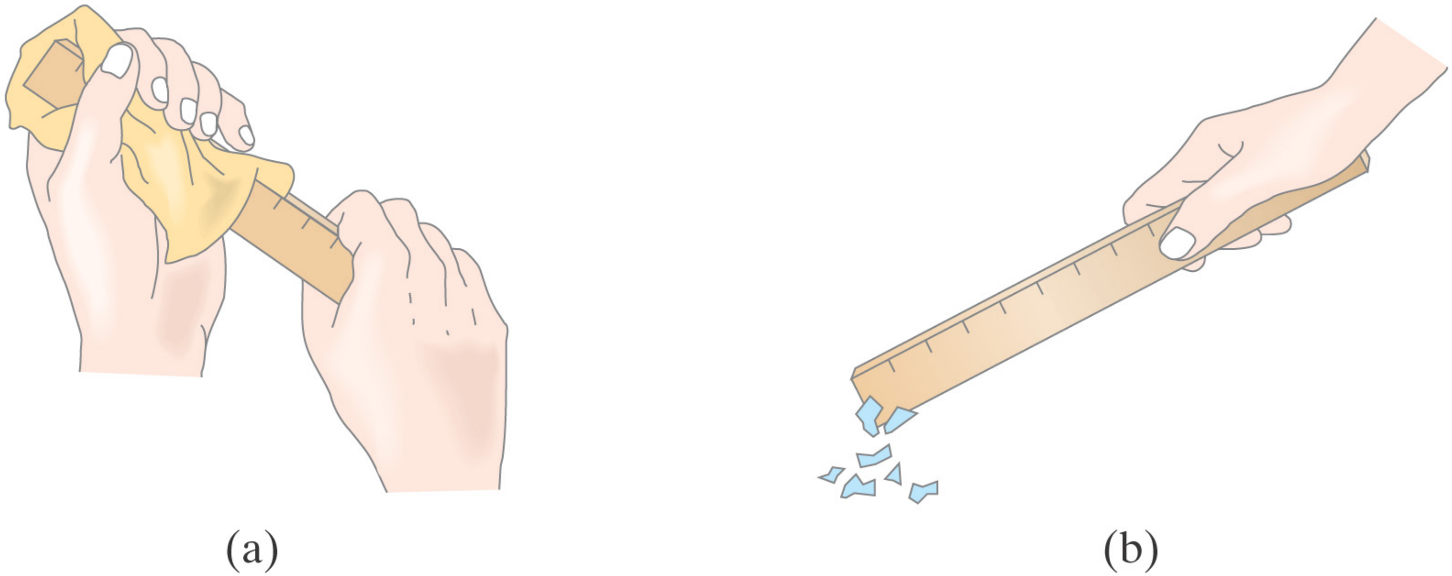
Chapter 16: Electric Charge and Field

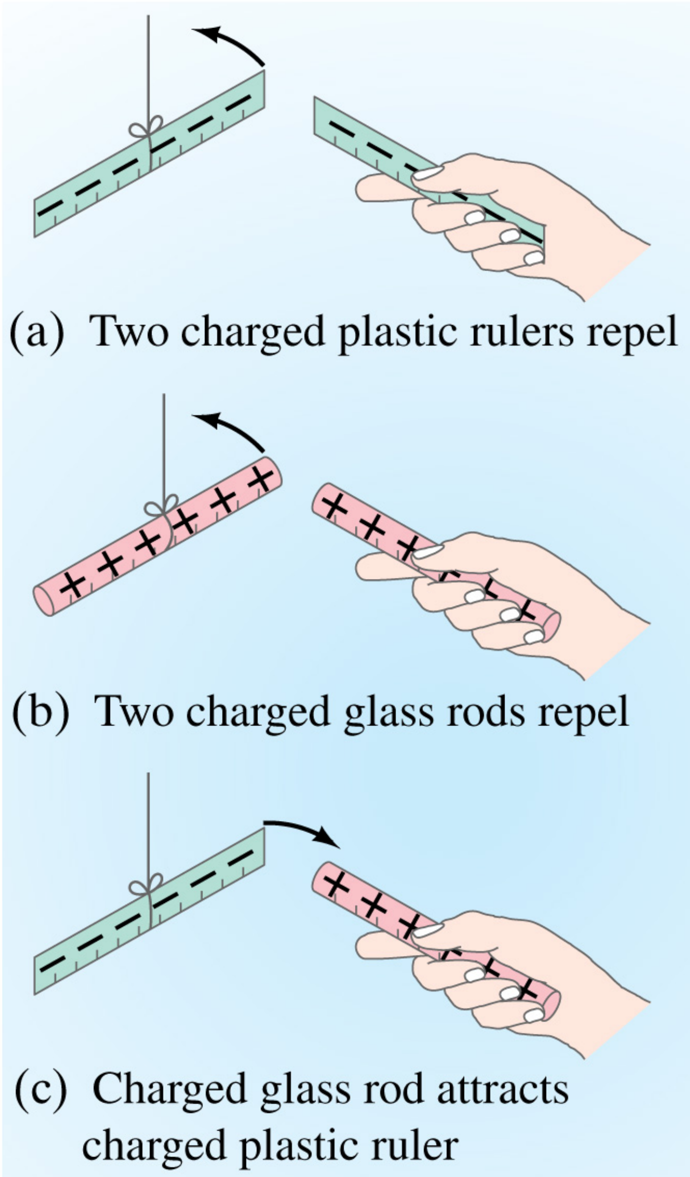
Electric Forces between atoms and molecules hold them together to form liquids and solids

Static Electricity – from Greek: *elektron*=amber (petrified tree resin)
Examples: rubbed plastic ruler, combing hair, synthetic blouse, shock from metal doorknob after sliding over a nylon carpet

Rubbed object possesses a net **electric charge**



Electric Charge



(a) Two charged plastic rulers repel

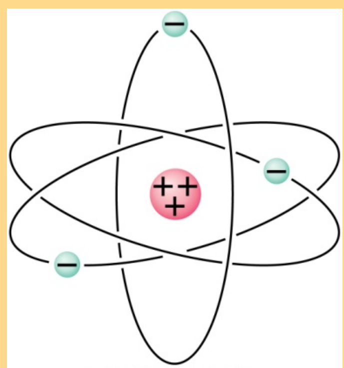
(b) Two charged glass rods repel

(c) Charged glass rod attracts charged plastic ruler

Charge comes in two types, **positive and negative**; *like charges repel and opposite charges attract*

Law of conservation of electric charge
The net amount of electric charge produced in any process is zero

Ex: plastic rulers rubbed with a paper towel acquire negative charge while the towel acquires an equal amount of positive charge.

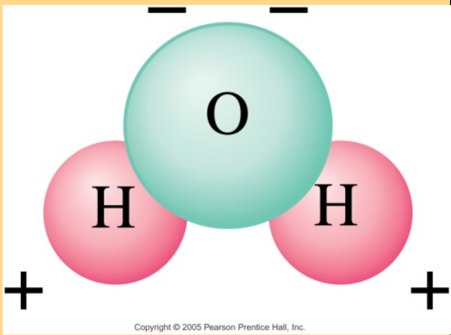


Atom:
Nucleus contains **protons (+)** and neutrons (no net electric charge) and is surrounded by **electrons (-)**
Neutral atom: no net charge
If it loses or gains electrons: **ions**

Insulators and Conductors

Plastic ruler becomes negatively charged by rubbing with a paper towel, that is, electrons are transferred from towel to ruler (towel becomes +)

Objects charged by rubbing return to neutral state, by leaking charge into water molecules in the air. This is more difficult in dry days. Water molecules are **polar**

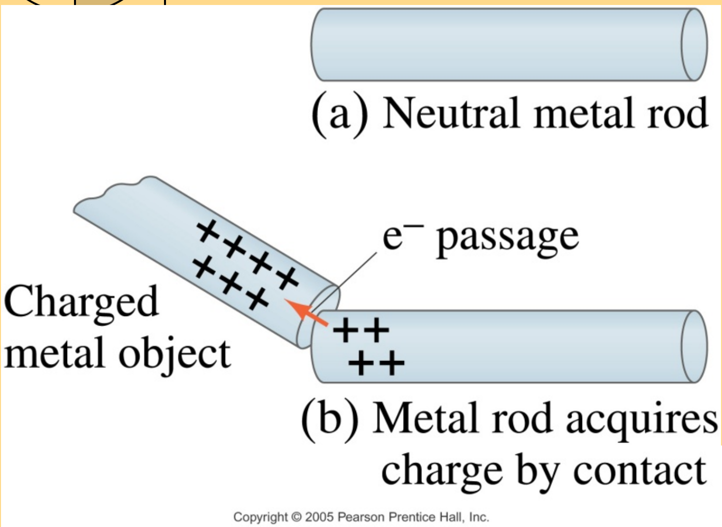


Metal are good **conductors**
Some of the electrons are bound very loosely and can move about freely within the material. *free electrons or conduction electrons*

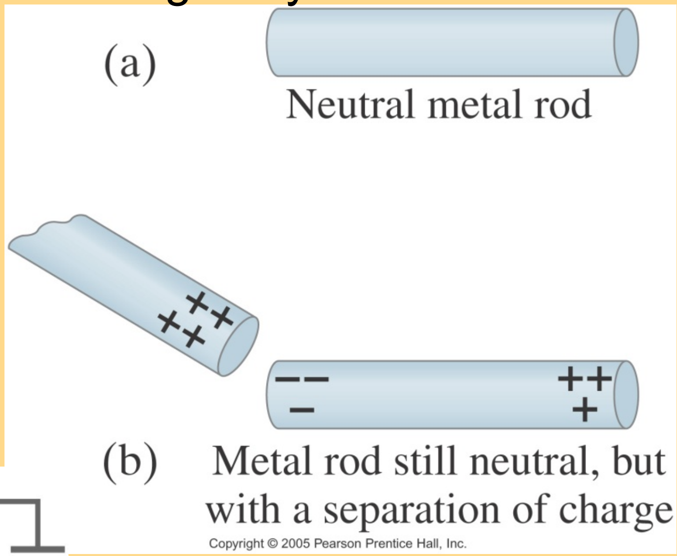
In **insulators** the electrons are bound very tightly to the nuclei.

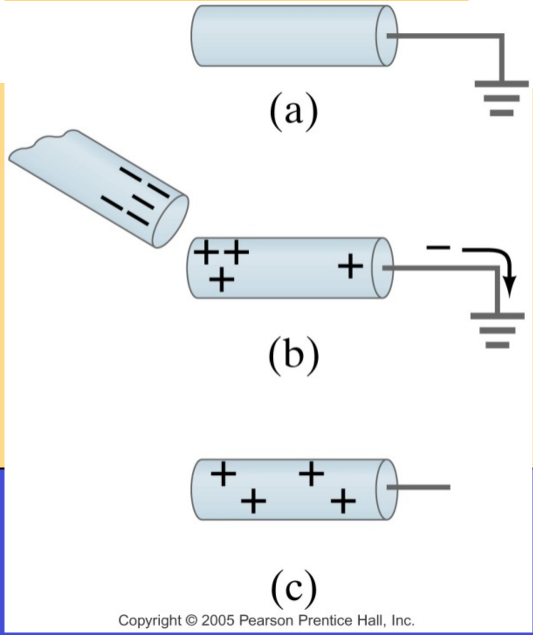
Induced Charge

Metal objects can be charged by **conduction**:



Metal objects can also be charged by **induction**:



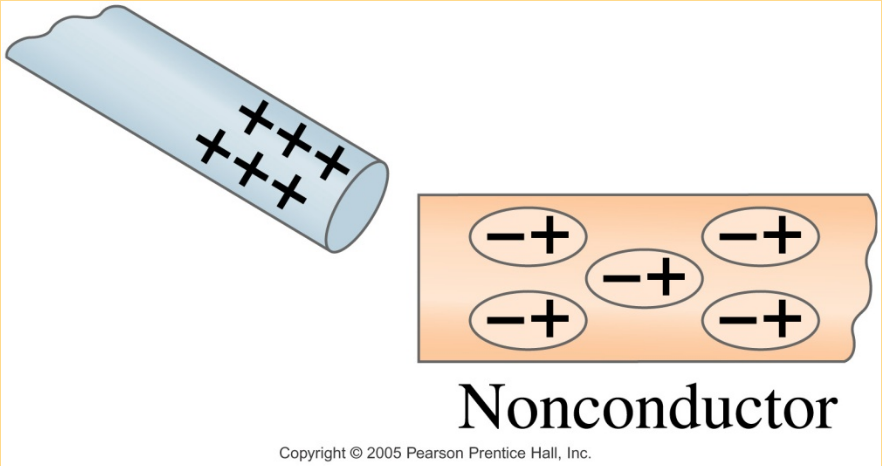


Here the metal is grounded, electrons leave the metal to Earth.

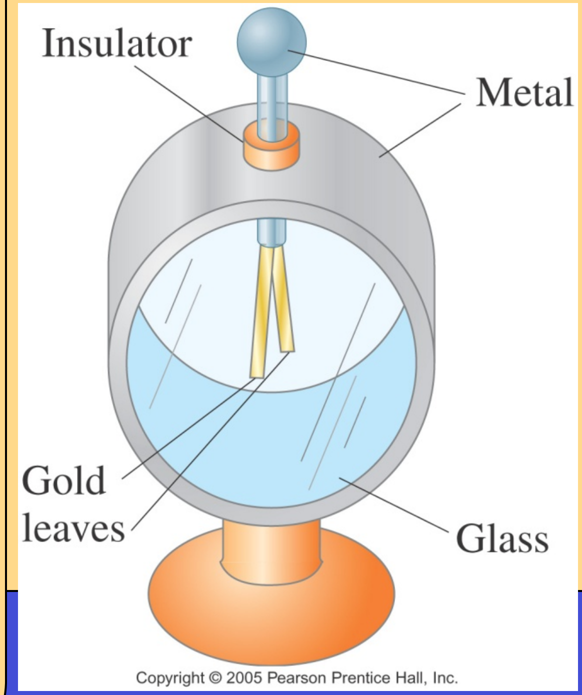
If the wire is cut, metal is positively charged

Charge Separation in nonconductors

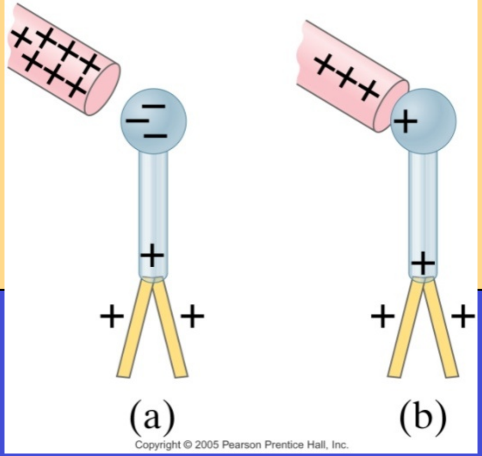
A charged object brought near an insulator causes a charge separation within the insulator’s molecules.



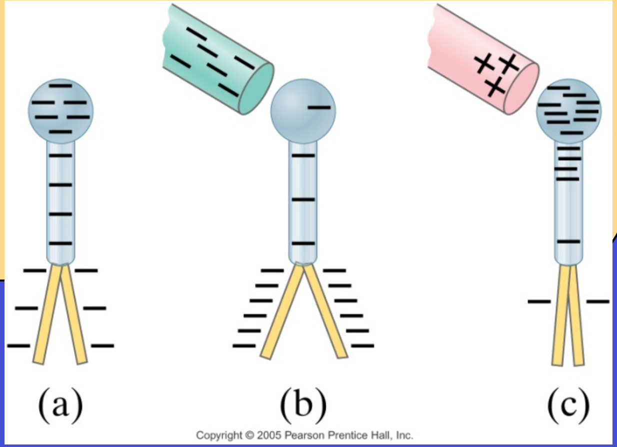
The **electroscope** can be used for detecting charge:



The electroscope can be charged either by conduction or by induction.

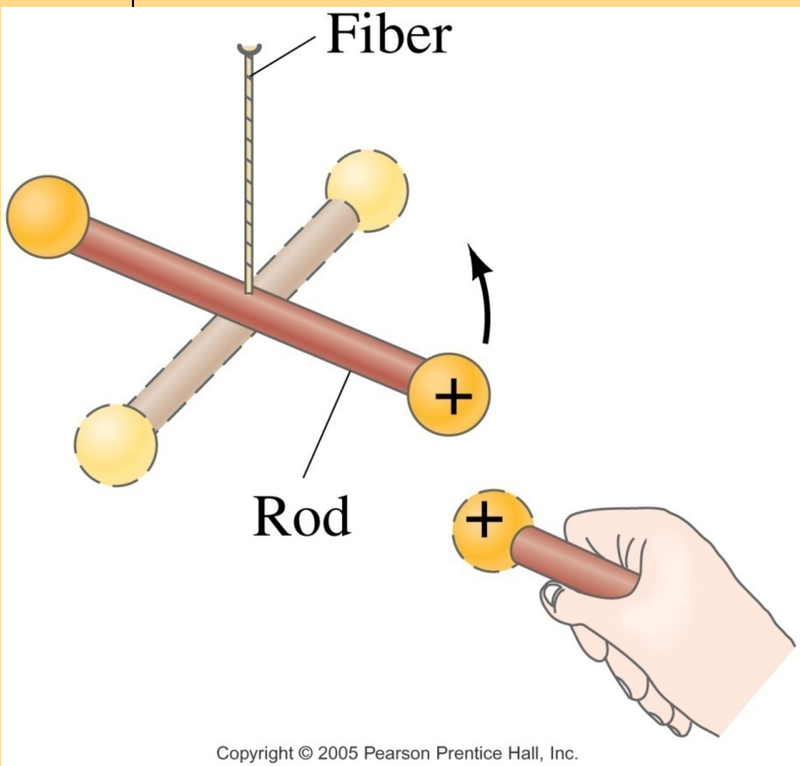


The charged electroscope can then be used to determine the sign of an unknown charge.



Coulomb's Law

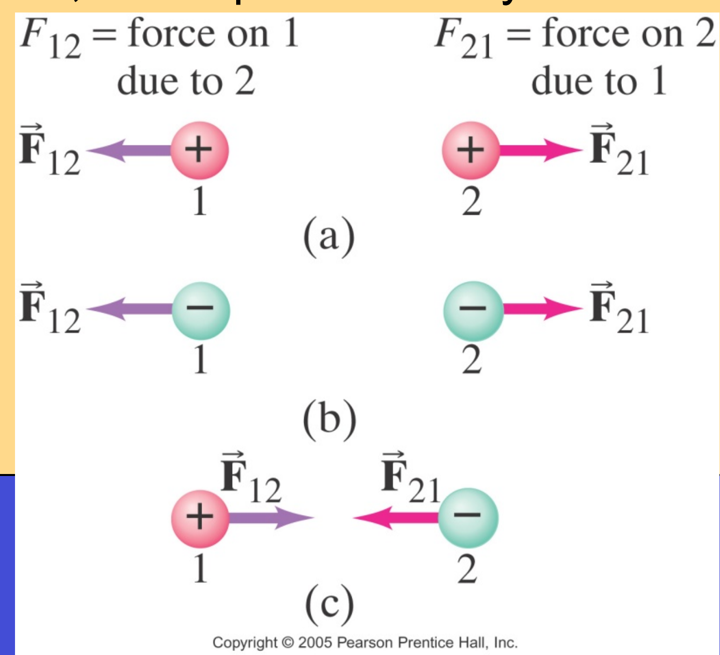
Experiment shows that the electric force between two charges is proportional to the product of the charges and inversely proportional to the distance between them.



$$F = k\frac{Q_1 Q_2}{r^2}$$

This equation gives the magnitude of the force.

The force is along the line connecting the charges, and is attractive if the charges are opposite, and repulsive if they are the same.



Coulomb's Law

$$F = k\frac{Q_1 Q_2}{r^2}$$

Unit of charge: coulomb, C

The proportionality constant in Coulomb's law is

$$k = 8.988 \times 10^9 \ \mathrm{N \cdot m^2/C^2}$$

We normally do not find charges as large as a coulomb. Charges produced by rubbing are typically around a microcoulomb: $1\ \mu\mathrm{C} = 10^{-6}\ \mathrm{C}$

Charge on the electron is the **smallest** charge found in nature and is equal to –e, where e is the *elementary charge* given by: $e = 1.602 \times 10^{-19}\ \mathrm{C}$

The charge on a proton is +e

Since an object cannot gain or lose a fraction of an electron, the net charge is an integral multiple of e -- electric charge is **quantized**

Coulomb's law looks a lot like the law of universal gravitation, but gravity is always attractive and the electric force can be either attractive or repulsive.

Coulomb's Law

The proportionality constant k can also be written in terms of ϵ_0, the permittivity of free space:

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}$$

$$\epsilon_0 = \frac{1}{4\pi k} = 8.85 \times 10^{-12}\ \mathrm{C^2/N \cdot m^2}$$

Coulomb's law strictly applies to **point charges**.

For finite-sized objects, it is not always clear what value to use for r. If two objects are spheres and the charge is uniformly distributed in each, then r is the distance between their centers.

Coulomb's law describes the force between two charges when they are at rest -- **ELECTROSTATICS**

Additional forces come into play when the charges are in motion: future chapters

Ex. 16-1 Determine the magnitude and direction on the electric force on the electron of a hydrogen atom exerted by the single proton that is the atom's nucleus. Assume the average distance between the revolving electron and the proton is $r = 0.53\times10^{-10}m,\ Q = 1.6\times10^{-19}C$

$$F = 8.2\times10^{-8}\,N$$

Principle of Superposition: for *multiple point charges*, the forces on each charge is the vector sum of the forces on that charge due to each of the others

Coulomb's Law: vectors

The net force on a charge is the vector sum of all the forces acting on it.

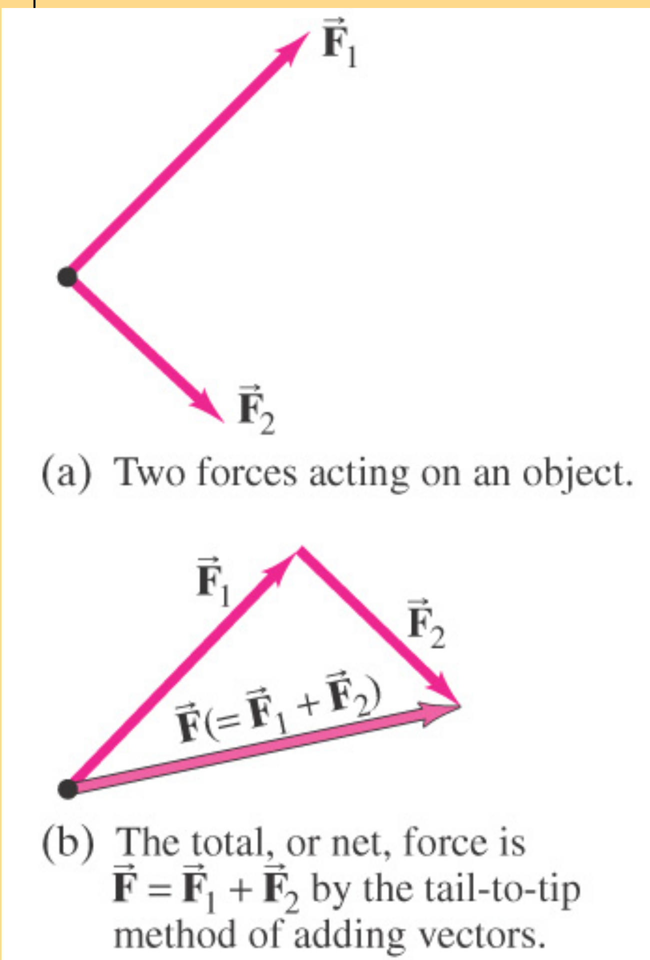
$$\vec{\mathbf{F}}_{net} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2 + \cdots$$

Vector addition review: tail-to-tip and parallelogram methods are good for getting a picture of what is going on.

For calculating the direction and magnitude of the resultant sum is better.

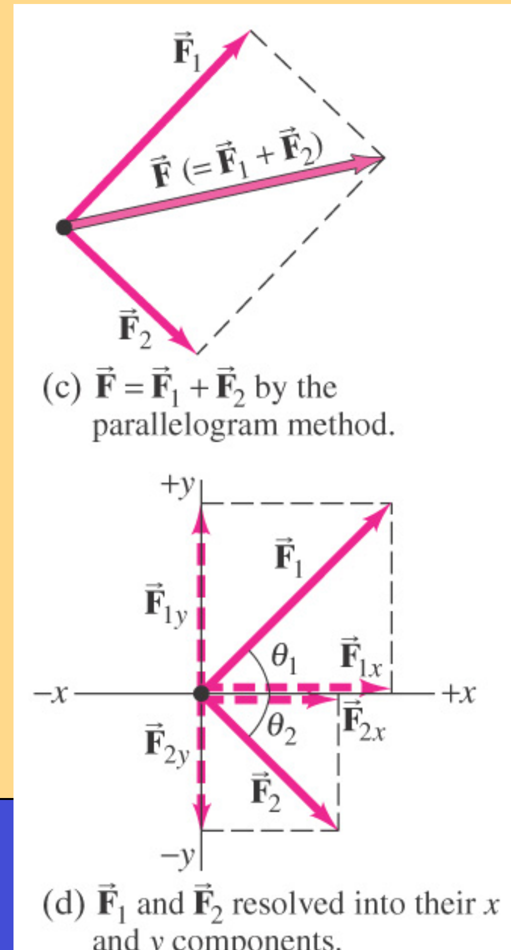
$$F = \sqrt{F_x^2 + F_y^2}$$

$$\tan\theta = \frac{F_y}{F_x}$$



(a) Two forces acting on an object.

(b) The total, or net, force is $\vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2$ by the tail-to-tip method of adding vectors.



(c) $\vec{\mathbf{F}} = \vec{\mathbf{F}}_1 + \vec{\mathbf{F}}_2$ by the parallelogram method.

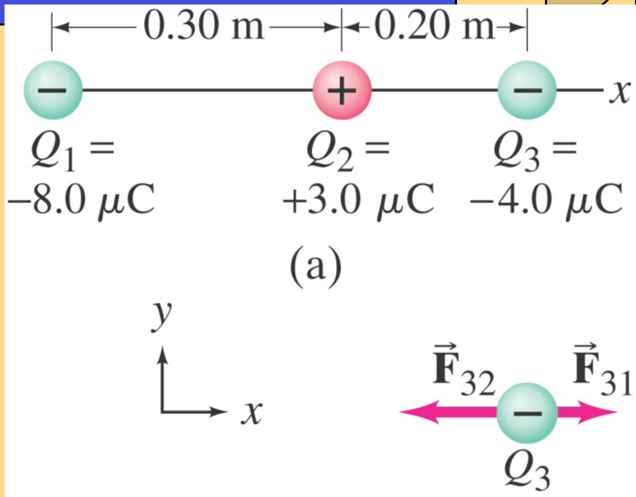
(d) $\vec{\mathbf{F}}_1$ and $\vec{\mathbf{F}}_2$ resolved into their x and y components.

Exercises

F_{31} = force exerted **ON** particle 3 **BY** particle 1

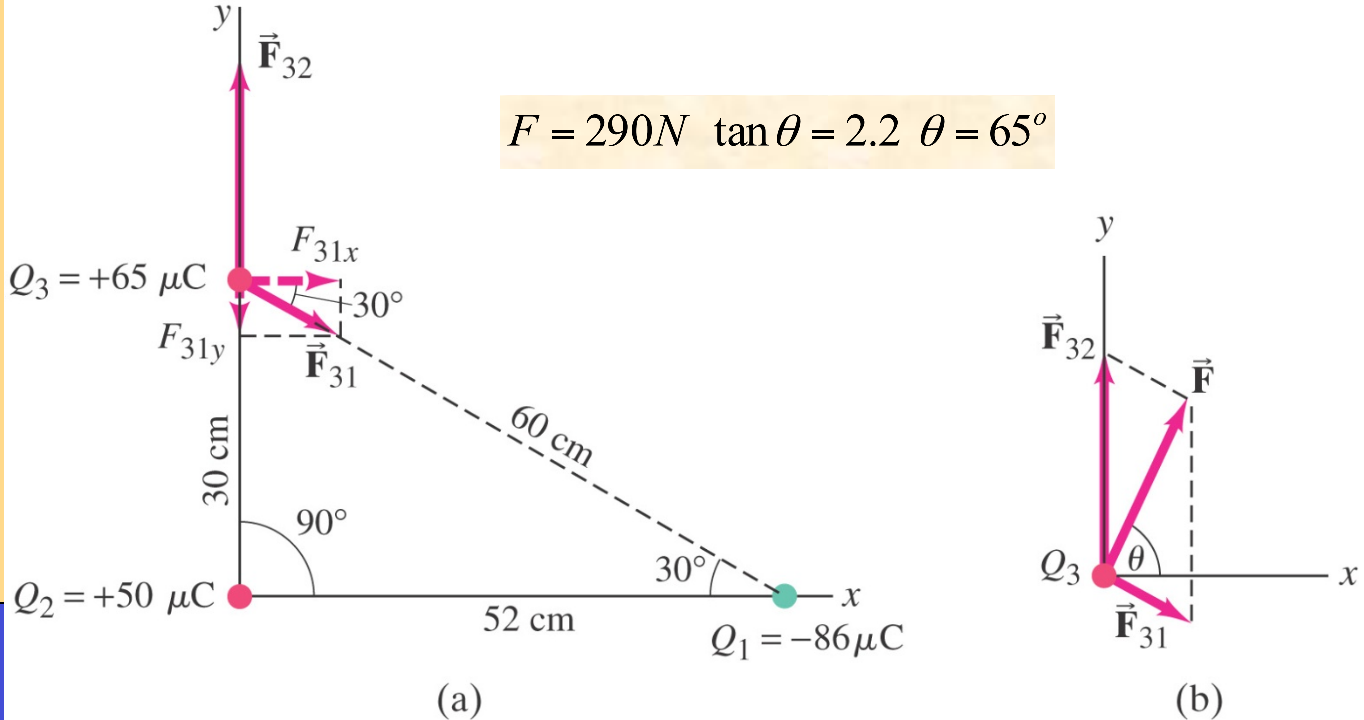
Ex. 16-3 Three charged particles are arranged in a line, as in the figure. Calculate the net electrostatic force on particle 3 due to the other two charges.

F_{31}=1.2N F_{32}=2.7 N F=-1.5N



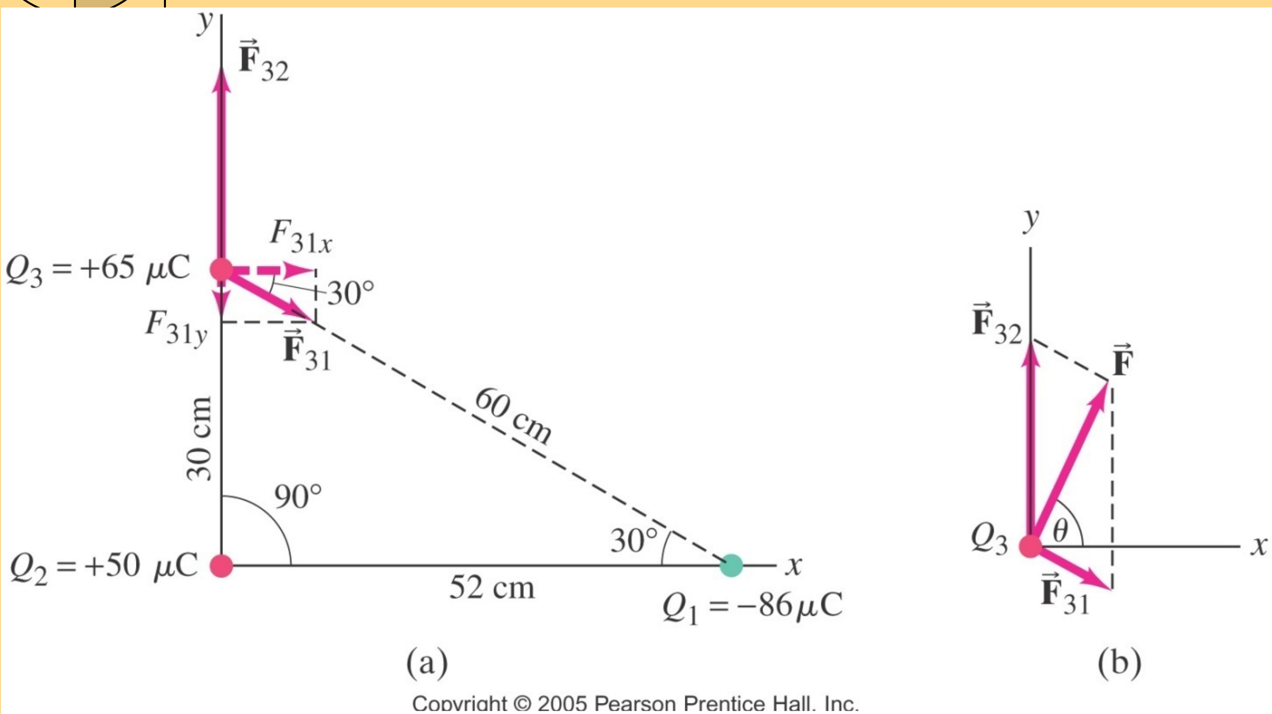
Ex. 16-4 Calculate the net electrostatic force on charge Q_3 shown in the figure due to the charges Q_1 and Q_2

$$F = 290N \quad \tan\theta = 2.2 \quad \theta = 65^o$$

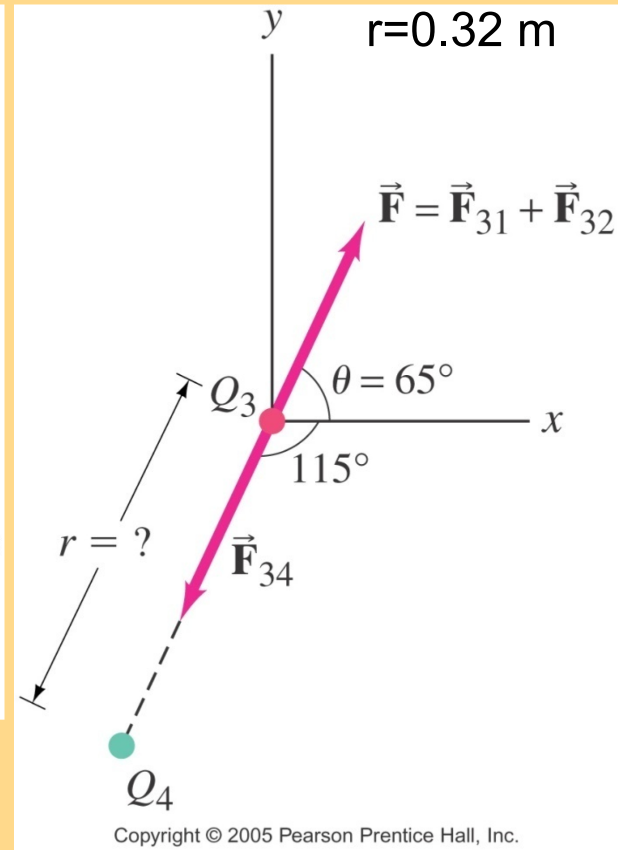


Exercises

Ex. 16-5 Where could you place a fourth charge Q4 so that the net force on Q3 would be zero? What distance r must Q4 be from Q3? $Q_4 = -50\mu C$



r=0.32 m



EX. 16-5 Consider two point charges of the same magnitude but opposite sign (+Q and –Q) fixed at a distance d apart. (a) Can you find a location where a 3rd positive charge could be placed so that the net electric force on this 3rd charge is zero? (b) What if the two charges were both +Q?

(a) NO (b) in the middle

Electric Field

Many common forces are "contact forces". But gravitational and electrical forces act over a distance, which was a difficult idea in the past. It helps to think in terms of **FIELD** as developed by Michael Faraday.

The electric field extends outward from a charge and permeates all space. A 2nd charge placed near it feels a force exerted by the electric field there.

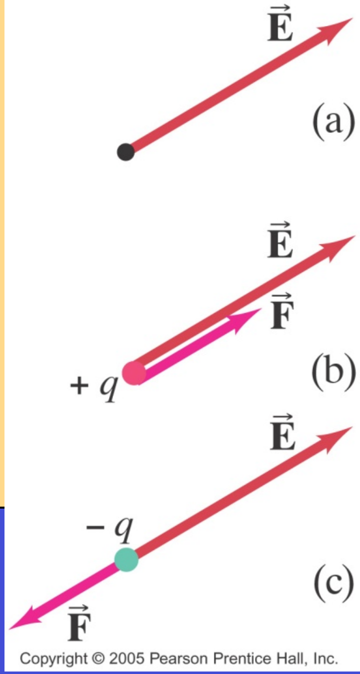
The electric field is the force on a small charge, divided by the charge: The charge (**test charge**) is so small that it does not affect the other particles which create the field UNITS: N/C

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

$$F = k\frac{qQ}{r^2} \Rightarrow$$

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

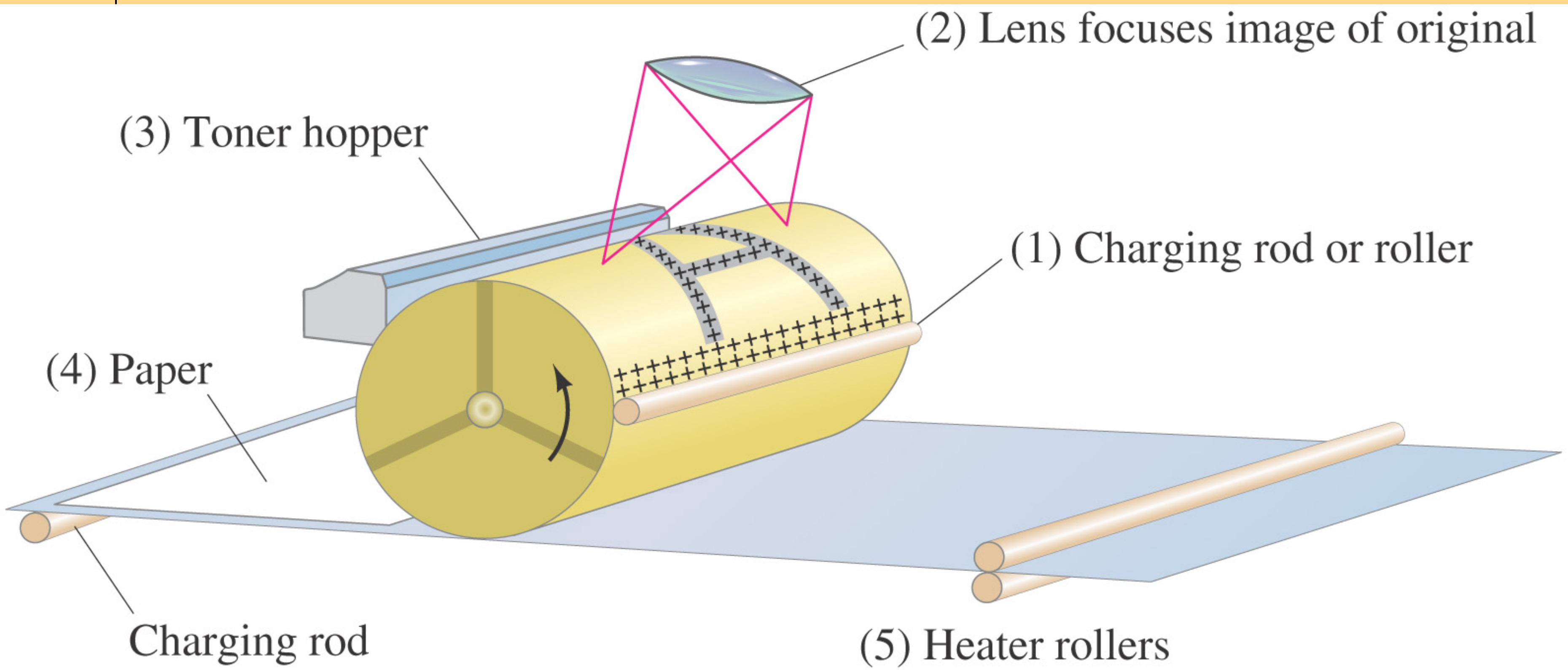
$$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}$$



F and E have the same direction if q is +, but opposite if q is -

Photocopy machine

- drum is charged positively (drum Al with a layer of selenium – photoconductivity)
- image is focused on drum
- only black areas stay charged and therefore attract toner particles
- image is transferred to paper and sealed by heat



Exercises

Ex. 16-6 A photocopy machine works by arranging positive charges (in the pattern to be copied) on the surface of a drum, then gently sprinkling negatively charged toner particles onto the drum. The toner particles temporarily stick to the pattern on the drum and are later transferred to paper and melted to produce the copy. Suppose each toner particle has a mass of 9.0x10^(-16)kg and carries an average of 20 extra electrons to provide an electric charge. Assuming that the electric force on a toner particle must exceed twice its weight in order to ensure sufficient attraction, compute the required electric field strength near the surface of the drum.

$$qE = 2mg \Rightarrow E = 5.5\times10^{3}\,N/C$$

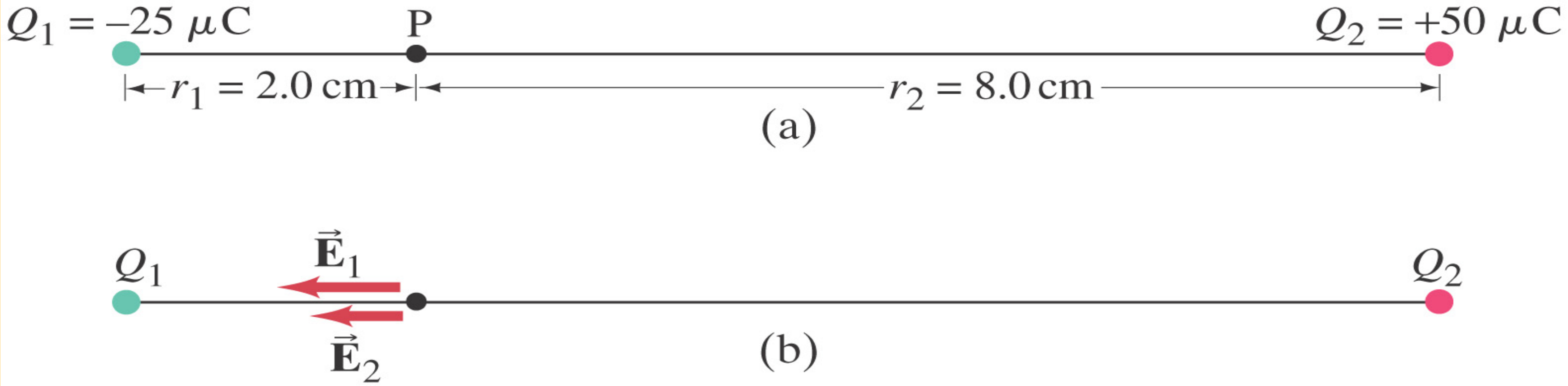
Ex. 16-7 Calculate the magnitude and direction of the electric field at a point P which is 30 cm to the right of a point charge Q=-3.0x10^(-6) C.

$$E = k\frac{Q}{r^2} \Rightarrow E = 3.0\times10^{5}\,N/C$$

Exercises

Superposition principle for electric fields: $\vec{\mathbf{E}} = \vec{\mathbf{E}}_1 + \vec{\mathbf{E}}_2 + \cdots$

Ex. 16-8 Two point charges are separated by a distance of 10.0 cm. One has a charge of $-25\,\mu C$ and the other $+50\,\mu C$. (a) Determine the direction and magnitude of the electric field at a point P between the two charges that is 2.0 cm from the negative charge. (b) If an electron is placed at rest at P and then released, what will be its initial acceleration (direction and magnitude)?



Field due to **negative** charge points **TO** it
Field due to **positive** charge points **AWAY** from it

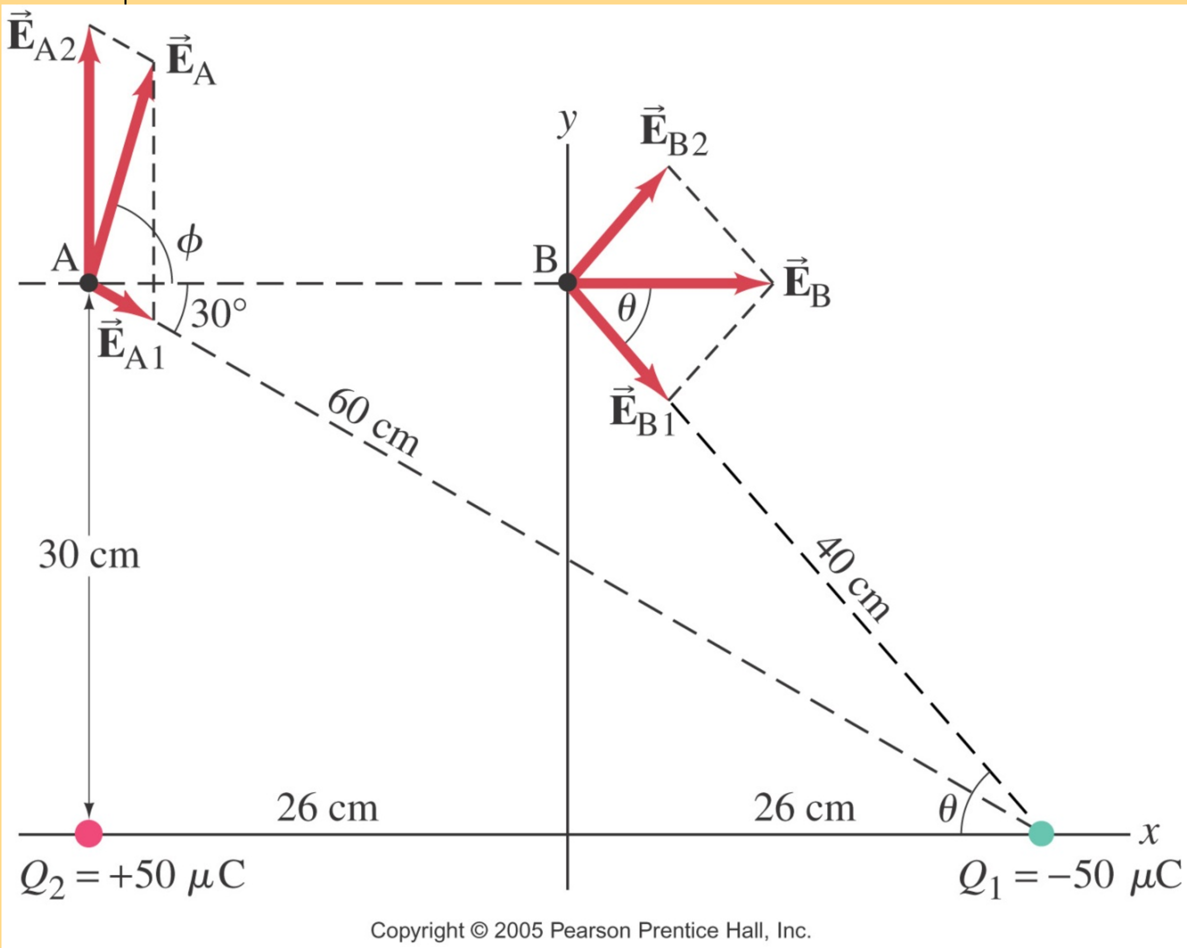
$m_e = 9.11\times10^{-31}kg$

$E = 6.3\times10^{8}\,N/C$

$a = 1.1\times10^{20}\,m/s^2$

Exercises

Ex. 16-9 Calculate the total electric field (a) at point A and (b) point B due to both charges.



$$E_{A1}, E_{A2}, E_{Ax}, E_{Ay}$$

$$E_A = 4.5\times10^6\ N/C$$

$$\phi = 76^o$$

$$E_{B1} = E_{B2}$$

$$E_B = 2E_{B1}\cos\theta$$

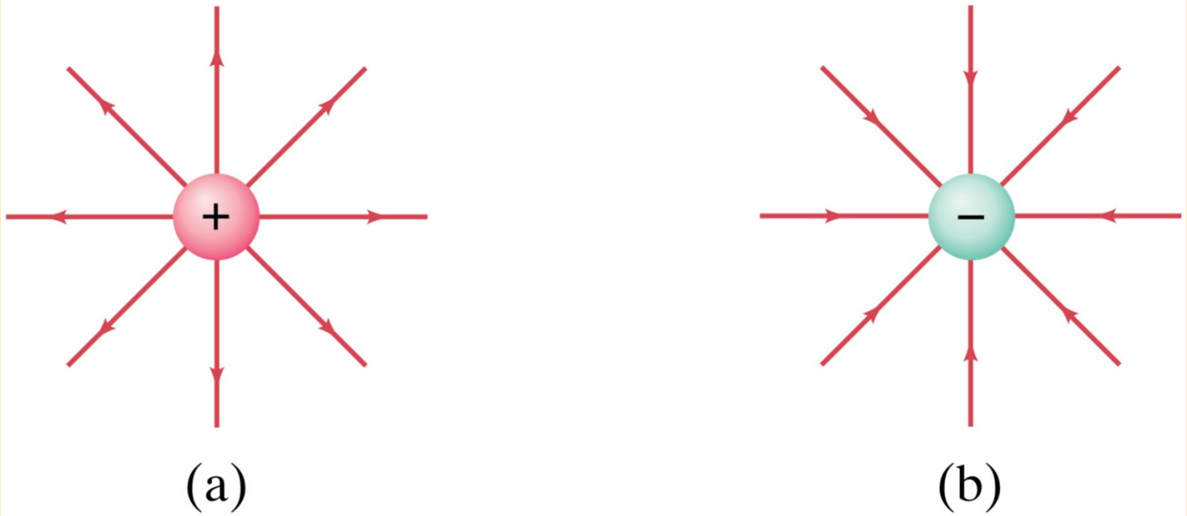
$$E_B = 3.6\times10^6\ N/C$$

Field Lines

The electric field can be represented by field lines. These lines start on a positive charge and end on a negative charge.

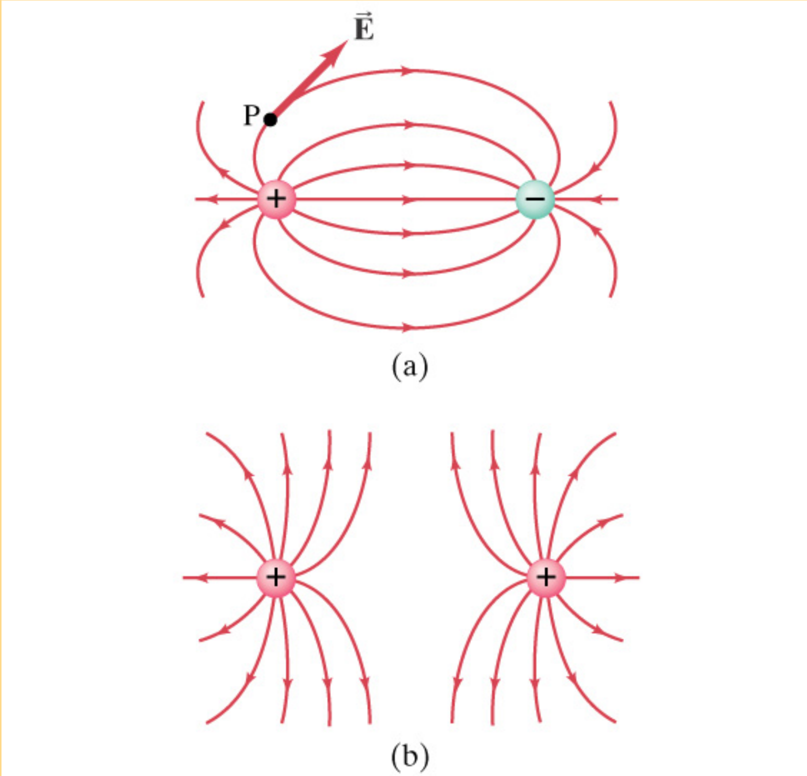
The number of field lines starting (ending) on a positive (negative) charge is proportional to the magnitude of the charge.

The electric field is stronger where the field lines are closer together.

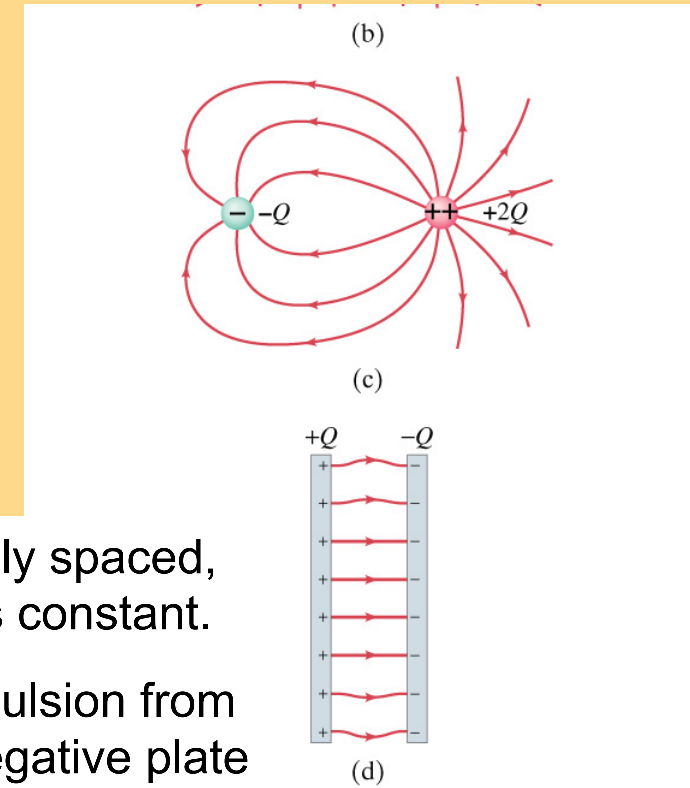


Field Lines

Electric dipole: two equal charges, opposite in sign:



The direction of the electric field at any point is tangent to the field line.



The electric field between two closely spaced, oppositely charged parallel plates is constant.

Test charge between plates feel repulsion from positive plate and attraction from negative plate

Field Lines

Summary of field lines:

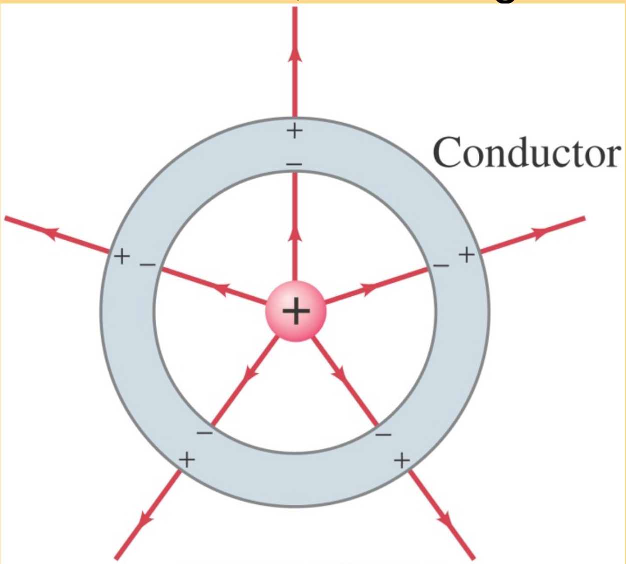
1. Field lines indicate the direction of the field; the field is tangent to the line.
2. The magnitude of the field is proportional to the density of the lines.
3. Field lines start on positive charges and end on negative charges; the number is proportional to the magnitude of the charge.

The field concept can also be applied to the gravitational force.
A **gravitational field** exists for every object that has mass
It is the force per unit mass.

Electric Fields and Conductors

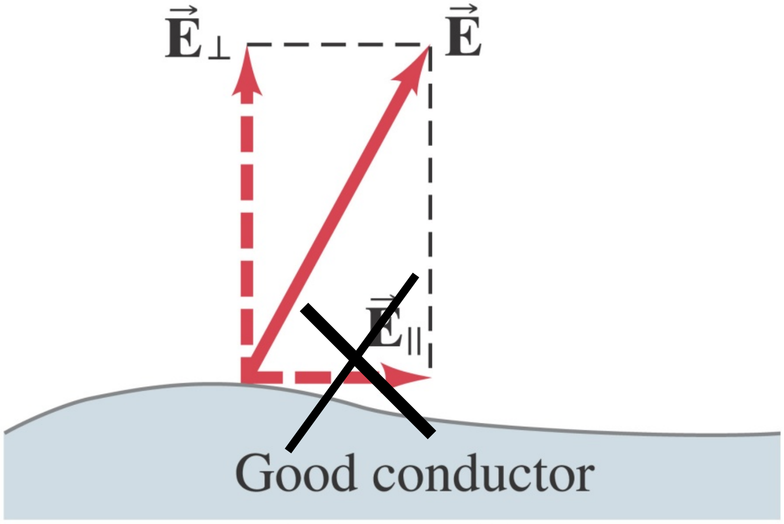
The static electric field inside a conductor is zero – if it were not, the charges would move.

The net charge on a conductor is on its surface.



Suppose a positive charge Q is surrounded by an isolated uncharged metal conductor whose shape is a spherical shell.
There can be no field inside the metal, so –Q is induced on the inner surface and +Q exists on the outer surface.
The shell is neutral

The electric field is perpendicular to the surface of a conductor – if it were not, charges would move.

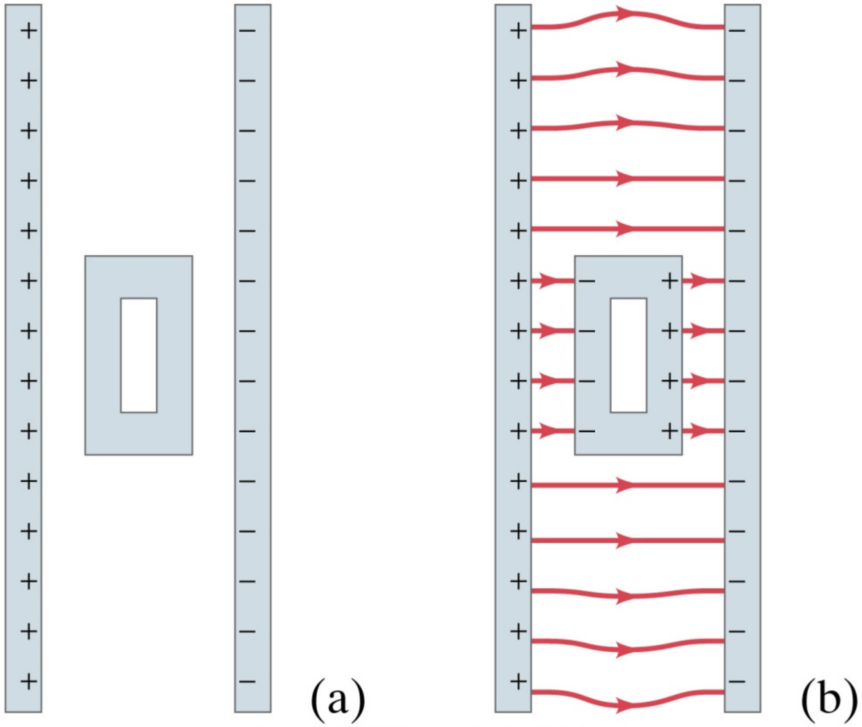


Faraday Cage

Shielding and safety in a storm

A neutral hollow metal box is placed between two parallel charged plates as in (a). What is the field like inside the box?

The electrons in the metal can move freely to the surface, hence the field inside the hollow metal box is zero. A conducting box used in this way is an effective device for shielding delicate instruments from unwanted external electric fields.



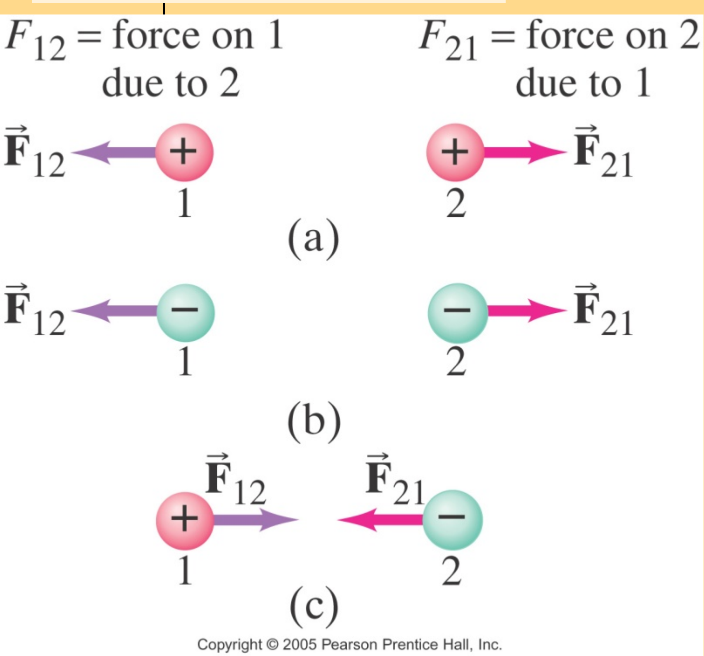
It also explains why it is safe to be inside a car during a lightning storm.

Summary

$$F = k\frac{Q_1 Q_2}{r^2}$$

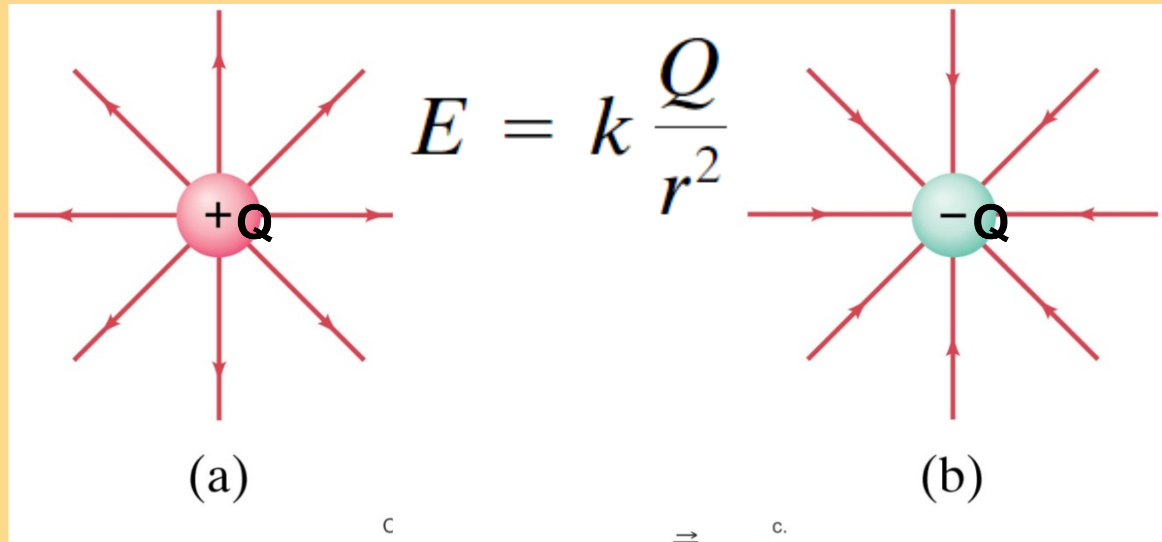
Electrostatic Force

Magnitude of the force.



Electric Field

Field lines start on a positive charge and end on a negative charge.



Small charge

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