Today

- Green sheet
- Online HW assignments
- Practice Problems
- Course overview

See course website:

- www.erbion.com/academicpage.html

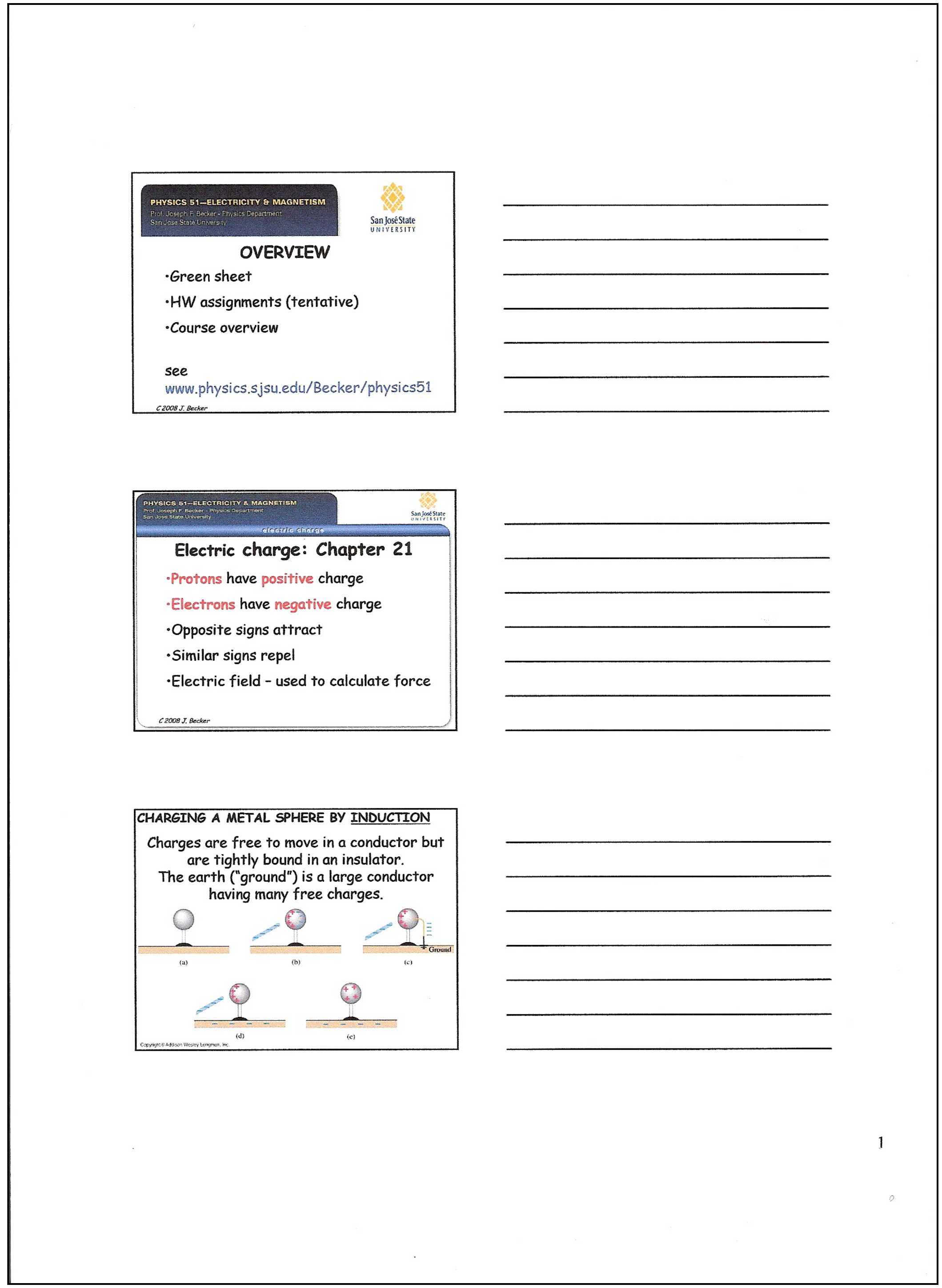
How to print several slides on a page

Open the lecture file,

Click print

On the print menu choose number of pages per sheet and see the preview.

If you are happy with the size of the fonts, finish the job by clicking print.



Chapter 21
Electric Field and Coulomb's Law

- Electric charge (sec. 21.1)
- Conductors, insulators, and induced charge(sec. 21.2)
- Coulomb's Law (sec. 21.3)
- Electric field lines (sec. 21.6)

Learning Goals - we will learn:

- The nature of electric charge.
- How objects become electrically charged.
- How to use Coulomb's Law to calculate the electric force between charges.
- How to calculate the electric field caused by electric charges.
- How to use the idea of electric field lines to visualize electric fields.

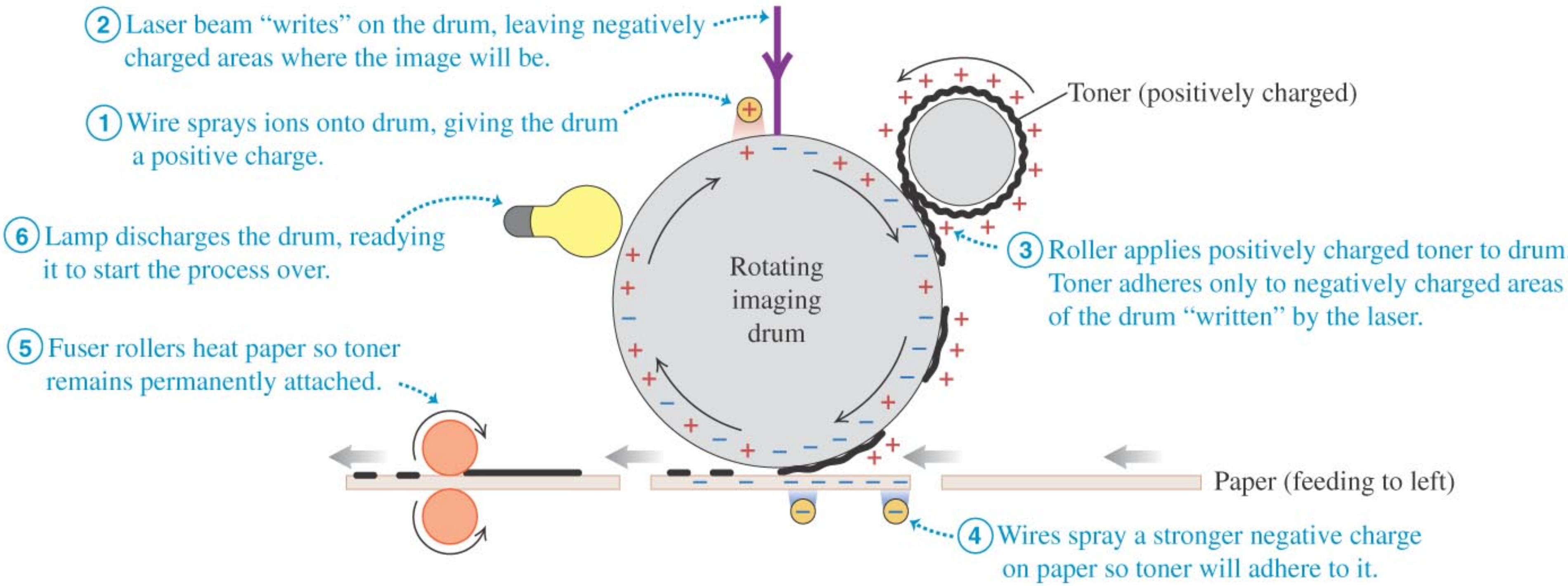
Electric Charge

- **Protons** have **positive** charge
- **Electrons** have **negative** charge
- Opposite sign charges attract each other
- Similar sign charges repel
- Electric field – used to calculate force between charges

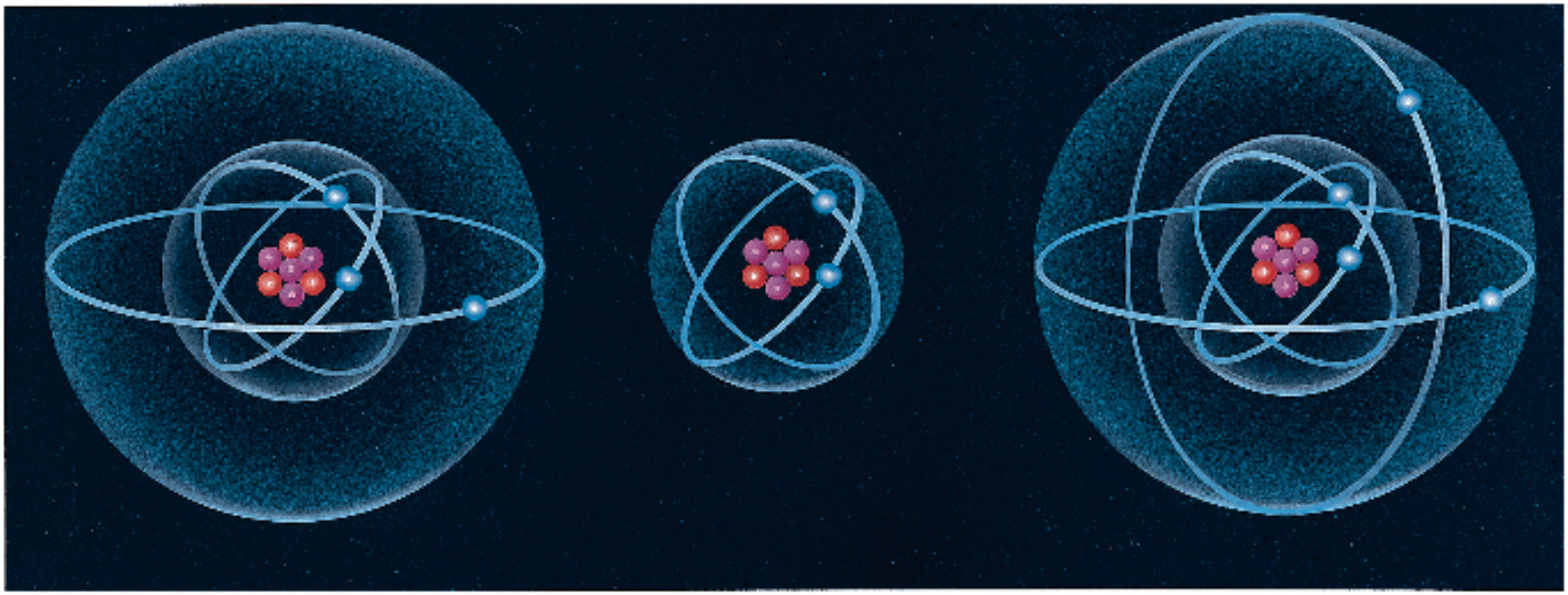
Applications of electric charge

- Photocopiers are amazing devices. They use electric charge to hold fine dust (toner) in patterns until the pattern may be transferred to paper and made permanent with heat.
- Atomic structure: all the molecules that constitute our world are build and held together my electric charges.
- Electric charges are responsible for all shapes and forms of material such as solid, liquid, plasma …

Copy machine



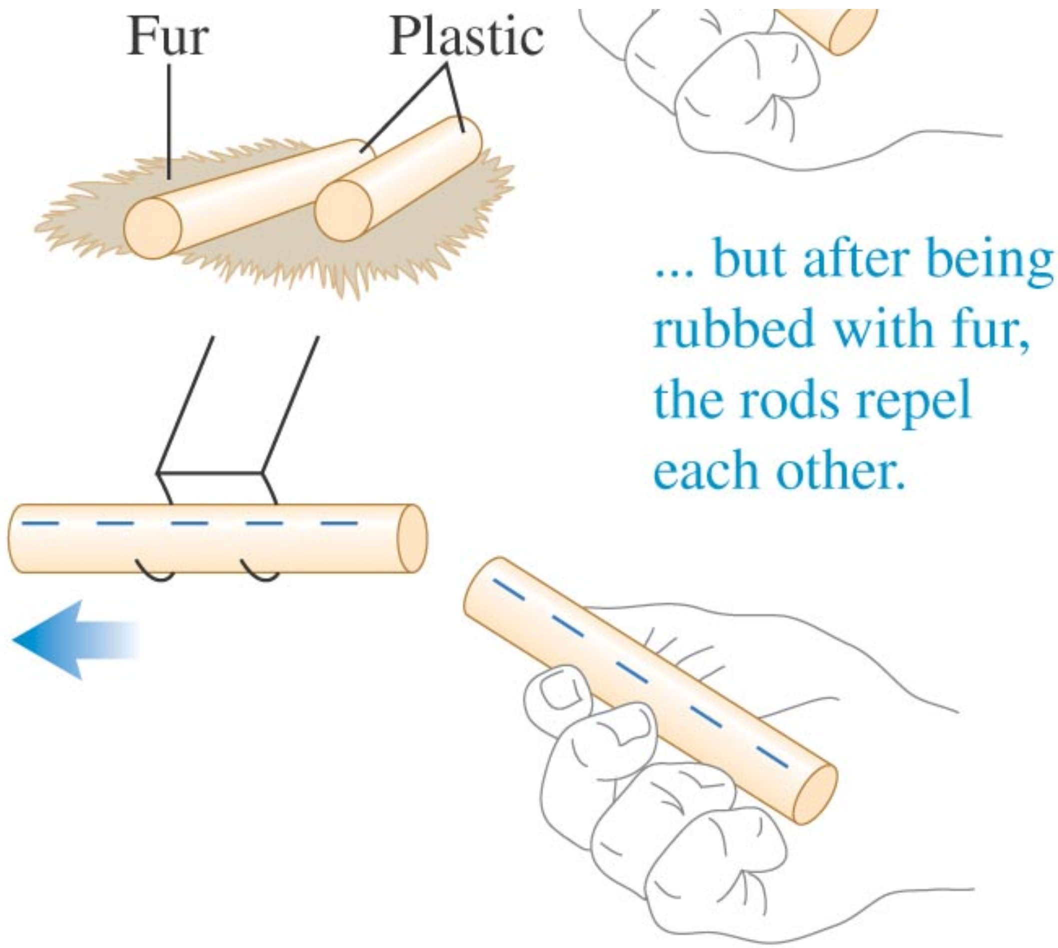
Atom, Positive ion, Negative ion



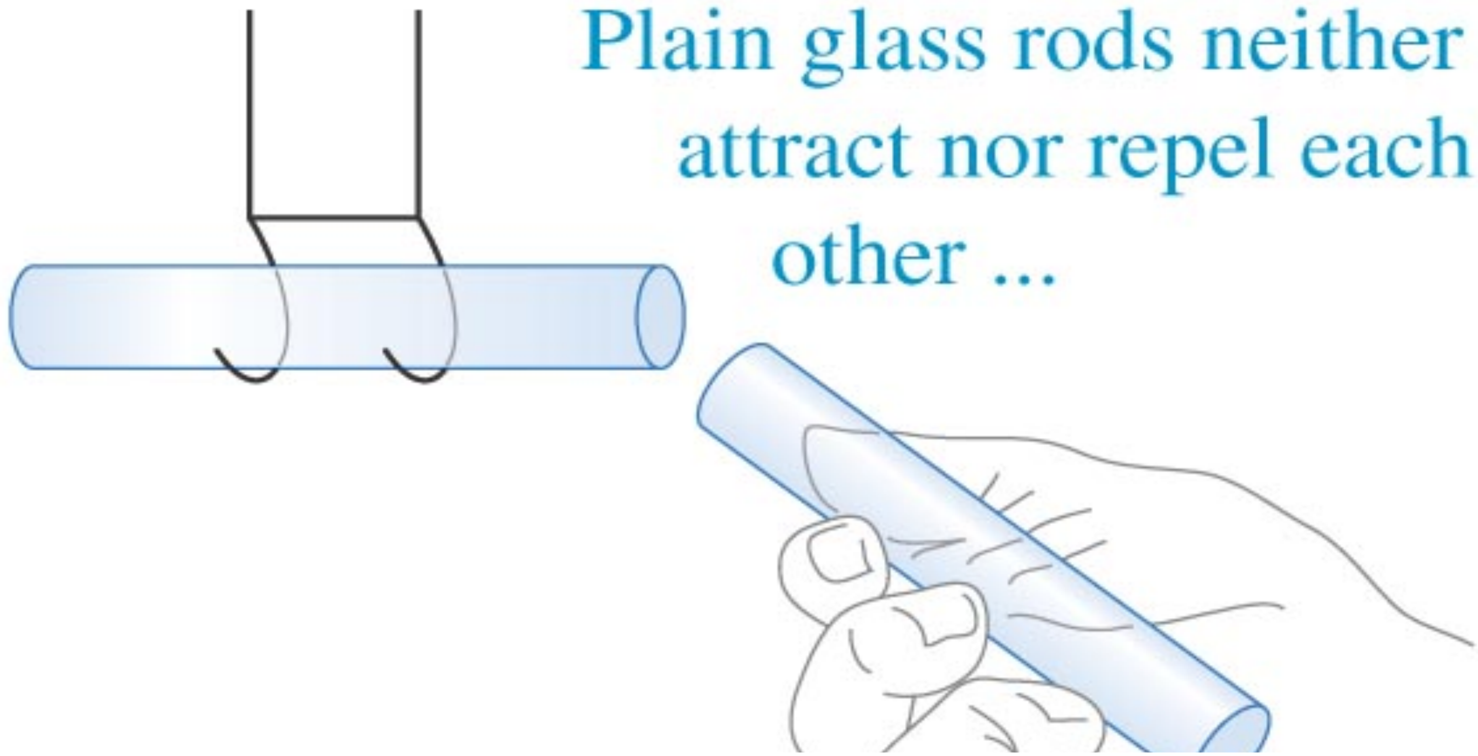
Identify electric forces in action in this picture

Interaction between plastic rods

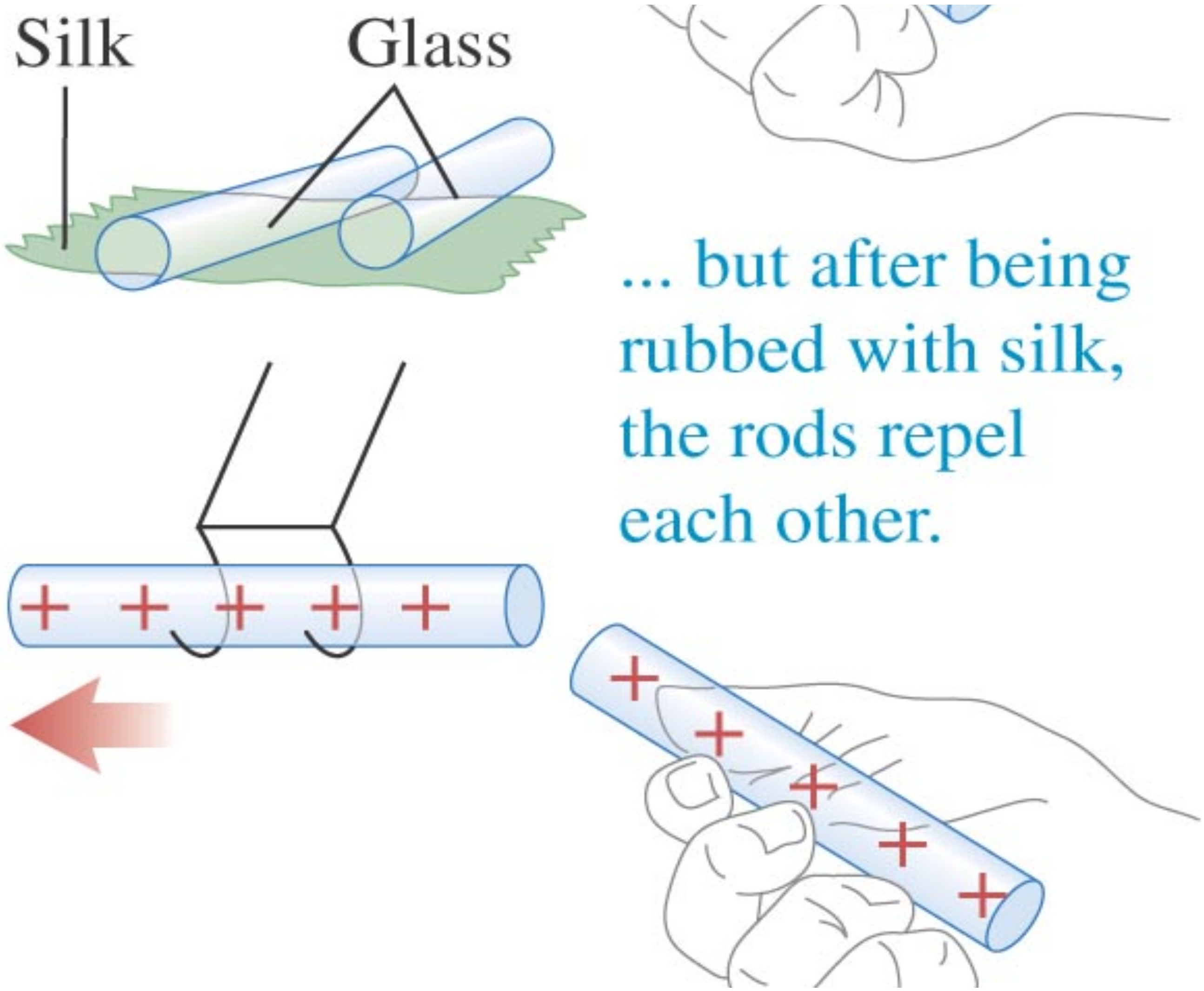
Interaction between plastic rods rubbed on fur



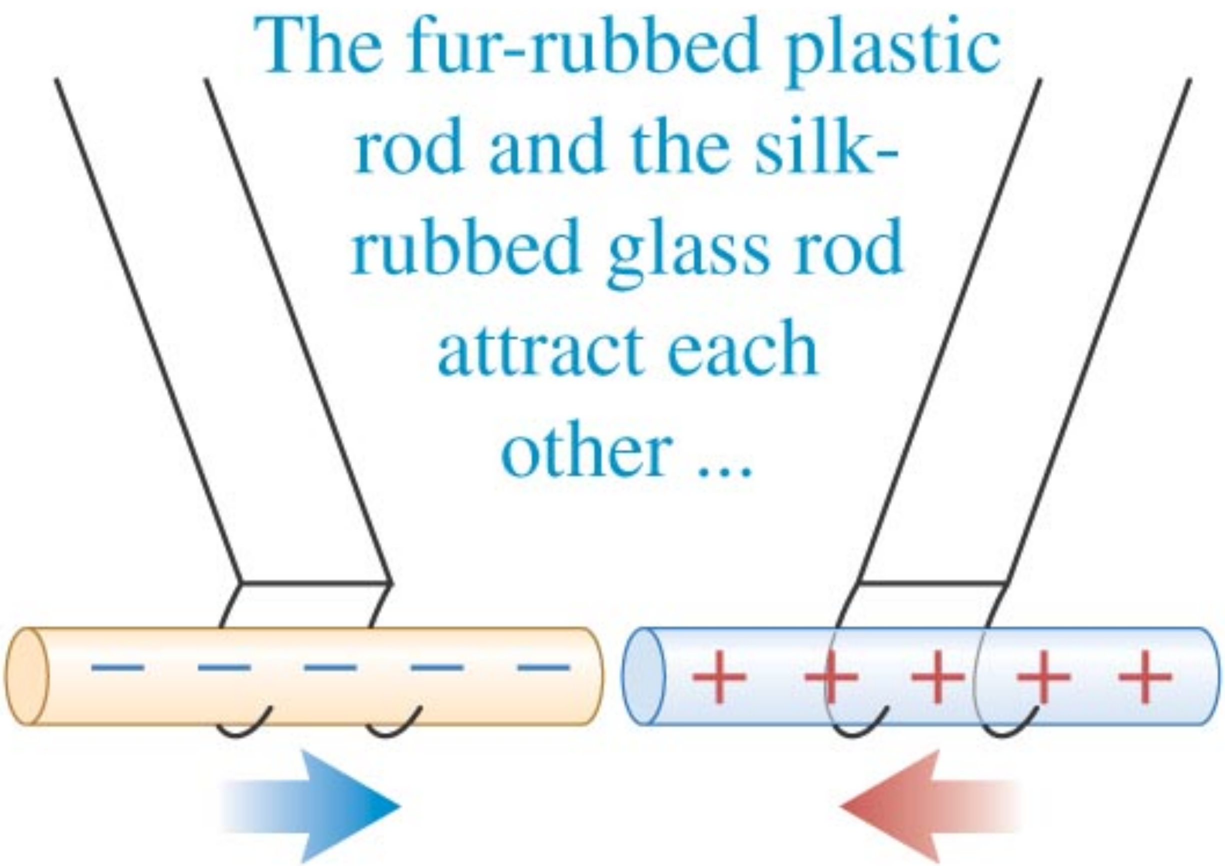
Interaction between glass rods



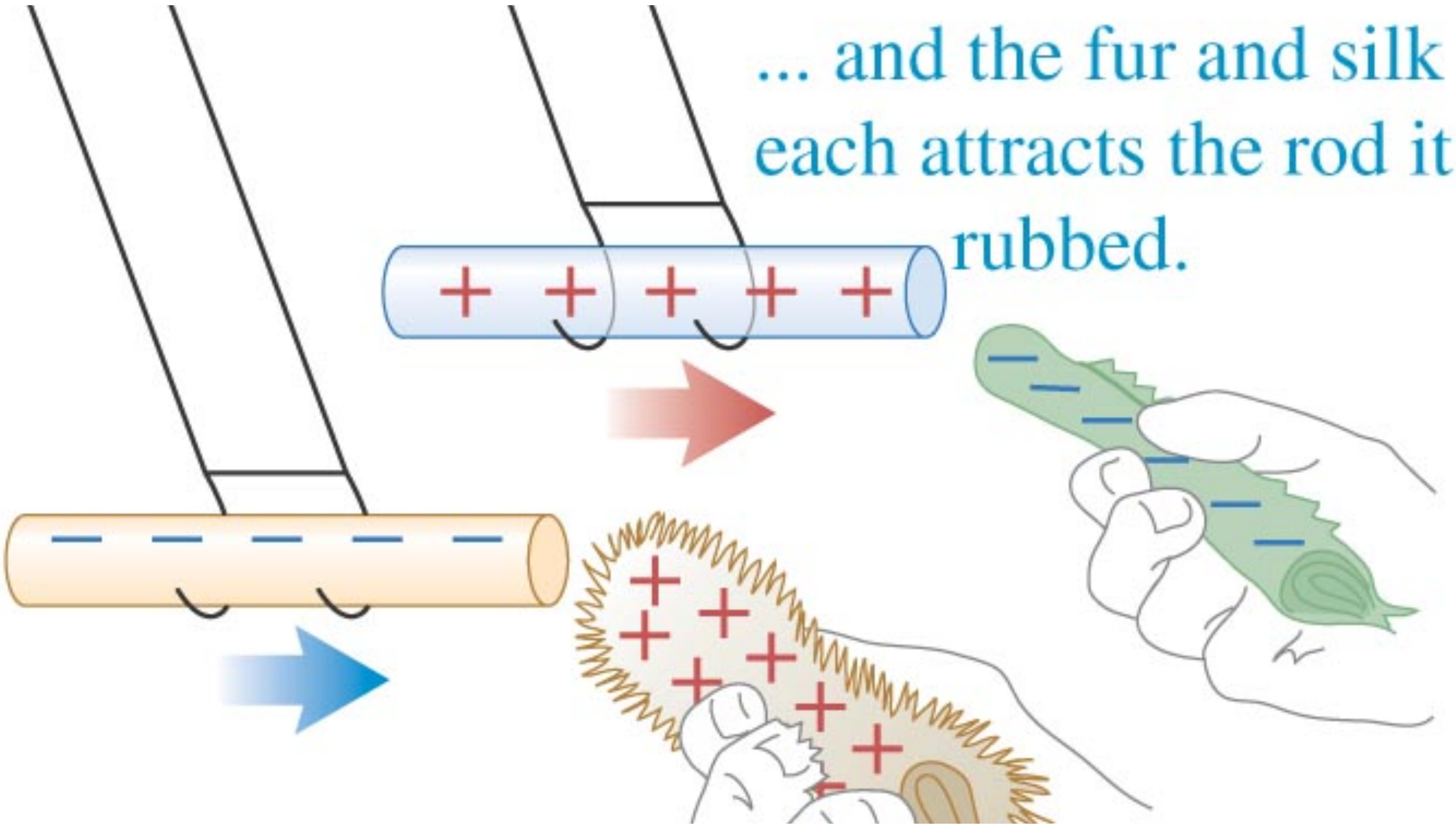
Interaction between glass rods rubbed on silk



Interaction between opposite charges

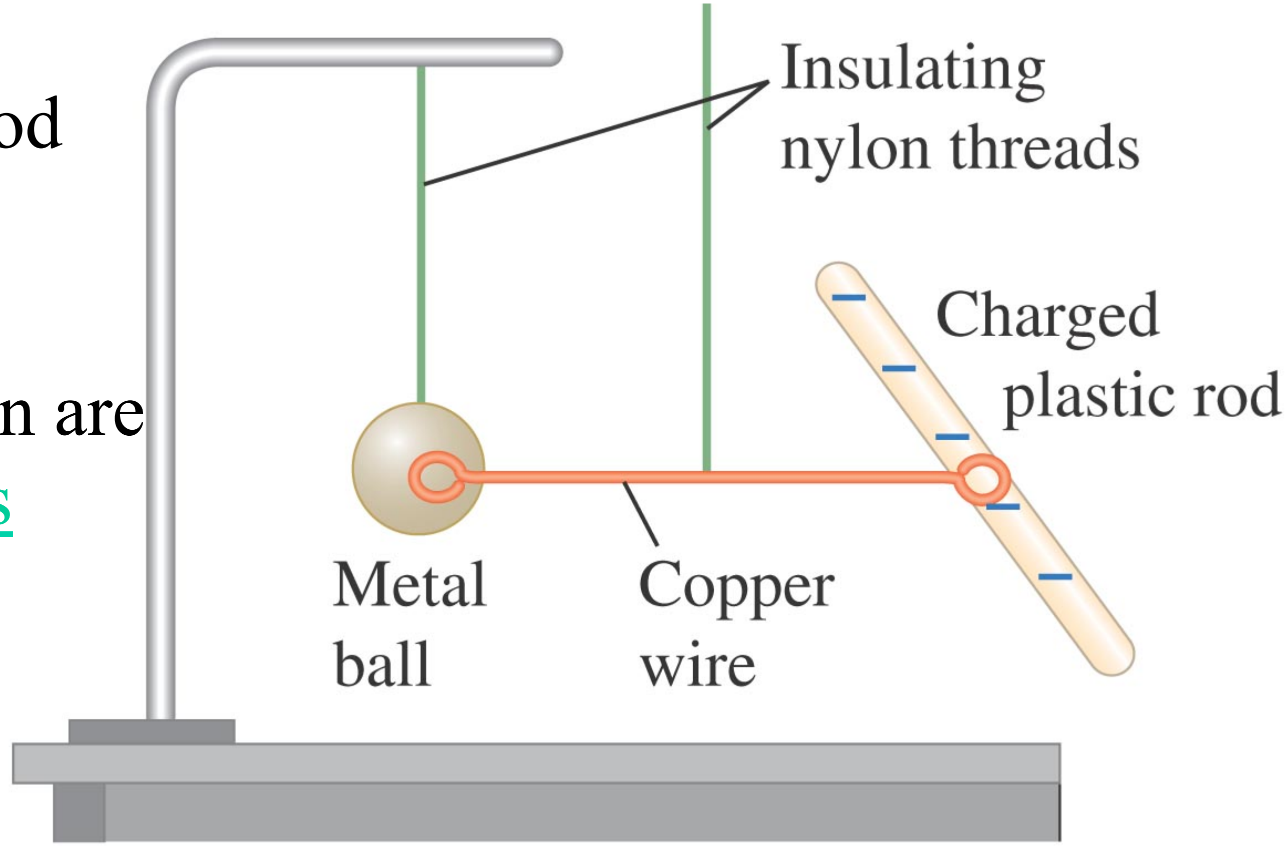


Interaction between opposite charges



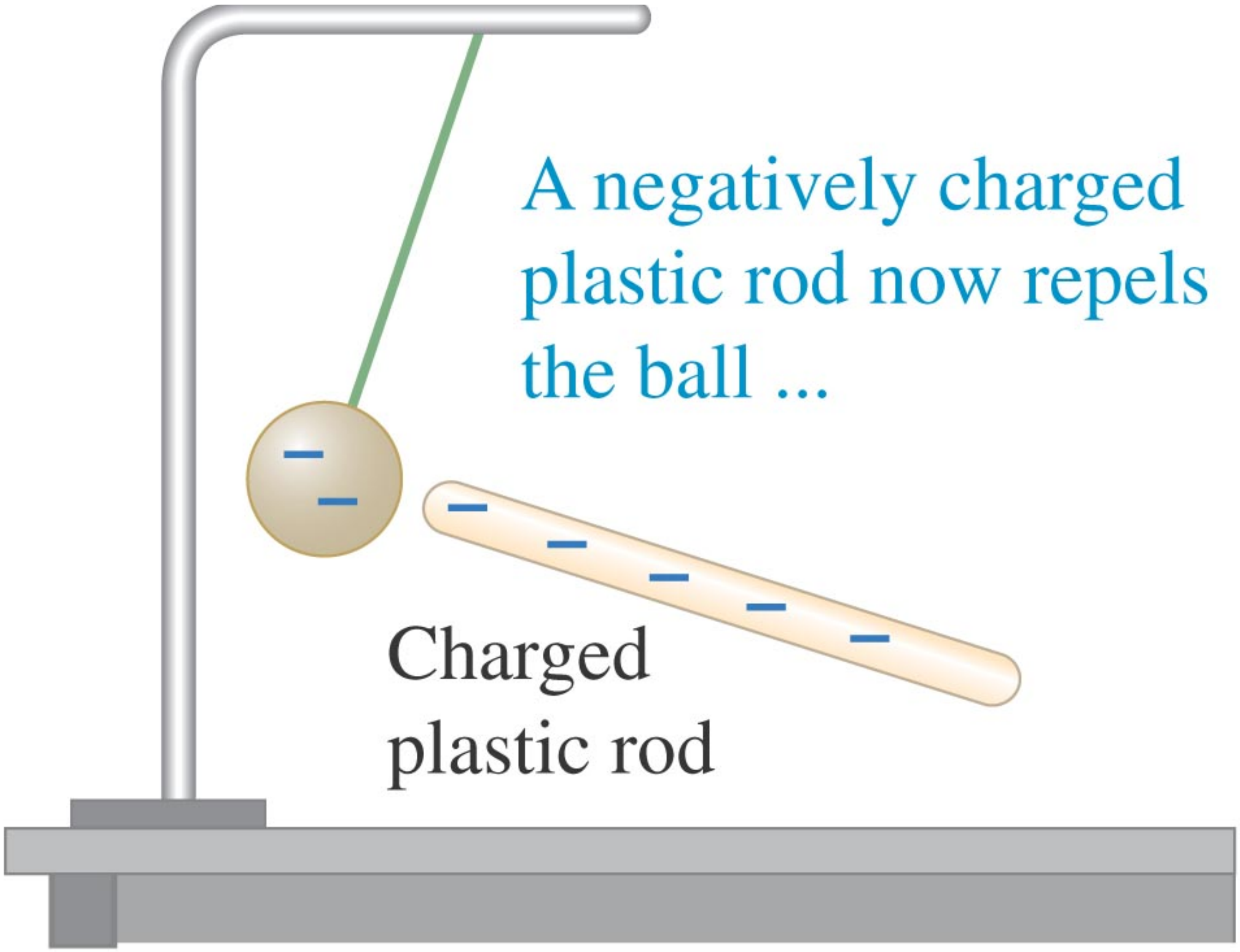
Conductors and insulators

- Copper is a good conductor of electricity
- Glass and nylon are good insulators

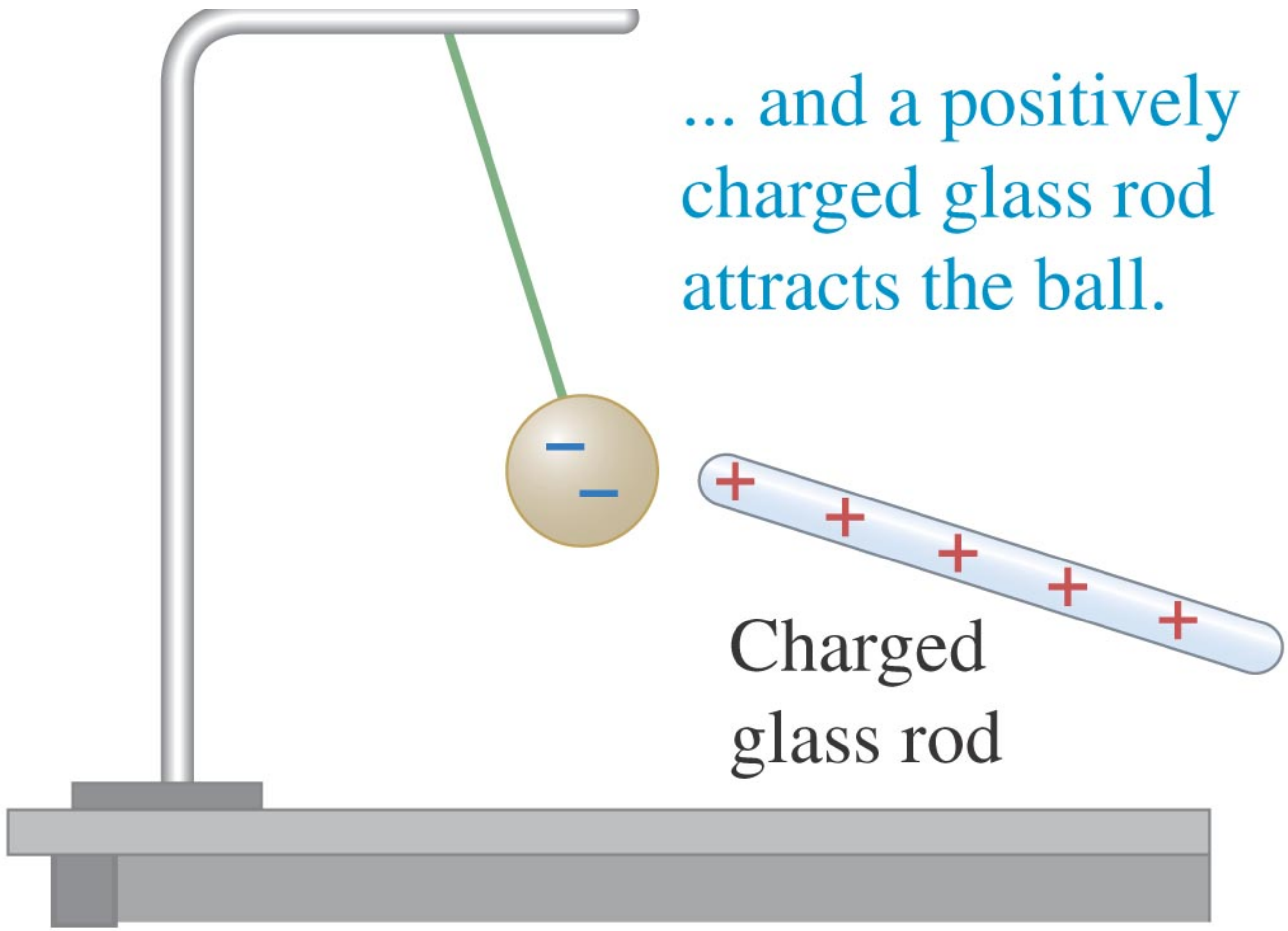


The wire conducts charge from the negatively charged plastic rod to the metal ball.

Like charges repel each other



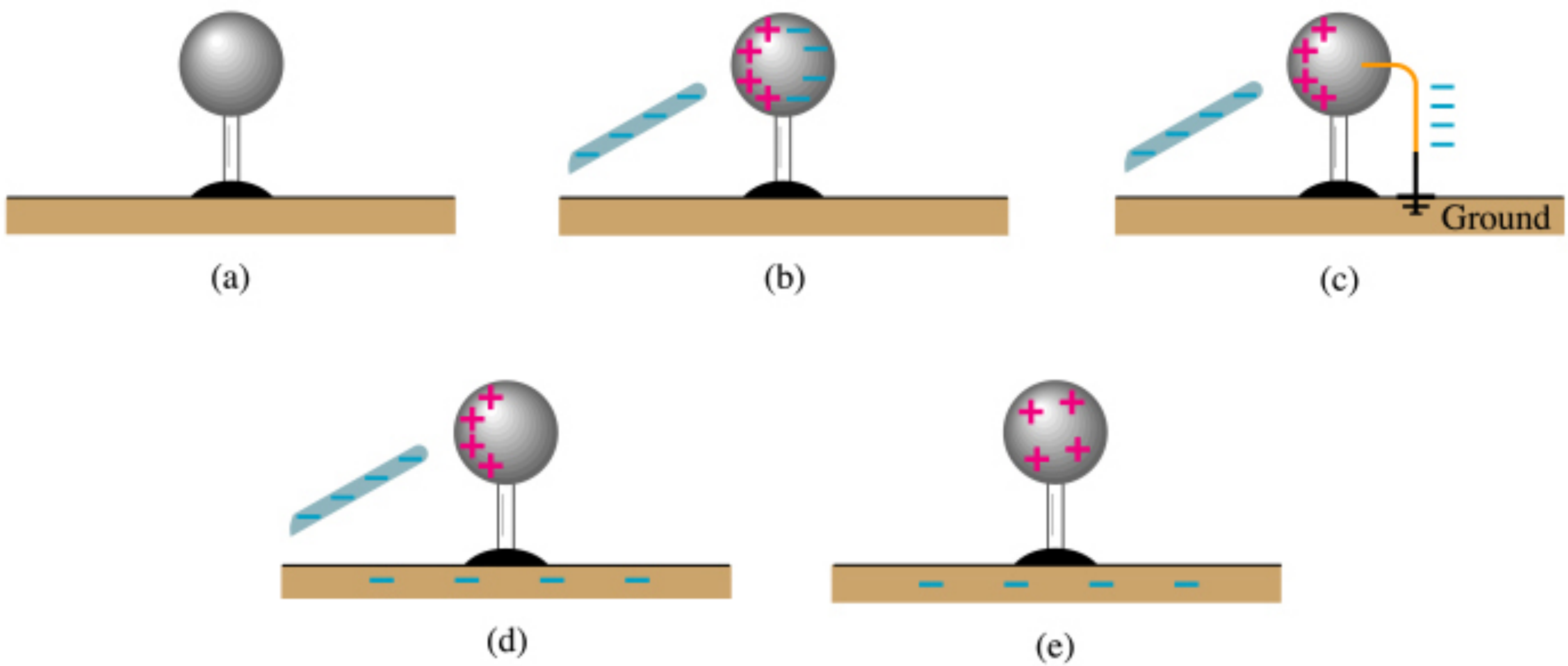
Opposite charges attract each other



Charges in conductors and insulators

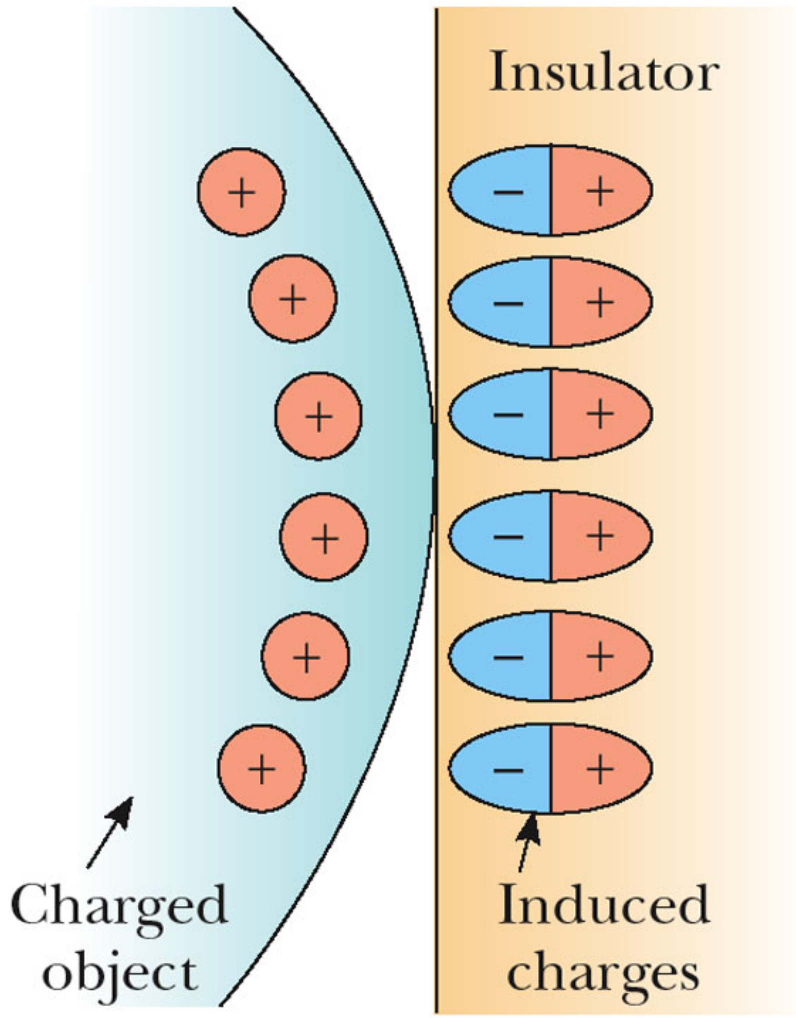
- Charges are free to move in a conductor
- Charges are tightly bound to their molecule in an insulator.
- The earth ("ground") is a large conductor having many free charges.

CHARGING A METAL SPHERE BY INDUCTION



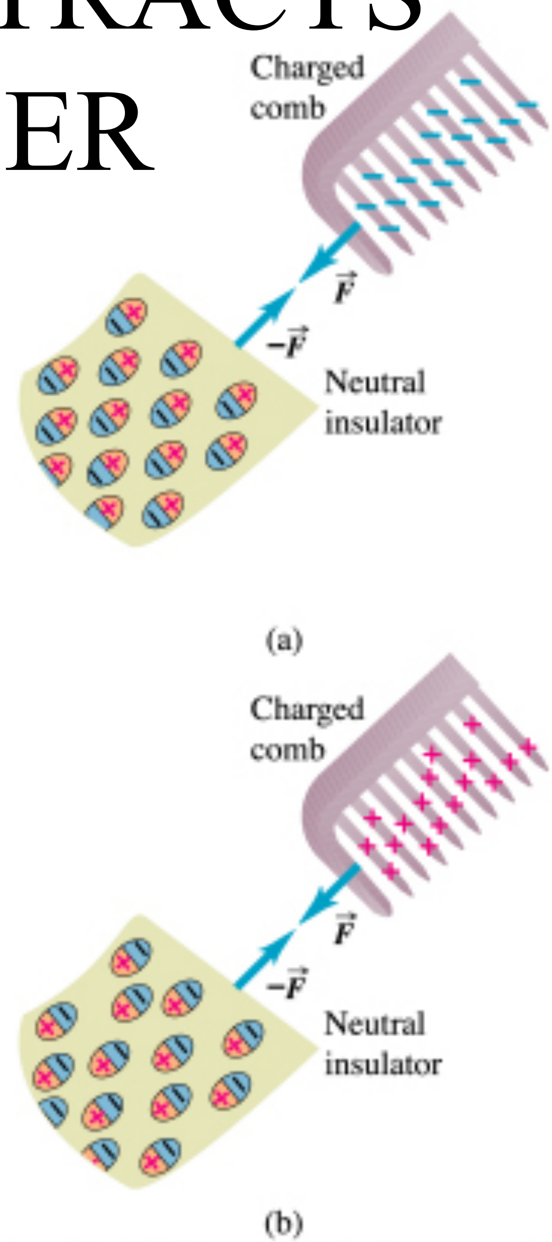
A charged comb picking up uncharged pieces of plastic by induction

How a charged object polarizes and attracts an insulator



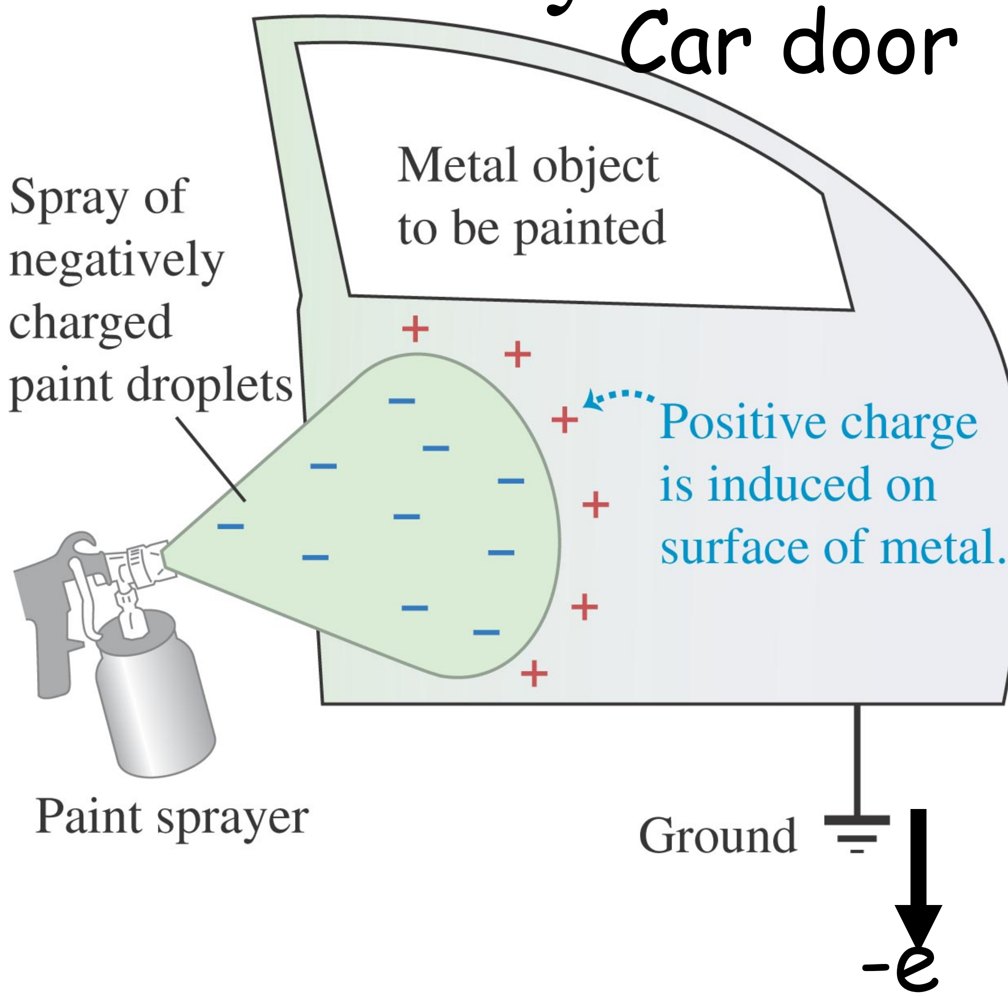
CHARGED COMB ATTRACTS A PIECE OF PAPER

- In an **insulator** the charges can move **slightly** (called polarization of the insulator).
- A piece of paper is attracted to a charged comb because the positive charges are closer to the negatively charged comb

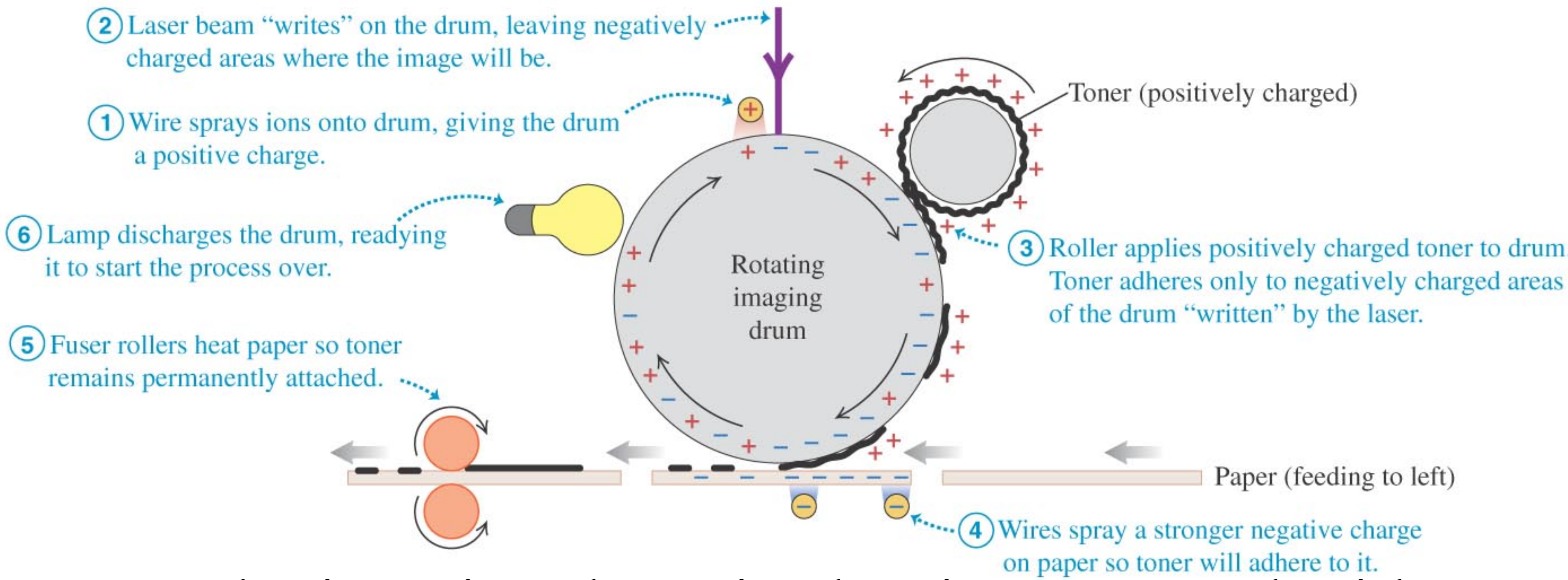


The electrostatic painting process in automotive industry

- The process minimizes overspray from clouds of stray paint particles
- The finish is very smooth
- Excess charges flow to or from "ground"



LASER PRINTER USES CHARGED TONER



- The imaging drum is aluminum coated with selenium, which changes from an insulator to a conductor when illuminated with light.

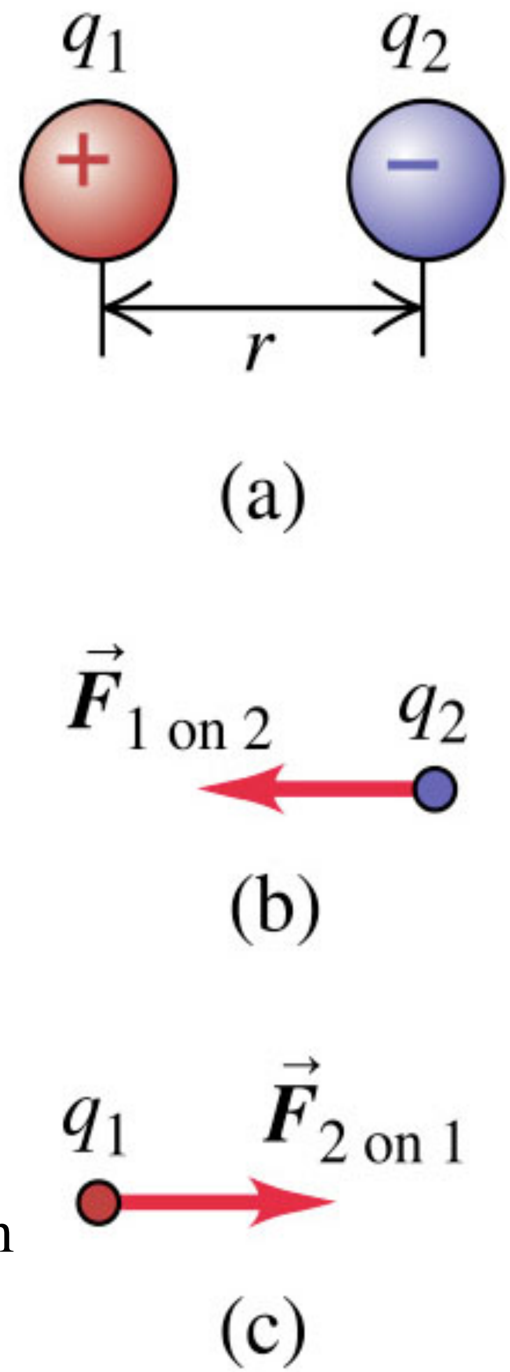
Coulomb's law (scalar form)

- The <u>amount</u> of **force** between two charges is given by **Coulomb's Law**:

$$F = k\frac{|q_1 q_2|}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1 q_2|}{r^2}$$

$$k = \frac{1}{4\pi\varepsilon_0} \simeq 8.8988\times 10^9 \frac{N.m^2}{C^2} \simeq 9.0\times 10^9 \frac{N.m^2}{C^2}$$

$$\varepsilon_0 = 8.854\times 10^{-12}\frac{C^2}{N.m^2}$$ is permittivity of vacuum

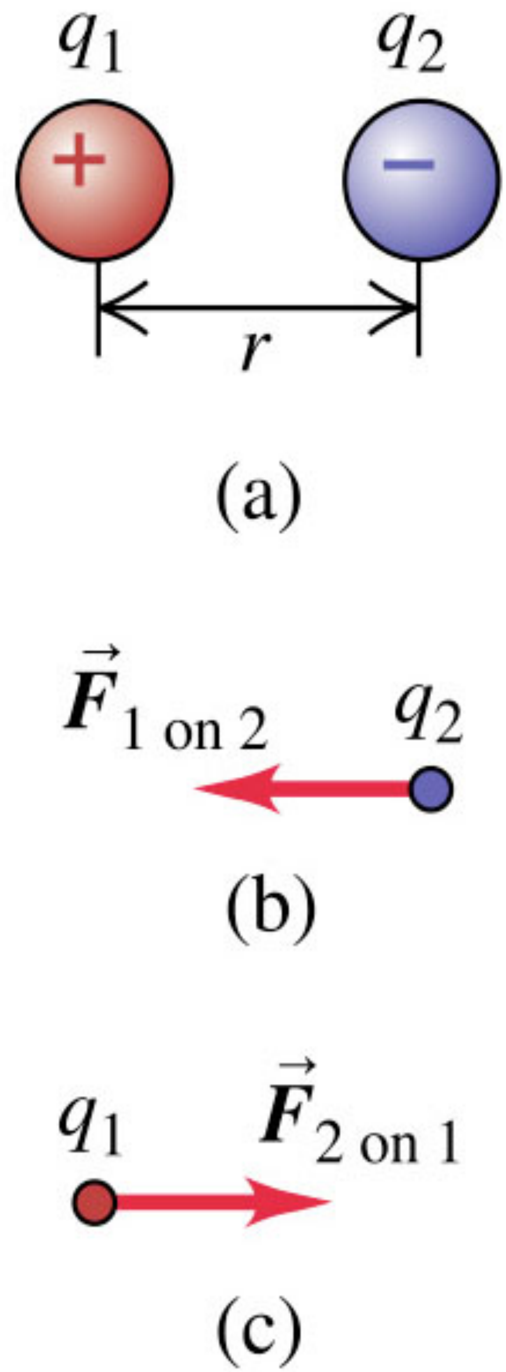


Coulomb's law (vector form)

$$\mathbf{F} = k\frac{q_1 q_2}{r^2}\hat{\mathbf{r}} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}$$

$\hat{\mathbf{r}}$ is a unit vector along the line connecting the two charges.

q_1 and q_2 can be positive or negative and that determines the direction of the force between the charges.



Gravitational Field vs. Electric Field (E)

Gravitational force between two masses m & M:

$$\mathbf{F}_g = G\frac{Mm}{r^2}\hat{\mathbf{r}} = \mathrm{m}\,\mathbf{g}$$

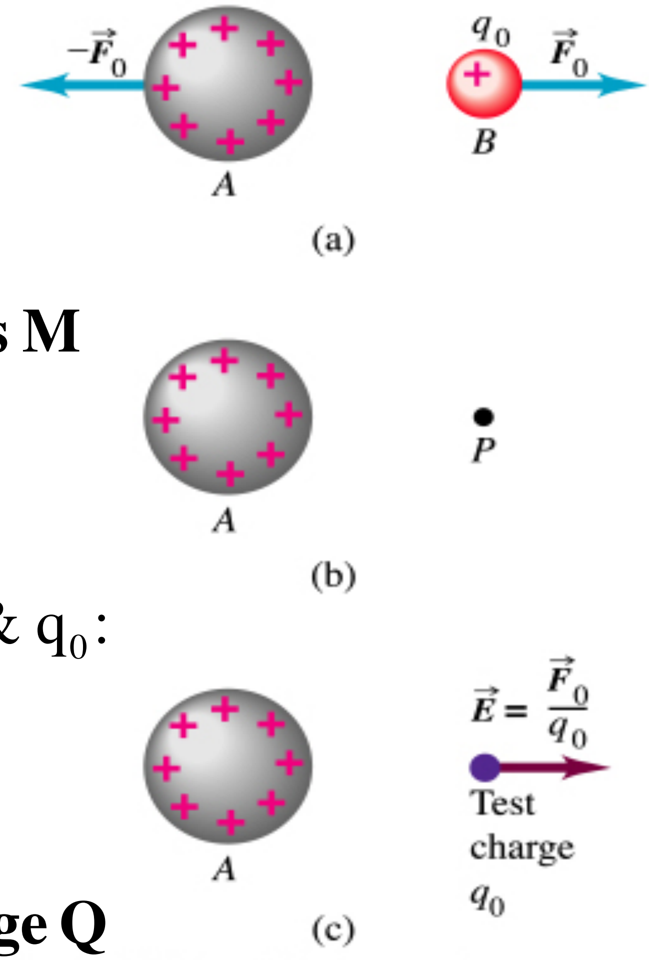
$$\mathbf{g} = G\frac{M}{r^2}\hat{\mathbf{r}}$$ is the **gravitational field of the mass M**

$$\left|\mathbf{g}_{earth}\right| = 9.8\,\frac{\mathrm{m}}{\mathrm{sec}^2}$$

Colomb (electric) force between the charges Q & q_0:

$$\mathbf{F}_0 = k\frac{Qq_0}{r^2}\hat{\mathbf{r}} = q_0\mathbf{E}$$

$$\mathbf{E} = k\frac{Q}{r^2}\hat{\mathbf{r}} = \frac{\mathbf{F}_0}{q_0}$$ is the **electric field of the charge Q**

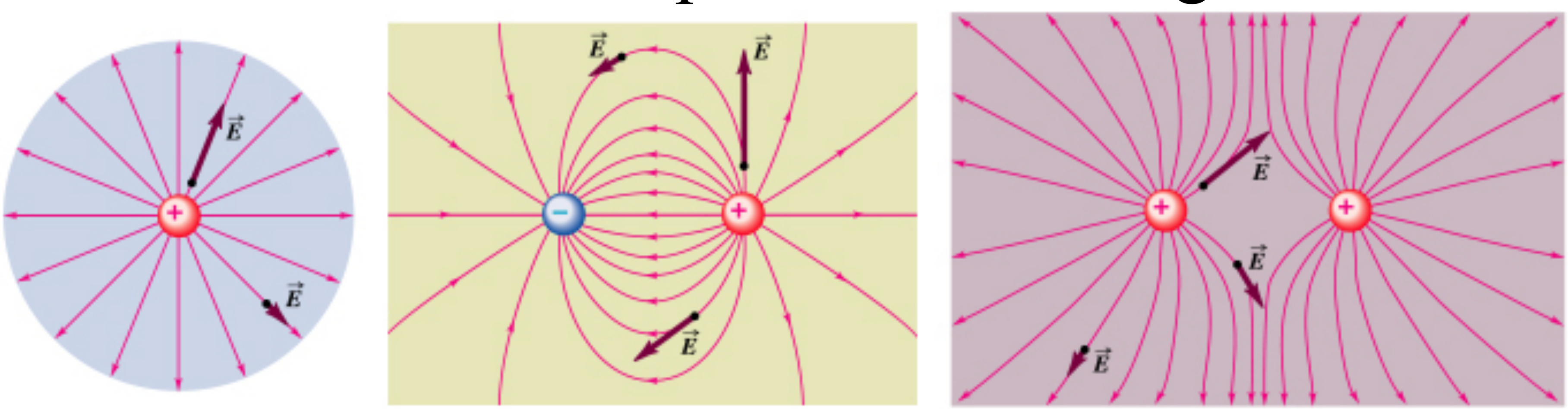


Comparison between the g and E fields

- Calculate ratio of the Coulomb force between two alpha particles to the gravitational force between them (an alpha particle is nucleus of a helium atom). (F_e/F_g=3.1E35)
- m=6.64E-27kg
- q=+2e=3.2E-19C
- k=9.0E+9N.m^2/C^2
- G=6.67E-11N.m^2/kg^2

ELECTRIC FIELD LINES START AND END AT ELECTRIC CHARGES

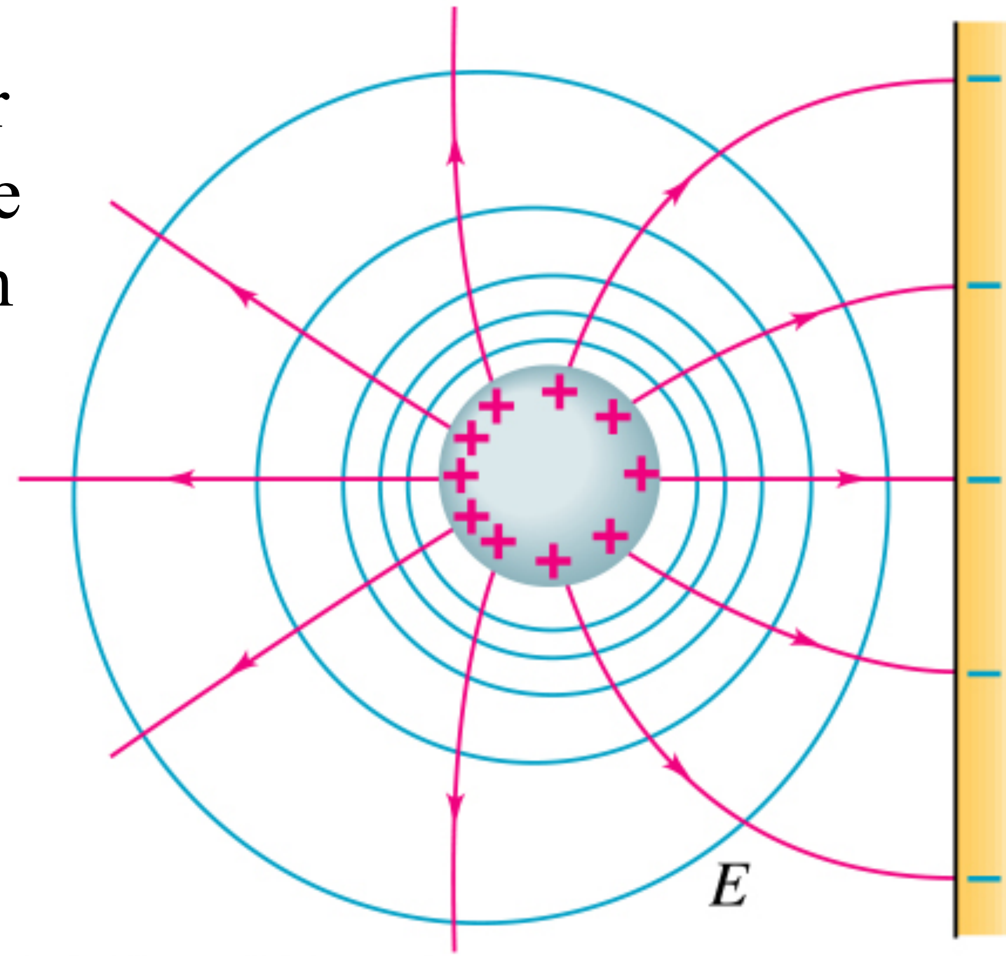
- An electric charge is surrounded by an electric field.
- Direction of the E-field lines is the direction of motion of the positive test charge



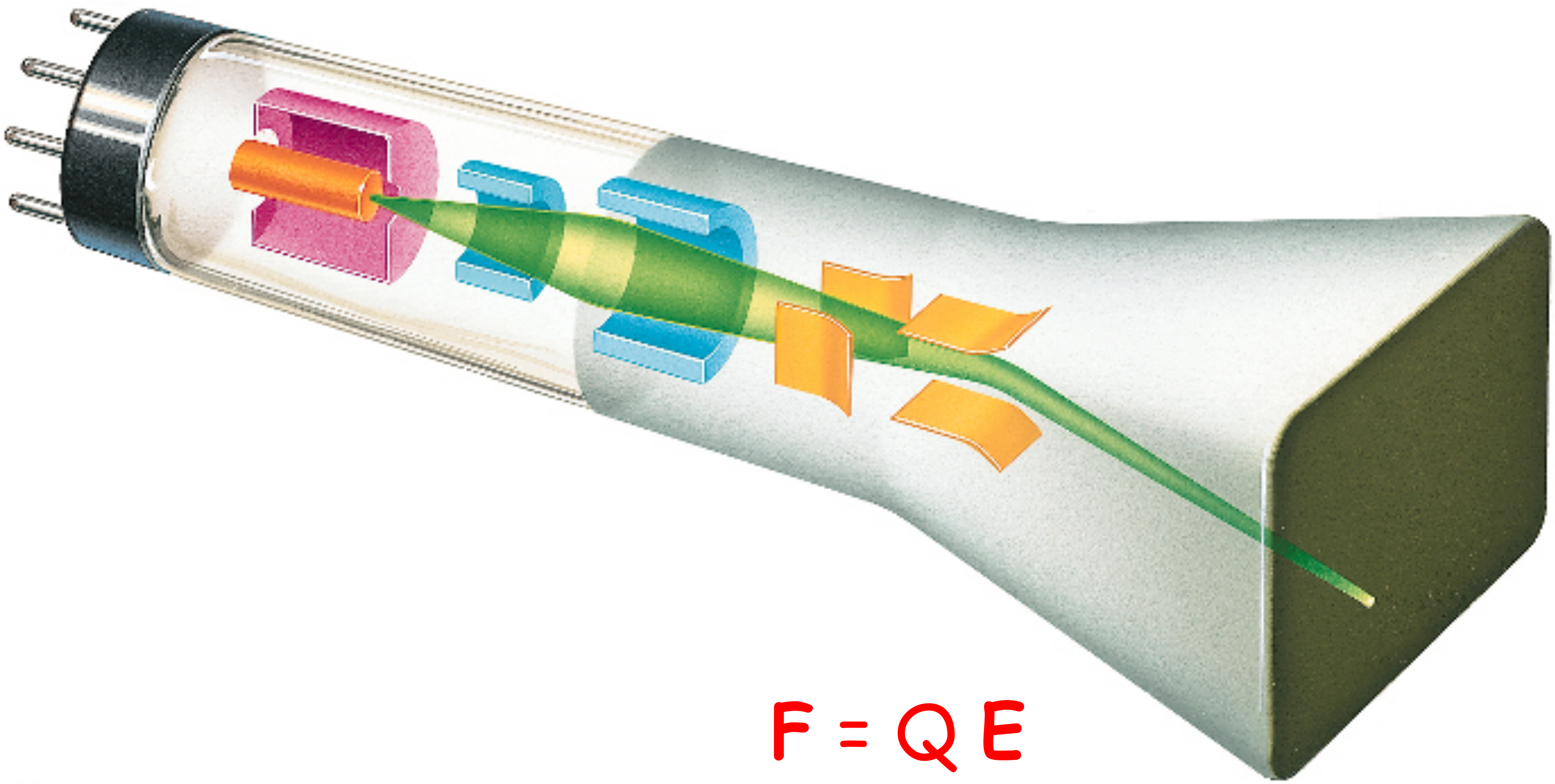
(a) (b) (c)

Electric field & equipotential lines are perpendicular to each other

- In Lab #2 a voltmeter is used to measure the equipotential lines (in Volts) in order to determine the magnitude and direction of the electric field lines.



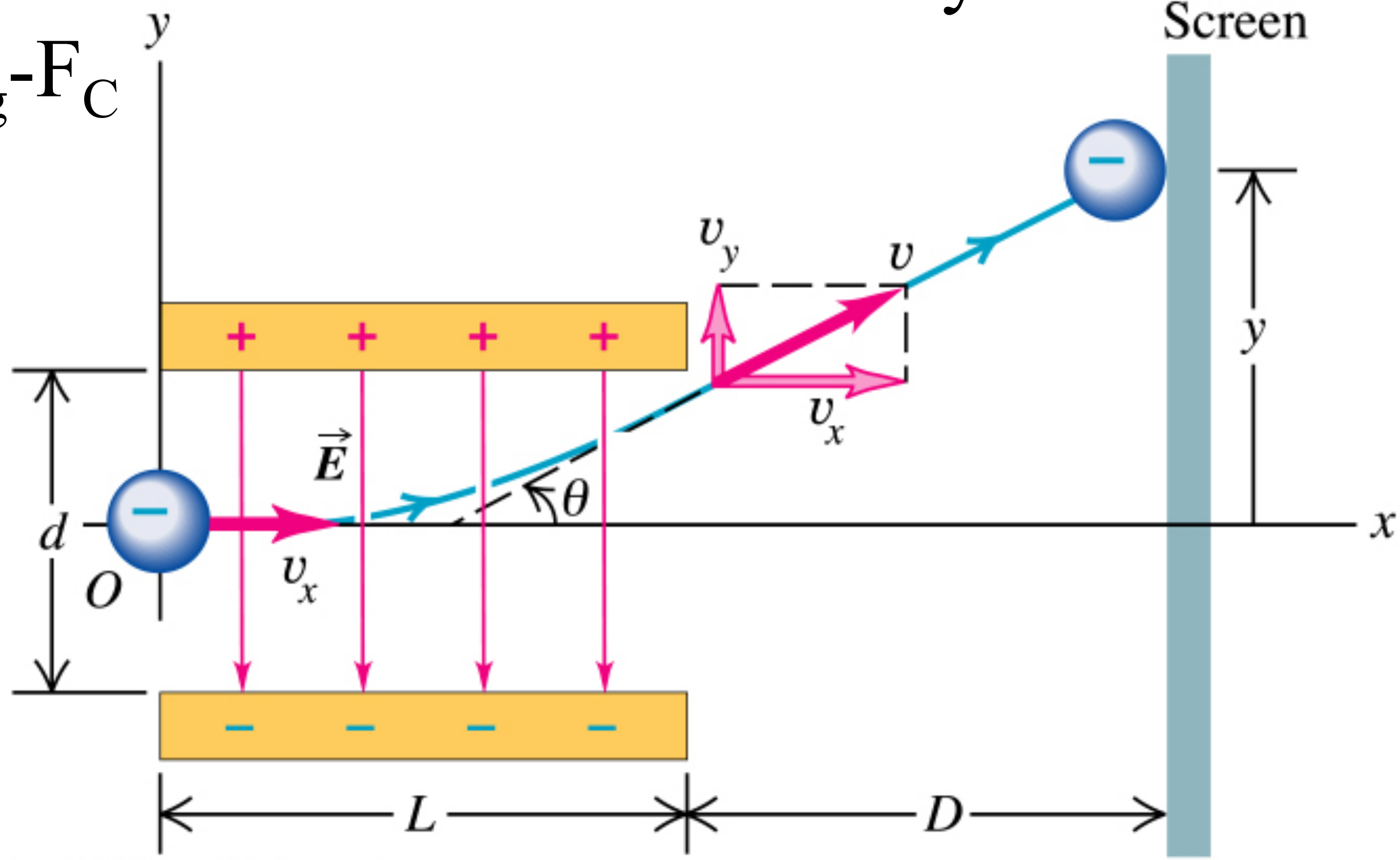
TV tube with electron-deflecting charged plates (orange)



$F = Q E$

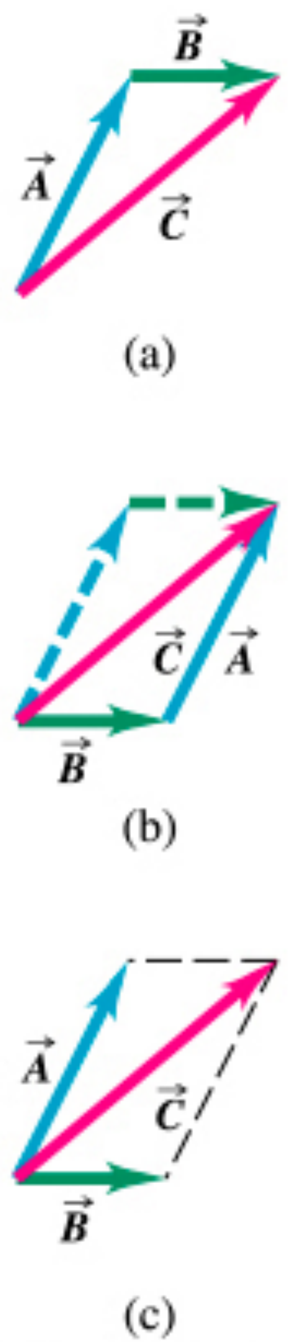
Problem of the motion of a charged particle in an external E-field

- It is like free fall with initial velocity and $F_{net} = F_g - F_C$



Math review and problems

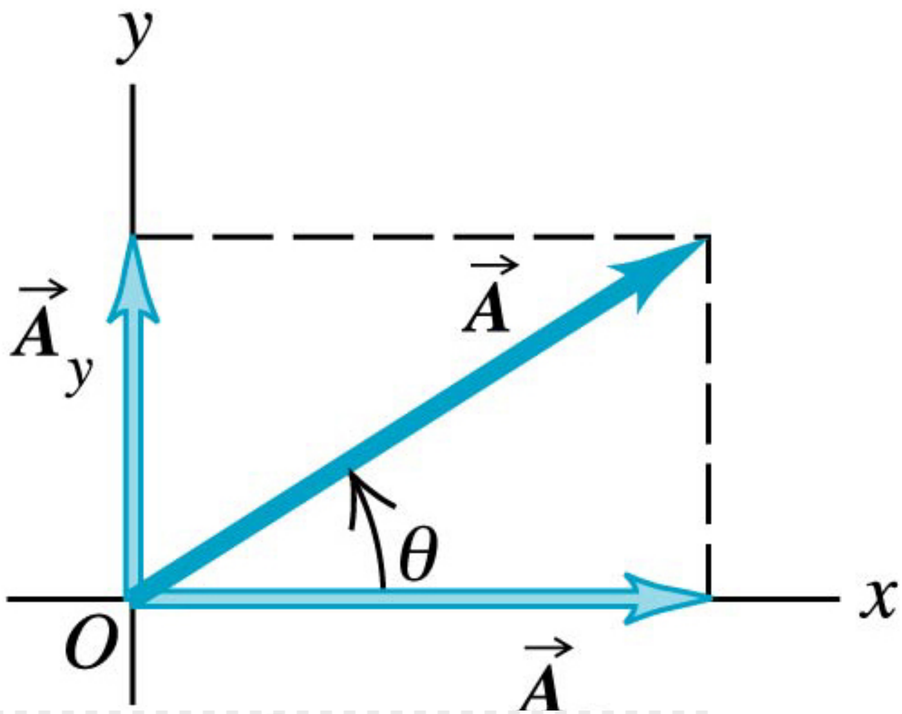
- Vectors, definition, presentation, decomposition,
- Vector operations, adding, subtracting, multiplying by an scalar, dot product, cross product.
- Understand what is the end result of each operation

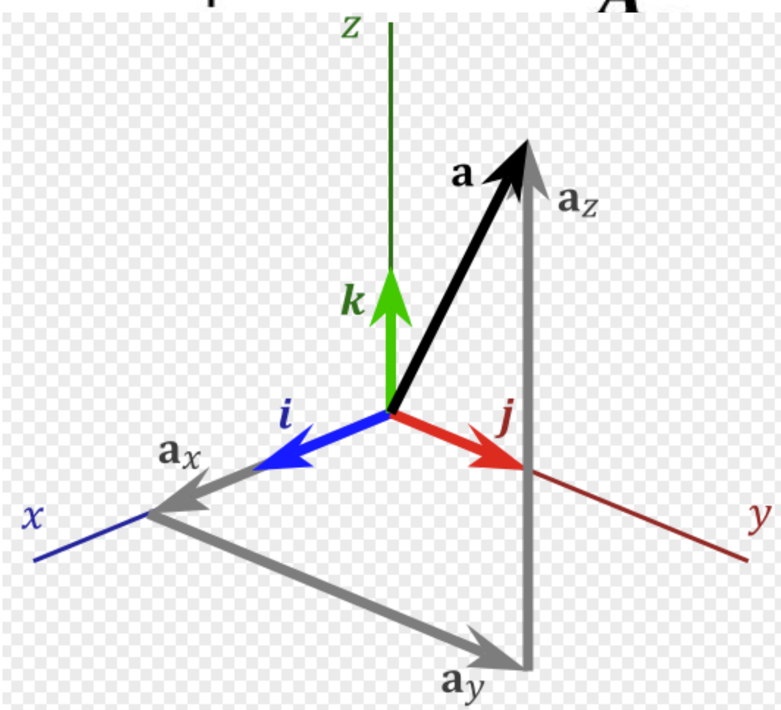


Vectors are quantities that have both **magnitude** and **direction**.

An example of a vector quantity is velocity. A velocity has both magnitude (speed) and direction, say 60 miles per hour in a DIRECTION due west.

(A scalar quantity is different; it has only magnitude – mass, time, temperature, etc.)





A vector may be composed of its x- and y- (and z-) components as shown.

$$A_x = A\cos\theta$$

$$A_y = A\sin\theta$$

$$A^2 = A_x^{\ 2} + A_y^{\ 2}$$

The scalar (or dot) **product** of two vectors is defined as

$$\vec{A} \bullet \vec{B} = AB\cos\theta = A_x B_x + A_y B_y + A_z B_z$$

Note: The **dot** product of two vectors results a **scalar** quantity.

The vector (or cross) **product** of two vectors is a vector where the direction of the vector product is given by the right-hand rule.

The MAGNITUDE of the vector product is given by:

$$\left|\vec{A}\times\vec{B}\right| = AB\sin\theta$$

Problem solving strategies & tactics
Identify, execute, evaluate

1) First sketch the problem

2) Identify known and unknowns (write them down)

3) Strategy: identify the concepts and how to use them to find the unknowns.

4) Tactic: identify how to execute the steps to get to the goal

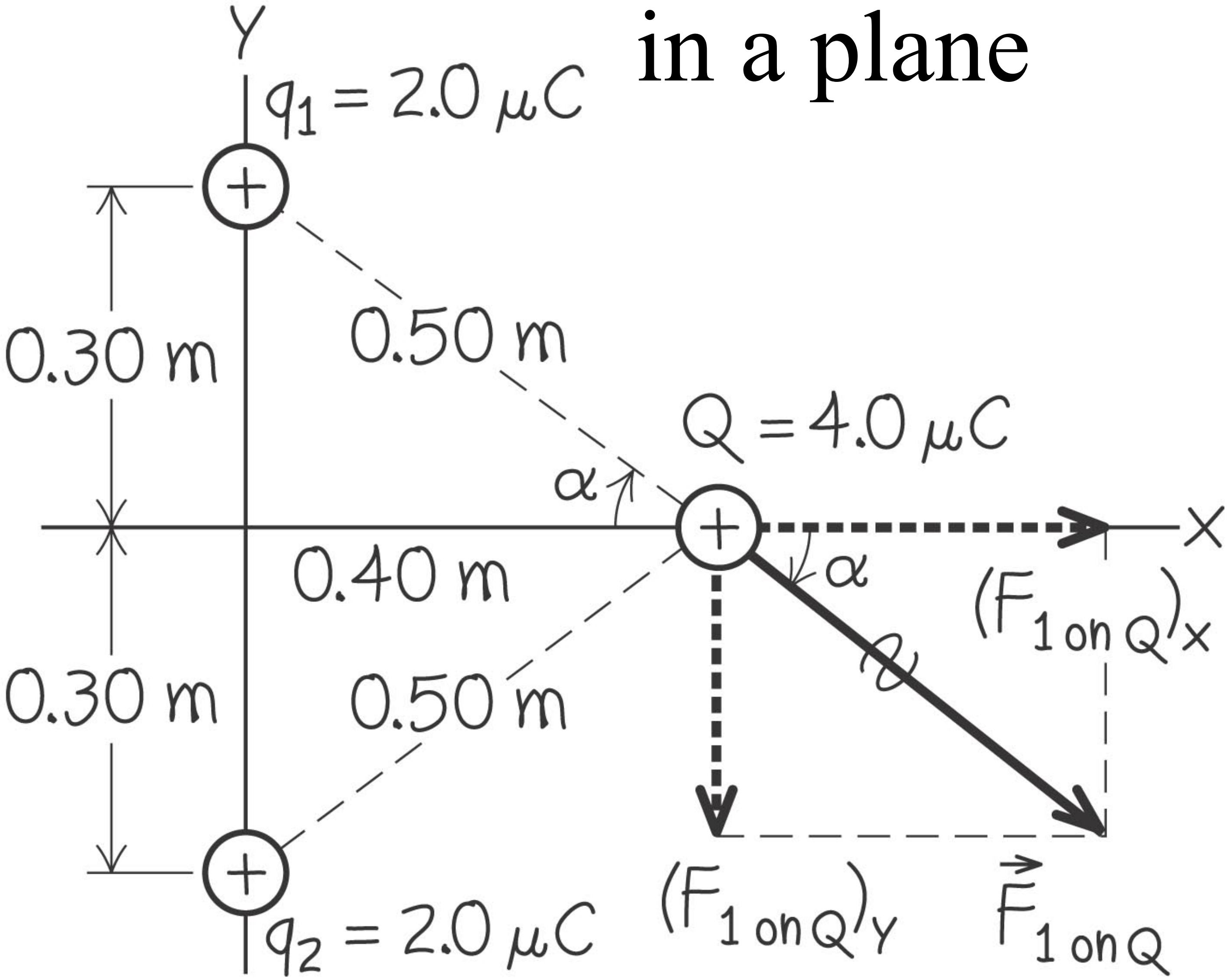
5) Evaluate validity of the answers

Vector addition of electric forces in a plane identify, strategy & tactic

Two equal positive point charges q_1 and q_2 each 2.0 μC are located at $(0,0.30m)$ and $(0,-0.3m)$ respectively. What are the magnitude and direction of the net electric force that these charges excert on a third point charge $Q = 4.0\mu C$ located at $(0.40m,0)$?

Take 5 minutes to sketch this problem

Vector addition of electric forces in a plane



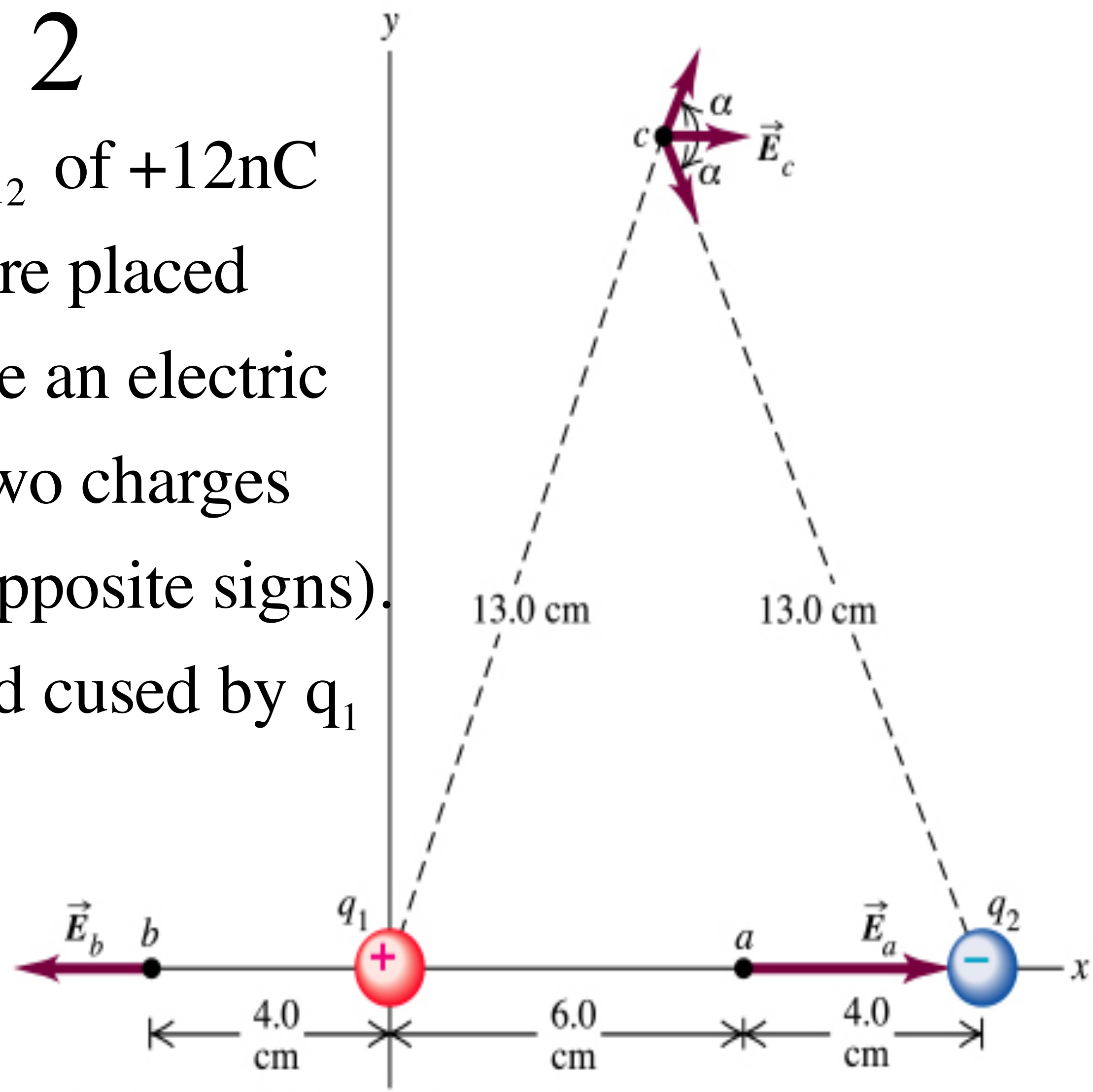
Field of an electric dipole related to lab 2

Point charges of q_1 and q_2 of +12nC and -12nC respectively are placed 0.10m apart that constiute an electric dipole (combination of two charges with equal amount and opposite signs). Compute the electric field cused by q_1 and q_2 at:

a) point a

b) point b

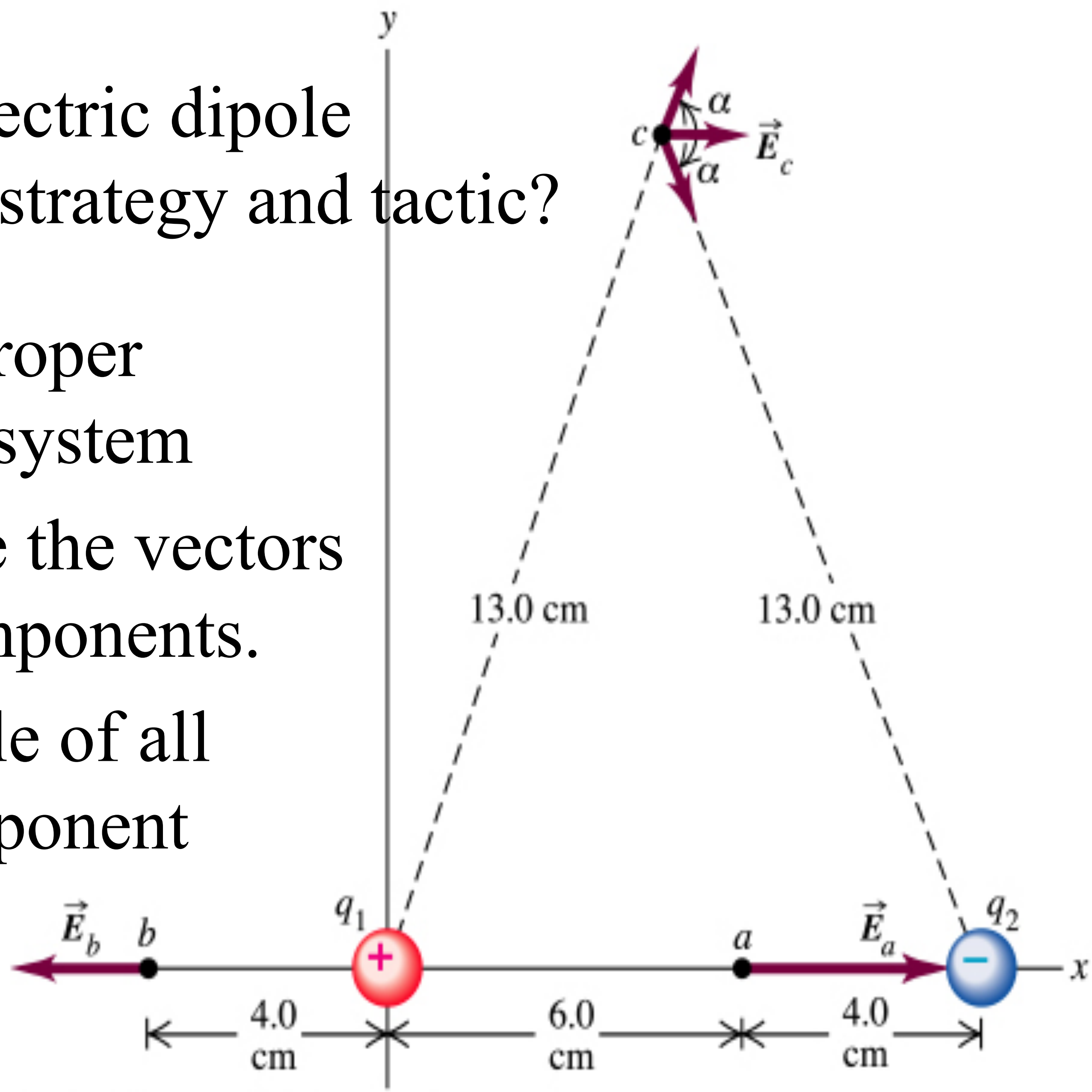
c) point c



Field of an electric dipole

What is your strategy and tactic?

- Choose a proper coordinate system
- Decompose the vectors to their components.
- Make a table of all vector component values.

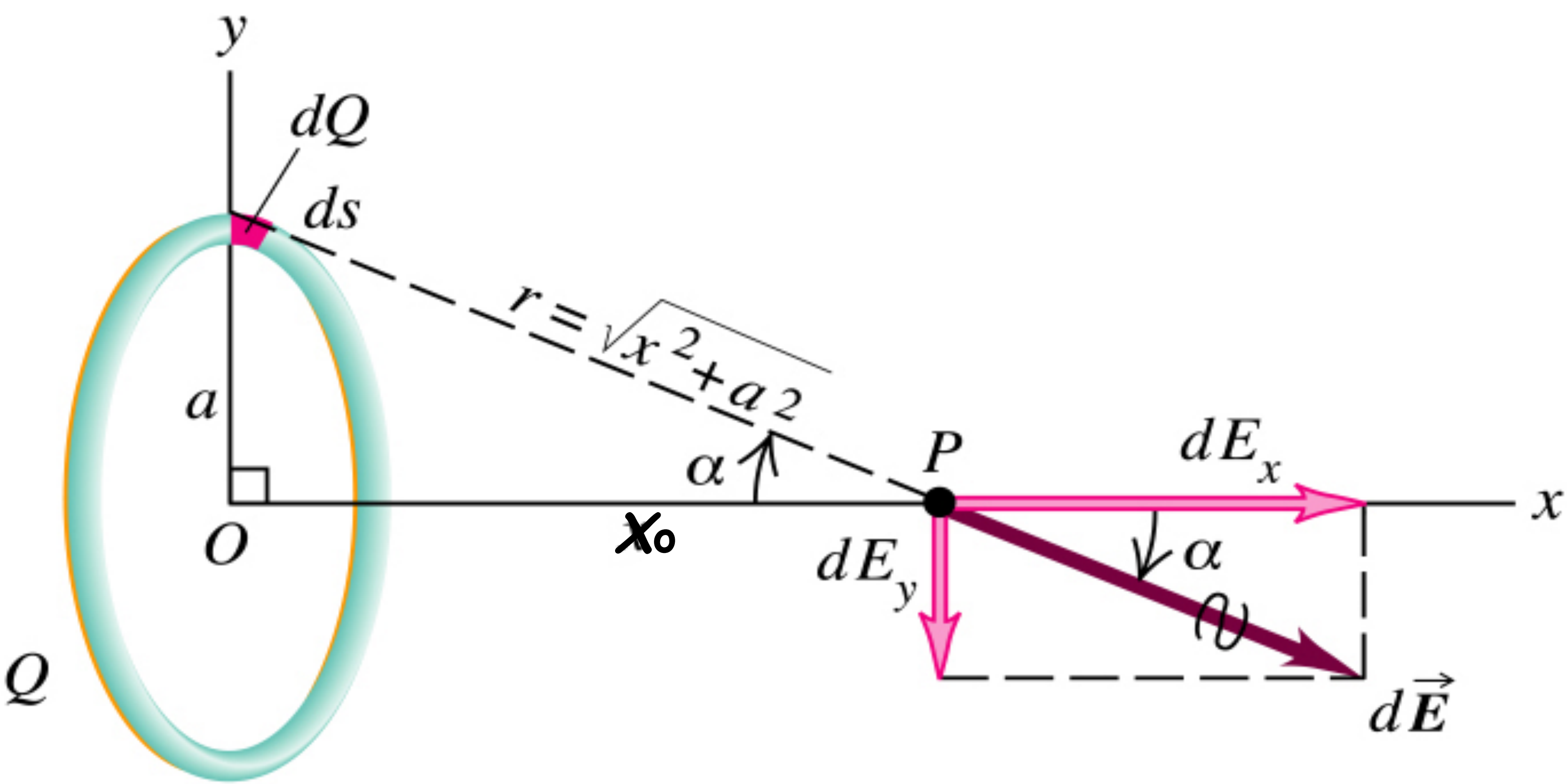


Field of a ring of charge

A ring shaped conductor with radius a carries a total charge Q uniformly distributed around it. Find the electric field at a point P that lies on the axis of the ring at a distance x_0 from its center.

1) construct a graph
2) put downt the known and unknowns
3) Identify the concepts
4) Choose a proper coordinate system
5) Solve the problem

Field of a ring of charge



Field of a line charge

Positive electric charge Q is uniformly distributed along a line with length 2a. Find the electric field at a point P that lies on the line that is perpendicular to the center of the rod at a distance x_0 from the rod's center.

1) Construct a graph
2) Put downt the known and unknowns
3) Identify the concepts
4) Choose a proper coordinate system
5) Solve the problem

Field of a line charge