cause death. For safety reasons you should be careful with any electric current, even from a lantern battery

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book | 107-114 |
| | | Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 108, 111, 112, 115, 122 |

**Series connection:** connecting the circuit components with one current path

***Properties of a series connection :***




1. The current throughout all resistors **is the same**.

$$I = I_1 = I_2 = \dots$$

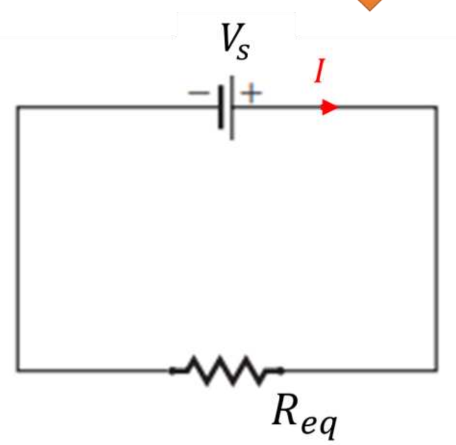
2. The source Voltage **is shared** between the resistors

$$V_s = V_1 + V_2 + \cdots$$

Where $V_1 = IR_1$ and $V_2 = IR_2$ ....

3. according to ohm's law, $\Delta V = IR$, the biggest Resistance gets the highest voltage drop across it's terminals .

Question: which resistance is higher?




4. The **equivalent resistor** can be calculated using :

$$R_{eq} = R_1 + R_2 + \dots$$

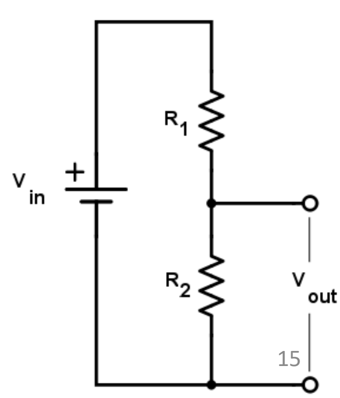
- If all resistors had the same resistance, then:

$$R_{eq} = nR$$

- The equivalent resistance **is larger than the largest resistance** in the circuit
- If a new resistor is added, $R_{eq}$ increases , lowering the current.
- The source current can be found from the equivalent circuit.

$$I = \frac{V_s}{R_{eq}}$$

**equivalent resistor:** one resistor that weighs the same as all resistors connected , if connected to the source, it draws the same amount of current as the original circuit.



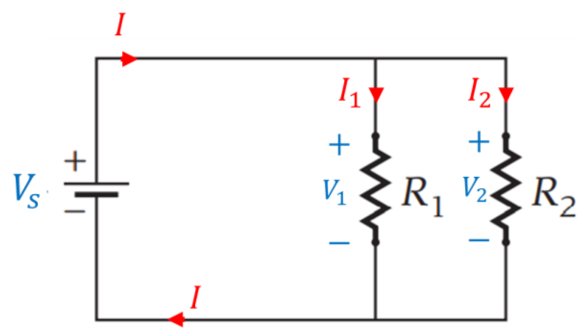

5. If one of the resistors break, the circuit is open and current ceases

6. Series connections are used as voltage divider circuits, which is a circuit used to lower the voltage supplied by the source to operate a load that needs a lower voltage

# paper questions

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book<br>Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 107-114<br>108, 111, 112, 115, 122 |

**Parallel connection:** a type of connection where the current flows in multiple paths




***Properties of a series connection :***

1. The voltage drop across each resistor is equal to the voltage provided by the source

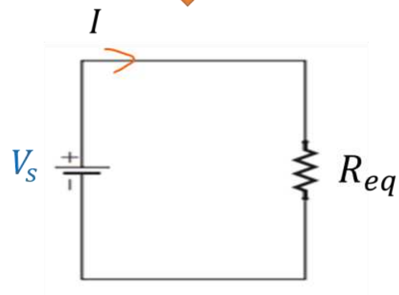
$$\mathbf{V_s = V_1 = V_2 = \cdots}$$

2. The source current **is shared** between the resistors

$$I = I_1 + I_2 + \ ...$$

Where $I_1 = \frac{V_s}{R_1}$ and $I_2 = \frac{V_s}{R_2}$

3. according to ohm's law, $\mathrm{I} = \frac{V}{R}$, the biggest R gets the lowest current through it.



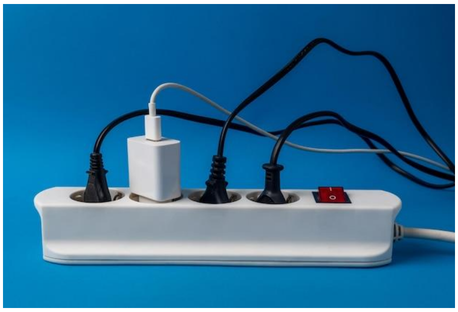

4. The equivalent resistor can be calculated using :

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} +$$

- If all resistors had the same resistance, then $R_{eq} = \frac{R}{n}$
- The equivalent resistance is **smaller than the smallest resistance in the circuit**
- If a new resistor is added, $R_{eq}$ decreases , increasing the drawn current.

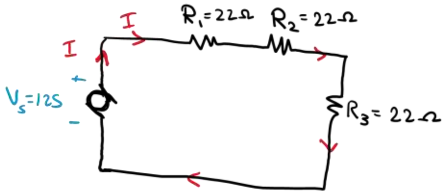
5. If one of the resistors break, only that branch stops working.

6. Parallel connections are used in domestical and industrial buildings (HOUSES)



**PRACTICE Problems** — ADDITIONAL PRACTICE

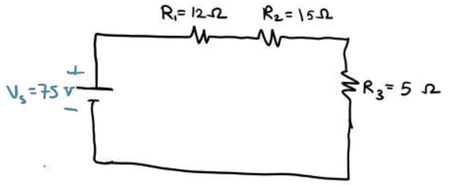
42. Three 22-Ω resistors are connected in series across a 125-V generator. What is the equivalent resistance of the circuit? What is the current in the circuit?




① $R_{eq} = nR = 3 \times 22 = 66\ \Omega$

② $I = \frac{V_s}{R_{eq}} = \frac{125}{66} = 1.9\ A$

43. A 12-Ω, a 15-Ω, and a 5-Ω resistor are connected in a series circuit with a 75-V battery. What is the equivalent resistance of the circuit? What is the current in the circuit?




① $R_{eq} = R_1 + R_2 + R_3 = 12 + 15 + 5 = 32\ \Omega$

② $I = \frac{V_s}{R_{eq}} = \frac{75}{32} = 2.3\ A$

# paper questions

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book<br>Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 107-114<br>108, 111, 112, 115, 122 |

**PRACTICE Problems** ADDITIONAL PRACTICE

44. A string of lights has ten identical bulbs with equal resistances connected in series. When the string of lights is connected to a 117-V outlet, the current through the bulbs is 0.06 A. What is the resistance of each bulb?

$R_{eq} = nR = 10R$

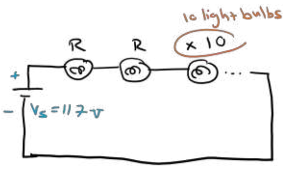
$I = \frac{V_s}{R_{eq}}$

$0.06 = \frac{117}{10R}$

$\frac{0.6R}{0.6} = \frac{117}{0.6}$

$R = 195\ \Omega$

each light bulb has a resistance of 195 Ω




45. A 9-V battery is in a circuit with three resistors connected in series.

a. If the resistance of one of the resistors increases, how will the equivalent resistance change?

a. if one of the resistances increase $R_{eq}$ increases (since its the sum of Resistances)

b. What will happen to the current?

b. since the current ↓ $I = \frac{V_s}{R_{eq}\uparrow}$ if $R_{eq}$ increases, I decreases

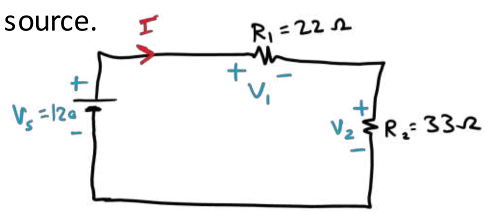
c. Will there be any change in the battery voltage?

c. no since battery Voltage doesn't change unless the chemical reaction in it finishes

50. The circuit in Example Problem 4 has unequal resistors. Explain why the resistor with the lower resistance will operate at a lower temperature.

*The lower the resistance, the lower potential difference drop (V) across its terminals. Which means it consumes less power, less power usage means less power heat losses*

52. A 22-Ω resistor and a 33-Ω resistor are connected in series and are connected to a 120-V power source.




a. What is the equivalent resistance of the circuit?

ⓐ $R_{eq} = R_1 + R_2 = 22 + 33 = 55\ \Omega$

a. What is the current in the circuit?

ⓑ $I = \frac{V_s}{R_{eq}} = \frac{120}{55} = 2.18\ A$

a. c. What is the potential difference across each resistor?

ⓒ $V_1 = IR_1 = 2.18 \times 22 = 47.96$

$V_2 = IR_2 = 2.18 \times 33 = 71.94\ V$

or $V_2 = V_s - V_1$

51. CHALLENGE A series circuit is made up of a 12-V battery and three resistors. The potential difference across one resistor is 1.2 V, and the potential difference across another resistor is 3.3 V. What is the voltage across the third resistor?

since its a series circuit, the battery Voltage is shared between the resistors

$V_s = V_1 + V_2 + V_3$

$12 = 1.2 + 3.3 + V_3$

$V_3 = 12 - 4.5$

$V_3 = 7.5\ V$

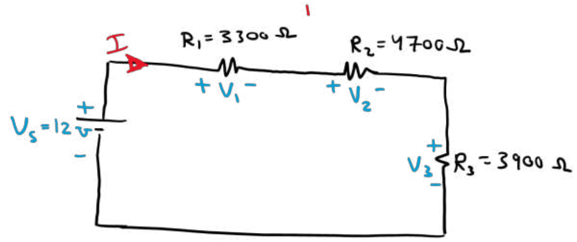
# paper questions

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book | 107-114 |
| | | Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 108, 111, 112, 115, 122 |

**PRACTICE Problems** ADDITIONAL PRACTICE

53. Three resistors of 3.3 kΩ, 4.7 kΩ, and 3.9 kΩ are connected in series across a 12-V battery.

a. What is the equivalent resistance?




ⓐ $R_{eq} = R_1 + R_2 + R_3 = 3300 + 4700 + 3900 = 11900\ \Omega$

b. What is the current through the resistors?

b $I = \frac{V_s}{R_{eq}} = \frac{12}{11900} = 1 \times 10^{-3}\ A$ (or 1 mA)

c. Find the total potential difference across the three resistors.

ⓒ $V_1 = IR_1 = 1\times10^{-3} \times 3300 = 3.3\ V$

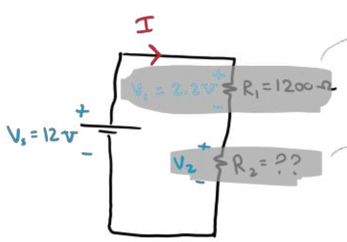
$V_2 = IR_2 = 1\times10^{-3} \times 4700 = 4.7\ V$

$V_3 = IR_3 = 1\times10^{-3} \times 3900 = 3.9\ V$

$V_1 + V_2 + V_3 = 11.9 \approx 12\ V$

same voltage as the battery

54. CHALLENGE Select a resistor to be used as part of a voltage divider along with a 1.2-kΩ resistor. The potential difference across the 1.2-kΩ resistor is to be 2.2 V when the supply is 12 V.




if u apply ohm's law on $R_1$, you get source current

$I = \frac{V_1}{R_1} = \frac{2.2}{1200} = 1.83 \times 10^{-3}\ A$

$V_2 = V_s - V_1 = 12 - 2.2$

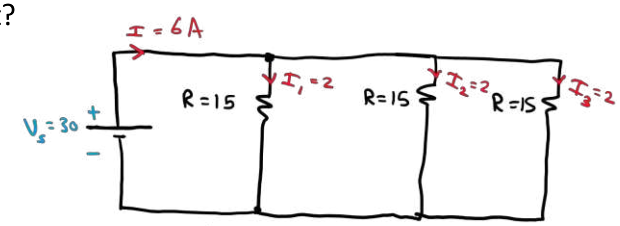
$V_2 = 9.8\ V$

$R_2 = \frac{V_2}{I} = \frac{9.8}{1.83\times10^{-3}} = 5355.2\ \Omega$

$= 5.35\ k\Omega$


55. You connect three 15.0-Ω resistors in parallel across a 30.0-V battery.

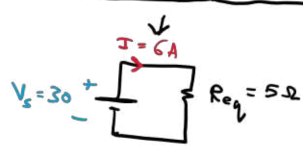
a. What is the equivalent resistance of the parallel circuit?




ⓐ $R_{eq} = \frac{R}{n} = \frac{15}{3} = 5\ \Omega$

b. What is the current through the entire circuit?

ⓑ $I = \frac{V_s}{R_{eq}} = \frac{30}{5} = 6\ A$




c. What is the current through each branch of the circuit?

ⓒ $I_1 = \frac{V_s}{R_1} = \frac{30}{15} = 2\ A$

$I_2 = \frac{V_s}{R_2} = \frac{30}{15} = 2\ A$

$I_3 = \frac{V_s}{R_3} = \frac{30}{15} = 2\ A$

# paper questions

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book | 107-114 |
| | | Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 108, 111, 112, 115, 122 |

**PRACTICE Problems** — ADDITIONAL PRACTICE

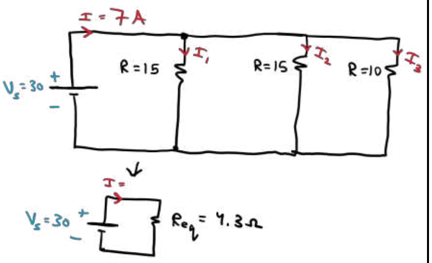
56. Suppose you replace one of the 15.0-Ω resistors in the previous problem with a 10.0-Ω resistor.

a. How does the equivalent resistance change?

ⓐ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

$\frac{1}{R_{eq}} = \frac{1}{15} + \frac{1}{15} + \frac{1}{10}$

$R_{eq} = 4.3\ \Omega$ (decreases)




b. How does the current through the entire circuit change?

ⓑ $I = \frac{V_s}{R_{eq}} = \frac{30}{4.3} = 7\ A$ (Increases)

c. c. How does the current through one of the 15.0-Ω resistors change?

ⓒ $I_1 = \frac{V_s}{R_1} = \frac{30}{15} = 2\ A$

$I_2 = \frac{V_s}{R_2} = \frac{30}{15} = 2\ A$

$I_3 = \frac{V_s}{R_3} = \frac{30}{10} = 3\ A$

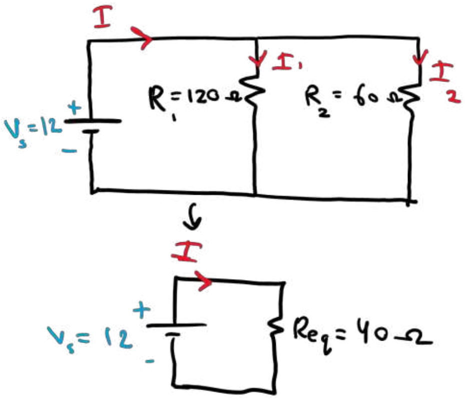
57. You connect a 120.0-Ω resistor, a 60.0-Ω resistor, and a 40.0-Ω resistor in parallel across a 12.0-V battery.

a. What is the equivalent resistance of the parallel circuit?

ⓐ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{R_{eq}} = \frac{1}{120} + \frac{1}{60}$

$R_{eq} = 40\ \Omega$




b. What is the current through the entire circuit?

ⓑ $I = \frac{V_s}{R_{eq}} = \frac{12}{40} = 0.3\ A$

c. What is the current through each branch of the circuit?

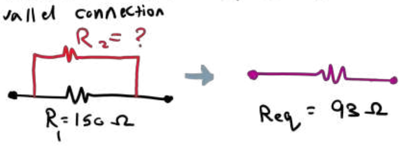
ⓒ $I_1 = \frac{V_s}{R_1} = \frac{12}{120} = 0.1\ A$

$I_2 = \frac{V_s}{R_2} = \frac{12}{60} = 0.2\ A$

or: $I_2 = I - I_1 = 0.3 - 0.1 = 0.2\ A$

58. CHALLENGE You are trying to reduce the resistance in a branch of a circuit from 150 Ω to 93 Ω. You add a resistor to this branch of the circuit to make this change. What value of resistance should you use, and how should you connect this resistor?

to reduce the resistance, we use parallel connection




$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$

$\frac{1}{93} = \frac{1}{150} + \frac{1}{R_2}$

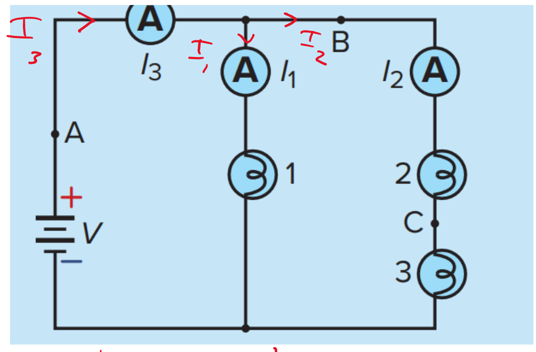
$\frac{1}{R_2} = \frac{1}{93} - \frac{1}{150} =$

$R_2 = 244.7\ \Omega$

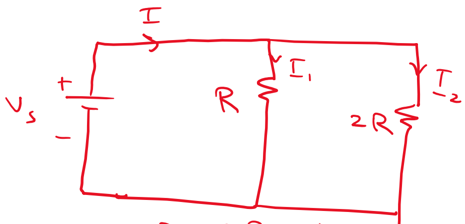
# paper questions

| | | | |
|---|---|---|---|
| 18 | 1. Explain the characteristics of a series and parallel circuits.<br>2. Define an equivalent resistance of a series and parallel circuits.<br>3. Calculate the equivalent resistance and the total current passing through a series and parallel circuits.<br>4. Explore connecting resistors in series and in parallel and determine the properties and uses of each kind of connection by studying the electric current and the potential difference across each resistor. | Student Book | 107-114 |
| | | Q42-Q46, Q47-Q51, Q52-Q54, Q55-Q58, Q70-Q74 | 108, 111, 112, 115, 122 |

**PRACTICE Problems** ADDITIONAL PRACTICE




70. How do the brightness of the bulbs compare?




Sinc R < 2R, the current through it will be higher, since both light bulbs have the same Voltage it means Light 1 will be brighter than 2 and 3 because it recieves more power

71. If I 3 is 1.7 A and I 1 is 1.1 A, what is the current through bulb 2?

$I_3 = 1.7$ A $I_1 = 1.1$ A

$I_2 = I_3 - I_1 = 1.7 - 1.1 = 0.6$ A

72. The wire at point C is broken, and a small resistor is inserted in series with bulbs 2 and 3. What happens to the brightness of the two bulbs? Explain.

the brightness decreases because the Voltage of the battery will be shared between 3 bulbs instead of 2 making the power delivered to each bulb less

73. A voltmeter connected across bulb 2 measures 3.8 V, and a voltmeter connected across bulb 3 measures 4.2 V. What is the potential difference across the battery?

$V_s = V_2 + V_3 = 3.8 + 4.2 = 8$ V

74. Using information from the previous problem, determine whether bulbs 2 and 3 are identical.

Since they have different potential difference across them they are not identical

# paper questions

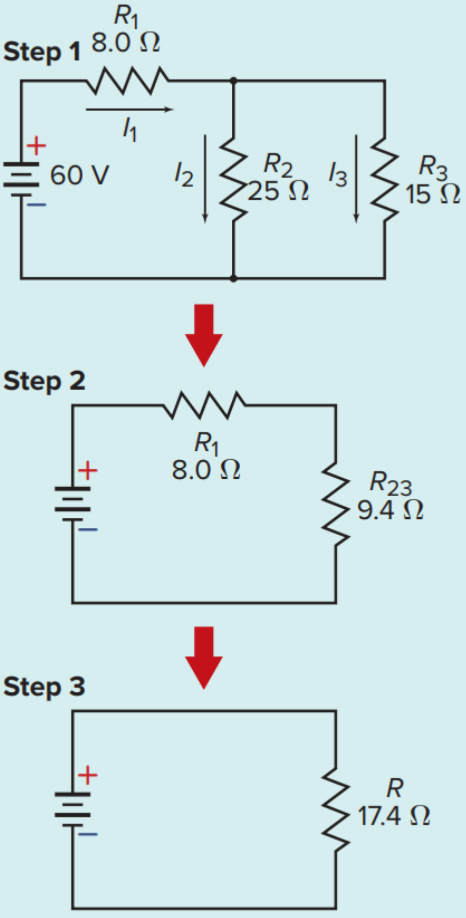
| | | | |
|---|---|---|---|
| 19 | 1. Calculate the equivalent resistance of combined series-parallel circuits.<br>2. Calculate the voltage, current, and power dissipation for any resistor in a combined series-parallel circuit.<br>3. Describe how magnetic materials can be turned into temporary magnets.<br>4. Describe the characteristics of magnetic fields and sketch the field lines around a permanent magnet.<br>5. Apply the right-hand rule to indicate the direction of the magnetic field in and around a solenoid carrying current. | Student Book | 119-122 |
| | | Q66-Q68, Q69-Q74; Q5-Q16 | 121, 122; 131-135 |

## PROBLEM-SOLVING STRATEGY

### SERIES-PARALLEL CIRCUITS

When analyzing a combination series-parallel circuit, use the following steps to break down the problem.

1. Draw a schematic diagram of the circuit.
2. Find any parallel resistors. Resistors in parallel have separate current paths. They must have the same potential differences across them. Calculate the single equivalent resistance of a resistor that can replace them. Draw a new schematic using that resistor.
3. Are any resistors (including the equivalent resistor) now in series? Resistors in series have one and only one current path through them. Calculate a single new equivalent resistance that can replace them. Draw a new schematic diagram using that resistor.
4. Repeat steps 2 and 3 until you can reduce the circuit to a single resistor. Find the total circuit current. Then go backward through the circuits to find the currents through and the potential differences across individual resistors.



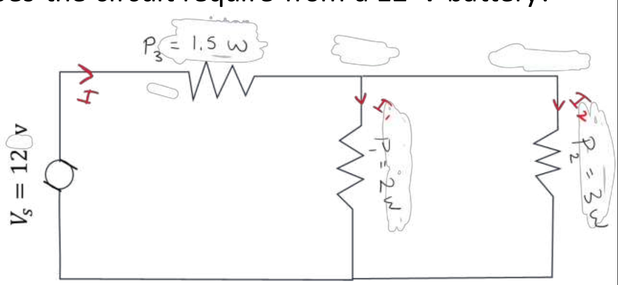

**PRACTICE Problems** ADDITIONAL PRACTICE

66. A series-parallel circuit, similar to the one in Example Problem 7, has three resistors: one uses 2.0 W, the second 3.0 W, and the third 1.5 W. How much current does the circuit require from a 12-V battery?

according to the law of energy conservation the power produced by the source is equal to the power consumed by the loads

$P_s = P_1 + P_2 + P_3 = 2 + 3 + 1.5 = 6.5$ W

$I_s = \frac{P_s}{V_s} = \frac{6.5}{12} = 0.54$ A



# paper questions

| | | | |
|---|---|---|---|
| 19 | 1. Calculate the equivalent resistance of combined series-parallel circuits.<br>2. Calculate the voltage, current, and power dissipation for any resistor in a combined series-parallel circuit.<br>3. Describe how magnetic materials can be turned into temporary magnets.<br>4. Describe the characteristics of magnetic fields and sketch the field lines around a permanent magnet.<br>5. Apply the right-hand rule to indicate the direction of the magnetic field in and around a solenoid carrying current. | Student Book<br>Q66-Q68, Q69-Q74; Q5-Q16 | 119-122<br>121, 122; 131-135 |

**PRACTICE Problems** ADDITIONAL PRACTICE

67. If the 13 lights shown in Figure 32 are identical, which of them will burn brightest?

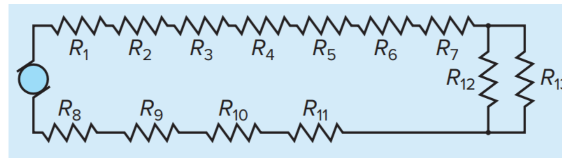
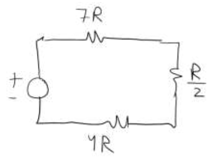


Figure 32




the resistor with lowest R will have the highest Voltage drop so (R/2) which is the two parallel resistors $R_{12}$ and $R_{13}$ will shine the brightest

↑ V = IR ↑

↑ P = IV ↑

68. CHALLENGE A series-parallel circuit has three appliances on it. A blender and a stand mixer are in parallel, and a toaster is connected in series as shown. Assume that the voltage of the socket is 120 v

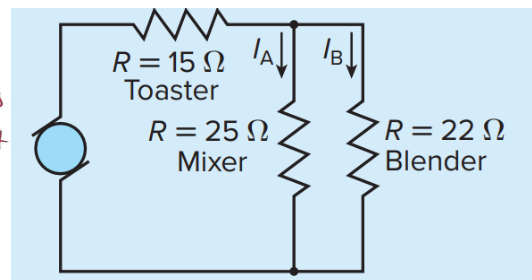


Figure 33

a. Find the equivalent resistance

① Find the equivalent Resistance.

$R_M$ and $R_B$ are in parallel

$$\frac{1}{R_{MB}} = \frac{1}{R_M} + \frac{1}{R_B} = \frac{1}{25} + \frac{1}{22}$$

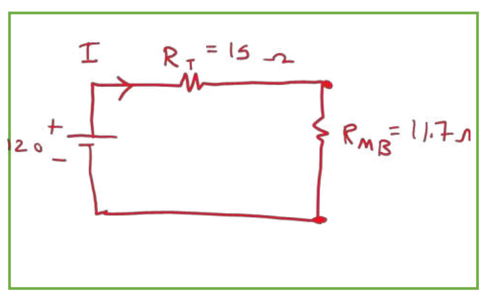
$$\frac{1}{R_{MB}} = 0.085$$

$$R_{MB} = 11.7\ \Omega$$

$R_T$ and $R_{MB}$ are in series

$$R_{eq} = R_T + R_{MB} = 15 + 11.7$$

$$R_{eq} = 26.7\ \Omega$$




b. Find the current through the toaster

$$I = \frac{V_s}{R_{eq}} = \frac{120}{26.7} = 4.5\ A$$

c. Find the potential difference across the toaster

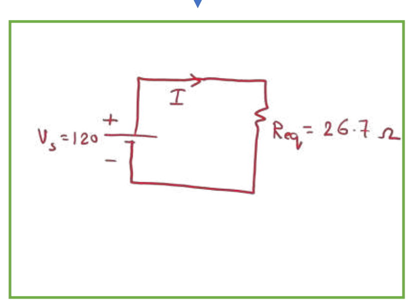
$$V_T = I R_T = 4.5 \times 15 = 67.5\ V$$

d. Find the voltage across the mixer and blender

$$V_{MB} = V_s - V_T = 120 - 67.5 = 52.5\ V$$

since $V_{MB}$ came from 2 parallel resistors $R_M$ and $R_B$

$$V_M = V_B = V_{MB} = 52.5\ V$$




e. Find the currents through the mixer and the blender

$$I_B = \frac{V_B}{R_B} = \frac{52.5}{22} = 2.39\ A$$

$$I_M = \frac{V_M}{R_M} = \frac{52.5}{25} = 2.1\ A$$

(or $I_M = I - I_B = 4.5 - 2.39 = 2.1\ A$)

# UNIT 2

DON'T STUDY ONLY FROM HAIKAL

| | | | |
|---|---|---|---|
| 10 | 1. Describe how magnetic materials can be turned into temporary magnets.<br>2. Describe magnetic domains and relate them to the magnetic properties of ferromagnetic materials. | Student Book | 130-133 |
| | | Q10-Q13, Q16, Q17 | 136 |

**Temporary magnets** Magnets also attract nails, paper clips, tacks, and other metal objects. These objects have no poles, and both the north and south poles of a magnet attract them. When a magnet touches one of these objects, such as the nail in **Figure 3,** the magnet polarizes the object, making it a temporary magnet. This process is called magnetization by induction.

**Figure 3** A common nail attached to a magnet becomes a temporary magnet by induction.

**Identify** *the north and south poles of the nail.*

Magnets only attract some metals. Brass, copper, and aluminum are common metals that are not attracted to magnets. Iron, nickel, and cobalt are strongly attracted. Materials containing these elements, called ferromagnetic materials, can become temporary magnets. A steel nail can become a temporary magnet because it is made of iron with tiny amounts of carbon and other materials. When you remove a nail from a magnet, the nail gradually loses most of its magnetism.

**Magnetic domains** What gives a permanent or temporary magnet its magnetic properties? Each atom in a ferromagnetic material acts like a tiny magnet; each has two poles. Each is part of a **domain,** which is a group of neighboring atoms whose poles are aligned. Look at the arrows in **Figure 4.** Each arrow represents a domain. Although domains can contain as many as $10^{20}$ individual atoms, they are tiny—usually from 10 to 1000 microns across. Even a small sample of a ferromagnetic material contains a huge number of domains.

In a ferromagnetic material that is not magnetized, each domain points in a random direction, as shown in the top panel of **Figure 4.** But if the ferromagnetic material is next to a strong magnet, most of the object's domains preferentially align to point in the same direction as the poles of the external magnet, as shown in the bottom panel of **Figure 4.** When its domains are aligned in the same direction, the material becomes a temporary magnet. When an external magnet is removed from a temporary magnet, the domains of the temporary magnet return to a random arrangement, and the material loses its magnetization. How long it takes for a temporary magnet to lose its magnetization depends on the interactions between the atoms, which depend on the microscopic structure of the material.

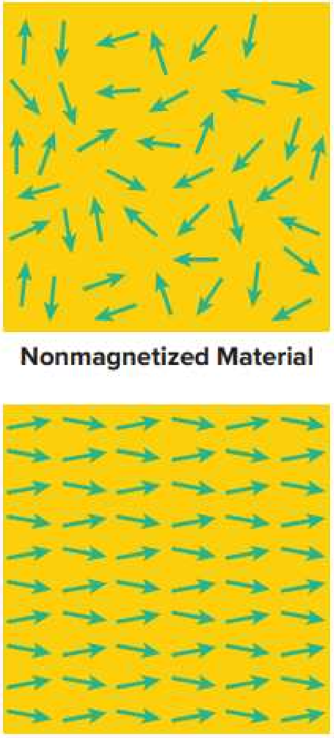



**Figure 4** Domains in a nonmagnetized ferromagnetic material point in random directions (top). When a strong magnet is placed near a ferromagnetic material, the domains in that ferromagnetic material align with those of the external magnet (bottom).

**Creating permanent magnets** The only naturally occurring magnet is the mineral magnetite. The lodestones that ancient sailors used were nothing more than pieces of magnetite. If magnetite is the only naturally occurring magnet, how, then, are commercial permanent magnets made?

When an object containing certain ferromagnetic materials is heated in the presence of a strong magnet, thermal energy frees the atoms in each of the object's domains. The domains can rotate and align with the magnet's poles. The object is then cooled while it is still in the presence of the strong magnet. After cooling, the object's atoms are less free to rotate. Therefore, when the strong magnet is removed from the object, the object remains magnetized. A permanent magnet has been created. If this permanent magnet is later reheated or dropped, however, the atoms can jostle out of alignment, reordering the domains and removing the magnetic properties.

PRACTICE Problems

ADDITIONAL PRACTICE

10. Explain how to construct an electromagnet.

You could connect either end of a wire to a source of current. The strongest electromagnets are solenoids, where wire in a circuit is wrapped around a ferromagnetic rod, such as iron, which increases field strength

11. What two things about a magnetic field can magnetic field lines represent?

Field lines represent the strength and the direction of a magnetic field.

12. Considering magnetic forces, how are forces at distance explained?

Magnetic forces, like other forces at a distance are explained using the concept of a field

13. Where on a bar magnet is the magnetic field the strongest?

at the poles

16. A glass sheet with iron filings sprinkled on it is placed over an active electromagnet. The iron filings produce a pattern. If this scenario were repeated with the direction of current reversed, what observable differences would result? Explain

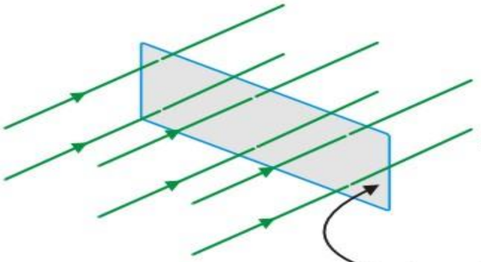
None; the filings would show the same field pattern. However, a compass would show that the magnetic polarity had reversed.

17. Magnetic Domains Explain what happens to the domains of a temporary magnet when the temporary magnet is removed from a magnetic field.

The domains return to a random arrangement because they no longer align with the domains of the field of the permanent magnet.

| 11 | Define magnetic flux. | Student Book | 132 |
|---|---|---|---|
| | | Q11, Q12, Q13 | 136 |

**Magnetic field lines** Scientists visualize magnetic fields using magnetic field lines, such as those shown in **Figure 7.** Like electric field lines, magnetic field lines are not real. They are used to show the direction as well as the strength of a magnetic field. The number of magnetic field lines passing through a surface perpendicular to the lines is the **magnetic flux.** The flux per unit area is proportional to the strength of the magnetic field. Magnetic flux is most concentrated at magnetic poles, where magnetic field strength is the highest.




| 12 | Describe the relationship between magnetic fields and electric currents. | Student Book | 133-134 |
|---|---|---|---|
| | | Q5-Q9, Q18 | 136 |

## Electromagnetism

In 1820, while doing a lecture demonstration, Danish physicist Hans Christian Oersted laid a wire across the top of a compass and connected the ends to a battery to complete an electric circuit. The compass was oriented so its needle was parallel to the wire, as shown in the left side of **Figure 9.**



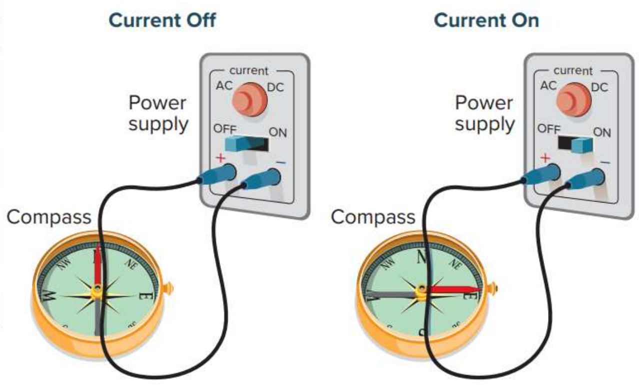



**Figure 9** The needle of a compass under a wire and originally parallel to the wire when current is off (left) moves so it is perpendicular to the wire when current is on (right).

When Oersted turned the current on, he was amazed to see that the needle moved so it was perpendicular to the wire, as it is in the right side of **Figure 9.** When Oersted placed the compass on top of the wire, the needle again became perpendicular to the wire, but it pointed in the other direction. The same thing happened when he reversed the current's direction: the compass needle reversed direction. When he turned off the current, the needle returned to its original position.

Oersted's conclusion—that a current produces a magnetic field—was the first hint that a connection exists between magnetism and electric currents. As you will read, the relationship between magnetism and electric current underlies the design and operation of many modern devices.

| | | | |
|---|---|---|---|
| 12 | Describe the relationship between magnetic fields and electric currents. | Student Book | 133-134 |
| | | Q5-Q9, Q18 | 136 |

**Magnetic fields from current-carrying wires** The magnetic field around a current-carrying wire is always perpendicular to that wire. Just as field lines around permanent magnets form closed loops, the field lines around current-carrying wires also form closed loops. The circular pattern of iron filings shown in the top panel of **Figure 10** represents these loops. The strength of the magnetic field around a long, straight wire is proportional to the current in that wire. Magnetic field strength also varies inversely with distance from the wire.

**Direction of the magnetic field** How can you find the direction of the magnetic field around a current-carrying wire? Scientists use right-hand rules to describe how the directions of electric and magnetic properties relate. In this case, imagine holding a length of wire with your right hand, as shown in **Figure 10.** If your thumb points in the direction of the conventional (positive) current, as it does in the bottom panel of **Figure 10,** the fingers of your hand encircling the wire will point in the direction of the magnetic field.

**Electromagnets** You just read that a current in a wire produces a magnetic field encircling that wire. What do you think happens to the magnetic field around a wire formed into a loop? An electric current in a single loop of wire forms a magnetic field all around the loop, as shown in the left panel of **Figure 11** on the next page. By applying a right-hand rule to any part of the loop in **Figure 11,** you can see that the direction of the magnetic field inside the loop is always the same.

**Right-Hand Rule**

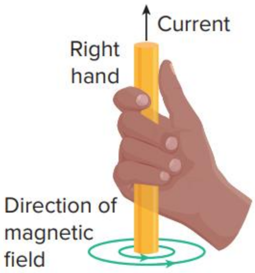



**Figure 10** The circular patterns formed by iron filings around a current-carrying wire (top) represent the magnetic field around the wire. You can determine the direction of the magnetic field around the wire using a right-hand rule (bottom).

**Analyze** *What happens to the magnetic field around a wire when current changes direction?*

**PRACTICE Problems** **ADDITIONAL PRACTICE**

5. How does the strength of a magnetic field that is 1 cm from a current-carrying wire compare with each of the following?

a. the strength of the field 2 cm from the wire

*Because magnetic field strength varies inversely with distance from the wire, the magnetic field at 1 cm will be twice as strong as the magnetic field at 2 cm.*

b. the strength of the field 3 cm from the wire

*Because magnetic field strength varies inversely with distance from the wire, the magnetic field at 1 cm will be three times as strong as the magnetic field at 3 cm*

6. A long, straight current-carrying wire lies in a north-south direction.

a. The north pole of a compass needle placed above this wire points toward the east. In what direction is the current?

*from south to north*

b. If a compass were placed underneath this wire, in which direction would the compass needle point?

*west*

7. A student makes a magnet by winding wire around a nail and connecting it to a battery, as shown in Figure 13. Which end of the nail—the pointed end or the head—is the north pole?

*the pointed end*

8. You have a battery, a spool of wire, a glass rod, an iron rod, and an aluminum rod. Which rod could you use to make an electromagnet that can pick up steel objects? Explain.

*Use the iron rod. Iron would be attracted to a permanent magnet and take on properties of a magnet, whereas aluminum or glass would not. This effect would support the magnetic field in the wire coil and thus make the strongest electromagnet.*

9. The electromagnet in the previous problem works well, but you would like to make the strength of the electromagnet adjustable by using a potentiometer as a variable resistor. Is this possible? Explain.

*Yes. Connect the potentiometer in series with the power supply and the coil. Adjusting the potentiometer for more resistance will decrease the current and the field strength.*

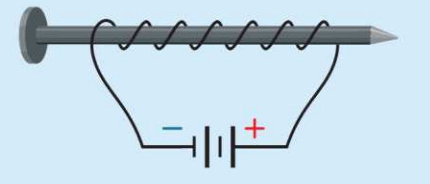



Figure 13

| 12 | Describe the relationship between magnetic fields and electric currents. | Student Book | 133-134 |
|---|---|---|---|
| | | Q5-Q9, Q18 | 136 |

PRACTICE Problems ADDITIONAL PRACTICE

18. Imagine a toy containing two parallel, horizontal metal rods, one above the other. The top rod is free to move up and down.

a. The top rod floats above the lower rod. When the top rod's direction is reversed, however, it falls down onto the lower rod. Explain how the rods could behave in this way.

The metal rods could be magnets with their axes parallel. If the top magnet is positioned so that its north and south poles are above the north and south poles of the bottom magnet, it will be repelled and float above. If the top magnet is turned end for end, it will be attracted to the bottom magnet.

b. Assume the toy's top rod was lost and another rod replaced it. The new rod falls on top of the bottom rod no matter its orientation. What type of material is in the replacement rod?

If the bar is made from a ferromagnetic material, such as iron, it will be attracted to the bottom magnet in any orientation.

| 14 | Explain how a current-carrying conductor placed in an external magnetic field experiences a magnetic force | Student Book | 138-139 |
|---|---|---|---|

# Forces on Current-Carrying Wires

When you put a magnet in a magnetic field, the magnet can move. What happens when you put a current-carrying wire in a magnetic field? Michael Faraday, who performed many electricity and magnetism experiments during the nineteenth century, discovered that a magnetic field produces a force on a current-carrying wire. The force on the wire is always at right angles to both the direction of the magnetic field and the direction of current, as shown in the left part of **Figure 14.** When current changes direction, so does the force.

**Direction of force** You can use a right-hand rule to determine the direction of force on a current-carrying wire in a magnetic field. Point the fingers of your right hand in the direction of the magnetic field. Point your thumb in the direction of the wire's conventional (positive) current. The palm of your hand will face in the direction of the force acting on the wire, as shown in the right part of **Figure 14.**

**Arrows in three dimensions** The relationship among magnetic field, electric current, and force is three-dimensional. How do you accurately represent directional arrows in three dimensions on a two-dimensional piece of paper?

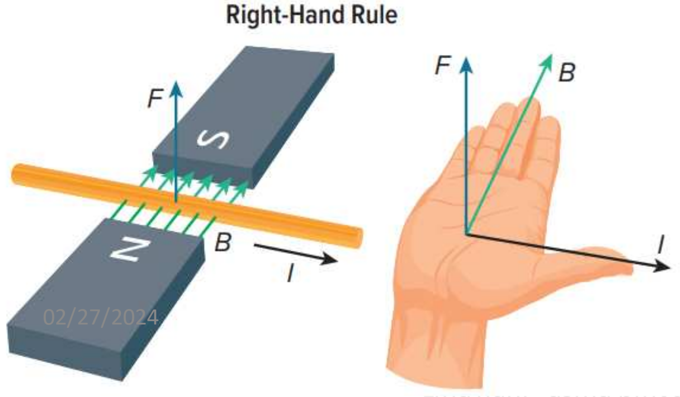



**Figure 14** You can use a right-hand rule to determine the direction of force when the current ($I$) and the magnetic field ($B$) are known.

**Predict** *what would happen to the force if the current changed direction.*

| | | | |
|---|---|---|---|
| 14 | Explain how a current-carrying conductor placed in an external magnetic field experiences a magnetic force | Student Book | 138-139 |

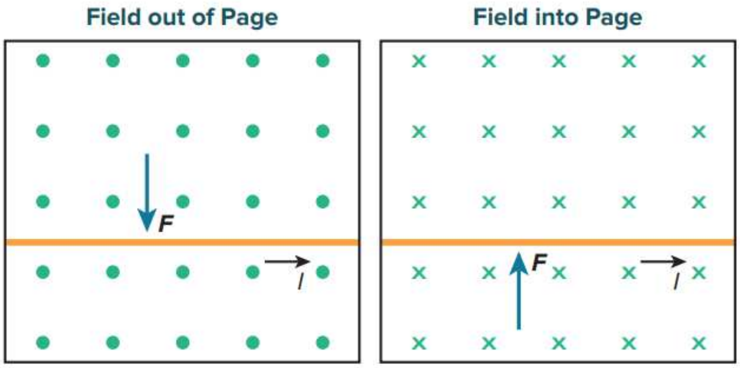
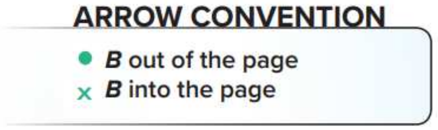



**Figure 15** Dots represent a magnetic field coming out of the page, toward you (left). Crosses represent a magnetic field going into the page, away from you (right). Note that the force on each wire is perpendicular to both the magnetic field and the current.

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|---|---|---|---|
| 15 | 1. Apply the equation F=ILB(sinθ) to calculate the magnitude of the force on a straight segment of a current carrying wire placed in a uniform magnetic field.<br>2. Apply the right-hand rule to find the direction of the force on a current-carrying wire placed in an external magnetic field. | Student Book | 137-140 |
| | | Q19-Q23 | 140 |

**Magnitude of force** You read that you use a right-hand rule to find the direction of the force from a magnetic field on a current-carrying wire. How do you find the magnitude of this force? Experiments show that the magnitude of the force ($F$) on a current-carrying wire is proportional to the wire's current ($I$), the wire's length ($L$), the strength of the magnetic field ($B$), and the sine of the angle between the current and the magnetic field ($\sin\theta$). Recall that you measure force in newtons (N) and current in amperes (A). You measure the strength of a magnetic field ($B$) in teslas (T). One T equals 1 N/(A·m).

### Force on a Current-Carrying Wire in a Magnetic Field

The magnitude of the force on a current-carrying wire in a magnetic field is equal to the product of the current, the length of the wire, the field strength, and the sine of the angle between the current and the magnetic field.

$$F = ILB(\sin\theta)$$

Note that $\sin 0° = 0$, and $\sin 90° = 1$. This means that when the current and the magnetic field are parallel to each other, the force on a current-carrying wire is zero. The force on the wire is greatest when the current and the magnetic field are perpendicular to each other.

**PRACTICE Problems** ADDITIONAL PRACTICE

19. Explain the method you could use to determine the direction of force on a current-carrying wire at right angles to a magnetic field. Identify what must be known to use this method

*You would use the right-hand rule for magnetic force on a wire. When you point the fingers of your right hand in the direction of the magnetic field and your thumb in the direction of the wire's conventional (positive) current, the palm of your hand will face in the direction of the force acting on the wire. To use this method, you would need to know the direction of the current and the direction of the field*

20. A wire that is 0.50 m long and carrying a current of 8.0 A is at right angles to a 0.40-T magnetic field. How strong is the force that acts on the wire?

$F = ILB = 8.0 \times 0.50 \times 0.40 = 1.6\ \text{N}$

21. A wire that is 75 cm long and carrying a current of 6.0 A is at right angles to a uniform magnetic field. The magnitude of the force acting on the wire is 0.60 N. What is the strength of the magnetic field?

$F = ILB$

$B = \frac{F}{IL} = \frac{0.60\ \text{N}}{(6.0\ \text{A})(0.75\ \text{m})} = 0.13\ \text{T}$

| | | | |
|---|---|---|---|
| 15 | 1. Apply the equation F=ILB(sinθ) to calculate the magnitude of the force on a straight segment of a current carrying wire placed in a uniform magnetic field.<br>2. Apply the right-hand rule to find the direction of the force on a current-carrying wire placed in an external magnetic field. | Student Book | 137-140 |
| | | Q19-Q23 | 140 |

**PRACTICE Problems** ADDITIONAL PRACTICE

22. A 40.0-cm-long copper wire carries a current of 6.0 A and weighs 0.35 N. A certain magnetic field is strong enough to balance the force of gravity on the wire. What is the strength of the magnetic field?

$F = ILB$, where $F$ = weight of the wire

$$B = \frac{F}{IL} = \frac{0.35\ \text{N}}{(6.0\ \text{A})(0.400\ \text{m})} = 0.15\ \text{T}$$

23. How much current would be required to produce a force of 0.38 N on a 10.0-cm length of wire at right angles to a 0.49-T field?

$$F = ILB$$

$$I = \frac{F}{BL} = \frac{0.38\ \text{N}}{(0.49\ \text{T})(0.100\ \text{m})} = 7.8\ \text{A}$$

## Paper questions

| | | | |
|---|---|---|---|
| 19 | 1. Calculate the equivalent resistance of combined series-parallel circuits.<br>2. Calculate the voltage, current, and power dissipation for any resistor in a combined series-parallel circuit.<br>3. Describe how magnetic materials can be turned into temporary magnets.<br>4. Describe the characteristics of magnetic fields and sketch the field lines around a permanent magnet.<br>5. Apply the right-hand rule to indicate the direction of the magnetic field in and around a solenoid carrying current. | Student Book | 119-122 |
| | | Q66-Q68, Q69-Q74; Q5-Q16 | 121, 122; 131-135 |

14. Magnetic Fields Two current-carrying wires are close to and parallel to each other and have currents with the same magnitude. If the two currents were in the same direction, how would the magnetic fields of the wires be affected? How would the fields be affected if the two currents were in opposite directions?

*If the currents were in the same direction, the magnetic field would be approximately twice as large; if the currents were in opposite directions, the field would be approximately zero*

15. Direction of the Field Describe how to use a right-hand rule to determine the direction of a magnetic field around a straight, current carrying wire.

*If you grasp the wire with your right hand with your thumb pointing in the direction of the conventional current, your fingers curl in the direction of the magnetic field.*