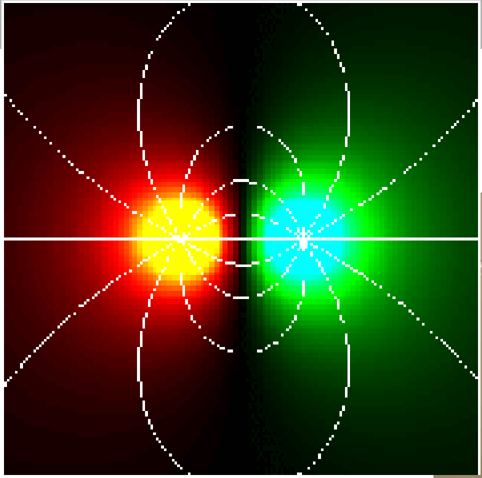
Electric forces & fields



PHY232 – Spring 2008

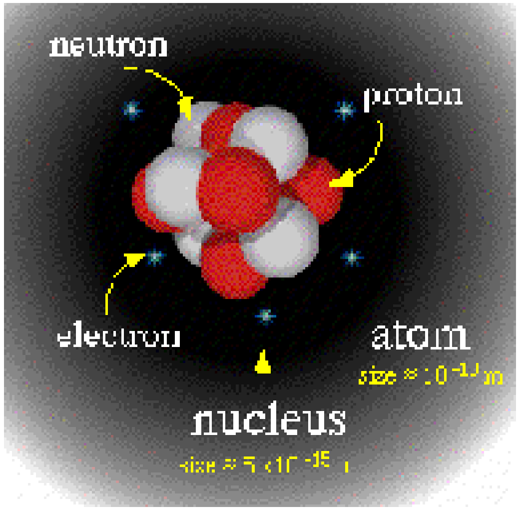
Jon Pumplin

http://www.pa.msu.edu/~pumplin/phy232

(original ppt courtesy of Remco Zegers)

MICHIGAN STATE UNIVERSITY

Electric Charges



- Two types of charge in atom:
  - positive (carrier: proton)
  - negative (carrier: electron)
- Nucleus consists of:
  - Protons (positive)
  - neutrons (neutral)
- Nucleus is surrounded by cloud of electrons (negative)
- If the atom is not ionized, it is neutral.
- By removing electrons, it becomes ionized and positively charged, since there are more protons than electrons
- Mass of the electron is much smaller than that of the proton or neutron
  - m_e=9.109x10^{-31} kg, m_p=1.6726x10^{-27} kg

Question

- **A neutral atom has**

b) more neutrons than protons

c) more protons than electrons

d) the same number of neutrons and protons

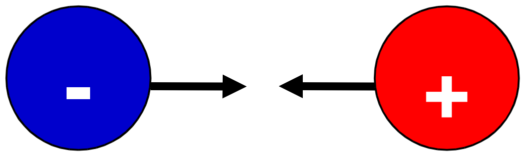
e) the same number of protons and electrons

f) the same number of neutrons, electrons and protons

Electric Forces

- **Unlike charges attract each other.**

(That's what keeps the electrons attached to their atom!)

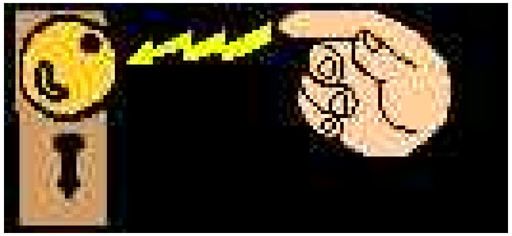


- **Like charges repel each other.**

(A different "strong" force keeps the protons attached to their nucleus!)

Conservation of charge

- **In a closed system, charge is conserved. This means that charge is not 'created' but can be transferred from one object to another.**

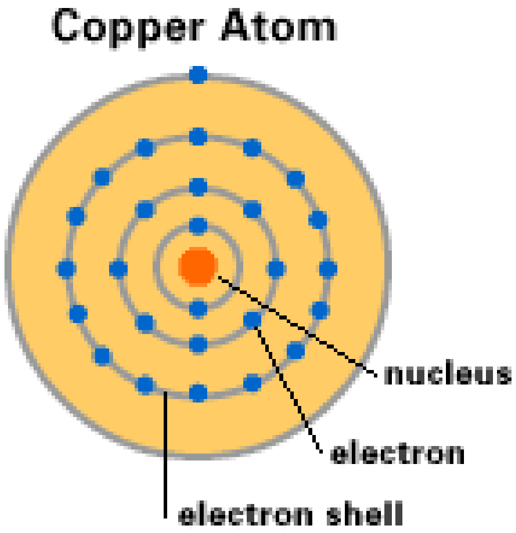


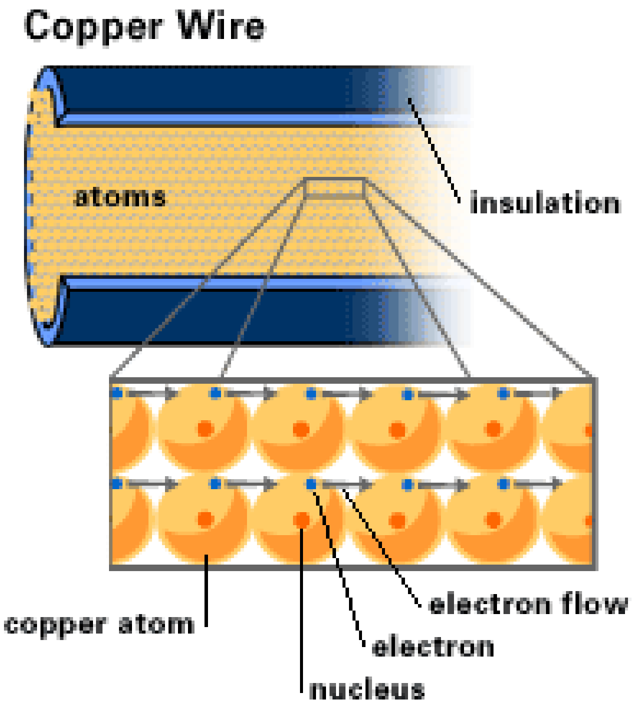
- **Charge is quantized; there are only discrete amounts of charge. The electron carries one unit of negative charge (-e) and the proton carries one unit of positive charge (+e). 1e=1.602x10^{-19} C (Coulomb)**

conductors

➢ **In *conductors* (i.e., conducting materials) electric charge can move freely. The *resistance* to the flow of charge is very small.**

Example: metals like Copper; one of the electrons from each atom can move freely.





Conductors, Insulators & Semiconductors

- **In *conductors*, charge can move freely - The *resistance* to flow of charge is very low.**
- **In *insulators*, charge cannot move freely - The *resistance* to flow of charge is very high.**
- ***Semiconductors* are materials whose properties are in between that of conductors and insulators (used in transistors).**

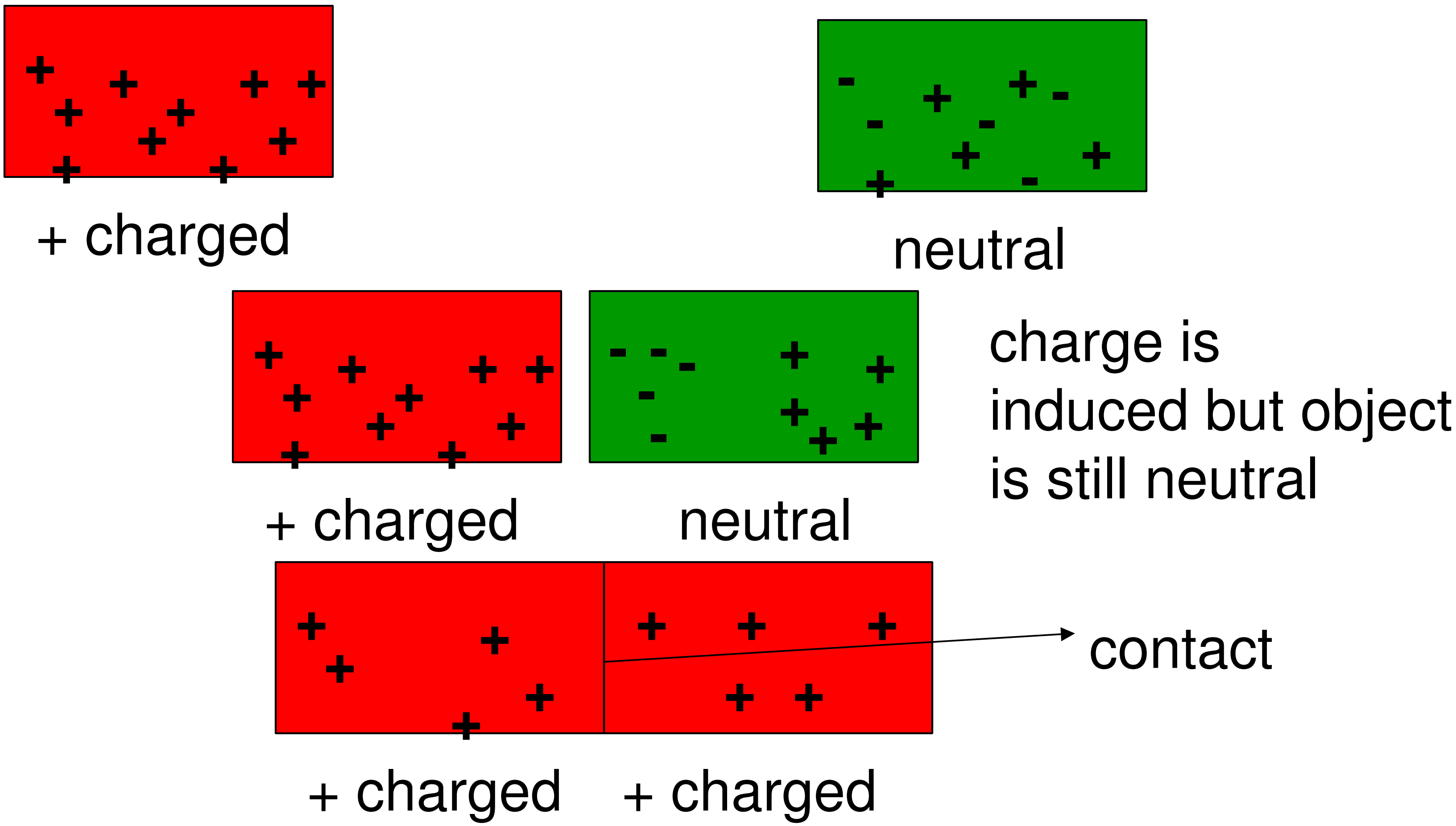
What makes a material a conductor or insulator or semiconductor?

It depends on the shell structure of the atoms involved.

We will discuss this later in the course.

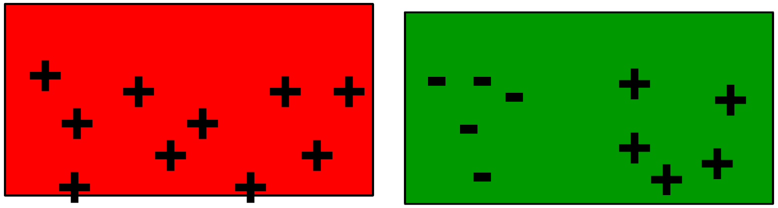
charging by conduction

- **An object can be charged by conduction:**

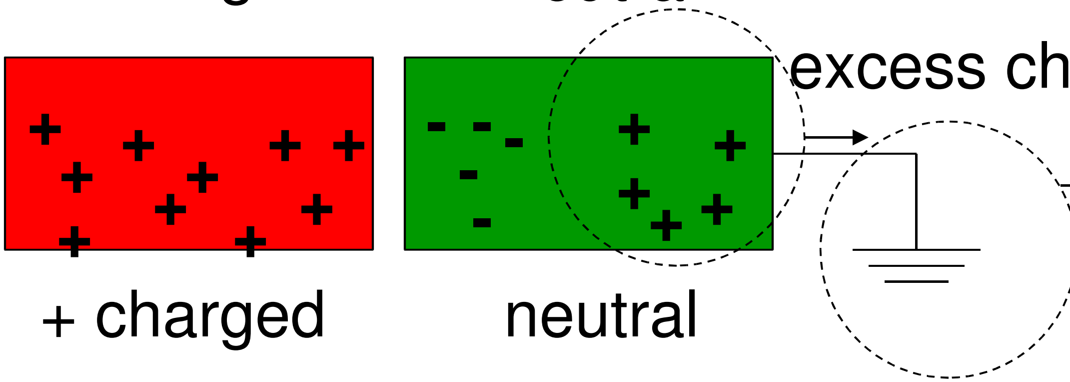


charge has moved by conduction

charging by induction



charge is induced:
object is still neutral but **polarized**

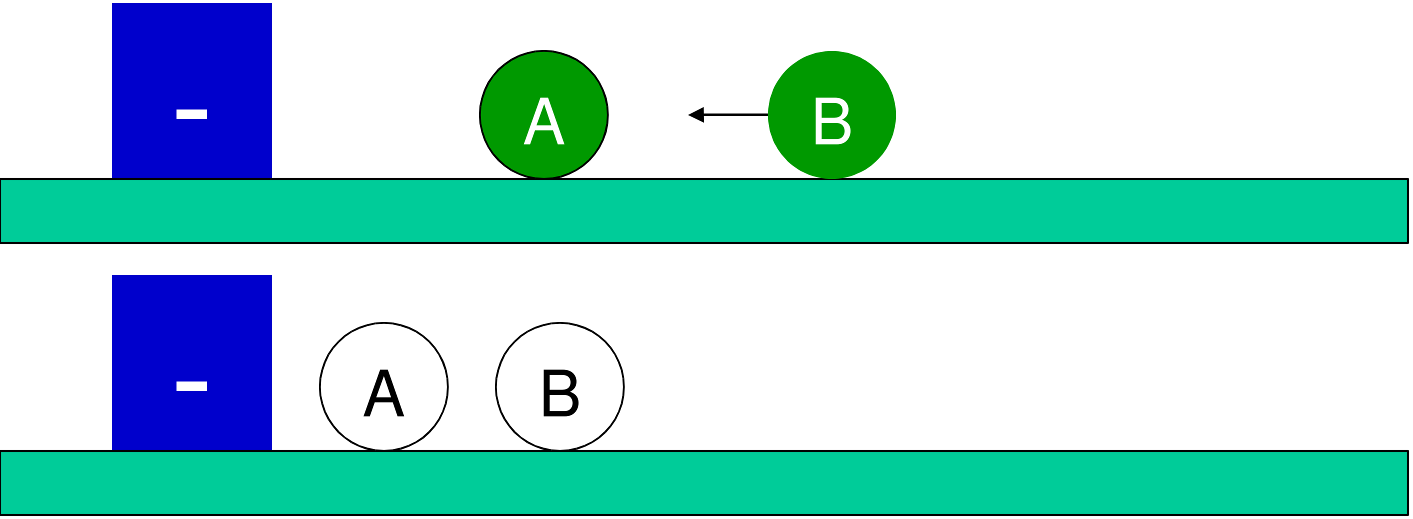


excess charge can escape

connected to earth

The earth is an "infinite" sink/source of electrons

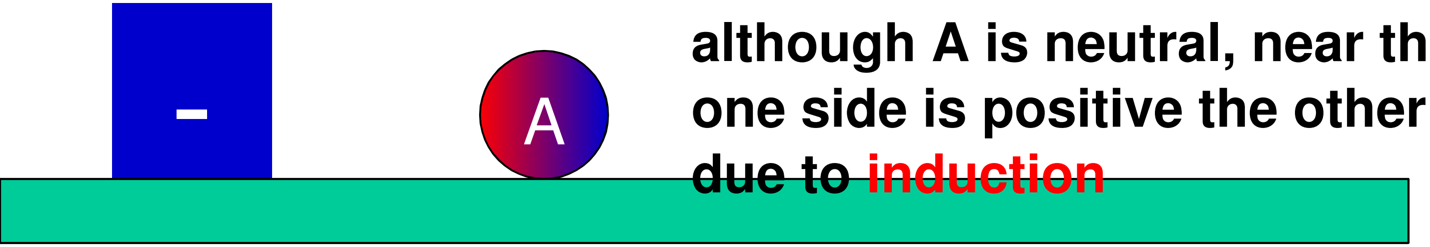
question



- a large negatively charged block is placed on an insulated table. A neutral metal ball (A) is rolled towards it and stops before it hits the block. Then, a second neutral metal ball (B) is rolled towards ball (A). After the collision, ball A stops closer to the block (but without touching) and ball B stops further away from the block. The block is then removed. What is the final charge on balls A and B?

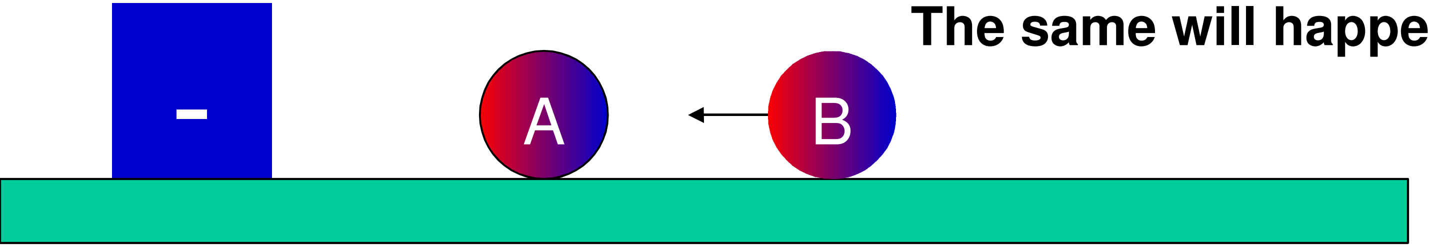
b) Ball A is positive, ball B is negative
c) Ball A is negative, ball B is positive
d) Both ball remain neutral
e) Both balls are positive

answer

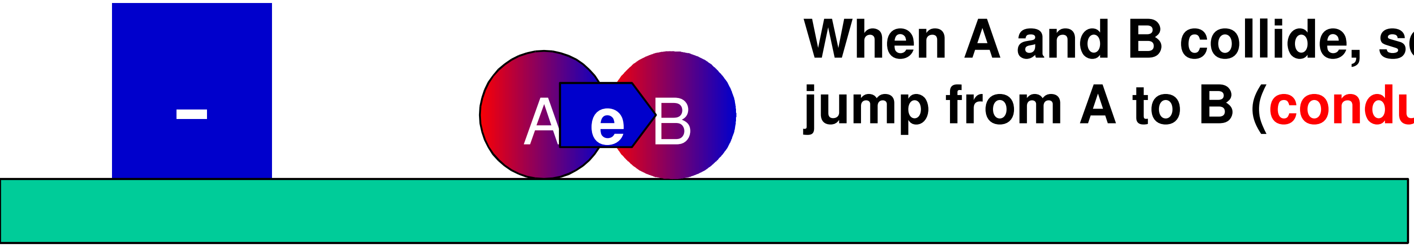


although A is neutral, near the block one side is positive the other negative due to **induction**

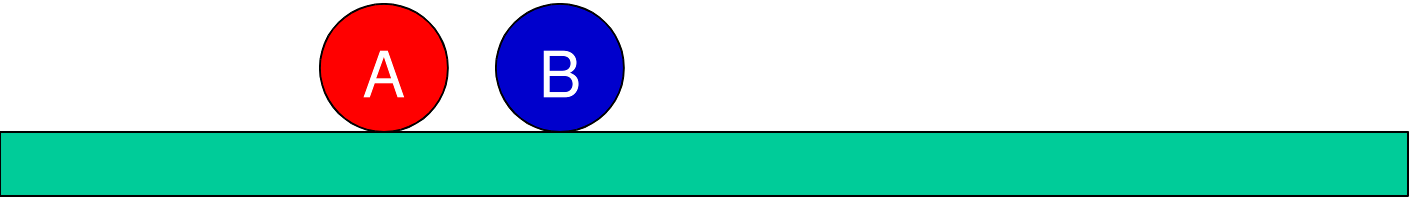
The same will happen for ball B



When A and B collide, some electrons will jump from A to B (**conduction**)



Correct answer: A

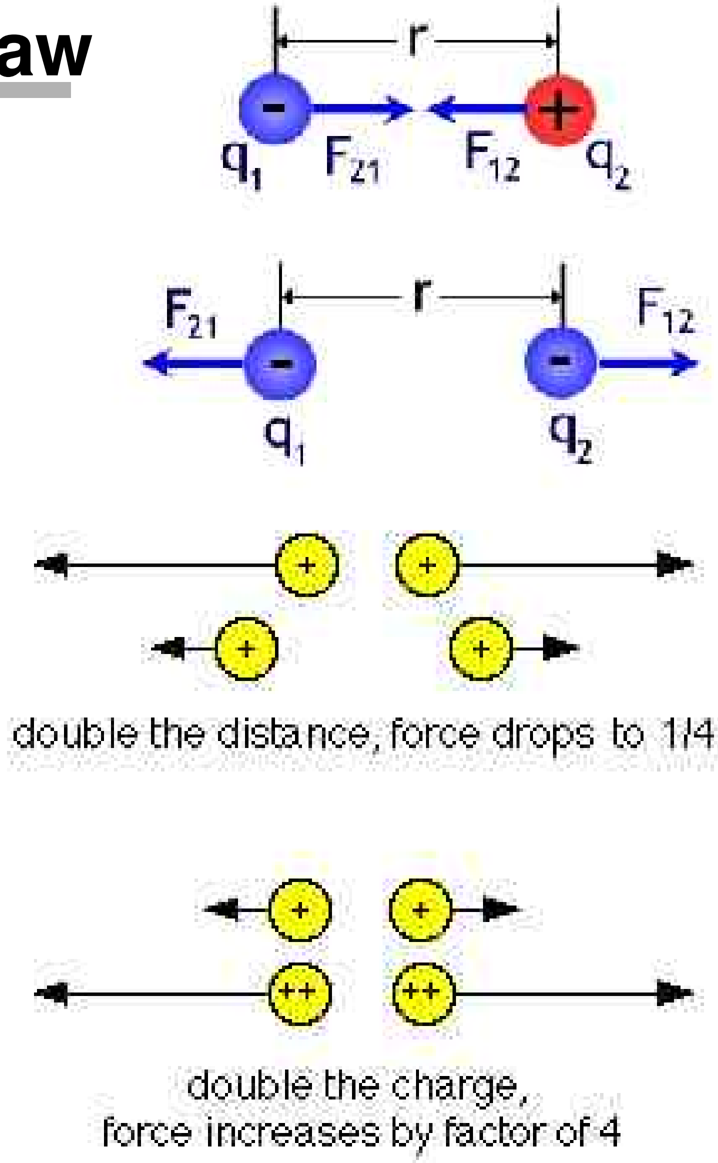


Coulomb's law

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

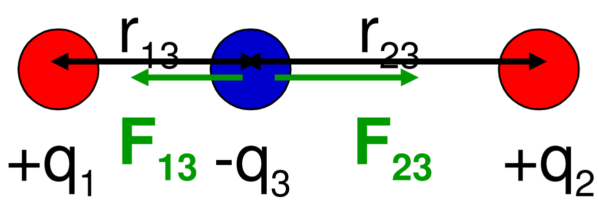
- directed along the line joining the two objects
- is attractive if the charges have the opposite sign
- is repulsive if the charge if the same sign
- k_e: Coulomb constant=$9\text{x}10^9$ Nm^2/C^2
- $\varepsilon_0=1/(4\pi k_e)=8.85\text{x}10^{-12}$ $C^2/(Nm^2)$

  to be used later…



Superposition Principle

- When more than one charge acts on the charge of interest, each exerts an electric force. Each can be computed separately **and then added as vectors**



$$F_{13} = k_e \frac{|q_1||q_3|}{r_{13}^2} \qquad F_{23} = k_e \frac{|q_2||q_3|}{r_{23}^2}$$

Add: $F_3 = F_{13} - F_{23}$

- in this case F_{13} and F_{23} are along the same line and can be added as numbers, but be careful with the sign!

- **Choose a coordinate system and stick to it!**

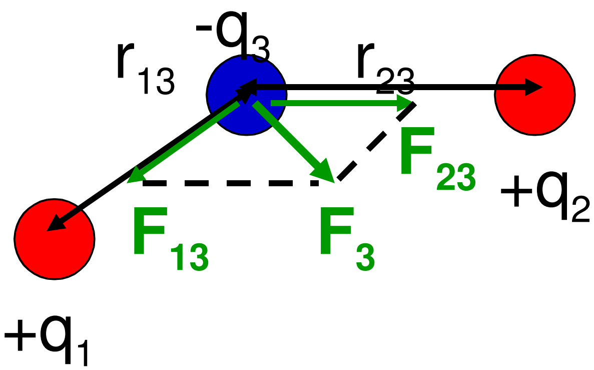
Superposition Principle II

Remember: forces are vectors, so treat them accordingly!

$$F_{13} = k_e \frac{|q_1||q_3|}{r_{13}^2}$$

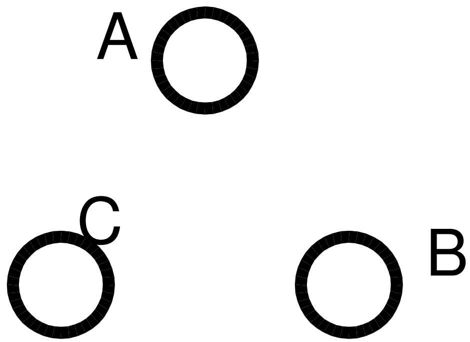
$$F_{23} = k_e \frac{|q_2||q_3|}{r_{23}^2}$$

$$\vec{F}_3 = \vec{F}_{13} + \vec{F}_{23}$$



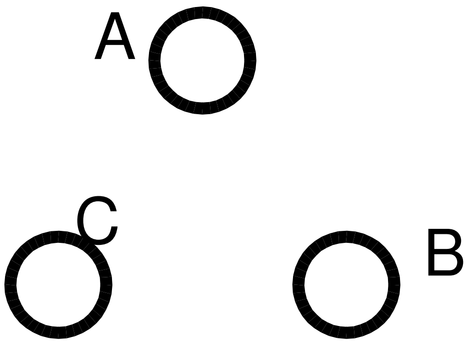
Add: In this case, you need to take into account the horizontal and vertical directions separately and then combine them to get the resultant force.

questions: true false



a) if A and C are positive, B is pushed away from A and C
b) if A is positive and B is positive, A and B will move further apart
c) if A is neutral and C is positive, B will move along the line BC
d) if A,B and C have the same charge, they will separate further

Answers to questions

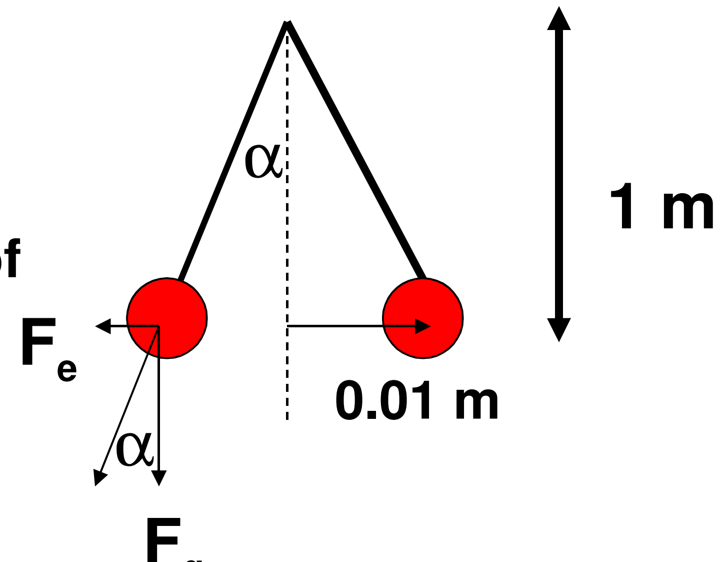


a) if A and C are positive, B is pushed away from A and C
b) if A is positive and B is positive, A and B will move further apart
c) if A is neutral and C is positive, B will move along the line BC
d) if A,B and C have the same charge, they will separate further

answers:
b) false, if B is negative it will move towards A and C
c) false, if C is negative and the absolute charge much larger than A and B, A and B could come closer
d) false, B might be neutral and not move at all
e) true, the will all feel an outward pointing force

A simple Electroscope

- Two equal masses are charged positively (both +1 μC) and hung from massless ropes. They separate as shown in the figure. What is the mass of each?



$\tan\alpha = 0.01/1 = F_e/F_g$

$F_e = k_e q_1 q_2 / r_{12}^2$ (coulomb force) $F_g = mg = 9.81m$ (gravitational force)

with $q_1 = q_2 = q$ and $r_{12} = 2*0.01 = 0.02$ m, $k = 8.99\text{x}10^9$ Nm²/C²

so: $m = F_e/(0.01g) = k_e q^2/(0.01 g r_{12}^2)$ ➔ m=229 kg

The electric force is very strong compared to the gravitational force of the masses on each other: Compare

$F_g = G m_1 m_2 / r_{12}^2$ with $G = 6.67\text{x}10^{-11}$ Nm²/kg²

$F_e = k_e q_1 q_2 / r_{12}^2$ with $k_e = 8.99\text{x}10^9$ Nm²/C²

Electric Fields

- Instead of a force acting on an object A by an object B magically over the distance between them, one can consider that object A is situated in a field arising from the presence of object B.
- Because object A is in the field created by object B, it feels a force.
- The electric field produced by a charge Q at the location of a small test charge q_0 is defined as:

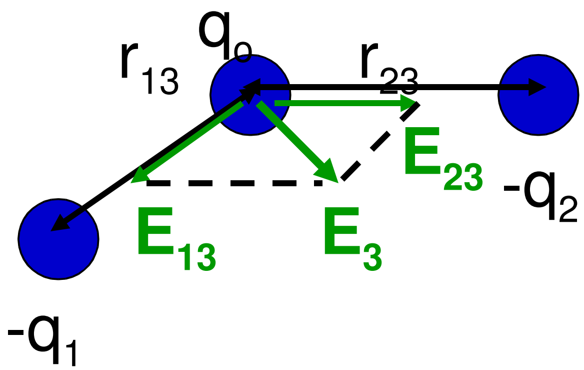
$$\vec{E} \equiv \frac{\vec{F}}{q_o} \Rightarrow \vec{F} = q_0 \vec{E}$$

$$|E| = k_e \frac{Q}{r^2}$$

The magnitude of E only depends on the charge of Q and not the sign and size of the test charge

electric fields II

- **To determine the electric field at a certain point 3, due to the presence of two other charges 1 and 2, use the superposition principle.**



$$E_{13} = k_e \frac{|q_1|}{r_{13}^2} \qquad E_{23} = k_e \frac{|q_2|}{r_{23}^2}$$

$$\vec{E}_3 = \vec{E}_{13} + \vec{E}_{23}$$

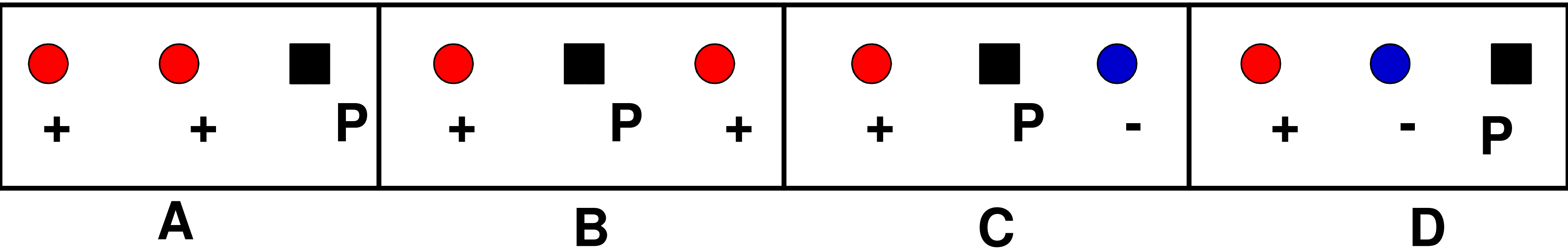
E_3 is independent of the test charge q_0

question

2 equal charges are lined up as shown in the figures.
A third point P (with no charge) is also defined.

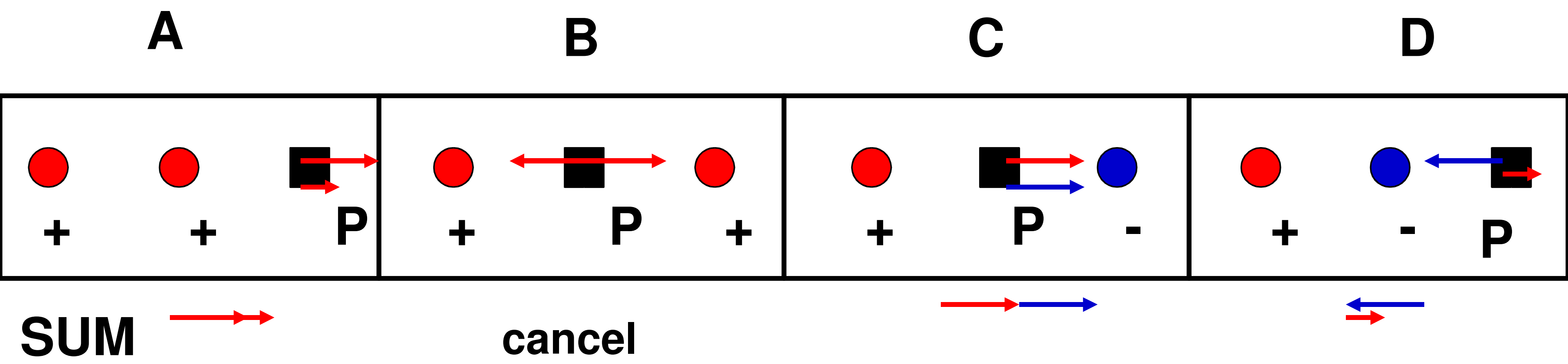
The distance between neighboring points is constant.

In which case is the *magnitude* of the electric field at P largest?



Answer to question

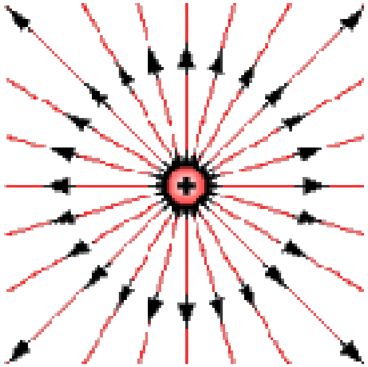
- 2 equal charges are lined up as shown in the figures. A third point (no charge) P is defined as well. In which case is the *magnitude* of the electric field at P largest? The distance between neighboring points is constant.

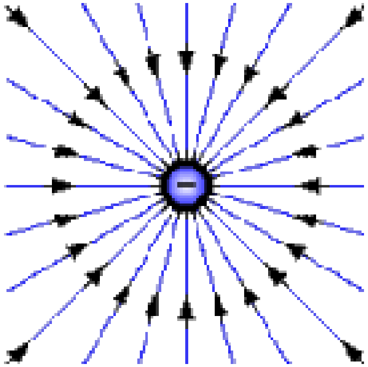


C is correct

electric field lines

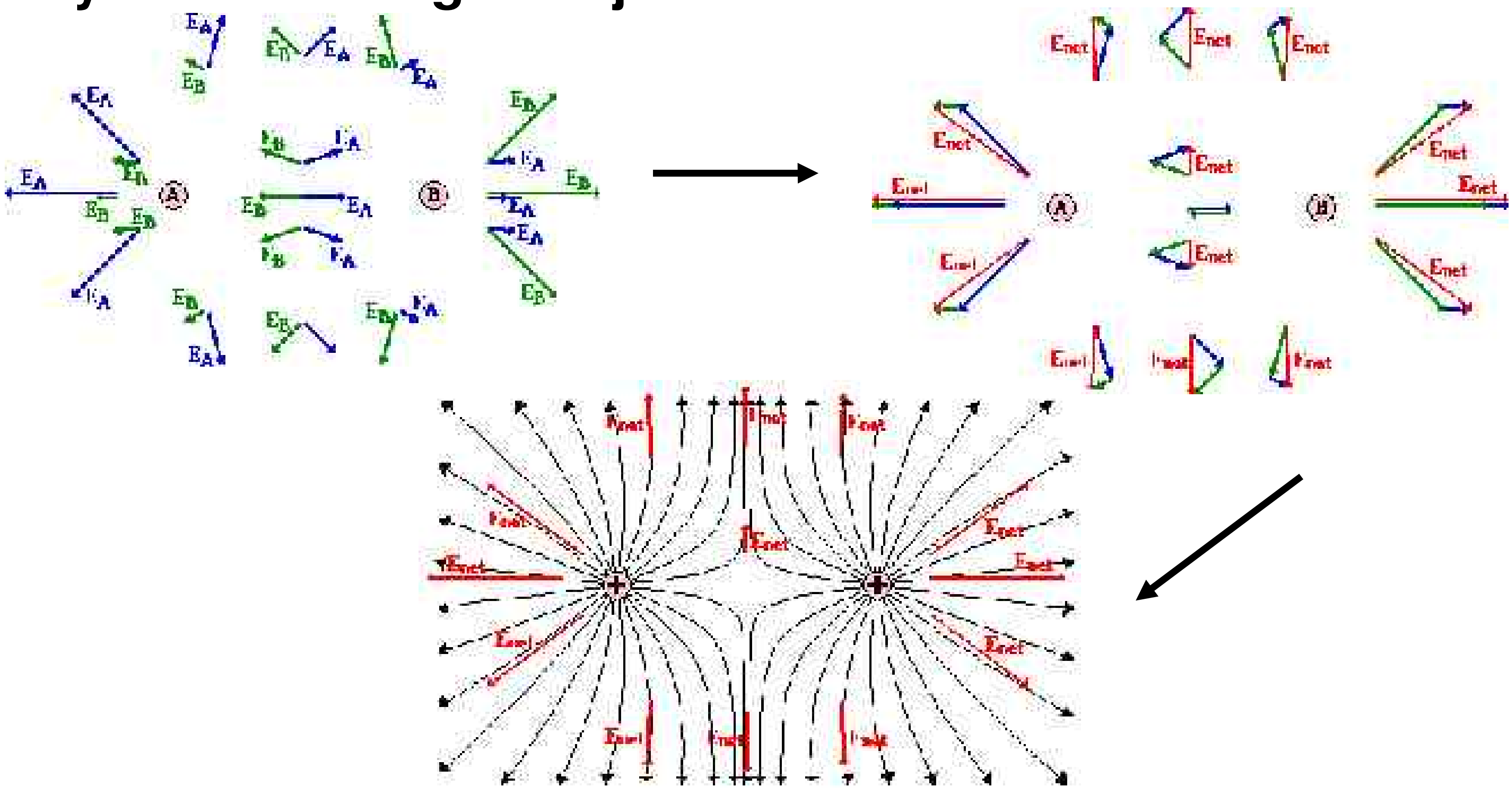
- To visualize electric fields, one can draw **field lines** that point in the direction of the field at any point following the following rules:
  - The electric field vector E is tangent to the electrical field lines at each point
  - The number of lines per unit area through a surface perpendicular to the lines is proportional to the field strength
  - field lines **start from a positive charge (or infinity)**
  - field lines **end at a negative charge (or infinity)**
  - field lines **never cross** (why not?)





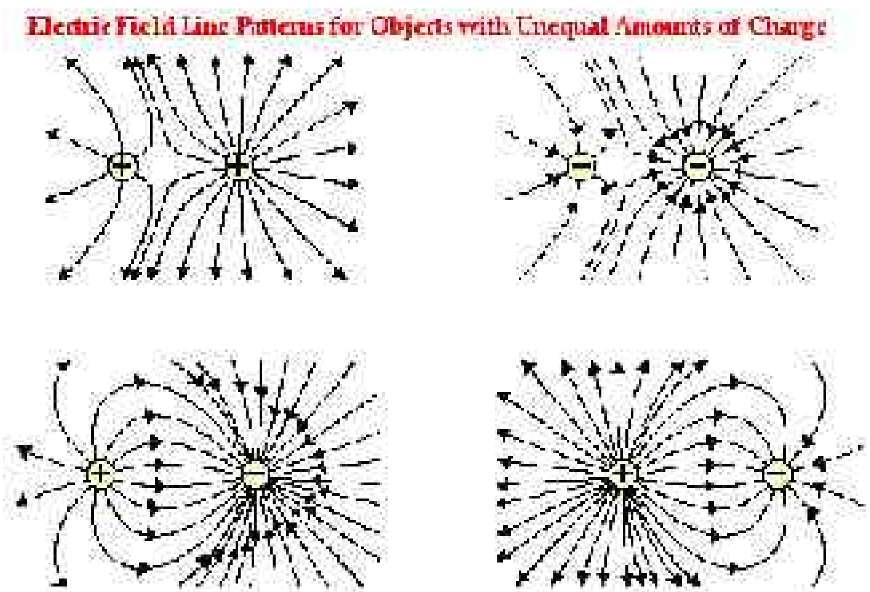
electric field lines II

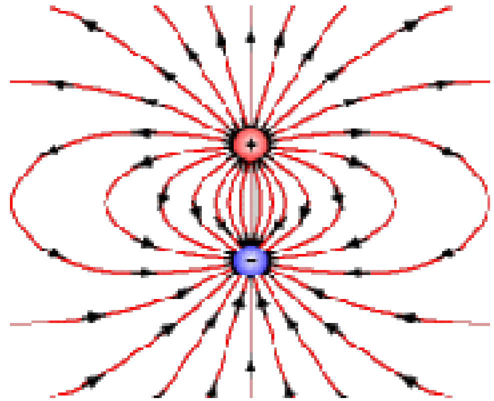
- **Following these rules one can draw the field lines for any system of charged objects**

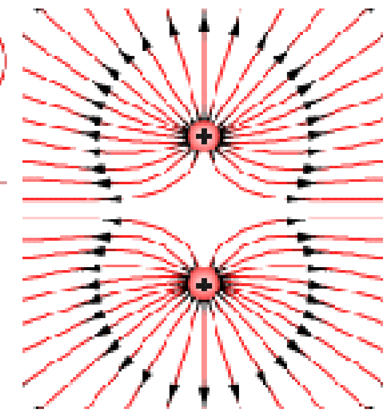


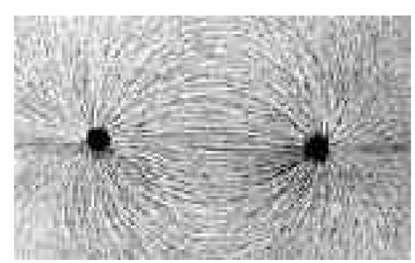
electric field lines III

- **examples**

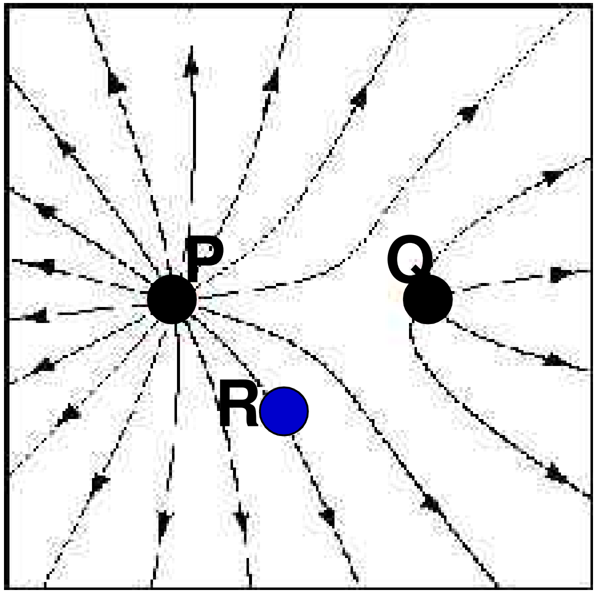






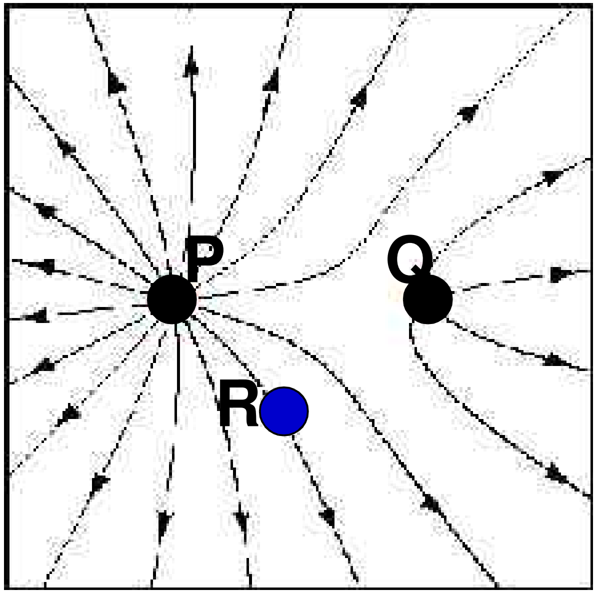


questions



- charge P is (a) positive or (b) negative
- charge Q is (a) positive or (b) negative
- charge P is (a) larger or (b) smaller than charge Q
- a negative charge at R would move
  (a) toward P (b) away from P (c) toward Q
  (d) none of the above

answers

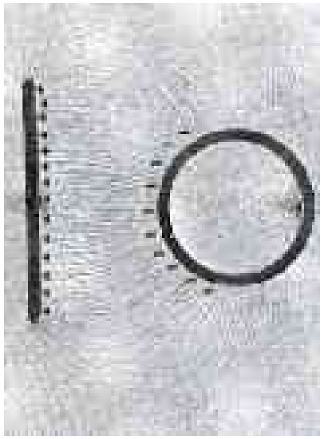


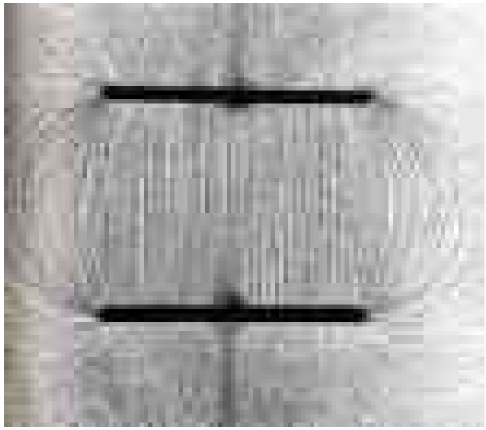
- charge P is (a) positive
- charge Q is (a) positive
- charge P is (a) larger than charge Q
- a negative charge at R would move
  (d) toward a point between P and Q

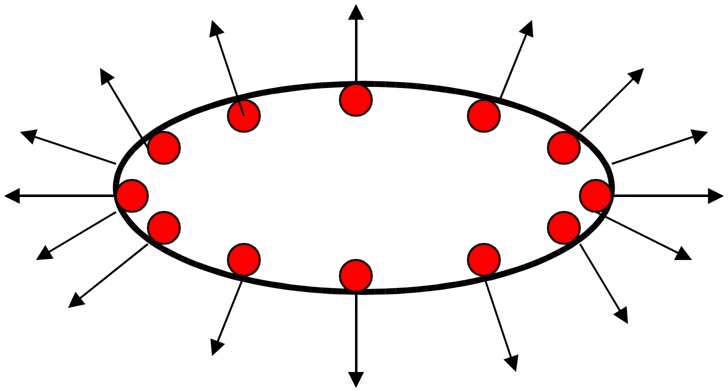
conductors

ElectroSTATICS: an insulated conductor is in equilibrium →

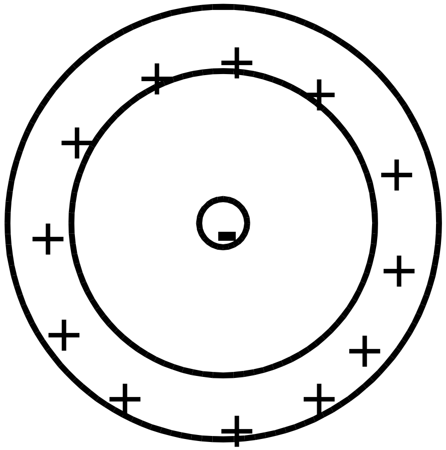
- The electric field is zero everywhere in the conductor
  - since net field would result in motion
- Any excess charge resides on the surface
  - since electric force ~$1/r^2$ excess charge is repelled
- The field just outside the conductor is perpendicular to the surface
  - otherwise charge would move over the surface
- Charge accumulates where the curvature of the surface is smallest
  - charges are farther apart at flatter surfaces







question



A point charge $-q$ is located at the center of a spherical shell with radius a and charge $+q$ uniformly distributed over its surface.

What is the E-field

g) anywhere outside the shell and

h) at a point inside the shell at distance r from the center.

question

A neutral object A is placed at a distance r=0.01 m away from a charge B of +1μC.

d) What is the electric field at point A?
e) What is the electric force on object A?
c) A is replaced by a charge of –1 μC. What is the force on it?
d) Then what is the force on B?

a) $E=kq_B/r_{AB}^2=9x10^9 \times 1x10^{-6} / 0.01^2=90x10^6$ N/C
b) $F=Eq_A=0$
c) $F=Eq_A=90x10^6 \times (1x10^{-6})=90$ N toward B
d) Same, but pointed toward A