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# Chap 15 Electric Charge, Forces, and Fields

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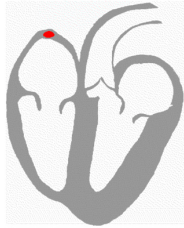
Dr. Coman

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## Guess what today's topic will be !

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- Guess what today's topic will be !



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## CREDITS

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- - College Physics, Serway
  - <http://hyperphysics.phy-astr.gsu.edu>
  - [www.uwinnipeg.ca](http://www.uwinnipeg.ca)
  - [www.bu.edu](http://www.bu.edu)
  - [www.utk.edu](http://www.utk.edu)
  - [www.prenhall.com/esm\\_wilson\\_physics](http://www.prenhall.com/esm_wilson_physics)
  - <http://www.walter-fendt.de/ph11e>
  - <http://www.lon-capa.org/~mmp/>
  - SERWAY COLLEGE PHYSICS 7E MEDIA LIBRARY

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# Objectives I

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- Recognize the quantum nature of the electric charge;
- Explain the interaction between electric charges;



- Use Coulomb's law to solve problems involving charge distributions;
- Explain the concept of force fields
- Use the concept of electric fields to explain action at a distance;
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# Outline I

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- Electric Charge, electrostatic charge
  - 1. Measuring Electrical Charge



- 3. Applications copy machines, printers
- Closer Look: Solar Cells
- Electric Force
  - Measuring Electrical Force



- Electric Field
  - Conductors and Electric Fields
- Gauss's Law for Electric Fields: A Qualitative Approach
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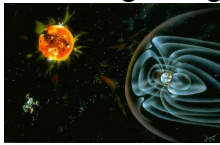
# Outline II

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- Electric Current
  - 1. Resistance
  - 2. AC and DC
- Electric Circuit
- A Closer Look: Hydrogen and Fuel Cells
- Voltages, Electrical Power and Work



- A Closer Look: Household Circuits and Safety
- Magnetism
  - 1. Moving Charges and Magnetic Fields



- 2. Magnetic Fields Interact
  - 3. A Moving Magnet Produces an Electric Field
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# Electric phenomena

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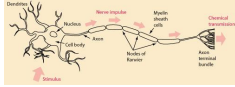
- We often experience the power of nature. One of the most fearsome natural phenomena is lightning.
- A thunderstorm produces an interesting display of electrical discharge



- Each bolt can carry over 150,000 Amperes of current
  - with a voltage of 100 million Volts
-

# Currents in nerve cells

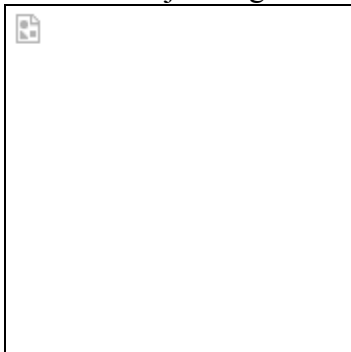
- In the human body, signals are sent back and forth between muscles and the brain;



- From our sensory receptors (eyes, ears, touch sensors, etc.) to the brain, along nerve cells.
- These nerve impulses are electrical signals that are transmitted along the body, or axon, of a nerve cell.
  - The axon is a long tube built to carry electrical signals.
- A potential difference of about *70milli Volts* exists across the cell membrane
  - due to a small imbalance in the concentration of ions inside and outside the cell.
  - The ions primarily responsible for the propagation of a nerve impulse are potassium  $K^+$  and  $Na^+$ .
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# Electrical signals in our heart

- ECG is a major diagnostic tool for the assessment of heart's health.



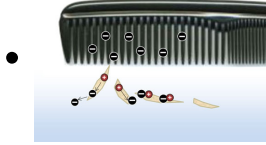
- It is a measurement taken at the surface of the skin
  - measurement which reflects the electrical phenomena in the heart
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# Electric charges

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- Electric charge is a fundamental property of the elementary particles which are the constituents of all matter.
  - electric charges may be positive or negative.
- The *static* that you often feel on your clothes on a dry day, is electric charge.



- Lightning is a flow of an enormous amount of electric charge through the air.
- After rubbing a balloon on your hair on a dry day, you will find that the balloon attracts bits of paper.
- You can easily electrify your body by vigorously rubbing your shoes on a wool rug.
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# Static electricity

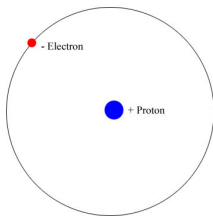
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- On a dry winter day, you can rub a balloon on your sweater and create enough static electricity in the balloon

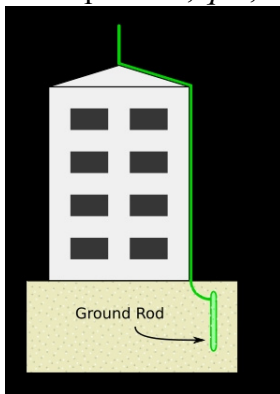


- A balloon charged with static electricity will attract small bits of paper or particles of sugar very easily.
-

# Static electricity



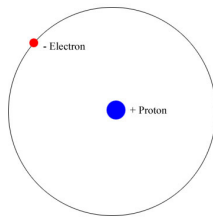
- Evidence of the electric charge on your body can be detected by lightly touching ( and startling) a friend.
- The atom consists of a small positive nucleus surrounded by a negative electron cloud.
- There are two kinds of electric charges, which were given the names:
  - positive,  $q^+$ , and negative,  $q^-$  by Benjamin Franklin ( 1706â€“ 1790).



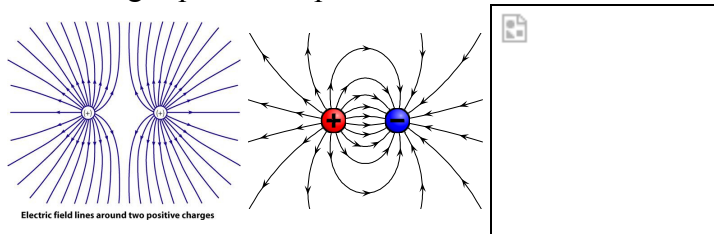
- Electrons are identified as having a negative charge
- Protons are positively charged.
  - Like charges repel; unlike charges attract.
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# Electric Theory of Charges

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- Electrons have a negative electrical charge.
- Protons have a positive electrical charge



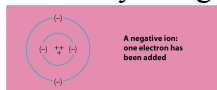
- These charges interact to create an electrical force.
- Like charges produce repulsive forces.



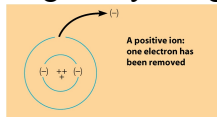
- Unlike charges produce attractive forces.
- 

## Electric charges as conserved properties

- Charge is conserved: can neither be created nor destroyed
  - Charges can be separated/transferred
  - Electrons -negatively charged orbit the positive nucleus because of their mutual attraction
- Charging, therefore, is a process of transfer of electrons:
  - Positively charging: Removal of electrons from an object.



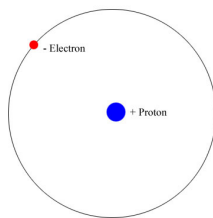
- Negatively charging: Addition of electrons to an object.



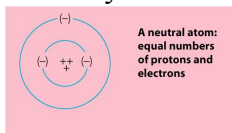
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# The atom and the charges

- A simplified model of an atom
- most of the mass in a small, dense center called the nucleus.



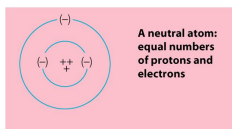
- The nucleus contains + protons and neutral neutrons.
- - electrons move around the nucleus a much greater distance than is suggested by this simplified model.
- Ordinary atoms are neutral :



- balance between the number of + protons and - electrons
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# Atoms as neutral objects

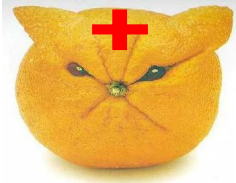
- (A) A neutral atom has no net charge because the numbers of electrons and protons are balanced.
- If the charge of an electron is  $q_e = -1.6 \cdot 10^{-19}$ , what is the charge a proton carries ?



- Removing an electron produces a net positive charge;
- the charged atom is called a positive ion.
- The addition of an electron produces a net negative charge and a negative ion.
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# Ions

- Electrons move from atom to atom to create ions.
- Positively charged ions result from the loss of electrons and are called *cations*



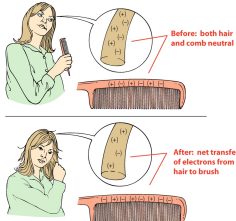
- Negatively charged ions result from the gain of electrons and are called *anions*
- 

# Ions

- The charge on an ion is called an electrostatic charge.
- An object becomes electrostatically charged by:
  - Friction, which transfers electrons between two objects in contact;
  - Contact with a charged body which results in the transfer of electrons;
  - Induction which produces a charge redistribution of electrons in a material;
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# Charging through friction

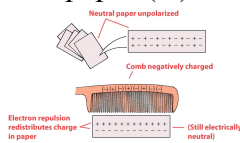
- The comb has become charged by friction, acquiring an excess of electrons.



-

## Charging by induction.

- A charged comb brought nearby a piece of paper
- The paper ( $A$ ) normally has a random distribution of  $+$  and  $-$  charges.



- When the charged comb is held close to the paper, there is a reorientation of charges because of the repulsion of the charges.
- This leaves a net positive charge on the side close to the comb, and since unlike charges attract, the paper is attracted to the comb

## Charging by conduction/contact.

- Bring the charged rod  $X$  with a positive charge in contact with  $Y$ .



- From  $Y$  some of the free electrons flow towards the rod  $X$  to neutralize the positive charge on it.
- As a result, there will be a deficiency of electrons on the sphere  $Y$  and surplus of positive charges.
- Thus  $Y$  gets positively charged.
- This method cannot be used to change an insulator where the electrons are firmly bound.

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## Applications -static electricity

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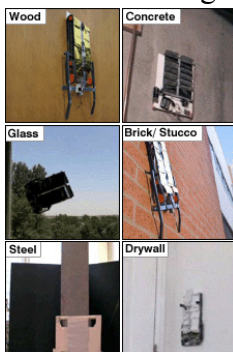
- The drum inside a copier acts a lot like a balloon -- you can charge it with a form of static electricity.
- 
- The drum can be selectively charged, so that only parts of it attracts a fine black powder known toner.
- Where the original sheet of paper is black, you create static electricity on the drum.
- Where it is white you do not.
- The white areas of the original sheet of paper should NOT attract toner. The way this selectivity is accomplished in a copier is with light -- this is why it's called a photocopier
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## Applications -static electricity

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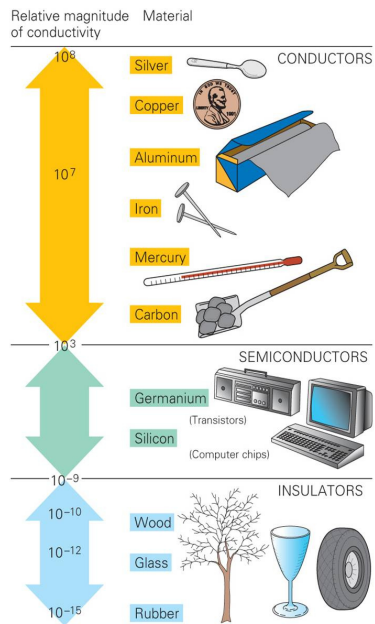
- Electrostatic precipitators trap particles by applying an electrical charge to them as they pass through the unit and depositing them on plates or filters
- Robots climbing walls



- MIT invented a way to induce charges on the wall using a power supply located on the robot," Â In some ways it is similar to rubbing a balloon and sticking it on the wall,
-

# Categorizing materials based on their ability to allow charges

- Electrical Conductors and Insulators.
- Electrical conductors are materials that can move electrons easily



- Good conductors include metals.
- Electrical nonconductors are materials that do not move electrons easily
- These are also known as insulators
- Semiconductors are materials that vary in their conduction and nonconduction, sometimes conducting sometimes not conducting.
- 

## Measuring Electrical Charges

- The magnitude of an electrical charge is dependent upon how many electrons have been moved to it or away from it.
- To determine the quantity of an electrical charge you simply multiply the number of electrons by the fundamental charge on an electron or:

$$Q_{total} = n_e \cdot q_e$$

- where  $q_e = 1.6 \cdot 10^{-19}$  C is the fundamental charge that one electron carries in Coulombs.
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## Units of charges

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- Electrical charge is measured in coulombs.
- A coulomb is the charge resulting from the transfer of  $6.24 \cdot 10^{18}$  electrons;
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## Total charge calculation:

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- A rubber balloon has become negatively charged from being rubbed with a wool cloth and the charge is measured to be  $1\text{ C}$ . How many electrons does the balloon contain? How many electrons do we need to make up a charge of  $1\text{ C}$ ?

$$Q_{net} = 1\text{ C} = q_e \cdot n_e = 1.6 \cdot 10^{-19}\text{ C} \cdot n_e \rightarrow n_e$$

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## Total charge calculation II:

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- A rubber balloon has become negatively charged from being rubbed with a wool cloth until an excess of a billion electrons is on the balloon. What is the magnitude of the charge on the balloon?

$$Q_{net} = q_e \cdot n_e = 1.6 \cdot 10^{-19}\text{ C} \cdot 10^9 = 1.6 \cdot 10^{-19+9} = 1.6 \cdot 10^{-10}\text{ C}$$

$$n_e = \frac{Q_{net}}{q_e} = \frac{1\text{ C}}{1.6 \cdot 10^{-19}\text{ C}} = \frac{1}{1.6} \cdot 10^{+19} = .625 \cdot 10^{+19} = 625 \cdot 10^{16}$$

- A coulomb is the charge resulting from the transfer of  $6.24 \cdot 10^{18}$  electrons;
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## Classroom task:

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- A plastic rod is rubbed against a wool shirt, thereby acquiring a charge of  $-0.80\mu\text{C}$ . How many electrons are transferred from the wool shirt to the plastic rod?

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## Chapter 21

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- Estimate the force required to bind the two protons in the  $He$  nucleus together.
- HINT: Model the protons as point charges.

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An estimate of the distance between them is  $10^{-15} \text{ m}$ .

- Solution:
  - Is the nucleus in equilibrium ?
  - Which forces balance each other ?
- 

## Classroom task:

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- A charge equal to the charge of Avogadro's number of protons  $N_A = 6.02 \times 10^{23}$  is called a faraday. Calculate the number of coulombs in a faraday.

- 

$$1F = N_A \cdot q_e$$


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## Example: problem

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- How many excess electrons does an object with a total charge of

$Q_{total} = -1.0 \cdot 10^{-9} \text{ C}$  have on it ? This is commonly encountered in static electricity.

- **Solution:**

$$Q_{total} = q_e \cdot n_e \rightarrow n_e$$

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## Classroom task

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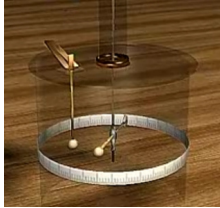
- A rubber balloon has become negatively charged from being rubbed with a wool cloth until an excess of a 700 billion electrons is on the balloon . What is the magnitude of the charge on the balloon ?

$$Q_{net} = q_e \cdot n_e = 1.6 \cdot 10^{-19} \text{ C} \cdot 700 \cdot 10^9 = ? \text{ C}$$

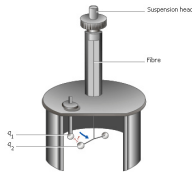
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# Measuring Electrical Forces:

- Coulomb constructed a torsion balance to test the relationships between:
  - the charges,



- the distance between the charges
- and the electrical force produced.



- He found the inverse square law held accurately for various charges and distances:
- coulomb-torsion-balance1.gif
- 

# Electrical Force, Coulomb's Law

- Force is proportional to
    - the product of the electrical charges
    - and inversely proportional to the square of the distance.
  - Coulomb's Law
- $$F_e \sim Q_1 \cdot Q_2$$
- The quantitative expression for the electrostatic force between stationary charges:

$$F_e = k \cdot \frac{Q_1 \cdot Q_2}{d^2}$$

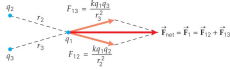
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# Coulomb's Law

- $F$  is the force
- $k$  is a constant and has the value of
 
$$k = 9.00 \cdot 10^9 \text{ Newton} \cdot \frac{\text{meters}^2}{\text{coulomb}^2} = 9.00 \cdot 10^9 \frac{N \cdot m^2}{C^2}$$
- $Q_1$  represents the electrical charge of object 1
- $Q_2$  represents the electrical charge of object 2
- $d$  is the distance between the two objects.
-

# Electrical Force, multiple point charges

- If there are multiple point charges, the force vectors must be added to get the net force.



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## Example: problem

- Calculate the force between 2 identical charges of  $Q_1 = 1.0 \cdot 10^{-9} \text{ C}$  separated by  $1.0 \text{ cm}$ . What is the force if the separation is increased by a factor of 4 and the charges are the same ?
- Solution:

$$F_{el} = k \cdot \frac{q_1 \cdot q_2}{d^2} = 9 \cdot 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \cdot \frac{1.0 \cdot 10^{-9} \text{ C} \cdot 1.0 \cdot 10^{-9} \text{ C}}{(0.01 \text{ m})^2}$$

- 

## Example: problem

- Calculate the force between 2 identical charges of  $Q_1 = 9.0 \cdot 10^{-6} \text{ C}$  separated by  $10^{-10} \text{ cm}$ . What is the force if the separation is increased by a factor of 4 and the charges are the same ?
- Solution:

$$F_{el} = k \cdot \frac{q_1 \cdot q_2}{r^2} = 9 \cdot 10^9 \frac{\text{N} \cdot \text{m}^2}{\text{C}^2} \cdot \frac{1.0 \cdot 10^{-9} \text{ C} \cdot 1.0 \cdot 10^{-9} \text{ C}}{(0.01 \text{ m})^2}$$

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# Force Fields.

[LINK: Faraday law jar](#)

[LINK: Faraday law magnetic field shown jar](#)

- TO BE Continued
- The condition of space around an object is changed by the presence of an electrical charge.
  - Electric Force field: concept introduced by Michael Faraday.

[LINK: Charges and fields jar](#)

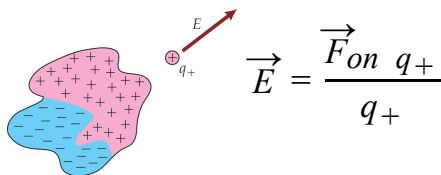
- The electrical charge produces a force field, that is called an electrical field since it is produced by electrical charge

[LINK: Electric hockey jar](#)

- All electrical charges are surrounded by an electrical field just like all masses are surrounded by gravitational fields.
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# Definition of the electric Field

- The direction of the field is the direction the force would be on a positive charge.



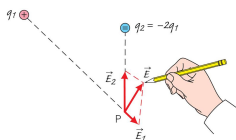
- Charges create electric fields,
  - these fields in turn exert electric forces on other charges.
- Electric field of a point charge:

$$E = k \frac{q}{r^2}$$

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# Electric fields For multiple charges

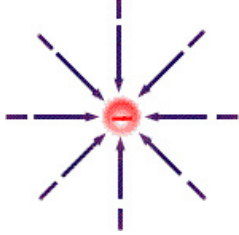
- For multiple charges, the total electric field is found using the superposition principle:
  - For a configuration of charges, the total, or net, electric field at any point is the vector sum of the electric fields due to the individual charges.



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# Identifying the properties of an electric field

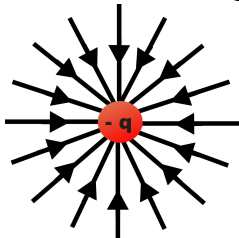
- A positive test charge is used by convention to identify the properties of an electric field.



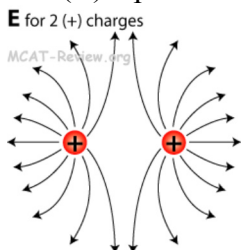
- The vector arrow points in the direction of the force that the test charge would experience
- 

## Force fields

- Lines of force diagrams for



- a negative charge (A)
- and (B) a positive charge when the charges have the same magnitude as the test charge.



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## Mapping out electric fields

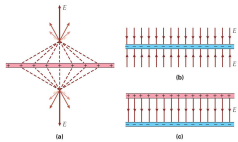
- A map of the electrical field can be made by bringing a positive test charge into an electrical field.
- When brought near a negative charge the test charge is attracted to the unlike charge and when brought near a positive charge the test charge is repelled.
- You can draw vector arrows to indicate the direction of the electrical field
- This is represented by drawing lines of force or electrical field lines
- These lines are closer together when the field is stronger and farther apart when it is weaker.
-

## Rules for drawing electric field lines

- Closer lines mean a stronger field.
- The field is tangent to the lines at every point.
- Field lines start on positive charges and end on negative charges.
- The number of lines entering or leaving a charge is proportional to the magnitude of the charge.
- Field lines never cross.
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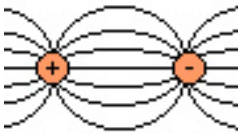
## Electric field lines due to parallel plates:

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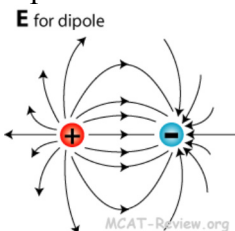


## Moving a charge through an electric field

- An electrical charge has an electrical field that surrounds it.
- In order to move a second charge through this field work must be done



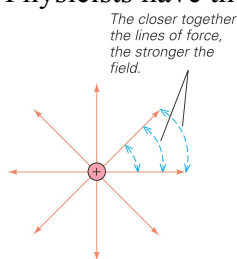
- Bringing a like charge particle into this field will require work since like charges repel each other
- Bringing an opposite charged particle into the field will require work to keep the charges separated.



- In both of these cases the electrical potential is changed.
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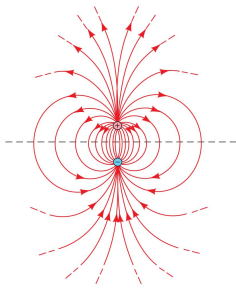
# The electric field, a force field

- Physicists have theorized that a field carries the electric force to other charges



(b) Electric field lines

- The condition of space around an object is changed by the presence of an electrical charge.
- The electrical charge produces a force field, that is called an electrical field



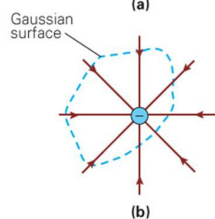
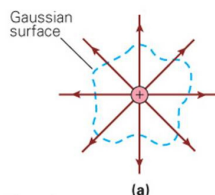
(b)

- All electrical charges are surrounded by an electrical field just like all masses are surrounded by gravitational fields.

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## Gauss's Law for Electric Fields: A Qualitative Approach

- A surface, called a Gaussian surface, that completely surrounds a point charge intercepts the same number of field lines regardless of its shape.



- For a positive charge, the lines exit the surface; for a negative one they enter it.

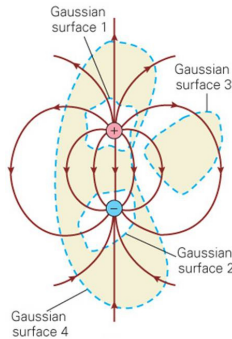
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# The underlying physical principle of Gauss's law

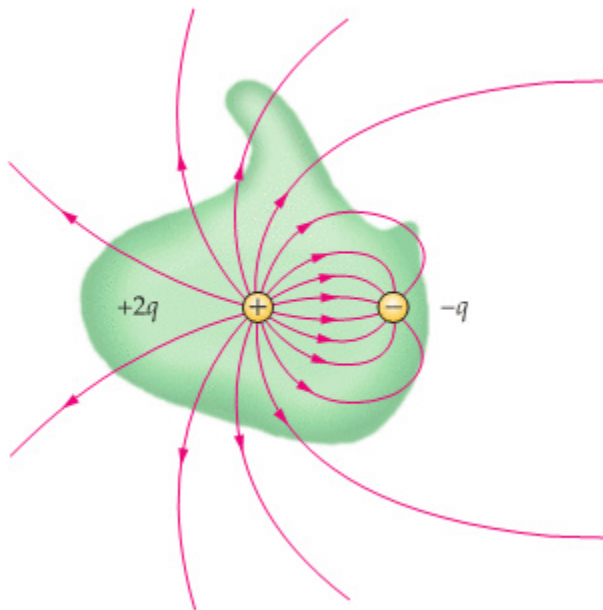
- The net number of electric field lines passing through an imaginary closed surface is proportional to the amount of net charge enclosed within that surface.



- For a positive charge, the lines exit the surface; for a negative one they enter it.
- Surface 1 surrounds the positive charge and has lines exiting it.
- Surface 4 encloses both charges; as they are equal in magnitude, the same number of lines exit the surface as enter it.
- What about surface 2?

## Gauss law

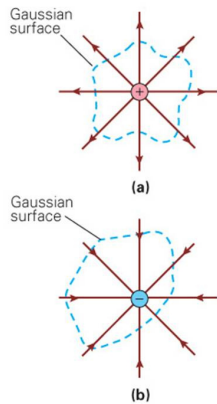
- one of Maxwells equations, the fundamental equations of electromagnetism
- equivalent with Coulombs law



- Used to calculating  $\vec{E}$  arising from some symmetrical charge distributions
- the net number of field lines out of any surface enclosing the charges is proportional to the net charge,  $Q$  enclosed by the surface

# Gauss's Law for Electric Fields: A Qualitative Approach

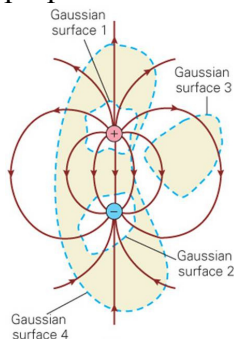
- A surface, called a Gaussian surface, that completely surrounds a point charge intercepts the same number of field lines regardless of its shape.



- For a positive charge, the lines exit the surface; for a negative one they enter it.
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## The underlying physical principle of Gauss's law

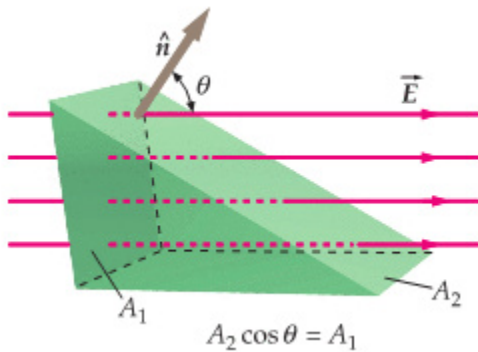
- The net number of electric field lines passing through an imaginary closed surface is proportional to the amount of net charge enclosed within that surface.



- For a positive charge, the lines exit the surface; for a negative one they enter it.
- Surface 1 surrounds the positive charge and has lines exiting it.
- Surface 4 encloses both charges; as they are equal in magnitude, the same number of lines exit the surface as enter it.
- What about surface 2?

# The electric flux

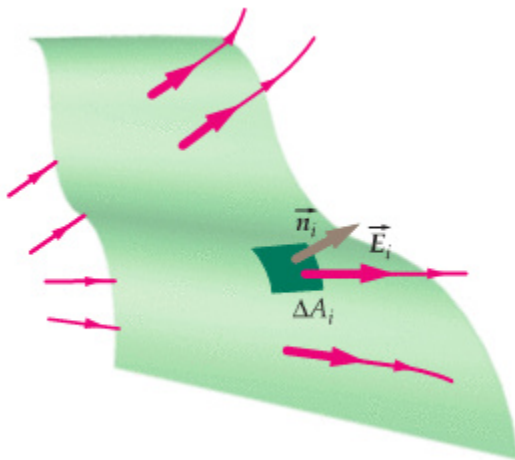
- [LINK Electric Flux swf](#)
- The mathematical quantity that corresponds to the number of field lines penetrating a surface
- $\Phi = EA \cos \theta$



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# The electric flux through a closed surface

- By convention: At points on the surface where  $\vec{E}_n$  is inward,  $E_n$  is negative.



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## The electric due to a solid sphere of radius $a$

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- What is the magnitude of the electric field due to a solid sphere of radius  $a$  with uniform charge density  $\rho = 6 \frac{C}{m^3}$ ?
  - Outside the sphere  $r > a$
  - Inside the sphere  $r < a$
- **Solution:** the system has spherical symmetry  $\rightarrow$  choose a spherical gaussian surface surrounding the sphere

$$EA \cos \theta = 4\pi r^2 E = \frac{q_{enclosed}}{\epsilon_0}$$

$$\text{since } q = \frac{4}{3}\pi a^3 \rho \rightarrow$$

$$E = \frac{\rho a^3}{3\epsilon_0 r^2} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

- same as  $E$  for a point charge
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## The electric due to a solid sphere of radius $a$ , and $\rho$

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- Inside the sphere  $r < a$
- **Solution:** the system has spherical symmetry  $\rightarrow$  choose a spherical gaussian surface surrounding the sphere

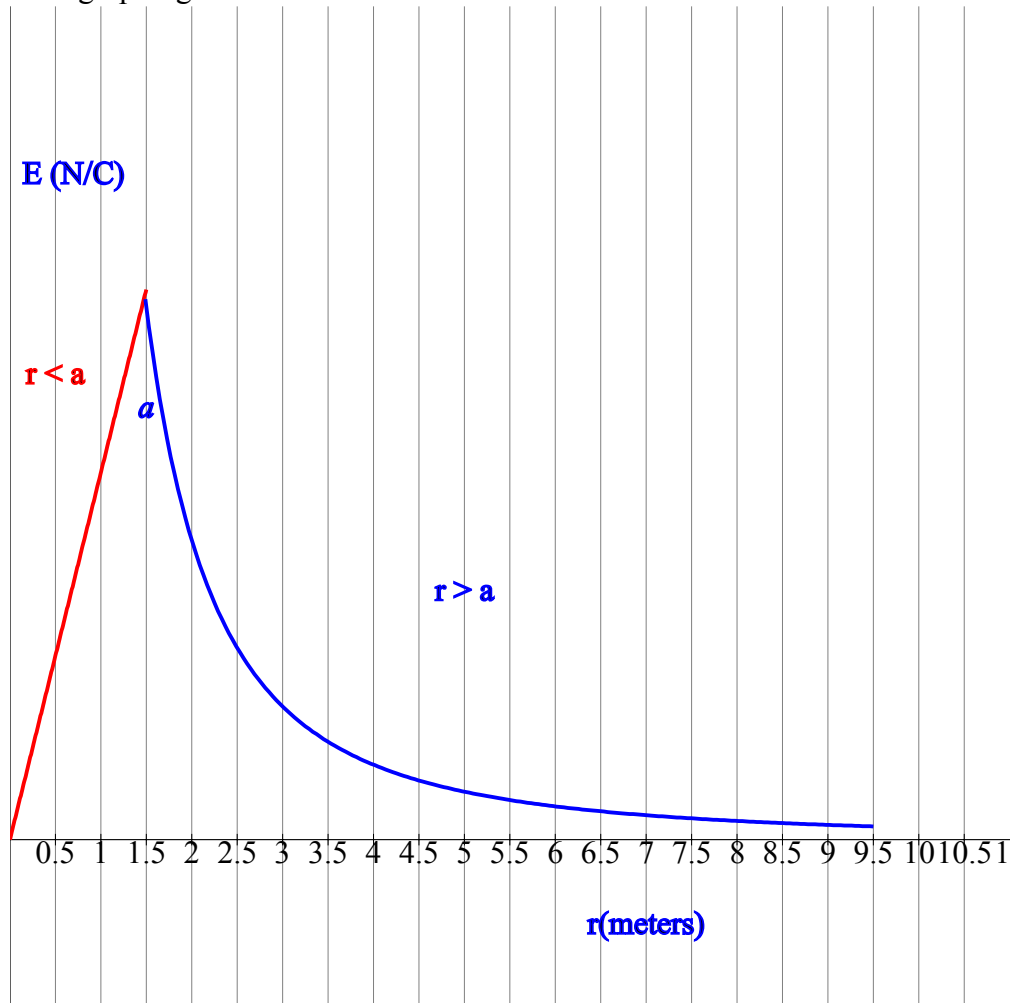
$$EA \cos \theta = 4\pi r^2 E = \frac{q_{enclosed}}{\epsilon_0}$$

$$\text{since } q = \frac{4}{3}\pi r^3 \rho \rightarrow E = \frac{4}{3}\pi r^3 \frac{\rho}{4 \cdot \pi \cdot r^2 \cdot \epsilon_0} = \frac{\rho}{3 \cdot \epsilon_0} r$$

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# $E$ of a solid sphere, graphically

- [Link graphing the electric field in html](#)



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