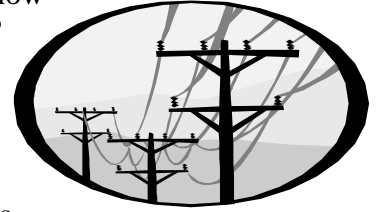


Ohm's Law and Circuits

2. Conductance, Insulators and Resistance

- A. A **conductor** in electricity is a material that allows electrons to flow through it easily. Metals, in general, are good conductors. Why?



The property of conductance (which measures how easily electrons are allowed to flow through), G , can be quantified. It is measured in Siemens (S).

- B. An **insulator** is a material that is a poor conductor of electricity. Examples include plastic, wood, ceramic and glass. What makes them poor conductors?



- C. **Resistance** is the inverse of conductance. It measures how difficult it is for electrons to flow through a material. In plain English, an insulator, like ceramic, has high resistance and poor conductance. A metal has low resistance and high conductance.

$$R = 1/G.$$

Resistance is measured in ohms, Ω .

Something with high resistance wastes the energy of electrons and generates heat.

Example 1: If the conductance of a material is 0.20 S, what is its resistance?

Example 2: If the resistance of a ceramic resistor is 50 Ω , what is its conductance?

Electricity, Energy and Magnetism

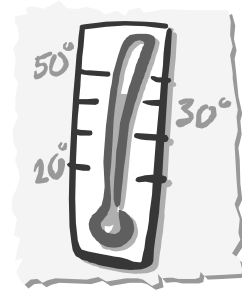
D. Factors Affecting Resistance

(1) The nature of the material

(2) The thickness of the wire

(3) The length of the wire

(4) The temperature



Example 1 How would you *lower* the resistance of the following wire?

Al at 38 °C

Example 2 Two wires, both made of brand new copper, did not have the same conductance, even though the wires were of identical length, thickness and at the same temperature. What could have been different, leading to different measurements, assuming that the same quality equipment was used to measure conductance?

Ohm's Law and Circuits

Exercises

1. A substance used in the manufacture of wire that will transport electrical energy should have two of the following properties:

1. Good resistance to corrosion
2. Poor resistance to corrosion
3. Good ductility
4. Poor ductility

Which two properties are they?

2. Porcelain is used to support electrical wires on poles. Which two properties of porcelain make it desirable for this use?

1. Is a good insulator
2. Is non-ductile
3. Does not rust
4. Breaks easily

3. Name 4 factors that influence the resistance of a metal conductor.

4. There are six electrical wires made of the same substance and having the same length : three have a diameter of 1.5 mm while the other three have a diameter of 3.0 mm.

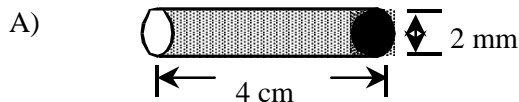
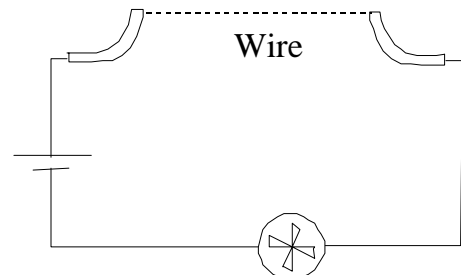
They are placed either end to end to increase the length of the wire or parallel to one another to increase the surface area of the wire.

Which three-wire arrangement offers the least resistance to the flow of electric current?

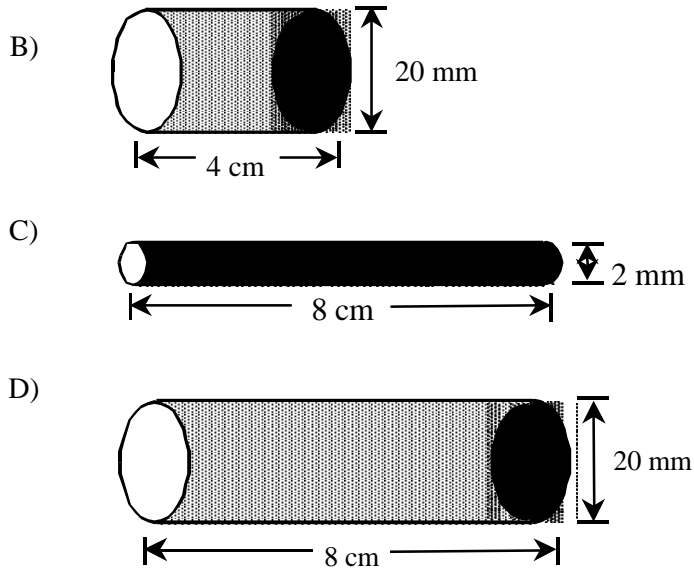
5. A device consists of a power supply, a fan and two connectors. You are to insert a piece of wire between these connectors.

Four nichrome wires are illustrated below. You insert each of these wires in turn. They are the same temperature, but of different sizes. These wires are not drawn to scale.

With which wire will the fan rotate the fastest?
(see next page for rest of multiple choice)



Electricity, Energy and Magnetism



6. Note the following substances:

1. Rubber
2. Plastic
3. Aluminum
4. Copper
5. Steel

Which of these substances are insulators?

7. Which of the following substances best conducts electricity?

- | | |
|-----------|-------------|
| A) Copper | C) Nichrome |
| B) Water | D) Plastic |

8. Which of the following would increase the electrical conductivity of a circuit?

- 1- A thicker wire
- 2- A longer wire
- 3- A decrease in the temperature of the wire
- 4- The use of porcelain wire

- | | |
|------------|------------|
| A) 1 and 2 | C) 2 and 4 |
| B) 1 and 3 | D) 3 and 4 |

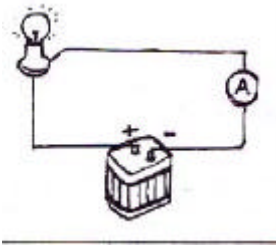
Ohm's Law and Circuits

9. What could be done to the temperature of a circuit in order to improve conductance?
10. Why does a wider wire conduct electricity better than a narrower one?
11. a. Of the following, which two metals are the best conductors?
Fe Cu Ag Au
b. Which of the above 4 is the worst?
12. In general, why do metals conduct electricity (Think of atomic structure.)
13. What is the unit of resistance? Give both word and the symbol.
14. What is the unit of conductance? Again, give both word and the symbol.
15. Convert the following. (Show your work)
 - a. $50 \text{ S} = \underline{\hspace{2cm}} \Omega$.
 - b. $0.100 \Omega = \underline{\hspace{2cm}} \text{ S}$.
 - c. If $G = 1/R$, then $R = \underline{\hspace{2cm}}$.
 - d. $R = 12 \text{ V}/0.5 \text{ A}$. (don't worry about the units until we study Ohm's law)
 $G = \underline{\hspace{2cm}} \text{ S}$

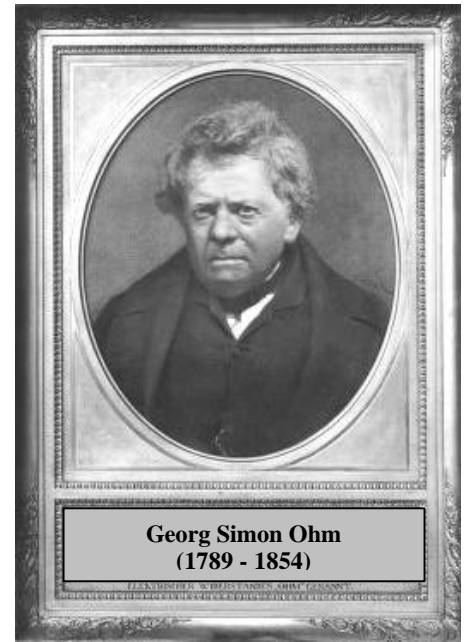
Electricity, Energy and Magnetism

3. Ohm's Law

A. Deriving the Formula



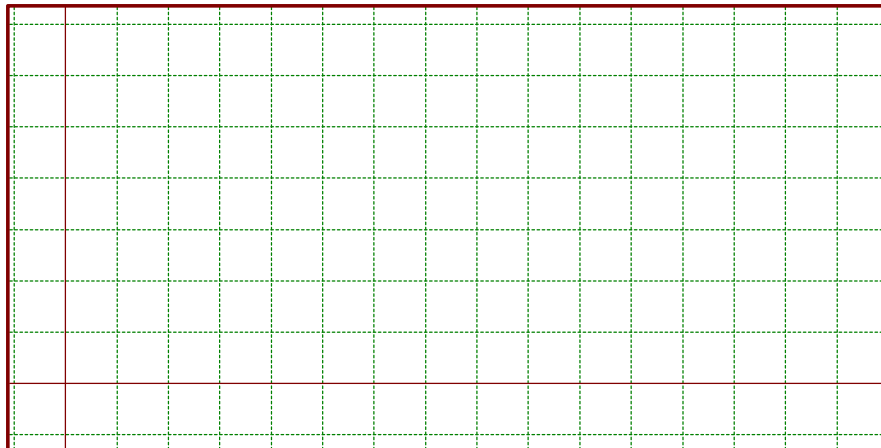
Suppose you had the following circuit. If you started with a low voltage and gradually increased it (by changing the battery or turning the button on a power source), what would happen to the current?



Example 1 What is the short hand way of drawing the above circuit? How would you measure the voltage of the battery?

Example 2 Graph the following data.

Voltage (Volts)	0.0	1.5	2.0	2.5	3.0
Current Intensity (Amps)	0.0	2.0	2.7	3.3	4.0



The slope on a *current(y) versus voltage(x)* graph is known as conductance, G , which is measured in Siemens (S)

Ohm's Law and Circuits

The electrical property more commonly used than conductance is **resistance**, which is measured in **ohms (Ω)**. Resistance is a measurement of how difficult it is for electrons to get through a substance. Resistance converts electrical energy into heat.

$$R = 1/G$$

Based on this, what is the relationship between V, I and R ?

Ohm's Law

Examples

1. A resistance of 10Ω is placed across a 9 V battery. What current flows through the battery?

2.
 - a. A resistor has a conductance of 0.100 S . What is its resistance?
 - b. What voltage is needed to cause a 500 mA current to flow through the circuit?

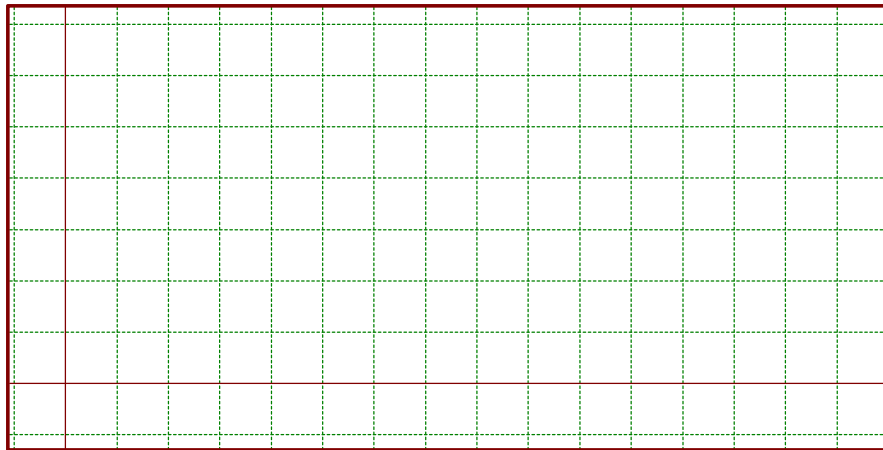
3. What is the overall resistance of a CD portable player if it is operated by a 3 V battery and 0.75 A flow through its circuitry?

Electricity, Energy and Magnetism

Exercises

1. What current flows between a potential difference of 120 V through a resistance of 30 Ω ?
2. A motor with an operating resistance of 30 Ω is connected to a voltage source. 4.0 A of current flow in the circuit. What is the voltage of the source?
3. If the conductance of a circuit is 0.25 S, and the current is 2.0 A, what is the overall voltage?
4. a. An ammeter measures current. What will the ammeter read when it is connected to a 90 V source and a 60 Ω resistor?
b. Draw a diagram to illustrate this circuit. The symbol for an ammeter is the letter "A" within a circle.
5. A. Draw a circuit diagram that includes a 16 Ω resistor, a battery and an ammeter that reads 1.75 A.
B. What will the voltmeter read when it is attached to the battery in the above circuit?
6. A. Draw a graph for the following and measure its slope.

Current Intensity (Amps)	0.0	1.5	2.0	2.5	4.0
Voltage (Volts)	0.0	1.0	1.3	1.6	3.0

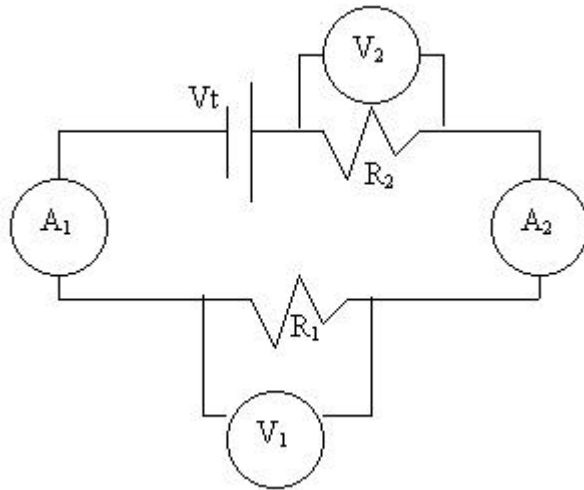
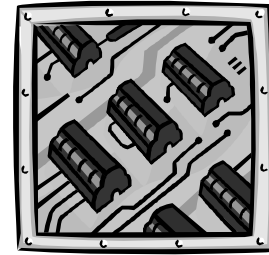


- b. What does the slope represent?

Ohm's Law and Circuits

4. Series Circuits

Imagine the current leaving a battery. If the resistors are connected in such a way that the current must entirely flow through every resistor before returning to the battery, then the circuit is a **series circuit**.



A_1 and A_2 represent two separate measurements of current intensity at two different points in the circuit. V_1 and V_2 represent two separate measurements of voltage or potential difference. *Note how we connect the voltmeter: one connection at each end of the resistor.*

For series circuits:

$$V_t = V_1 + V_2$$

As the electrons flow through each resistor they lose their potential energy in sequence, in a similar way that skiers gradually lose potential energy on the way down a ski hill. When they take the lift back up, they are re-energized.

$$I_1 = I_2 = \text{constant.}$$

The current is constant. The same number of electrons flows through the circuit per second.

If we divide each voltage by the constant current, according to Ohm's Law we will obtain resistance:

$$R_t = R_1 + R_2$$

If there are more resistors in the circuit, then the same rules apply:

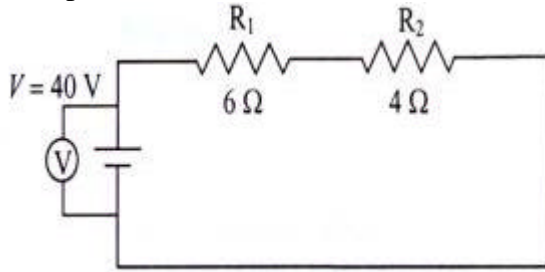
$$V_t = V_1 + V_2 + V_3 + \dots$$

$$I_1 = I_2 = I_3 = \text{constant}$$

$$R_t = R_1 + R_2 + R_3 + \dots$$

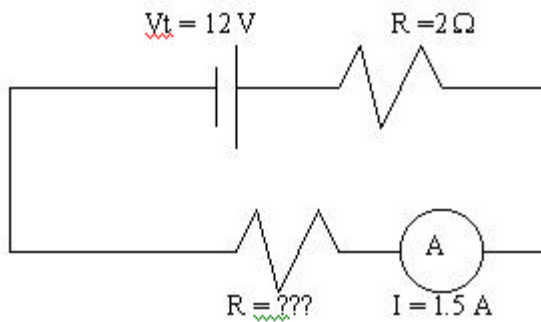
Electricity, Energy and Magnetism

Example 1



- What is the total resistance of the circuit?
- What current would be measured in between the two resistors?
- What voltage (V_1) would be measured across R_1 ? Across R_2 ?

Example 2

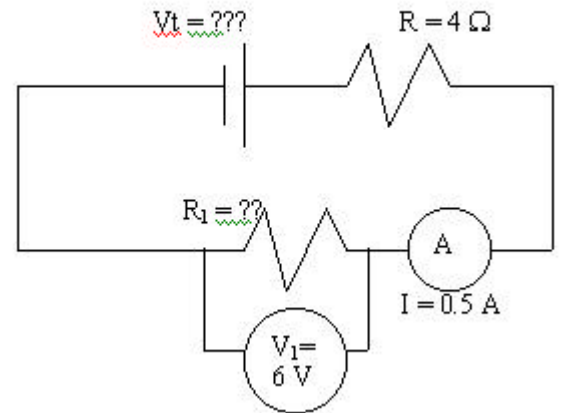


- Find the missing resistance in the circuit shown, which consists of a 12 V battery hooked to two resistors.
- If the two resistors represented two light bulbs, and one of the light bulbs was off, would you be able to turn the other bulb on?

Ohm's Law and Circuits

Example 3

- a. Find the value of R_1 in the circuit shown.
- b. What is the voltage of the battery?



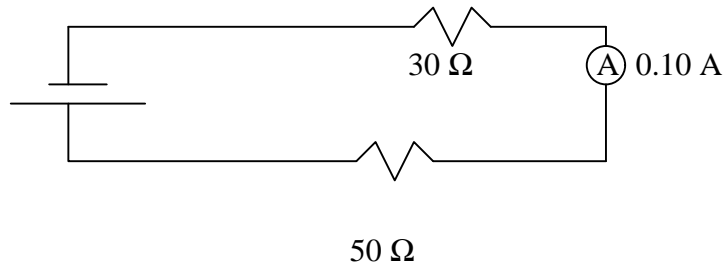
Additional Examples

Electricity, Energy and Magnetism

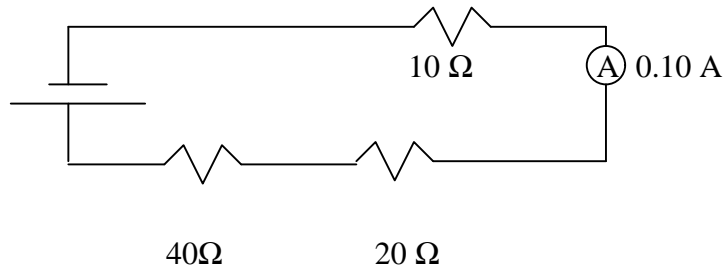
Exercises

1. Three $20\ \Omega$ resistors are connected in series across a $120\ \text{V}$ generator. What current flows through the circuit?
2. Ten Xmas lights gave equal resistances. When connected to a $120\ \text{V}$ outlet, a current of $0.50\ \text{A}$ flows through each bulb. What is the resistance of one bulb?
3. A lamp with a resistance of $10\ \Omega$ is connected across a $12\ \text{V}$ battery. What resistance must be connected to the lamp to create a current of $0.50\ \text{A}$?
4. A $20\ \Omega$ resistor and a $30\ \Omega$ resistor are connected in series and placed across potential difference of $100\ \text{V}$. Find the voltage drop across each resistor.
5. Find the voltage across each resistor, as well as the total voltage.

a.

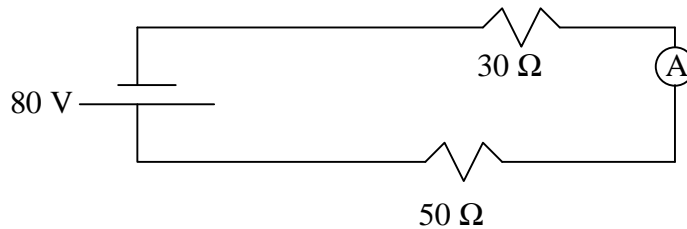


b.



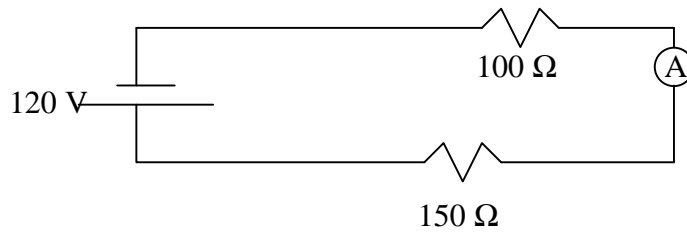
6. Find the current as well as the voltage across each resistor.

a.

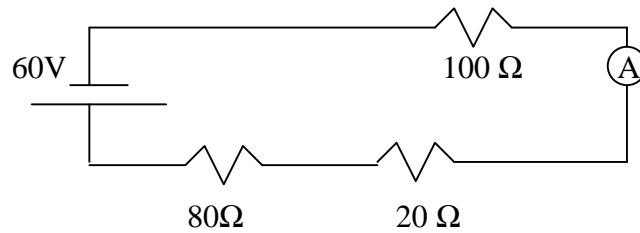


Ohm's Law and Circuits

b.



c.

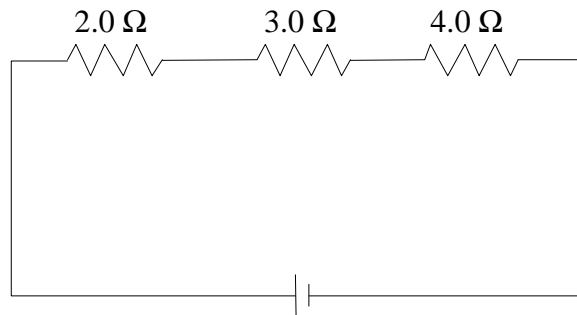


7. a. Draw a circuit consistent with the following information:

- $V_1 = 5.0 \text{ V}$ and R_1 is an unknown resistor
- There is a 2.0 A current measured by the ammeter next to the power source
- $R_2 = 2.0 \Omega$.

- b. Calculate R_1
c. Find the voltage of the power source.

8. Three known resistances are connected in series to the terminals of a power source. The potential difference at the terminals of the 3.0 Ω resistance is 12 V.

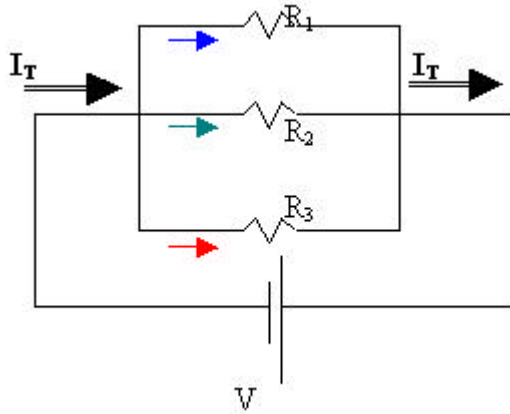


- a. What is the potential difference of the power source?
b. What is the voltage drop across the 4.0 Ω resistor?
c. What is the voltage drop across the 2.0 Ω resistor?

Ohm's Law and Circuits

5. Parallel Circuits

Imagine an electric current leaving a battery. If the resistors are connected in such a way that part of the current can go through one resistor and the rest of the current can go through another resistor, then the circuit is a **parallel circuit**.



I_T is the total current of the parallel circuit. You would measure this current anywhere before or after the three-way split leading to the three resistors. In between the junction and R₁, you would measure I₁. Between the junction and R₂, you would measure I₂ etc.

Since the total current, I_T, splits up into three different groups of electrons, each traveling their route,

$$I_T = I_1 + I_2 + I_3 + \dots$$

In parallel circuits, all resistors, regardless of their resistances, experience the same voltage drop or potential difference because they all have the same entry and exit points (junctions).

$$V_T = V_1 = V_2 = V_3 = V_n$$

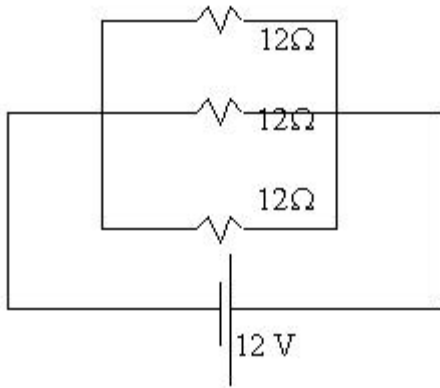
If we divide the current formula by the voltage relationship we obtain:

$$\frac{I_T}{V_T} = \frac{I_1}{V_1} + \frac{I_2}{V_2} + \frac{I_3}{V_3} + \dots$$
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

$$\text{or } R_T = [R_1^{-1} + R_2^{-1} + R_3^{-1} + \dots]^{-1}$$

Electricity, Energy and Magnetism

Example 1



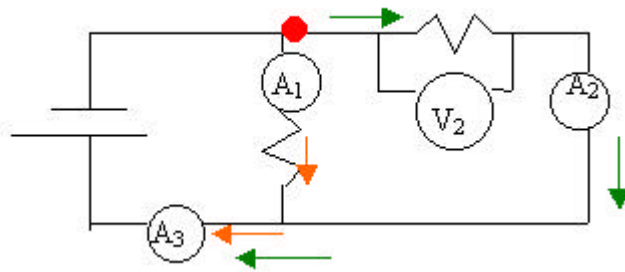
- a. What is the total resistance of the circuit?
- b. What is the total current?
- c. What voltage (V_1) would be measured across each individual resistor?

- c. What current is drawn out by each resistor?

Example 2

The drawing seems confusing, but note that it is a parallel circuit because the electrons have a “choice”. At the junction (shown by the red dot) the electrons either follow the green route or the orange route.

Use $I_1 = 1A$; $I_2 = 0.5 A$; $R_1 = 10W$.



- a. Find V_2 .

- b. Find R_2 .

- c. Use two methods to arrive at R_T .

Ohm's Law and Circuits

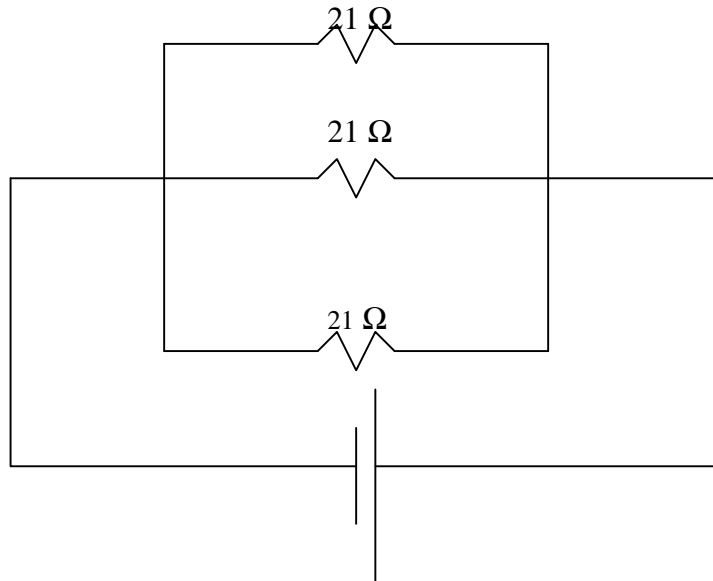
Example 3

In a parallel circuit, what effect does adding **more** resistors have on total current?

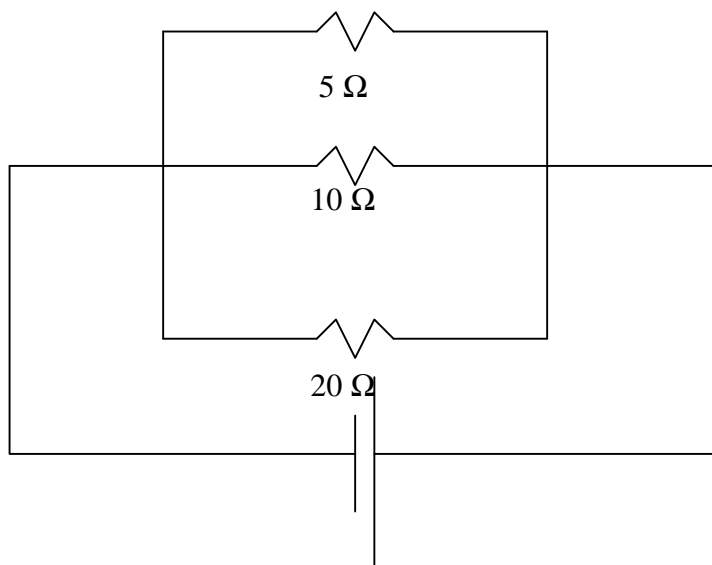
Exercises

1. Find the total resistance in each case.

a.

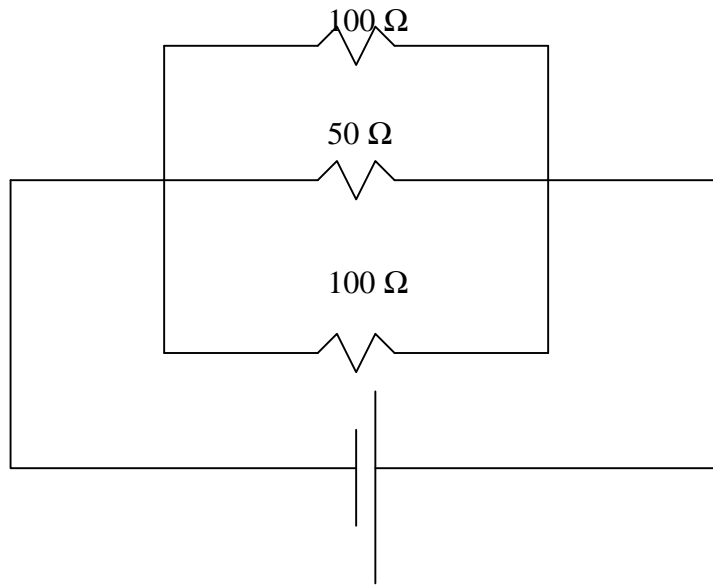


b.



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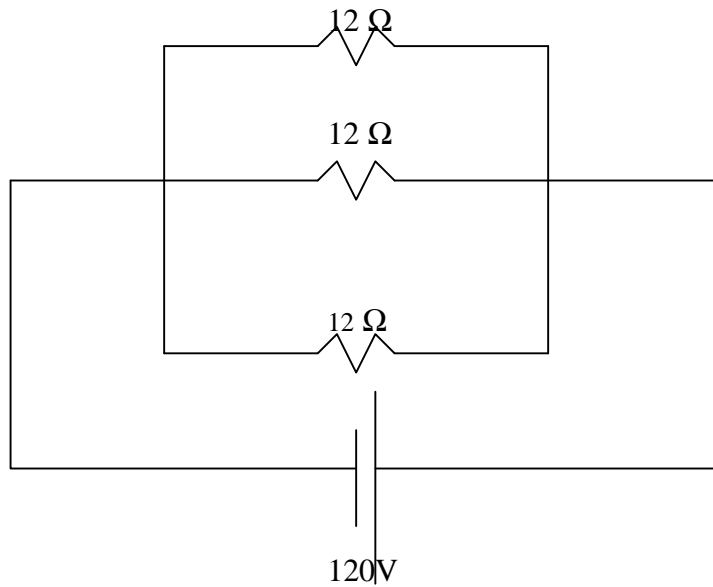
c.



(answer: $25\ \Omega$.)

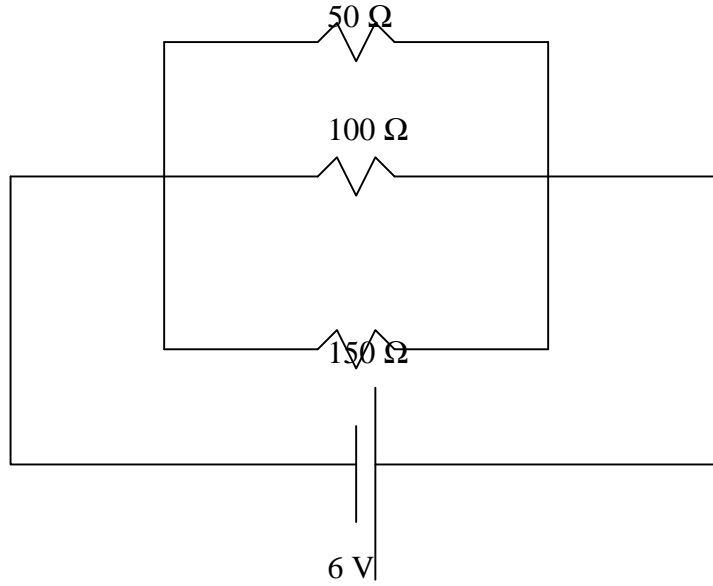
2. Find the current passing through each resistor.

a.

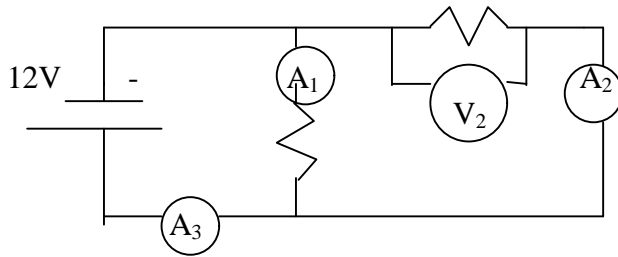


Ohm's Law and Circuits

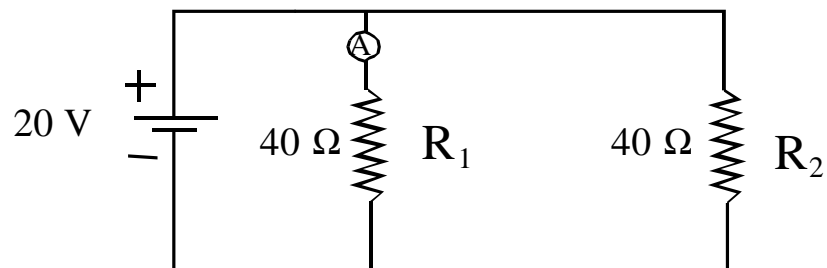
b.



3. Find the missing reading for each meter. $R_1 = 20\ \Omega$ and $R_2 = 40\ \Omega$.



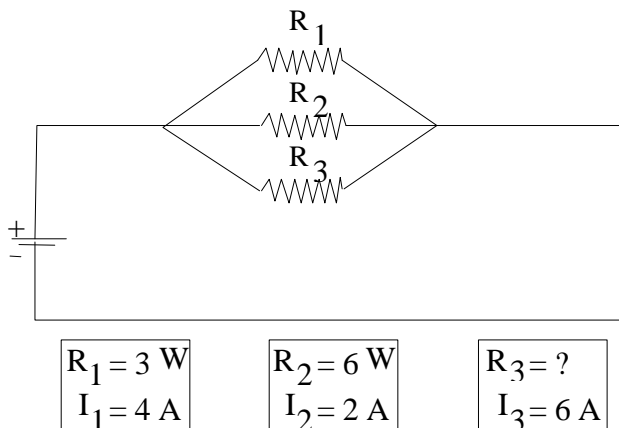
4. The electric circuit shown below consists of an ammeter A, a power supply, and resistors R_1 and R_2 connected in parallel.



What is the current intensity (I) flowing through the ammeter?

Electricity, Energy and Magnetism

5. The following diagram shows a parallel circuit consisting of three resistors.

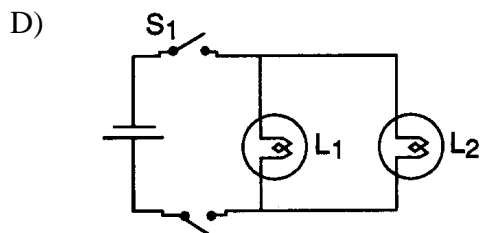
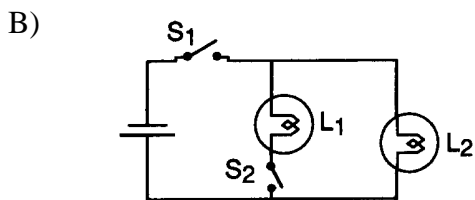
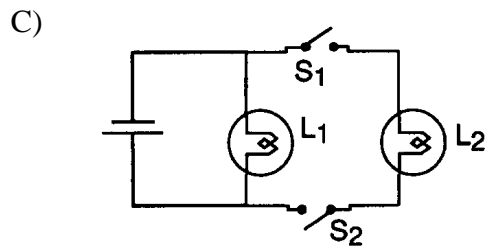
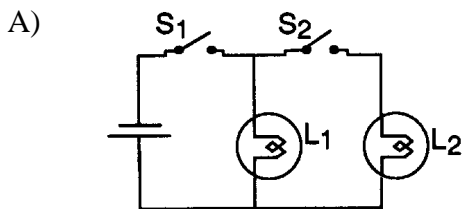


What is the value of resistor R_3 ?

6. An electrical circuit consists of a power source, two switches (S_1 and S_2) and two light bulbs (L_1 and L_2). The following table shows what happens to both light bulbs:

Switch		Light Bulb	
S_1	S_2	L_1	L_2
open	open	out	out
closed	open	bright	out

Which of the following circuit diagrams illustrates the results shown in the table above?

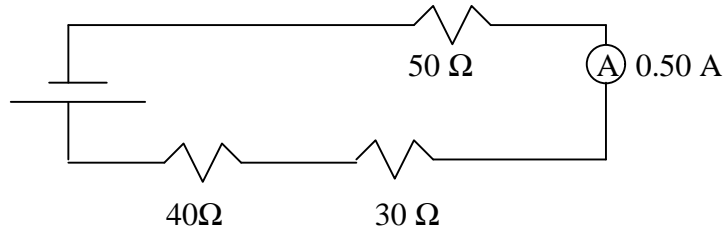


Ohm's Law and Circuits

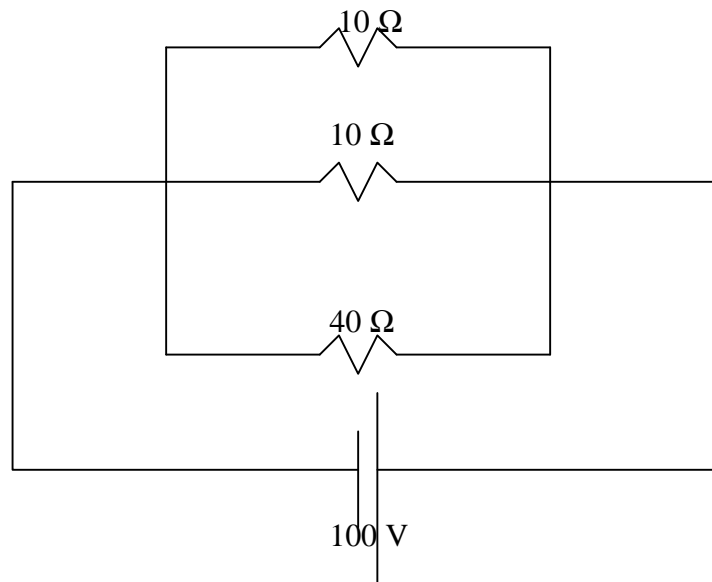
Exercises (parallel and series)

1. Find the total resistance and the voltmeter reading at each resistor:

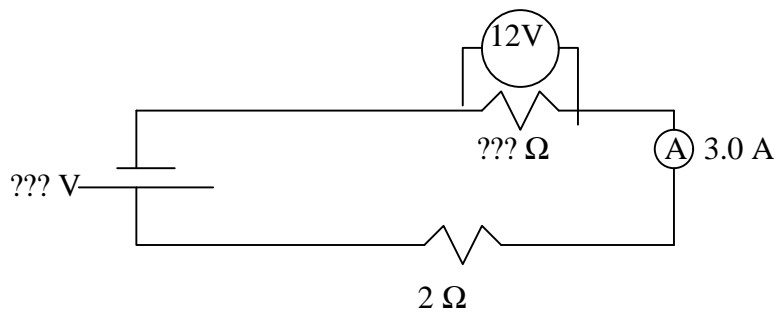
a.



b.

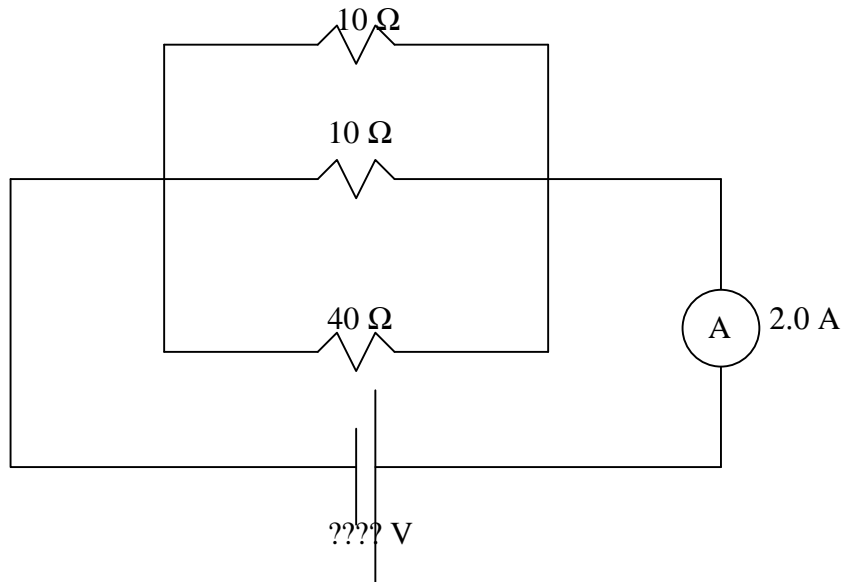


2. Two resistors are connected in parallel. Each draws $2.0\ \text{A}$ of current. If the total voltage is $12\ \text{V}$, find R_1 and R_2 .
3. Two resistors are connected in series. The total current is $0.500\ \text{A}$. The potential difference at the resistors is $2\ \text{V}$ and $5\ \text{V}$, respectively. Find R_1 and R_2 .
4. Find the missing voltage and resistance.

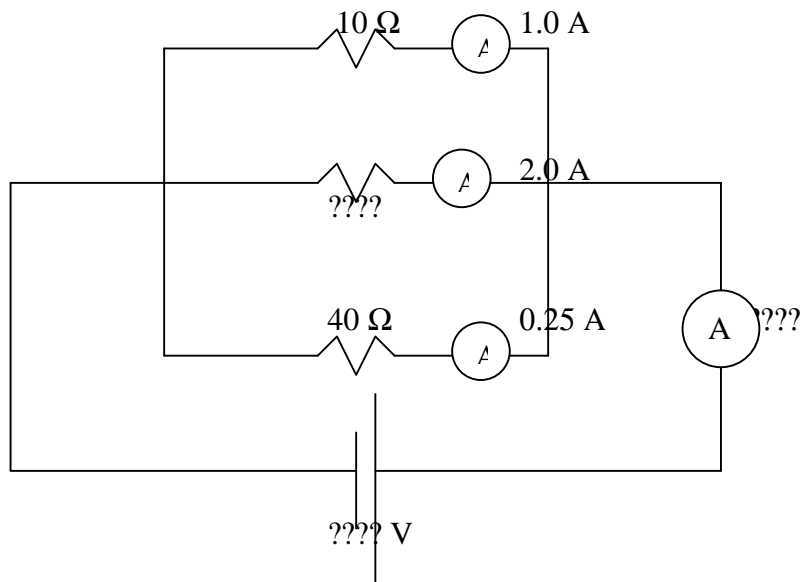


Electricity, Energy and Magnetism

5. Find the missing voltage.



6. Find the missing resistance, the total current, and the missing voltage

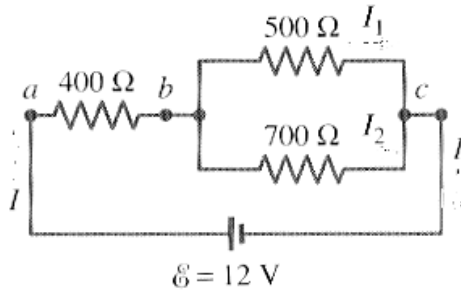


7. a. In a series circuit, what measurement is constant at each resistor?
 b. In a parallel circuit, what measurement is constant at each resistor?

Ohm's Law and Circuits

6. Combination Circuits

Combination circuits combine the features of parallel circuits with those of series circuits. The key to surviving these is to keep in mind the distinctive features of those circuits in mind.



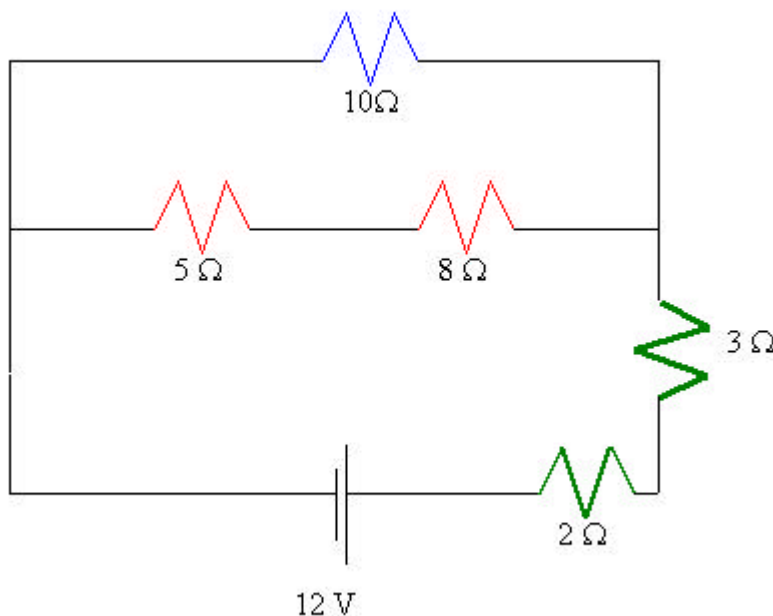
Example 1

- a. What is the overall resistance of this circuit?

- b. What is the potential difference measured from *a* to *b*?

- c. What currents would be measured within the parallel branch? (see diagram for I_1 and I_2)

Example 2

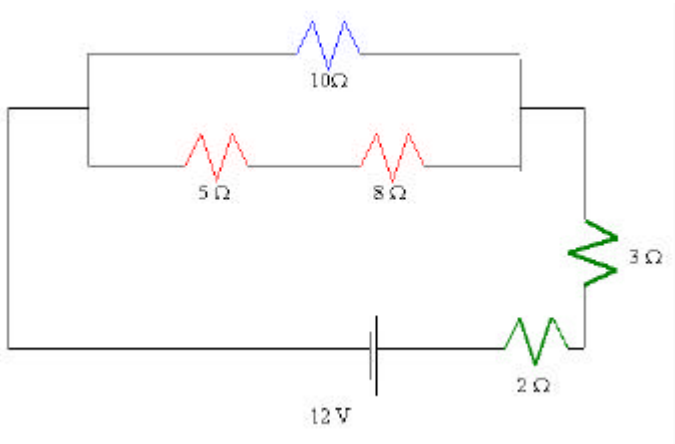


- a. Find the total current in the following:

First, we'll redraw the circuit to make sure we realized that the 5 and 8 Ω resistor are in series, but they in turn are in

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parallel to the $10\ \Omega$ resistor. The parallel branch is then series with both the 3 and $2\ \Omega$ resistors.

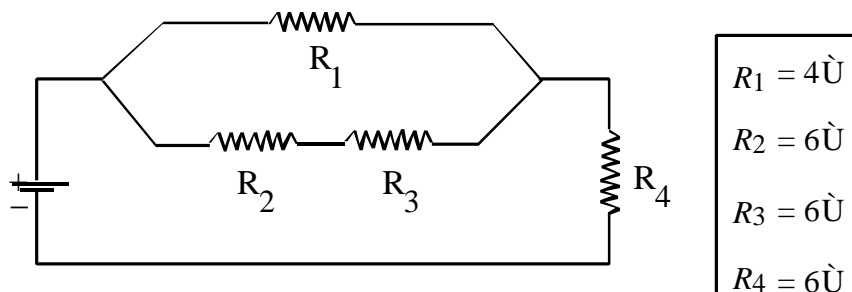


- b. What is the voltage drop across the $8\ \Omega$ resistor?

Example 3 Connect four $5\ \Omega$ resistors in such a way that their total resistance is $5\ \Omega$.

Exercises

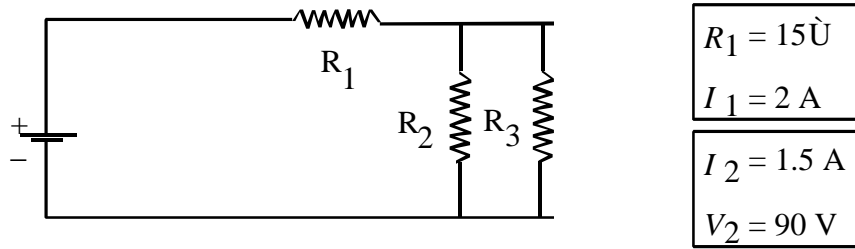
1. An electric circuit is illustrated below.



What is the equivalent resistance of this circuit?

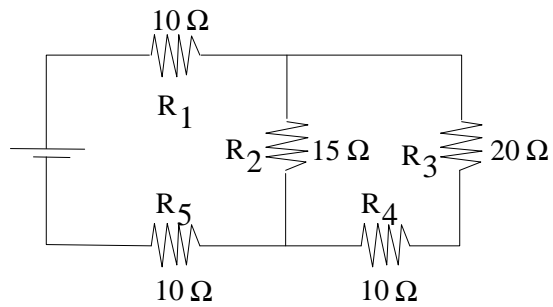
Ohm's Law and Circuits

2. An electric circuit is illustrated below.



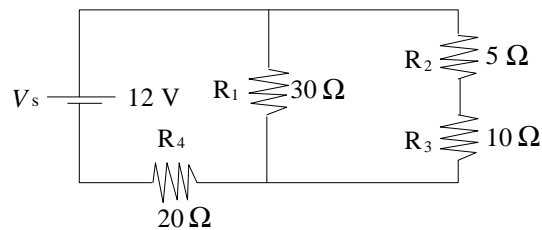
What is the value of resistor R_3 ?

3. A series-parallel electric circuit is illustrated below.



Find R_T

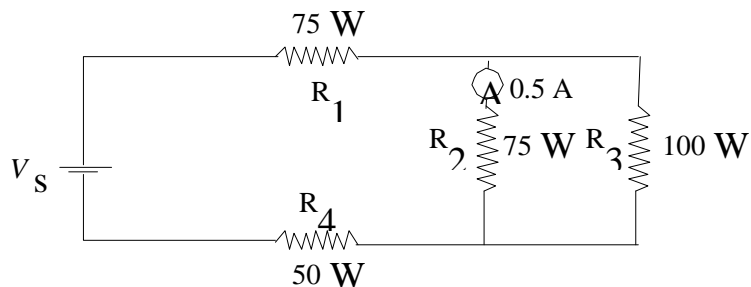
4. A series-parallel electric circuit is illustrated below.



What is the potential difference across the terminal of resistor R_1 ?

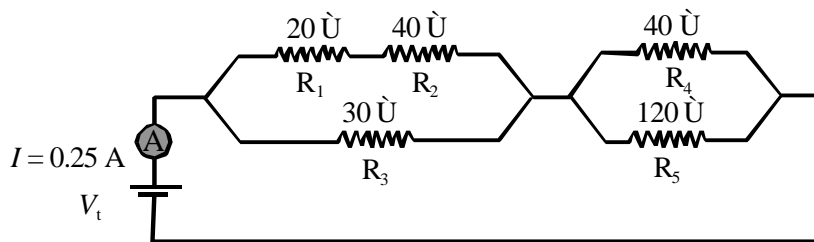
Electricity, Energy and Magnetism

5. A series-parallel electric is illustrated below.



What is the intensity of the current flowing from the power source, I_s ?

6. The following electric circuit consists of a power supply, five resistors (R_1 , R_2 , R_3 , R_4 and R_5) and an ammeter ⓐ .

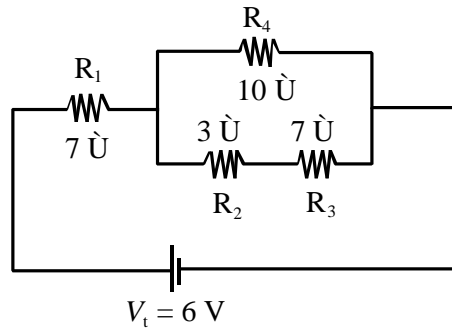


The ammeter reads 0.25 A.

- What is the potential difference (voltage), V_t , across the terminals of the power supply?
- What is the potential difference across R_3 ?
- What is the potential difference across R_1 ?
- What current flows through R_5 ?

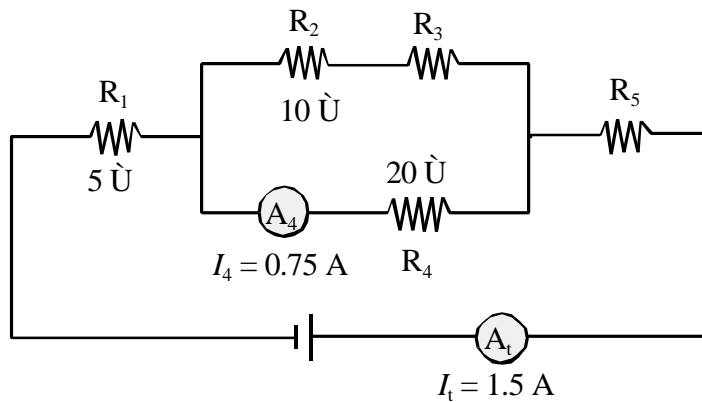
Ohm's Law and Circuits

7. An electric circuit is illustrated below.



What is the current intensity, I , in resistors R_2 and R_3 ?

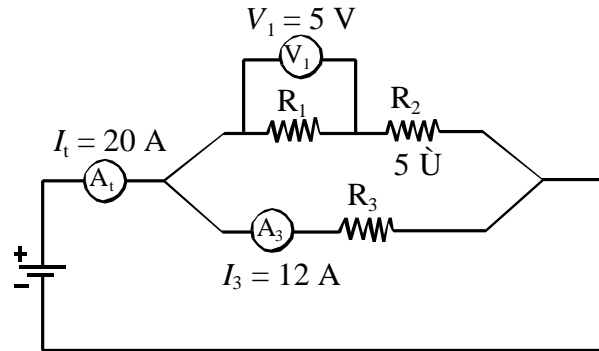
8. The following electric circuit consists of a power source, five resistors (R_1 , R_2 , R_3 , R_4 and R_5) and two ammeters (A_4 and A_t).



What is the potential difference (voltage) across the terminals of resistors R_3 ?

Electricity, Energy and Magnetism

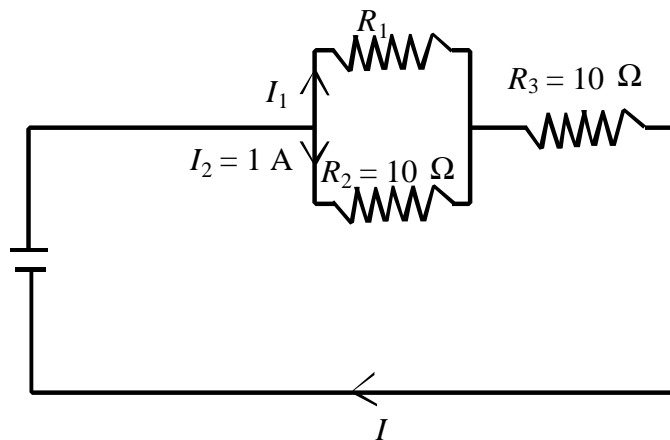
9. The following circuit consists of a power source, two ammeters A_1 and A_3 , a voltmeter V_1 and three resistors (R_1 , R_2 and R_3).



The total current intensity I_t is 20 A. Current intensity I_3 is 12 A. The potential difference (voltage) V_1 across the terminals of resistor R_1 is 5 V.

What is the resistance of resistor R_3 ?

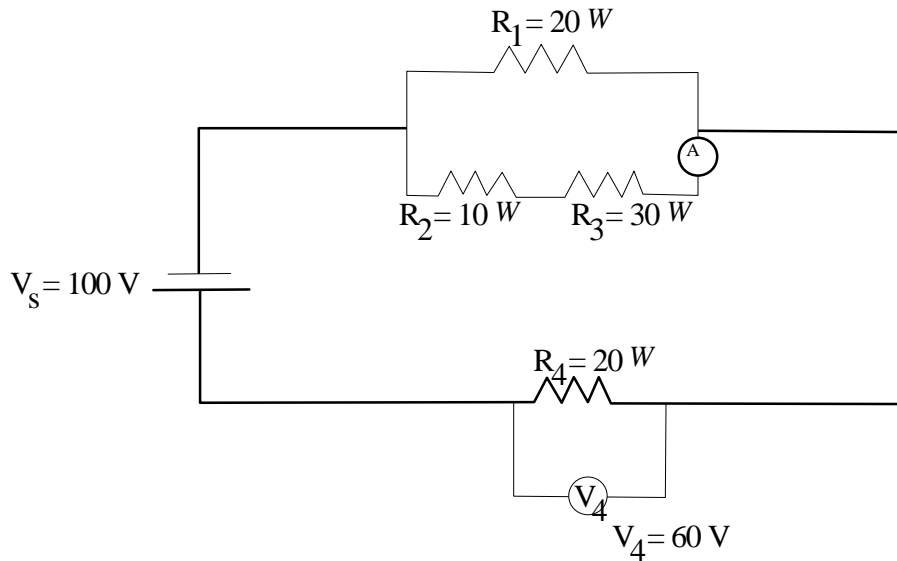
10. A source with a potential difference of 30 V is connected to the circuit shown below.



What is the current intensity I across the circuit?

Ohm's Law and Circuits

11. The following electrical circuit consists of a power source, four resistors (R_1 , R_2 , R_3 and R_4) and a voltmeter V_4 ($V_s = V_{\text{total}}$).



What is the current intensity (I_3) through R_3 ?

12. How can one 25Ω and two 100Ω resistors be connected so that their total resistance is 75Ω ?
13. How can four 1.0Ω resistors and one 2.0Ω resistor be connected to give a combined resistance of 1.5Ω ?
14. Four identical resistors are connected as shown. If the total voltage is 12V , find the voltage across each resistor.

