Chapter 21

Electric Charge and Electric Field

PowerPoint® Lectures for

***University Physics*, 14th Edition, Global Edition**

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Learning Goals for Chapter 21

Looking forward at …

- how objects become electrically charged, and how we know that electric charge is conserved.
- how to use Coulomb's law to calculate the electric force between charges.
- the distinction between electric force and electric field.
- how to use the idea of electric field lines to visualize and interpret electric fields.
- how to calculate the properties of electric charge distributions, including dipoles.

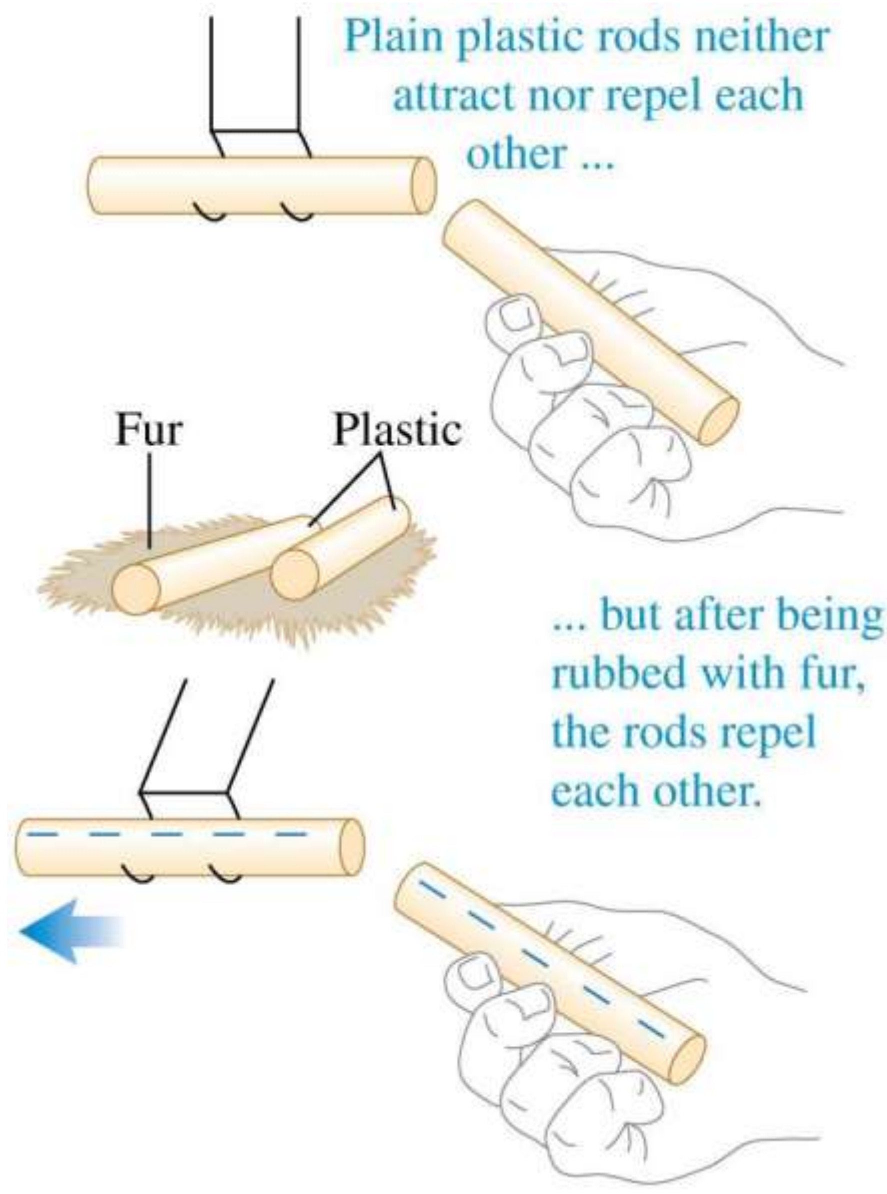
Introduction

- Water makes life possible: The cells of your body could not function without water in which to dissolve essential biological molecules.

- What electrical properties of the water molecule allow it to be such a good solvent?
- We now begin our study of *electromagnetism*, one of the four fundamental forces.
- We start with electric charge and look at electric fields.

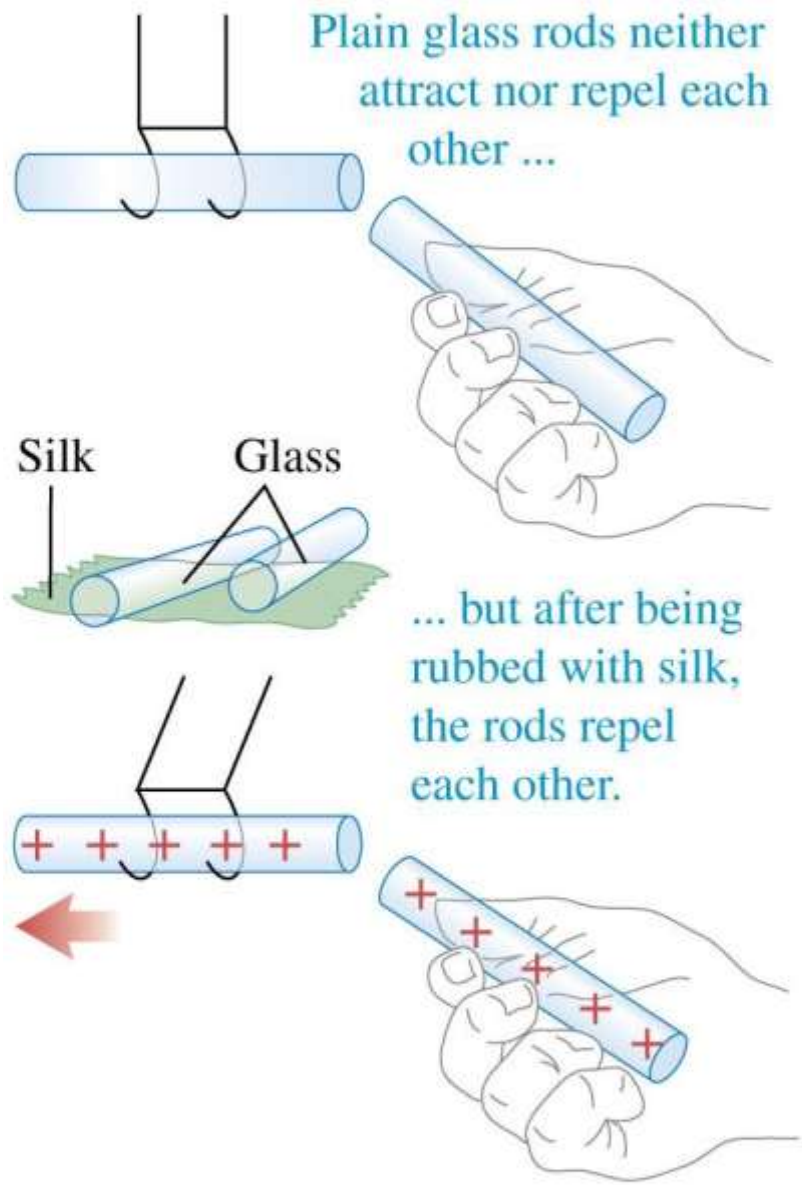
Electric charge

- Plastic rods and fur (real or fake) are particularly good for demonstrating **electrostatics**, the interactions between electric charges that are at rest (or nearly so).
- After we charge both plastic rods by rubbing them with the piece of fur, we find that the rods *repel* each other.



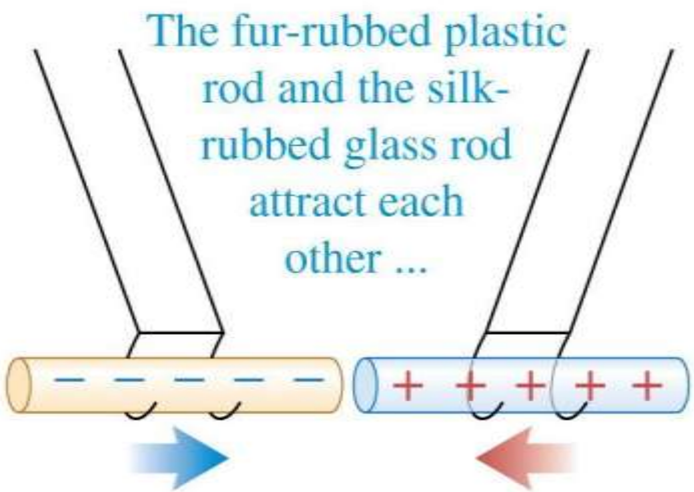
Electric charge

- When we rub glass rods with silk, the glass rods also become charged and repel each other.

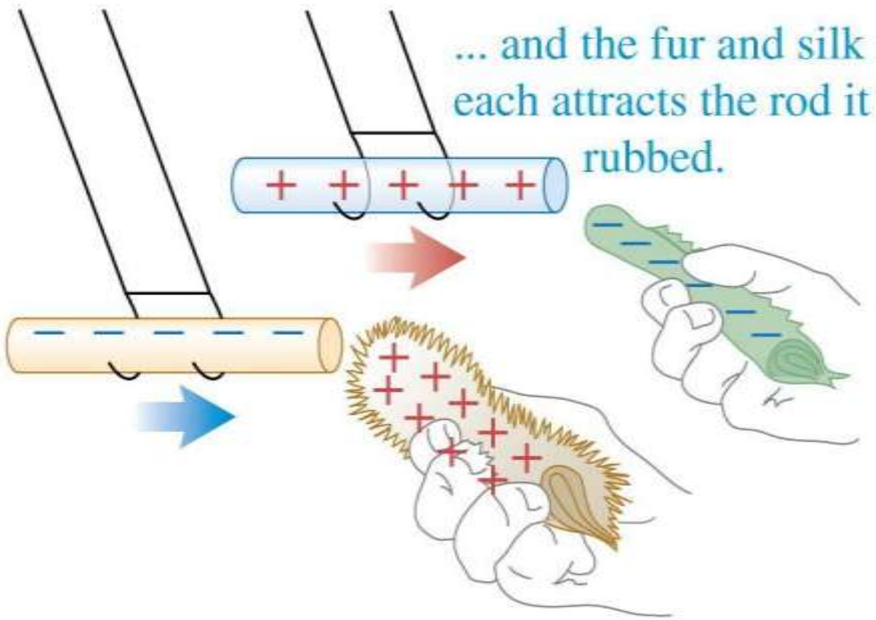


Electric charge

- A charged plastic rod *attracts* a charged glass rod; furthermore, the plastic rod and the fur *attract* each other, and the glass rod and the silk *attract* each other.

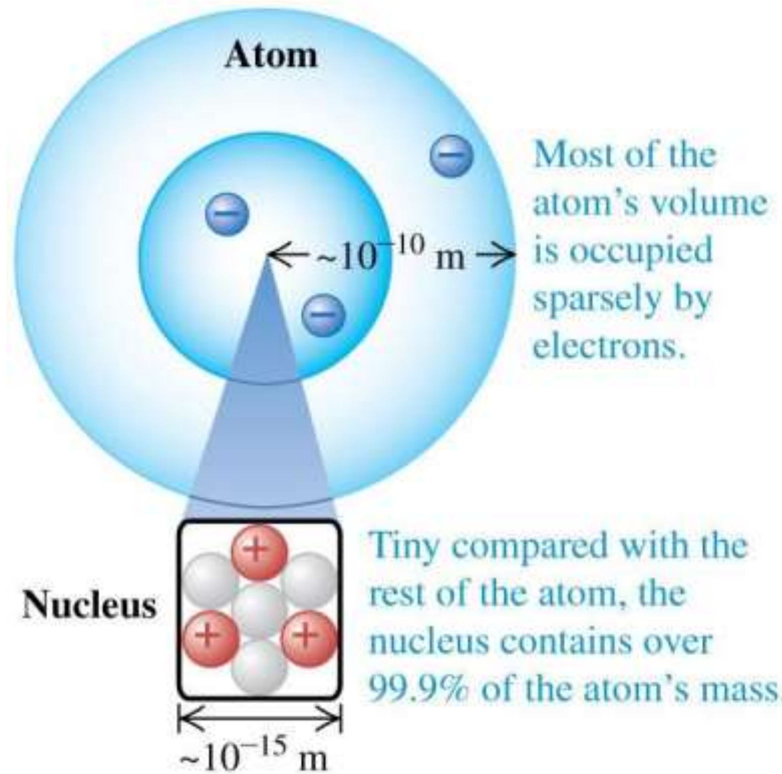


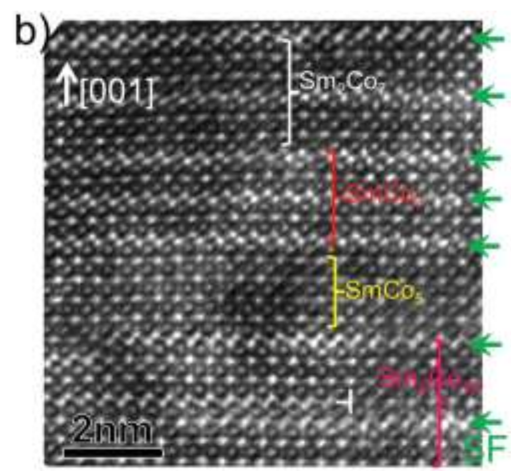
- These experiments and many others like them have shown that there are exactly two kinds of electric charge: The kind on the plastic rod rubbed with fur (*negative*) and the kind on the glass rod rubbed with silk (*positive*).



Electric charge and the structure of matter

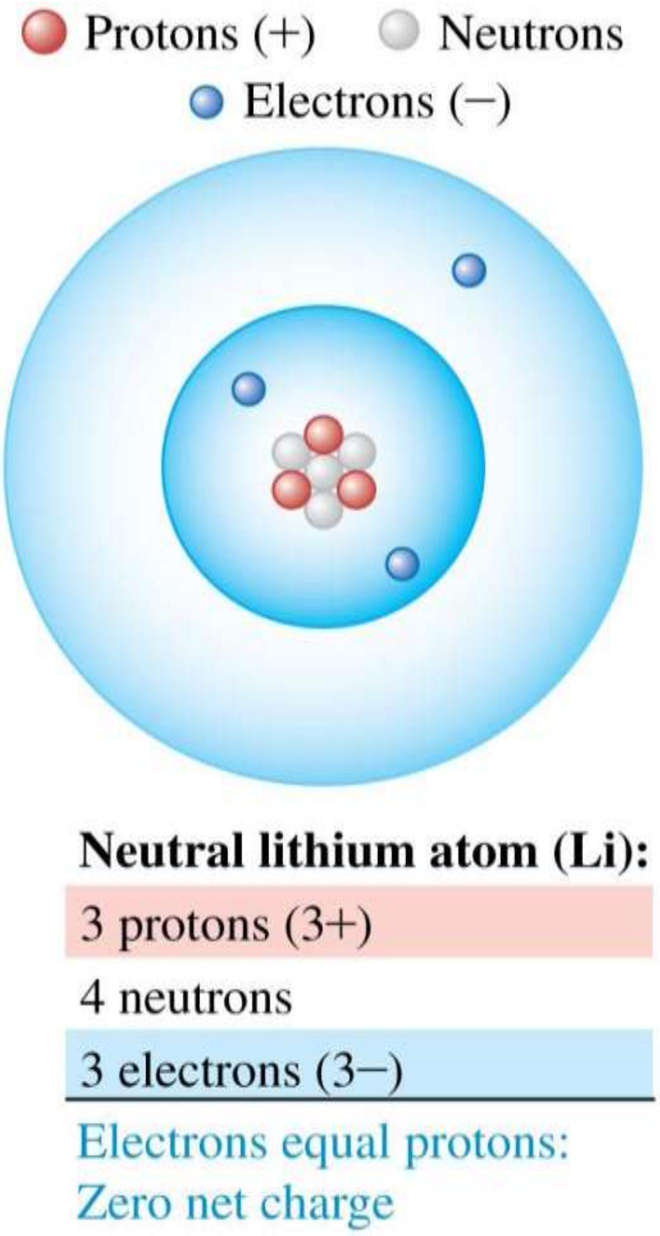
- The particles of the atom are the negative *electrons* (dark blue spheres in this figure), the positive *protons* (red spheres), and the uncharged *neutrons* (gray spheres).
- Protons and neutrons make up the tiny dense nucleus, which is surrounded by electrons.





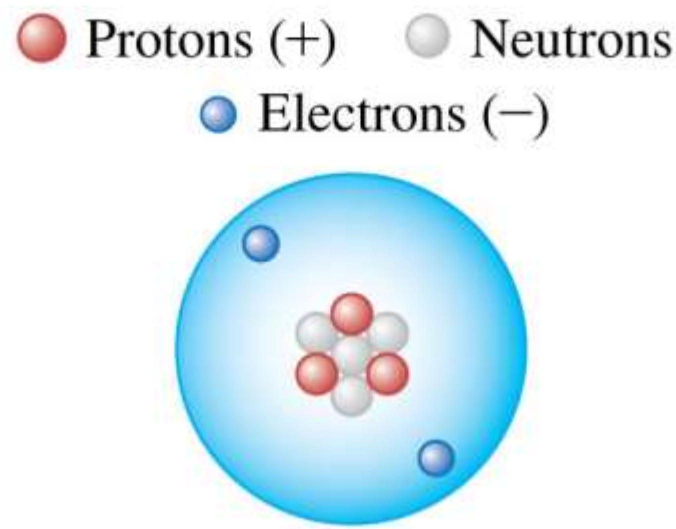
Atoms and ions

- A neutral atom has the same number of protons as electrons.
- The electron "shells" are a schematic representation of the actual electron distribution, a diffuse cloud many times larger than the nucleus.



Atoms and ions

- A *positive ion* is an atom with one or more electrons removed.



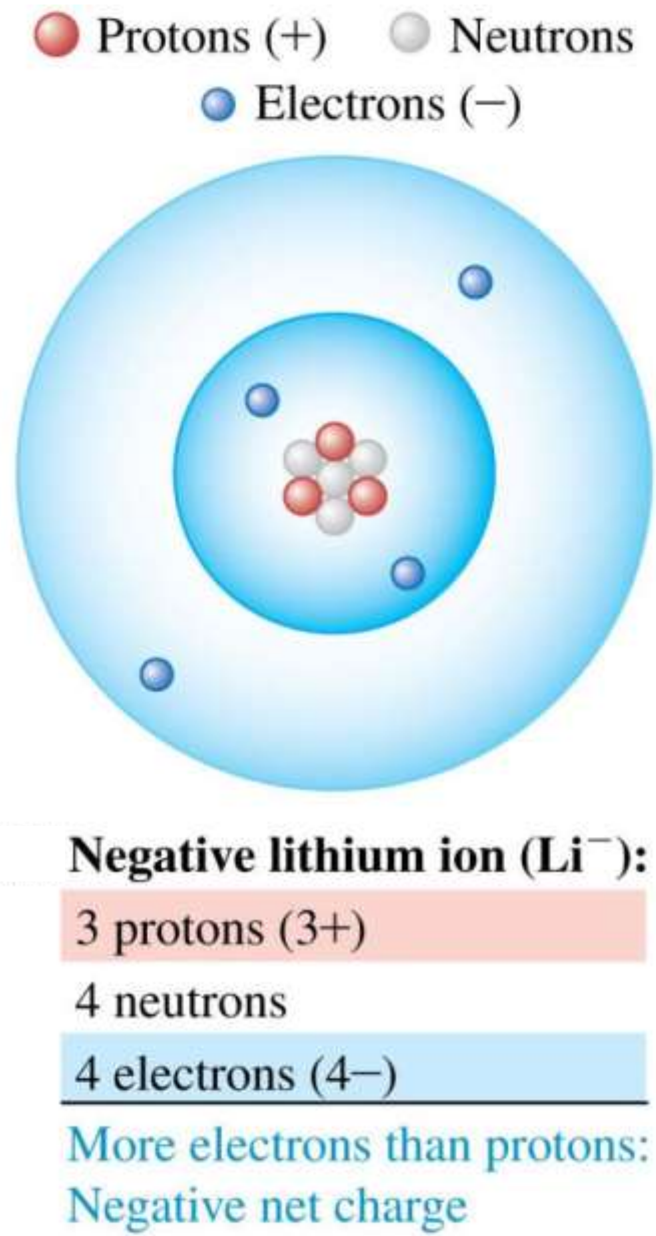
Positive lithium ion (Li^+):

3 protons (3+)
4 neutrons
2 electrons (2−)

Fewer electrons than protons:
Positive net charge

Atoms and ions

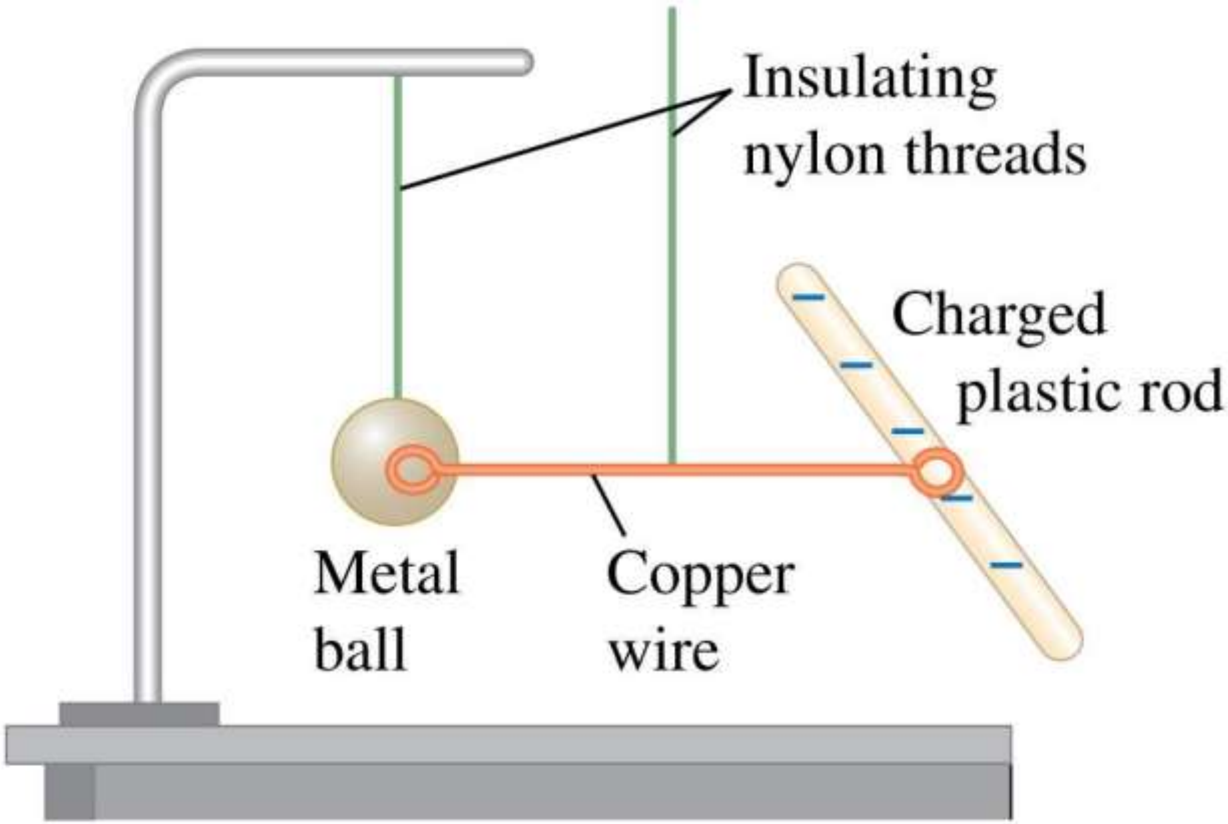
- A *negative ion* is an atom with an excess of electrons.



Conservation of charge

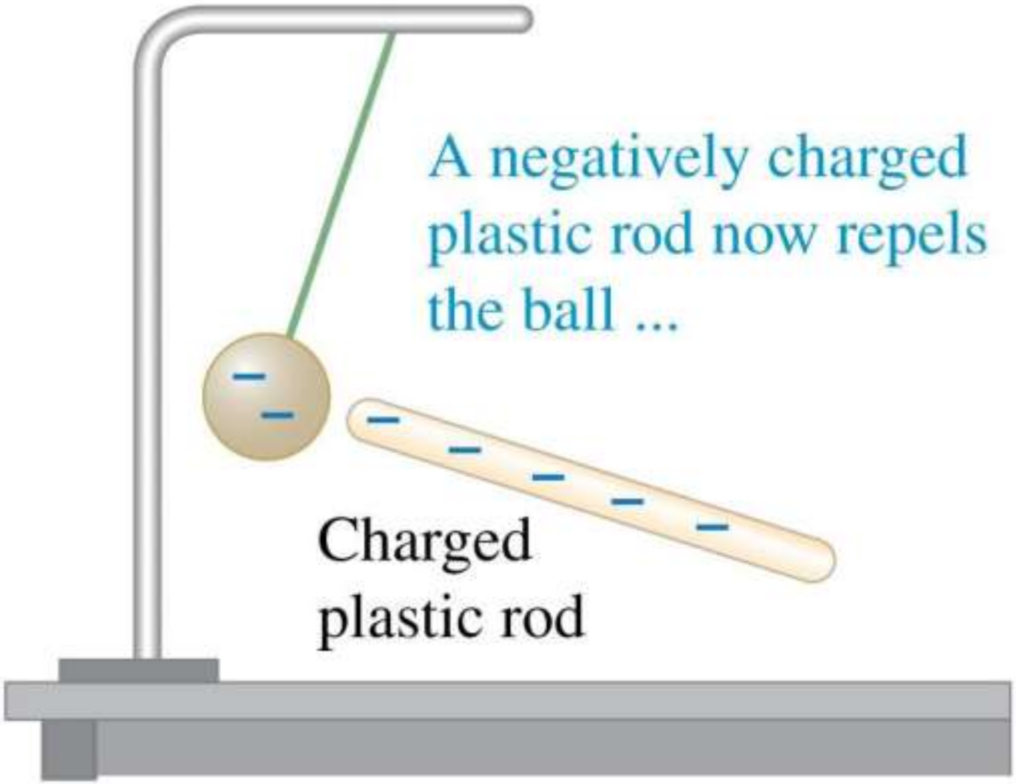
- The proton and electron have the same magnitude charge.
- The magnitude of charge of the electron or proton is a natural unit of charge. All observable charge is *quantized* in this unit.
- The universal **principle of charge conservation** states that the algebraic sum of all the electric charges in any closed system is constant.

Conductors and insulators



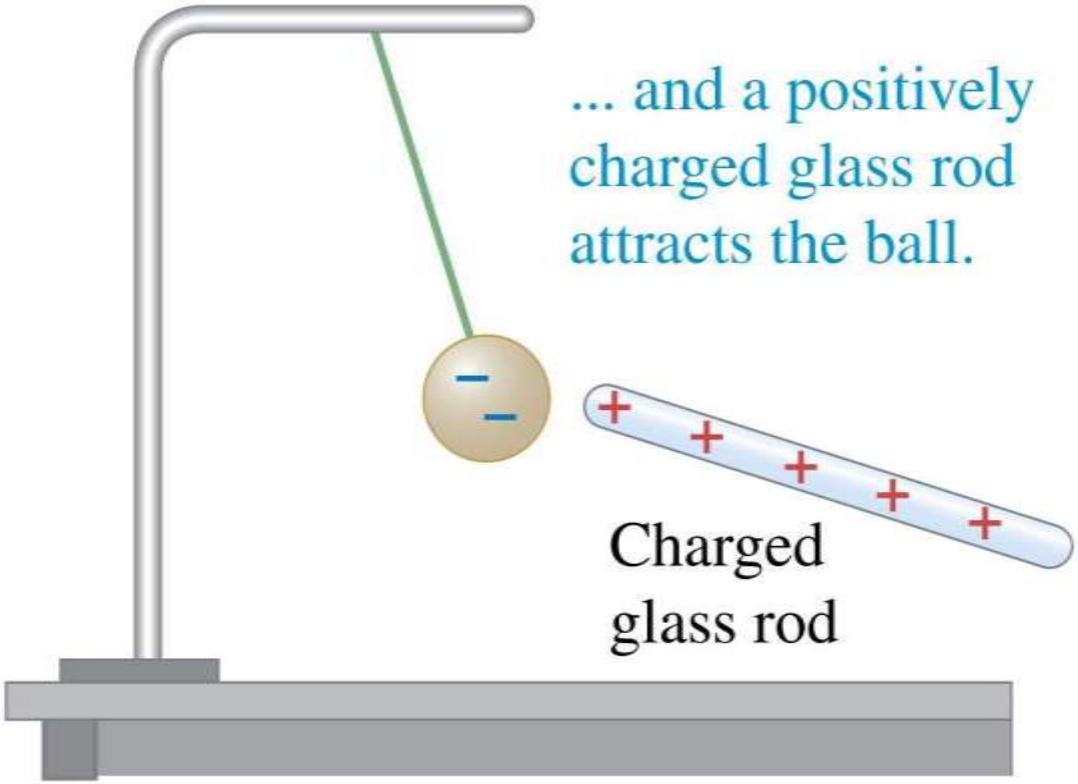
- Copper is a good conductor of electricity; nylon is a good insulator. The copper wire shown conducts charge between the metal ball and the charged plastic rod to charge the ball negatively.

Conductors and insulators



- After it is negatively charged, the metal ball is repelled by a negatively charged plastic rod.

Conductors and insulators

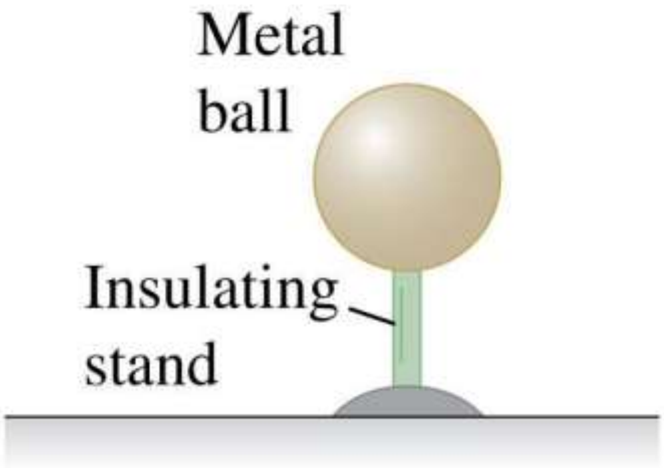


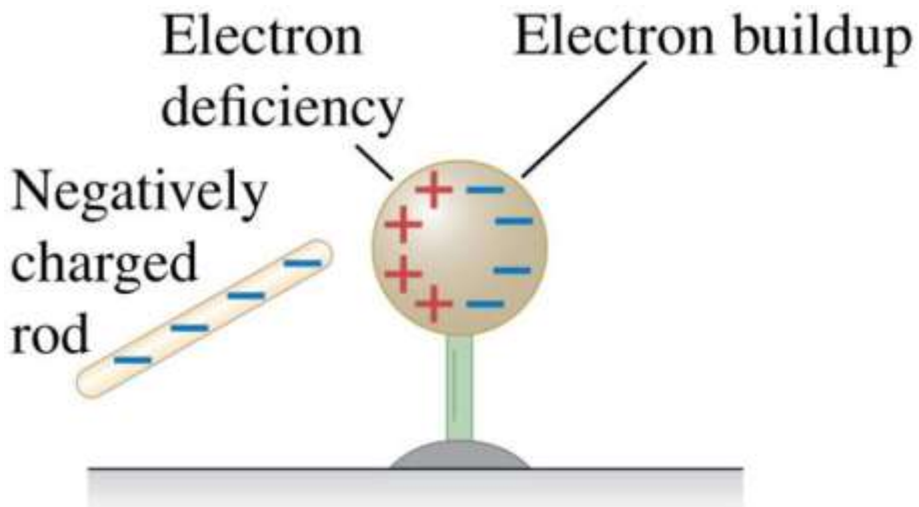
- After it is negatively charged, the metal ball is attracted by a positively charged glass rod.

Charging by induction in 4 steps: Steps 1 and 2

1. Start with an uncharged metal ball supported by an insulating stand.

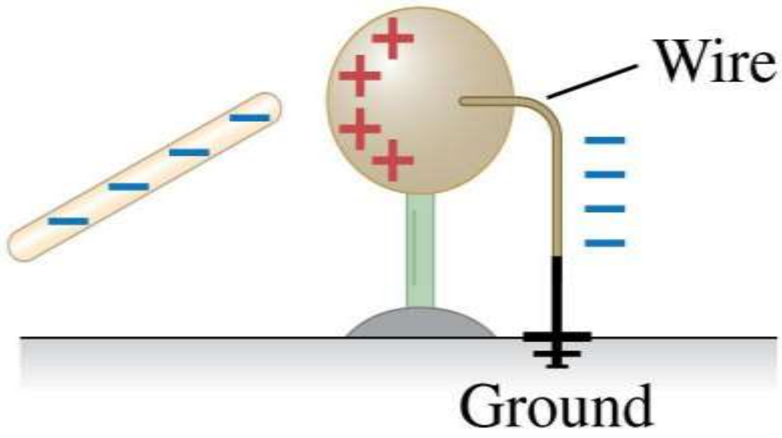
2. When you bring a negatively charged rod near it, without actually touching it, the free electrons in the metal ball are repelled by the excess electrons on the rod, and they shift toward the right, away from the rod.



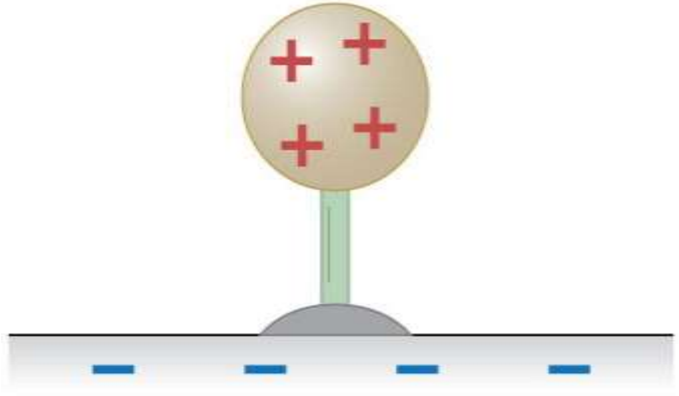


Charging by induction in 4 steps: Steps 3 and 4

3. While the plastic rod is nearby, you touch one end of a conducting wire to the right surface of the ball and the other end to the ground.



4. Now disconnect the wire, and then remove the rod. A net positive charge is left on the ball. The earth acquires a negative charge that is equal in magnitude to the induced positive charge remaining on the ball.



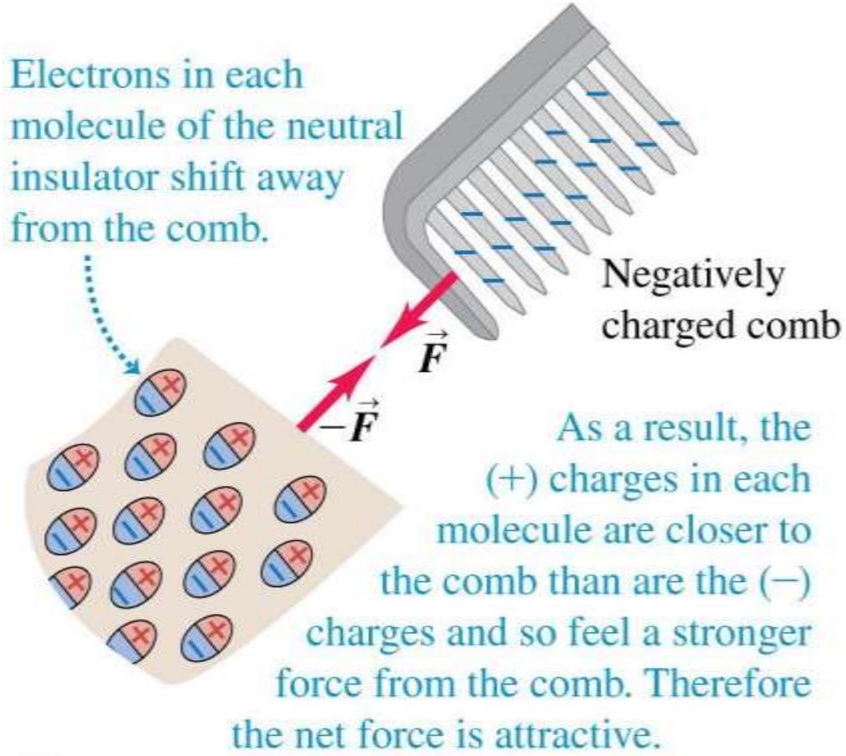
Electric forces on uncharged objects

- A charged body can exert forces even on objects that are not charged themselves.
- If you rub a balloon on the rug and then hold the balloon against the ceiling, it sticks, even though the ceiling has no net electric charge.
- After you electrify a comb by running it through your hair, you can pick up uncharged bits of paper or plastic with it.

- How is this possible?

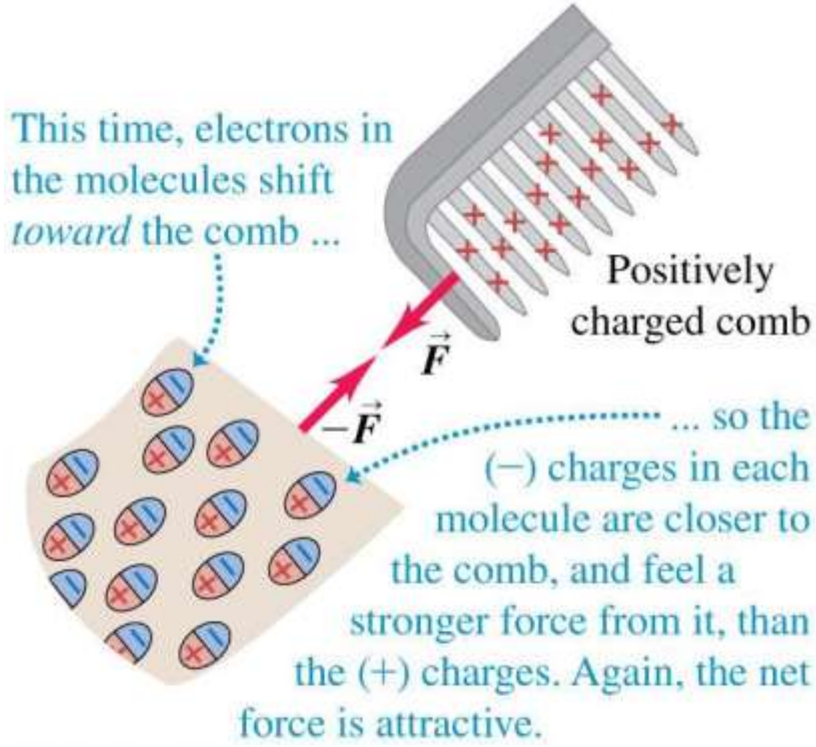
Electric forces on uncharged objects

- The negatively charged plastic comb causes a slight shifting of charge within the molecules of the neutral insulator, an effect called **polarization**.



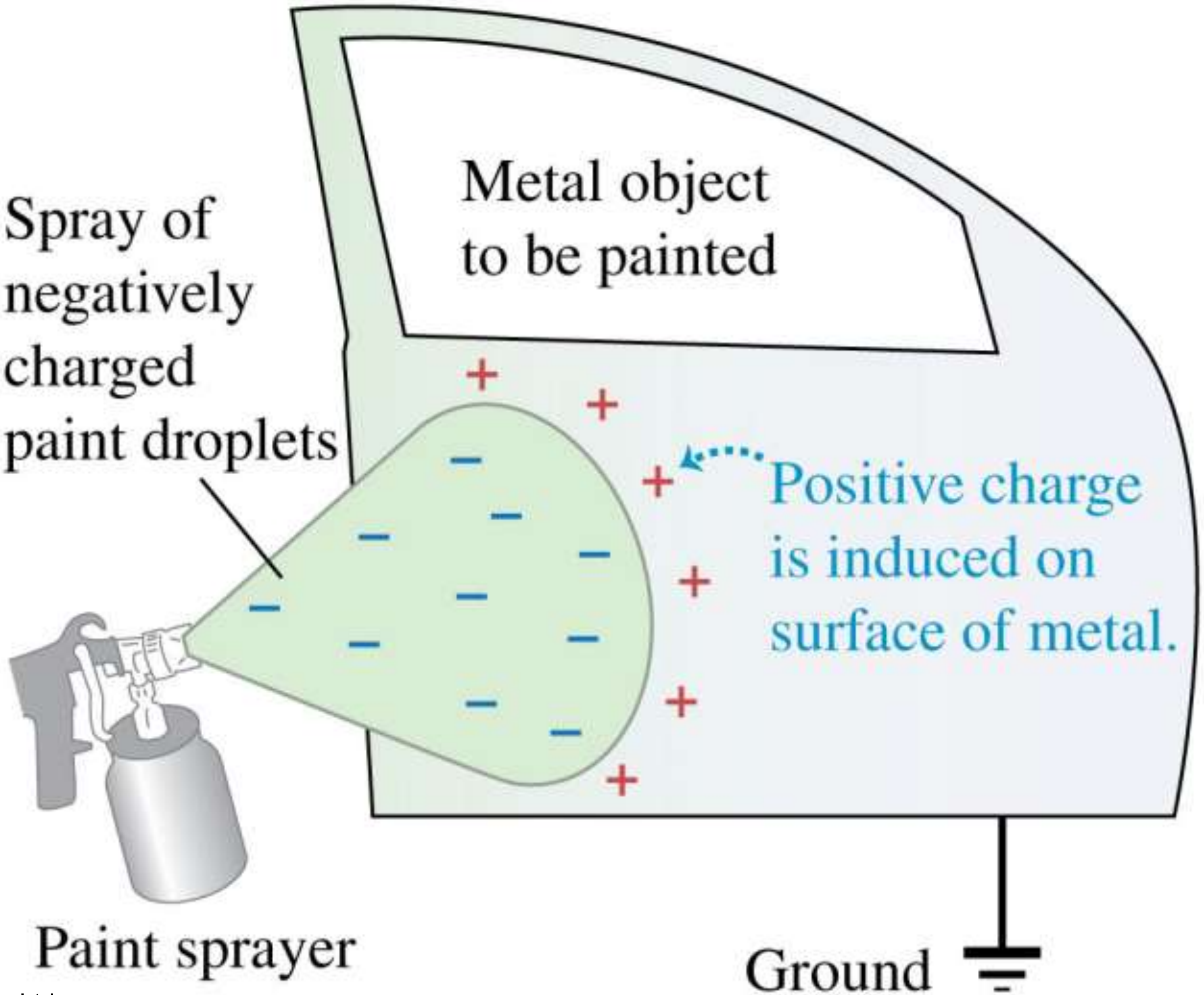
Electric forces on uncharged objects

- Note that a neutral insulator is also attracted to a *positively* charged comb.
- A charged object of *either* sign exerts an *attractive* force on an uncharged insulator.



Electrostatic painting

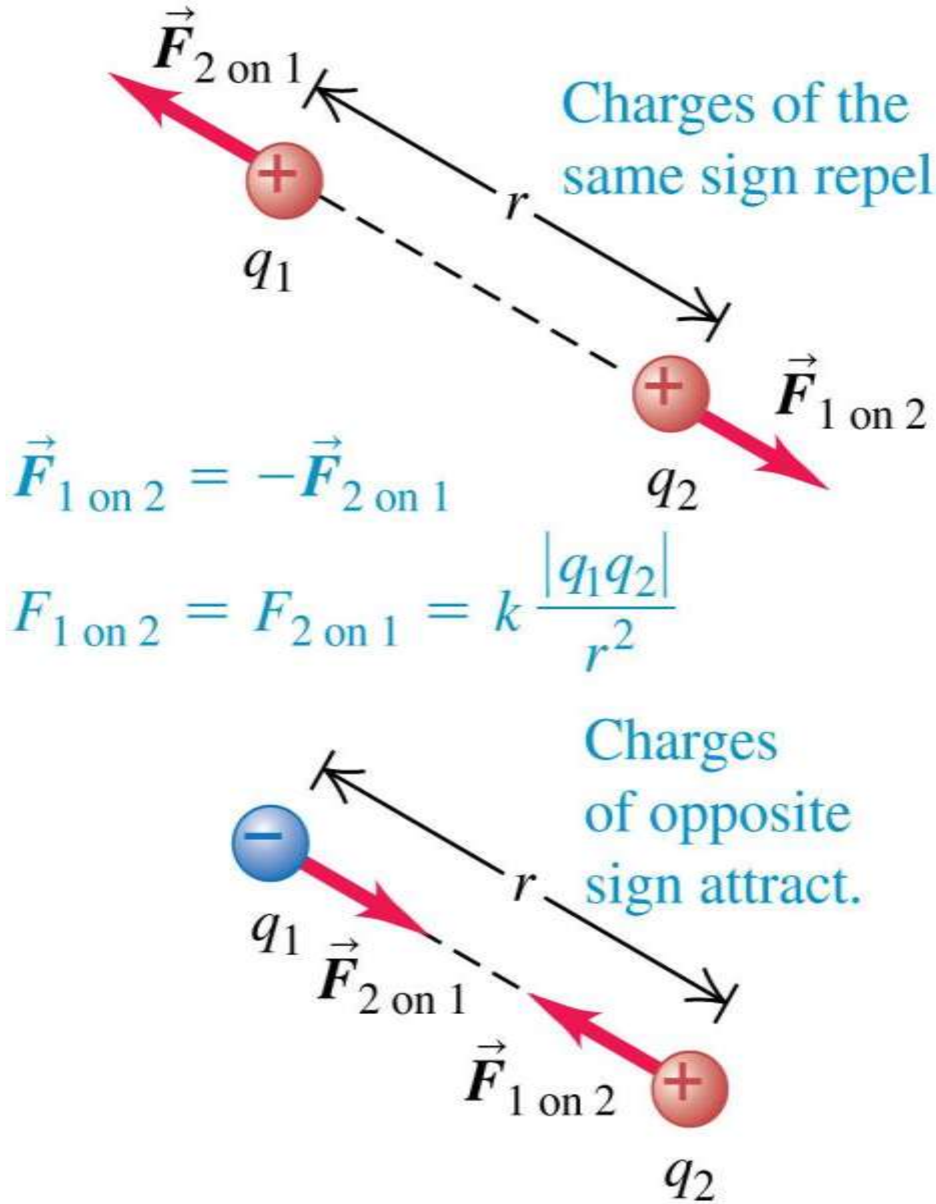
- Induced positive charge on the metal object attracts the negatively charged paint droplets.



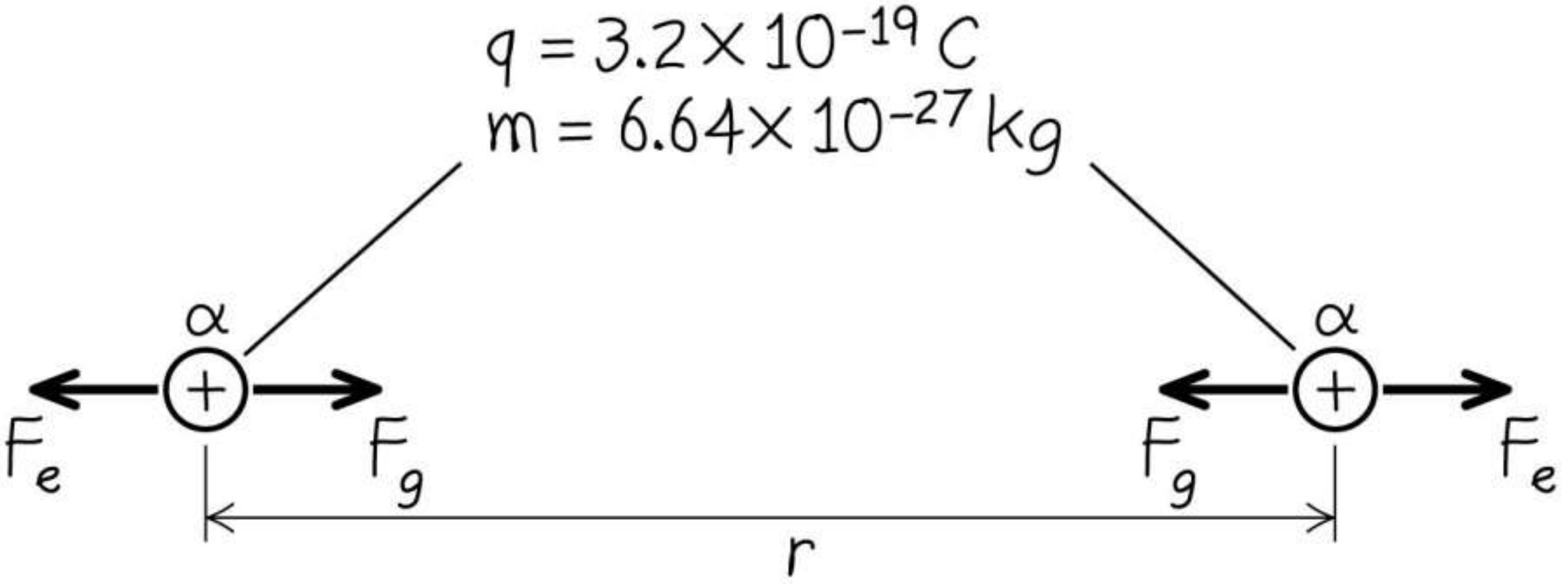
Coulomb's Law

- **Coulomb's Law**: The magnitude of the electric force between two point charges is directly proportional to the product of their charges and inversely proportional to the square of the distance between them.

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

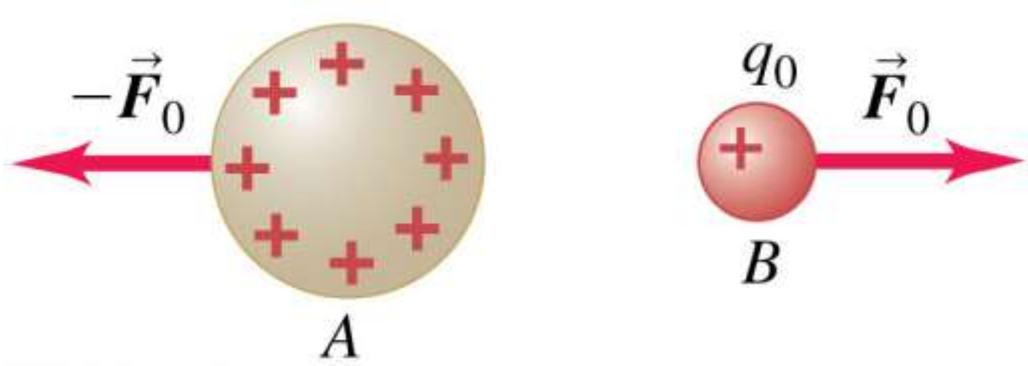


Exp. 21.1



Electric field: Introduction Slide 1 of 3

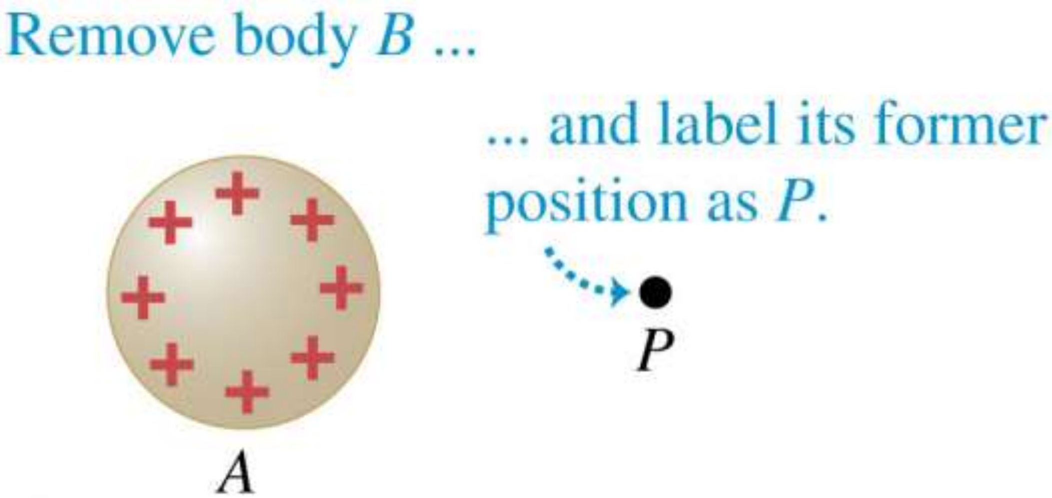
A and *B* exert electric forces on each other.



- To introduce the concept of **electric field**, first consider the mutual repulsion of two positively charged bodies *A* and *B*.

Electric field: Introduction Slide 2 of 3

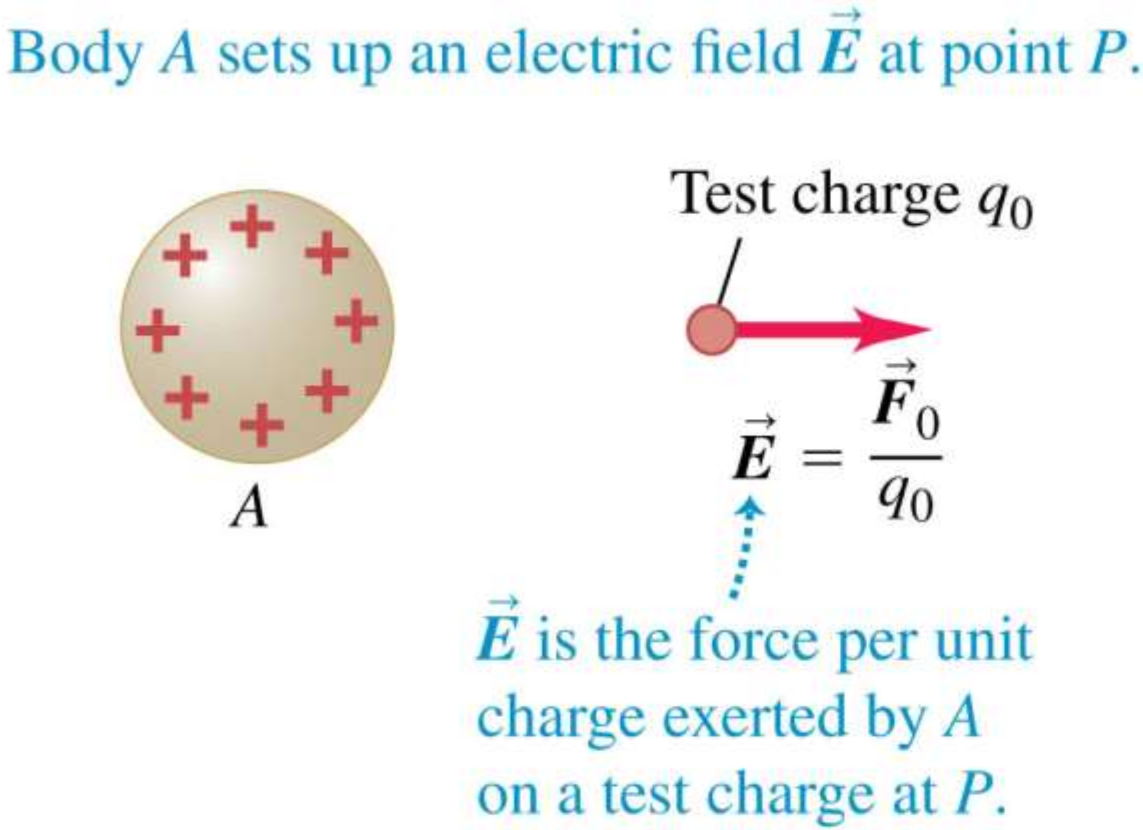
- Next consider body *A* on its own.



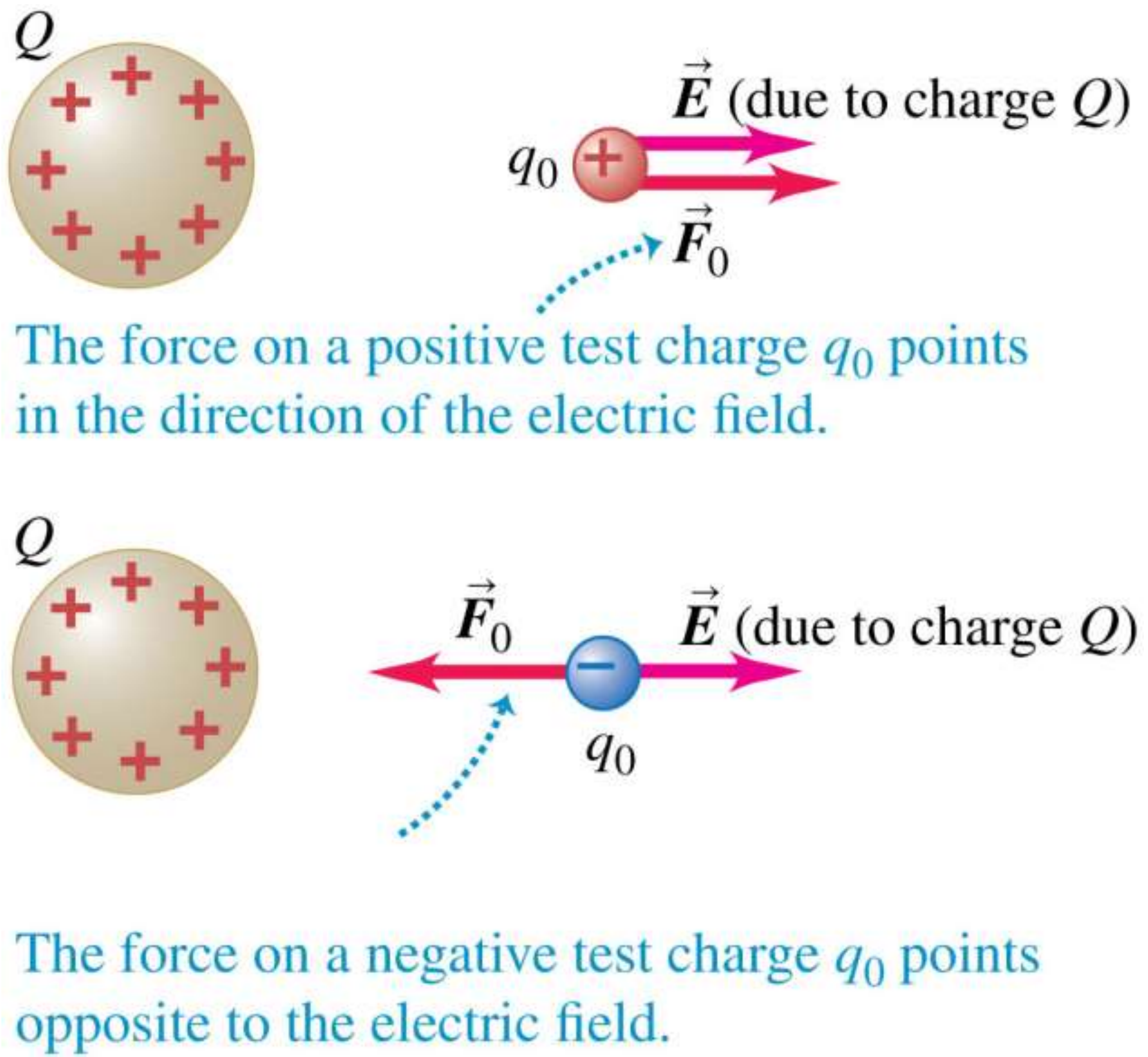
- We can say that body *A* somehow *modifies the properties of the space* at point *P*.

Electric field: Introduction Slide 3 of 3

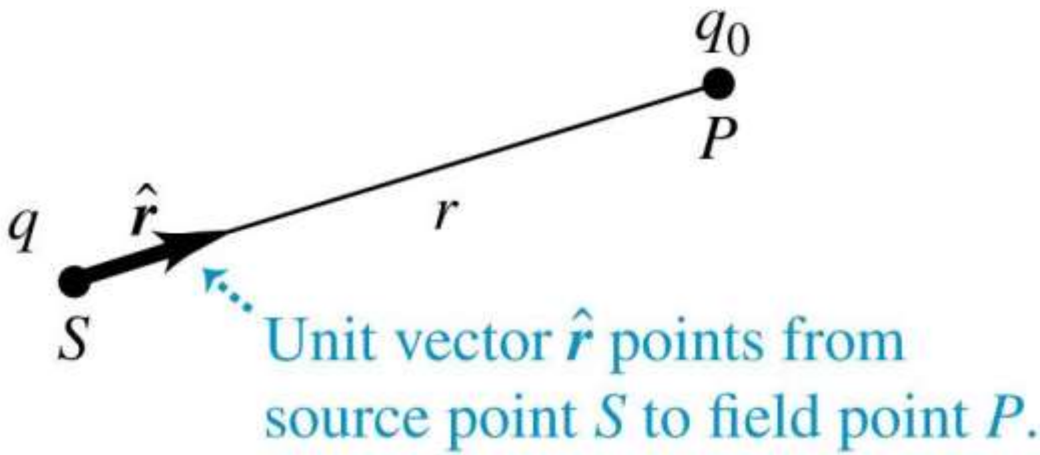
- We can measure the electric field produced by *A* with a test charge.

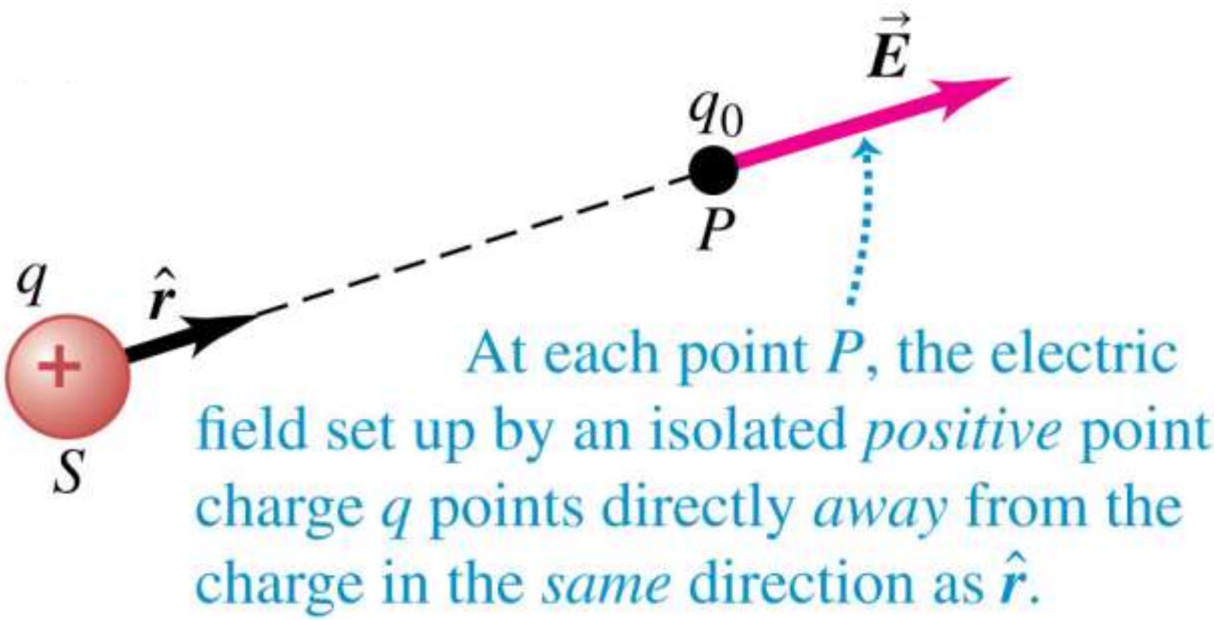


Electric force produced by an electric field



The electric field of a point charge





The electric field of a point charge

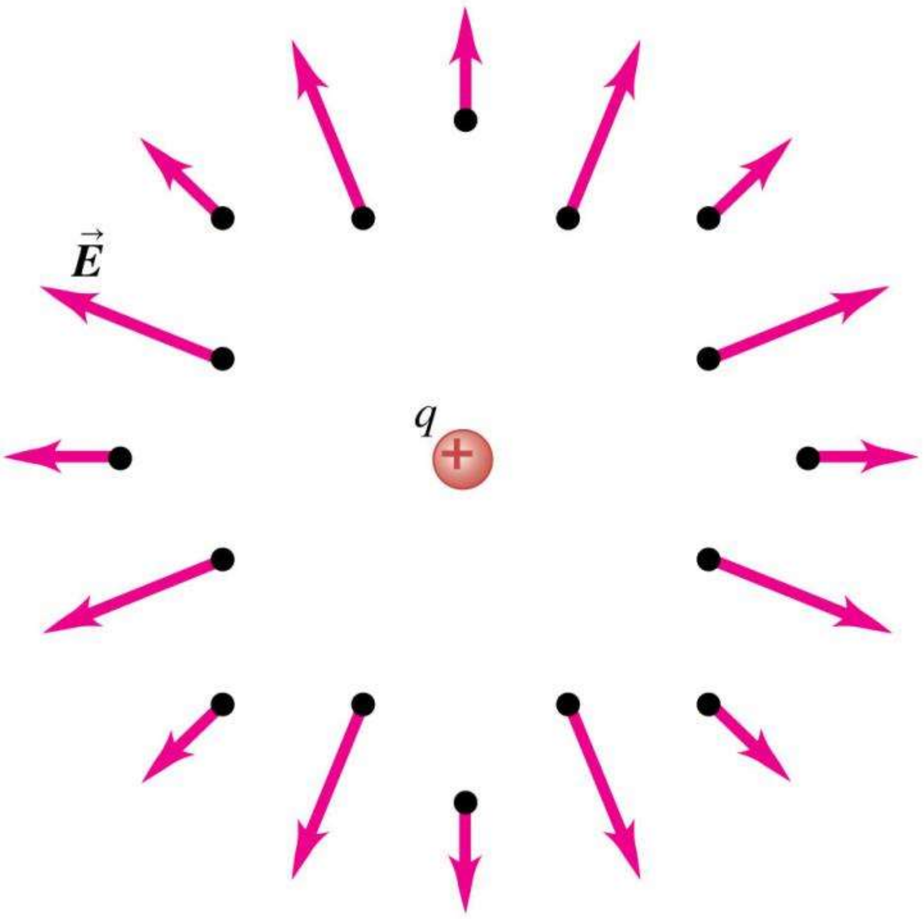
- Using a unit vector that points away from the origin, we can write a vector equation that gives both the magnitude and the direction of the electric field:

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$

- $\vec{E}$: Electric field due to a point charge
- q: Value of point charge
- $\hat{r}$: Unit vector from point charge toward where field is measured
- r: Distance from point charge to where field is measured
- ϵ_0: Electric constant

Electric field of a point charge

- A point charge q produces an electric field at *all* points in space.
- The field strength decreases with increasing distance.
- The field produced by a positive point charge points *away from* the charge.



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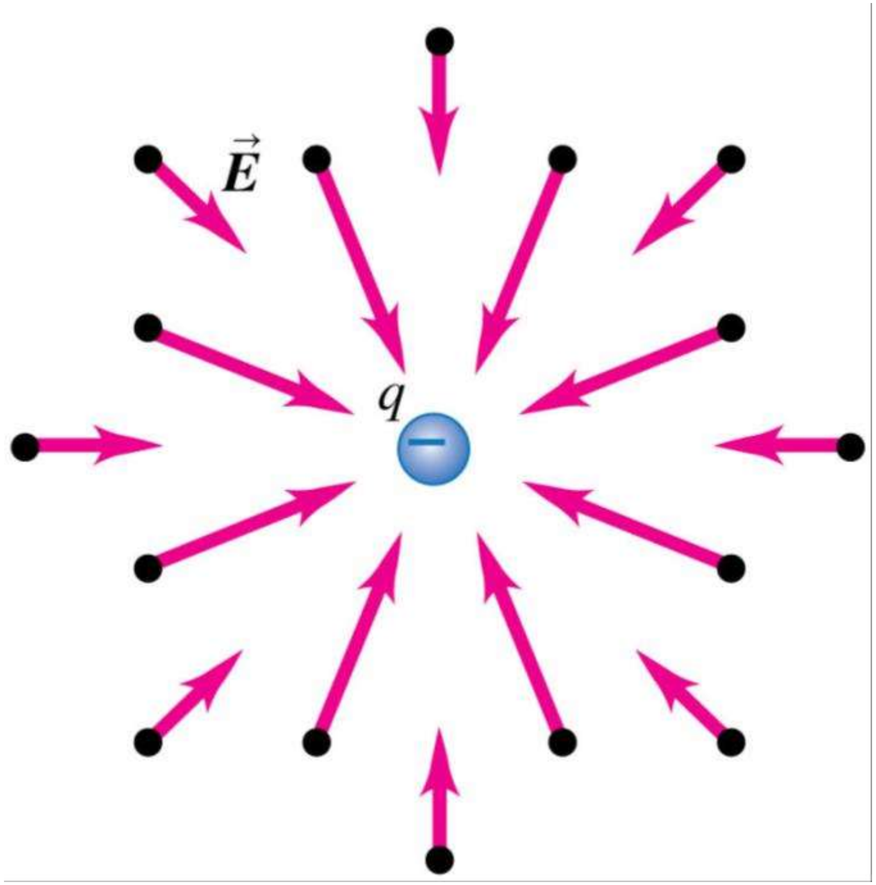
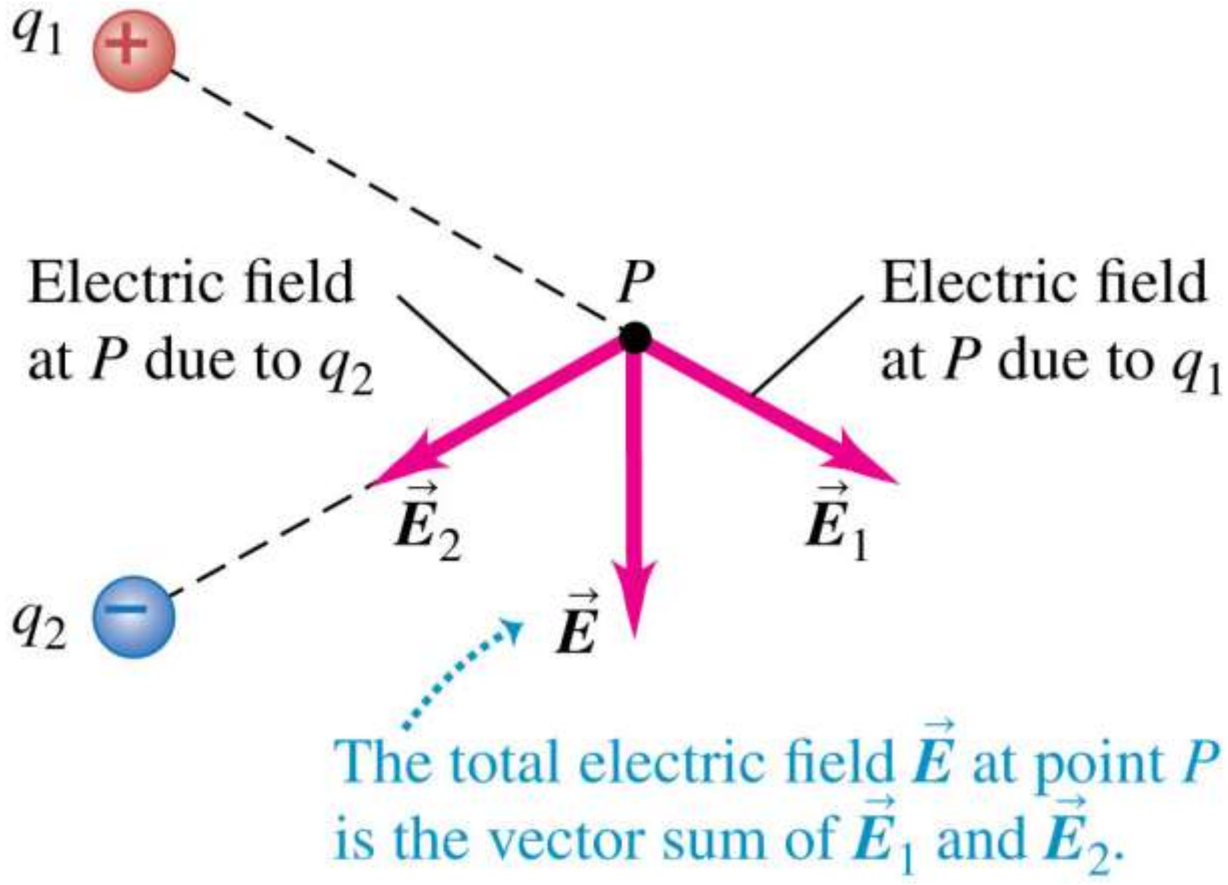
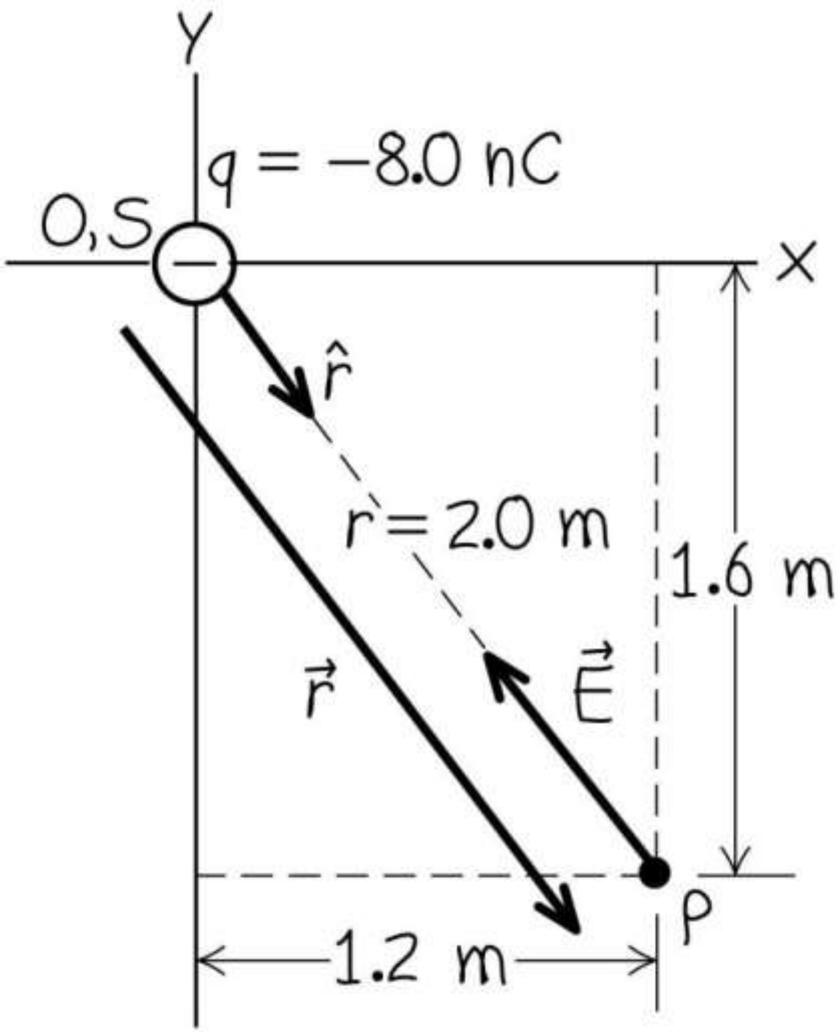


Superposition of electric fields

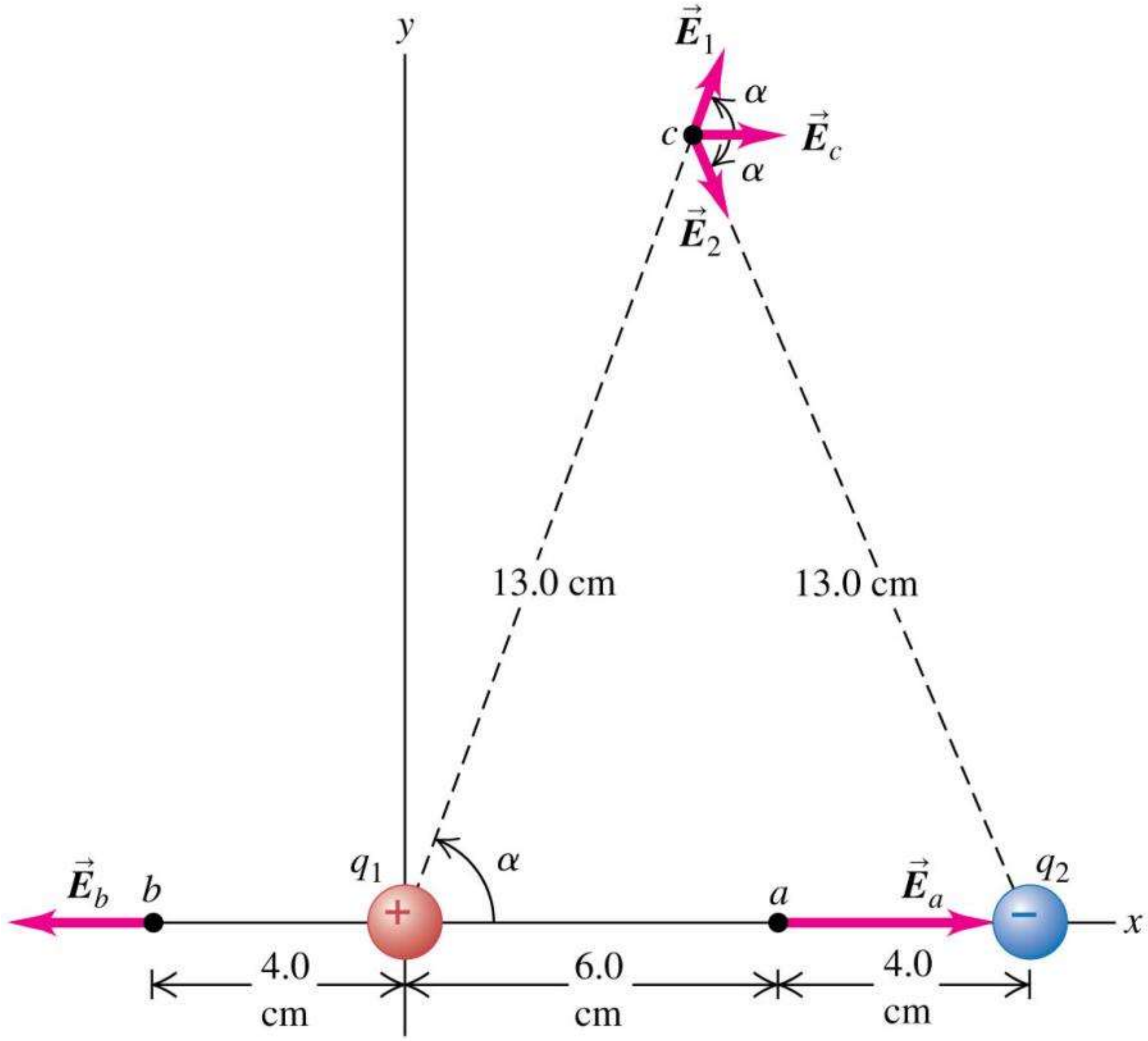
- The total electric field at a point is the vector sum of the fields due to all the charges present.



Exp. 21.6

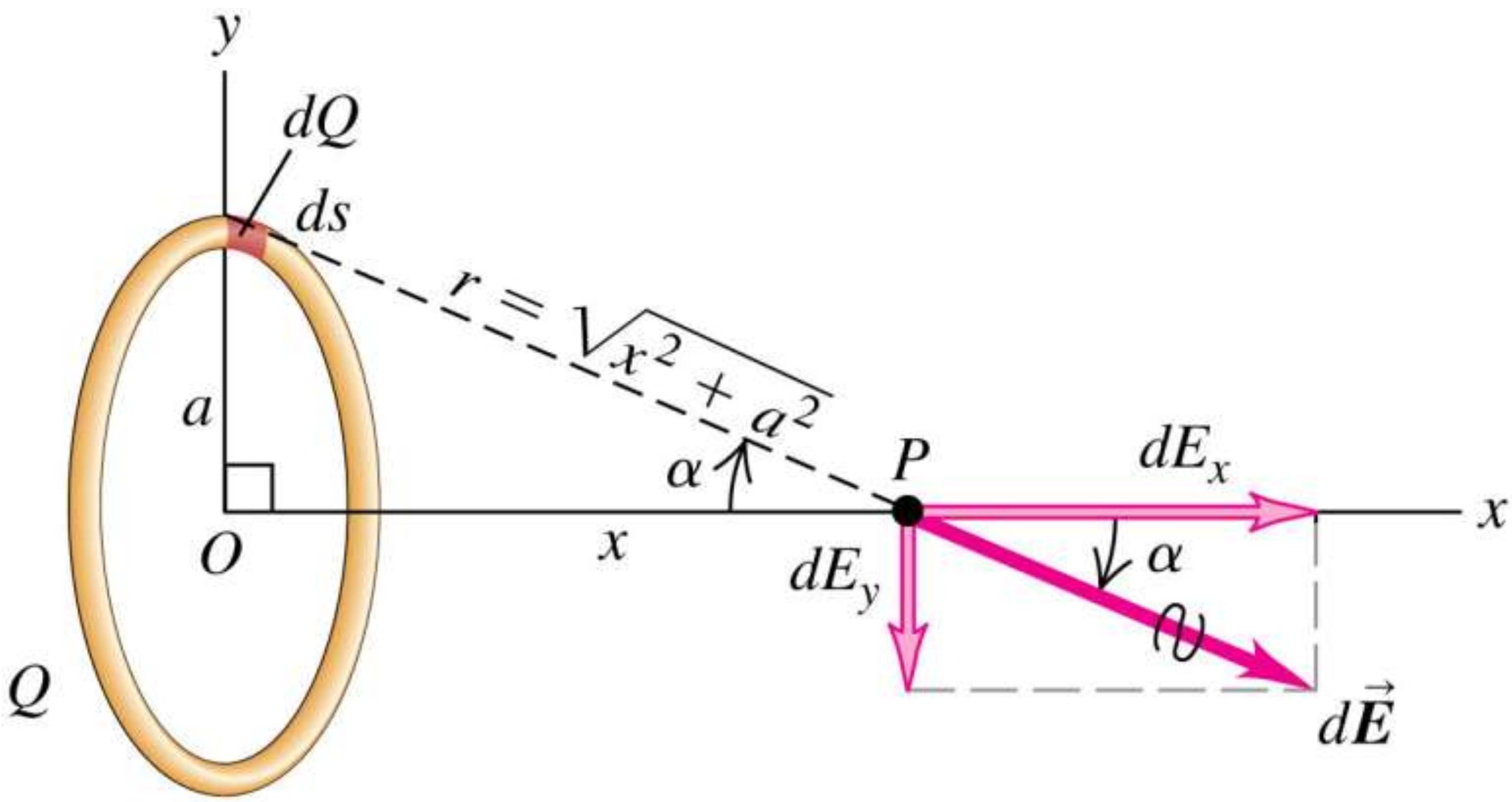


Exp. 21.8



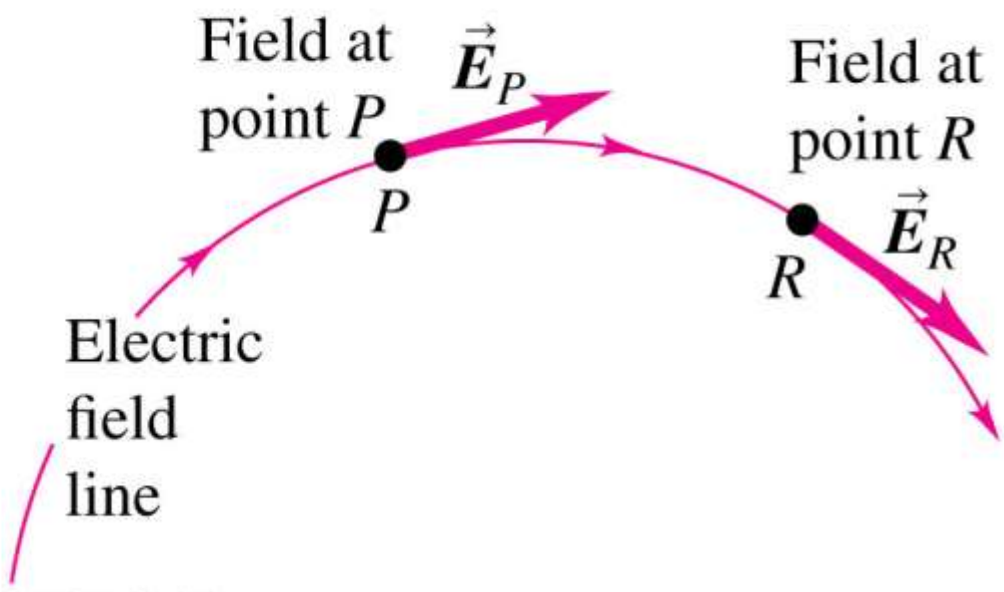
y
$\vec{E}_1$
α
c
$\vec{E}_c$
α
$\vec{E}_2$
13.0 cm
13.0 cm
$\vec{E}_b$
b
q_1
α
a
$\vec{E}_a$
q_2
x
4.0 cm
6.0 cm
4.0 cm

Exp. 21.9



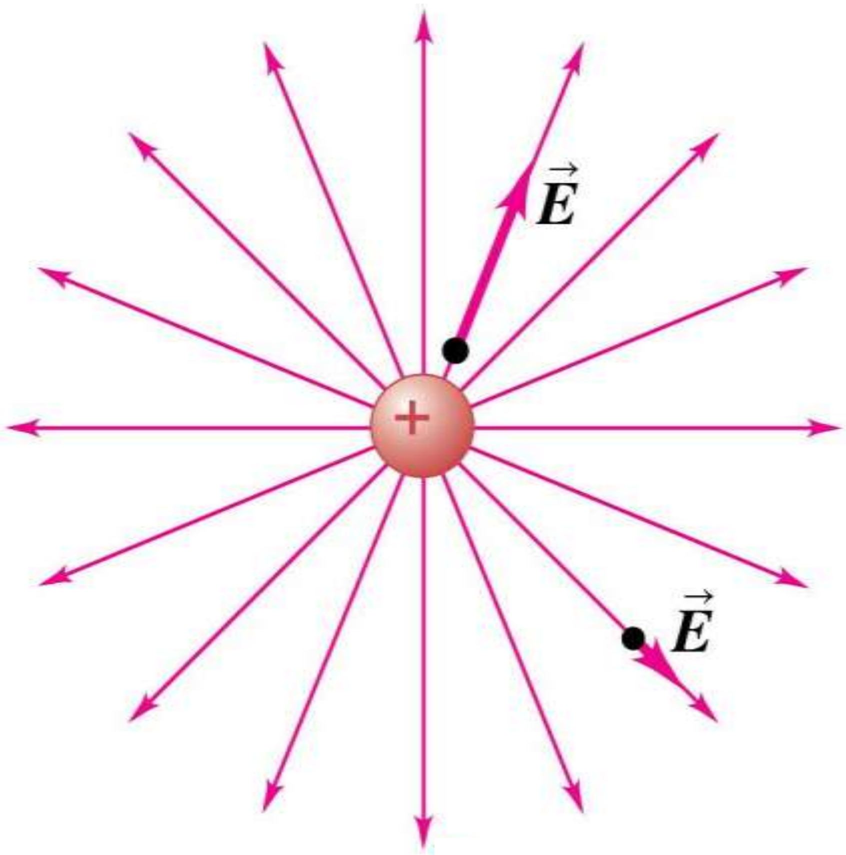
Electric field lines

- An **electric field line** is an imaginary line or curve whose tangent at any point is the direction of the electric field vector at that point.



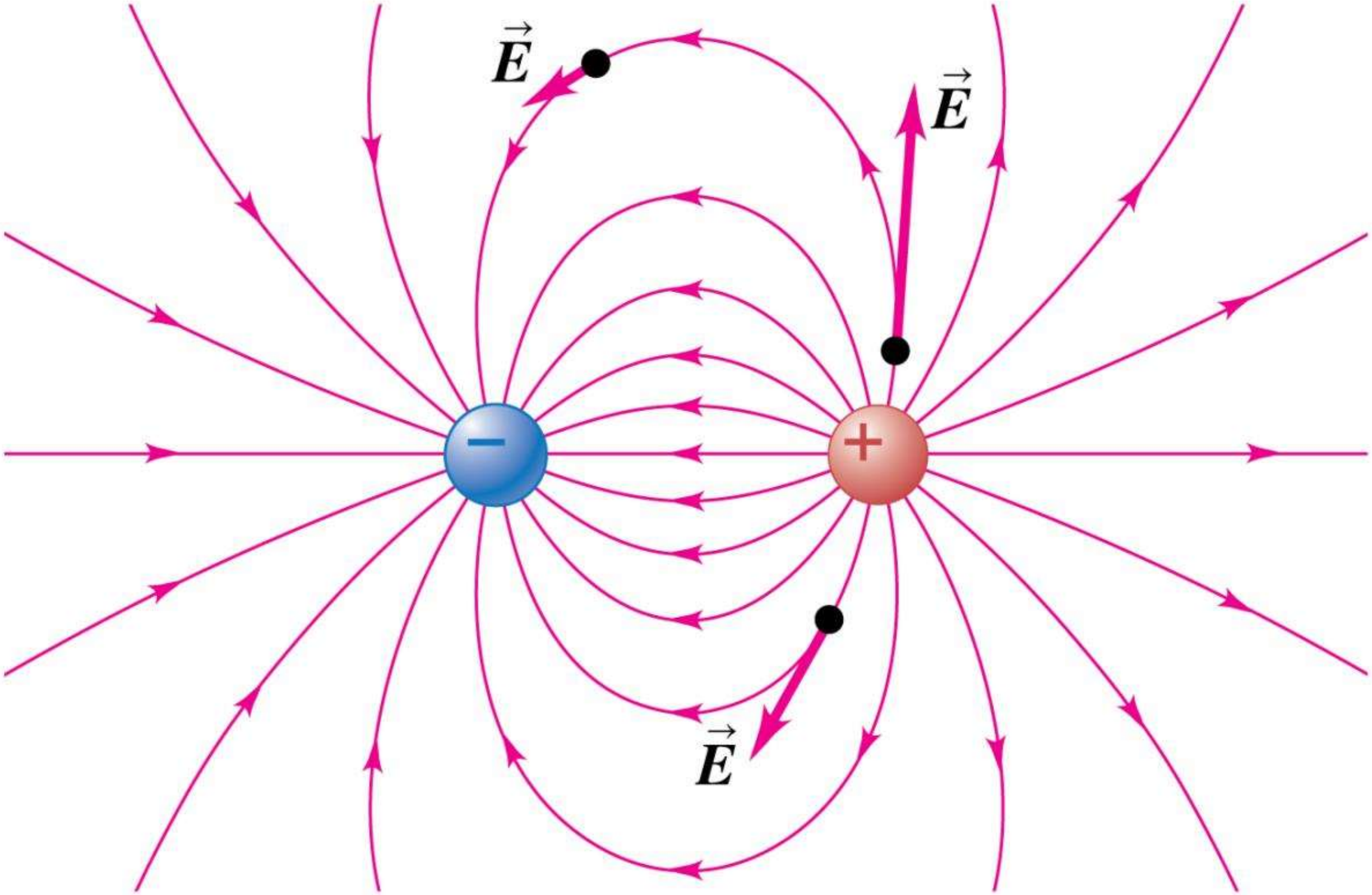
Electric field lines of a point charge

- Electric field lines show the *direction* of the electric field at each point.
- The spacing of field lines gives a general idea of the *magnitude* of the electric field at each point.



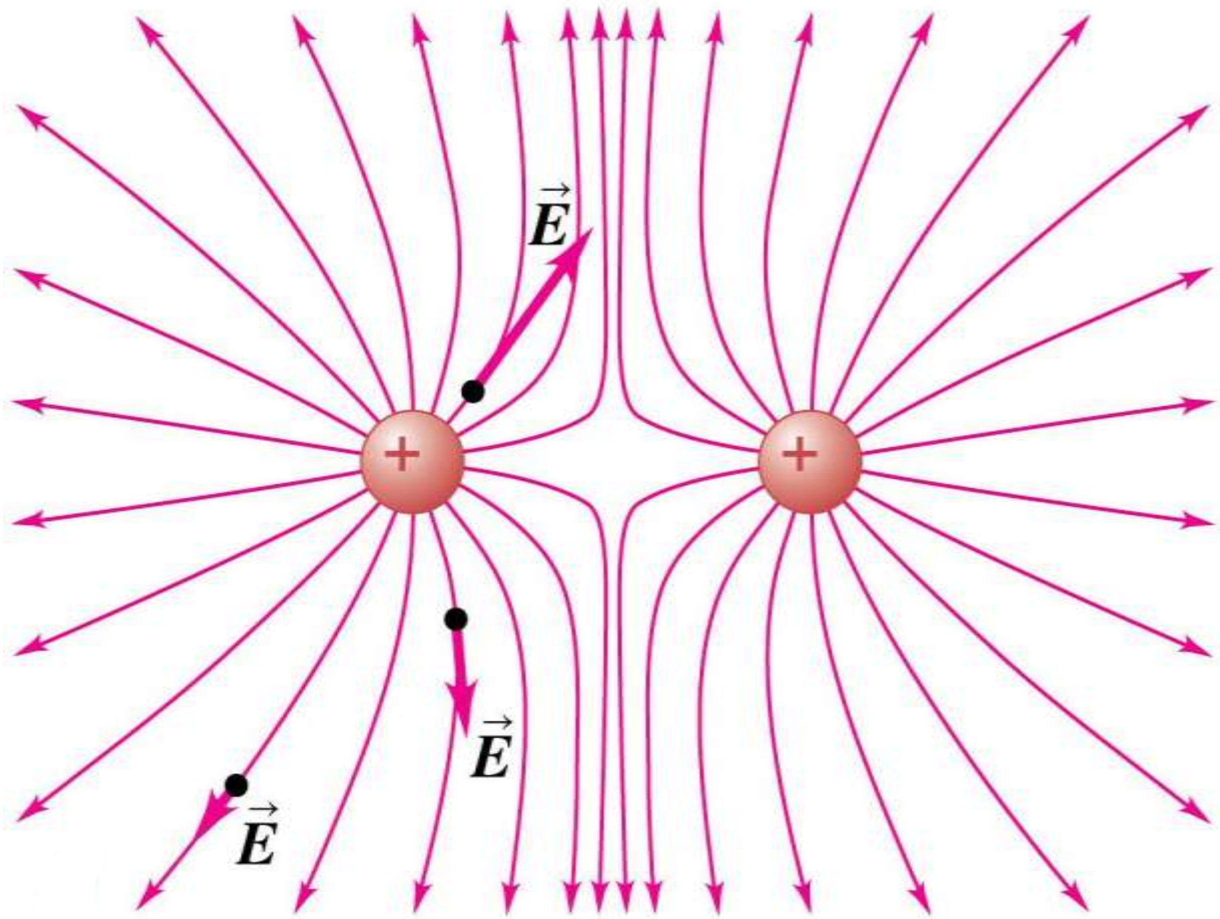
Electric field lines of a dipole

- Field lines point away from + charges and toward – charges.



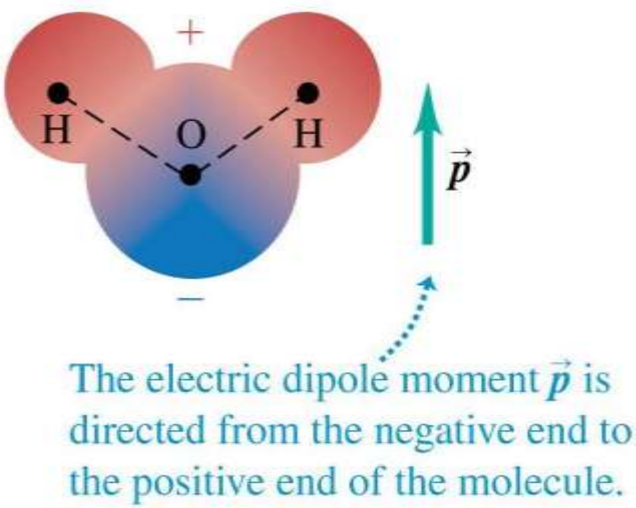
Electric field lines of two equal positive charges

- At any point, the electric field has a unique direction, so *field lines never intersect*.



The water molecule is an electric dipole

- The water molecule as a whole is electrically neutral, but the chemical bonds within the molecule cause a displacement of charge.
- The result is a net negative charge on the oxygen end of the molecule and a net positive charge on the hydrogen end, forming an electric dipole.

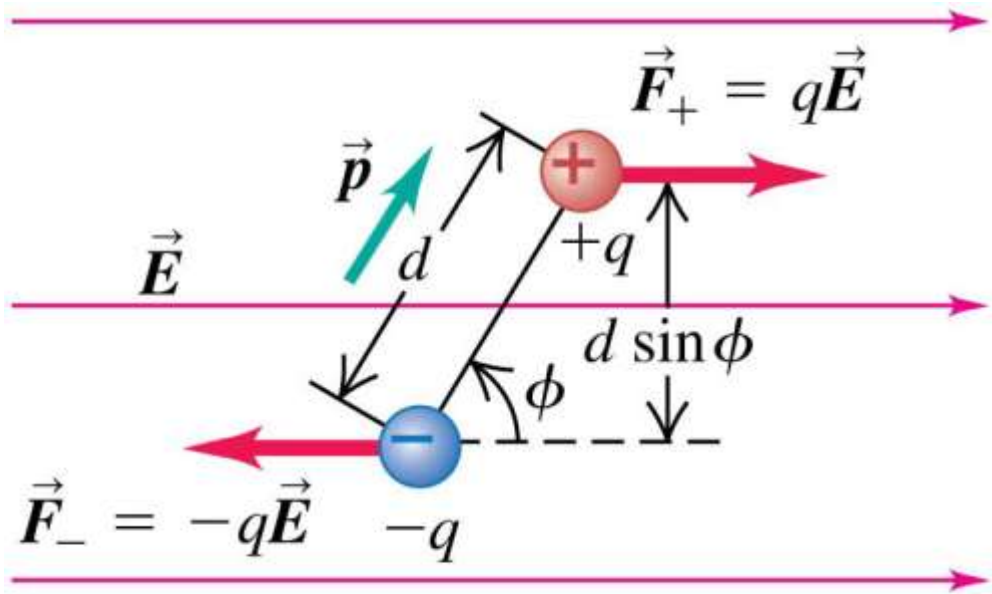


The water molecule is an electric dipole

- When dissolved in water, salt dissociates into a positive sodium ion and a negative chlorine ion, which tend to be attracted to the negative and positive ends of water molecules.
- This holds the ions in solution.
- If water molecules were not electric dipoles, water would be a poor solvent, and almost all of the chemistry that occurs in aqueous solutions would be impossible!

Force and torque on a dipole

- When a dipole is placed in a uniform electric field, the net *force* is always zero, but there can be a net *torque* on the dipole.



$$\vec{F}_g = m_0\vec{g}$$