

Electric Charges and Fields

“We evaluate electricity not by knowing what it is, but by scrutinizing what it does.”

I don't know who made this statement but it truly and philosophically describes much of modern physics.

The **four fundamental forces** that physicists use to describe all the currently known occurrences in the universe:

Gravity – the attraction between two masses

Electromagnetism – the attraction and repulsion of electrically charged objects

Subatomic weak force – the force that holds the electrons in orbit around the nucleus of the atom

Strong force – force that holds the nucleus of the atom together

What is an electric charge?

An **electric charge** is one of the basic properties of certain elementary particles of which all matter is composed. There are two kinds of charges, a **positive charge** carried by protons and a **negative charge** carried by electrons. The **only particles that move about are electrons** and any object that has an electric charge will have an excess (negative charge) or deficiency (positive charge) of electrons. Opposite charges are attracted to each other and like charges repel each other.

Think back to chemistry. All matter as we know it is composed of compounds. Compounds are composed of elements and elements are composed of protons, neutrons, and electrons.

Mass and charge of atomic particles

Particle	Mass (kg)	Charge (C)
Electron	9.109×10^{-31}	-1.6×10^{-19} C
Proton	1.673×10^{-27}	$+1.6 \times 10^{-19}$ C
Neutron	1.675×10^{-27}	No charge

Observe that the mass between the electron and the proton are considerably different but the charge of the two particles is equal but opposite.

Electrical charges cannot be created or destroyed. Why? Electrons (matter) cannot be created nor destroyed. Not only do we have **conservation of matter** but we also have **conservation of charge**. Electrical charges can be equalized or transferred. Electrical charges can cause a real bad hair day!

As you scuff electrons from your feet while walking across a rug, are you negatively or positively charged? Is the rug negatively or positively charged? What happens when you touch a doorknob? What happens when you touch your younger brother's or sister's ear?

Static electricity – an electrical charge that **does not move** also **electrostatic** – charges that are stationary

Static electricity discharges occur when the electrons move from one object to another object. The discharge can be observed from lightning strikes, discharges from a Van de Graf generator, static cling, and bad hair days. The discharge can be felt when (on a dry day) when you grab a doorknob or touch your younger siblings ear.

Electric charges are transferred by the movement of electrons. Stability is an objective of matter and to be stable the matter wants a neutral charge and thus a transfer of electrons.
Two primary methods:

1. Charging by contact – electrons will move between objects that come in direct contact. Electrons will spread to all parts of the surface of a conductor. Electrons will have a less uniform distribution of a charge on a non-conductor.

2. Charging by induction – A charged object brought near a conducting surface, the electrons will redistribute on the conducting surface to form a positive charge and a negative charge. The negative is removed by grounding and the conducting surface will contain a positive charge.

Charge polarization – the rearrangement of the position of charges within the atoms and molecules in a substance. One side is slightly more positive and the other side is slightly more negative.

Examples: comb attracting hair or pieces of paper, balloon sticking to a wall

Certain materials allow the transfer of a charge while some materials hinder the transfer of a charge.

Conductors – materials that transfers an electric charge easily – metals

Insulators – materials that do not transfer an electric charge easily – nonmetals

Semiconductors – pure, function as insulators but with impurities, act as conductors

Coulomb's Law (named for French physicist Charles Coulomb; 1736-1806) – states that for charged particles of objects that are small compared to the distance between them, the **force (electric)** between the charges varies directly as the product of the charges and inversely as the square of the distance between them (the inverse-square law). The formula for the electric force between two charged objects is:

$$F_{\text{electric force}} = k_c \frac{q_1 q_2}{d^2}$$

F - electric force (N)

q_1 – charge of particle one (C)

q_2 – charge of particle two (C)

d – distance between the charged particles (m)

k_c – $9 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$

Does the formula for electric force look familiar?

Remember the formula for the force of gravity between two objects is $F = G \frac{m_1 m_2}{r^2}$.

The law of electrostatic forces and the law of gravity are similar but there are major differences:

1. Gravity always attracts.
2. Electrical forces can either attract or repel.
3. Electrical forces are dramatically stronger than gravitational forces.

The **SI** unit for electrical charge is the **coulomb (C)** and the charge of **1C** is equal to 6.25×10^{18} electrons. In perspective this is the approximate number of electrons that passes through a 100W light bulb in one second.

Problem: Calculate the **magnitude of the electric force** and **gravitational force** between a proton and an electron that is separated by a distance of 5.3×10^{-11} meters.

F_{electric} _____
 F_{gravity} _____

Which of these two has the greatest magnitude? _____

Electric Fields

Consider gravity, the Earth exerts a **gravitational force** on the Moon thousands of miles away. Similarly an electric charge exerts a force on another charge that has a space in between them. The space between Earth and Moon is filled with a **gravitational field**. The **space between two charged objects is filled with an electric field**. What is a field? It is perhaps a kind of aura that extends through space. Composition of an electric field is ... ??????? ... Don't ask, no one really knows for sure ... for lack of any viable explanation, it is _____ (a word scientists don't like).

An **electric field** has both **magnitude** and **direction**.

1. A **positive charge** will have the lines of force **moving away** from it and thus the vector lines also extend away from the charge.
2. A **negative charge** will have the lines of force **moving to** the charge and thus the vector lines point to the charge.

In the space below, draw a graphical representation electric field lines around a positive charge, a negative charge, between two objects with the same charge and two objects with opposite charges.

Electric force – each object exerts a force on another object; two charged objects near one another may experience motion either toward or away from each other (think back to the electroscope)

The distance between the two objects affects the magnitude of the electric force between them.

What happens when there are more than two charges present? Apply Coulomb's law, the resultant force on any single charge equals the vector sum of the individual forces exerted on that charge by all the other individual charges that are present. This is an example of the principle of superposition. The vector forces are combined as learned in chapter 3. Honors classes ... Ya'll get to work on these problems.

Electric Field Strength

A charged object has an electric field in the space around it. The strength of the electric field is expressed with the following formula:

$$E = \frac{F_{electric}}{q_o}$$

E strength of electric field in Newtons per coulomb (**N/C**)

$F_{electric}$ electric force in Newtons (**N**)

q_o electric charge in coulombs (**C**)

The **SI** units for E is a ratio of Newtons to Coulombs. This is a vector quantity and the direction of the vector (to or from the charge) is determined by the charge of the object.

Factors that determine the strength of an electric field is the **quantity of the charge** and the **distance from a test charge**.

Electric Potential Energy

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Remember that **work** is done when a force moves a mass in the direction of the force.

$$W(J) = F(N) \times d(m)$$

Also remember that an object has **potential energy** by virtue of its location, say in a force field.

$$PE(J) = m(kg)g(m/s^2)h(m)$$

A charged object will have **PE** by virtue of its location in an electric field. A small positive charge is pushed toward a large sphere that also has a positive charge. As the small positive charge moves closer to the sphere, it (small positive charge) gains more potential energy because of the amount of work required to push it to the large sphere. It can be expressed mathematically by:

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

If the small positive charge near the sphere is released, then the **PE** is converted into **KE**.

The **SI** unit for electric potential is the **volt** (sometimes called **voltage**), named after Italian physicist Allesandro Volta (1745 – 1827). Potential energy is the Joule and charge is the coulomb.

$$1 \text{ volt} = 1 \frac{\text{joule}}{\text{coulomb}}$$

Putt this in perspective ... You have a 9 volt battery that you are going to put into your transistor radio. That means it is prepared to give 9 Joules of energy to every coulomb that is moved from one terminal to the other terminal.

Note: Electricity and Magnetism cannot answer what a charge is or what a field is. Electricity and Magnetism can only describe how the charges and fields behave.