Ship Electricity

WEEK 1

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Grading

Midterm Exam : 30%
Quizzes (3 - 4) : 30%
Final Exam : 40%

Total : 100%

Ship Electricity

1) Introduction and basic concepts
2) Basics of Direct Current
3) Basics of Alternating Current
4) Semiconductors
5) Basics of electromagnetism
6) Ship Applications of Alternators and Synchronous Motors
7) Induction Motors and applications for Ships
8) Fundamentals of Ship Power Systems and Devices
9) Electrical Drives for Ships

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Book for the Course

- **Principles and Applications of Electrical Engineering, Giorgio Rizzoni, Mc Graw Hill Book Comp.**
- **Elektroteknik, Mehmet Dalfes (YTU ve Seç Yayın)**
- **Gemi Elektriği, Fahrettin Küçükşahin, Akademi Denizcilik, 2001**

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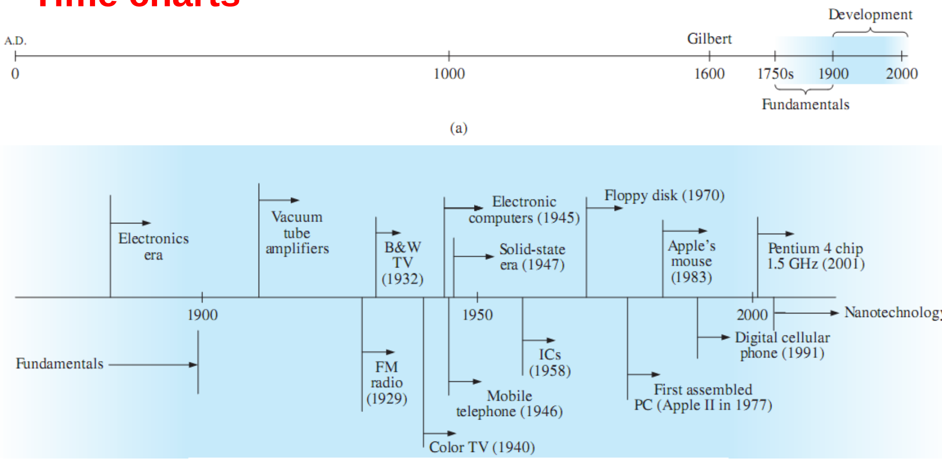
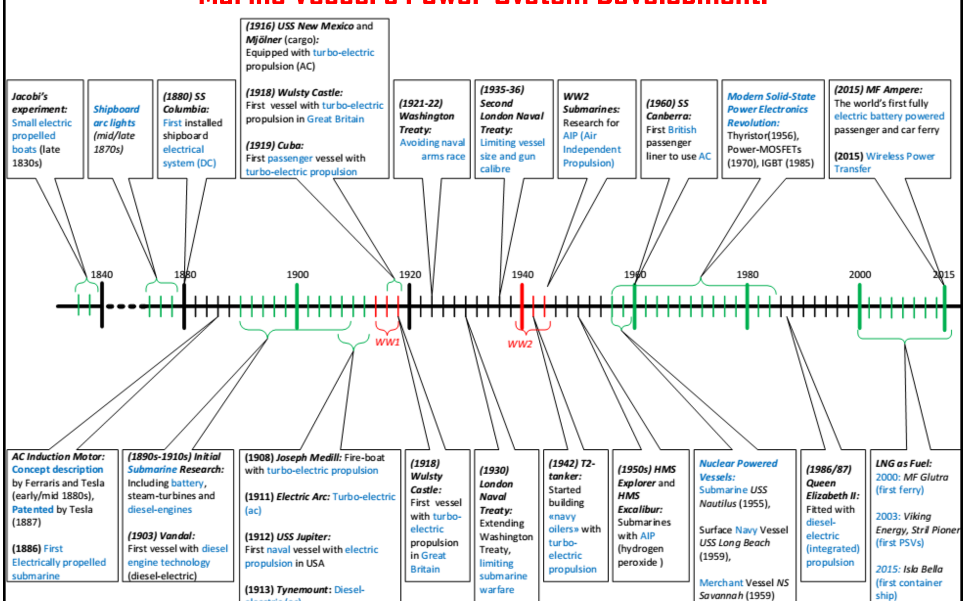
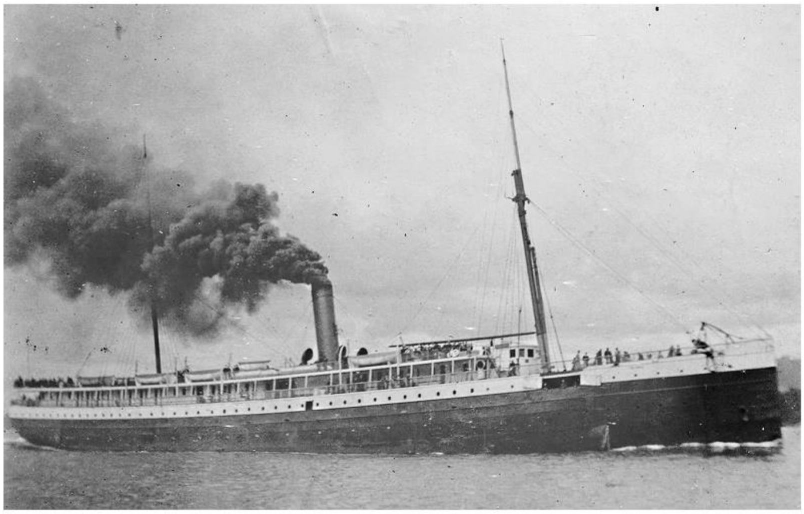
Time charts



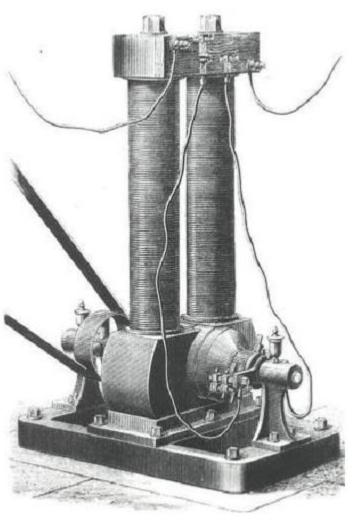
Time-line with the historical highlights of the Marine Vessel's Power System Development.



Edison's lighting system first installed in a ship in 1880, aboard *SS Columbia*.

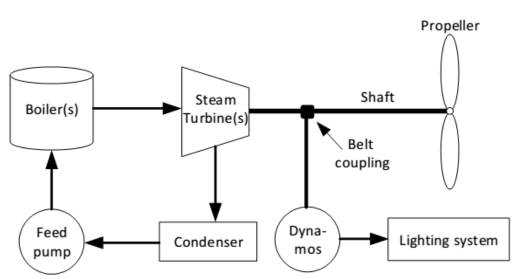


(a) Passenger and cargo vessel *SS Columbia* (1880-1907), owned by the Oregon Railroad and Navigation Company and later the Union Pacific Railroad, was the first ship with Edison's lighting system. Courtesy [10].



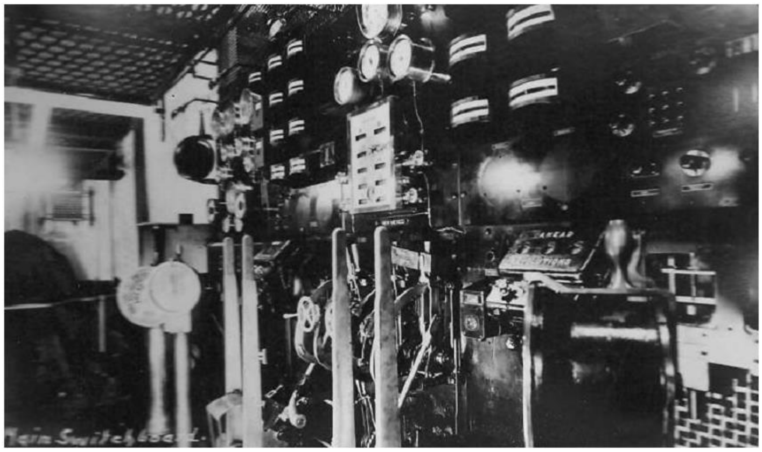
(b) Edison's belt driven "jumbo" dynamo (with the nick name *long-legged Mary-Ann* [11]) was one of the main components in *SS Columbia*'s lighting system. Courtesy [12].

The SS Columbia was equipped with 120 incandescent lights, which were distributed on several circuits and powered by four belt-driven 6kW dynamos. Each dynamo could supply 60 lamps, each rated 16 candlepower.



Simplified drawing of the propulsion and lighting system installed in SS Columbia

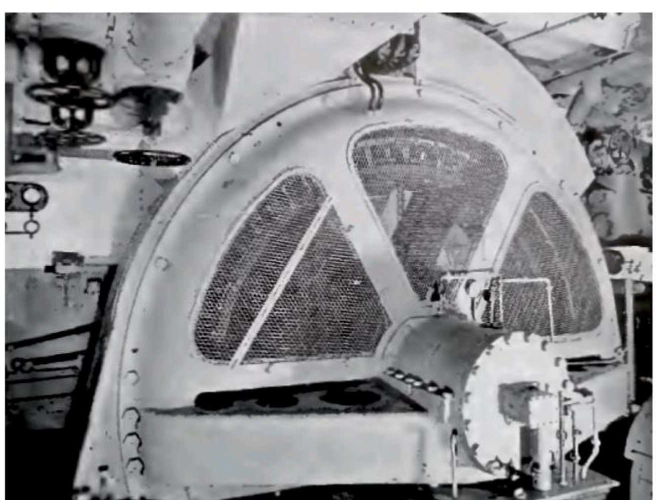
USS New Mexico was one of the first US vessels with turbo-electric propulsion.



(a) *USS New Mexico*'s main switchboard and control station. Change of speed and direction was done with manual levers. Courtesy [28].

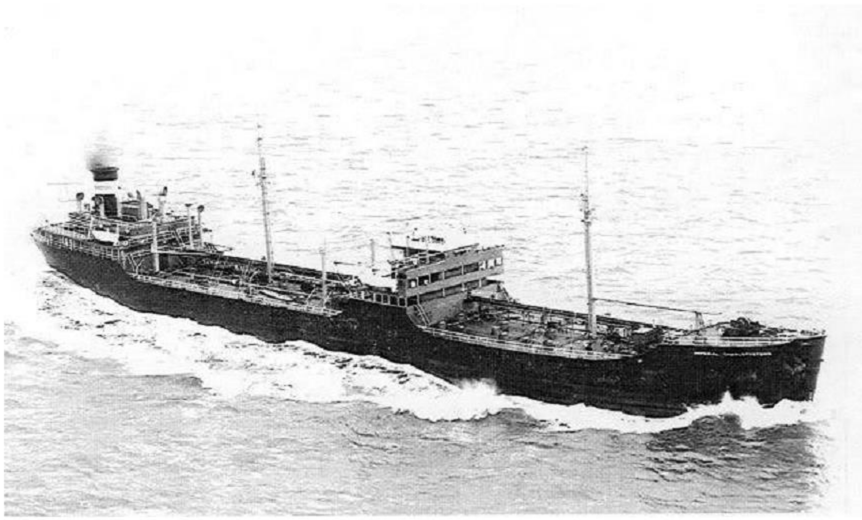
The *New Mexico* used two 11.5MW, 3,000V/4,242V dual voltage, variable frequency ac generators that powered four 7,500hp 24-/36- pole induction motors, and was able to maintain a speed of 21 knots. The vessel also had six 300kW auxiliary turbo-generators for lighting and nonpropulsion electrical machinery.

Cuba was the first passenger vessel in the world with turbo-electric propulsion.



(b) *Cuba*'s 3,000 horsepower, 1,150 volt, 1,180 ampere electric propulsion motor. Courtesy [29], [30].

The T2 tanker (World War II), with electric propulsion.



(a) The *Sag Harbor*, built for USMC by the *Sun Shipbuilding and Dry Dock Company* in 1944. Courtesy [55].

The USS K-5 submarine (World War I) , with electric propulsion.

(b) *USS K-5* (built 1914) underway on the Mississippi River, 1919. The vessel was built by the *Fore River Shipbuilding* and launched 17 March 1914. Courtesy [56].

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- *USS Nautilus* was the first nuclear-powered submarine, commissioned in 1954 (cold war submarine).
- *USS Long Beach* was the first nuclear-powered navy surface vessel, launched in 1959 .
- *NS Savannah* was the first nuclear-powered Merchant (passenger-cargo) vessel, launched in 1959.
- *MF Glutra* was the first LNG-powered vessel in the world. The ferry was set in operation in 2000.
- *Viking Energy* and *Stril Pioner* were the first LNG powered cargo vessels, both launched in 2003.
- *Isla Bella* was the first LNG-powered container ship, launched in 2015.

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Comparison of the English and metric systems of units.

English	Metric		SI
	MKS	**CGS**	**SI**
Length: Yard (yd) (0.914 m)	Meter (m) (39.37 in.) (100 cm)	Centimeter (cm) (2.54 cm = 1 in.)	**Meter (m)**
Mass: **Slug** (14.6 kg)	Kilogram (kg) (1000 g)	Gram (g)	**Kilogram (kg)**
Force: **Pound** (lb) (4.45 N)	Newton (N) (100,000 dynes)	Dyne	**Newton (N)**
Temperature: Fahrenheit (°F) $\left(= \frac{9}{5}°C + 32\right)$	Celsius or Centigrade (°C) $\left(= \frac{5}{9}(°F - 32)\right)$	Centigrade (°C)	**Kelvin (K)** K = 273.15 + °C
Energy: Foot-pound (ft-lb) (1.356 joules)	Newton-meter (N•m) or joule (J) (0.7376 ft-lb)	Dyne-centimeter or erg (1 joule = 10^7 ergs)	**Joule (J)**
Time: Second (s)	Second (s)	Second (s)	**Second (s)**

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The International System of Units

TABLE 1.1 The International System of Units (SI)

Quantity	Basic Unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	degree kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

TABLE 1.2 Derived Units in SI

Quantity	Unit Name (Symbol)	Formula
Frequency	hertz (Hz)	s^{-1}
Force	newton (N)	$kg \cdot m/s^2$
Energy or work	joule (J)	$N \cdot m$
Power	watt (W)	J/s
Electric charge	coulomb (C)	$A \cdot s$
Electric potential	volt (V)	J/C
Electric resistance	ohm (Ω)	V/A
Electric conductance	siemens (S)	A/V
Electric capacitance	farad (F)	C/V
Magnetic flux	weber (Wb)	$V \cdot s$
Inductance	henry (H)	Wb/A

TABLE 1.3 Standardized Prefixes to Signify Powers of 10

Prefix	Symbol	Power
atto	a	10^{-18}
femto	f	10^{-15}
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
centi	c	10^{-2}
deci	d	10^{-1}
deka	da	10
hecto	h	10^{2}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

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Express the following in engineering notation:

10×10^{4} Volts

0.1×10^{-3} Watts

250×10^{-7} seconds

- Convert 0.002 km to millimeters.
- Convert 6.8 min to seconds.
- Convert 0.24 m to centimeters.
- Convert 0.1 MV to kilovolts (kV).

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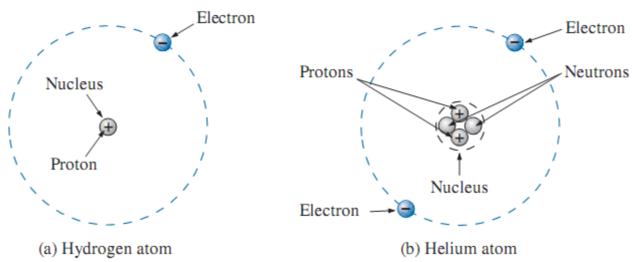
ATOM

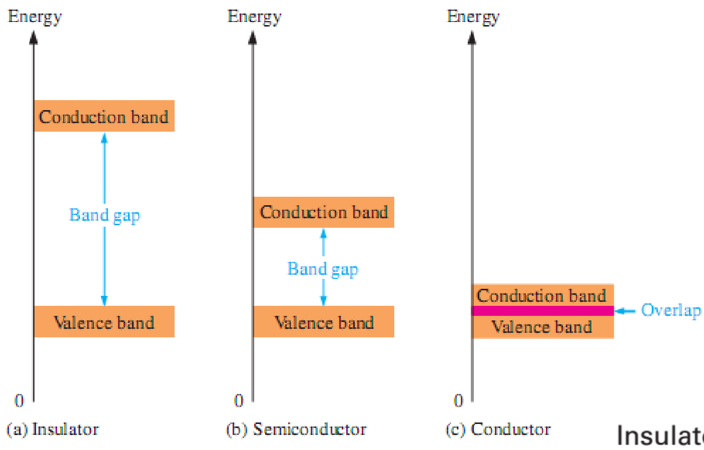


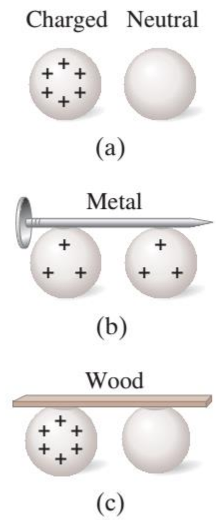
Electron is assumed to be negatively charged Proton is assumed to be positive charged neutrons, which are slightly heavier than protons and have no electrical charge.

- The mass of electron is 9×10^{-28} gr
- The mass of proton and neutron is 1.672×10^{-24} gr
- The mass of the proton (or neutron) is therefore approximately 1836 times that of the electron.

Band Gap

The difference in energy between the valence band and the conduction band is called an energy gap or band gap.





Insulators and Conductors

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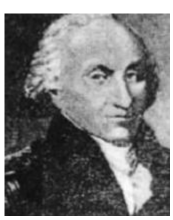
Coulomb's Law



Charles Augustin Coulomb.
French (Angoulême, Paris)
(1736–1806) Scientist and Inventor

$$F = k\frac{Q_1 Q_2}{r^2} \quad \text{(newtons, N)}$$

$$6.242 \times 10^{18} \ \textit{electrons} = 1 \ \textit{Coulombs}$$

$$\frac{\textit{Electrical charge}}{\textit{Electron}} = \frac{1}{6.242 \times 10^{18}} \textit{Coulomb}$$
$$= 1.602 \times 10^{-19} \ \textit{Coulomb}$$

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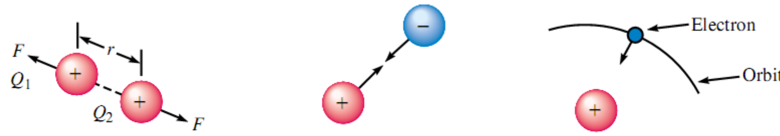
Coulomb's Law



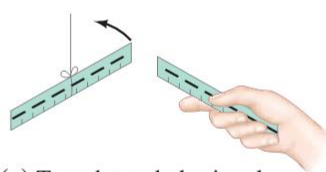
(a) Like charges repel

(b) Unlike charges attract

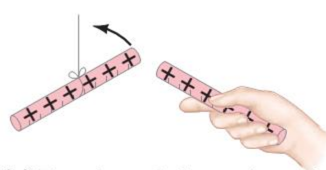
(c) The force of attraction keeps electrons in orbit

The charge of an electron and proton are;

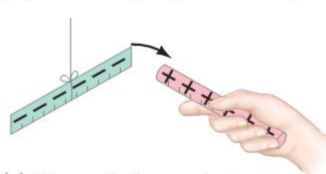
$$q_e = -1.602 \times 10^{-19}\ C \quad q_p = +1.602 \times 10^{-19}\ C$$



(a) Two charged plastic rulers repel



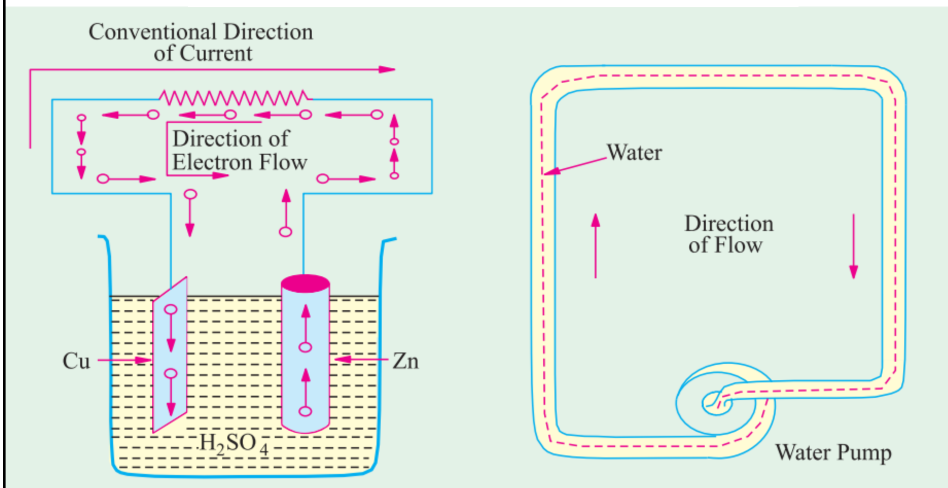
(b) Two charged glass rods repel

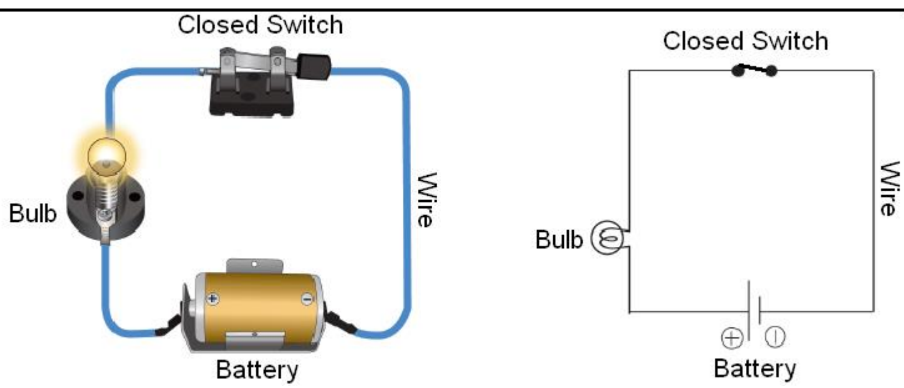


(c) Charged glass rod attracts charged plastic ruler

LAW OF CONSERVATION OF ELECTRIC CHARGE

The Idea of Electric Potential



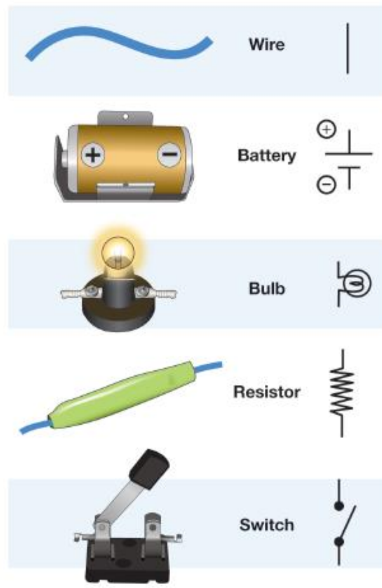


Actual Circuit **Schematic Diagram**

Electric circuits are represented by drawn ***schematic diagrams*** like the one on the right.

In the diagram, ***symbols*** are used to represent each part of the circuit.

Electrical symbols **are quicker and easier to draw than realistic pictures of the components.**



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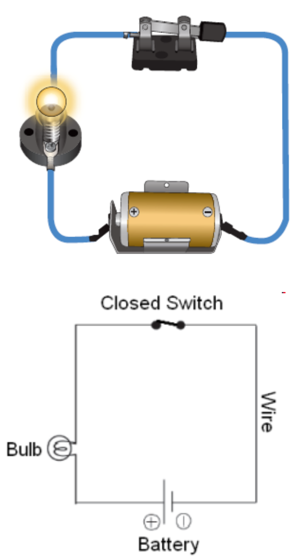
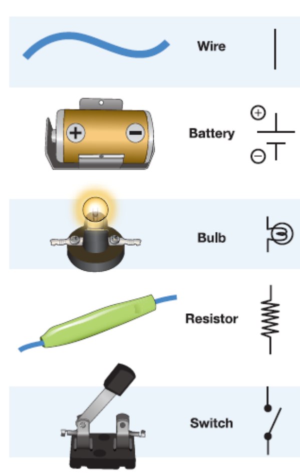
Circuit Diagrams and Electrical Symbols





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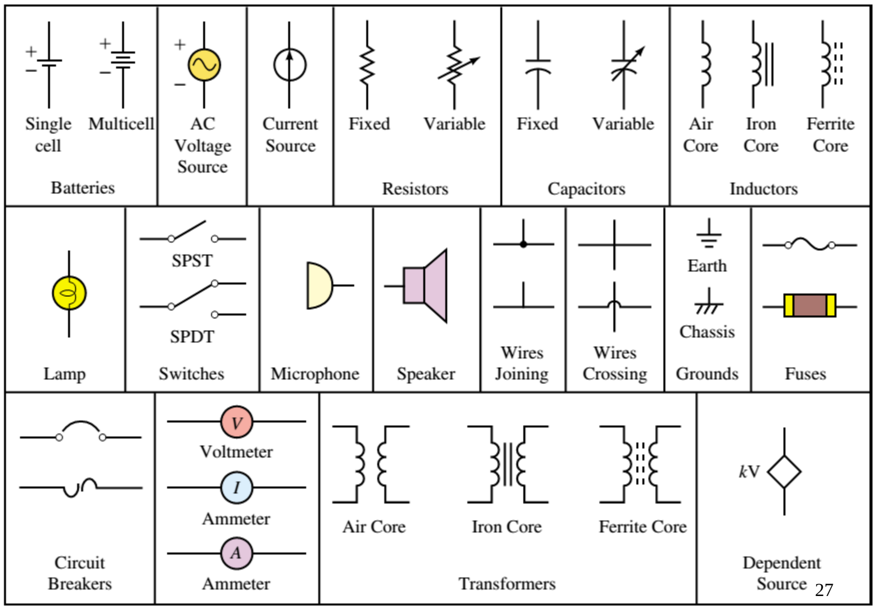
SCHEMATIC CIRCUIT SYMBOLS

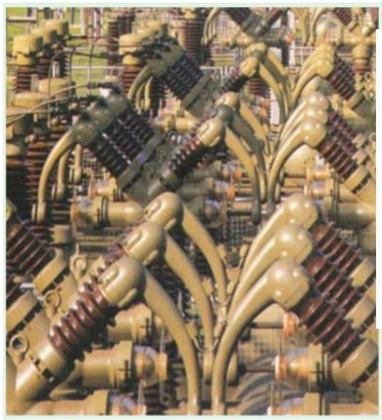


Ohm's Law

V=IR

Resistance

It may be defined as the property of a substance due to which it opposes (or restricts) the flow of electricity (*i.e.*, electrons) through it.


Cables are often covered with materials that do not carry electric current easily

Metals (as a class), acids and salts solutions are good conductors of electricity. Amongst pure metals, silver, copper and aluminium are very good conductors in the given order.* This, as discussed earlier, is due to the presence of a large number of free or loosely-attached electrons in their atoms. These vagrant electrons assume a directed motion on the application of an electric potential difference. These electrons while flowing pass ***through*** the molecules or the atoms of the conductor, collide and other atoms and electrons, thereby producing heat.

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Resistance

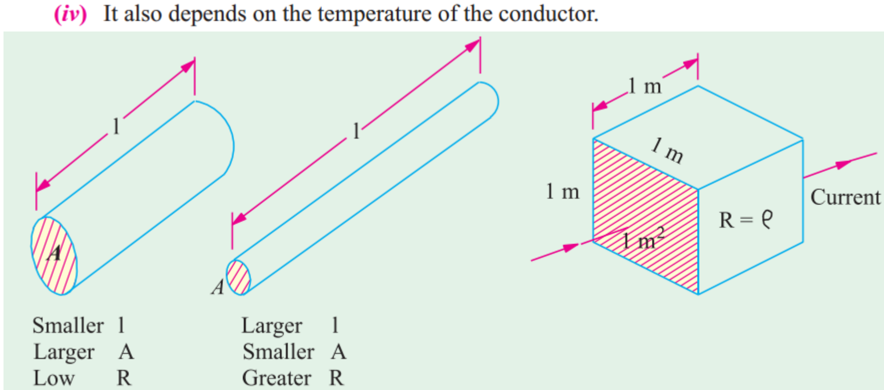
The resistance *R* offered by a conductor depends on the following factors :

(i) It varies directly as its length, *l*.

(ii) It varies inversely as the cross-section *A* of the conductor.

(iii) It depends on the nature of the material.

(iv) It also depends on the temperature of the conductor.



$$R \propto \frac{l}{A} \quad \text{or} \quad R = \rho\frac{l}{A}$$

$$\rho = \frac{A\ \text{metre}^2 \times R\ \text{ohm}}{l\ \text{metre}} = \frac{AR}{l}\ \text{ohm-metre}$$

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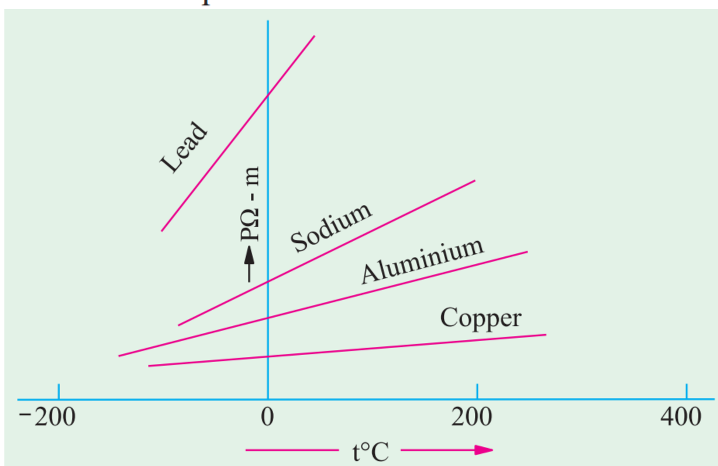
Variations of Resistivity with Temperature

Not only resistance but specific resistance or resistivity of metallic conductors also increases with rise in temperature and ***vice-versa***.



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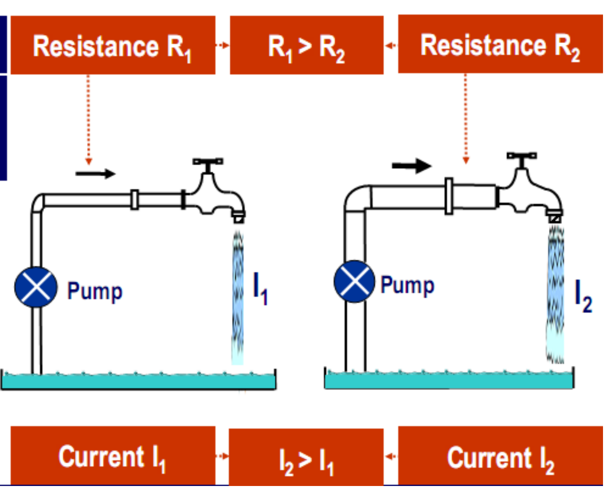
Resistance

Definition

Resistance is the reaction of a pipe against water flow



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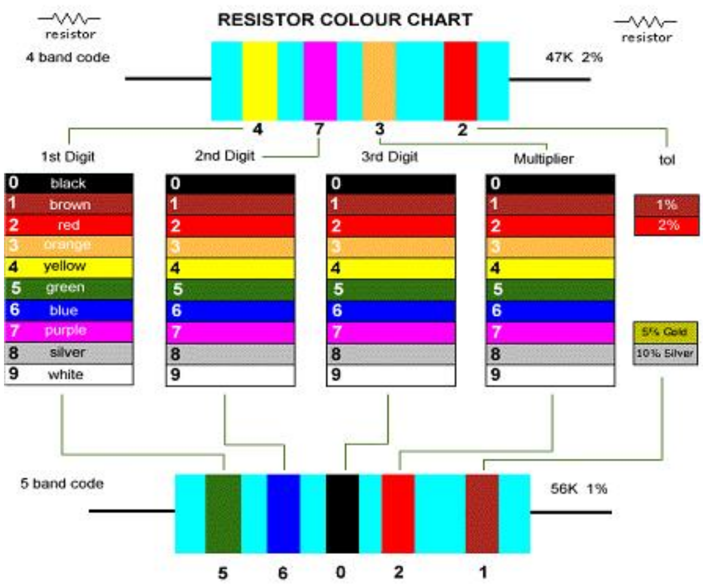

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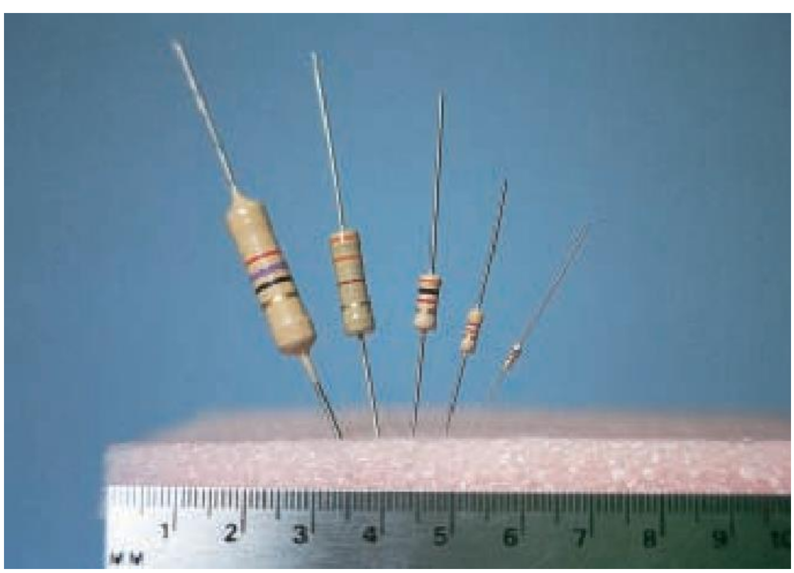
Actual size of carbon resistors



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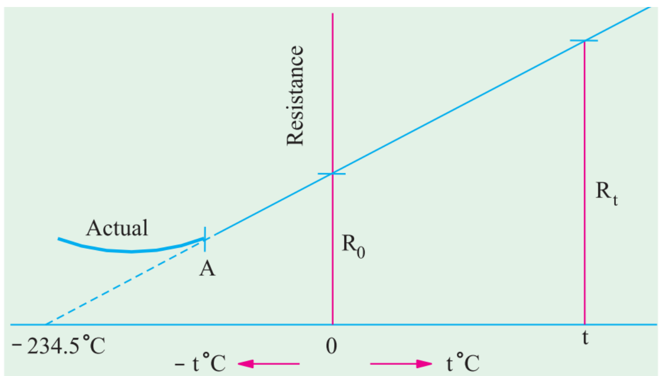
Effect of Temperature on Resistance

(i) to ***increase*** the resistance of pure metals.

(ii) to ***increase*** the resistance of alloys,
like Eureka (60% Cu and 40% Ni) and manganin

(iii) to ***decrease*** the resistance of electrolytes, insulators (such as paper, rubber, glass, mica etc.)

$R_t = R_0\left(1+\frac{t}{234.5}\right)$ or $R_t = R_0\,(1 + \alpha\, t)$ where $\alpha = 1/234.5$ for copper



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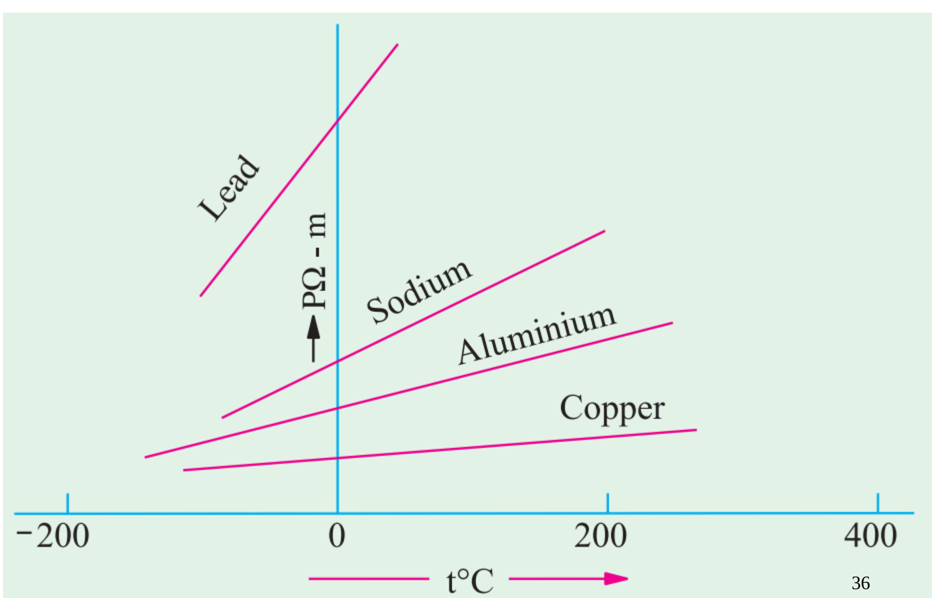
Variations of Resistivity with Temperature



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Conductance and Conductivity

Conductance (G) is reciprocal of resistance*. Whereas resistance of a conductor measures the *opposition* which it offers to the flow of current, the conductance measures the *inducement* which it offers to its flow.

$$R = \rho \frac{l}{A} \quad \text{or} \quad G = \frac{1}{\rho} \cdot \frac{A}{l} = \frac{\sigma A}{l}$$

where σ is called the ***conductivity* or *specific conductance*** of a conductor. The unit of conductance is siemens (S). Earlier, this unit was called mho.

It is seen from the above equation that the conductivity of a material is given by

$$\sigma = G \frac{l}{A} = \frac{G \text{ siemens} \times l \text{ metre}}{A \text{ metre}^2} = G \frac{l}{A} \text{ siemens/metre}$$

Hence, the unit of conductivity is siemens/metre (S/m).

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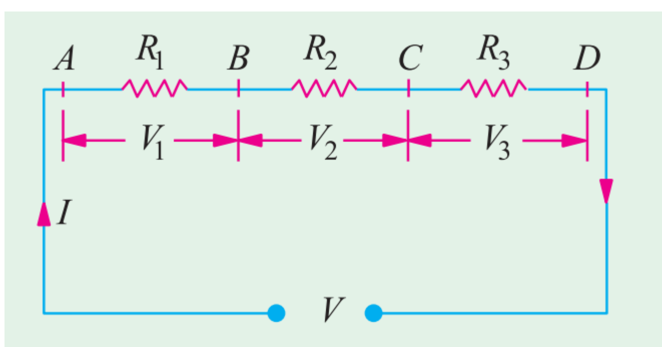
Resistance in Series



$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$$

$$V = IR$$

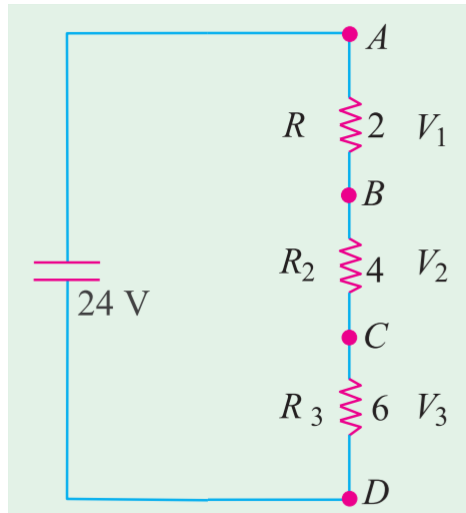
$$IR = IR_1 + IR_2 + IR_3 \quad \text{or} \quad R = R_1 + R_2 + R_3$$

$$\frac{1}{G} = \frac{1}{G_1} + \frac{1}{G_2} + \frac{1}{G_3}$$

Voltage Divider Rule

Total resistance

$$R = R_1 + R_2 + R_3 = 12\ \Omega$$



$$V_1 = V \cdot \frac{R_1}{R} = 24 \times \frac{2}{12} = 4\ \text{V}$$

$$V_2 = V \cdot \frac{R_2}{R} = 24 \times \frac{4}{12} = 8\ \text{V}$$

$$V_3 = V \cdot \frac{R_3}{R} = 24 \times \frac{6}{12} = 12\ \text{V}$$

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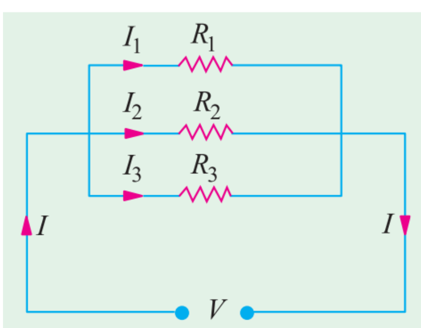
Resistances in Parallel



$$I = I_1 + I_2 + I_3 = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

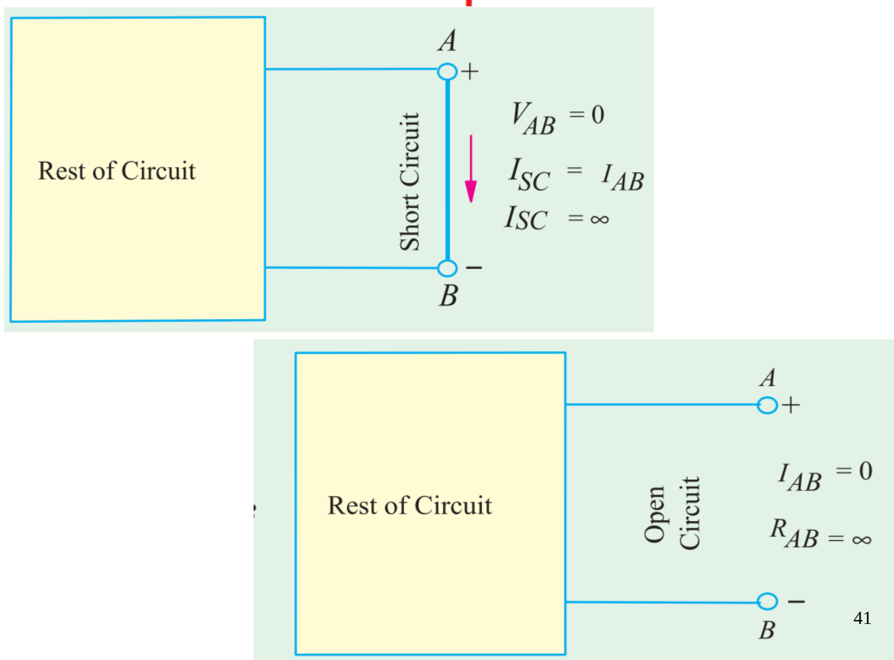
$I = \frac{V}{R}$ where V is the applied voltage.

R = equivalent resistance of the parallel combination.

$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \quad \text{or} \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$G = G_1 + G_2 + G_3$$

Short and Open Circuits



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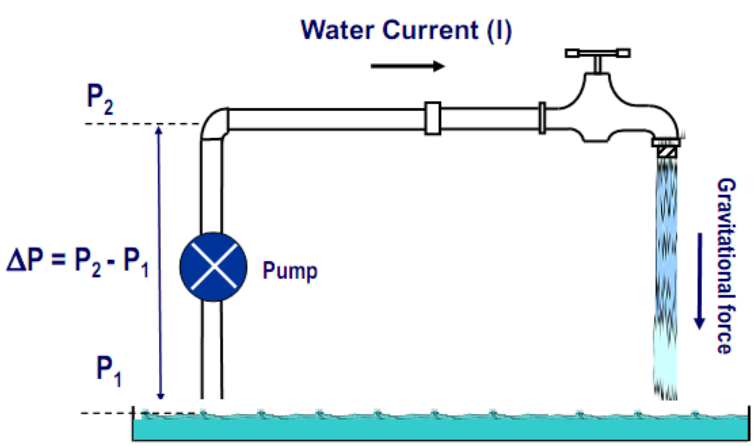
Water Circuit



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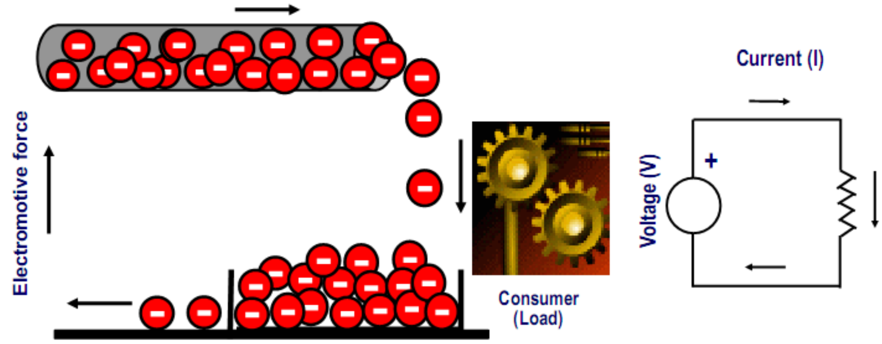
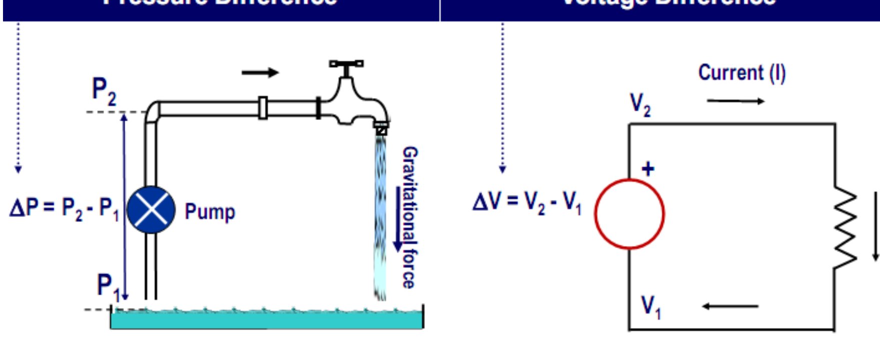
Electrical Circuit



Voltage Difference

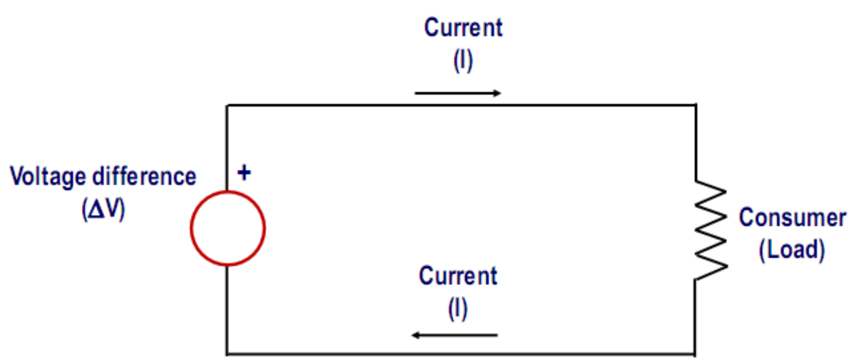
Pressure Difference	Voltage Difference



Electrical Current

Current = no. of electrons transferred / time duration
$I = \Delta Q / \Delta t$
1 Amp = 1 Coulomb / 1 Seconds

Charge = Current x Time duration
$\Delta Q = I \times \Delta t$



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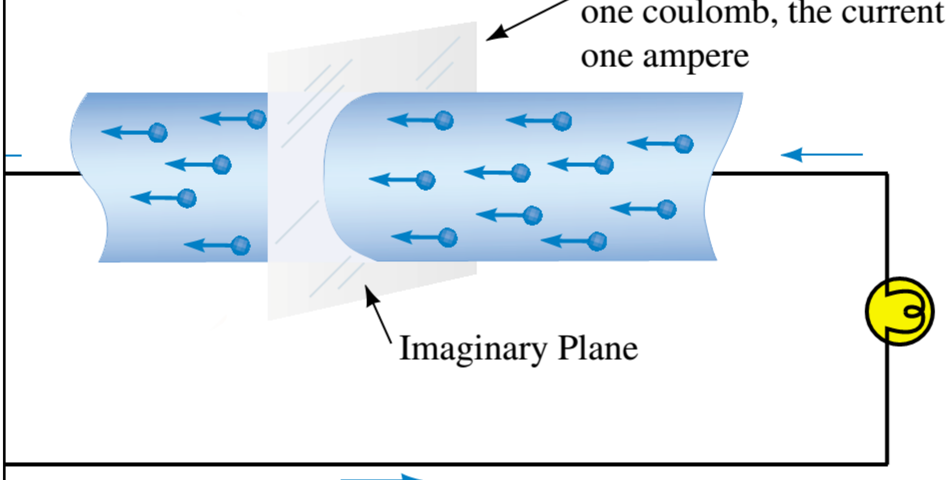
When the amount of charg
passes a point in one seco
one coulomb, the current i
one ampere



Movement of electrons through the wire

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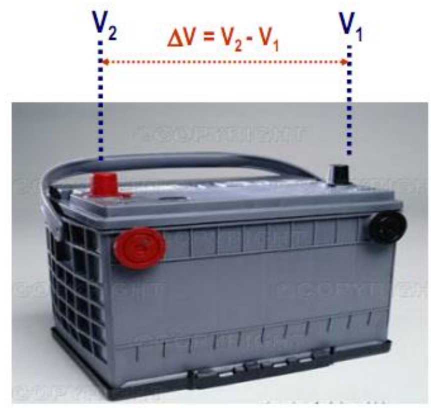
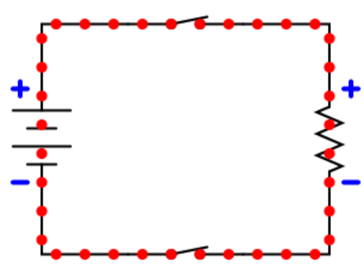
Electrical Current
DC (Direct Current) Sources



Direction of electron motion

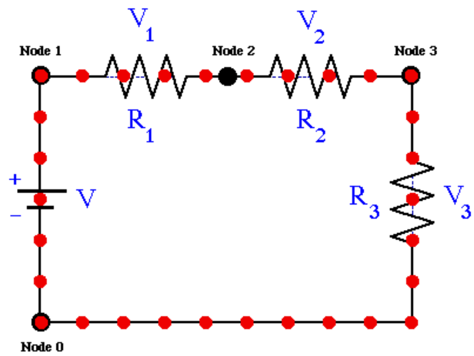


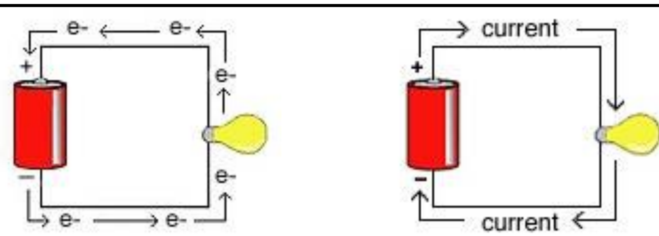
Electrons flow from the ***negative*** terminal to the ***positive*** terminal.

Their energy is provided by the battery.

Convention For Current Direction In A Circuit

For current flow, the convention is to show current in the external circuit directed ***away*** from the positive terminal and ***toward*** the negative terminal of the battery.





This convention for current arose from a guess made about the direction of movement of positive charge. For this reason the direction of conventional current is the direction opposite the electron flow.

This convention was established long before the discovery of electrons. It turned out that movement of negative charge (electrons) was in the opposite direction.

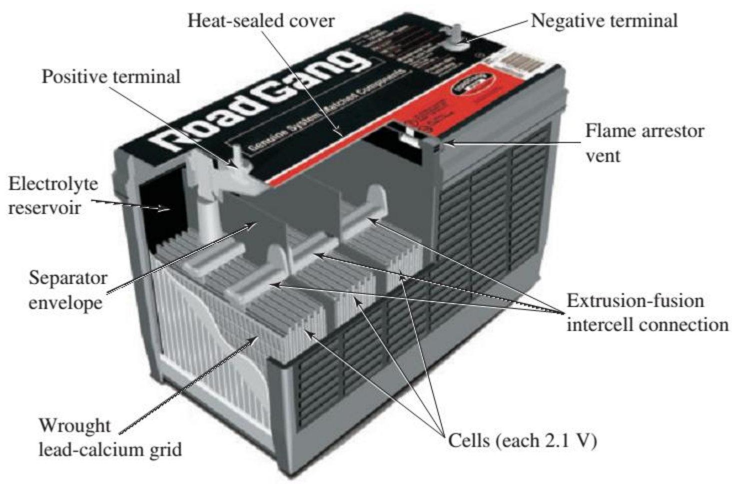
Yes, this is outdated, but it is still the convention when talking about current.

Voltage

- **Voltage is created by**
  - **a chemical cell (battery) when it changes chemical energy to electrical energy**
  - **by a generator when it changes mechanical energy to electrical energy**
  - **by a solar cell when it changes light energy to electrical energy.**

Batteries

lead-acid battery



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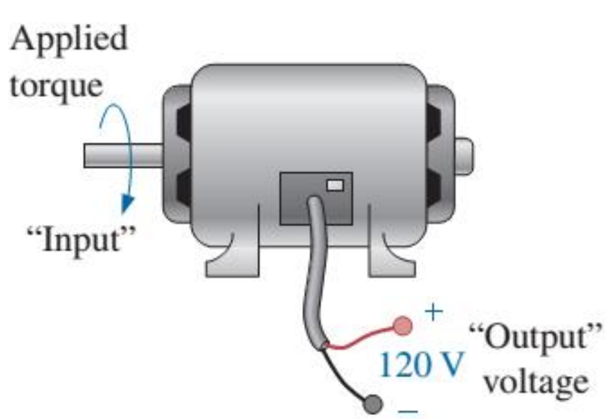
DC generator



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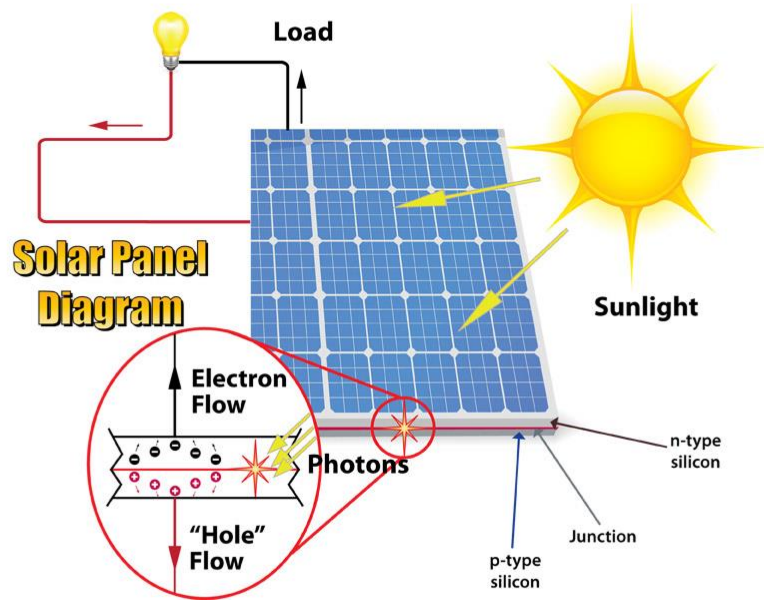
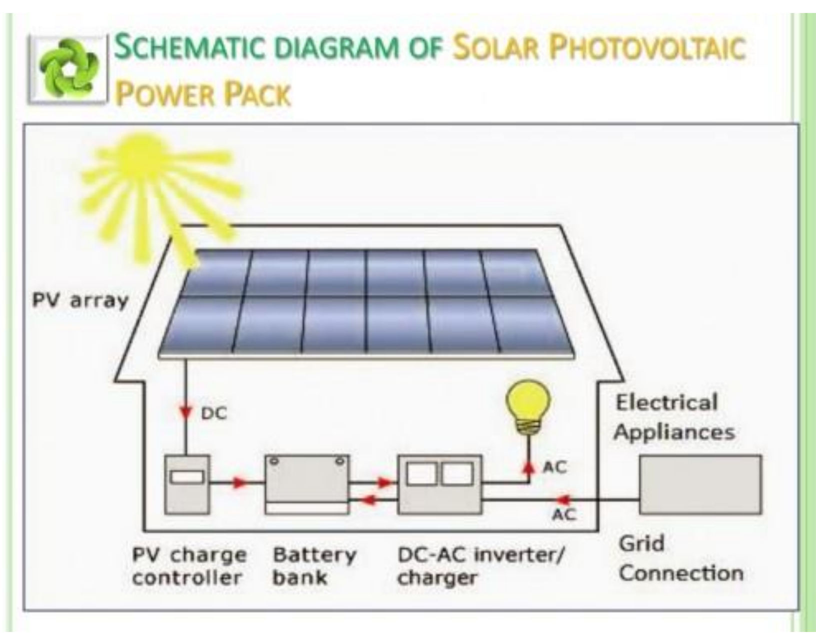


Load
Solar Panel
Diagram
Sunlight
Electron
Flow
Photons
"Hole"
Flow
n-type
silicon
Junction
p-type
silicon

55



SCHEMATIC DIAGRAM OF SOLAR PHOTOVOLTAIC
POWER PACK
PV array
DC
AC
AC
Electrical
Appliances
PV charge
controller
Battery
bank
DC-AC inverter/
charger
Grid
Connection

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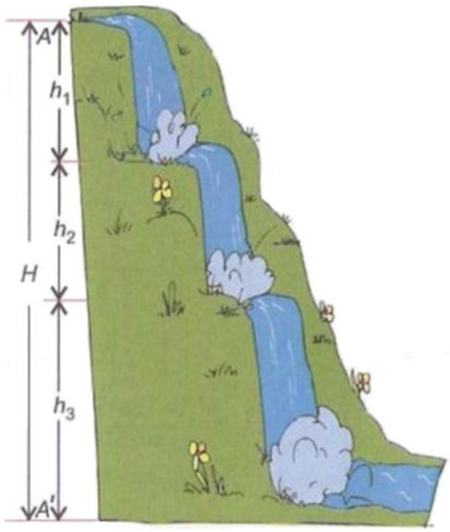
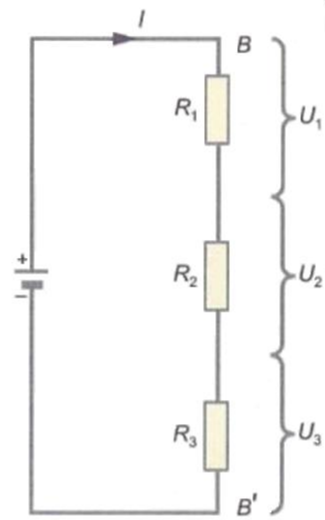
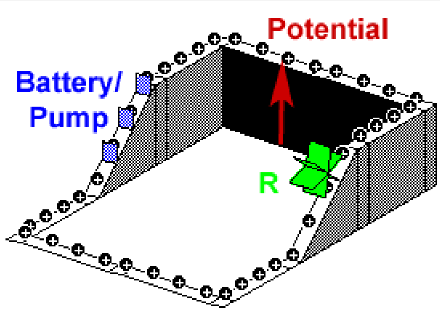
Voltage



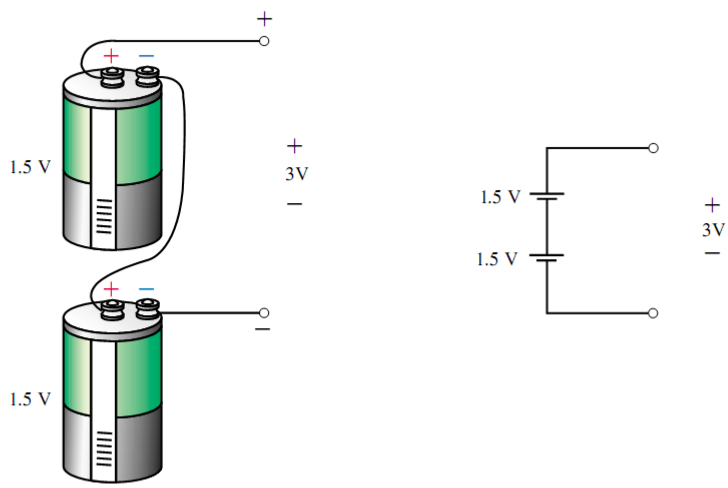




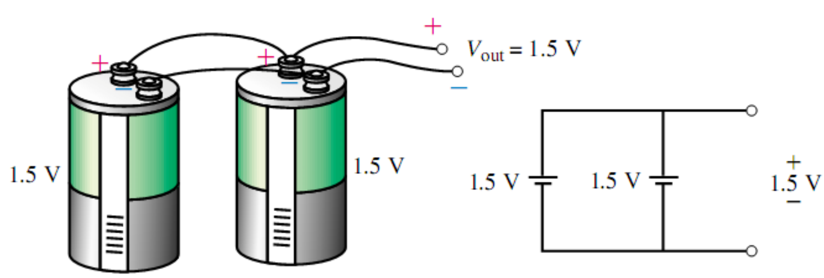
In this animation you should notice the following things:

1. The charges are only flowing in ***one direction*** so this would be considered ***direct current*** (**DC**).
2. The battery or **source** is represented by an escalator which ***raises charges to a higher level of energy.***
3. As the charges move through the **resistor** (represented by the paddle wheel) they do ***work on the resistor*** and as a result, they ***lose energy***.
4. By the time each charge makes it back to the battery, it has ***lost all the energy given to it by the battery.***

Cells in Series



Cells in Parallel



(a) Terminal voltage remains unchanged.

(b) Schematic representation