An Introduction to Electrical Engineering

Occupational Title	SOC Code	Employment, 2008	Projected Employment, 2018
Engineers	17-2000	1,571,900	1,750,300
Aerospace engineers	17-2011	71,600	79,100
Agricultural engineers	17-2021	2,700	3,000
Biomedical engineers	17-2031	16,000	27,600
Chemical engineers	17-2041	31,700	31,000
Civil engineers	17-2051	278,400	345,900
Computer hardware engineers	17-2061	74,700	77,500
Electrical and electronics engineers	17-2070	301,500	304,600
Electrical engineers	17-2071	157,800	160,500
Electronics engineers, except computer	17-2072	143,700	144,100
Environmental engineers	17-2081	54,300	70,900
Industrial engineers, including health and safety	17-2110	240,400	273,700
Health and safety engineers, except mining safety engineers and inspectors	17-2111	25,700	28,300
Industrial engineers	17-2112	214,800	245,300
Marine engineers and naval architects	17-2121	8,500	9,000
Materials engineers	17-2131	24,400	26,600
Mechanical engineers	17-2141	238,700	253,100
Mining and geological engineers, including mining safety engineers	17-2151	7,100	8,200
Nuclear engineers	17-2161	16,900	18,800
Petroleum engineers	17-2171	21,900	25,900
All other engineers	17-2199	183,200	195,400

Bureau of Labor Statistics, U.S. Department of Labor, 2010

Earnings distribution by engineering specialty, May 2008

Specialty	Lowest 10%	Lowest 25%	Median	Highest 25%	Highest 10%
Aerospace engineers	$58,130	$72,390	$92,520	$114,530	$134,570
Agricultural engineers	43,150	55,430	68,730	86,400	108,470
Biomedical engineers	47,640	59,420	77,400	98,830	121,970
Chemical engineers	53,730	67,420	84,680	105,000	130,240
Civil engineers	48,140	58,960	74,600	94,470	115,630
Computer hardware engineers	59,170	76,250	97,400	122,750	148,590
Electrical engineers	52,990	64,910	82,160	102,520	125,810
Electronics engineers, except computer	55,330	68,400	86,370	106,870	129,920
Environmental engineers	45,310	56,980	74,020	94,280	115,430
Health and safety engineers, except mining safety engineers and inspectors	43,540	56,190	72,490	90,740	106,220
Industrial engineers	47,720	59,120	73,820	91,020	107,270
Marine engineers and naval architects	43,070	57,060	74,140	94,840	118,630
Materials engineers	51,420	63,830	81,820	102,040	124,470
Mechanical engineers	47,900	59,230	74,920	94,400	114,740
Mining and geological engineers, including mining safety engineers	45,020	57,970	75,960	96,030	122,750
Nuclear engineers	68,300	82,540	97,080	115,170	136,880
Petroleum engineers	57,820	80,040	108,020	148,700	>166,400
Engineers, all other	49,270	67,360	88,570	110,310	132,070

Bureau of Labor Statistics, U.S. Department of Labor, 2010

Average Starting Salaries: July 2009 survey by the National Association of Colleges and Employers

Petroleum	$83,121
Chemical	64,902
Mining and Mineral	64,404
Computer	61,738
Nuclear	61,610
Electrical/electronics and communications	60,125
Mechanical	58,766
Industrial/manufacturing	58,358
Materials	57,349
Aerospace/aeronautical/astronautical	56,311
Agricultural	54,352
Bioengineering and biomedical	54,158
Civil	52,048

Bureau of Labor Statistics, U.S. Department of Labor, 2010

Overview

-Brief history, disciplines, curriculum

-Review of electrical principles

<u>Guest Speaker: </u> Dr. Jerry Daniels, Ph.D.

Lab visit: Daniels Lab

What is electrical engineering?

The study of ELECTRICITY along with its numerous applications

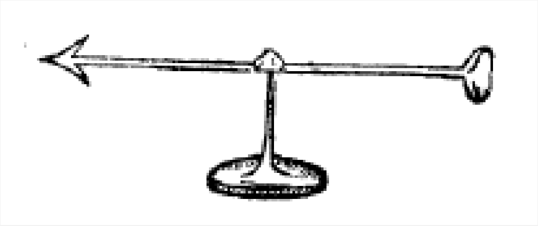
A brief history

In 1600, William Gilbert called the property of attracting particles after being rubbed *"electricus"*.

De Magnete was a treatise of electricity and magnetism, noting a long list of elements that could be electrified.

Gilbert invented the versorium, a device that detected statically-charged bodies

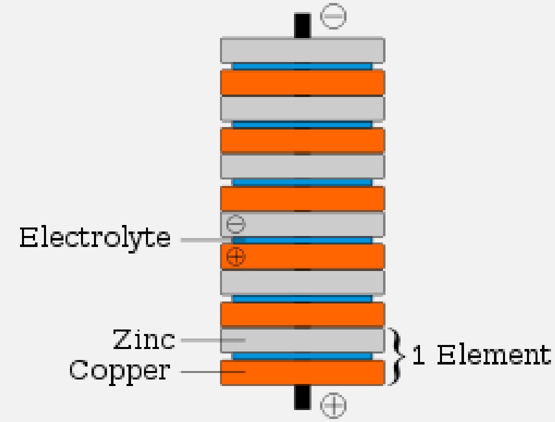
William Gilbert, arguably the first electrical engineer



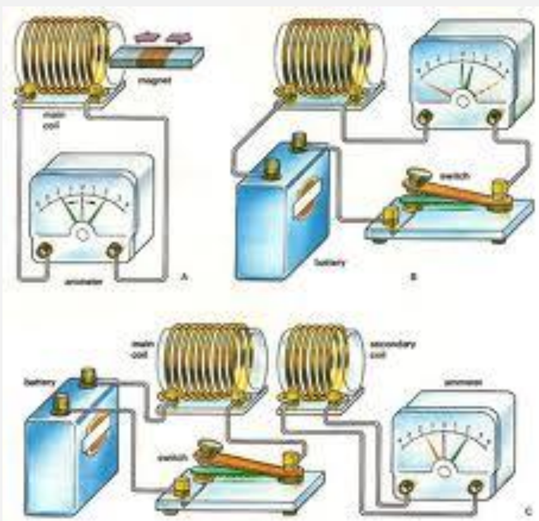
A versorium

A brief history

1800 – voltaic pile developed by Alessandro Volta, a precursor to the **battery**



Voltaic pile



Circuits containing inductors

1831 – Michael Faraday discovers **electromagnetic induction**

1873 – *Electricity and Magnetism* published by James Maxwell, describing a **theory for electromagnetism**

$$\nabla \cdot \mathbf{D} = \rho$$
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$
$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

Maxwell's equations

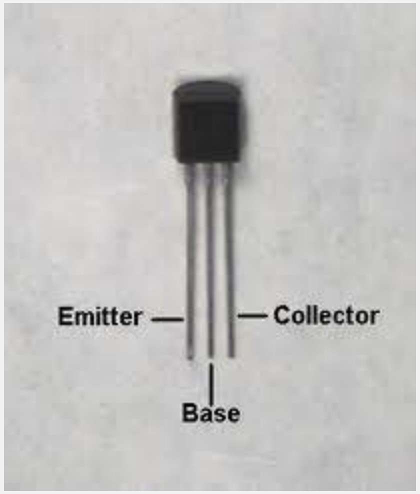
A brief history

Spark-gap transmitter

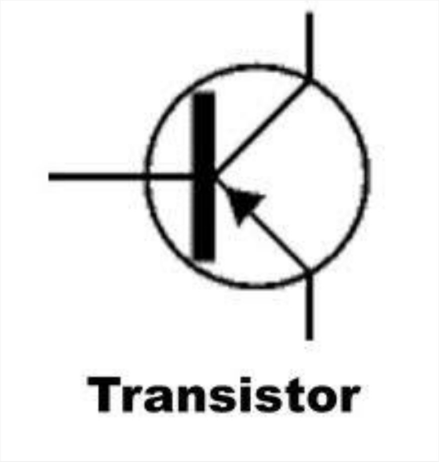
1888 – Heinrich Hertz transmits and receives **radio signals**

Z3 computer

1941 – Konrad Zuse introduces the first ever **programmable computer**



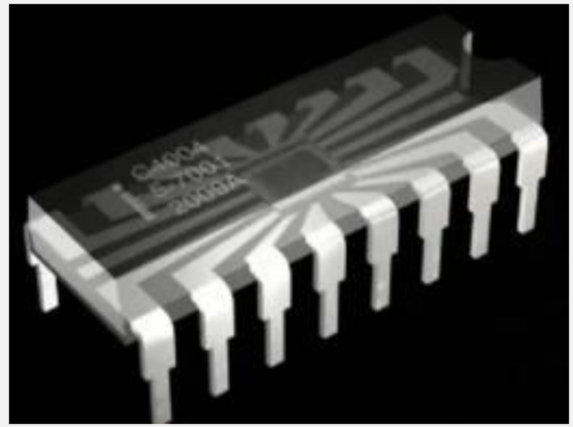
Transistor

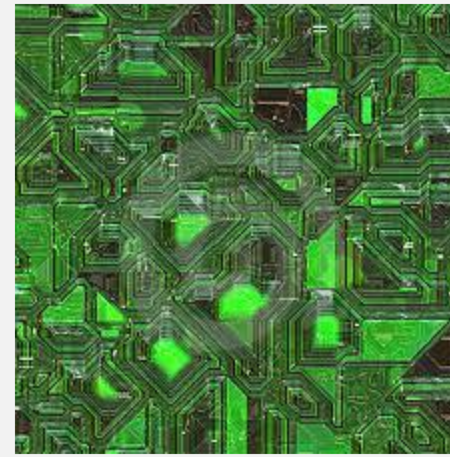


1947 – invention of **transistor**

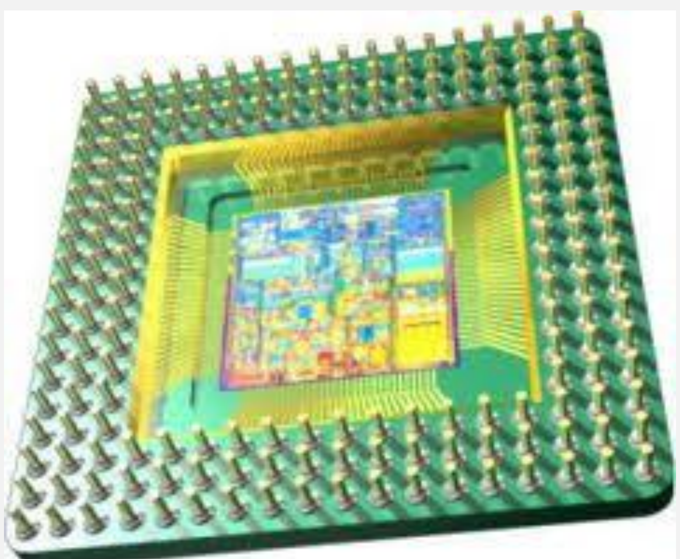
A brief history

1958 – **integrated circuit** developed by Jack Kilby





Integrated circuits



Microprocessor

1968 – first **microprocessor** is developed

So where is the field now?

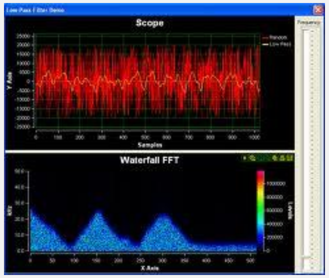
Fields of study

Power:
Creation, storage, and distribution of electricity

Control:
Design of dynamic systems and controllers for the systems

Electronics/Microelectronics:
Design of integrated circuits, microprocessors, etc.

Signal Processing: Analysis of signals



Fields of study

Telecommunications:
Design of transmission systems (voice, data)

Computer:
Design and development of computer systems

Instrumentation:
Design of sensors and data acquisition equipment

Basic concepts

Electricity
Charge
Current
Voltage
Power and Energy

Electricity

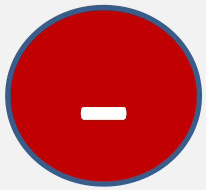
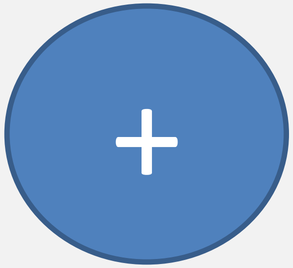
Physical phenomenon arising from the existence and interactions of ***electric charge***

Charge

Where can we observe/experience/use charge?

Charge

Characteristic property of subatomic particles responsible for electric phenomena

Electron   Proton

−1.602   10−19 C   1.602   10−19 C

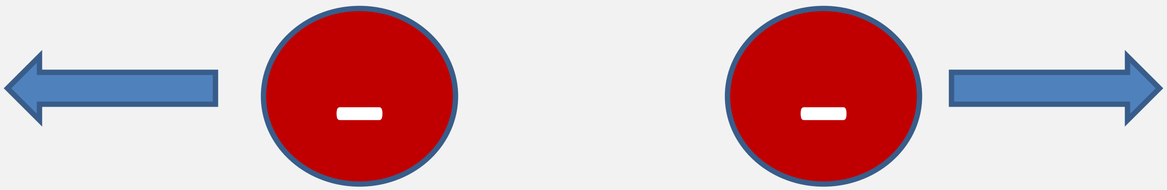
The unit of quantity of electric charge is **coloumb (C)**

1 coloumb = 6.25   1018 ***e***

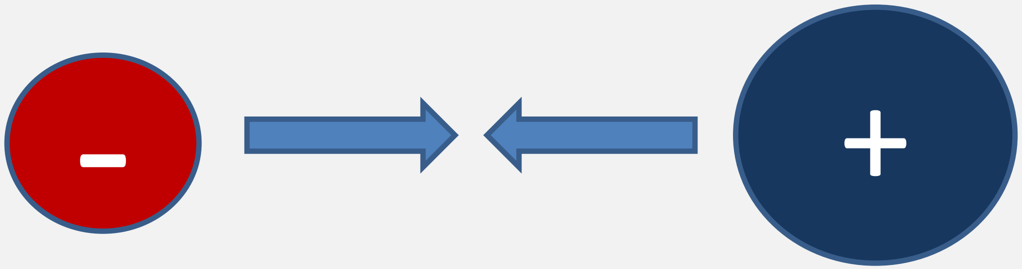
***e* = elementary charge = charge of proton**

Charge

“Charged” particles exhibit forces



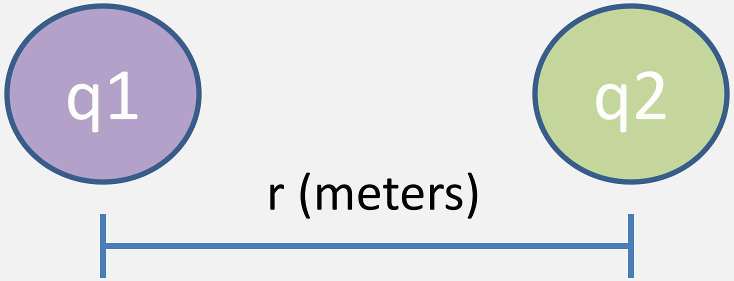
Like charges repel each other



Opposite charges attract one another

Charge is the source of one of the fundamental forces in nature (others?)

Coulomb's Law



$$F_{1,2} = k_e \frac{q1q2}{r^2} \quad \text{(Newtons)}$$

$F_{1,2}$ is the electrostatic force exerted on charge 1 due to the presence of charge 2

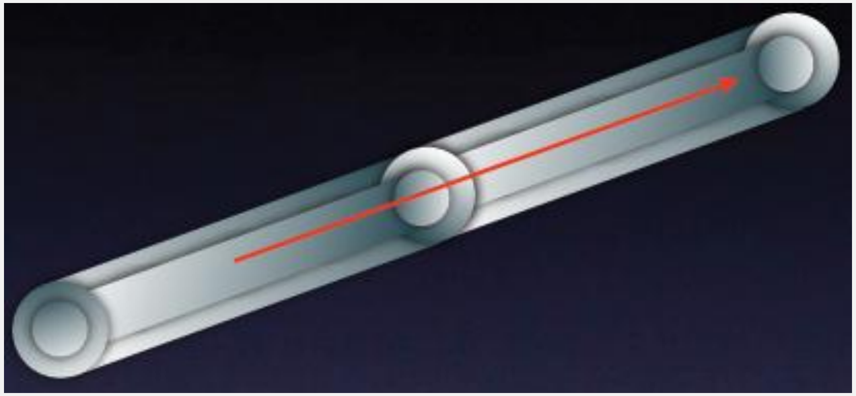
k_e is the Coulomb constant $\qquad k_e = 8.987 \times 10^9\ N*m^2*C^{-2}$

Electric current

Describes charge in motion, the flow of charge

This phenomenon can result from moving electrons in a conductive material or moving ions in charged solutions

Electric current



$$I = \frac{\text{charge}}{\text{time}} = \frac{\text{coulombs}}{\text{seconds}}$$

$$I = \frac{Q}{t} \text{ amperes}$$

An **ampere (A)** is the number of electrons having a total charge of 1 C moving through a given cross section in 1 s.

As defined, current flows in direction of **positive charge** flow

Electrical Circuits

Electric circuit

*An electric circuit is an interconnection of **electrical elements** linked together in a **closed path** so that electric current may flow continuously*

Circuit diagrams are the standard for electrical engineers

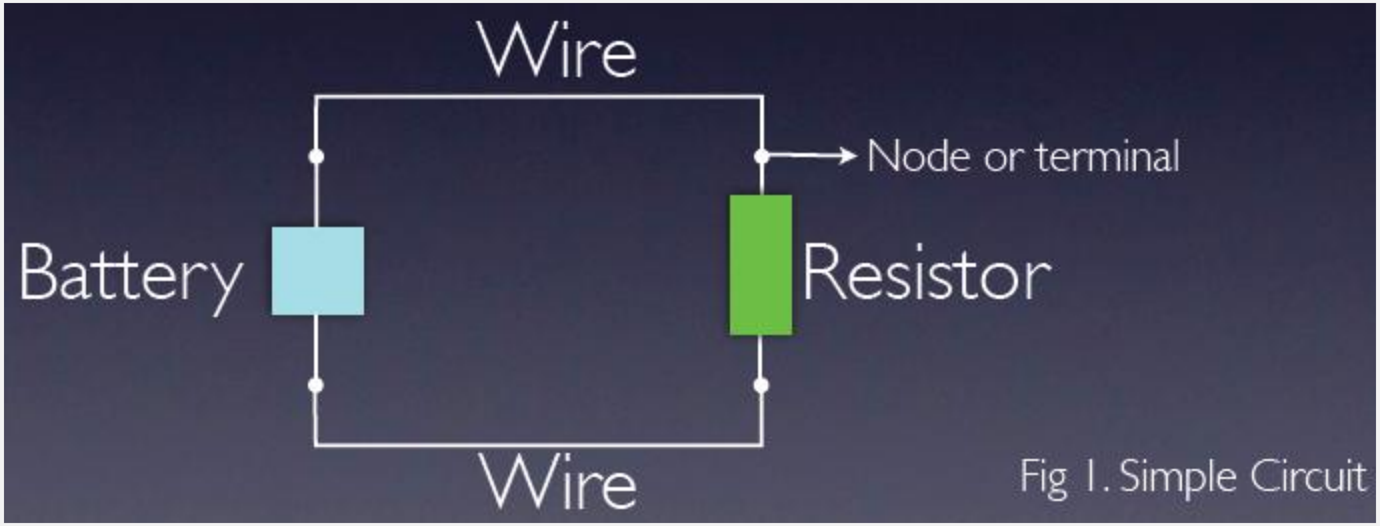
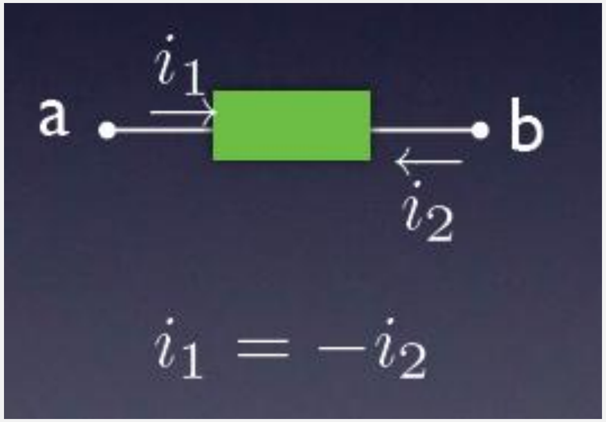


Fig 1. Simple Circuit

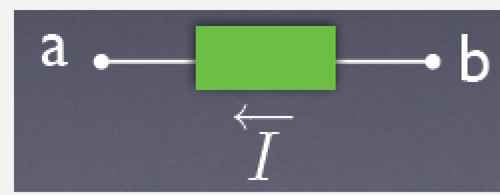


$\underset{\longrightarrow}{i_1}$ Rate of flow of charge form **node a to node b**

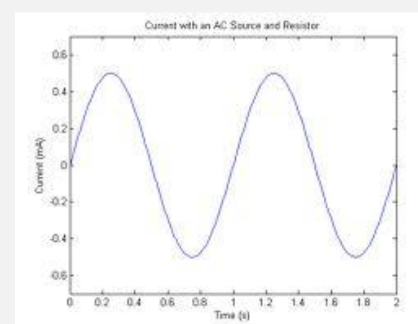
$\overset{\longleftarrow}{i_2}$ Rate of flow of charge form **node b to node a**

(i = current)

A **direct current (dc)** is a current of constant magnitude

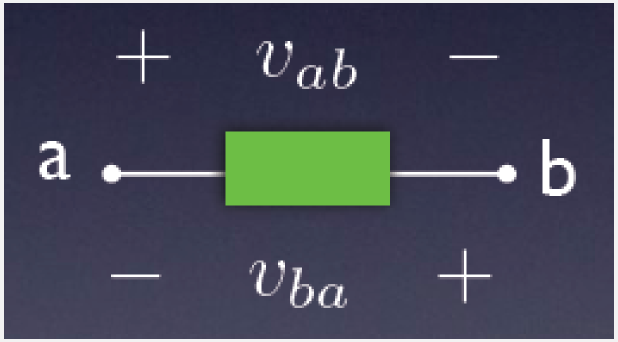


An **alternating current (ac)** is a current of varying magnitude and direction



Voltage

Driving "force" of electrical current between two points



V_{ab} Voltage at terminal a with respect to terminal b

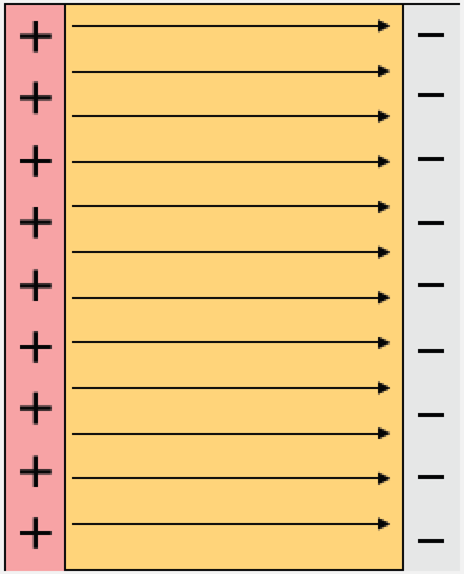
V_{ba} Voltage at terminal b with respect to terminal a

$$V_{ab} = -V_{ba}$$

Note: In a circuit, voltage is often defined relative to **"ground"**

Voltage

The voltage across an element is the work (energy) required to move a unit of positive charge from the “**−**” terminal to the “**+**” terminal



$$V = \frac{W}{Q} = \frac{\text{joules}}{\text{coulombs}} = \text{volts}$$

A **volt** is the potential difference (voltage) between two points when **1 joule of energy** is used to move **1 coulomb of charge** from one point to the other

Power

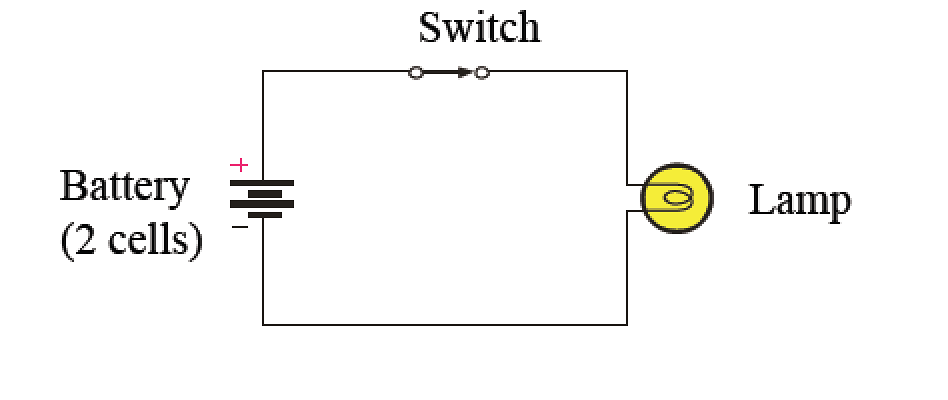
The rate at which energy is converted or work is performed

$$P = \frac{W}{t} = \frac{\text{joules}}{\text{second}} = \text{watt}$$

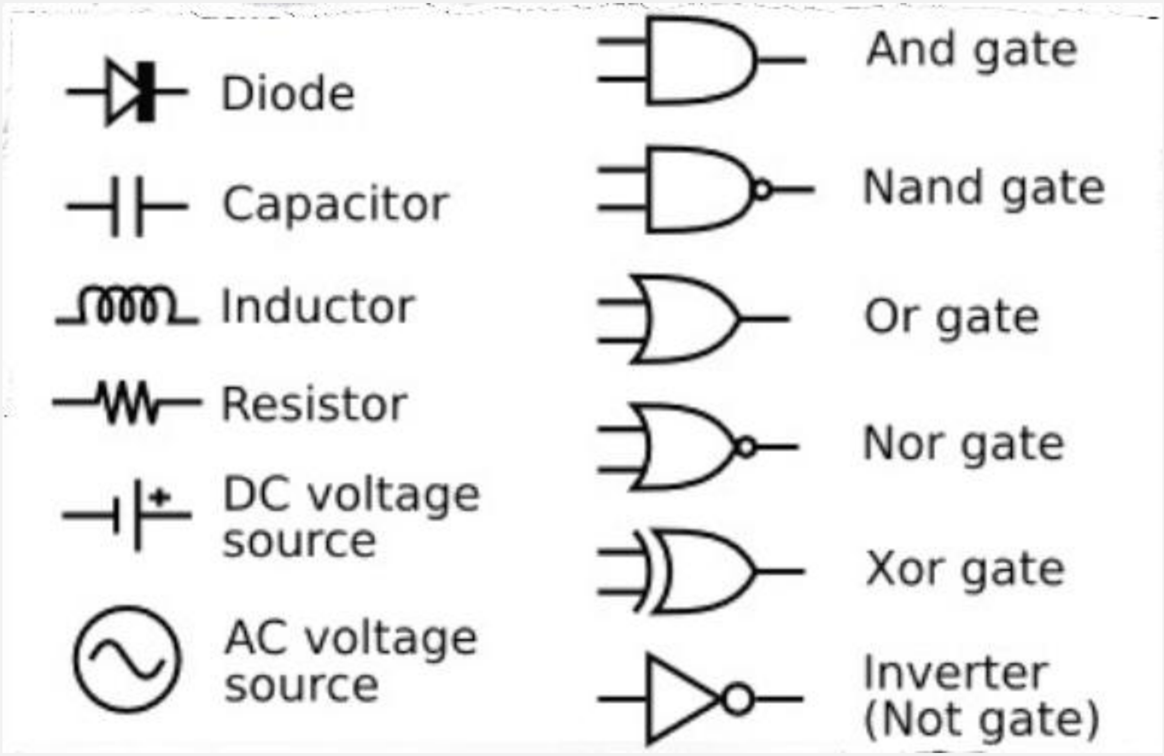
$$P = IV$$

A **watt** results when **1 joule of energy** is converted or used in **1 second**

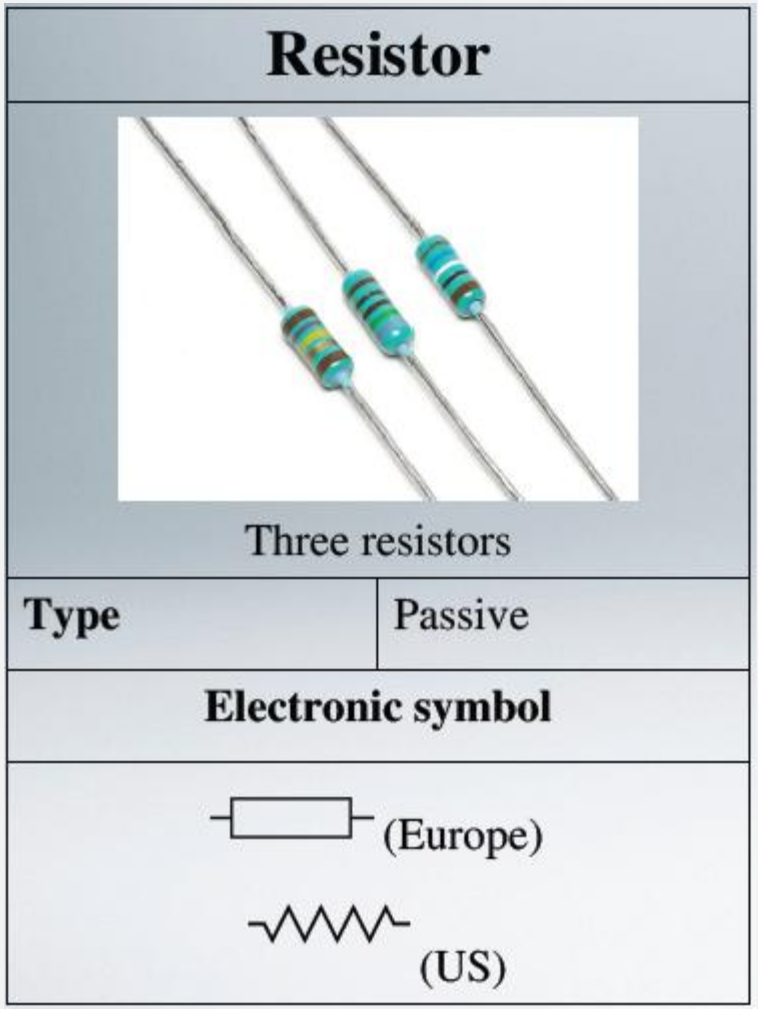
Circuit schematic example



Circuit elements



Resistors



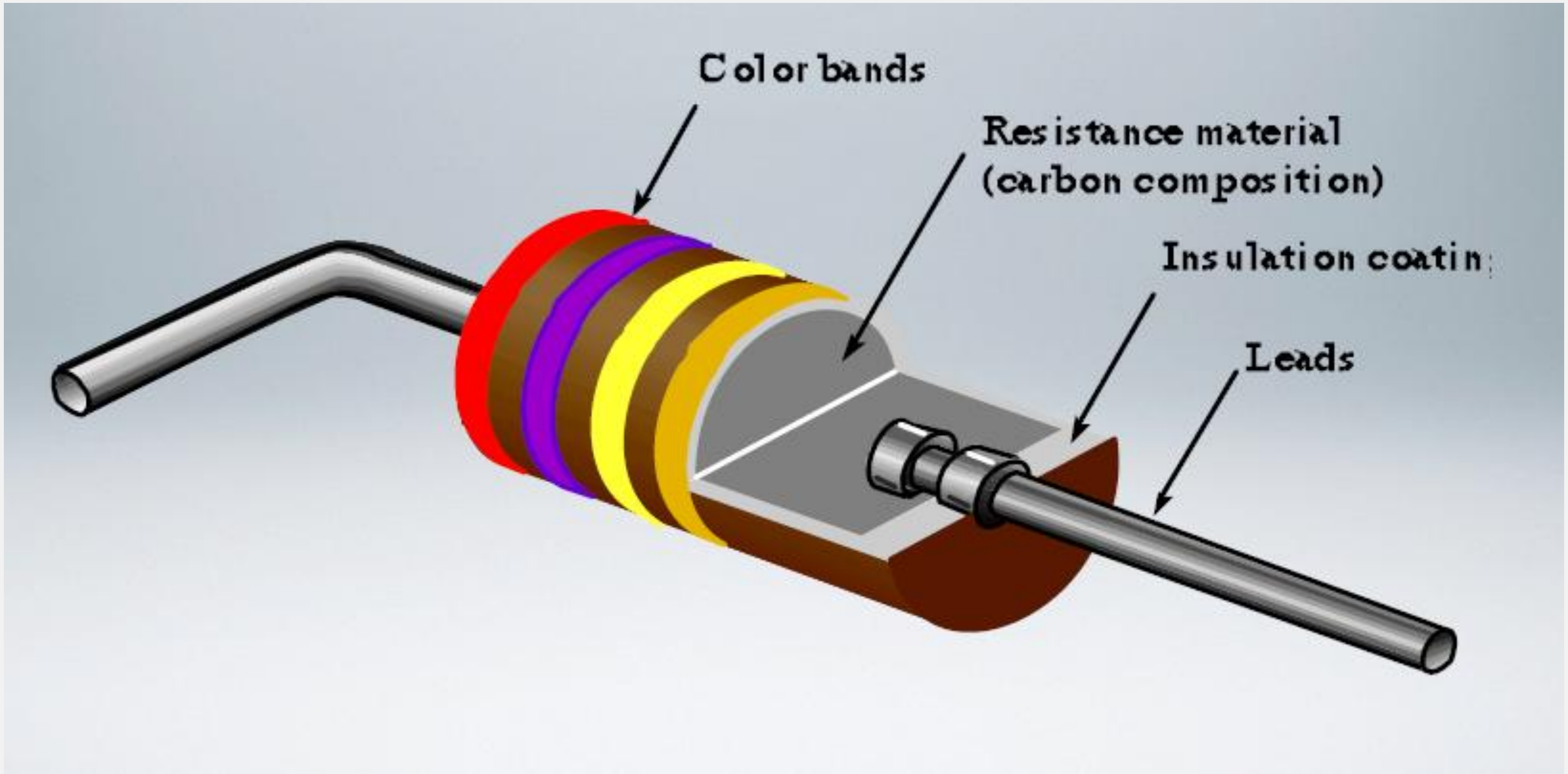
Resistance (R) is the physical property of an element that impedes the flow of current . The units of resistance are **Ohms (Ω)**

Resistivity (ρ) is the ability of a material to resist current flow. The units of resistivity are **Ohm-meters (Ω-m)**

Example:

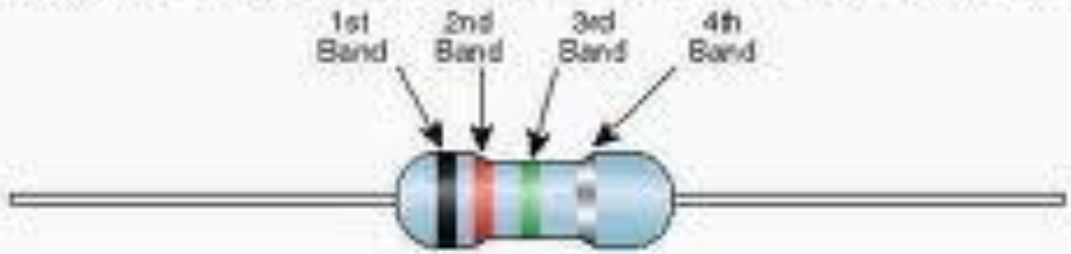
Resistivity of copper	$1.68\ \ 10^{-8}$ Ω·m
Resistivity of glass	10^{10} to 10^{14} Ω·m

Resistors


Color bands
Resistance material
(carbon composition)
Insulation coatin
Leads

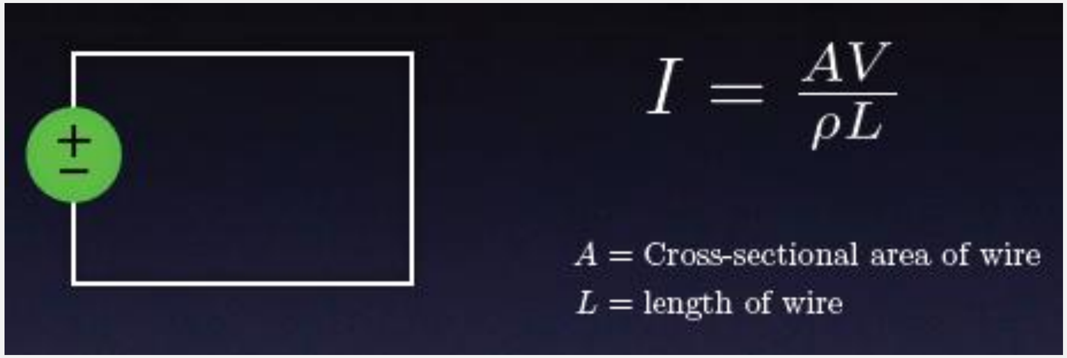
Resistors

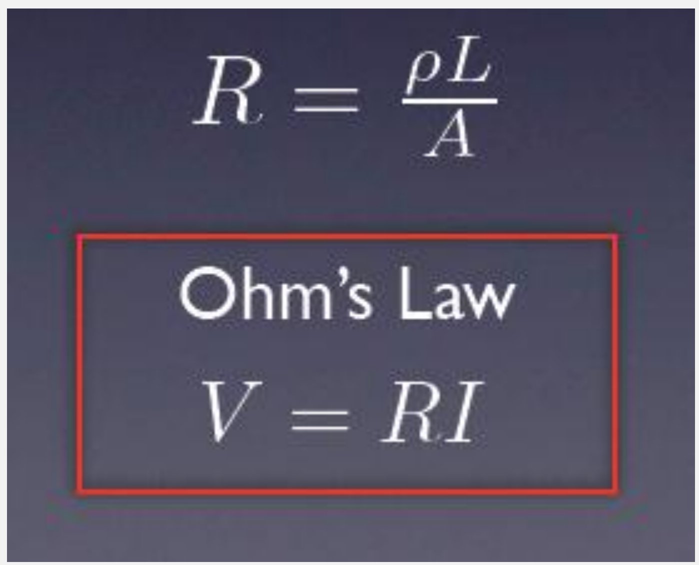
Standard EIA Color Code Table **4 Band**: ±2%, ±5%, and ±10%



Color	1st Band (1st figure)	2nd Band (2nd figure)	3rd Band (multiplier)	4th Band (tolerance)
Black	0	0	10^0	
Brown	1	1	10^1	
Red	2	2	10^2	±2%
Orange	3	3	10^3	
Yellow	4	4	10^4	
Green	5	5	10^5	
Blue	6	6	10^6	
Violet	7	7	10^7	
Gray	8	8	10^8	
White	9	9	10^9	
Gold			10^{-1}	±5%
Silver			10^{-2}	±10%

Ohm’s Law





(remember, R is in Ω and ρ is in Ω-m)

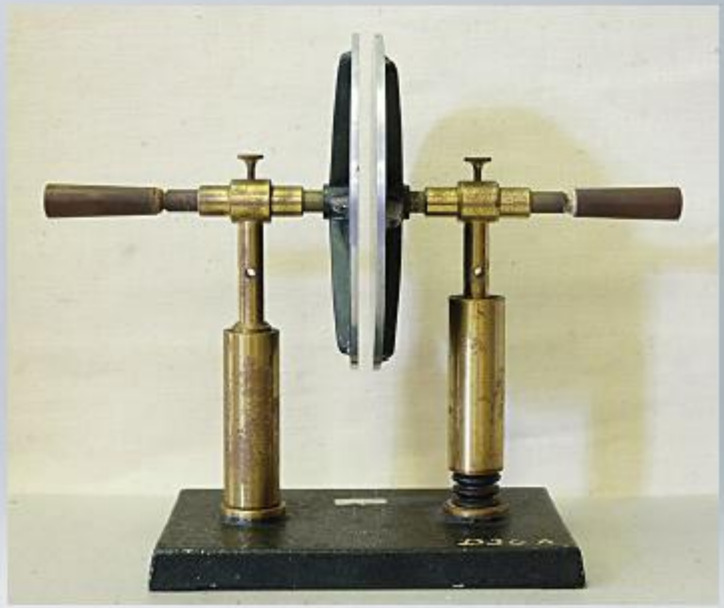
Capacitors

Capacitor

Modern capacitors, by a cm rule

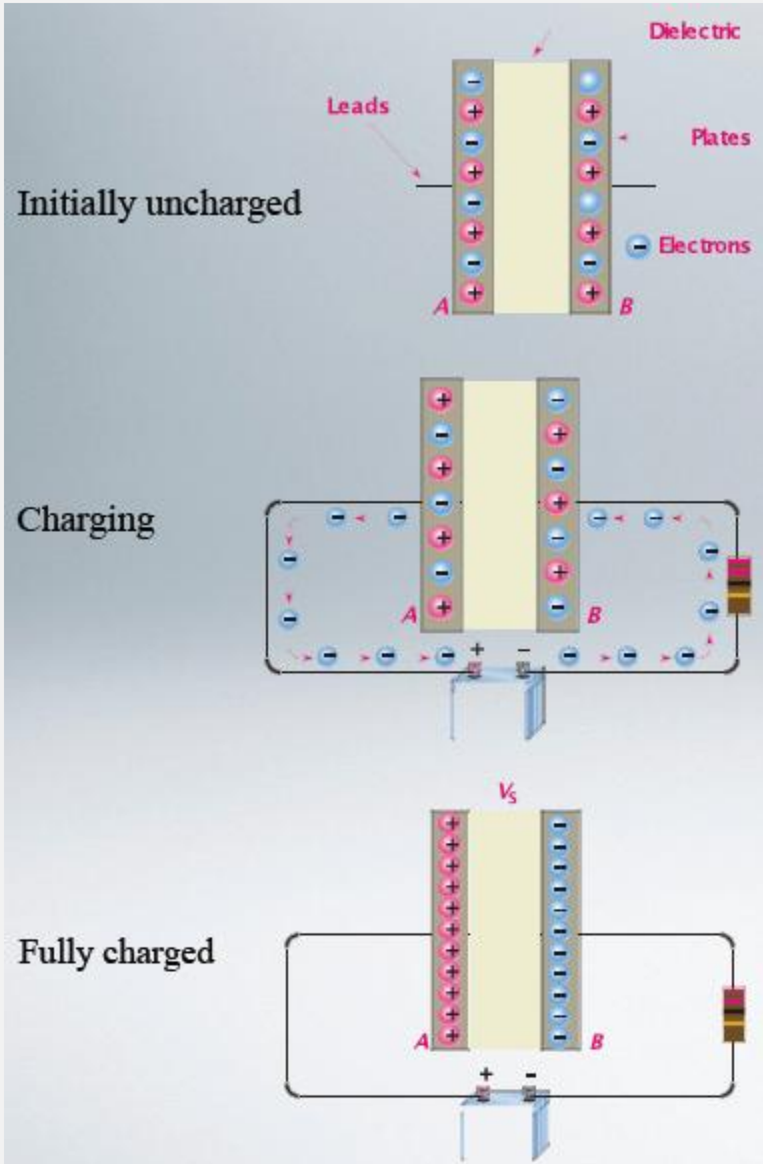
Type	Passive
Invented	Ewald Georg von Kleist (October 1745)

Electronic symbol



A simple demonstration of a parallel-plate capacitor

Capacitors



*A **capacitor** consists of a pair of conductors separated by a dielectric (insulator).*

$$C = \frac{\epsilon A}{d} \qquad \begin{array}{r} \epsilon = permitivity \\ A = area \\ d = distance \end{array}$$

(ε indicates how penetrable a subtance is to an electric field)

Electric charge is stored in the plates – a capacitor can become "charged"

When a voltage exists across the conductors, it provides the energy to move the charge from the positive plate to the other plate.

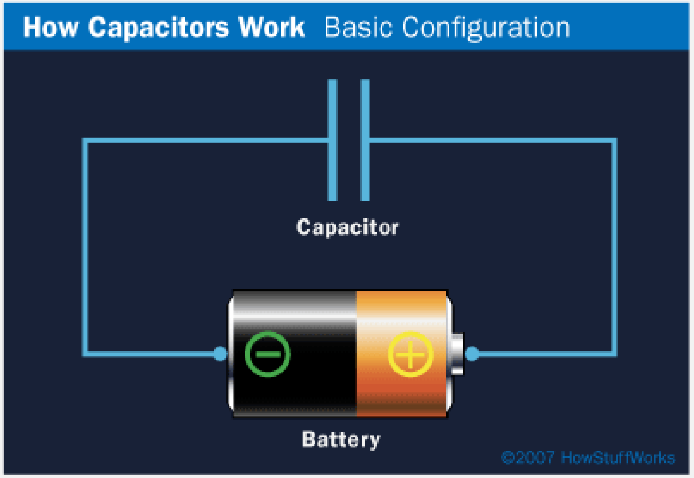
Capacitors

Capacitance (C) *is the ability of a material to store charge in the form of* ***separated charge or an electric field****. It is the ratio of charge stored to voltage difference between two plates.*

Capacitance is measured in **Farads (F)**

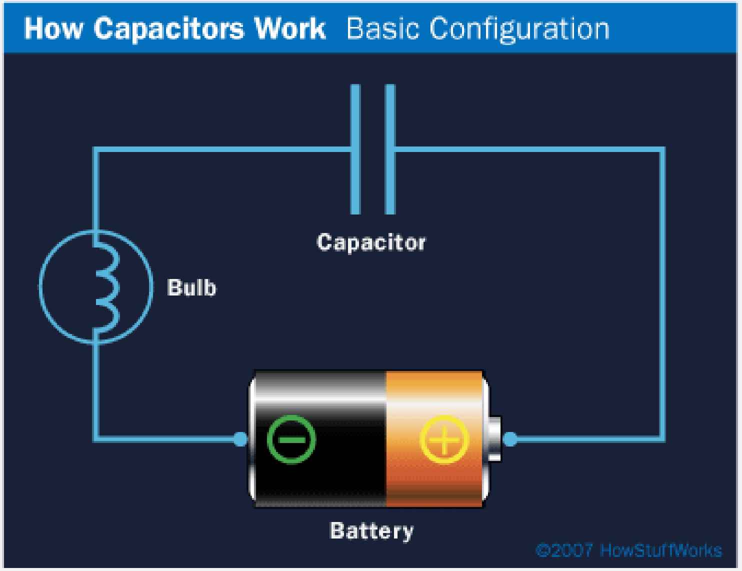
$$C = \frac{Q}{V} = \frac{Coloumb}{Volt} = Farad$$

Capacitors



The capacitor plate attached to the **negative terminal** accepts **electrons** from the battery.

The capacitor plate attached to the **positive terminal** accepts **protons** from the battery.



What happens when the light bulb is initially connected in the circuit?

What happens if you replace the battery with a piece of wire?

Energy storage

Work must be done by an **external influence** (e.g. a battery) to separate charge between the plates in a capacitor. The charge is stored in the capacitor until the external influence is removed and the separated charge is given a path to travel and dissipate.

Work exerted to charge a capacitor is given by the equation:

$$W = \frac{1}{2}CV^2$$

Inductors

Inductor	
 A selection of low-value inductors	
Type	Passive
Working principle	Electromagnetic induction
First production	Michael Faraday (1831)
Electronic symbol	
	

An **inductor** is a two terminal element consisting of a winding of N turns capable of **storing energy in the form of a magnetic field**

Inductance (L) is a measure of the ability of a device to store energy in the form of a **magnetic field**. It is measured in **Henries (H)**

Inductors

Inductance in a cylindrical coil

$$L = \frac{\mu_0 K N^2 A}{l}$$

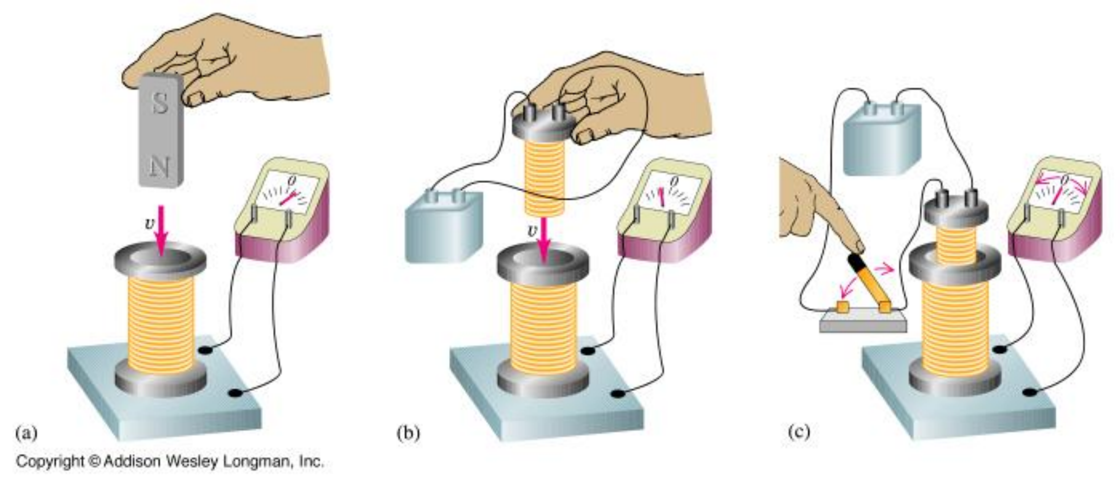
μ_0 = permeability of free space = $4\pi \quad 10^{-7}$ H/m
K = Nagaoka coefficient
N = number of turns
A = area of cross-section of the coil in m^2
l = length of coil in m

Inductors

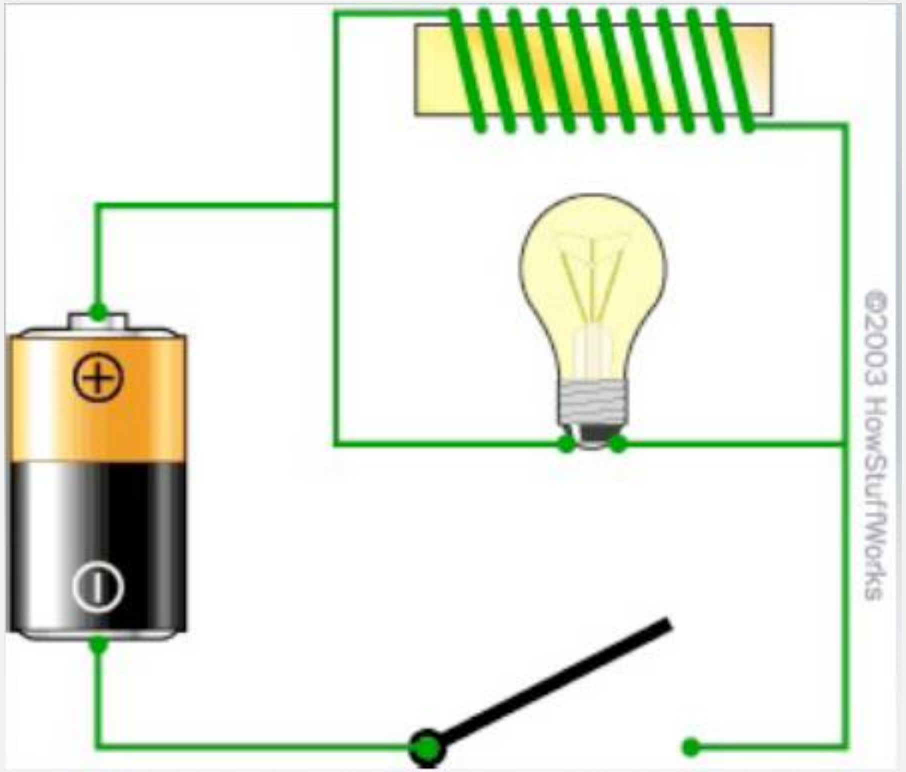
The magnetic field from an inductor can generate an induced voltage, which can be used to drive current

$$v = L\frac{di}{dt}$$

While building the magnetic field, the inductor **resists current flow**



Inductors



What happens to the light bulb when the switch is closed?

What happens to the light bulb when the switch is then opened?

Energy storage

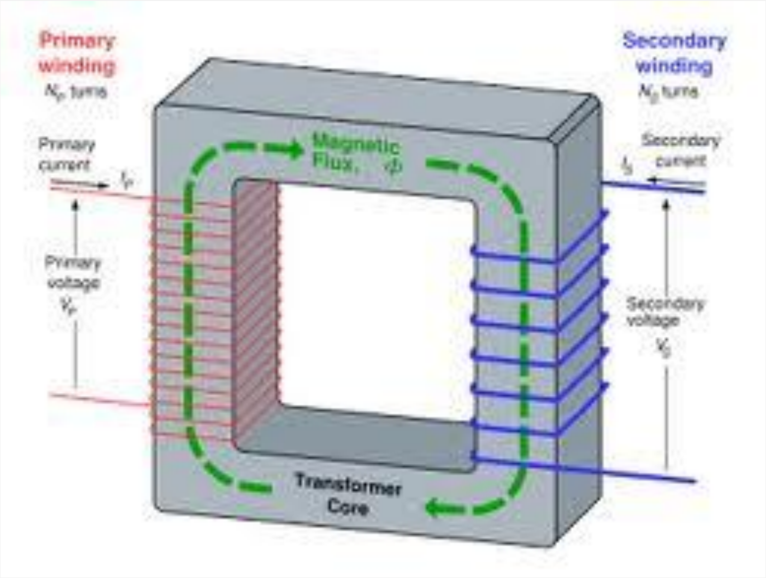
Inductors can store energy in the form of a magnetic field when a current is passed through them.

The work required to establish current through the coil, and therefore the magnetic field, is given by

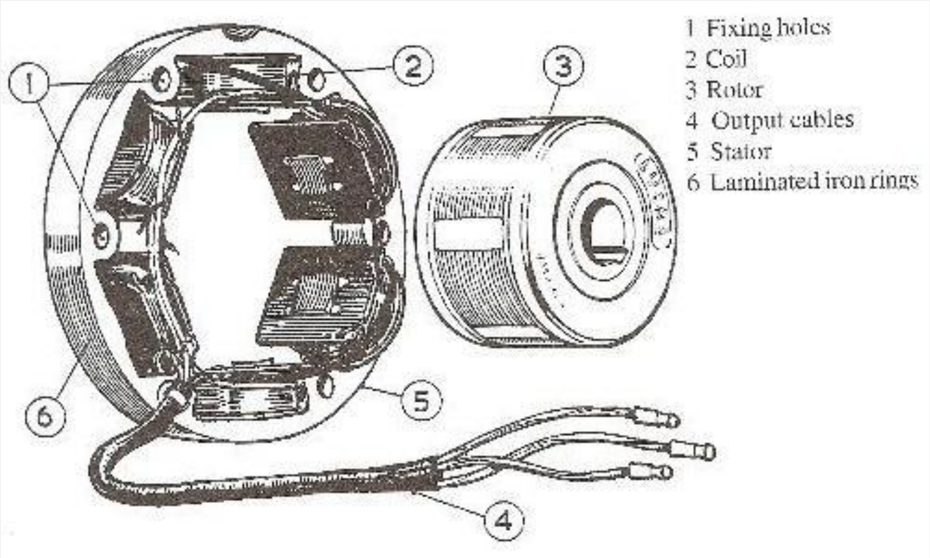
$$W = \frac{1}{2}LI^2$$

Transformers and alternators

Inductors are located in both **transformers** and **alternators**, allowing **voltage conversion** and **current generation**, respectively

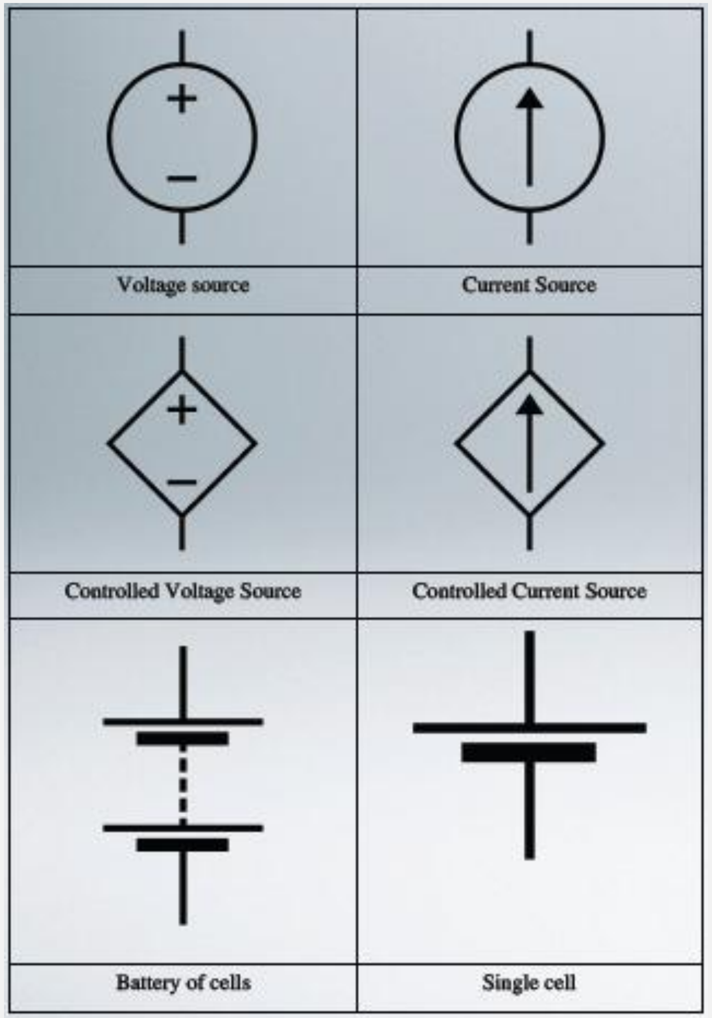


Transformer converts from one voltage to another



Alternator produces AC current

Electrical sources



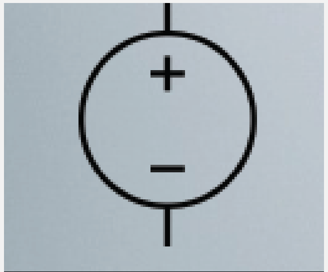
An **electrical source** is a **voltage** or **current generator** capable of supplying energy to a circuit

Examples:

-AA batteries
-12-Volt car battery
-Wall plug

Ideal voltage source

An **ideal voltage source** is a circuit element where the **voltage across the source is independent of the current through it**.


Voltage source

Recall Ohm's Law: V=IR

The internal resistance of an ideal voltage source is zero.

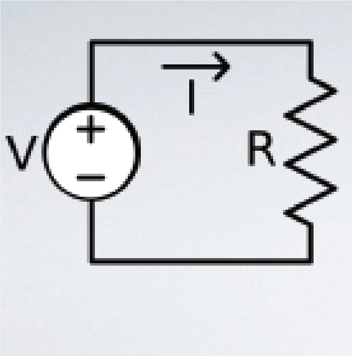
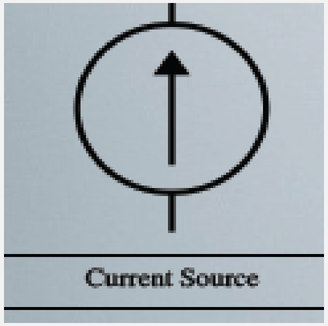


Figure 1: An ideal voltage source, *V*, driving a resistor, *R*, and creating a current *I*

If the current through an ideal voltage source is completely determined by the external circuit, it is considered an **independent voltage source**

Ideal current source

An **ideal current source** is a circuit element where the **current through the source is independent of the voltage across it**.



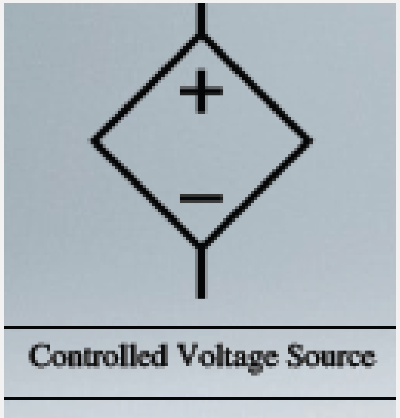
Recall Ohm's Law: I = V/R

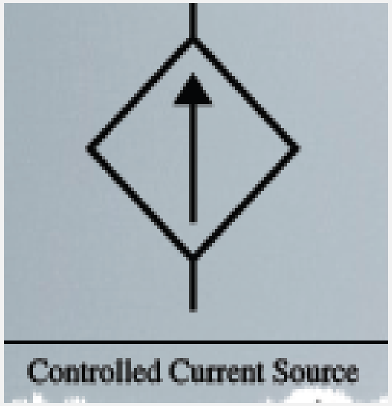
The internal resistance of an ideal current source is infinite.

If the voltage across an **ideal current source** is completely determined by the external circuit, it is considered an **independent current source**

Dependent Sources

A **dependent** or **controlled** source depends upon a different voltage or current in the circuit

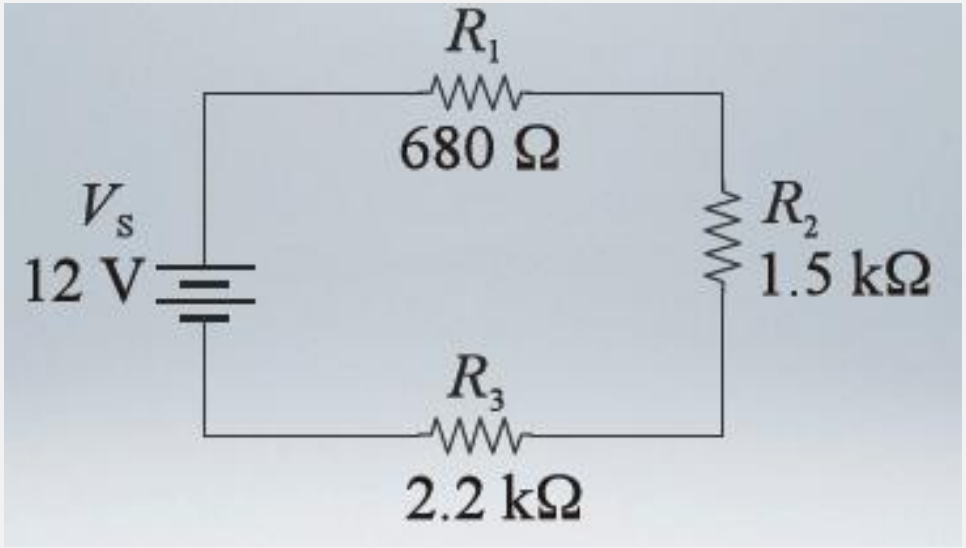




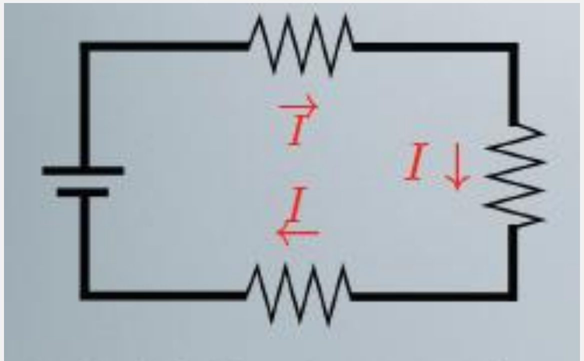
Electric Circuit Design Principles

Example: Resistors in series

The resistors in a series circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?



Series circuits

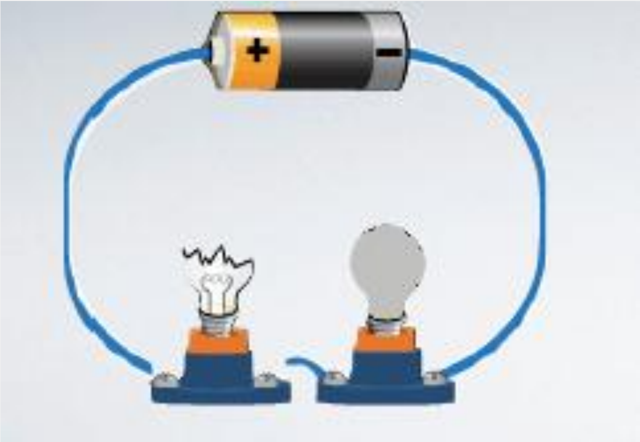


A series circuit with a voltage source (such as a battery) and 3 resistors

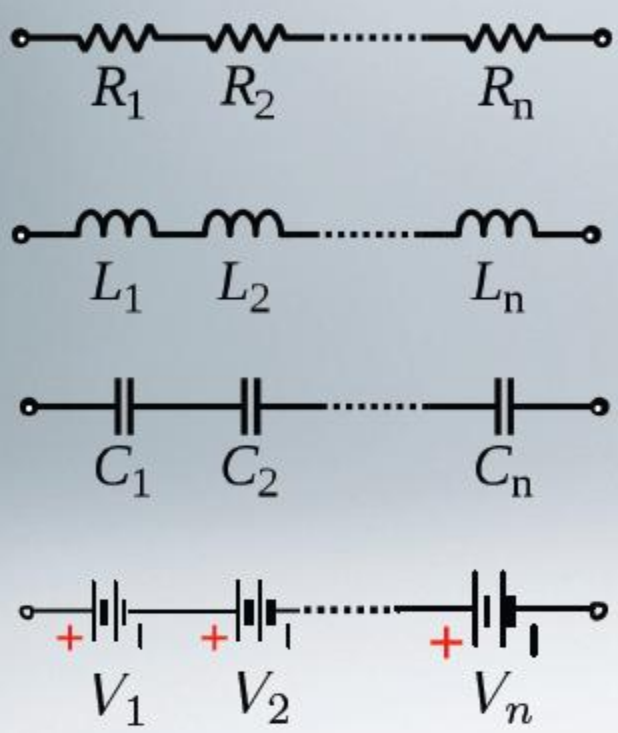
A **series circuit** has only **one current path**

Current through each component is the same

In a series circuit, all elements must function for the circuit to be complete



Multiple elements in a series circuit



$$R_{total} = R_1 + R_2 + \ldots + R_n$$

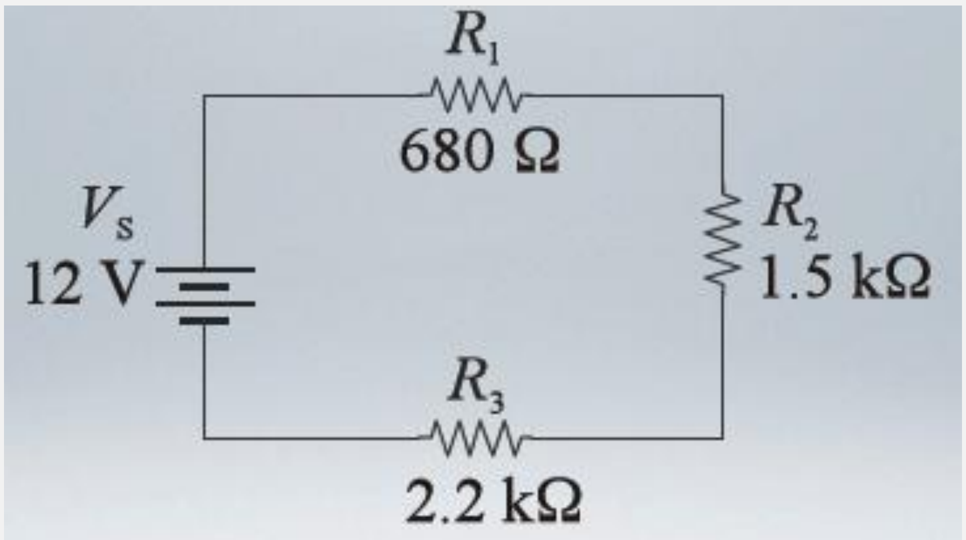
$$L_{total} = L_1 + L_2 + \ldots + L_n$$

$$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots + \frac{1}{C_n}$$

$$V_{total} = V_1 + V_2 + \ldots + V_n$$

Example: Resistors in series

The resistors in a series circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?



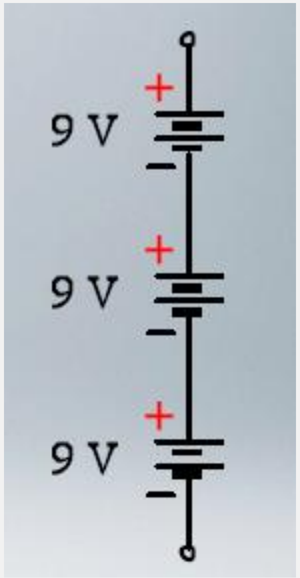
$$\begin{aligned} R_{total} &= R_1 + R_2 + R_3 \\ &= 680\Omega + 1500\Omega + 2200\Omega \\ &= 4380\Omega \\ &= 4.38k\Omega \end{aligned}$$

The current through each resistor?

$$I = \frac{V}{R_{total}} = \frac{12V}{4380\Omega} = 2.74mA$$

Example: Voltage sources in series

Find the total voltage of the sources shown

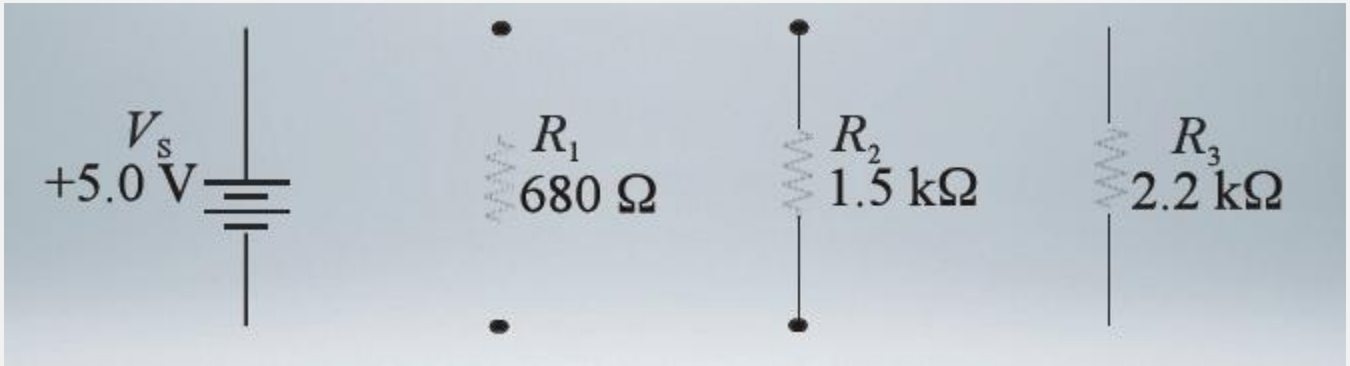


$$V_{total} = V_1 + V_2 + V_3 = 27V$$

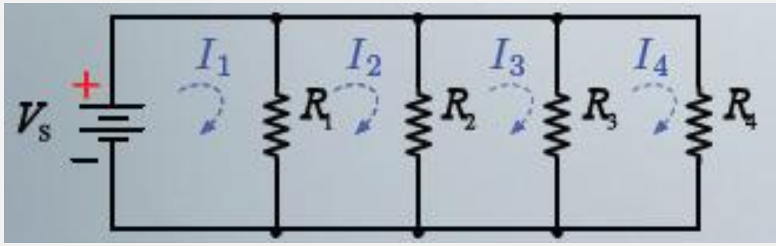
What happens if you reverse a battery?

Example: Resistors in parallel

The resistors in a parallel circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ. What is the total resistance?

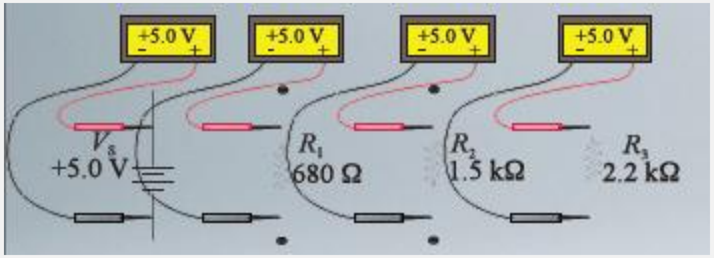


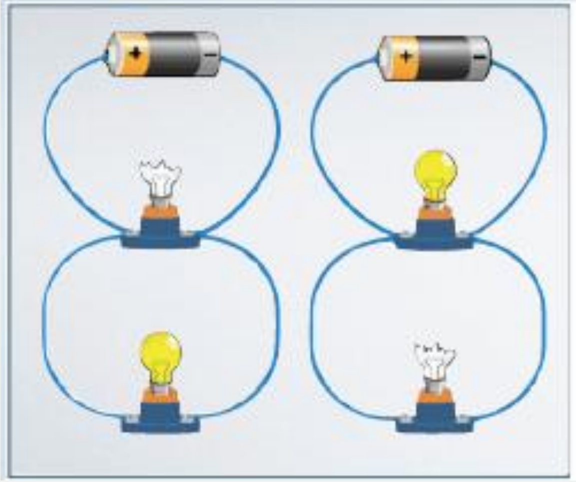
Parallel circuits



A **parallel circuit** has **more than one current path** branching from the energy source

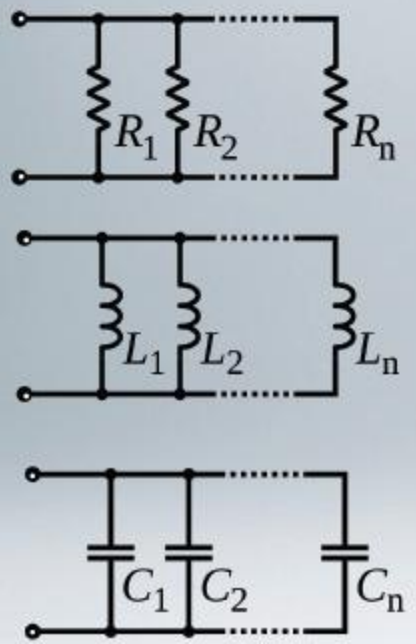
Voltage across each pathway is the same





In a parallel circuit, separate current paths function independently of one another

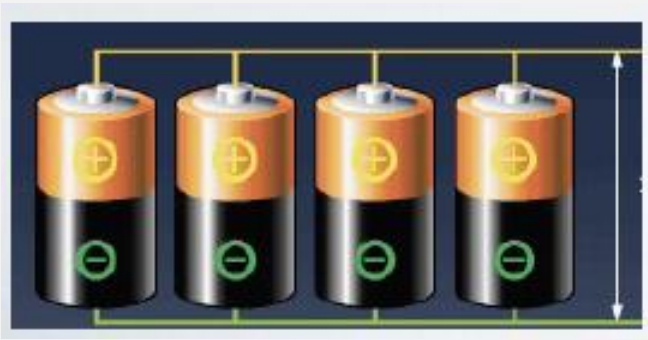
Multiple elements in a parallel circuit



$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots + \frac{1}{R_n}$$

$$\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots + \frac{1}{L_n}$$

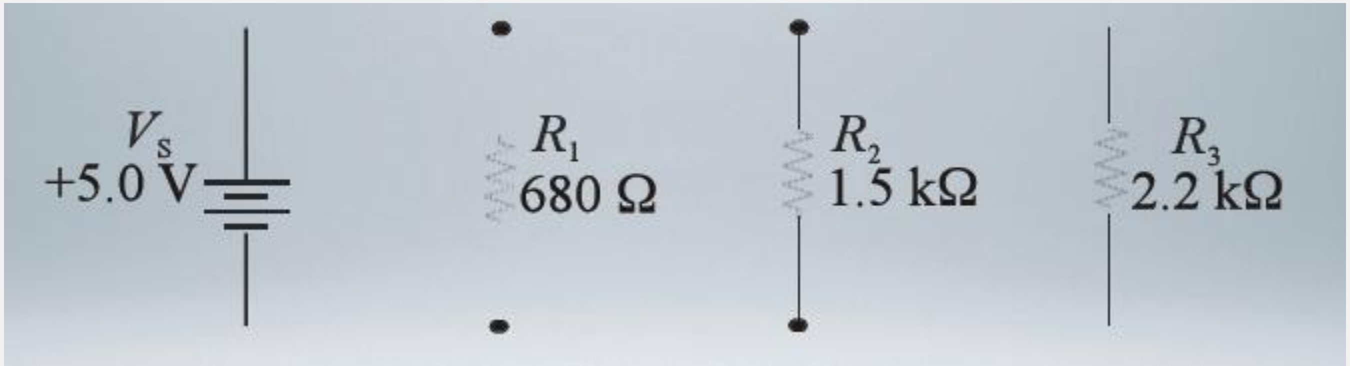
$$C_{total} = C_1 + C_2 + \ldots + C_n$$



For parallel voltage sources, the voltage is the same across all batteries, but the current supplied by each element is a fraction of the total current

Example: Resistors in parallel

The resistors in a parallel circuit are 680 Ω, 1.5 kΩ, and 2.2 kΩ.
What is the total resistance?



$$R_{total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$
$$= 386\Omega$$

Voltage across each resistor?

Current through each resistor?