Electrical Energy

Objective: Learning about Electric Force, Electric Field, Ohm’s Law, Simple Circuits and Electric Power.

Key concepts:

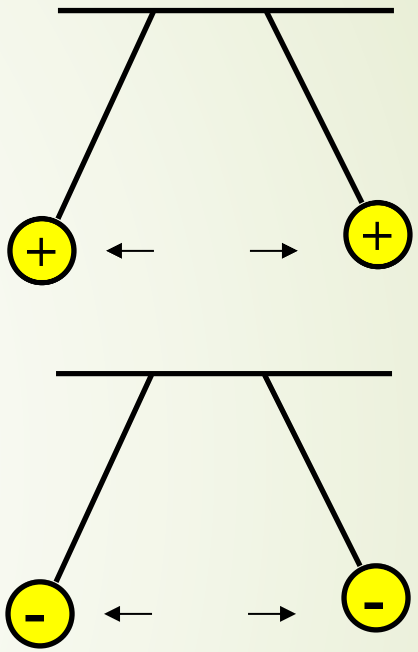
- ❖ Electric charge and charge conservation
- ❖ Electric force and fields
- ❖ Voltage, Current and Resistance
- ❖ Ohm’s law
- ❖ Electric Power
- ❖ Series and Parallel Circuit

Electric charge

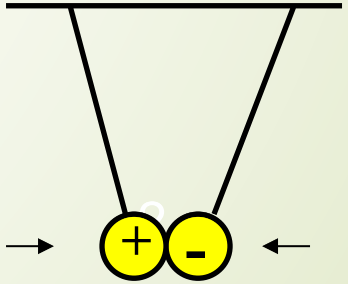
Electric charge is a fundamental property of matter.

- Charge comes in two varieties, positive and negative.
- Protons carry the same positive charge, which is known as the elementary charge $e = 1.6 \times 10^{-16}$ *C*. Electrons carry the same negative charge, $-e$.
- Any positive or negative charge q will be multiples of e, *i.e. charge is quantized!* $q = n\,e\,;\; n = \pm 1, \pm 2, \pm 3 \ldots$.
- Electric charge is conserved: the net charge of a closed region remains constant.
- Law of conservation of charge states that charge can neither be created nor destroyed, and the total charge is constant in any process.

Like Charges repel one another



Unlike charges attract one another

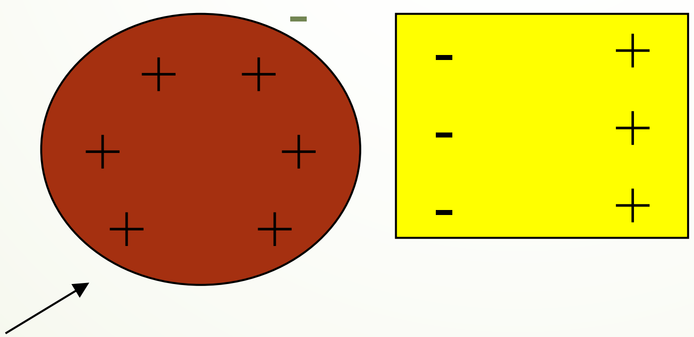


How can materials be charged?

- By rubbing against each other: One material loses electrons (get positively charged) while the other collects (captures) more electrons (get negatively charged)

- Touching a charged object to a neutral object: The neutral object will acquire the same charge as the charged object.

- Induction: By bringing the object closer (not touch) to an already charged object



Charges on the second object separates

Positively charged object

Electric Force

Electric force or Coulomb force is a fundamental force of nature and acts without physical contact between two objects.

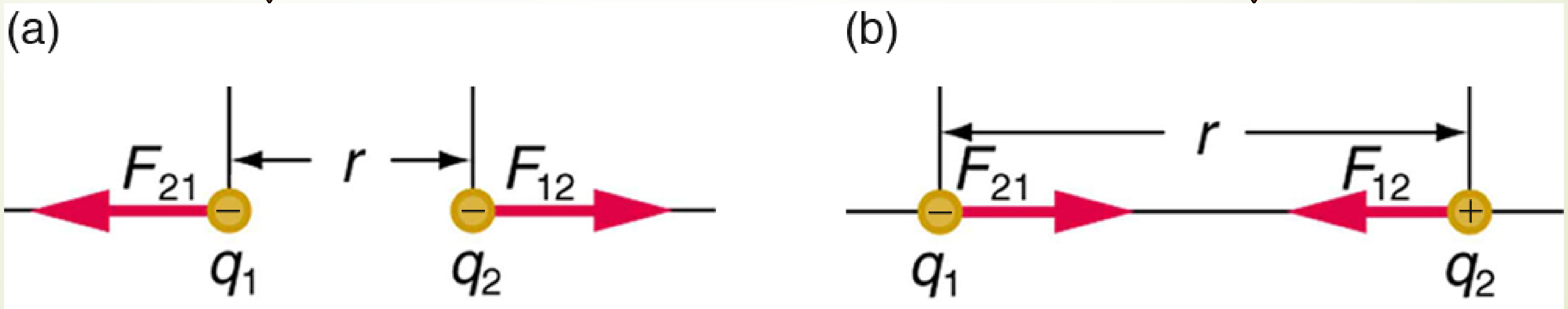
- The magnitude of the force depends on the magnitude of the charges and the inverse square of the distance between them.
- Both gravity and coulomb force are inverse square law, but coulomb force is incredibly stronger!

$$F = k\frac{q_1\ q_2}{r^2}$$

k = 9 x 10^9 Nm^2/C^2

F is repulsive

F is attractive



Electric Force

Relationship between charge and force is Coulomb's Law:

$$F = k\frac{q_1\ q_2}{r^2}$$

(A) Relationship between force of interaction F and **charge** (q_1 or q_2) is

(B) Relationship between force of interaction F and distance **d** between charges is

(C) If either q_1 or q_2 is doubled, the force of interaction F will be

(D) If the distance between the charges is doubled, the force F will be

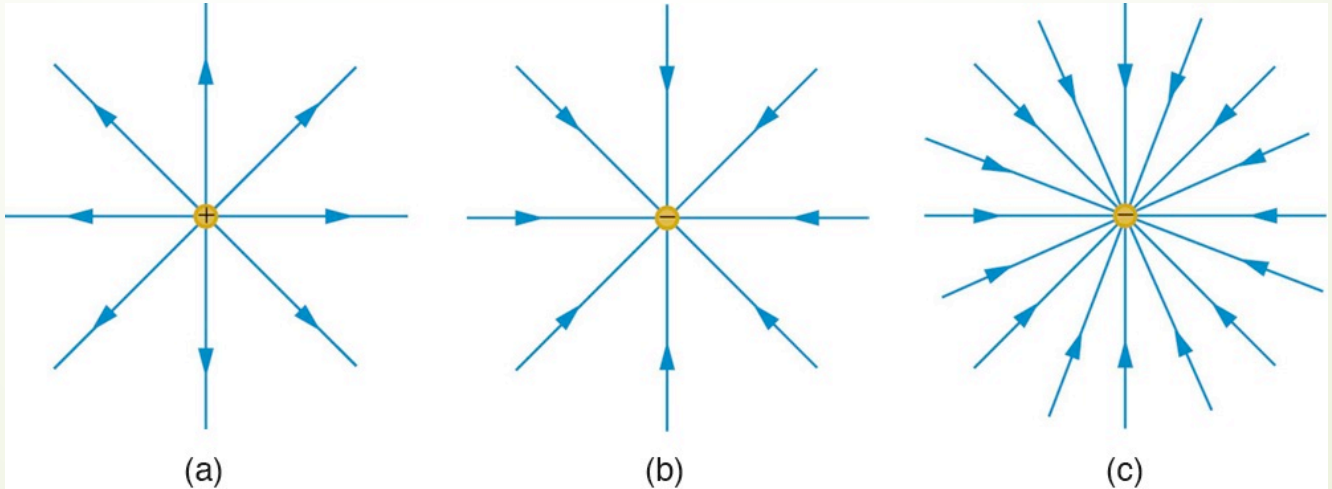
Electric Field and Field lines

Electric field occupies the space that surrounds any charged object.

- Electric field is a vector quantity (having magnitude and direction)
- Magnitude of Electric field at any point is force per unit charge,

$$|\boldsymbol{E}| = \frac{|\boldsymbol{F}|}{q} = k\frac{Q}{r^2}$$

- Obeys the inverse-square law for a point charge.
- Field line are used to visualize the electric field.
- Direction of electric field—*away from positive charge and toward negative charge.*
- *Number of field lines show intensity of electric field!*



Electric Potential

When a charge q is accelerated by an electric field, its electric potential energy is converted to kinetic energy.

- The potential difference ΔV between two points is defined as the ratio of the $\Delta P.E.$ and the charge q.

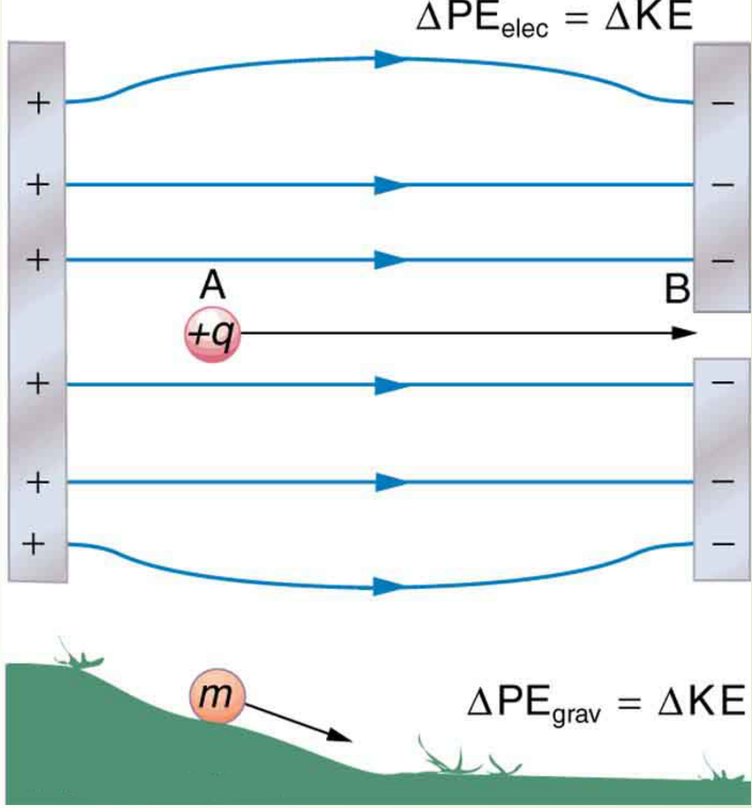
$$\Delta V = V_B - V_A = \frac{\Delta PE}{q}.$$

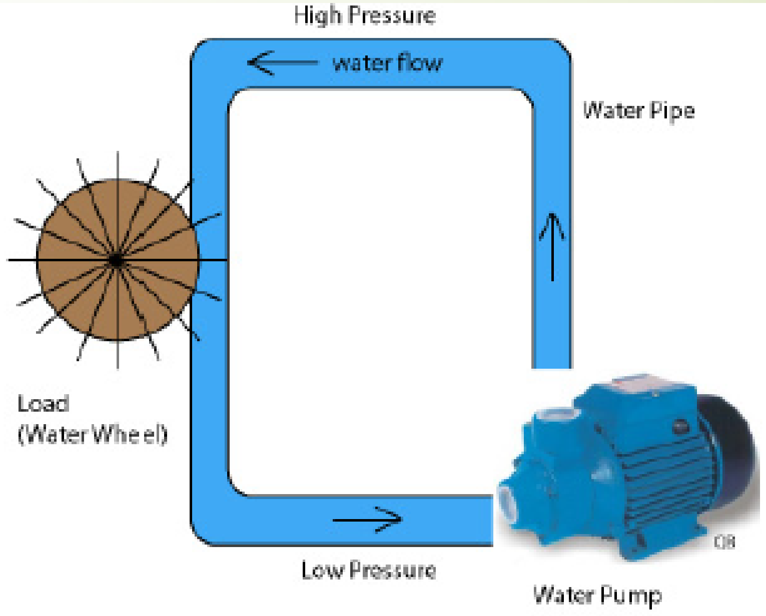
$$\text{Voltage} = \frac{\text{potential energy}}{\text{unit charge}}$$

$$\text{Volt (V)} = \frac{\text{Joule (J)}}{\text{Coulomb (C)}}$$

- Just as gravitational PE can be converted to KE, electric PE is converted to KE of electrical charge.

- Charges flow in a wire when there is a difference in electrical potential. *Electrical voltage provides the energy to push the charges (Current) through the wire, and a Pump provides energy to create the flow of water through the water pipe.*





Electric Current and Resistance

Electric Current: the rate at which flow of electric charge.

$$I = \frac{\Delta Q}{\Delta t},$$

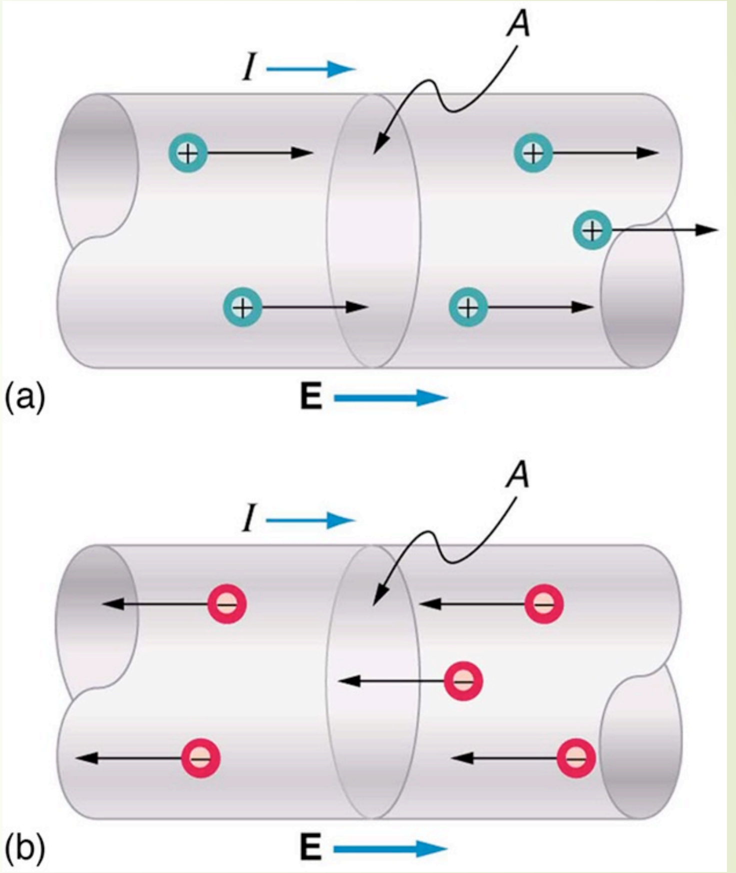
- The SI unit for current is the **ampere** (A), an ampere is one coulomb per second or 6.25 billion billion electrons per second

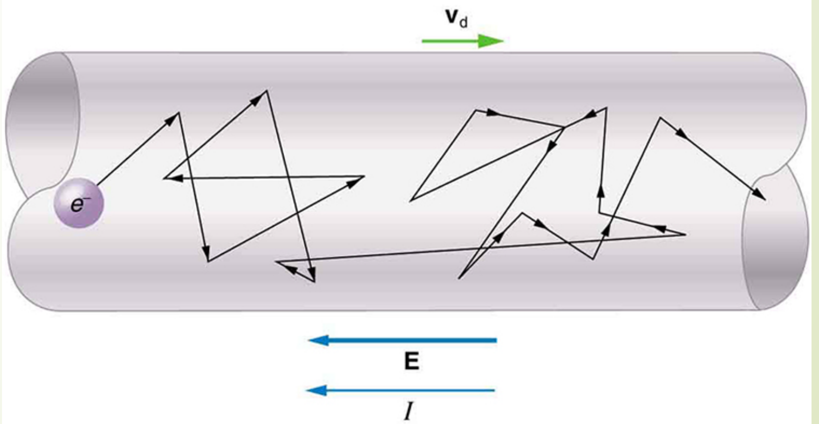
$$1\ \text{A} = 1\ \text{C/s}$$

- The direction of conventional current is the direction that positive charge would flow.

Resistance: The electric property that impedes current (crudely similar to friction and air resistance) is called **resistance** *R*.

- Collisions of moving charges with atoms and molecules in a substance transfer energy to the substance and limit current.
- The SI unit for resistance is **ohm** (Ω).





Ohm's Law

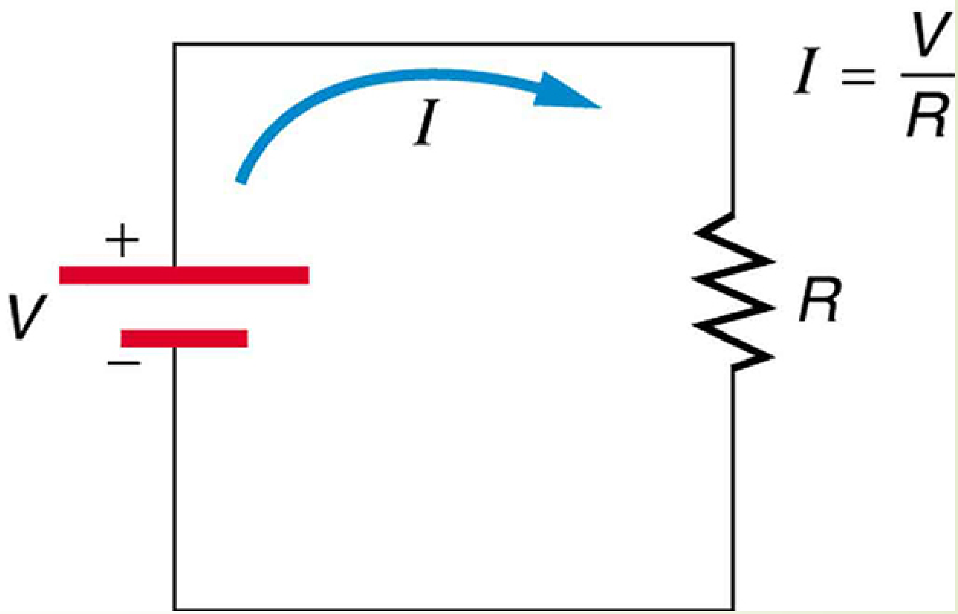
Relationship between voltage, current and resistance is called **Ohm's Law**.

- The current that flows through most substances is directly proportional to the voltage *V* applied to it.
- The current that flows through most object is inversely proportional to the resistance of that object.
- **Ohm's law** is commonly expressed as,

$$\text{current} = \frac{\text{voltage}}{\text{resistance}} \quad \text{or} \quad I = \frac{V}{R}$$

- Most substances for which Ohm's law holds are called **ohmic**.

****Ohm's law is not universally valid!*



$$\text{Amperes(A)} = \frac{\text{volts(v)}}{\text{ohms}(\Omega)}$$

Ohm's Law

Relationship between voltage, current and resistance is called Ohm's Law:

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

(A) Relationship between current and voltage is

(B) Relationship between current and resistance is

(C) Relationship between voltage and resistance is

(D) If you double the voltage, the current will be times _____

(E) If you double the resistance, the current will be times _____

** Try the tutorial to verify your understanding https://www.walter-fendt.de/html5/phen/ohmslaw_en.htm

Ohm's Law

Practice problems: $V = IR \quad \text{or} \quad I = \frac{V}{R}$

(A) How much current flows through a 12 V radio speaker having a resistance of 8 Ω?

(B) If an appliance draws a current of 20 A running off of a 120 V line, what is its resistance?

Electric Power

Electric Power: Rate of doing work.

- Relationship between electric power, voltage and current is: P = IV

$$P = IV$$

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

$$P = I^2R.$$

- SI Unit for power: Watts (W) = amperes (A) x volts (V)

(A) Relationship between power and current is

(B) Relationship between power and voltage is

If you triple the voltage, the power will be times _____

Electric Power

Practice problems

$$P = IV$$

(A) A 50 W light bulb draws 0.40 A current. What is the voltage?

(B) A 6 V appliance draws 2 A of current. What is the power usage of this appliance?

Electric circuits – series and parallel

Most electric circuits are series, parallel or a combination of them.

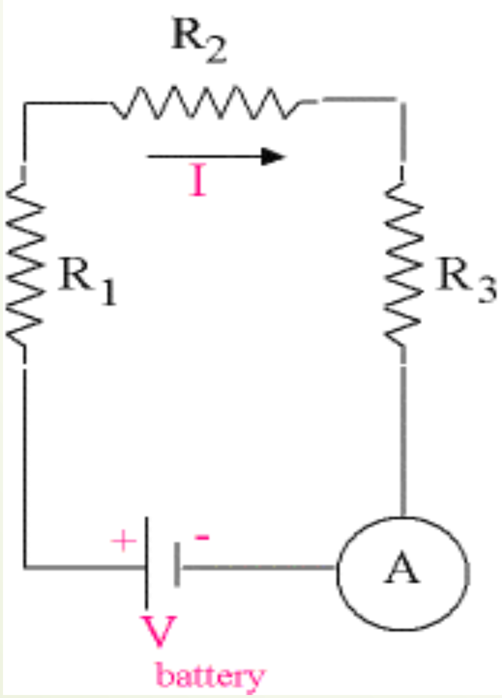
Series: Only one path for the current to flow.

- Same current passes through all series resistors

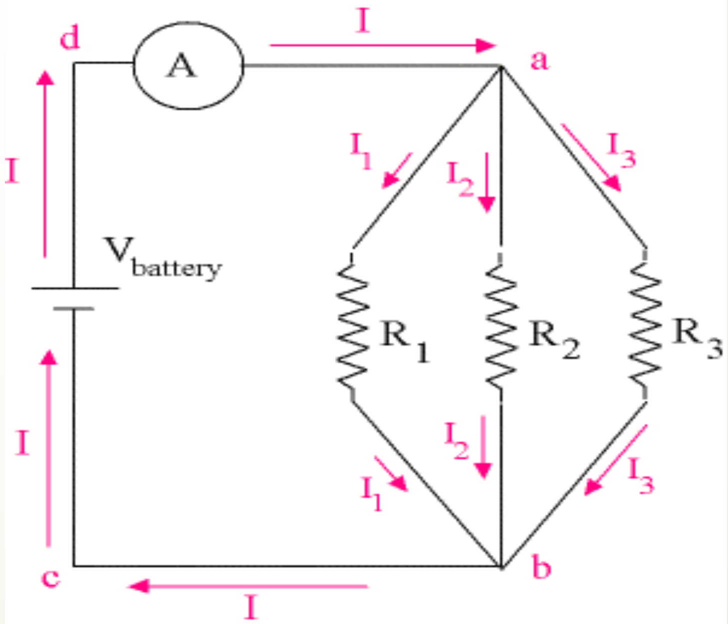
Parallel: More than one path for the current to flow.

- Same voltage difference between opposite end of each parallel path.

Series ➡ $R_{eq} = R_1 + R_2 (+R_3 + \ldots)$



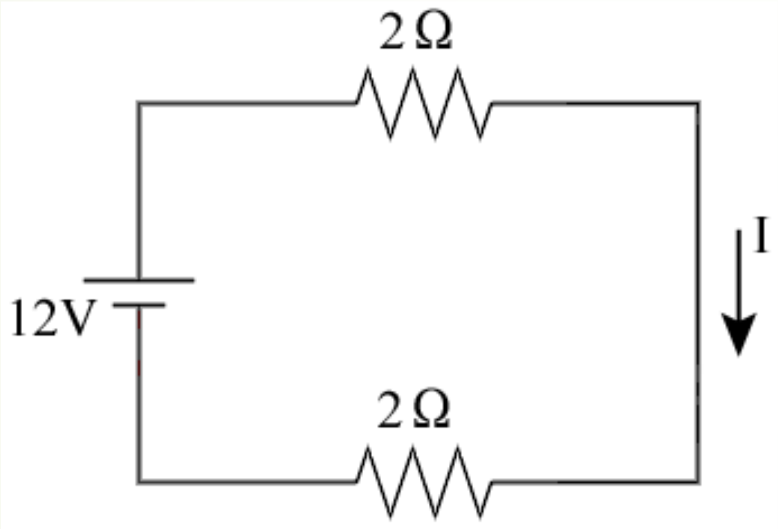
Parallel ➡ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \left(\frac{1}{R_3} + \ldots\right)$



*At home we have more parallel circuits

SERIES Circuit Example

First, **Find the Total Resistance = ________**



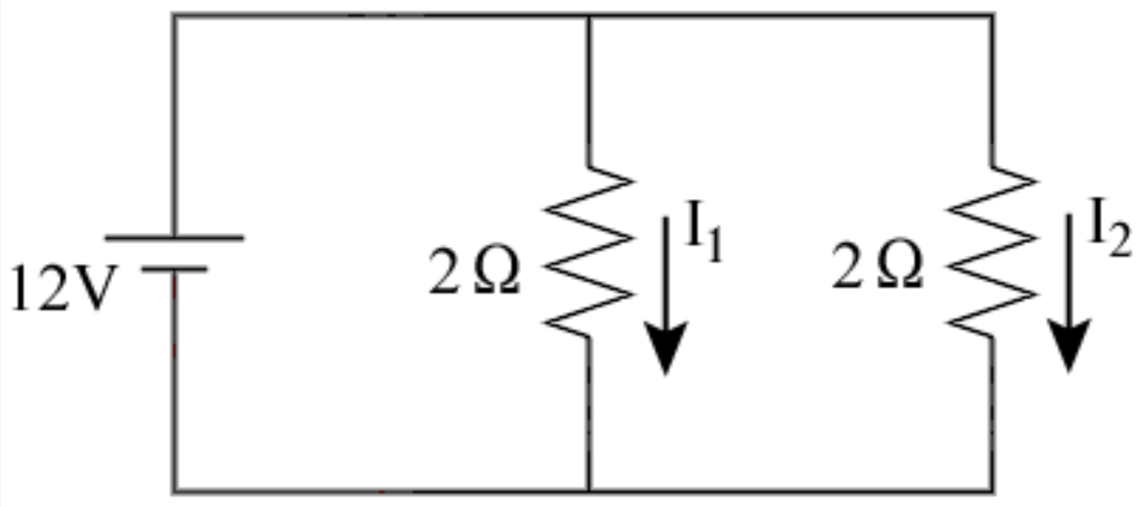
Second, **Find the Net Current = I = __________**

** Try the tutorial to verify your understanding https://www.walter-fendt.de/html5/phen/combinationresistors_en.htm

Parallel Circuit Example

First, **Find I_1 =** ___________

and also **Find I_2 =** ___________



Second, **Find the Net Current** = _________

and the effective combined R = V / I = ___________

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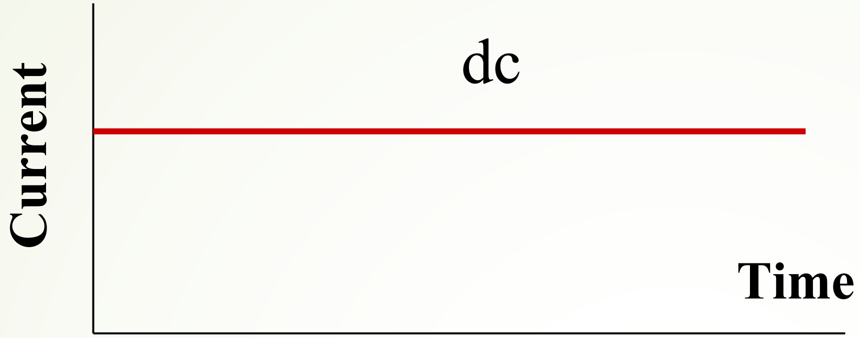
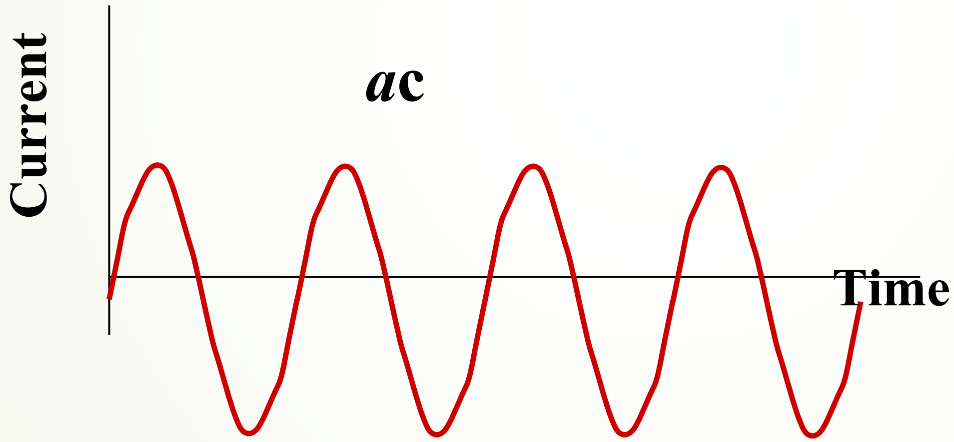
Direct current (dc) and Alternating current (ac)



Current flows in one
Direction (e.g. Batteries)



Current changes direction
(e.g. Household Power Supply)

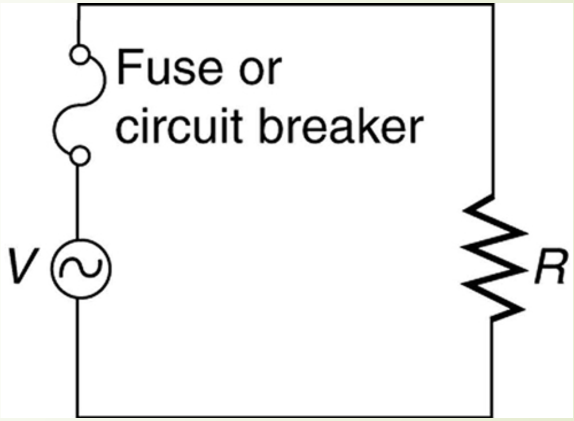
Frequency 60 Hertz (Hz) → current changes direction back and forth 60 times a second in U.S.

Electric Hazards and Safety

The current that flows through the body causes electric shock

- Dry body ~ 500,000 Ω
- Wet body ~ only few hundred Ω - easy to get an electric shock

Current (A)	Effect
0.001	Can be felt
0.005	Is painful
0.01	Causes involuntary contractions
0.015	Causes loss of muscle control
0.070	Can be fatal



**When a circuit carry more than a safe amount of current the circuit is said to be overloaded. When too many appliances are used at once in parallel combination, it may cause overloading of the circuit. We use fuses or circuit breakers to prevent damages to appliances and the circuit.

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