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Electrostatics

Physics Rapid Learning Series

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Learning Objectives

By completing this tutorial, you will:

- Understand the nature of electric charge.
- Apply Coulomb's law to electric forces.
- Describe the electric field of charged objects.
- Explain the concept of electric potential.
- Apply these concepts to explain physical phenomena.

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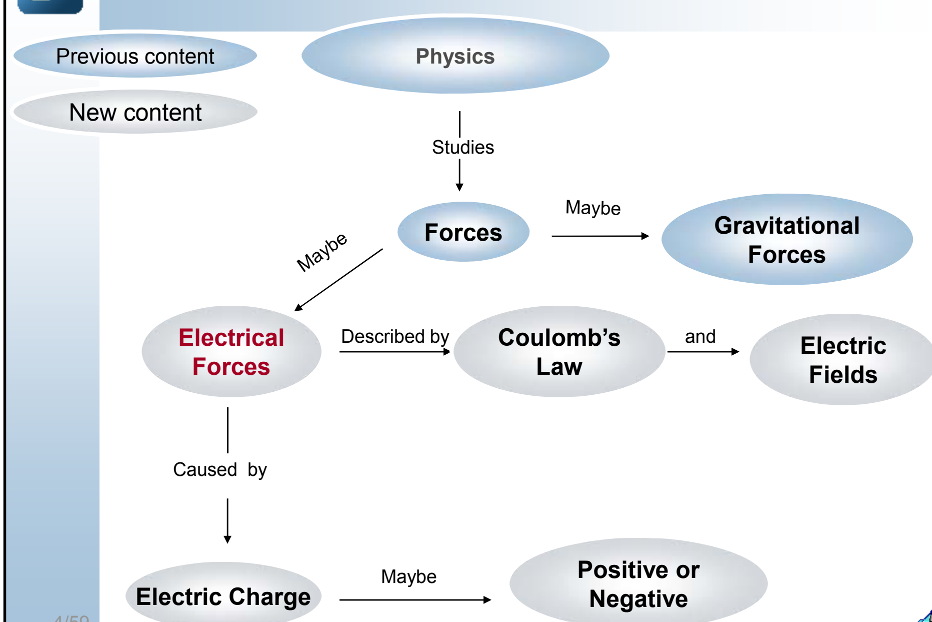
Electrostatics



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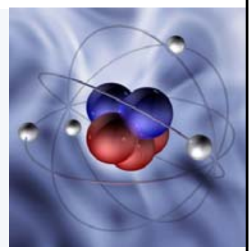
Electric Charge



Although it may not be immediately noticeable, electric charge is all around you.

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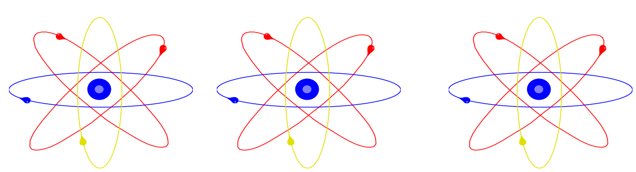
Electric Charges

Electric charge is a fundamental quantity that is responsible for all electric phenomena.

Charge is a property of all atomic particles.



Charge can be positive, negative, or neutral.

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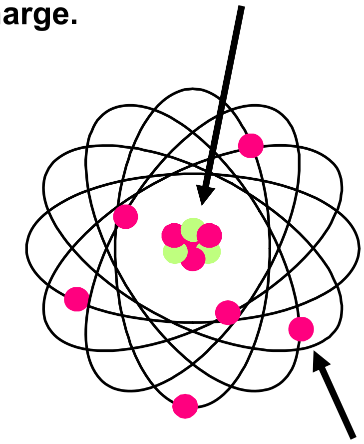
Atoms

In general, the heavy nuclei of atoms have a positive charge.



The small, light, negative electrons reside in shells or orbits outside the nucleus.

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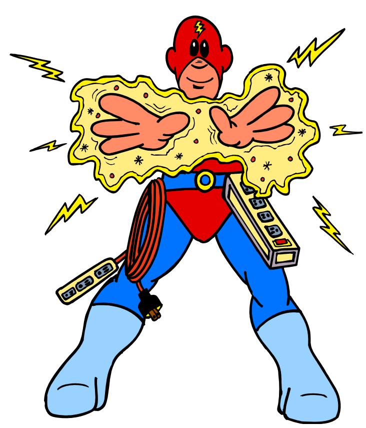
Electrons and You

Your body contains an astronomical number of electrons. (Far more than would be needed to electrocute a person.)



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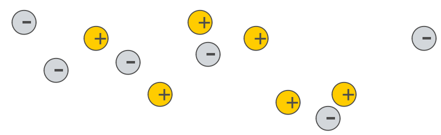
Balance of Charge

The negative electrons are balanced by an approximately equal number of positive protons.



This balance gives a net charge of zero (neutral).

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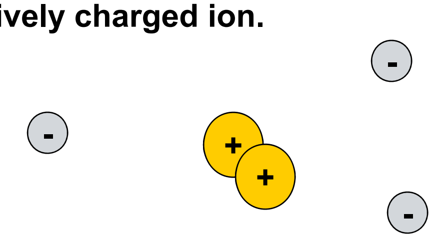
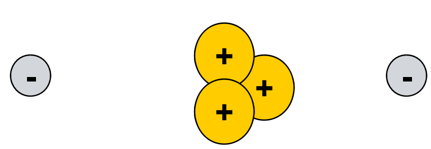
Ions

While your body, and most other atoms are typically neutral, sometimes there is an imbalance of charge.

If there is an excess of electrons, you have a negatively charged ion.



If there is a lack of electrons, you have a positively charged ion.



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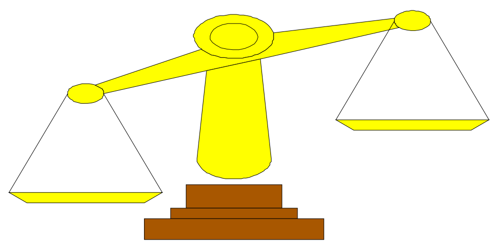
Conservation of Charge

When one item has "extra" electrons, this means that something else must have "lost" electrons.



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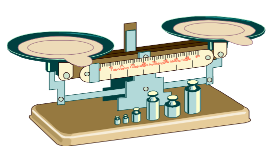
Conserved Quantities

Just as mass, energy, and momentum are conserved, so is electric charge.



You can't create or destroy electric charge, it is just transferred or moved from one object to another.

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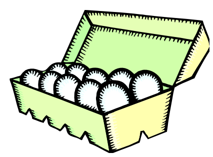
Charge Unit

Since electrons are much too small and numerous to be counted individually, they are counted in groups called Coulombs.

1 Coulomb, C, = 6.25×10^{18} electrons.



This is analogous to a dozen containing 12 items.

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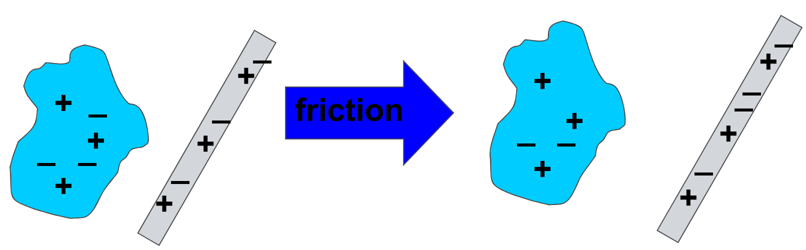
Charging by Contact

Simply rubbing one object against another can transfer electrons. This makes one positive and one negatively charged object.



<u>Before:</u> both neutral

<u>After:</u> Silk positive, glass negative

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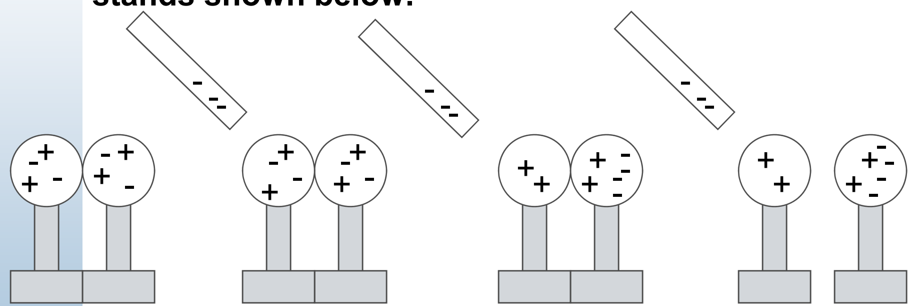
Charging by Induction

Even without direct contact, you can induce the electrons to move due to the electric force acting on them. Consider the metal spheres on insulating stands shown below.



1. Both neutral at first

2. Negative rod separates charges.

3. Separate the spheres

4. Remove rod, spheres are now charged.

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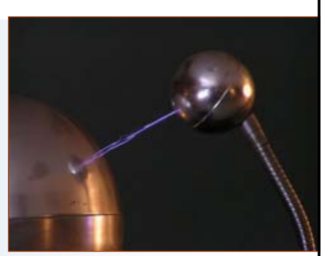
Coulomb's Law and Electric Forces



In this section of the tutorial, you will explore the nature of electrical forces.

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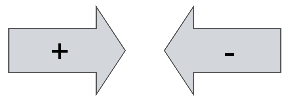
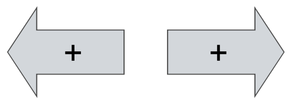
Electrical Forces

Opposites attract.



Likes repel.



This is due to a force arising from the electric charge on particles.

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Coulomb's Law

The law that quantitatively relates the attraction or repulsion of electric charges.

$$F_E = \frac{kq_1q_2}{r^2}$$

- **Constant = $9\text{x}10^9$ Nm^2/C^2** (k)
- **Two electric charges, C.** (q_1, q_2)
- **Electric Force, N** (F_E)
- **Distance between two charges, m.** (r)

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Another Form

In **Coulomb's Law**, k may be replaced with:

$$k = \frac{1}{4\pi \varepsilon_o}$$

ε_o= permittivity of free space=8.85 x 10 $^{-12}$ $C^2/N\ m^2$

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Coulomb's Law Example

Imagine that a +2x10^{-5} C charge is located 2m away from a +3x10 $^{-5}$ C charge. What force acts on them? Is it repulsive or attractive?

3 x 10^{-5} C

2 x 10^{-5} C

2m

F = ???

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Example Solution

$$F_E = \frac{kq_1q_2}{r^2}$$

$$F_E = \frac{(9\times10^9\,Nm^2/C^2)(+2\times10^{-5}\,C)(+3\times10^{-5}\,C)}{(2m)^2}$$

Notice how the units cancel out.

$$F_E = +1.35N$$

Since both charged were positive, the resulting force is repulsive.

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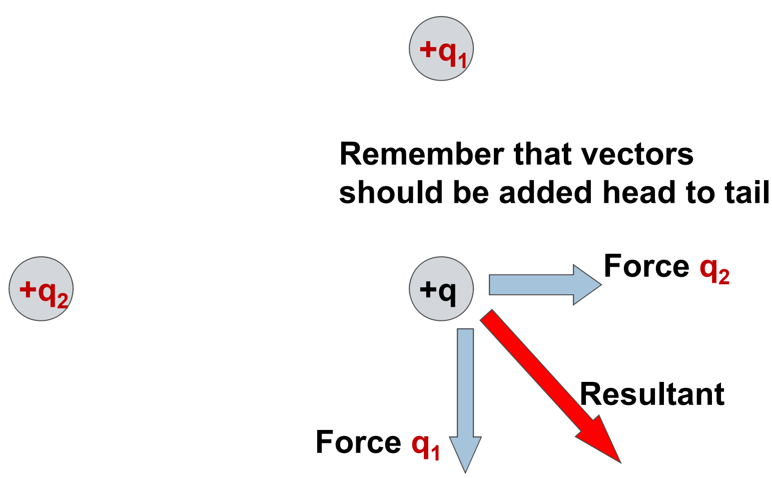
Forces in 2 Dimensions

Problems involving Coulombs law may be in one or more directions.



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Physics Formulas

Coulomb's law looks very similar to what other law (formula) you may have learned in a previous tutorial?

Newton's universal law of gravitation.

$$F_G = \frac{G\, m_1 m_2}{d^2} \quad \Longleftrightarrow \quad F_E = \frac{k\, q_1 q_2}{r^2}$$

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Similarities and Differences

- Both are inverse square laws.
- Both have a constant (G, k).
- Both depend on a fundamental property (mass, charge).
- However, the electric force can be attractive or repulsive. The gravitational force is only attractive.

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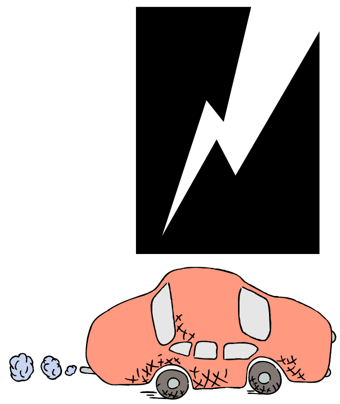
Lightning Strike Safety

If you are inside your car when it is struck by lightning, you will survive. Why?



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Lightning Strike Explanation

The electrons repel themselves to the extreme outside of the car.

Two electrons wouldn't want to be near each other on the inside by you.

The electricity flows around the outside of the car, not through you.

This would happen even if there were no rubber tires at all on the car!

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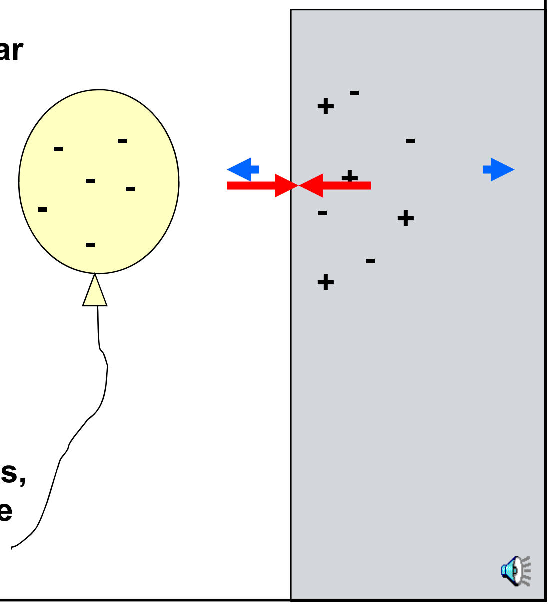
Charge Polarization

Imagine bringing a charged balloon near a neutral wall.

Notice how the wall is still neutral, but the charge is separated, or <u>polarized</u>.

Since the opposite charges are closer than the like charges, a net attractive force is present.



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Electric Fields

Any type of field shows the influence of a particular force, this section will specifically describe electric fields.

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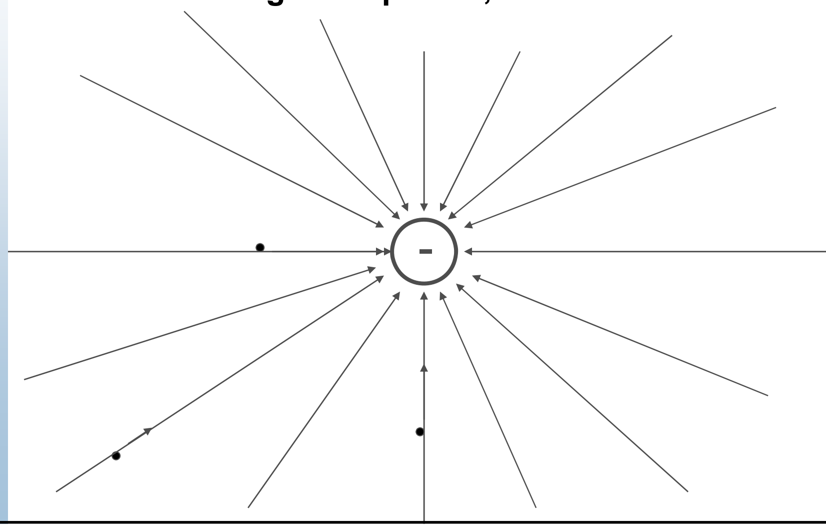
Electric Field

Imagine there is a cluster of – charge as shown.

If a small + charge was placed, what force would it feel?



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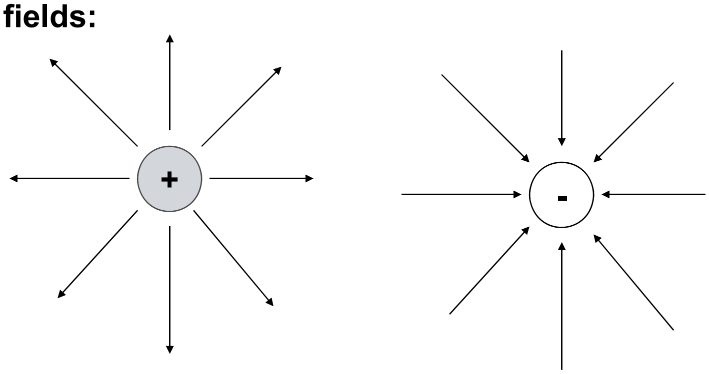
Force Lines

This "map of force lines" shows what a small positive test charge will do when exposed to any particular field.

When lines are closer together, that means the force is stronger. Here are some pictures of various fields:



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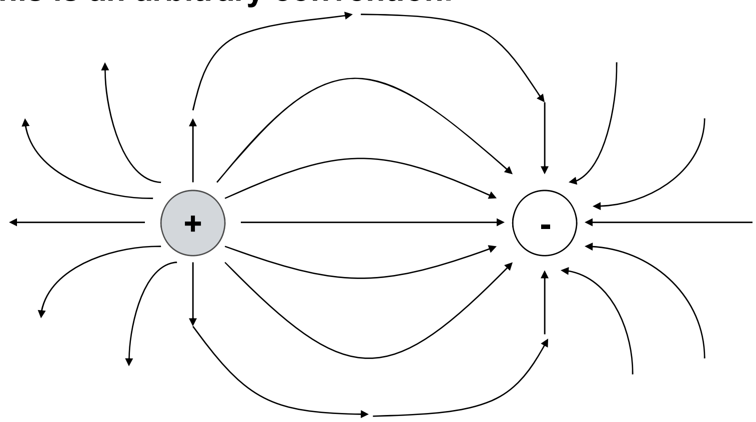
Field Lines

Notice how the field lines always go from + to -. This is an arbitrary convention.



Also, they never simply stop in empty space. Lines may go off the paper, but they actually continue indefinitely…

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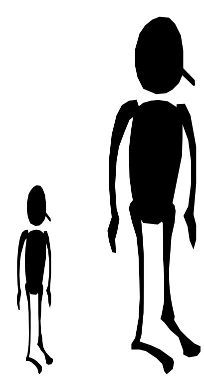
Test Charges

Compared to the other charges, the positive test charge must be small so that the force between it and the existing charges doesn't disturb or alter the situation.



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E Field Strength

The strength of the E field can be found by a ratio of the force on the test charge, and the magnitude of the test charge itself.

$$\vec{E} = \frac{F}{q}$$

Electric field, N/C

Electric Force, N

Electric charge, C

Electric field is a vector quantity.

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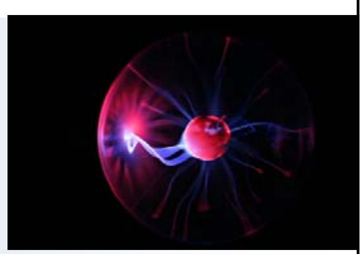
Electric Potential



Electric potential, or voltage, is a particularly abstract concept that will be explained in detail in this section.

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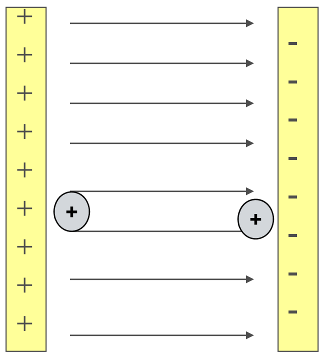
Work and the Electric Field

Imagine two oppositely charged metal plates and the electric field between them.



Work is done by the electric field in moving a positive charge.

If the charge were moved counter to the field, work would be required.

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Electric Potential Definition

How much work is done, depends on the amount of charge.

Electric potential describes how much work is done, per amount of charge. It is the work needed to bring the charge from some arbitary zero point to the position of interest.

$$\text{Electric Potential} = \frac{\text{Electric Potential Energy}}{\text{Charge}}$$

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Electric Potential Formula

Electric potential, or just potential is the potential energy per unit charge.

Thus, if the charge is larger, more work is done.

$$V = \frac{PE}{q}$$

Electric potential, V

Electric potential energy, J

Electric charge, C

Sometimes potential energy is written as U_E instead of PE.

$$U_E = Vq$$

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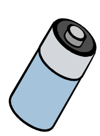
Electric Potential Unit

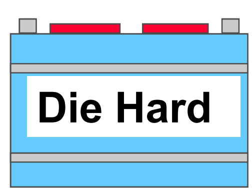
A Joule per Coulomb is defined as a Volt.

1 V = 1 J / 1C

A volt is the basic unit of electric potential difference which is sometimes called voltage.

Named after Alessandro Volta, who invented the electric battery.





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Electron-Volt

A Joule represents a fairly large unit of energy. For some electrical and chemical purposes a smaller unit is more useful.

Remember: $U_E = qV$

An electron volt is one electron moving through a potential difference of 1V.

$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$

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Vocabulary Caution

Despite the name similarity, electric potential is NOT the same as potential energy.

Electric potential describes how much work could be done per amount of charge.

Electric potential energy is simply an amount of energy or work due to static charge.

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Mechanical and Electrical Energy

Just as the concept of conservation of mechanical energy can be very useful, so can conservation of electrical energy. There are many other similarities too.

Gravitational potential energy is derived from the earth's gravitational field. Electrical potential energy, is derived from an electric field.

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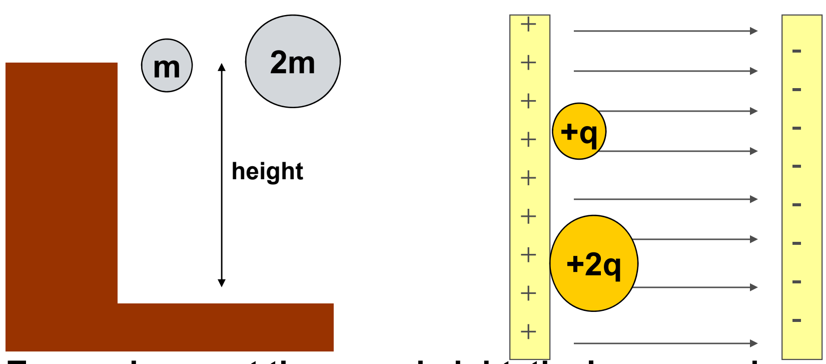
Mechanical / Electrical Energy



Two rocks are at the same height, the larger one has more PE.

Two charges have the same electric potential, the larger charge has more PE.

The height or location is equivalent to the electric potential.

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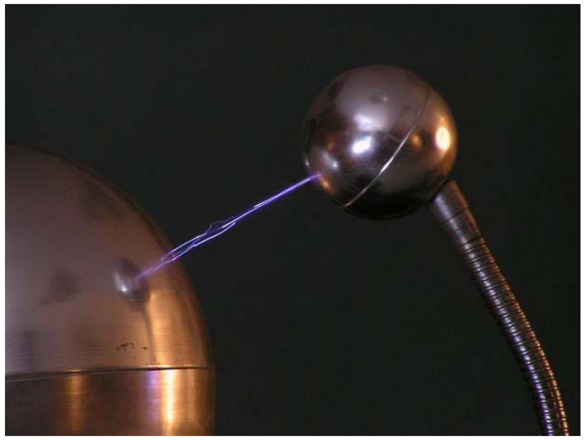
VanDeGraff Generator



Charge accumulates on the metal dome, when enough electrons build up, and a high enough voltage is reached they repel so much that they jump through the air creating a spark!

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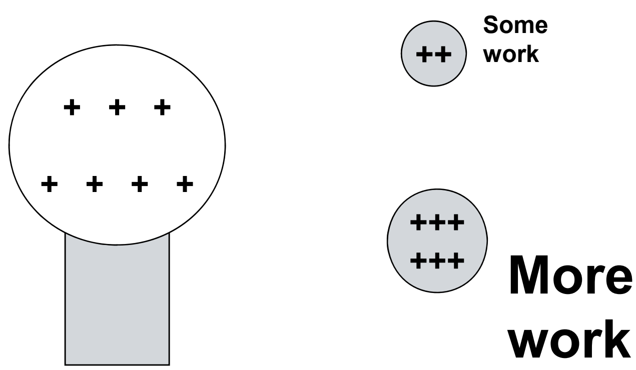
High Voltage



Both groups of charges on the side are at the same electric potential (voltage).

However, it would take much more work to move the lower one closer since it has a larger charge...

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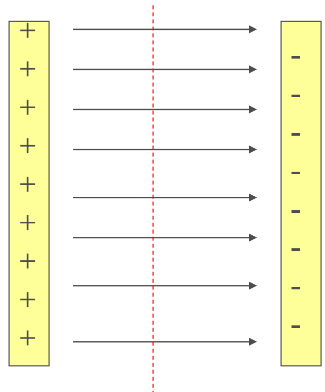
Electric Potential & Electric Fields

Imagine an electric field produced between two parallel charged plates. A relationship between the E field and the potential can be derived.



Any charge along this dotted line would have the same electric potential.

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Equipotential Lines Analog

In a topographic map, contour lines show areas of equal elevation. This means that every point on that line has the same gravitational potential energy.

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Equipotential Lines

A similar "map" could be made for equal potential lines in an E field.

All equipotential lines must be perpendicular to the E field lines.

If this weren't true, it would require work to move a charge along an equipotential line, thus violating the idea of equal potential!

Recall that no work is done if F is perpendicular to distance.

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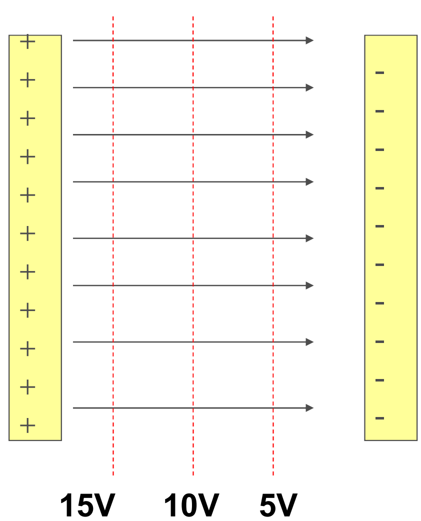
Equipotential Diagram

Solid lines are E field lines.

Dotted lines are equipotential lines.

No work would be required to move a charge along these equipotential lines.

Each would represent a different electric potential.



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Electric Point Potential Formula

The electric potential from a single point charge at any distance can be found using:

$$V = k\frac{q}{r}$$

- Electric potential, V
- Electric charge, C
- Constant = $9x10^9 Nm^2/C^2$
- Radius or distance, m

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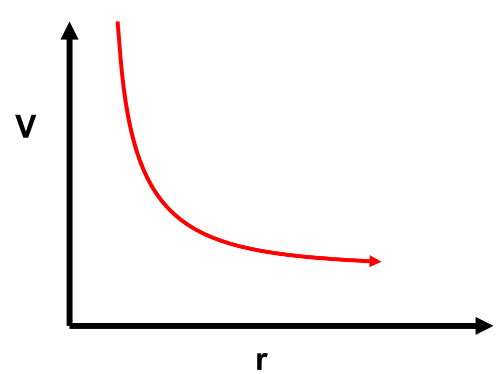
Electric Potential vs Distance

Notice that electric potential, V, decreases with the first power of the distance. Whereas the electric field and force decrease with the square of the distance.



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Scalar Quantity

If a point is acted on by two or more charges, the electric potential is simply the sum of those potentials.

Since Electric potential is a scalar, you don't have to worry about direction.

However, keep track of the signs...

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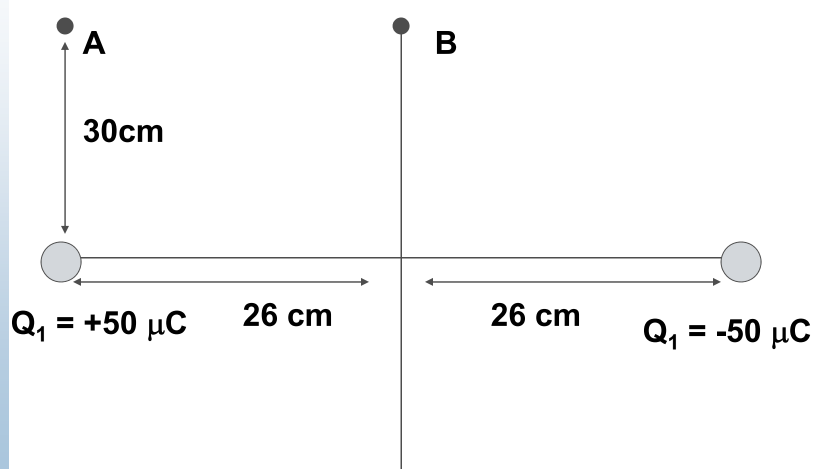
Combined Point Charge Example

Find the electric potential at points A and B.



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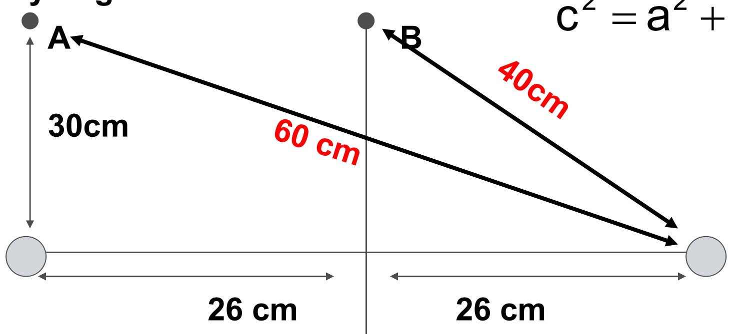
Solution Setup

First find the distances needed by using the Pythagorean theorem:

$$c^2 = a^2 + b^2$$



$$c = \sqrt{30cm^2 + 52cm^2} \qquad c = \sqrt{30cm^2 + 26cm^2}$$

$$c = 60cm \qquad c = 40cm$$

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Unit Conversion

Next, convert the micro Coulomb unit into regular Coulombs.

$$50\ \mu C \times \frac{1C}{1\text{x}10^6\ \mu C} = 5\text{x}10^{-5}\ C$$

Multiply by the proper conversion fraction.

Cancel out units.

Do math to obtain correct value.

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Electric Potential Calculation A

$$V = k\frac{q_1}{r_1} + k\frac{q_2}{r_2}$$

$$V = (9x10^9 Nm^2/C^2)\frac{5x10^{-5}C}{.3m} + (9x10^9 Nm^2/C^2)\frac{-5x10^{-5}C}{.6m}$$

$$v = 1.5x10^6 V - 7.5x10^5 V$$

$$v_A = +7.5x10^5 V$$

Keep track of the signs, use the correct values. Notice that the total electric potential is a combination of the influence of the two point charges.

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Electric Potential Calculation B

$$V = k\frac{q_1}{r_1} + k\frac{q_2}{r_2}$$

$$V = (9x10^9 Nm^2/C^2)\frac{5x10^{-5}C}{.4m} + (9x10^9 Nm^2/C^2)\frac{-5x10^{-5}C}{.4m}$$

$$v = 1.12x10^6 V - 1.12x10^6 V$$

$$v_B = 0V$$

Keep track of the signs, use the correct values. Notice that the total electric potential is a combination of the influence of the two point charges.

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Learning Summary

- E fields are shown by the arrows that indicate the force on a + charge.
- Charge is a conserved, fundamental property of all atoms.
- Electric potential from a point charge: $V = k\frac{q}{r}$
- $F_E = \frac{kq_1q_2}{r^2}$ Coulomb's Law
- V = PE/q

  Electric Potential = energy/charge

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Congratulations

You have successfully completed the tutorial

Electrostatics

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What's Next …

Step 1: Concepts – Core Tutorial (Just Completed)

→ **Step 2: Practice – Interactive Problem Drill**

Step 3: Recap – Super Review Cheat Sheet

Go for it!

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