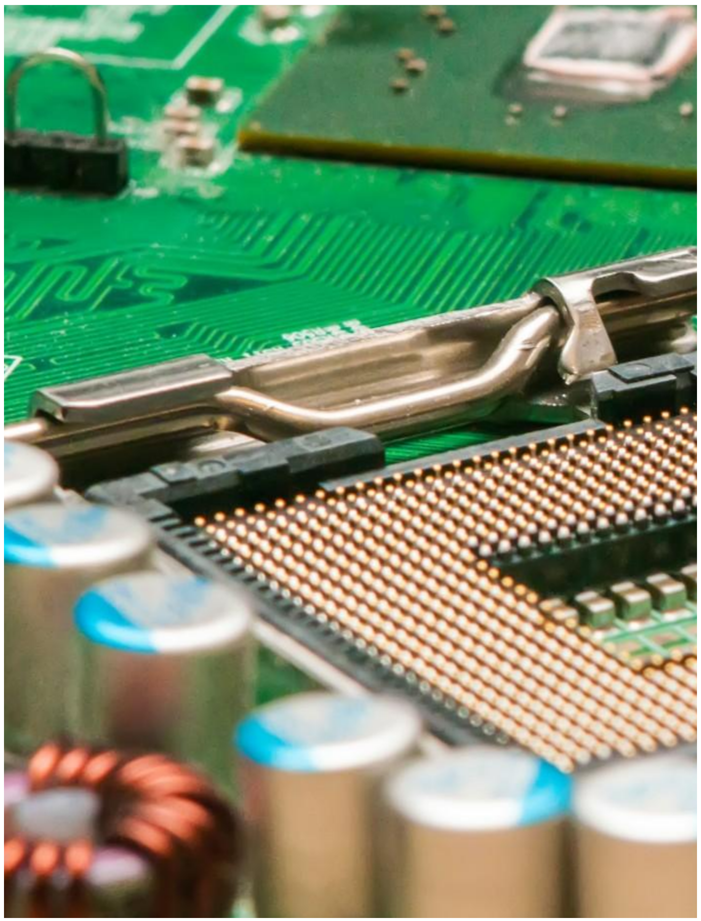
# Fundamentals of Electrical & Electronic Engineering

Prof. John G. Breslin, Electrical & Electronic Engineering



## Lecture 3

### Ohm's Law, Energy, and Power

Ollscoil na Gaillimhe
University of Galway

# Summary (1 of 35)

## Review of *V*, *I*, and *R*

***Voltage*** is the amount of energy per charge available to move electrons from one point to another in a circuit and is measured in volts.

***Current*** is the rate of charge flow and is measured in amperes.

***Resistance*** is the opposition to current and is measured in ohms.

# Summary (2 of 35)

## Ohm's law

The most important fundamental law in electronics is **Ohm's law**, which relates voltage, current, and resistance.

Georg Simon Ohm (1787–1854) formulated the equation that bears his name:

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

**Question:**

What is the current in a circuit with a 12 V source if the resistance is 10 Ω?

# Summary (3 of 35)

## Ohm's law

The most important fundamental law in electronics is **Ohm's law**, which relates voltage, current, and resistance.

Georg Simon Ohm (1787–1854) formulated the equation that bears his name:

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

**Question:**

What is the current in a circuit with a 12 V source if the resistance is 10 Ω? 1.2 A

# Summary (4 of 35)

## Ohm’s law

If you need to solve for voltage, Ohm’s law is: $V = IR$

**Questions:**

What is the voltage across a 680 Ω resistor if the current is 26.5 mA?

What is the voltage across a 1.5 MΩ resistor if the current is 4.0 μA?



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# Summary (5 of 35)

## Ohm's law

If you need to solve for voltage, Ohm's law is: $V = IR$

**Questions:**

What is the voltage across a 680 Ω resistor if the current is 26.5 mA? 18.0 V

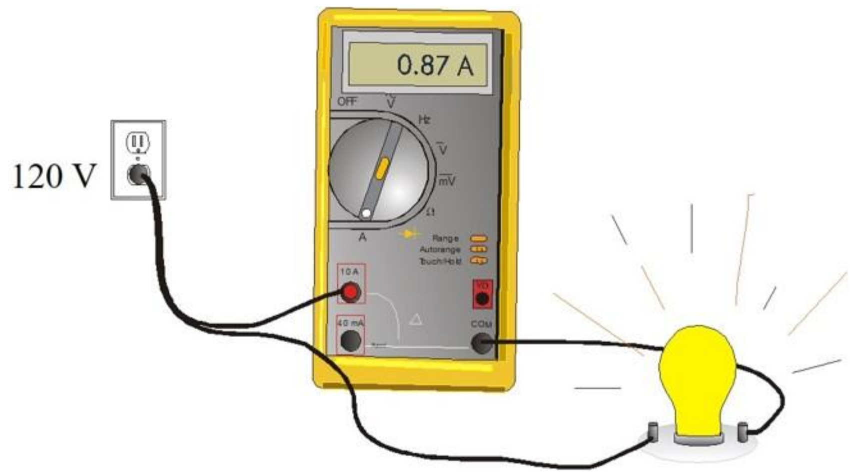
What is the voltage across a 1.5 MΩ resistor if the current is 4.0 μA? 6.0 V

## Ohm’s law

If you need to solve for resistance, Ohm’s law is: $R = \frac{V}{I}$

**Question:**

What is the (hot) resistance of the bulb?



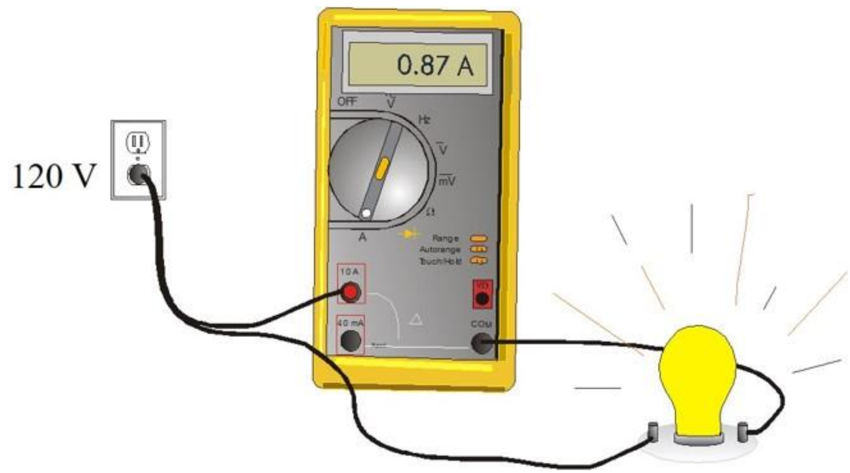
# Summary (7 of 35)

## Ohm’s law

If you need to solve for resistance, Ohm’s law is: $R = \dfrac{V}{I}$

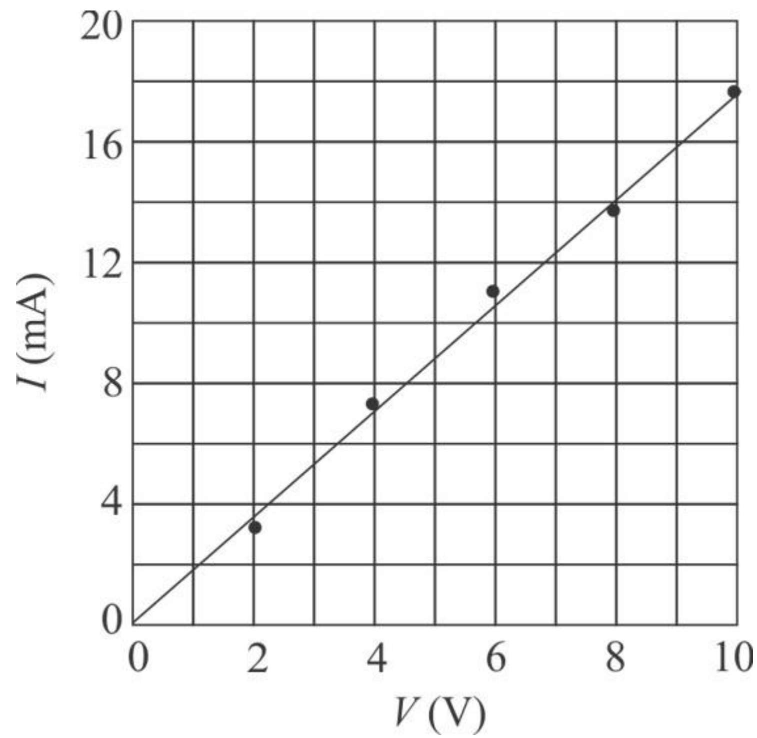
**Question:**

What is the (hot) resistance of the bulb? 138 Ω



# Summary (8 of 35)

**Example** A student takes data for a resistor and fits the straight line shown to the data. What is the conductance and the resistance of the resistor?



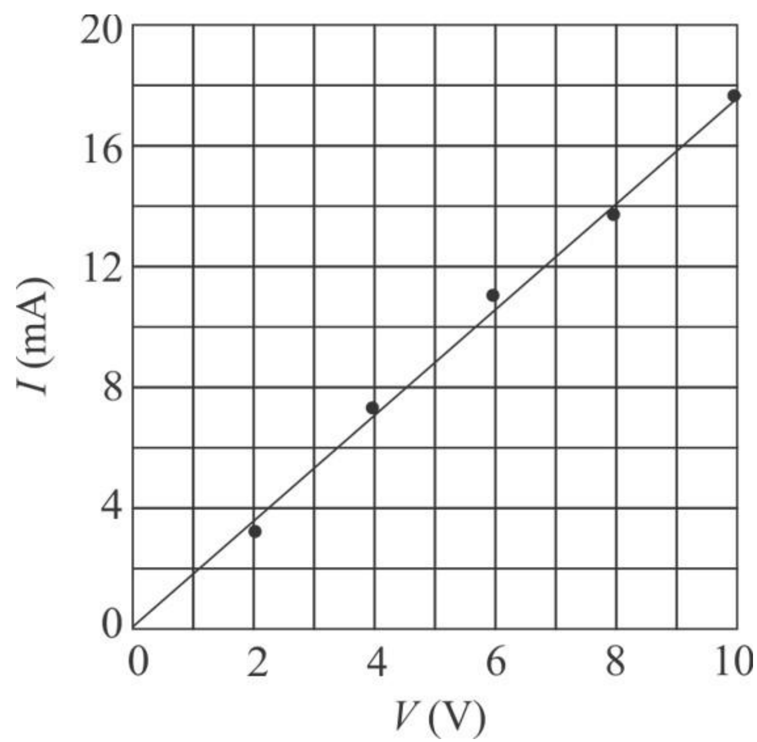
**Example** A student takes data for a resistor and fits the straight line shown to the data. What is the conductance and the resistance of the resistor?

The slope represents the conductance.

$$G = \frac{\overset{17.8\text{ mA}}{\cancel{14.8\text{ mA}}} - 0\text{ mA}}{10.0\text{ V} - 0\text{ V}} = \overset{1.78\text{ mS}}{\cancel{1.48\text{ mS}}}$$

The reciprocal of the conductance is the resistance:

$$R = \frac{1}{G} = \frac{1}{\underset{1.78\text{ mS}}{\cancel{1.48\text{ mS}}}} = \underset{562\ \Omega}{\cancel{676}}$$



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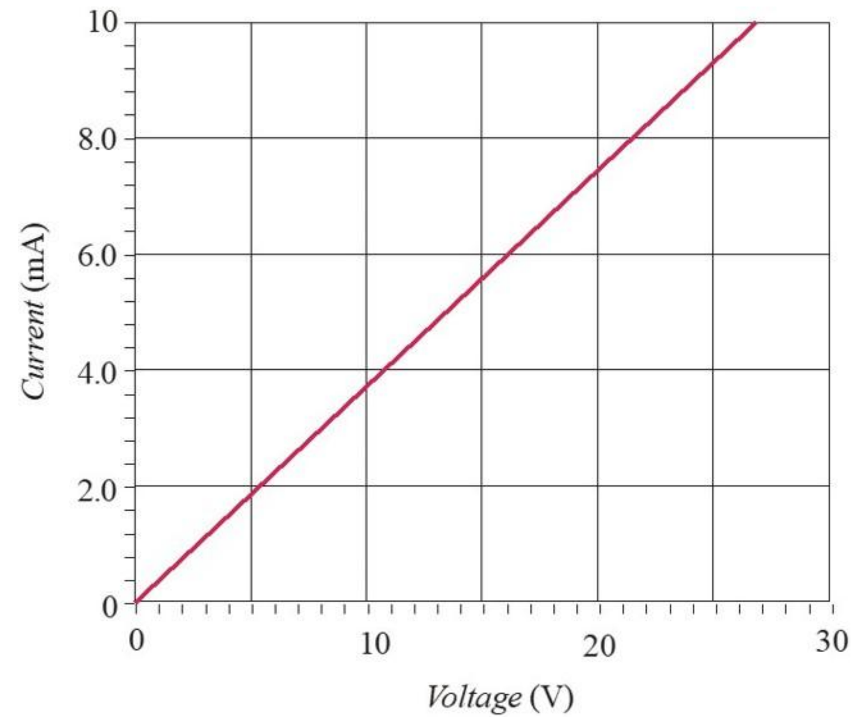
# Summary (10 of 35)

## Graph of Current versus Voltage

Notice that the plot of current versus voltage for a fixed resistor is a line with a positive slope. What is the resistance indicated by the graph?

What is its conductance?



# Summary (11 of 35)

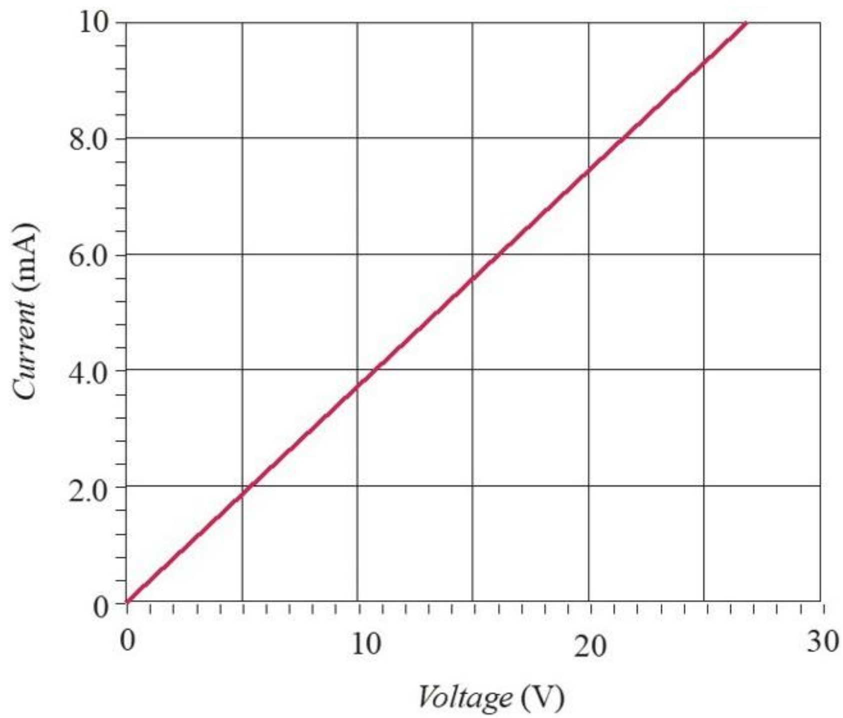
## Graph of Current versus Voltage

Notice that the plot of current versus voltage for a fixed resistor is a line with a positive slope. What is the resistance indicated by the graph?

2.7 kΩ

What is its conductance?

0.37 mS

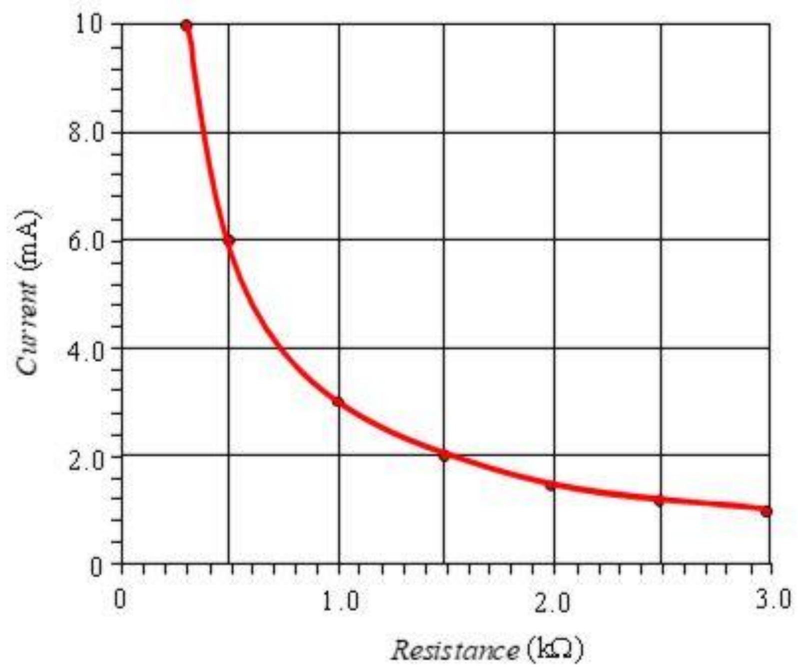


# Summary (12 of 35)

## Graph of Current versus Resistance

If resistance is varied for a constant voltage, the current versus resistance curve plots a hyperbola.

The curve shown is for a fixed 3 V source.



# Summary (13 of 35)

## Application of Ohm’s law

**Example:**

Assume a 15.0 V power supply is connected across each resistor, one at a time. What is the current in each case?

$$R = 1.0\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\text{ V}}{1.0\,\text{k}\Omega} =$$

$$R = 6.8\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\text{ V}}{6.8\,\text{k}\Omega} =$$

$$R = 27\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\text{ V}}{27\,\text{k}\Omega} =$$

# Summary (14 of 35)

## Application of Ohm's law

**Example:**

Assume a 15.0 V power supply is connected across each resistor, one at a time. What is the current in each case?

$$R = 1.0\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\,\text{V}}{1.0\,\text{k}\Omega} = 15.0\,\text{mA}$$

$$R = 6.8\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\,\text{V}}{6.8\,\text{k}\Omega} = 2.21\,\text{mA}$$

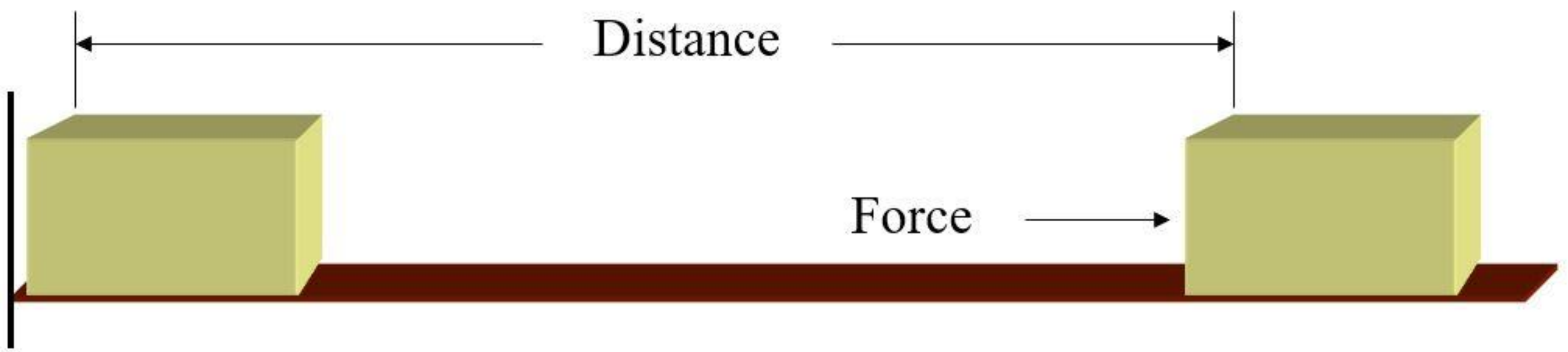
$$R = 27\,\text{k}\Omega \quad I = \frac{V}{R} = \frac{15.0\,\text{V}}{27\,\text{k}\Omega} = 556\,\mu\text{A}$$

# Summary (15 of 35)

## Energy and Power

When a constant force is applied to move an object over a distance, the work is the force times the distance.

The force must be measured in the same direction as the distance. The unit for work is the newton-meter (N-m) or joule (J).

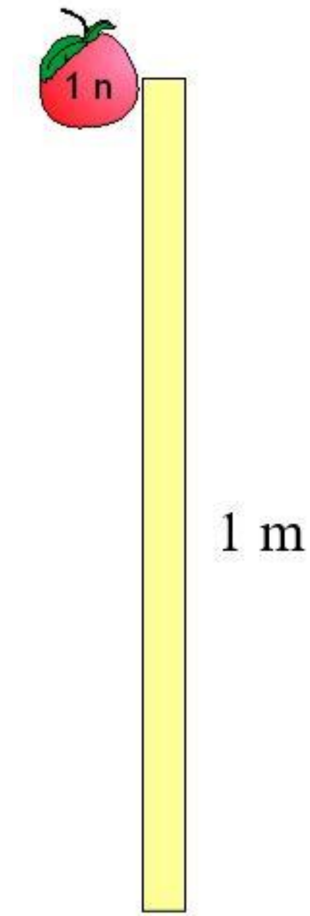


# Summary (16 of 35)

## Energy and Power

One joule is the work done when a force of one newton is applied through a distance of one meter. A joule is a small amount of work approximately equal to the work done in raising an apple over a distance of 1.0 m.

The symbol for energy, *W*, represents work, but should not be confused with the unit for power, the watt, W.



# Summary (17 of 35)

## Energy and Power

Energy is closely related to work. Energy is the ability to do work. As such, it is measured in the same units as work, namely the newton-meter (N-m) or joule (J).

**Example** What amount of energy is converted to heat in sliding a box along a floor for 5.0 meters if the force to move it is 400 n?

$$W = Fd = (400\ \text{N})(5.0\ \text{m}) = 2000\ \text{N-m} =$$

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# Summary (19 of 35)

## Energy and Power

Power is the rate of doing work. Rate means a time unit is required. The unit is the joule per second (J/s), which defines a watt (W).

$$P = \frac{W}{t}$$

**Example**

What power is developed if the box in the previous example is moved in 10 s?

$$P = \frac{W}{t} = \frac{2000\ \text{J}}{10\ \text{s}} =$$

## Energy and Power

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**Example**

What power is developed if the box in the previous example is moved in 10 s?

$$P = \frac{W}{t} = \frac{2000\text{ J}}{10\text{ s}} = 200\text{ W}$$

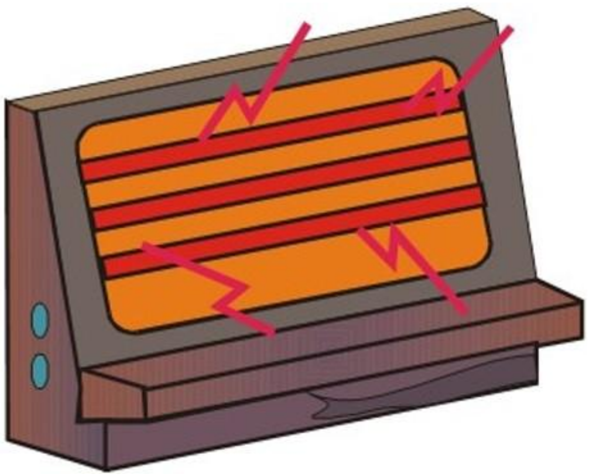
# Summary (21 of 35)

## Energy and Power

The kilowatt-hour (kWh) is a much larger unit of energy than the joule. There are $3.6 \times 10^6$ J in a kWh. The kWh is convenient for electrical appliances.

**Question:**

What is the energy used in operating a 1200 W heater for 20 minutes?





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# Summary (22 of 35)

## Energy and Power

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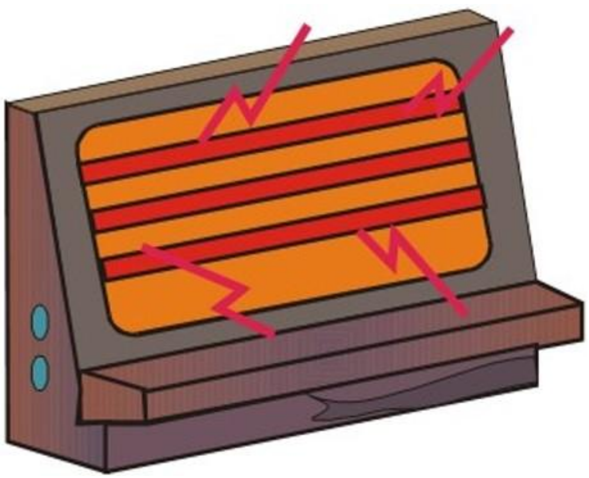


$1200 \text{ W} = 1.2 \text{ kW}$

$20 \text{ min} = 1/3 \text{ h}$

$1.2 \text{ kW X } 1/3 \text{ h} = 0.4 \text{ kWh}$

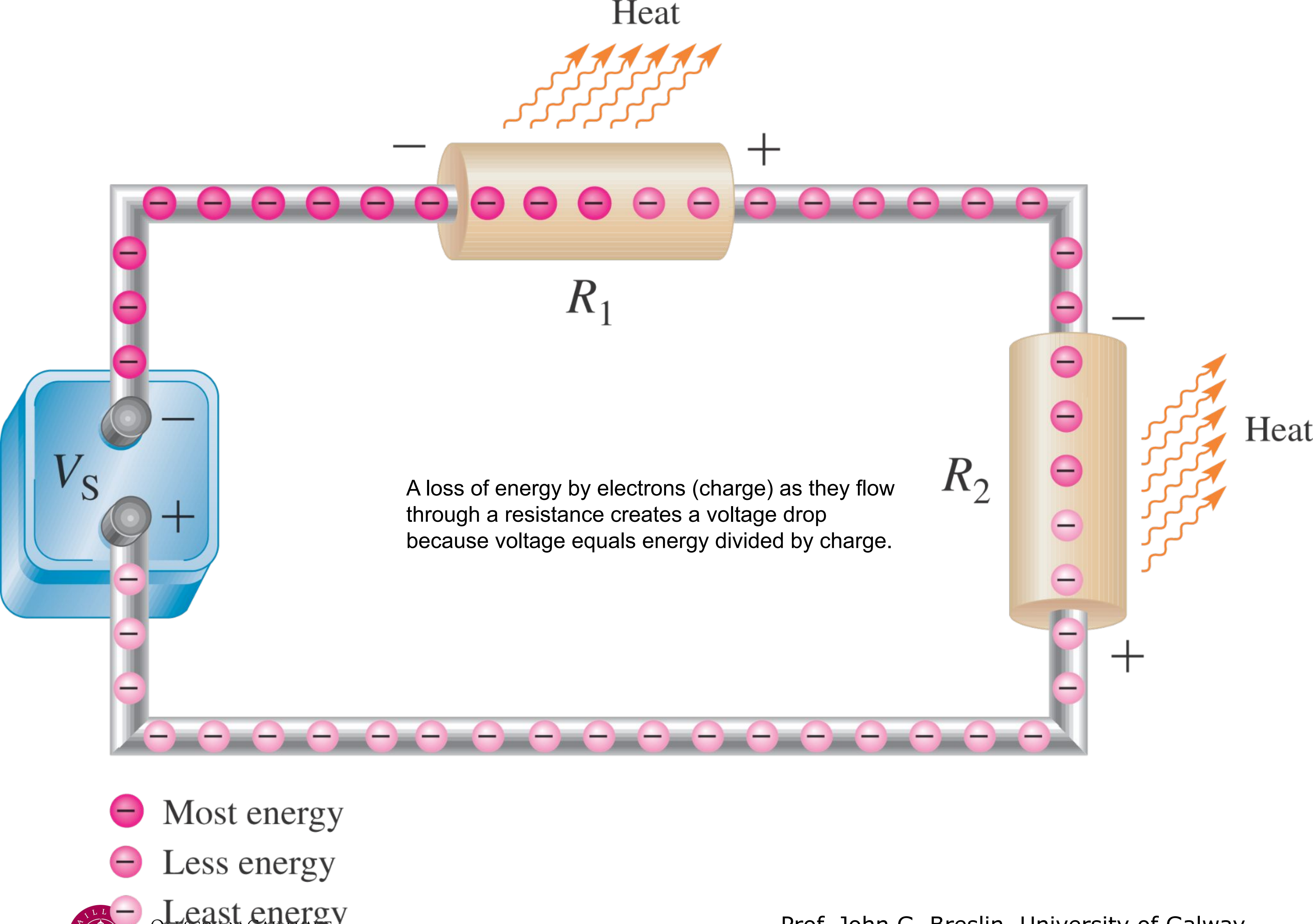
# Summary (23 of 35)

## Energy and Power

In electrical work, the rate energy is dissipated can be determined from any of three forms of the power formula.

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

Together, the three forms are called Watt's law.




A loss of energy by electrons (charge) as they flow through a resistance creates a voltage drop because voltage equals energy divided by charge.

# Summary (24 of 35)

## Energy and Power

**Example 1:**

What power is dissipated in a 27 Ω resistor if the current is 135 mA?

## Energy and Power

**Example 1:**

What power is dissipated in a 27 Ω resistor if the current is 135 mA?

**Solution:**

Given that you know the resistance and current, substitute the values into $P = I^2R$.

$$P = I^2R$$

$$= (0.135\ \text{A})^2 (27\ \Omega)$$

$$= 0.492\ \text{W}$$

## Energy and Power

**Example 2:**

What power is dissipated by a heater that draws 12 A of current from a 120 V supply?

## Energy and Power

**Example 2:**

What power is dissipated by a heater that draws 12 A of current from a 120 V supply?

**Solution:**

The most direct solution is to substitute into $P = IV$.

$$\begin{aligned} P &= IV \\ &= (12\text{ A})(120\text{ V}) \\ &= 1440\text{ W} \end{aligned}$$



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# Summary (28 of 35)

## Energy and Power

**Example 3:**

What power is dissipated in a 100Ω resistor with 5 V across it?

# Summary (29 of 35)

## Energy and Power

**Example 3:**

What power is dissipated in a 100Ω resistor with 5 V across it?

**Solution:**

The most direct solution is to substitute into

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

$$= \frac{(5\ \text{V})^2}{100\Omega} = 0.25\ \text{W}$$

Small resistors should be checked for the anticipated power even when the voltage is low.

# I was on a train in France last year and saw this…


If 100 W is the maximum power that can be provided, what is the maximum current that can be drawn?




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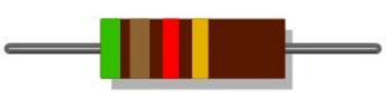
# Summary (30 of 35)

## Resistor failures

Resistor failures are unusual except when they have been subjected to excessive current, leading to overheating. Look for discoloration (sometimes the color bands appear burned). Test with an ohmmeter by disconnecting one end from the circuit to isolate it and verify the resistance. Correct the cause of the heating problem (circuit failure, larger wattage resistor, wrong value, etc.).

A thermal imaging camera can be used to identify a component that is too hot.



Normal

Overheated

Photo courtesy of FLIR Systems, Inc.

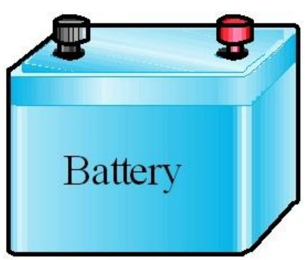
## Ampere-hour Rating of Batteries

The battery life of batteries is specified as the ampere-hours (Ah) rating. Various factors (including level of current draw, age of battery, temperature), affect the Ah rating, so the actual value depends on the application and external conditions.

As a battery discharges, its internal resistance will increase and its terminal voltage while connected to a load will decrease. The Ah rating is defined as the time the battery can deliver a specified current before its terminal voltage drops to a specific test voltage level.

**Question:**

How many hours of life can you expect to obtain from a battery that delivers 0.5 A and is rated for 10 A h?



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As a battery discharges, its internal resistance will increase and its terminal voltage while connected to a load will decrease. The Ah rating is defined as the time the battery can deliver a specified current before its terminal voltage drops to a specific test voltage level.

**Question:**

How many hours of life can you expect to obtain from a battery that delivers 0.5 A and is rated for 10 A h?


20 h

## Troubleshooting

**Analyze** the cause of a failure. Some questions to ask before starting any troubleshooting are:

1. Has the circuit ever worked?
2. If the circuit once worked, under what conditions did it fail?
3. What are the symptoms of the failure?
4. What are the possible causes of the failure?

# Summary (34 of 35)

## Troubleshooting

Continue to **analyze** the problem by reviewing pertinent information:

1. Schematics
2. Instruction manuals

3. Review when and how the failure occurred. The analysis step is very important and may lead you directly to the problem, saving time.

# Summary (35 of 35)

## Troubleshooting

The analysis should help determine the next step. You may **plan** to go to a specific area of the circuit to find the problem. Another approach is to start at the middle of a circuit and work in toward the failure. This approach is called half-splitting.


Based on the plan, make **measurements** as needed to localize the problem. Modify the plan if necessary as you proceed.

After solving the problem, it is useful to ask, “How can I prevent this failure in the future?” It is also useful to see that the symptoms, sometimes missed, all pointed to the problem, so the good troubleshooter uses each problem as a learning tool.

# Selected Key Terms (1 of 2)

***Ohm's law*** A law stating that current is directly proportional to voltage and inversely proportional to resistance.

***Linear*** Characterized by a straight-line relationship.

***Energy*** The ability to do work. The unit is the joule (J).

***Power*** The rate of energy usage.

***Joule*** The S I unit of energy.

# Selected Key Terms (2 of 2)

***Watt*** The unit of power. One watt is the power when one J of energy is used in one second.

***Kilowatt-hour*** A common unit of energy used mainly by utility companies.

***Ampere-hour rating*** A number determined by multiplying the current (A) times the length of time (h) that a battery can deliver that current to a load.

***Efficiency*** The ratio of output power to input power of a circuit, usually expressed as a percent.

# Quiz (1 of 11)

1. Holding the voltage constant, and plotting the current against the resistance as resistance is varied will form a

   a. straight line with a positive slope.
   b. straight line with a negative slope.
   c. parabola.
   d. hyperbola.

# Quiz (2 of 11)

2. When the current is plotted against the voltage for a fixed resistor, the plot is a

   a. straight line with a positive slope.

   b. straight line with a negative slope.

   c. parabola.

   d. hyperbola.

# Quiz (3 of 11)

3. For constant voltage in a circuit, doubling the resistance means

   a. doubling the current.

   b. halving the current.

   c. there is no change in the current.

   d. depends on the amount of voltage.

# Quiz (4 of 11)

4. A four-color resistor has the color-code red-violet-orange-gold. If it is placed across a 12 V source, the expected current is

   a. 0.12 mA.

   b. 0.44 mA.

   c. 1.25 mA.

   d. 4.44 mA.

# Quiz (5 of 11)

5. If the current in a 330Ω resistor is 15 mA, the voltage across it is approximately

   a. 5.0 V.
   b. 22 V.
   c. 46 V.
   d. 60 V.



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# Quiz (6 of 11)

6. A unit of power is the

   a. joule.
   b. kilowatt-hour.
   c. both of the above.
   d. none of the above.



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# Quiz (7 of 11)

7. The SI unit of energy is the

   a. volt.

   b. watt.

   c. joule.

   d. kilowatt-hour.

# Quiz (8 of 11)

8. If the voltage in a resistive circuit is doubled, the power will be

   a. halved.
   b. unchanged.
   c. doubled.
   d. quadrupled.



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# Quiz (9 of 11)

9. The approximate power dissipated by a 330Ω resistor with 9.0 V across it is

   a. ¼ W.

   b. ½ W.

   c. 1 W.

   d. 2 W.



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# Quiz (10 of 11)

10. Before troubleshooting a faulty circuit you should find out

a. if the circuit ever worked.

b. the conditions that existed when it failed.

c. the symptoms of the failure.

d. all of the above.



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# Quiz (11 of 11)

Answers:

| | | | |
|---|---|---|---|
| 1. | d | 6. | d |
| 2. | a | 7. | c |
| 3. | b | 8. | d |
| 4. | b | 9. | a |
| 5. | a | 10. | d |