



# Coulomb's Law

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**Charges, Qualitative: Electroscope**

- The Phenomena
  - Charge electroscope with rubber rod which has been rubbed with fur. Leaves separate.
    - » Bring same rubber rod close to top of electroscope. observe leaves separate further.
    - » Bring glass rod (rubbed with silk) close to top of electroscope. observe leaves approach each other.
  - Now repeat experiment, but charge with glass rod. Leaves still separate.
    - » Now rubber rod causes leaves to approach each other.
    - » Glass rod causes leaves to separate.
- Explanation?
  - There exist two kinds of charge
  - Unlike charges attract; like charges repel.

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**More about conductors and charging electroscopes**

- Inside a conductor charges (electrons) are free to move
- The electroscope is made out of conductors
  - conducting main electrode
  - 2 conducting gold leaves
- Add some negative charge
  - add electrons
- Add some positive charge
  - subtract electrons

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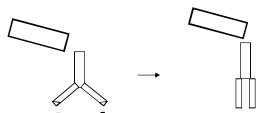
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**More about conductors and charging electroscopes (continued)**

- Add some positive charge to negatively charged leaves
  - subtract electrons




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**Conductors & Insulators**

Increasing Conducting Ability →



← **Insulators:** In these materials, once they are charged, the charges ARE NOT FREE TO MOVE. Plastics, glass, and other "bad conductors of electricity" are good examples of insulators.

← **Conductors:** In these materials, the charges ARE FREE TO MOVE. Metals are good examples of conductors.

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**Charge**

- Standard unit of charge

**Coulomb (C)**

Coulomb is a huge unit of charge

Charge on one electron or proton is:

$1.602 \times 10^{-19}C$  - often given letter *e*

A small spark between your finger and a door knob on the order of

microcoulombs

$\mu C = 10^{-6}C$



Helium atom




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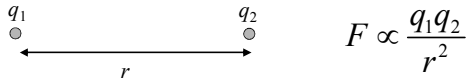
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**Law of Electrical Force**  
**Charles-Augustin Coulomb**  
 (1736 - 1806)



"The repulsive force between two small spheres charged with the same sort of electricity is in the inverse ratio of the squares of the distances between the centers of the spheres"



$$F \propto \frac{q_1 q_2}{r^2}$$

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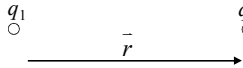
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**Coulomb's Law**

The force from 1 acting on 2



$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

MKS Units:

- $r$  in meters
- $q$  in Coulombs
- $\vec{F}$  in Newtons

$$\Rightarrow \frac{1}{4\pi\epsilon_0} = 9 \cdot 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$$

$\epsilon_0$  is permittivity of free space

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N m}^2$$

We call this group of constants " $k$ " as in:

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

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**Summary**

- Charges come in two varieties
  - ◀ negative and positive
  - ◀ in a conductor, *negative* charge means extra mobile electrons, and *positive* charge means a deficit of mobile electrons

• Coulomb Force 
$$\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

- Law of Superposition

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

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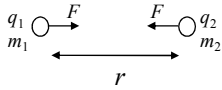
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### Gravitational vs. Electrical Force



$$F_{elec} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$F_{grav} = G \frac{m_1 m_2}{r^2}$$

$$\rightarrow \frac{F_{elec}}{F_{grav}} = \frac{q_1 q_2}{m_1 m_2} \frac{4\pi\epsilon_0}{G}$$

For an electron:

$$* |q| = 1.6 \times 10^{-19} \text{ C}$$

$$m = 9.1 \times 10^{-31} \text{ kg}$$

$$\rightarrow \frac{F_{elec}}{F_{grav}} = 4.17 \times 10^{42}$$

\* smallest charge seen in nature!

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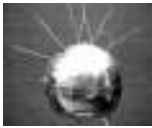
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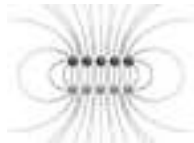
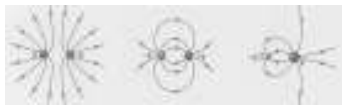
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# Electric Fields




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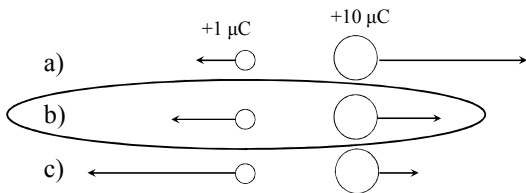
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Two charges  $q = +1 \mu\text{C}$  and  $Q = +10 \mu\text{C}$  are placed near each other as shown in the figure.

Which of the following diagrams best describes the forces acting on the charges:




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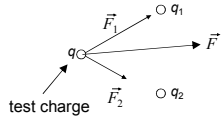
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## The Electric Field

- The net Coulomb force on a given charge is always proportional to the strength of that charge.



$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

- We can now define a quantity, the electric field, which is independent of the test charge,  $q$ , and depends only on position in space:

Electric Field Applet

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

The  $q_i$  are the *sources* of the electric field

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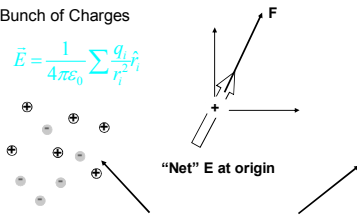
## The Electric Field

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

With this concept, we can "map" the electric field anywhere in space produced by any arbitrary:

Bunch of Charges

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \sum \frac{q_i \hat{r}_i}{r_i^2}$$



"Net" E at origin

These charges or this charge distribution "source" the electric field throughout space

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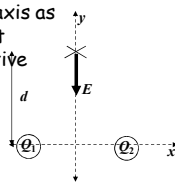
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## Example

Two charges,  $Q_1$  and  $Q_2$ , fixed along the  $x$ -axis as shown produce an electric field,  $E$ , at a point  $(x,y)=(0,d)$  which is directed along the negative  $y$ -axis.

- Which of the following is true?

- (a) Both charges  $Q_1$  and  $Q_2$  are positive
- (b) Both charges  $Q_1$  and  $Q_2$  are negative
- (c) The charges  $Q_1$  and  $Q_2$  have opposite signs




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### Example

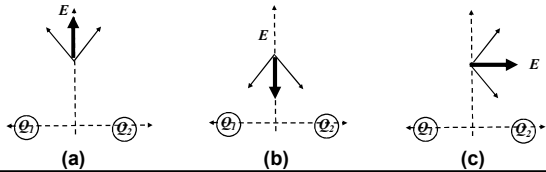
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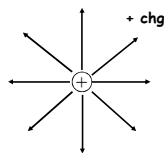
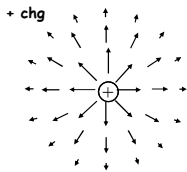
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### Ways to Visualize the E Field

Consider the E-field of a positive point charge at the origin

vector map

field lines




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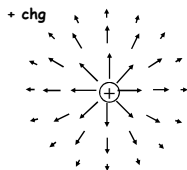
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### Rules for Vector Maps



- Direction of arrow indicates direction of field
- Length of arrows  $\propto$  local magnitude of  $E$

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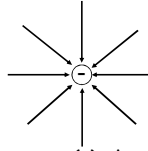
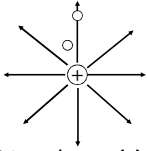
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### Rules for Field Lines



- Lines leave (+) charges and return to (-) charges
- Number of lines leaving/entering charge  $\propto$  amount of charge
- Tangent of line = direction of  $E$
- Local density of field lines  $\propto$  local magnitude of  $E$
- Field at two white dots differs by a factor of 4 since  $r$  differs by a factor of 2
- Local density of field lines also differs by a factor of 4 (in 3D)

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A negative charge is placed in a region of electric field as shown in the picture. Which way does it move ?

- a) up       c) left      e) it doesn't move  
 b) down      d) right

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Compare the field strengths at points A and B.

- a)  $E_A > E_B$   
 b)  $E_A = E_B$   
 c)  $E_A < E_B$

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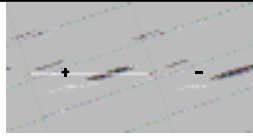
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Two equal, but opposite charges are placed on the  $x$  axis. The positive charge is placed at  $x = -5$  m and the negative charge is placed at  $x = +5$  m as shown in the figure above.

3) What is the direction of the electric field at point A?  
a) up   b) down   c) left   **d) right**   e) zero

4) What is the direction of the electric field at point B?  
a) up   b) down   **c) left**   d) right   e) zero

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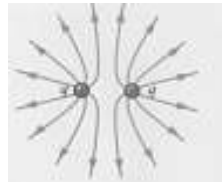
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### Field Lines From Two Like Charges

- There is a zero halfway between the two charges



- $r \gg a$ : looks like the field of point charge ( $+2q$ ) at origin

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