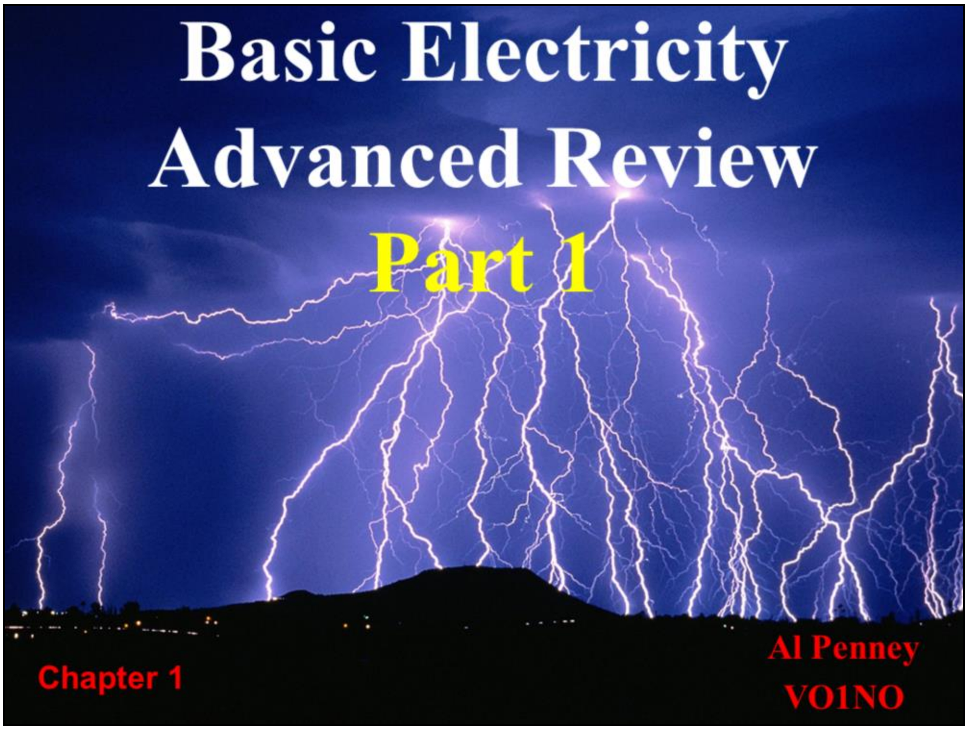
Basic Electricity
Advanced Review
Part 1
Chapter 1
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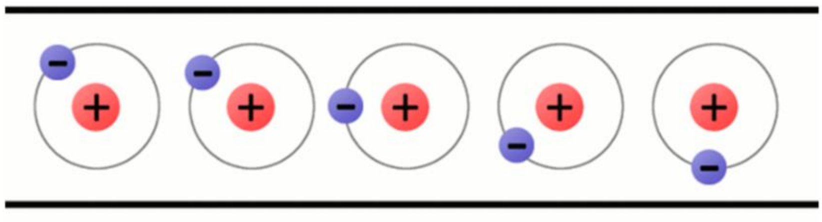
Electric Current



Electric current is the flow of electrons through a conductor.

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Insulators

- Valence electrons are hard to dislodge, and so electric current cannot flow easily.
- Typical insulators include:
  - Glass
  - Rubber
  - Most plastics
  - Teflon
  - Ceramics

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Some Definitions

- A single electron has too small a charge for practical purposes.
- The coulomb is defined as the charge of 6.28 x 10^{18} electrons.
- The coulomb is used in the definition of the ampere…

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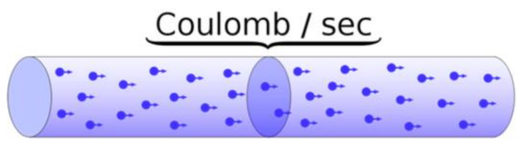
The charges in static electricity from rubbing materials together are typically a few microcoulombs. The amount of charge that travels through a lightning bolt is typically around 15 C, although large bolts can be up to 350 C

Ampere

- Unit of electric current i.e.: the rate of flow of electrons in a conductor.
- 1 ampere = flow of 1 coulomb/second.



- Ampere abbreviated "A".
- Current abbreviated "I", e.g.: I = 5A.

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Ampere

- Current measured using Ammeters.


- Milliamperes (mA) = 1/1,000 amperes.
- Microamperes (µA) = 1/1,000,000 amperes.

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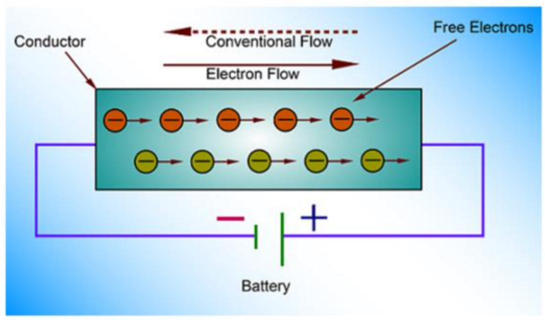
Conventional Current

- Electron flow is negative to positive.
- Conventional Current is positive to negative.



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Voltage

- Valence electrons held in place by electrostatic force.
- For current to flow, work must be done to make electrons move.
- The work done to put an electric charge on a body by adding electrons is measured in Volts.
- Also known as Electromotive Force (EMF) and Potential Difference.

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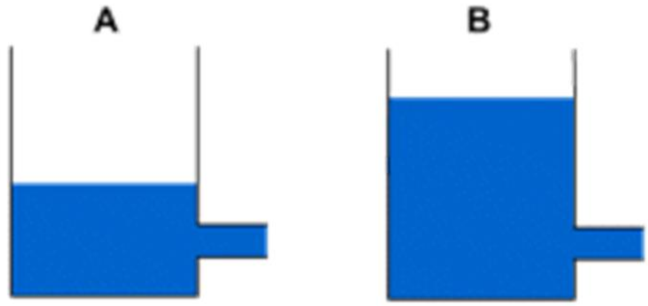
Voltage, **electrical potential difference**, **electric tension** or **electric pressure** (denoted ΔV and measured in units of electric potential: volts, or joules per coulomb) is the electric potential difference between two points, or the difference in electric potential energy of a unit charge transported between two points.[1] Voltage is equal to the work done per unit charge against a static electric field to move the charge between two points. A voltage may represent either a source of energy (electromotive force), or lost, used, or stored energy (potential drop). A voltmeter can be used to measure the voltage (or potential difference) between two points in a system; usually a common reference potential such as the ground of the system is used as one of the points. Voltage can be caused by static electric fields, by electric current through a magnetic field, by time-varying magnetic fields, or some combination of these three.[2][3]

Voltage

- Think of voltage as the "pressure" that pushes electrons through a conductor.



Lower pressure = lower voltage   Higher pressure = higher voltage

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Voltage

- Electric Potential Difference between two points.
- 1 Volt = 1 Joule / Coulomb
- Symbol is “E” e.g.: E = 5V
- Typical voltages:
  - Alkaline cell: 1.5 volts DC
  - Car battery: 12.6 volts DC
  - Household outlet: 120 volts AC

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Voltage

- Measured with a Voltmeter.

- Millivolt (mV) = 1/1,000 volts.
- Microvolt (μV) = 1/1,000,000 volts.

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Resistance

- Opposition to the flow of current.
- Unit of resistance is the ohm.
- Symbol is the Greek letter Omega: Ω
- Abbreviation for resistance is “R”: e.g.: R = 5 Ω

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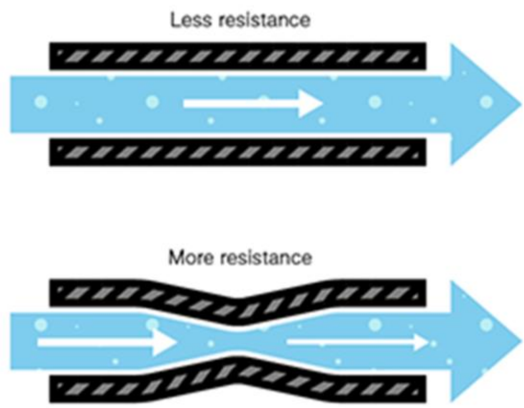
Resistance



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Factors affecting Resistance

- Specific resistance of material e.g. copper is a better conductor than iron.
- Length of the conductor. Longer = greater resistance.
- Diameter of the conductor. Greater diameter = less resistance.
- Temperature:
  - Positive Temperature Coefficient = Resistance increases with temperature (e.g.: most pure metals).
  - Negative Temperature Coefficient = Resistance decreases with temperature (e.g.: semiconductors).

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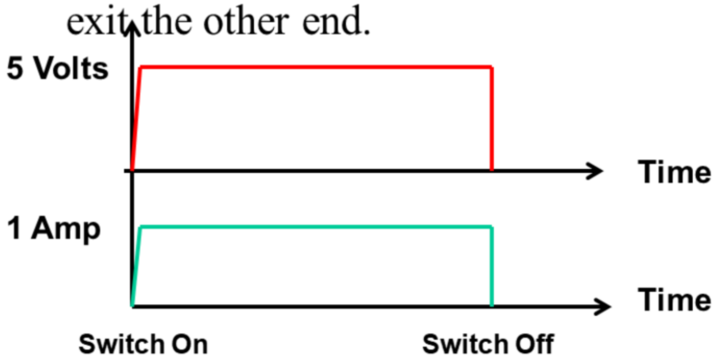
Direct Current (DC)

- Current flows in one direction only.
- Electrons enter one end of a conductor, and exit the other end.



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Alternating Current

- Current flows in one direction, and then another at a regular periodic rate.
- Number of alterations per second is frequency.
- In North America frequency is 60 cycles per second, or 60 Hertz.
- So, 1 cycle per second = 1 Hertz, abbreviated Hz.

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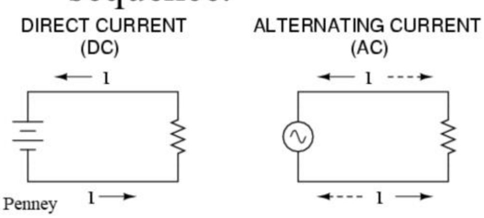
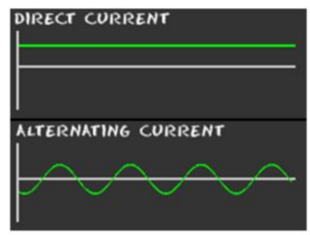
Direct vs Alternating Current

- Direct Current (DC) – flows in one direction only.
- Alternating Current (AC) – flows in one direction, then the other, in a regular sequence.





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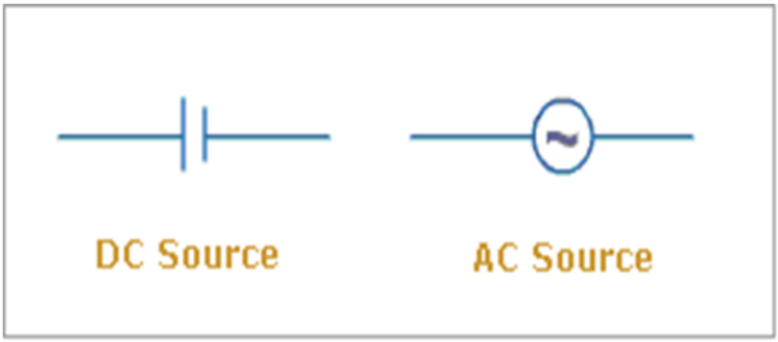

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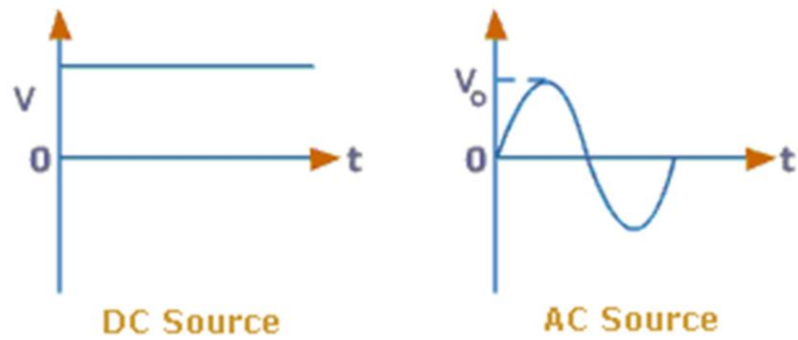
Direct vs Alternating Current



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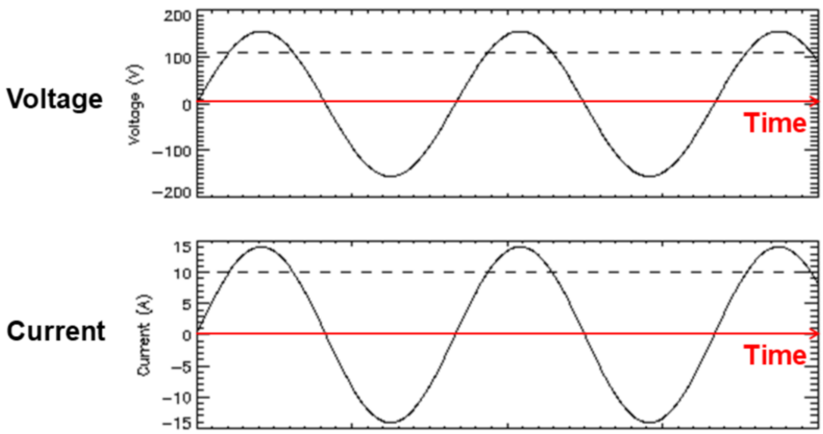
AC Voltage and Current



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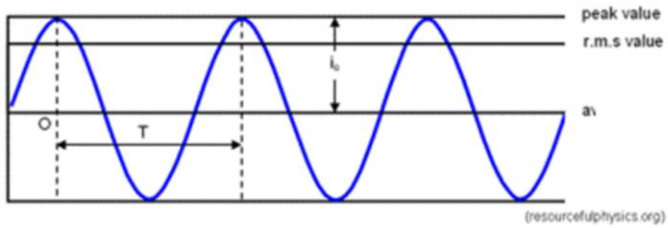
Energy of AC versus DC

- For AC waveform to have same energy as DC, the peak AC voltage must be greater.
- For energy equivalence, peak AC voltage = 1.414 DC voltage, or DC = 0.707 peak AC voltage.
- This is the Root Mean Square value (RMS value).



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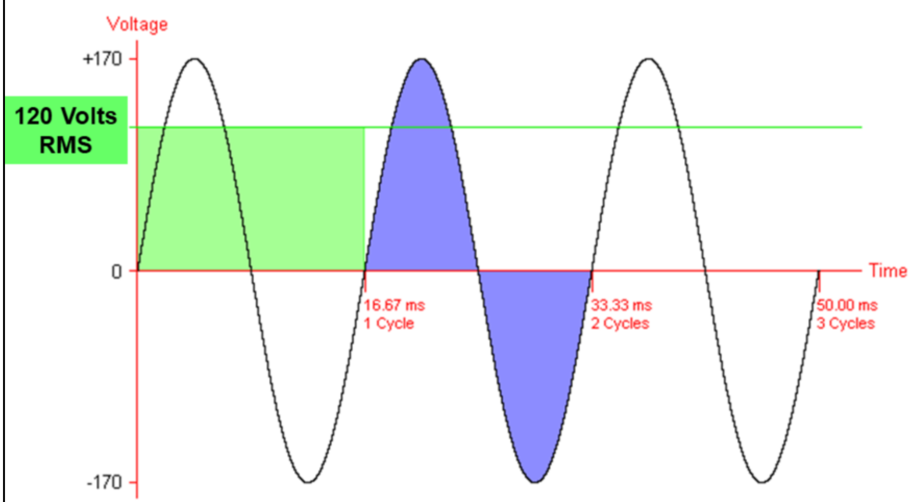

RMS Voltage = 0.707 x Peak AC voltage
= 0.707 x 170 volts
= 120 volts

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Conductance

- Sometimes easier to consider how well a material conducts rather than its resistance.
- Conductance is reciprocal of resistance.
- Symbol for Conductance is G: $G = 1/R$
- Unit of measure is the siemen, abbreviated S (formerly the mho – ohm spelled backwards).
- Example: If $R = 10\ \Omega$, then $G = 1/10$ S = 0.1 S

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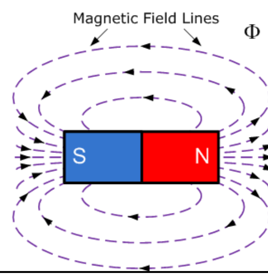
Magnets

- Magnetism is one of 4 basic forces of nature.
- A force of attraction or repulsion that acts at a distance.
- Magnets have a North and South pole.



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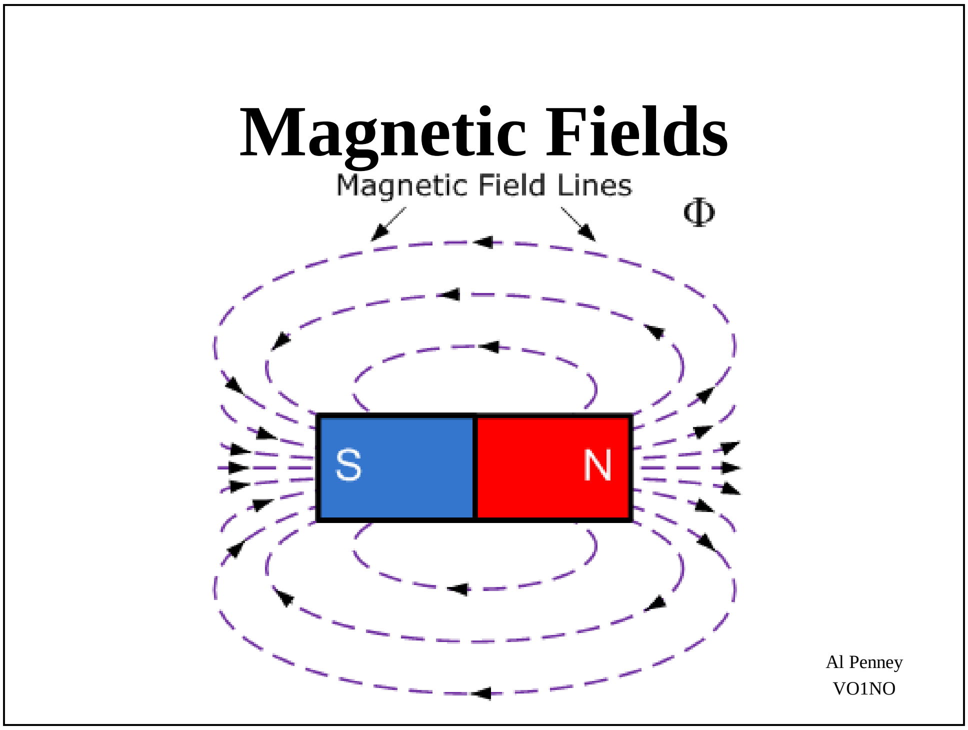
Magnetic Fields

What is a magnetic field? The space surrounding a magnet, in which magnetic force is exerted, is called a magnetic field. If a bar magnet is placed in such a field, it will experience magnetic forces. However, the field will continue to exist even if the magnet is removed. The direction of magnetic field at a point is the direction of the resultant force acting on a hypothetical North Pole placed at that point.

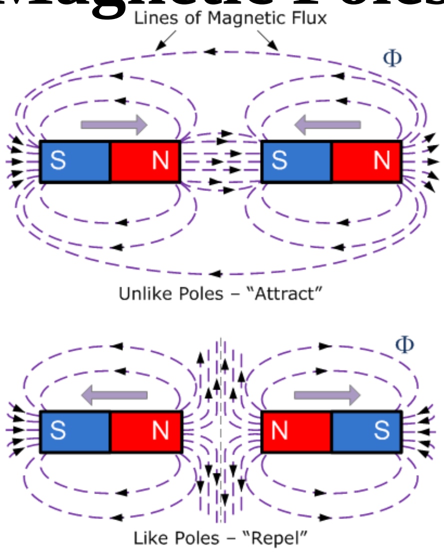
As shown above, the magnetic field is strongest near to the poles of the magnet were the lines of flux are more closely spac



However, magnetic flux does not actually flow from the north to the south pole or flow anywhere for that matter as magnetic flux is a static region around a magnet in which the magnetic force exists. In other words magnetic flux does not flow or move it is just there and is not influenced by gravity. Some important facts emerge when plotting lines of force:

1. - Lines of force NEVER cross.
2. - Lines of force are CONTINUOUS.
3. - Lines of force always form individual CLOSED LOOPS around the magnet.
4. - Lines of force have a definite DIRECTION from North to South.
5. - Lines of force that are close together indicate a STRONG magnetic field.
6. - Lines of force that are farther apart indicate a WEAK magnetic field.

Magnetic Poles



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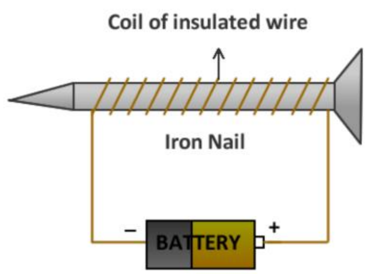
Magnetic forces attract and repel like electric forces and when two lines of force are brought close together the interaction between the two magnetic fields causes one of two things to occur:

1. - When adjacent poles are the same, (north-north or south-south) they REPEL each other.

2. - When adjacent poles are not the same, (north-south or south-north) they ATTRACT each other.

It can be remembered by the famous expression that "opposites attract" and this interaction of magnetic fields is easily demonstrated with iron fillings. The effect upon the magnetic fields of the various combinations of poles as like poles repel and unlike poles attract can be seen below.

Types of Magnets



SIMPLE ELECTROMAGNET

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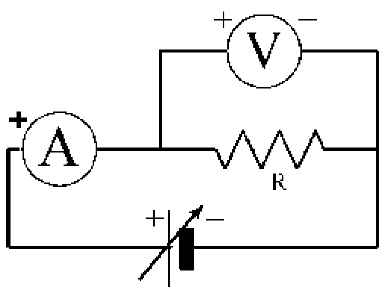
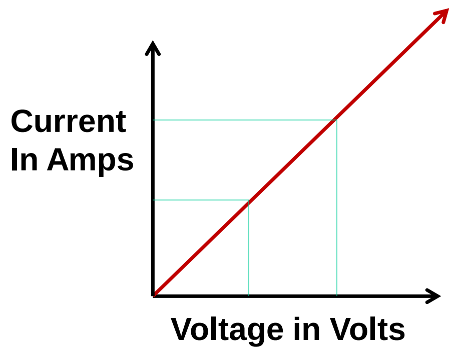
Voltage and Current





As Voltage is increased, Current also increases.

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Ohm's law states that the current through a conductor between two points is directly proportional to the potential difference across the two points. Introducing the constant of proportionality, the resistance,[1] one arrives at the usual mathematical equation that describes this relationship:[2]

where *I* is the current through the conductor in units of amperes, *V* is the potential difference measured *across* the conductor in units of volts, and *R* is the resistance of the conductor in units of ohms. More specifically, Ohm's law states that the *R* in this relation is constant, independent of the current.[3]

The law was named after the German physicist Georg Ohm, who, in a treatise published in 1827, described measurements of applied voltage and current through simple electrical circuits containing various lengths of wire. He presented a slightly more complex equation than the one above (see History section below) to explain his experimental results. The above equation is the modern form of Ohm's law.

Ohm's Law

- Relationship between Voltage, Current and Resistance can be expressed mathematically as:

$$E = I \times R$$

Where

E is measured in Volts;

I is measured in Amps; and

R is measured in Ohms.

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Ohm's Law

The equation can be re-written to determine any of the 3 variables if the other two are known:

$$I = E / R$$

And

$$R = E / I$$

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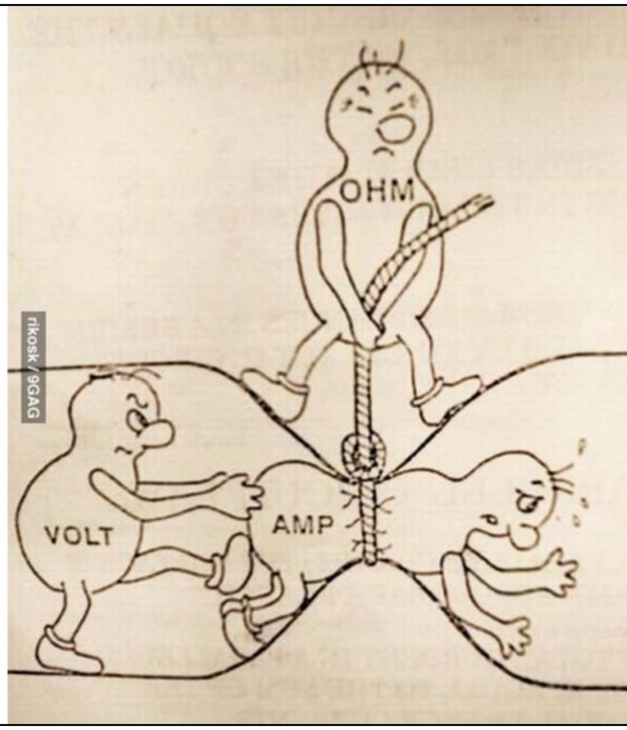

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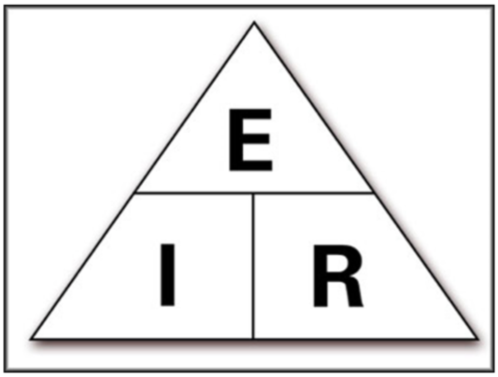
Ohms Law Triangle



Remember the Units:
- E is measured in **VOLTS**
- I is measured in **AMPS**
- R is measured in **OHMS**

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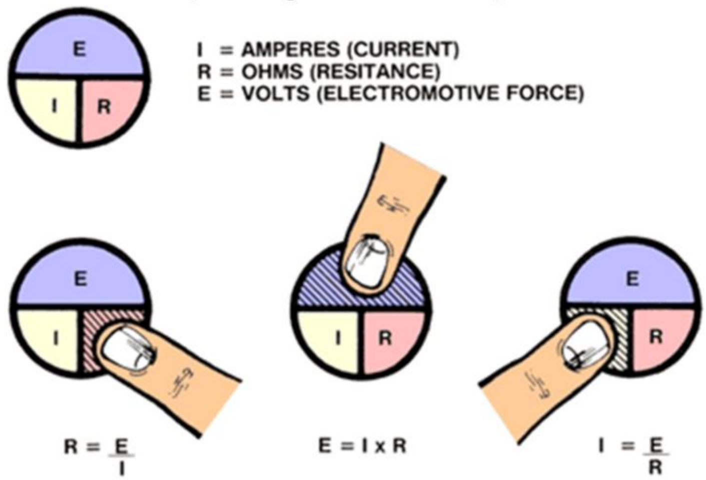
Ohms Law Triangle

(Okay – Circle!)



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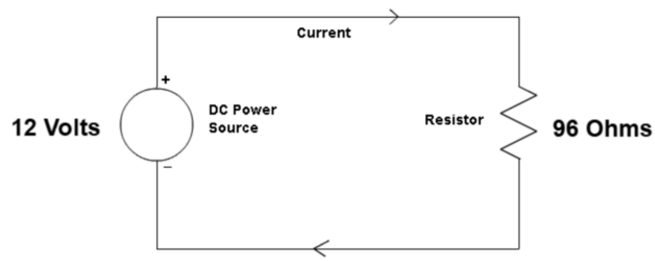
Ohms Law Problem #1

What is the current?



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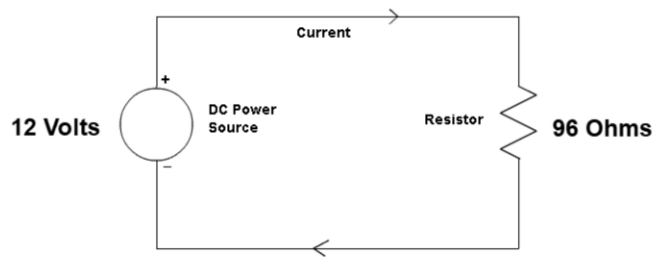
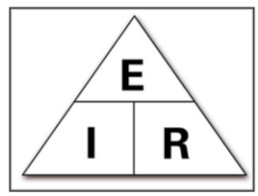
Ohms Law Problem #1

What is the current?



Consult the Ohms Law Triangle:



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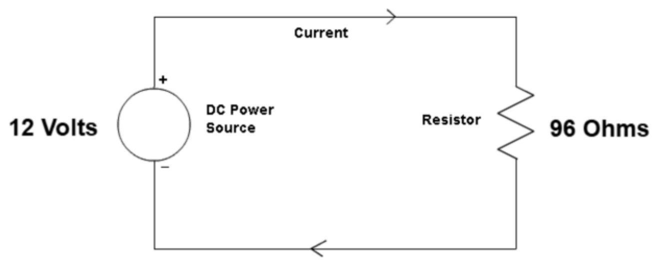
Ohms Law Problem #1

What is the current?



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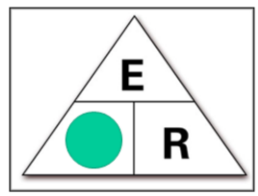

I = E / R

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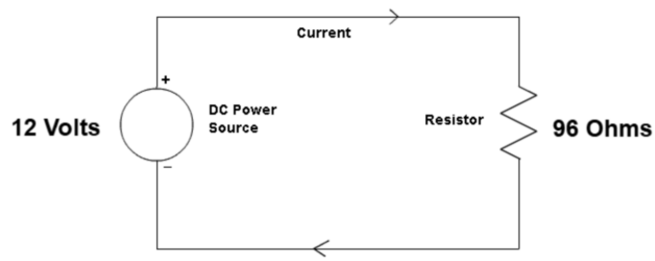
Ohms Law Problem #1

What is the current?



I = E / R
I = 12 Volts / 96 Ohms
I =

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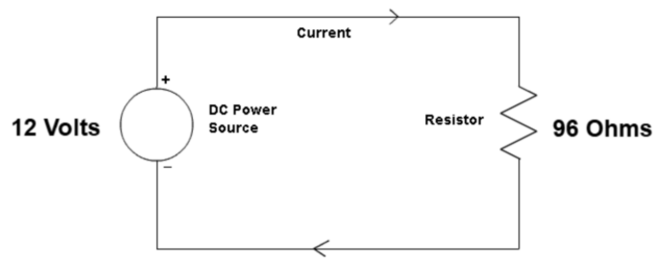
Ohms Law Problem #1

What is the current?



I = E / R

I = 12 Volts / 96 Ohms

I = 0.125 Amps

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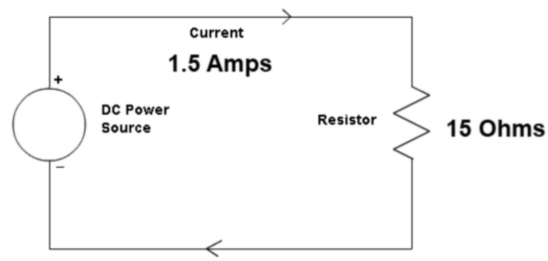
Ohms Law Problem #2

What is the voltage?



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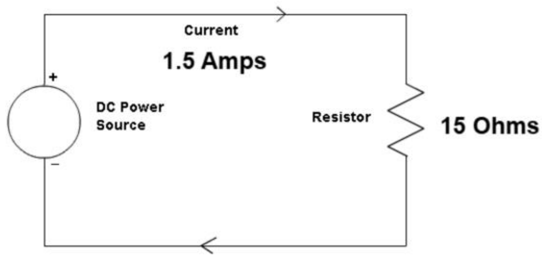
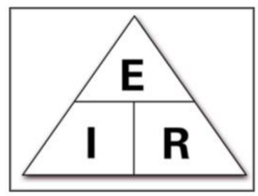
Ohms Law Problem #2

What is the voltage?



Consult the Ohms Law Triangle:



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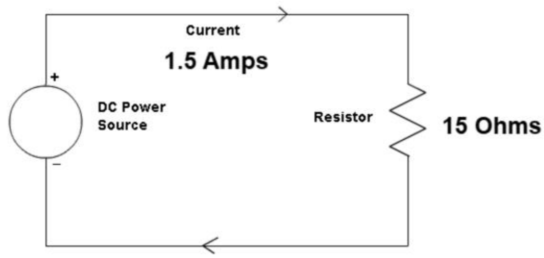
Ohms Law Problem #2

What is the voltage?



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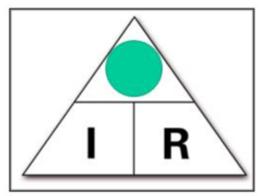

E = I x R

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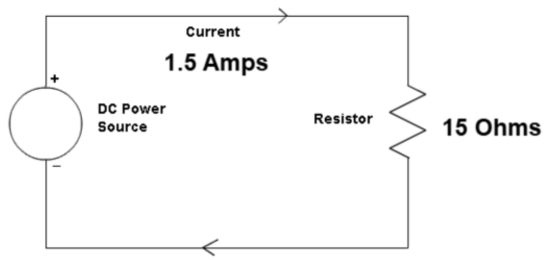
Ohms Law Problem #2

What is the voltage?



$E = I \times R$

$= 1.5 \text{ Amps} \times 15 \text{ Ohms}$

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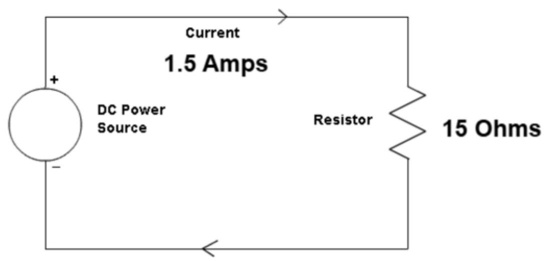
Ohms Law Problem #2

What is the voltage?



E = I x R

= 1.5 Amps x 15 Ohms

= 22.5 Volts

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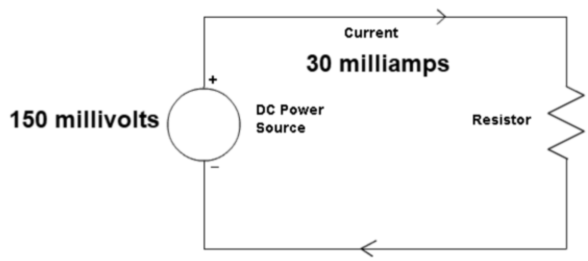
Ohms Law Problem #3

What is the resistance?



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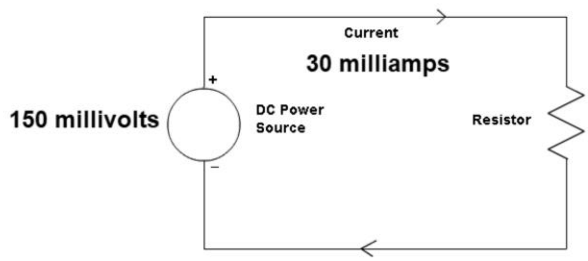
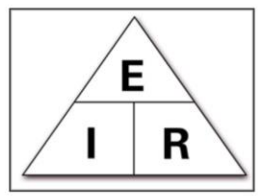
Ohms Law Problem #3

What is the resistance?



Consult the Ohms Law Triangle:



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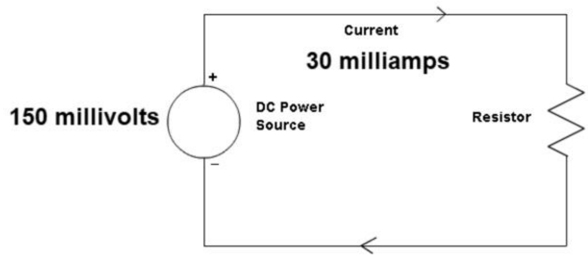
Ohms Law Problem #3

What is the resistance?



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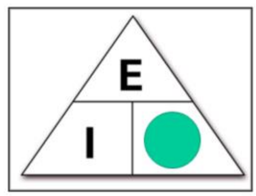

R = E / I

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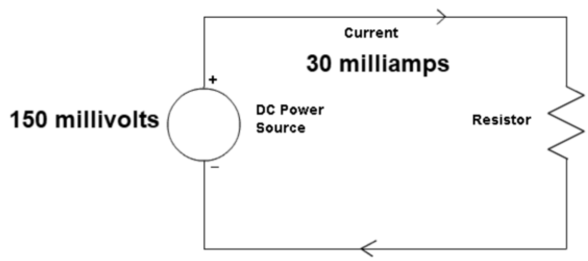
Ohms Law Problem #3

What is the resistance?



R = E / I

= 150 millivolts / 30 milliamps

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Ohms Law Problem #3

- **REMEMBER the UNITS!**
  - 150 **millivolts** = 150 / 1000 volts = 0.15 **volts**
  - 30 **milliamps** = 30 / 1000 amps = 0.03 **amps**

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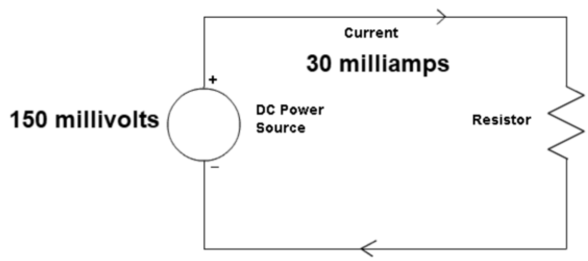
Ohms Law Problem #3

What is the resistance?



R = E / I

= 150 millivolts / 30 milliamps

= 0.15 Volts / 0.03 Amps

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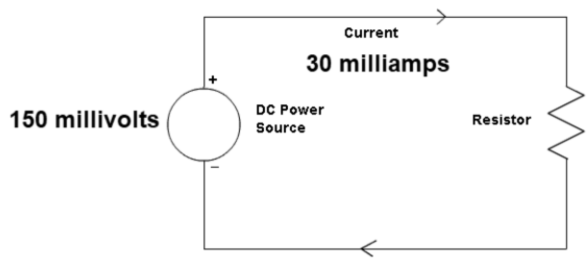
Ohms Law Problem #3

What is the resistance?



R = E / I

= 150 millivolts / 30 milliamps

= 0.15 Volts / 0.03 Amps

= 5 Ohms

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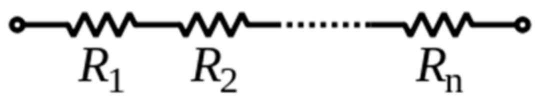
Resistors in Series

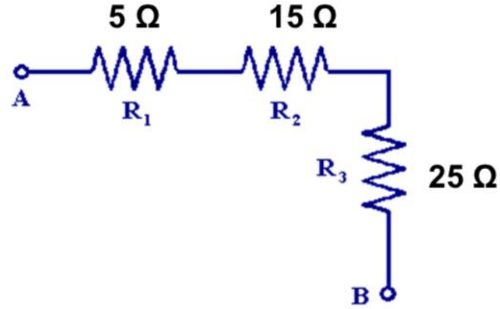
- When resistors are in **SERIES**, the total resistance is the **SUM** of the individual resistances.



$$R_{Total} = R_1 + R_2 + R_3 + \ldots.. + R_N$$

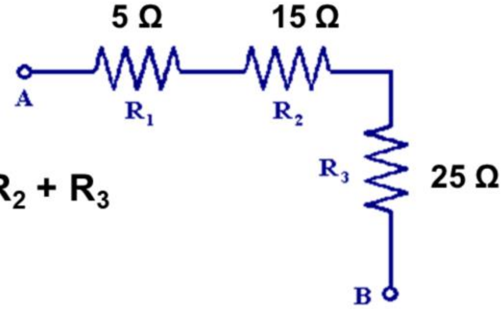
Al Penney
VO1NO

Resistors in Series



Al Penney
VO1NO

Resistors in Series



$R_{Total} = R_1 + R_2 + R_3$

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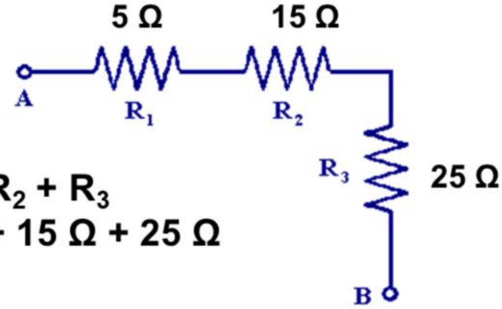
Resistors in Series



$R_{Total} = R_1 + R_2 + R_3$

$R_{Total} = 5\ \Omega + 15\ \Omega + 25\ \Omega$

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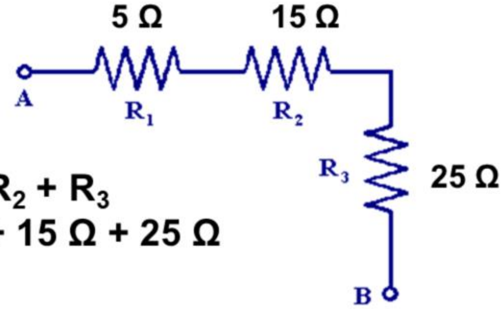
Resistors in Series



$R_{Total} = R_1 + R_2 + R_3$

$R_{Total} = 5\ \Omega + 15\ \Omega + 25\ \Omega$

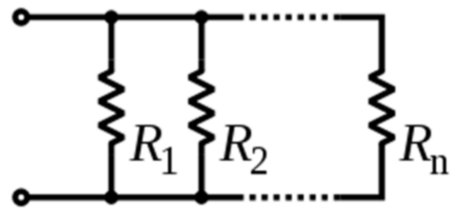
$R_{Total} = 45\ \Omega$

Al Penney
VO1NO

Resistors in Parallel

- When resistors are in Parallel, the total resistance is given by the following equation:

$$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots.. + 1/R_N$$



Al Penney
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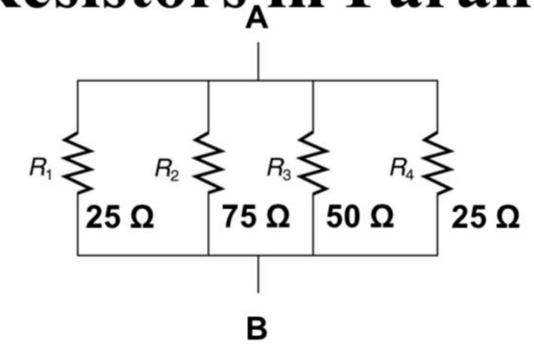
Resistors in Parallel



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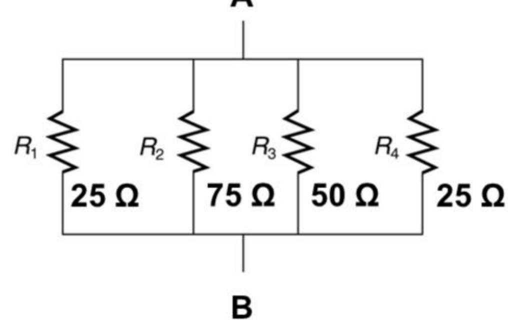
Resistors in Parallel



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$

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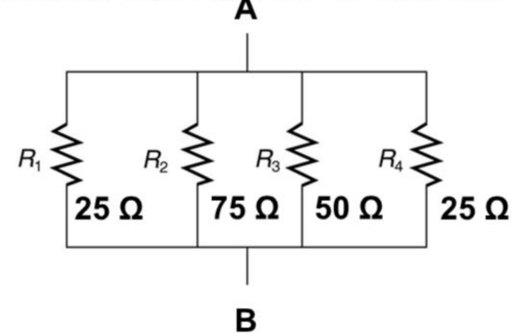
Resistors in Parallel



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$
$1/R_{Total} = 1/25 + 1/75 + 1/50 + 1/25$

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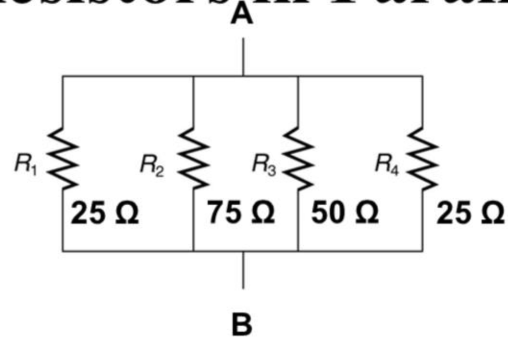
VO1NO

Resistors in Parallel



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$

$1/R_{Total} = 1/25 + 1/75 + 1/50 + 1/25 = 6/150 + 2/150 + 3/150 + 6/150$

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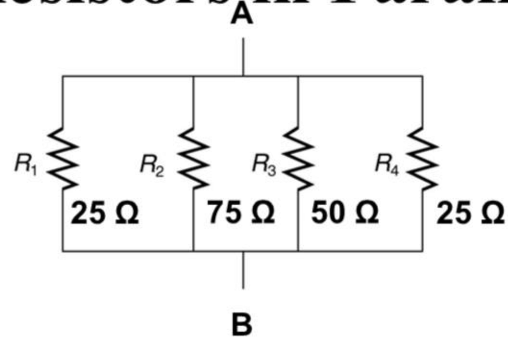
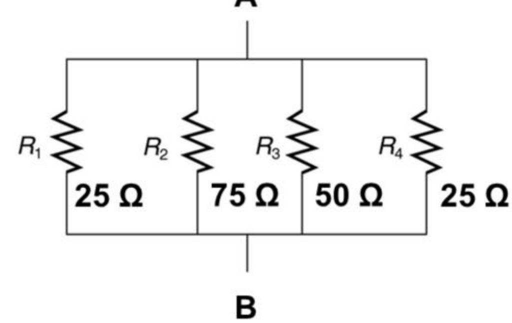
Resistors in Parallel



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$
$1/R_{Total} = 1/25 + 1/75 + 1/50 + 1/25 = 6/150 + 2/150 + 3/150 + 6/150$
$1/R_{Total} = 17/150\ \Omega$

Al Penney
VO1NO

Resistors in Parallel



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3 + 1/R_4$

$1/R_{Total} = 1/25 + 1/75 + 1/50 + 1/25 = 6/150 + 2/150 + 3/150 + 6/150$

$1/R_{Total} = 17/150\ \Omega$

$R_{Total} = 150/17\ \Omega = 8.82\ \Omega$

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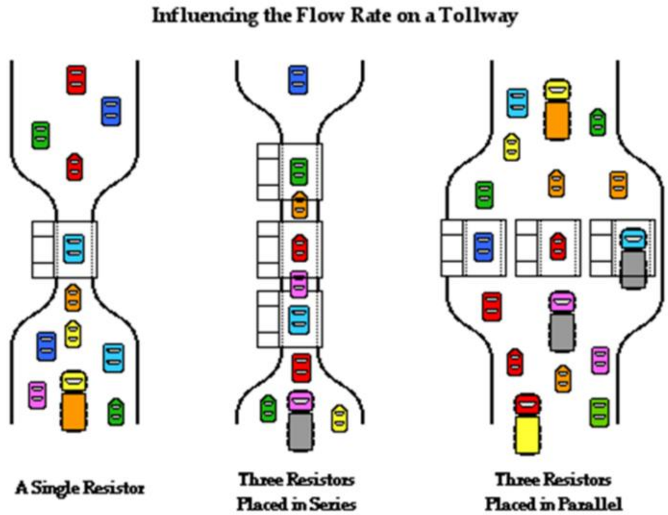

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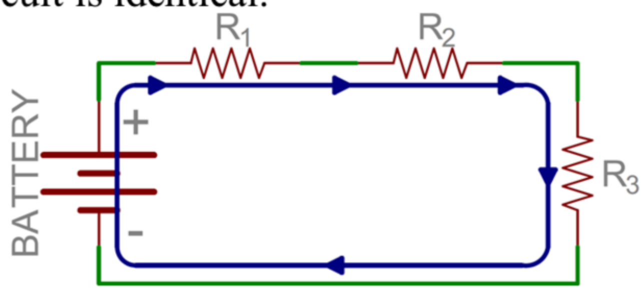
VO1NO

Current in a Series Circuit

- The current through each resistor in a Series Circuit is identical.



$I_{Total} = I_{R1} = I_{R2} = I_{R3}$

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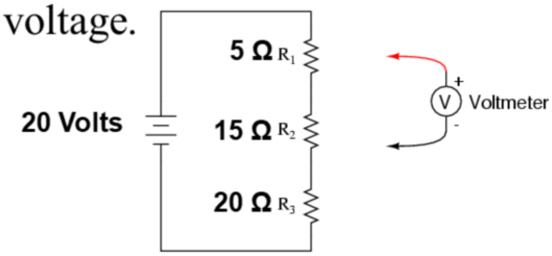
Voltage in Series Circuits

- The sum of all the voltages across each resistor in a Series Circuit will equal the source voltage.



$$E_{source} = E_{R1} + E_{R2} + E_{R3}$$

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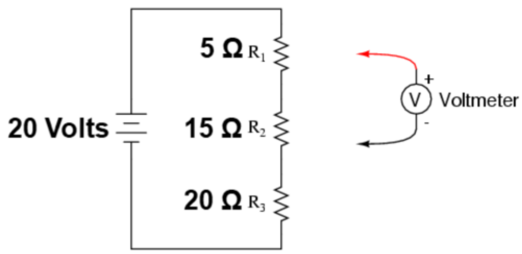
VO1NO

To Calculate Voltage Drop…



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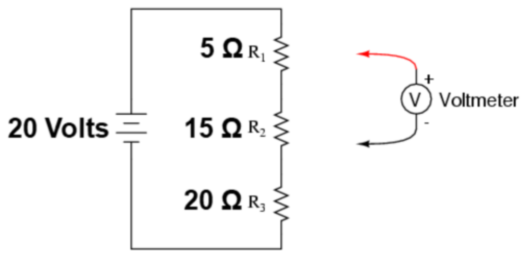
1. Determine Total Resistance



$R_{Total} = R_1 + R_2 + R_3$

$R_{Total} =$

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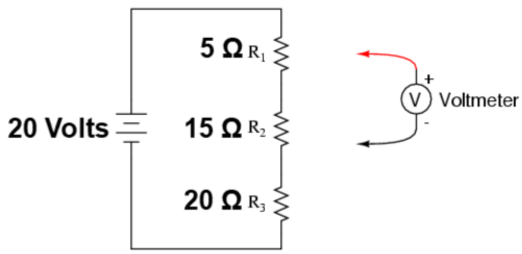
1. Determine Total Resistance



$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

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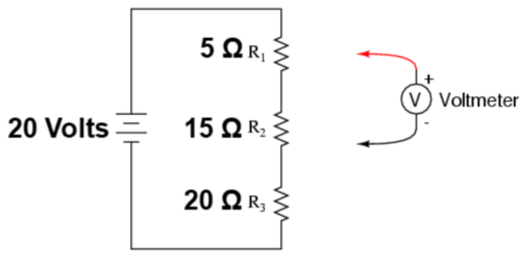
2. Determine Current

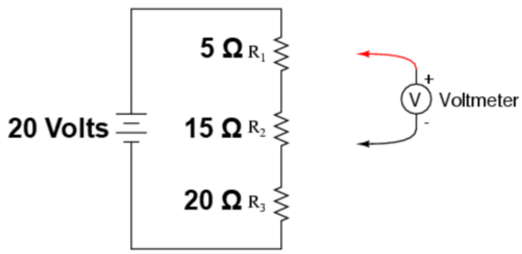


$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

$I = E / R$
$I =$

Al Penney
VO1NO

2. Determine Current



$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

$I = E / R$
$I = 20$ Volts / 40 Ohms
$I = 0.5$ Amps

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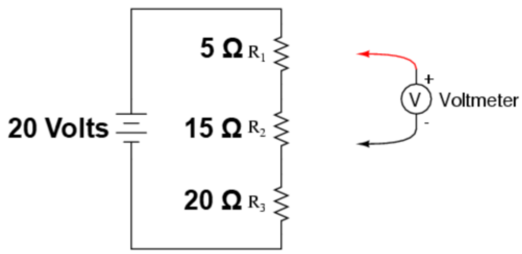
VO1NO

3. Determine Voltage Drops



$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

I = E / R
I = 20 Volts / 40 Ohms
I = 0.5 Amps

$E_{R1} = I \times R_1$
$E_{R1} =$

$E_{R2} = I \times R_2$
$E_{R2} =$

$E_{R3} = I \times R_3$
$E_{R3} =$

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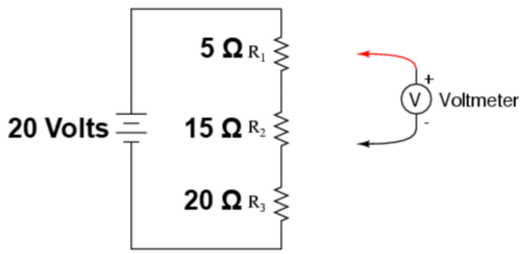
VO1NO

3. Determine Voltage Drops



$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

$I = E / R$
$I = 20$ Volts / 40 Ohms
$I = 0.5$ Amps

$E_{R1} = I \times R_1$
$E_{R1} = 0.5$ Amps x $5\ \Omega$
$E_{R1} = 2.5$ Volts

$E_{R2} = I \times R_2$
$E_{R2} = 0.5$ Amps x $15\ \Omega$
$E_{R2} = 7.5$ Volts

$E_{R3} = I \times R_3$
$E_{R3} = 0.5$ Amps x $20\ \Omega$
$E_{R3} = 10$ Volts

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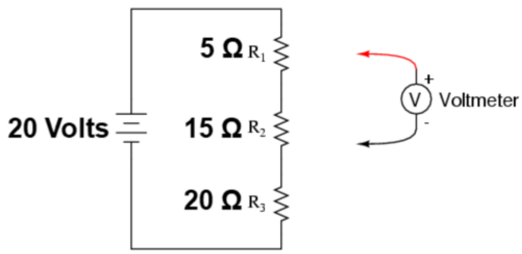
4. Check Your Results!



$R_{Total} = R_1 + R_2 + R_3$
$R_{Total} = 5\ \Omega + 15\ \Omega + 20\ \Omega$
$R_{Total} = 40\ \Omega$

$I = E / R$
$I = 20$ Volts / 40 Ohms
$I = 0.5$ Amps

$E_{R1} = I \times R_1$
$E_{R1} = 0.5$ Amps x 5 Ω
$E_{R1} = 2.5$ Volts

$E_{R2} = I \times R_2$
$E_{R2} = 0.5$ Amps x 15 Ω
$E_{R2} = 7.5$ Volts

$E_{R3} = I \times R_3$
$E_{R3} = 0.5$ Amps x 20 Ω
$E_{R3} = 10$ Volts

$$E_{source} = E_{R1} + E_{R2} + E_{R3}$$
$$E_{source} = 2.5V + 7.5V + 10V = 20V$$

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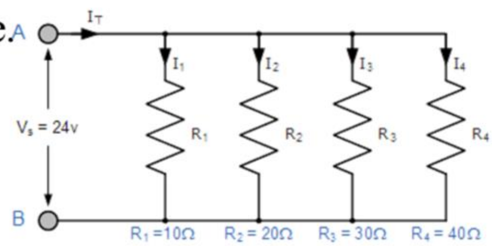
VO1NO

Voltage in Parallel Circuits

- The voltage applied to each resistor in a Parallel Circuit is the same as the source voltage.



$$E_{source} = E_{R1} = E_{R2} = E_{R3} = E_{R4}$$

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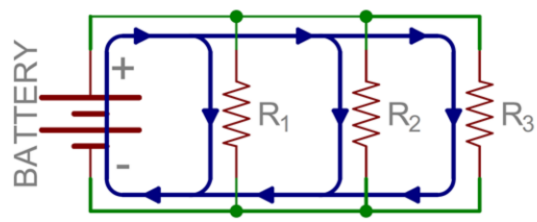
Current in a Parallel Circuit

- The total current in a Parallel Circuit is divided among the resistors.
- The sum of the currents through each resistor equals the total current.



$$I_{Total} = I_{R1} + I_{R2} + I_{R3}$$

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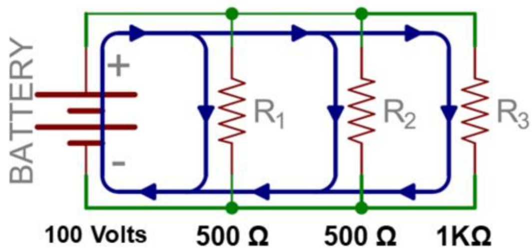
To Calculate Currents…



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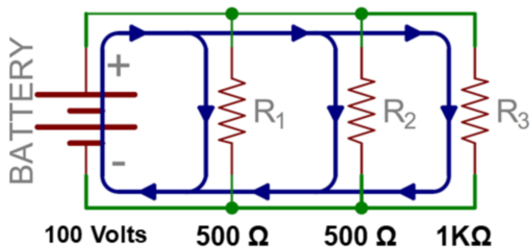
Determine Equivalent Resistance



$1/R_{Total} =$

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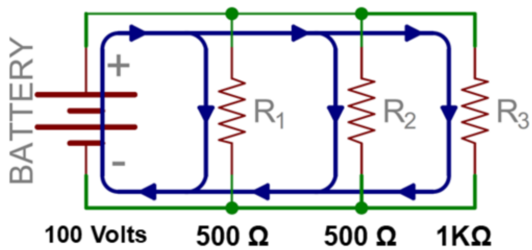
Determine Equivalent Resistance



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$

$1/R_{Total} = 1/500 + 1/500 + 1/1K$

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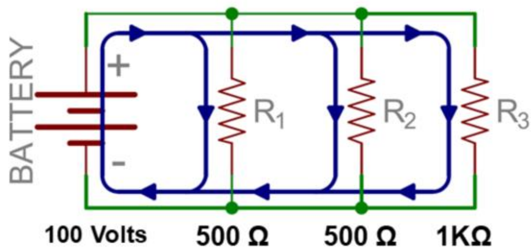
Determine Equivalent Resistance



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$

$1/R_{Total} = 1/500 + 1/500 + 1/1K$

$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$

$1/R_{Total} = 5/1000$

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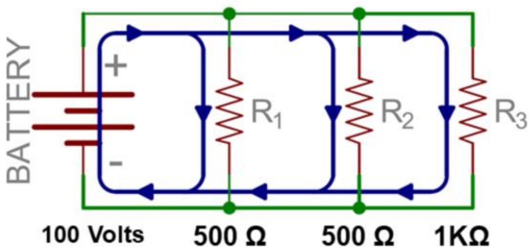
Determine Equivalent Resistance



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

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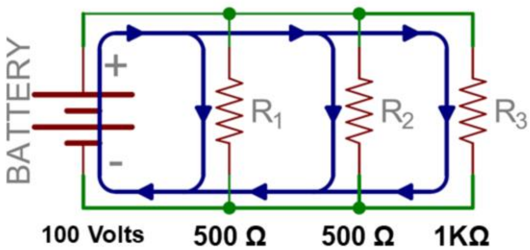
Determine Overall Current



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

I =

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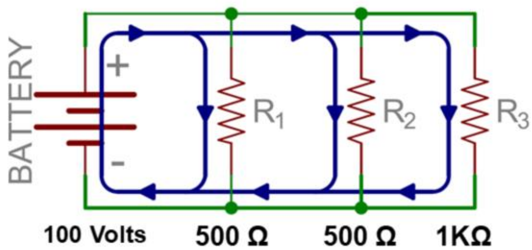
Determine Overall Current



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$

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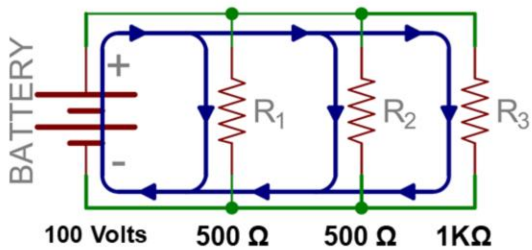
Determine Overall Current



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

I = E / R
I = 100 V / 200 Ω
I = 0.5 Amps

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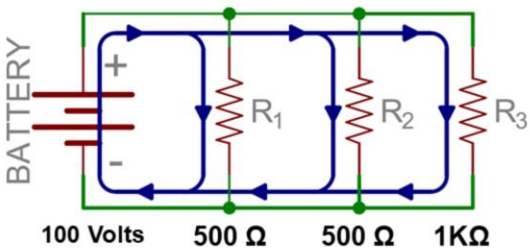
Determine Individual Currents



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$

$1/R_{Total} = 1/500 + 1/500 + 1/1K$

$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$

$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$

$I = 100\ V / 200\ \Omega$

$I = 0.5$ Amps

$I_{R1} =$

$I_{R2} =$

$I_{R3} =$

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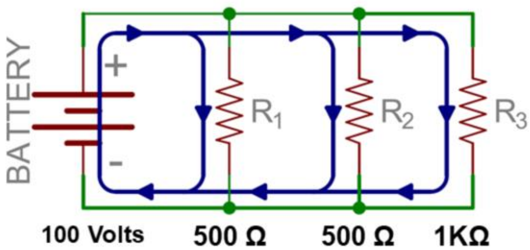
VO1NO

Determine Individual Currents



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$ $I_{R2} = E / R_2$ $I_{R3} = E / R_3$

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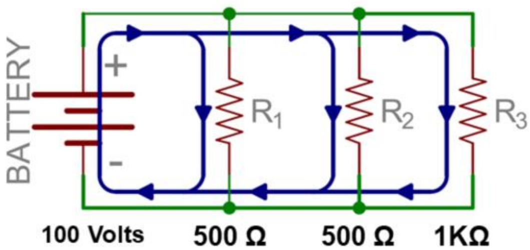
Determine Individual Currents



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$
$I_{R1} = 100\ V / 500\ \Omega$
$I_{R1} =$

$I_{R2} = E / R_2$
$I_{R2} = 100\ V / 500\ \Omega$
$I_{R2} =$

$I_{R3} = E / R_3$
$I_{R3} = 100\ V / 1000\ \Omega$
$I_{R3} =$

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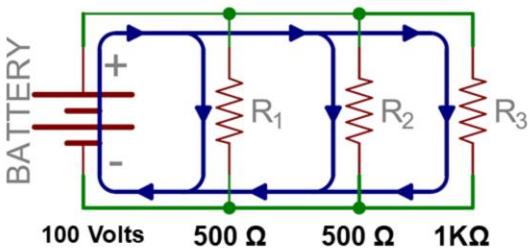
Determine Individual Currents



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$
$I_{R1} = 100\ V / 500\ \Omega$
$I_{R1} = 0.2$ Amps

$I_{R2} = E / R_2$
$I_{R2} = 100\ V / 500\ \Omega$
$I_{R2} = 0.2$ Amps

$I_{R3} = E / R_3$
$I_{R3} = 100\ V / 1000\ \Omega$
$I_{R3} = 0.1$ Amps

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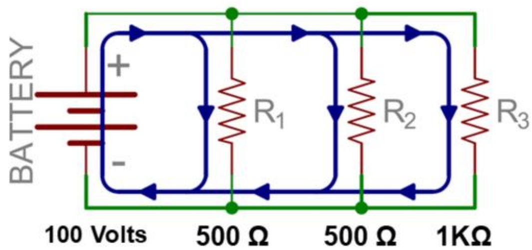
Check your Answer!



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$
$I_{R1} = 100\ V / 500\ \Omega$
$I_{R1} = 0.2$ Amps

$I_{R2} = E / R_2$
$I_{R2} = 100\ V / 500\ \Omega$
$I_{R2} = 0.2$ Amps

$I_{R3} = E / R_3$
$I_{R3} = 100\ V / 1000\ \Omega$
$I_{R3} = 0.1$ Amps

$I_{Total} =$

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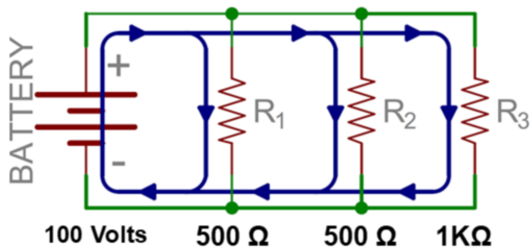
VO1NO

Check your Answer!



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
$1/R_{Total} = 1/500 + 1/500 + 1/1K$
$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$
$I_{R1} = 100\ V / 500\ \Omega$
$I_{R1} = 0.2$ Amps

$I_{R2} = E / R_2$
$I_{R2} = 100\ V / 500\ \Omega$
$I_{R2} = 0.2$ Amps

$I_{R3} = E / R_3$
$I_{R3} = 100\ V / 1000\ \Omega$
$I_{R3} = 0.1$ Amps

$I_{Total} = I_{R1} + I_{R2} + I_{R3} =$

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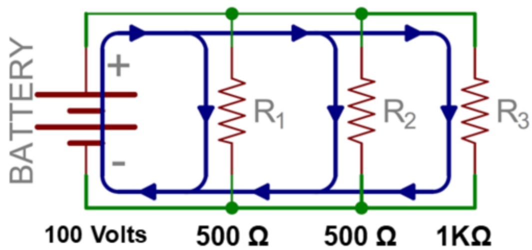
Check your Answer!



$1/R_{Total} = 1/R_1 + 1/R_2 + 1/R_3$
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$1/R_{Total} = 2/1000 + 2/1000 + 1/1000$
$1/R_{Total} = 5/1000$

$R_{Total} = 1000/5 = 200\ \Omega$

$I = E / R$
$I = 100\ V / 200\ \Omega$
$I = 0.5$ Amps

$I_{R1} = E / R_1$
$I_{R1} = 100\ V / 500\ \Omega$
$I_{R1} = 0.2$ Amps

$I_{R2} = E / R_2$
$I_{R2} = 100\ V / 500\ \Omega$
$I_{R2} = 0.2$ Amps

$I_{R3} = E / R_3$
$I_{R3} = 100\ V / 1000\ \Omega$
$I_{R3} = 0.1$ Amps

$I_{Total} = I_{R1} + I_{R2} + I_{R3} = 0.2 + 0.2 + 0.1 = 0.5$ Amp

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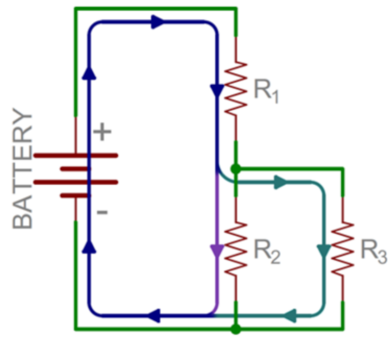
Series Parallel Combinations



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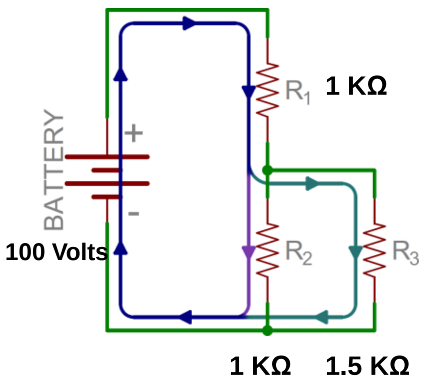
Series Parallel Combinations



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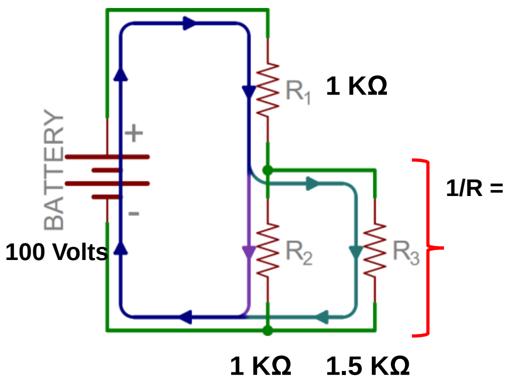
Series Parallel Combinations



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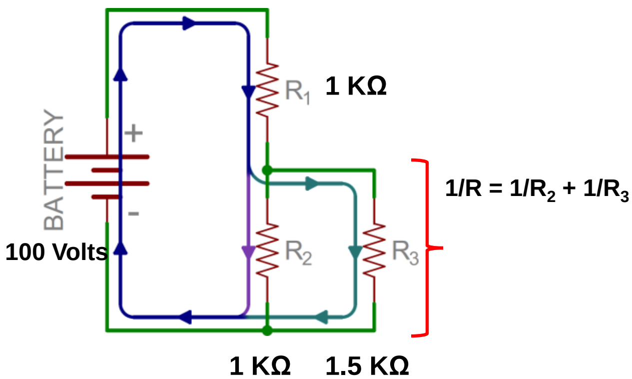
Series Parallel Combinations



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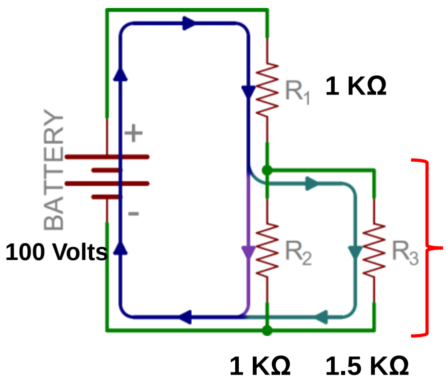
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$

$1/R = 1/1\ K + 1/1.5\ K$

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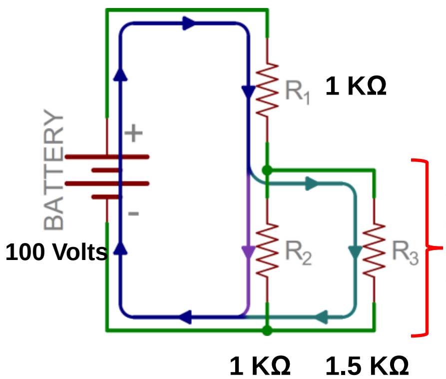
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$

$1/R = 1/1\ K + 1/1.5\ K$

$1/R = 3/3\ K + 2/3\ K$

$1/R = 5/3\ K$

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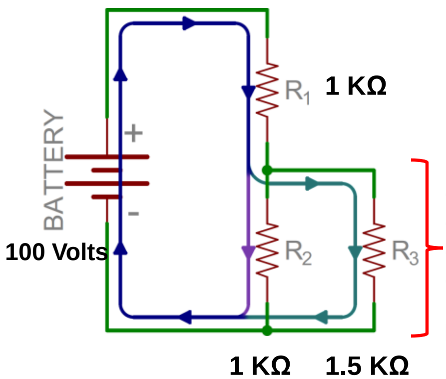
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$

$1/R = 1/1\ K + 1/1.5\ K$

$1/R = 3/3\ K + 2/3\ K$

$1/R = 5/3\ K$

$R = 3000/5 = 600\ \Omega$

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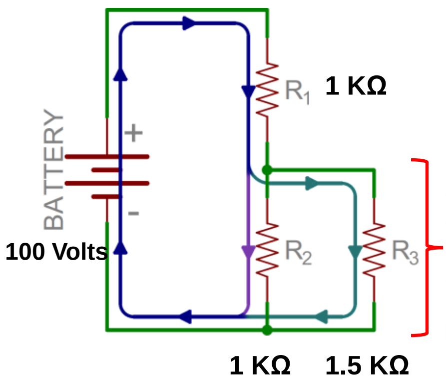
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$
$1/R = 1/1\text{ K} + 1/1.5\text{ K}$
$1/R = 3/3\text{ K} + 2/3\text{ K}$
$1/R = 5/3\text{ K}$

$R = 3000/5 = 600\ \Omega$

$R_{Total} =$

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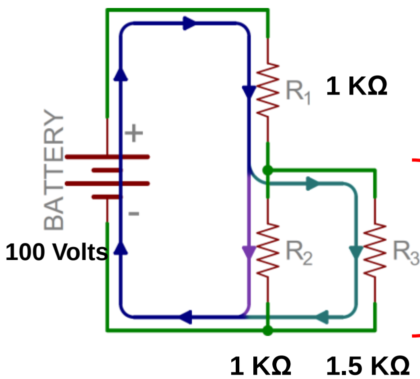
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$

$1/R = 1/1\ K + 1/1.5\ K$

$1/R = 3/3\ K + 2/3\ K$

$1/R = 5/3\ K$

$R = 3000/5 = 600\ \Omega$

$R_{Total} = 1\ K\Omega + 600\ \Omega$

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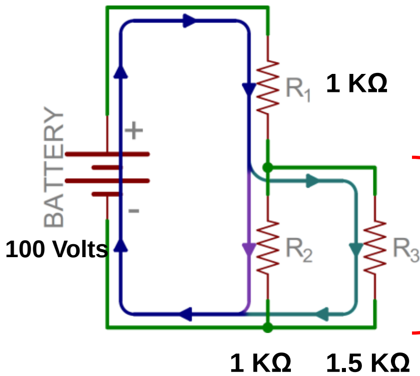
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$
1/R = 1/1 K + 1/1.5 K
1/R = 3/3 K + 2/3 K
1/R = 5/3 K

R = 3000/5 = 600 Ω

R_{Total} = 1 KΩ + 600 Ω
R_{Total} = 1600 Ω

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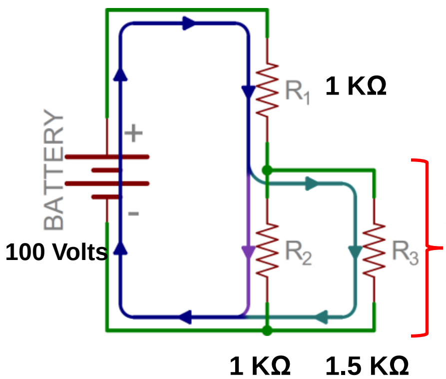
Series Parallel Combinations



$1/R = 1/R_1 + 1/R_2$
$1/R = 1/1\text{ K} + 1/1.5\text{ K}$
$1/R = 3/3\text{ K} + 2/3\text{ K}$
$1/R = 5/3\text{ K}$

$R = 3000/5 = 600\ \Omega$

$R_{Total} = 1\text{ K}\Omega + 600\ \Omega$
$R_{Total} = 1600\ \Omega$
$R_{Total} = 1.6\text{ K}\Omega$

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Energy and Power

- Energy is the ability to do work.
- Two types: Kinetic and Potential
- A cell has Potential Energy – it stores chemical energy that can be released to do work.
- When electrons move against a resistance, work is done.
- The rate at which work is done is called Power

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Power

- Basic unit of Power is the Watt, abbreviated W.
- In electrical systems, we can calculate power if we know any two of
  - Voltage;
  - Current; or
  - Resistance.

$$P = E \times I = E^2 / R = I^2 \times R$$

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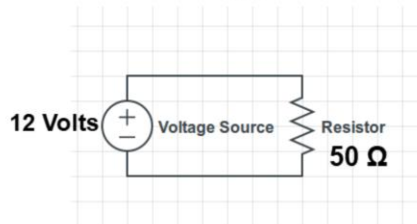
Calculating Power #1



$$P = E \times I = E^2 / R = I^2 \times R$$

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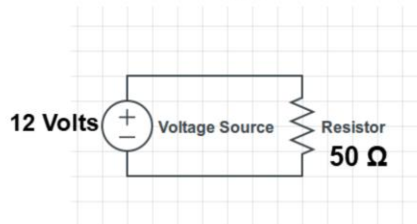
Calculating Power #1



$P = E \times I = E^2 / R = I^2 \times R$

$P = E^2 / R$

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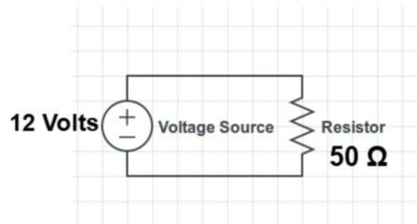
Calculating Power #1



$P = E \times I = E^2 / R = I^2 \times R$

$P = E^2 / R$

$P = 12^2 / 50$

$P = 144 / 50$

P = 2.88 Watts

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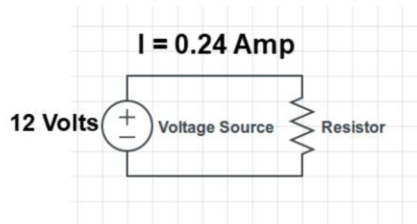
Calculating Power #2



$$P = E \times I = E^2 / R = I^2 \times R$$

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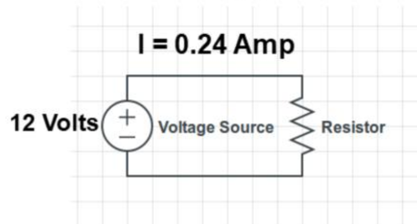
Calculating Power #2



$P = E \times I = E^2 / R = I^2 \times R$

$P = E \times I$

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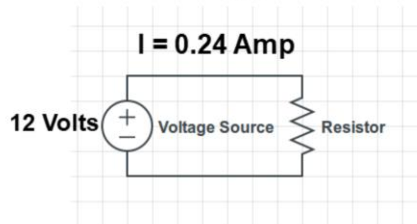
Calculating Power #2



$P = E \times I = E^2 / R = I^2 \times R$

$P = E \times I$

$P = 12 \times 0.24$

$P = 2.88$ Watts

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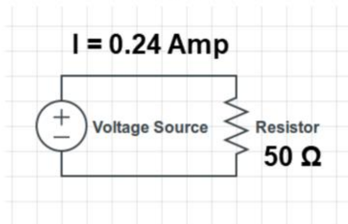
Calculating Power #3



$$P = E \times I = E^2 / R = I^2 \times R$$

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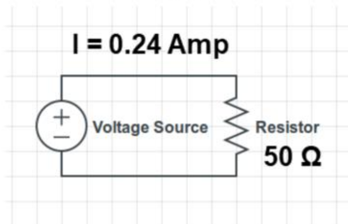
Calculating Power #3



$P = E \times I = E^2 / R = I^2 \times R$

$P = I^2 \times R$

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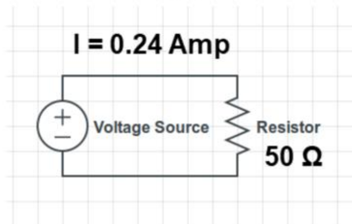
Calculating Power #3



$P = E \times I = E^2 / R = I^2 \times R$

$P = I^2 \times R$

$P = 0.24^2 \times 50$

$P = 0.0576 \times 50$

P = 2.88 Watts

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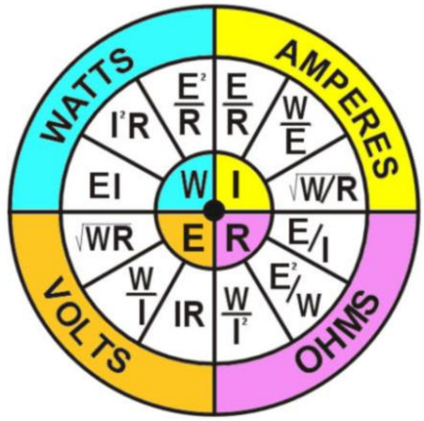
Circuit Calculator



Remember the Units – Ohms, Volts, Amps, Watts!!

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Capacitance

- **Capacitance** is the property of an electrical circuit that **opposes a change in voltage**.
- When a **voltage** applied across a circuit is **increased or decreased, capacitance resists that change.**

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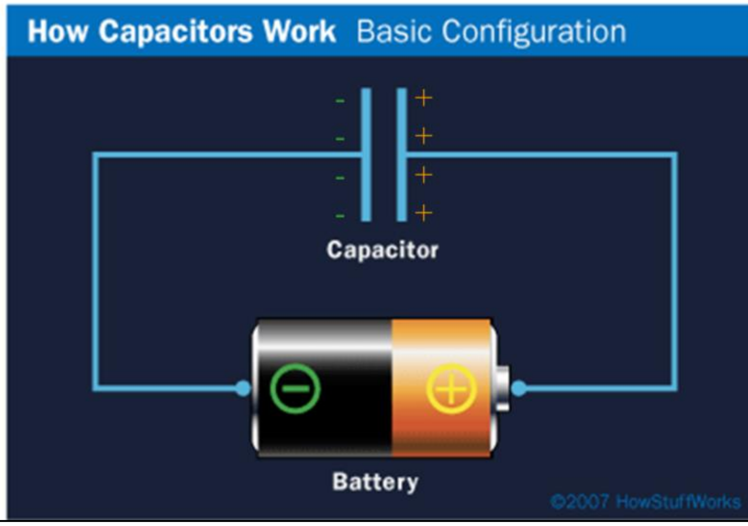
Capacitors in a DC Circuit



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Capacitors in a DC Circuit

- When **first connected** to a battery, **electrons flow** from the **negative battery terminal** to the **capacitor plate** and remain there because the dielectric prevents them from traveling to the opposite plate.
- **Electrons** on the **opposite plate** are **attracted** to the **positive battery terminal.**
- Eventually, the capacitor reaches the **same voltage** as the battery, and **no more electrons flow.**
- The capacitor is then said to be **Charged.**
- **Capacitors block the flow of DC.**

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Capacitors in an AC Circuit

- **Current cannot** pass through a capacitor but **Alternating Current appears to.**
- If the **voltage** across the plates of the capacitor is **continuously varied,** the **number of electrons varies.**
- As the voltage changes then, **it appears as though a current is flowing** even though **electrons do not actually traverse** the dielectric.

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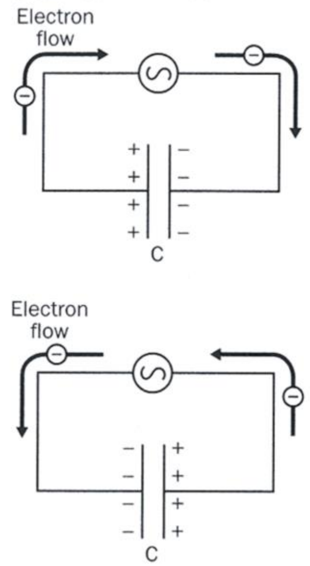
Capacitors in an AC Circuit



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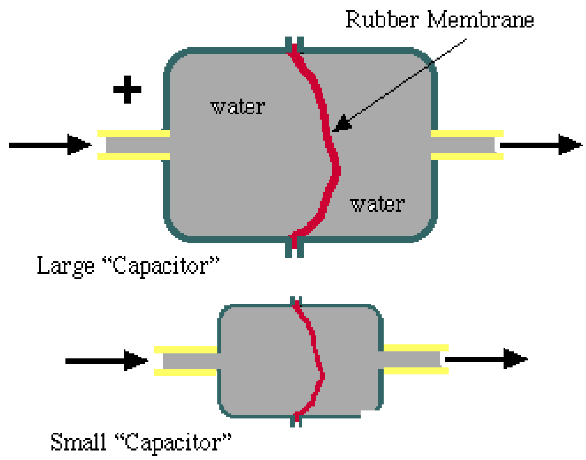
Water Reservoir Analogy



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A capacitor stores electricity. If you pump electrical current into it, the capacitor develops a voltage that exerts a force that resists additional current. In this experiment, you will use a hand crank that pumps current into very large capacitors. These capacitors are constructed such that for each Coulomb of charge you pump in it will push back with one volt. These capacitors are a lot like rechargable batteries. The big difference between batteries and capacitors is that a battery supplies a nearly constant voltage, whereas a capacitor works at all voltages up to its maximum safe rating. As you charge the capacitors with the hand cranked generator you can actually feel the capacitor "filling up."

A capacitor is like a closed water tank with two inlets separated by a rubber membrane. The more water (charge) you pump in one inlet (wire), the more back pressure (voltage) will build up. The pressure (voltage) opposes the addition of more water (charge). So, the more water (charge) you add the harder it gets to add more. Also note that whatever water (charge) flows in one inlet (wire), the same amount of water (charge) comes out the other. But because of the membrane, no steady water flow (current) can be maintained through the tank (capacitor). A large tank (capacitor) can absorb a lot of water (charge) before generating a large back pressure (voltage). We could measure the capacity of a tank (capacitor) as the ratio of water volume to pressure (charge to voltage, which is the definition of a farad).

Electrons

- **Individual electrons** are **too small** to have an effect in everyday electronics, so we use a **larger number** of them to make **practical measurements.**
- The **Coulomb** is equal to **6.3×10^{18} electrons** (6,300,000,000,000,000,000 electrons).
- For example, one Ampere = 1 Coulomb per Second.

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The Farad

- The **unit of measure** for capacitance is the **Farad.**
- One **Farad** is the **capacitance** in which a charge of **1 Coulomb** produces a **difference of 1 Volt** between the plates.
- One **Farad** is **much too large** a value for practical circuits however.

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Practical Capacitor Units

- Practical capacitors are measured in:
  - **Microfarads**, or **millionths of a Farad.** They are abbreviated as **μf**, and equal to $\mathbf{1 \times 10^{-6}}$ **Farads.** The old abbreviation was mfd.
  - **Picofarads**, or **millionth millionths of Farads**, are equal to $\mathbf{1 \times 10^{-12}}$ **Farads.** They are abbreviated as pf. They were originally called Micromicrofarads, and you may still encounter the abbreviation mmf.

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Factors Affecting Capacitance

- **Plate Area:** The **larger the plate area**, the **greater the capacitance.**
- **Distance Between the Plates:** The **closer together** the plates, the **greater the capacitance.** Of course, it is necessary to **prevent the charge** from **jumping the gap (arcing).**
- **Changing the Dielectric: Greater capacitance** can be obtained by using a **dielectric other than air.** Glass, mica, oil and mylar are some of the materials that have a greater **Dielectric Constant** than air. This is because they **permit the plates** to be **closer together,** and because they have **electrons** that can **move slightly.**

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Dielectric Materials

Relative Dielectric Constants of Common Capacitor Dielectric Materials

Material	*Dielectric Constant (k)*	*(O)rganic or (I)norganic*
Vacuum	1 (by definition)	I
Air	1.0006	I
Ruby mica	6.5 - 8.7	I
Glass (flint)	10	I
Barium titanate (class I)	5 - 450	I
Barium titanate (class II)	200 - 12000	I
Kraft paper	≈ 2.6	O
Mineral Oil	≈ 2.23	O
Castor Oil	≈ 4.7	O
Halowax	≈ 5.2	O
Chlorinated diphenyl	≈ 5.3	O
Polyisobutylene	≈ 2.2	O
Polytetrafluoroethylene	≈ 2.1	O
Polyethylene terephthalate	≈ 3	O
Polystyrene	≈ 2.6	O
Polycarbonate	≈ 3.1	O
Aluminum oxide	≈ 8.4	I
Tantalum pentoxide	≈ 28	I
Niobium oxide	≈ 40	I
Titanium dioxide	≈ 80	I

(Adapted from: Charles A. Harper, *Handbook of Components for Electronics*, p 8-7.)

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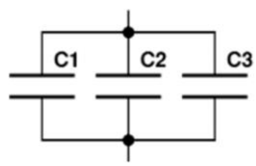
Capacitors in Parallel

- **Capacitors** in **Parallel add their values.**
- This is because it is **equivalent** to a **single capacitor** with a **greater surface area.**



$$C_T = C1 + C2 + C3$$

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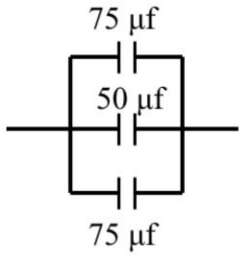
Example of Capacitors in Parallel



$C_T = C1 + C2 + C3$

$C_T = 75\mu f + 50\mu f + 75\mu f$

$C_T = 200\mu f$

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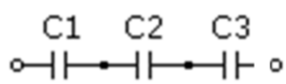
Capacitors in Series

- Capacitors in Series must be treated the same way that resistors and inductors in parallel are treated.



$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

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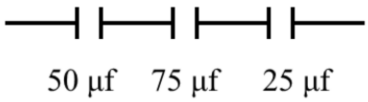
Example of Capacitors in Series



$$C_T = \frac{1}{\frac{1}{C1} + \frac{1}{C2} + \frac{1}{C3}}$$

$$C_T = \frac{1}{\frac{1}{50} + \frac{1}{75} + \frac{1}{25}}$$

$$C_T = \frac{1}{\frac{3}{150} + \frac{2}{150} + \frac{6}{150}}$$

$$C_T = \frac{1}{\frac{11}{150}} = 150/11\mu f = 13.64\mu f$$

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Working Voltage

- All capacitors have a **characteristic working voltage**, sometimes called the **voltage rating.**
- It is the **maximum DC voltage** that the capacitor can **sustain continuously** without **excessive leakage** or **breaking down** – ie: having the charge jump from one plate to the other **(arc).**
- **Arcing** will **destroy most capacitors.** Electrolytics can **self-heal** after small arcs. Even **air-gap variable capacitors** can be **damaged** by arcing.

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Surge Voltage

- **Surge voltage** is the **maximum voltage** that can be **withstood** for a **few seconds** after the start-up of a circuit.
- It was an important parameter for **tube circuits,** but is **not very relevant** for modern solid-state circuits.

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Reactance

- **Reactance** is the **opposition** to the **flow of Alternating Current (AC).**
- **Reactance** has **no effect** on the flow of **Direct Current (DC).**

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Capacitive Reactance

- **Capacitive Reactance** is the **opposition** to the **flow of AC by capacitance.**
- As the **frequency of the AC increases, Capacitive Reactance decreases.**
- The **Symbol** for **Capacitive Reactance** is $\mathbf{X_C}$**.**
- $\mathbf{X_C}$ is expressed in **ohms.**
- Even though it is expressed in ohms, **power is not dissipated by Reactance!** Energy **stored in a capacitor** during **one part of the AC cycle** is simply **returned to the circuit** during the **next part of the cycle!**

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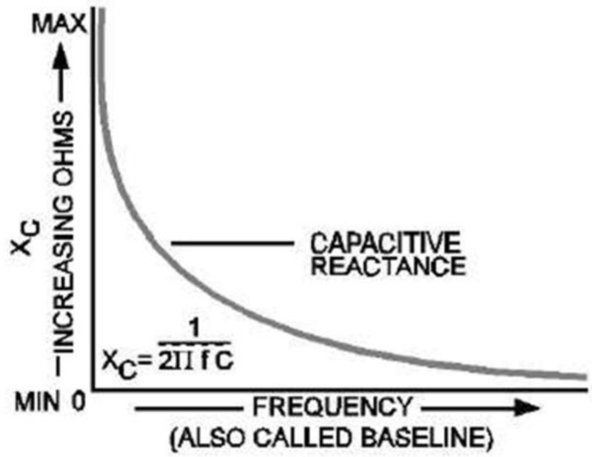
Capacitive Reactance



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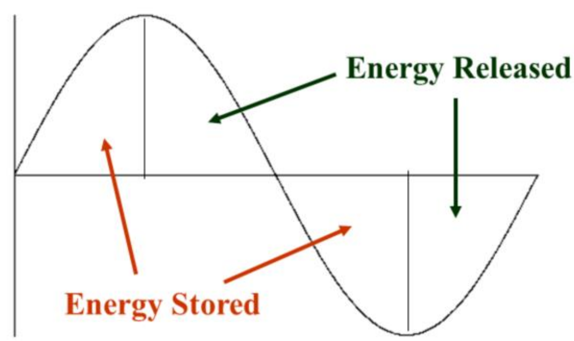
Energy Storage and Release



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Capacitive Reactance

$$X_C = \frac{1}{2 \pi f C}$$

- Where:

  F = frequency in Hertz

  C = capacitance in Farads

  π = 3.14

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Capacitive Reactance

$$X_C = \frac{1}{2 \pi f C}$$

However, Farads and Hertz are **cumbersome units,** so we can use other units:

F = frequency in Megahertz (MHz)

C = capacitance in Microfarads (µf)

π = 3.14

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Capacitive Reactance Example 1

- What is the capacitive reactance of a 470 pf capacitor at a frequency of 7.15 MHz?
  - Remember that 470 pf = 0.000470 µf.

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi \times 7.15\ \text{MHz} \times 0.000470\ \mu\text{F}}$$

$$= \frac{1\,\Omega}{0.0211} = 47.4\,\Omega$$

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Capacitive Reactance Example 2

- What is the capacitive reactance of that same 470 pf capacitor at a frequency of 14.29 MHz?
  - Again, remember that 470 pf = 0.000470 μf.

$$X_C = \frac{1}{2\pi f C}$$

$$= \frac{1}{2\pi \times 14.30 \text{ MHz} \times 0.000470\ \mu\text{F}}$$

$$= \frac{1\,\Omega}{0.0422} = 23.7\,\Omega$$

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Capacitive Reactance Examples

- Note that as the **frequency increased** from 7.15 MHz to 14.290 MHz, the **Capacitive Reactance decreased** from 47.4 ohms to 23.7 ohms.
- **Remember:**
  - **Capacitors block DC;**
  - Capacitors **store energy** as an electrical charge; and
  - As the **frequency increases, capacitive reactance decreases (and vice versa!).**

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Questions?

Let's take a break!

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