Chap 21
Electric Charge and Electric field

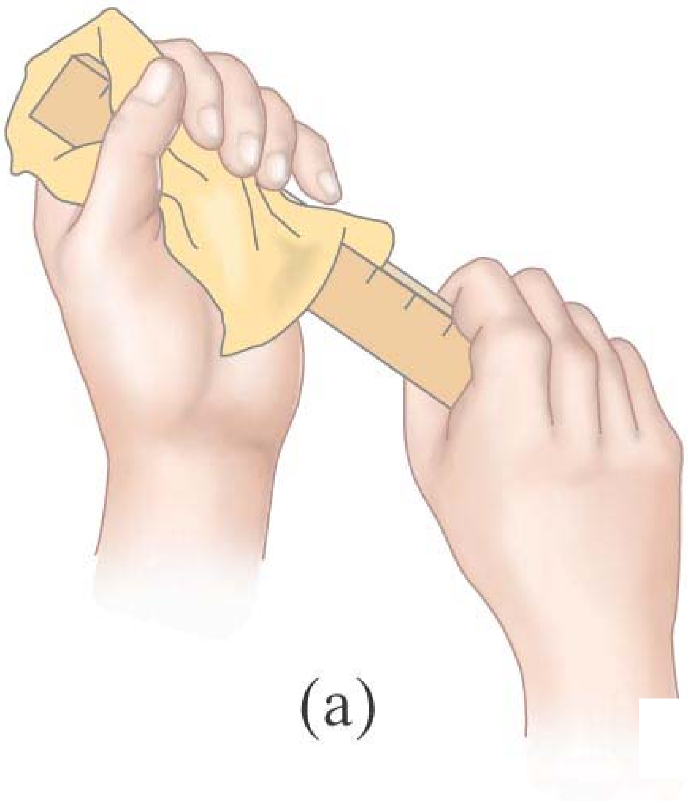
Read/study all parts of the chapter with main emphasis on sections 1 to 10 and lite coverage of sections 12 and 13

HW problems are assigned in class LISTED IN THE LECTURE NOTES and are do the next session with a grace period usualy one more session. Once answer keys are given out your HW has no value unless in comes in on the day the key is distributed

21-1 Static Electricity; Electric Charge and Its Conservation

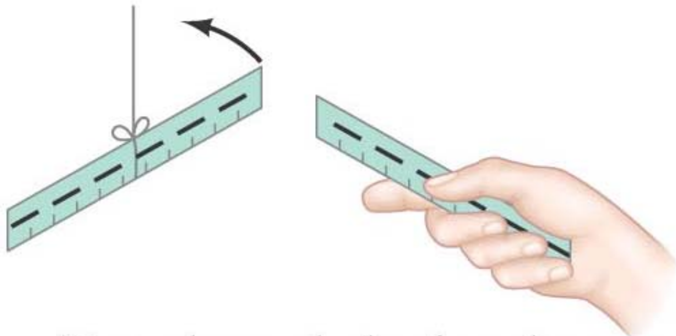
Objects can be charged by rubbing.

Why?

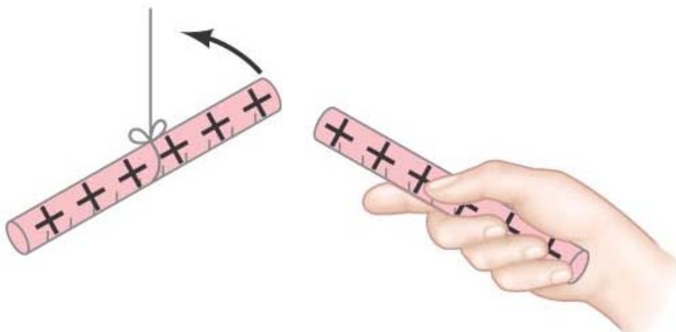


(a)

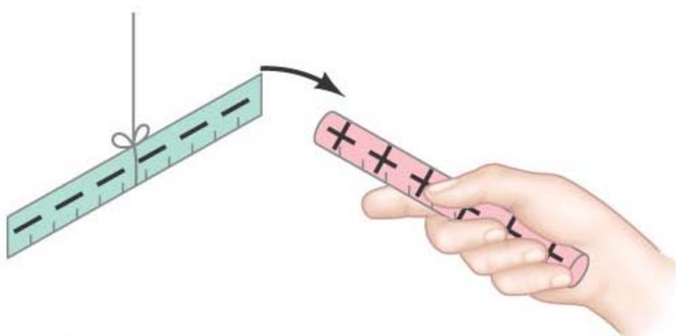
21-1 Static Electricity; Electric Charge and Its Conservation



Two charged plastic rulers repel



Two charged glass rods repel



Charged glass rod attracts
charged plastic ruler

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

21-1 Static Electricity; Electric Charge and Its Conservation

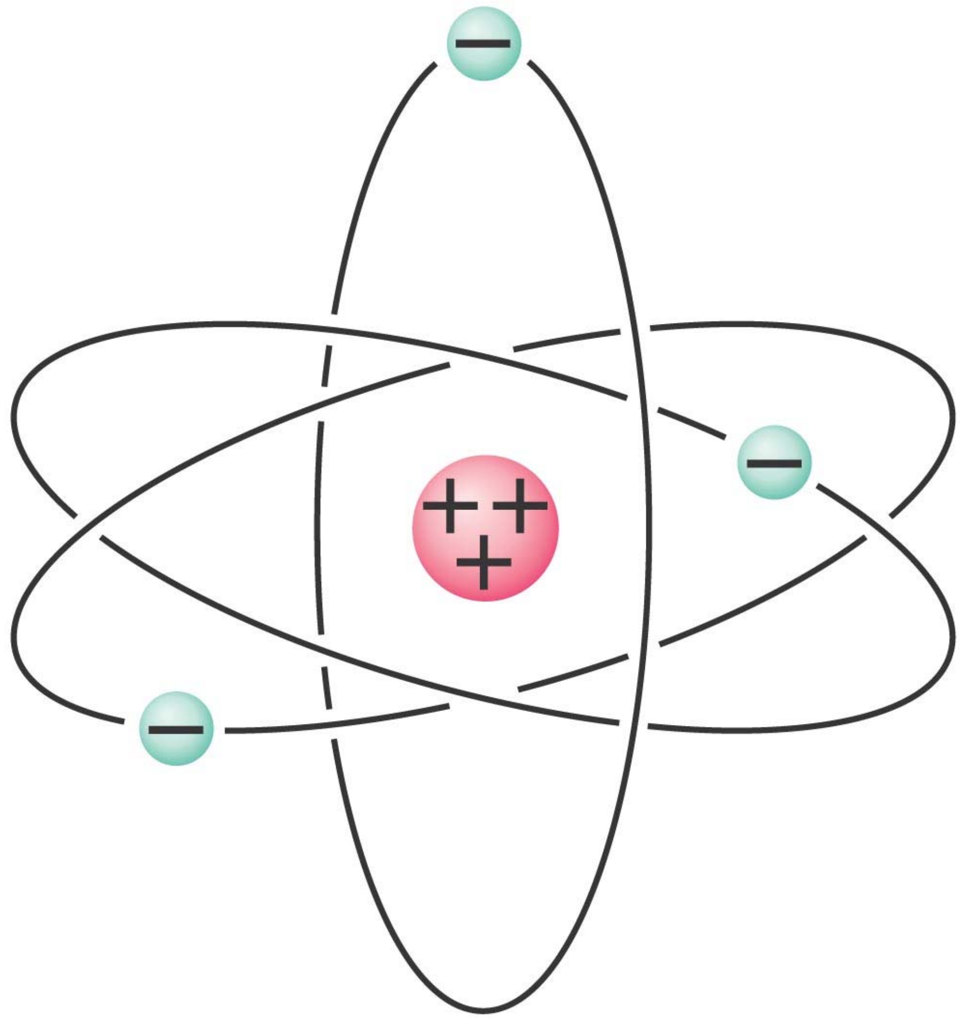
Electric charge is conserved – the arithmetic sum of the total charge cannot change in any interaction.

21-2 Electric Charge in the Atom

Atom:

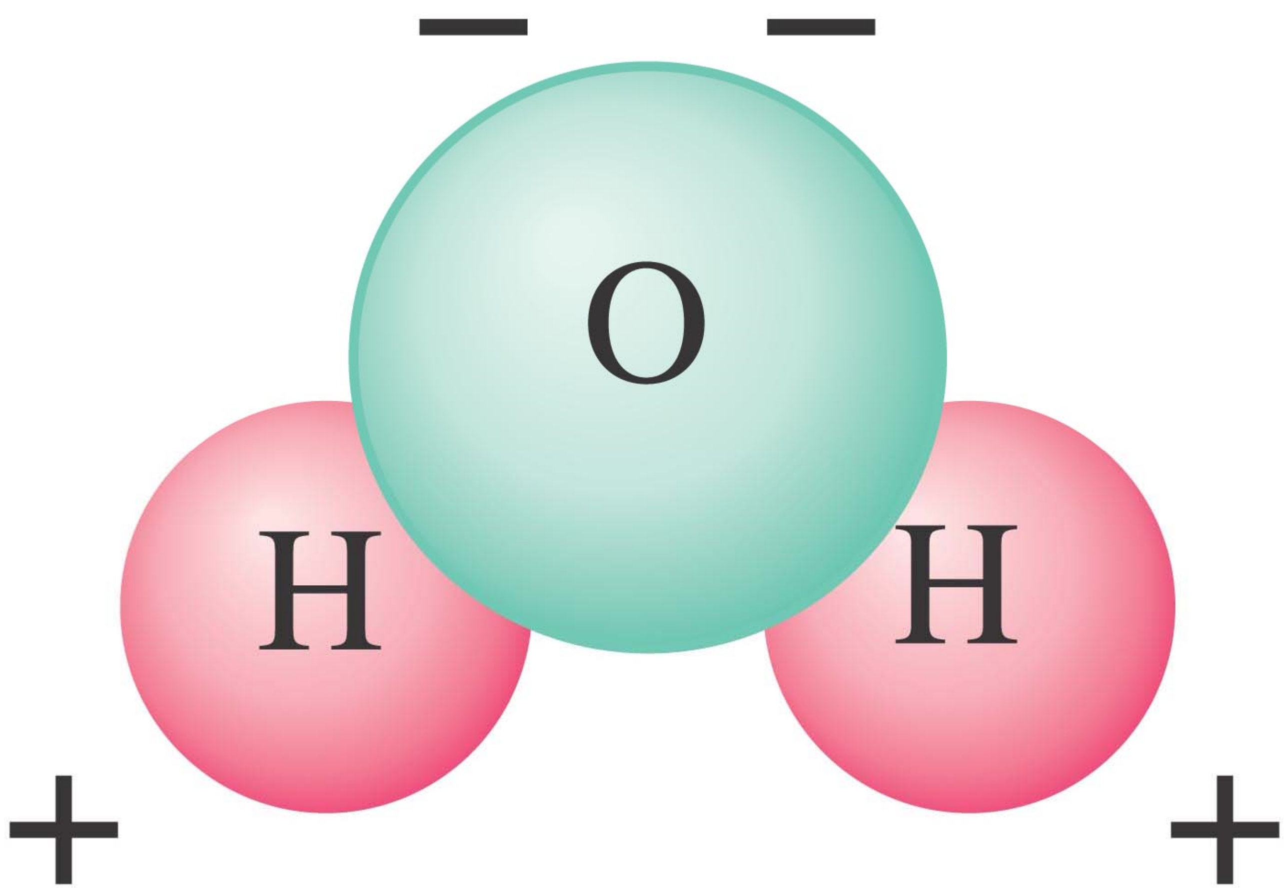
Nucleus (small, massive, positive charge)

Electron cloud (large, very low density, negative charge)



21-2 Electric Charge in the Atom

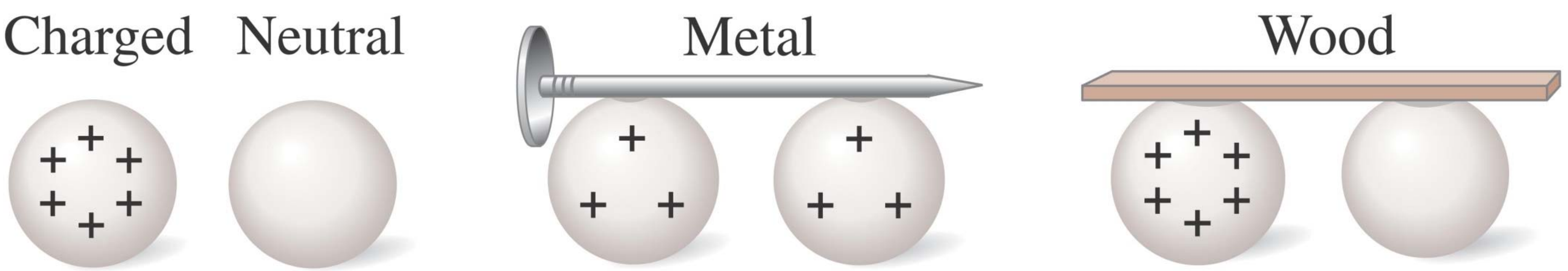
Polar molecule: neutral overall, but charge not evenly distributed



21-3 Insulators and Conductors

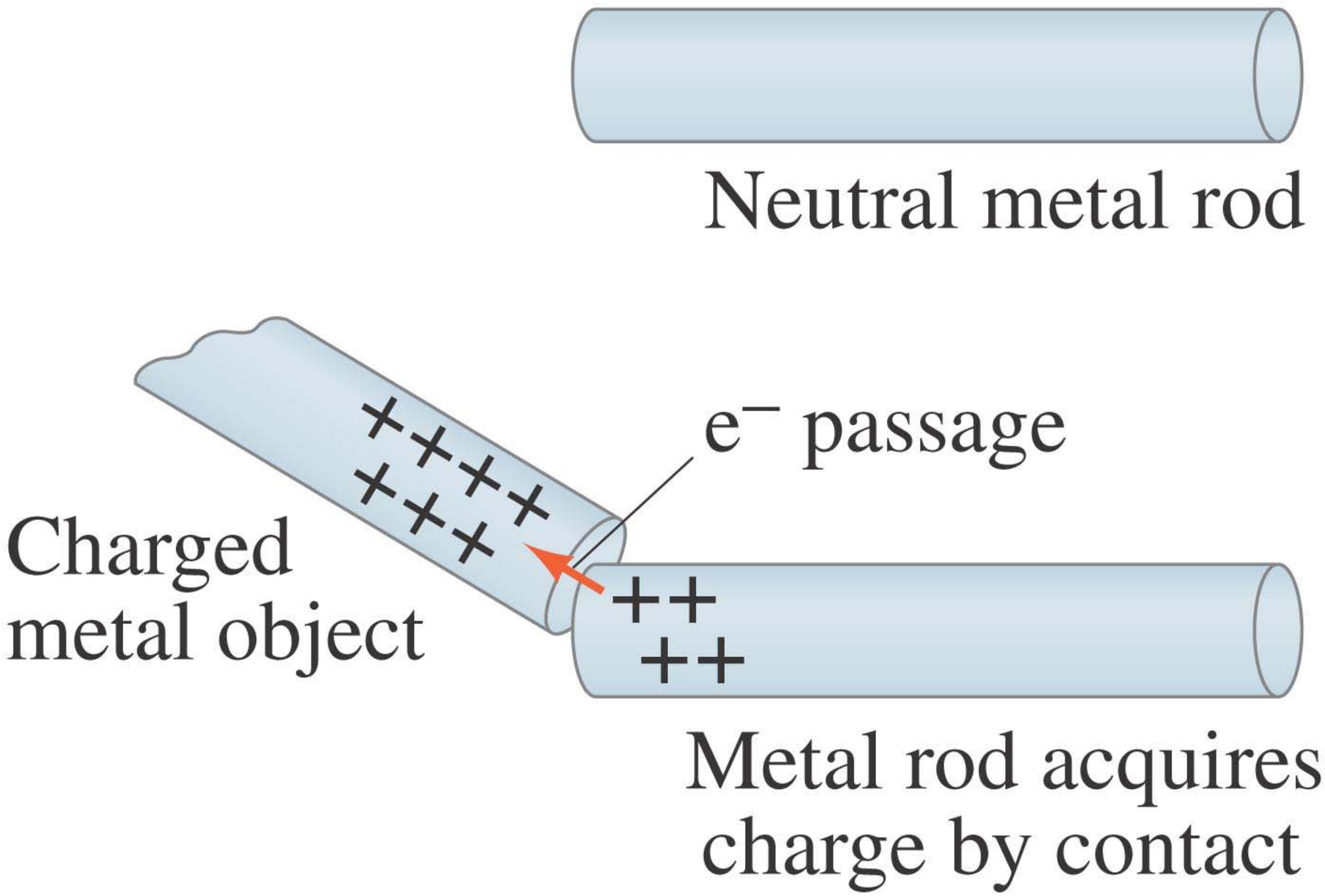
Conductor:	Insulator:
Charge flows freely	Almost no charge flows
Metals	Most other materials

Some materials are semiconductors.



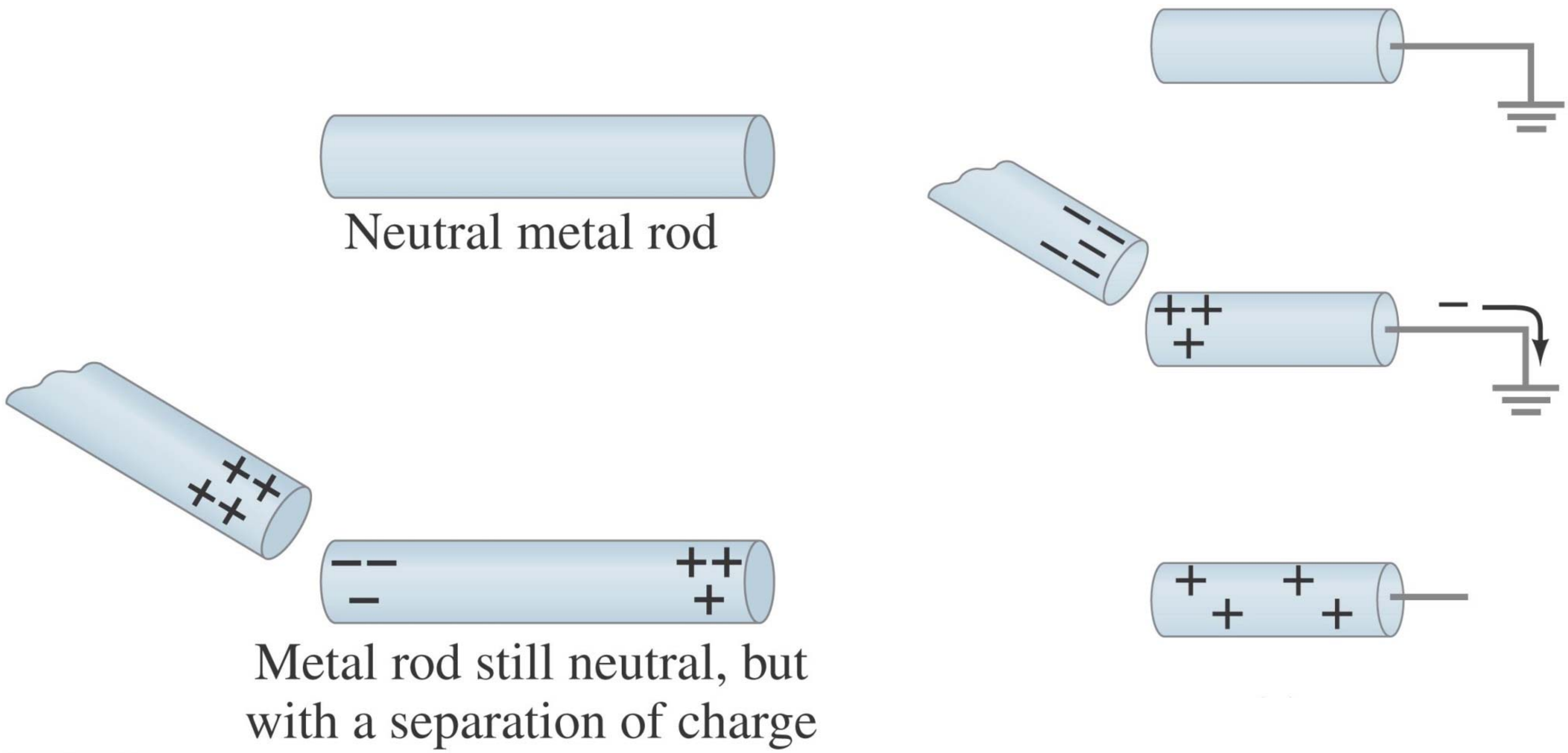
21-4 Induced Charge; the Electroscope

Metal objects can be charged by conduction:



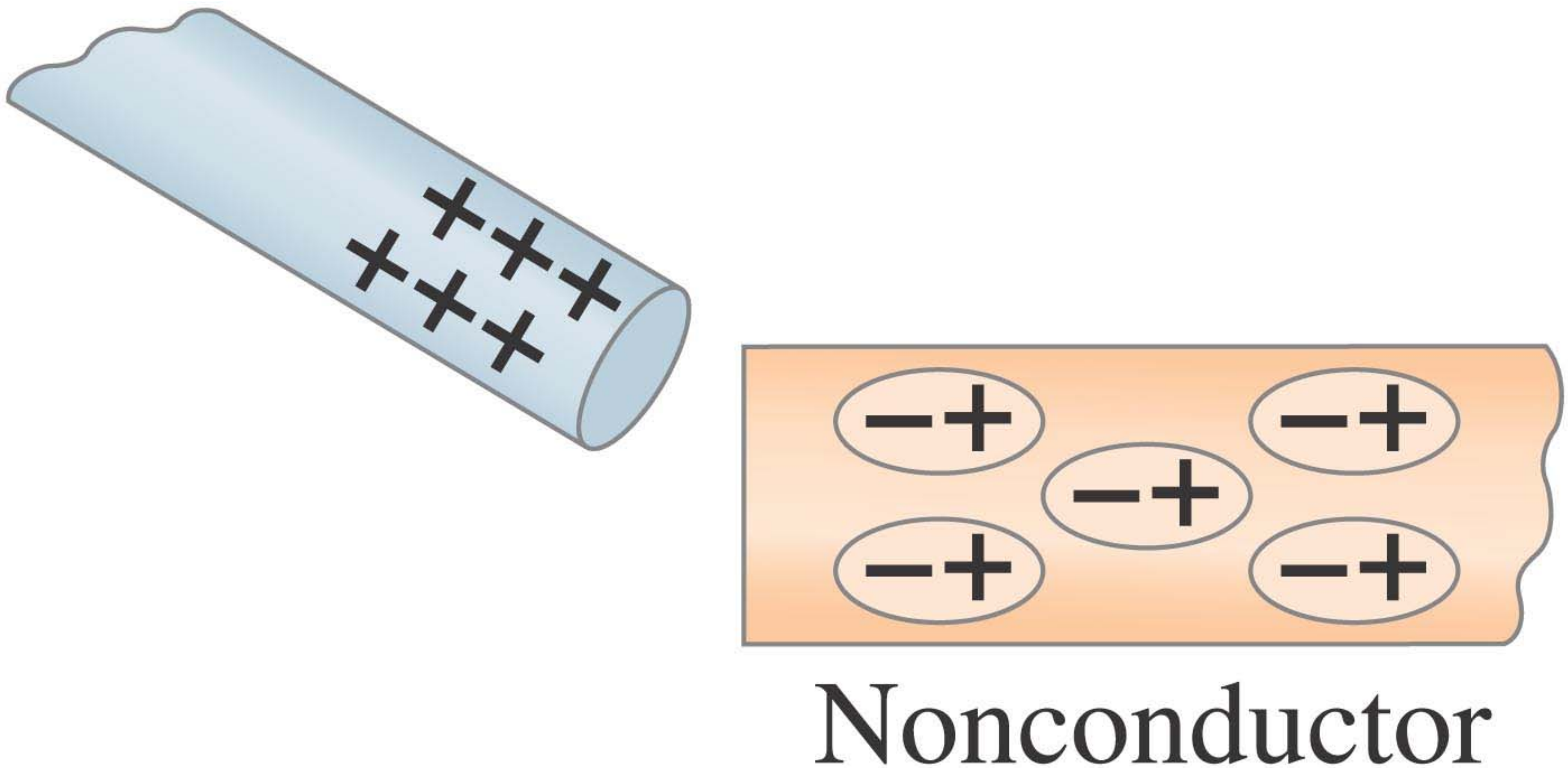
21-4 Induced Charge; the Electroscope

They can also be charged by induction, either while connected to ground or not:



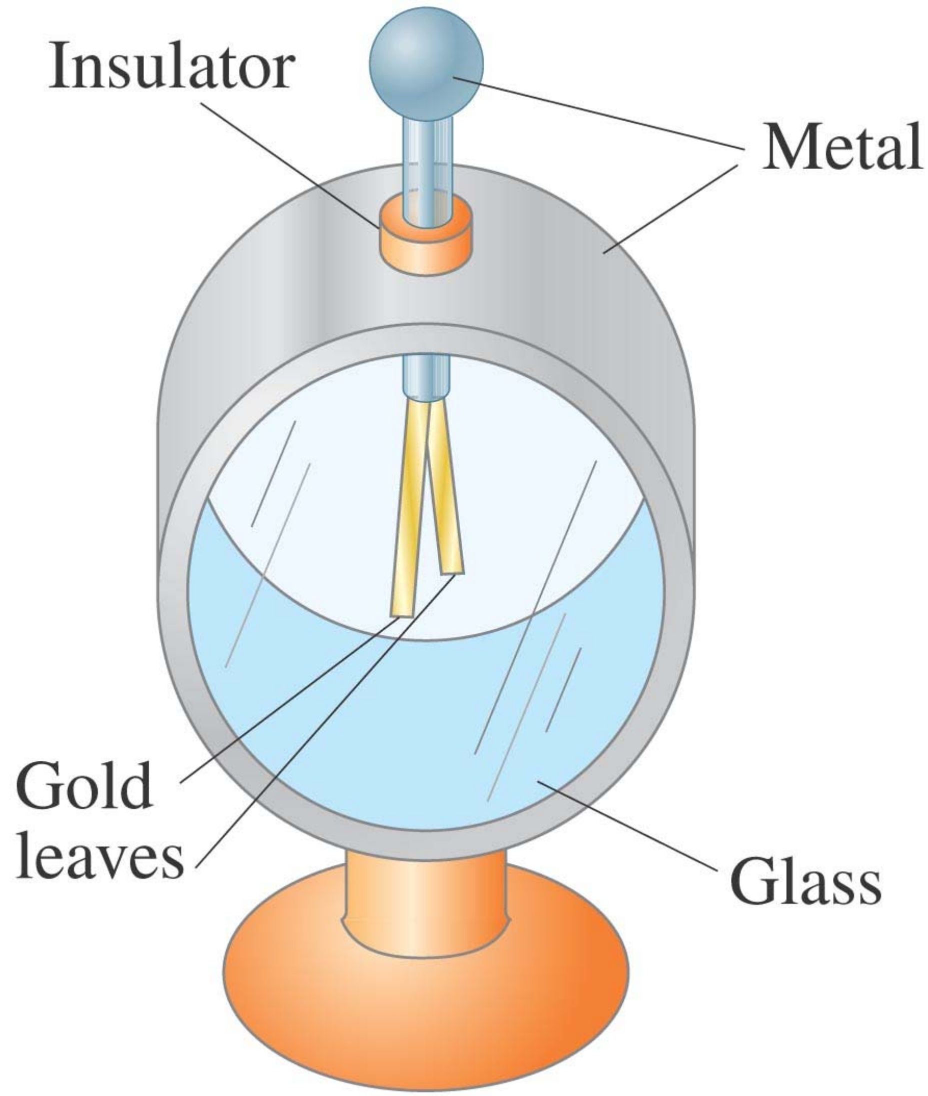
21-4 Induced Charge; the Electroscope

Nonconductors won't become charged by conduction or induction, but will experience charge separation:



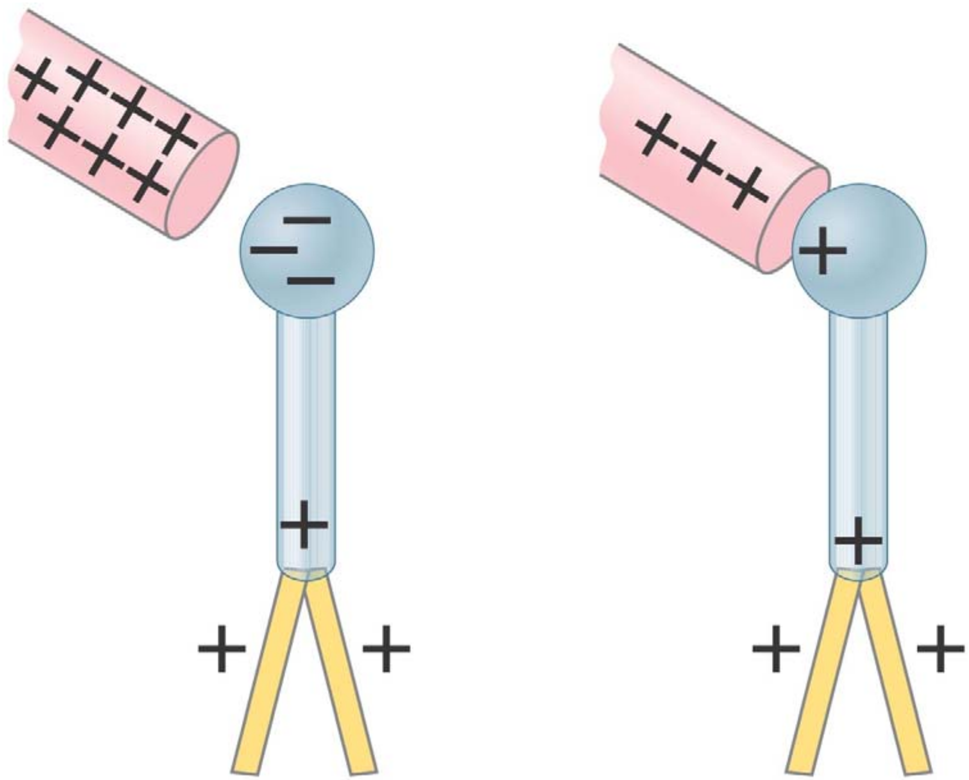
21-4 Induced Charge; the Electroscope

The electroscope can be used for detecting charge.



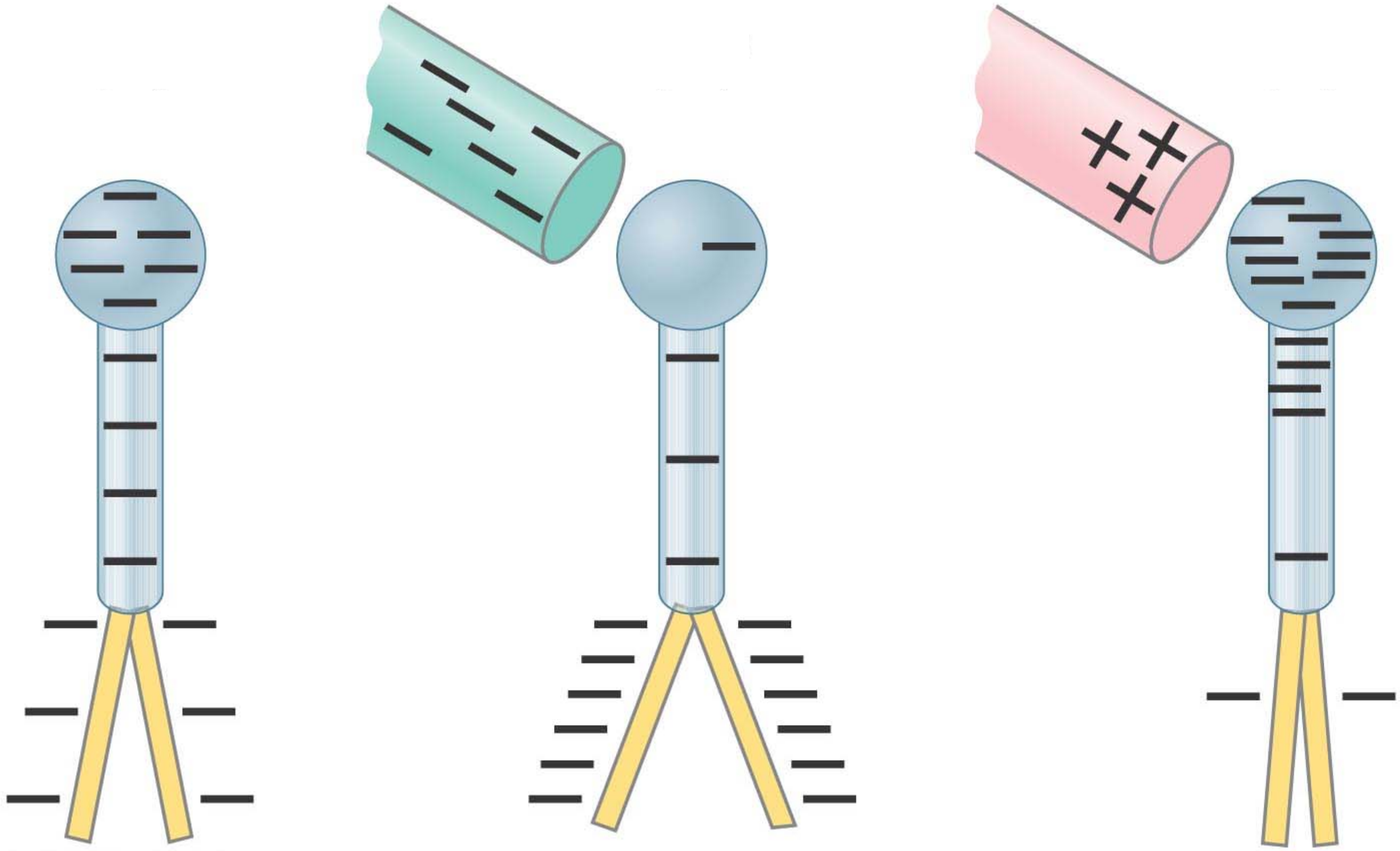
21-4 Induced Charge; the Electroscope

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



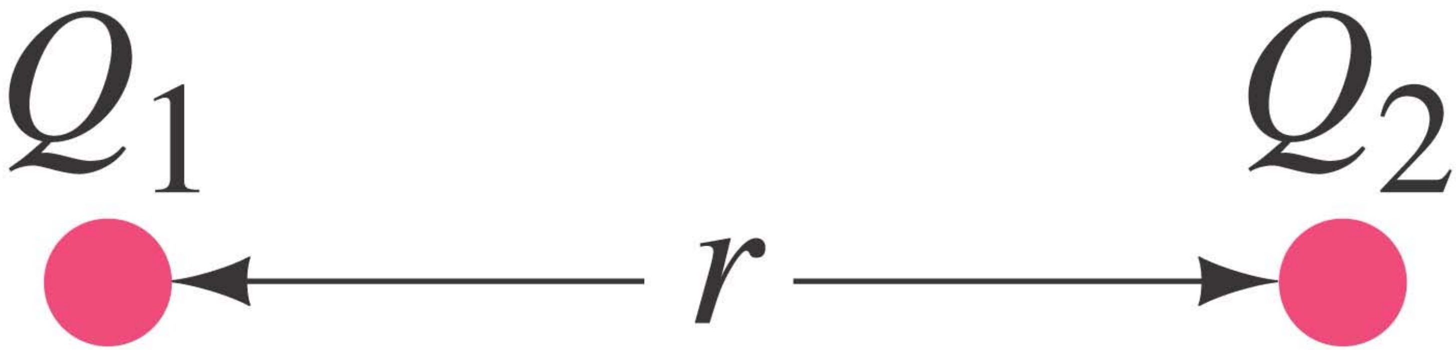
21-4 Induced Charge; the Electroscope

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



21-5 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.



21-5 Coulomb's Law

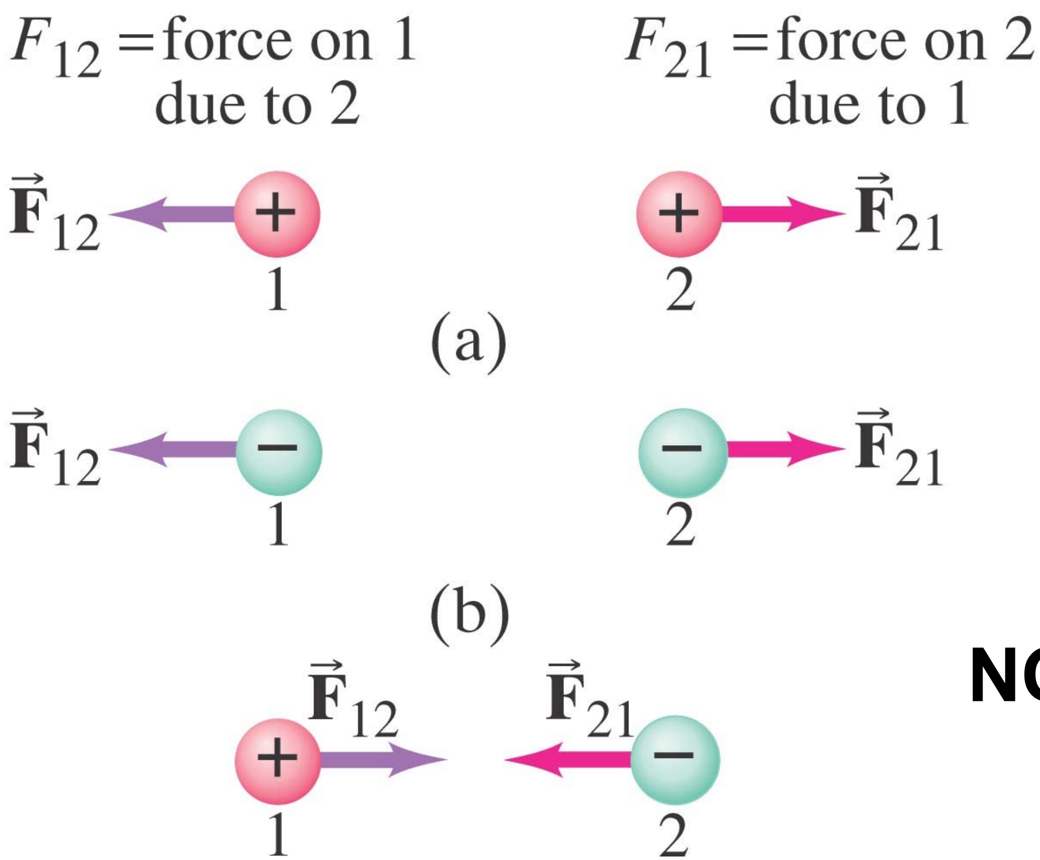
Coulomb's law:

$$F = k\frac{Q_1 Q_2}{r^2}. \qquad \text{[magnitudes]}$$

This equation gives the magnitude of the force between two charges.

21-5 Coulomb's Law

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



$F_{12} = k\, Q_1 Q_2 / l^2$

$F_{21} = k\, Q_2 Q_1 / l^2$

NOTE $F_{12} = -F_{21}$

21-5 Coulomb's Law

Unit of charge: coulomb, C.

The proportionality constant in Coulomb's law is then:

$$k = 8.99 \times 10^9\ \mathrm{N \cdot m^2/C^2}.$$

NOTE THE UNITS!!!!!

Charges produced by rubbing are typically around a microcoulomb:

$$1\ \mu\mathrm{C} = 10^{-6}\ \mathrm{C}.$$

21-5 Coulomb's Law

Charge on the electron:

$$e = 1.602 \times 10^{-19}\ \mathrm{C}.$$

Electric charge is quantized in units of the electron charge.

21-5 Coulomb's Law

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

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

where

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

ε_0 is related to c =speed of light
Light is an E&M wave or photon
We explore later. I use k mostly!!!

21-5 Coulomb's Law

Conceptual Example 21-1: Which charge exerts the greater force?

Two positive point charges, $Q_1 = 50\ \mu C$ and $Q_2 = 1\ \mu C$, are separated by a distance ℓ. Which is larger in magnitude, the force that Q_1 exerts on Q_2 or the force that Q_2 exerts on Q_1?

$F_{12} = k\ Q_1Q_2/l^2$

$F_{21} = k\ Q_2Q_1/l^2$

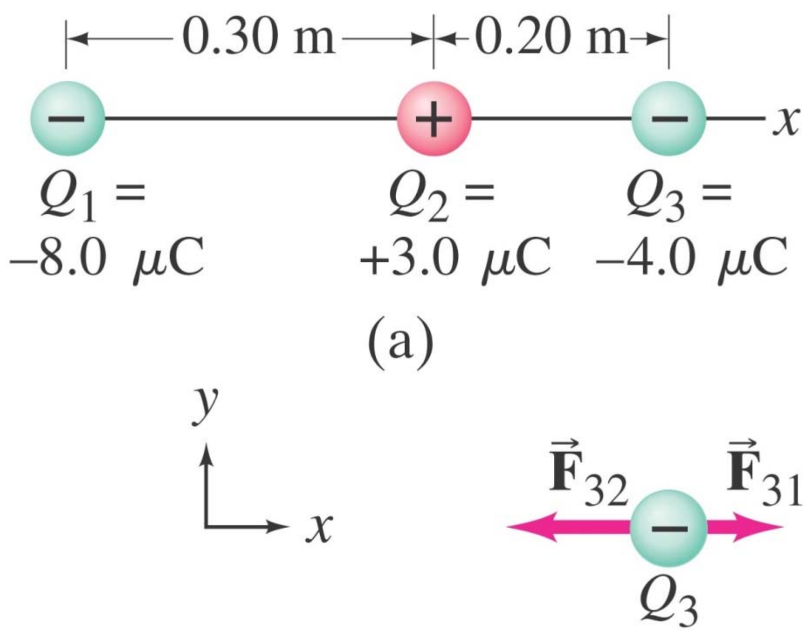
$F_{21} = -F_{12}$ as vectors = opposite and equal..Newton's 3rd LAW!

Magnitude=? And direction on each? Everyone solve now in class! Recall $k = 8.99 \times 10^9\ N\cdot m^2/C^2$.

21-5 Coulomb's Law

Example 21-2: Three charges in a line.

Three charged particles are arranged in a line, as shown. Calculate the net electrostatic force on particle 3 (the -4.0 μC on the right) due to the other two charges.



$$F_{31} = k\, Q_3 Q_1 / r_{31}^2$$

$$F_{32} = k\, Q_3 Q_2 / r_{32}^2$$

$$\Sigma F = F_{31} - F_{32}$$

21-5 Coulomb's Law

Example 21-3: Electric force using vector components…Calculate the net electrostatic force on charge Q_3 shown in the figure due to the charges Q_1 and Q_2.

$\Sigma F_x = F_x = F_{31x}$

$\Sigma F_y = F_y = F_{32} - F_{31y}$

$F = (F_x^2 + F_y^2)^{1/2}$ and

$\tan\theta = F_y/F_x$ Define **F**

Solve now!

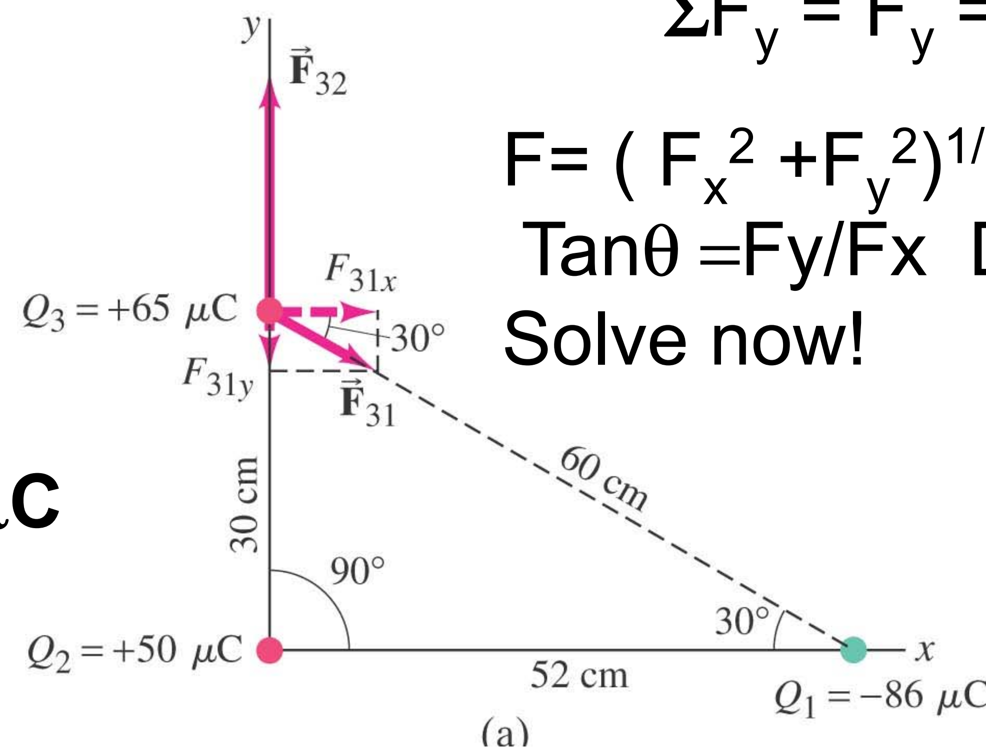
Q_3=+65μC

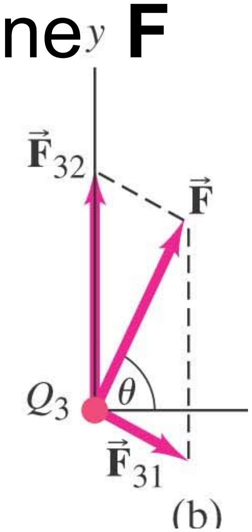
30 cm

Q_2 =50μC

52cm

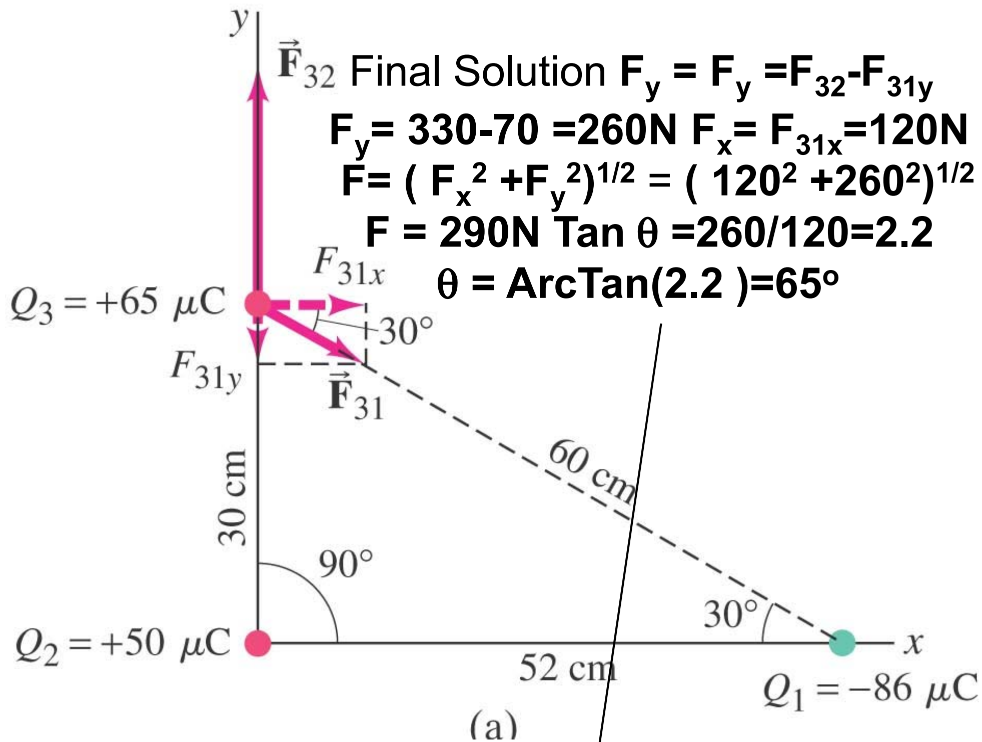
Q_1 =-86μC





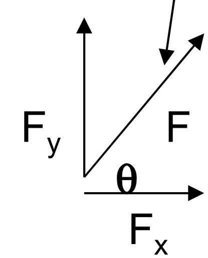
1. **Sketch the situation(text solved this)**
2. **Knowns (put large and small numbers in Scientific notation)**

Q_1=-86 10^{-6} C= -8.6 x 10^{-5} C
Q_2 =50 X 10^{-6} C = 5.0 x10^{-5} C
Q_3= 65 X 10^{-6}C = 6.5 x 10^{-5} C
r_{32} = 30 cm =0.30m r_{31}= 60 cm =0.60m



Final Solution **F_y = F_y =F_{32}-F_{31y}**
F_y= 330-70 =260N F_x= F_{31x}=120N
F= (F_x^2 +F_y^2)$^{1/2}$ = (120^2 +260^2)$^{1/2}$
F = 290N Tan θ =260/120=2.2
θ = ArcTan(2.2)=65°

3. FORMULAS/LAWS NEEDED
$F=kQ_i Q_j /r^2$
APPLIED TO PROBLEM (A VECTOR ONE)
LOOK FOR ALGEBRAIC SOLUTION
$F_{32} =kQ_2Q_3 /r_{32}^2$ $F_{31} =kQ_1Q_3 /r_{31}^2$
$F_x = F_{31x}$ $F_{31x} =F_{31} \cos 30$
$F_y = F_y =F_{32}-F_{31y}$ $F_{31y} =F_{31} \sin 30$
resultant will be F= (F_x^2 +F_y^2)$^{1/2}$
Tan θ =Fy/Fx θ = ArcTan(Fy/Fx)



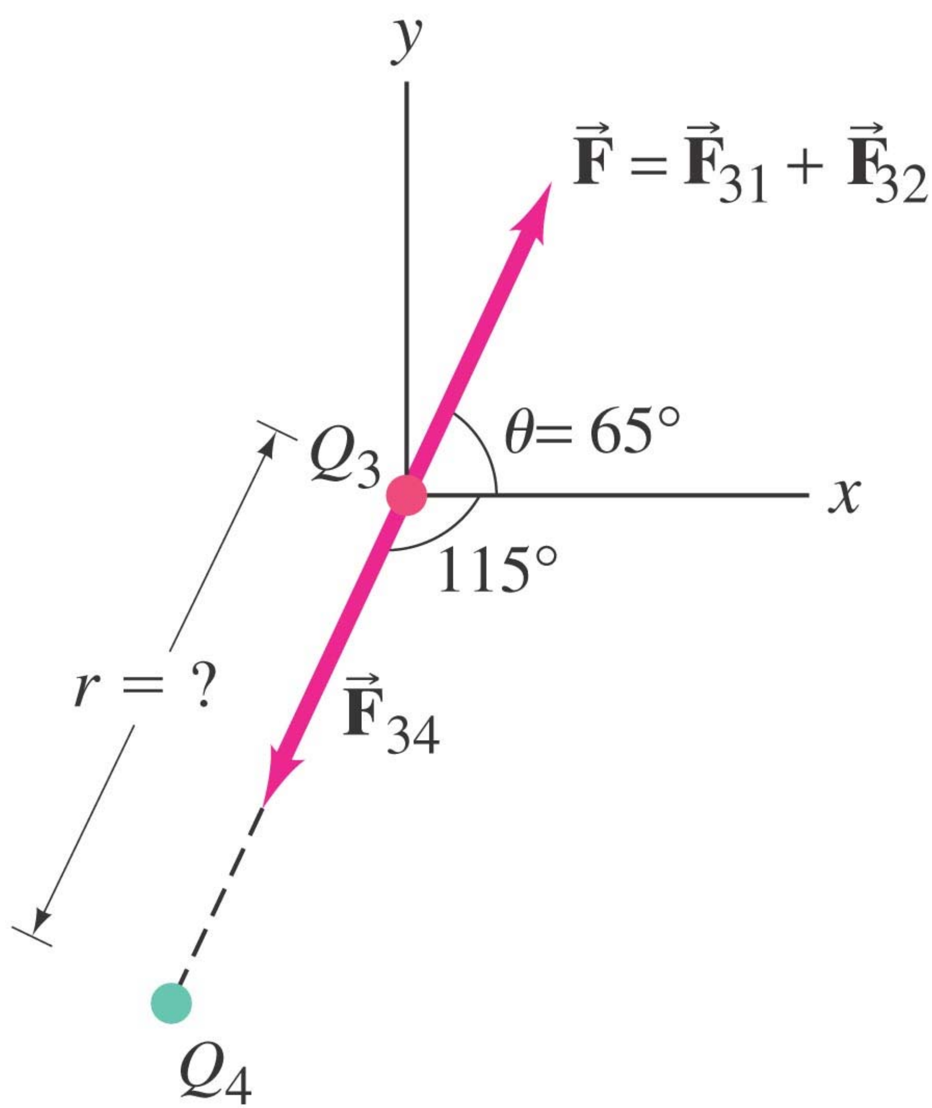
4. We have the algebraic solution we need
Values here and show work as we substitute
Numerical values. Sometimes its also a good idea to put units in
But not always necessary only when your not sure of your formula
These are straight forward. The text example example 21-3 shows the units.

$F_{32} =kQ_2Q_3 /r_{32}^2$ = 9 x 10^9 x 5.0 x10^{-5} C x 6.5 x 10^{-5} C/$(0.30m)^2$ =330 N
$F_{31} =kQ_1Q_3 /r_{31}^2$ = 9 x 10^9 x -8.6 x10^{-5} C x 6.5 x 10^{-5} C/$(0.30m)^2$ = -140 N
The – indicates attraction only if you used it (text does not) The figure shows that in terms Of Direction the y component of F_{31} is negative in direction and its x component is +!
$F_{31x} =F_{31} \cos 30$ = 140cos30=120N
F_{31y} = - F_{31} sin 30 – 140 sin30 = -70N

21-5 Coulomb's Law

Conceptual Example 21-4: Make the force on Q_3 zero. From previous

In the figure, where could you place a fourth charge, Q_4 = -50 μC, so that the net force on Q_3 would be zero? Solve now!



HW: WORK OUT IN PENCIL, HAND IN WITH YOUR NAME ON THE PAPER. STAPLE MULTIPLE SHEETS IS A MUST TO AVOID LOSS SKETCH FIRST THEN SOLVE ALGEBRAICALLY and THEN PLUG IN NUMBERS FOR FINAL CALCULATIONS. (SHOW THE LATTER FOR FULL CREDIT

1.. The force of attraction between a -40.0 μC and +108 μC charge is 4.00 N. What is the separation between these two charges?

2. Charges are placed on the x-axis as follows: q1 = + 2μC at x = 0, q2 = –3 μC at x = 2m, q3 = –4μC at x = 3 m, and q4 = + 1 μC at x = 3.5 m. What is the magnitude and direction of the force on q3?

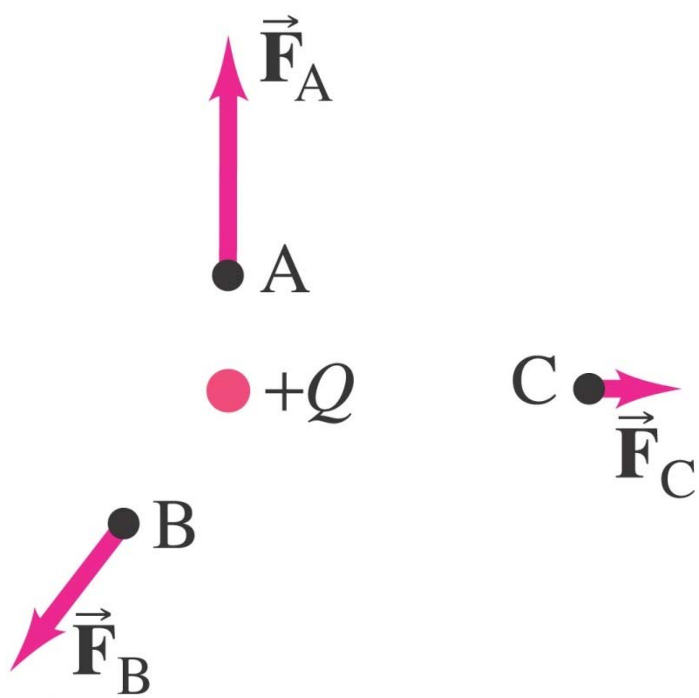
3. Two small identical spheres, each of mass m, are each attached to light strings of length L. They are each given charge q and suspended from a common point. What angle does each string make with the vertical and with each other? m = 0.02kg, L = 0.10m, and q = 8 × 10– 8C. HINT recall gravity and Tension to find the angles

4. Q_1 = 8.0 nC is at (0.30 m, 0); Q_2 = -2.0 nC is at (0, 0.10 m); Q_3 = 9.0 nC is at (0, 0). What is the magnitude and direction of the net force on the 9.0 nC charge? Force vectors are needed here its 2 D! MAG &angle!

21-6 The Electric Field

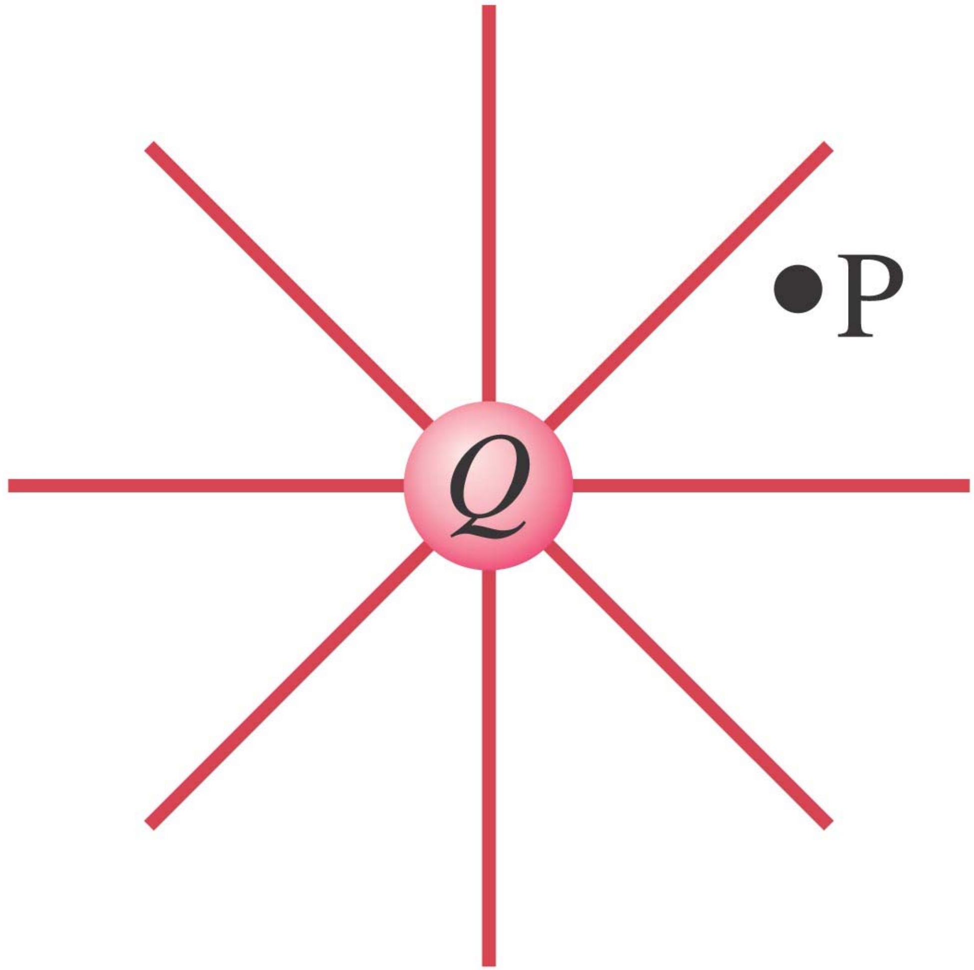
The electric field is defined as the force on a small charge, divided by the magnitude of the charge:

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



21-6 The Electric Field

An electric field surrounds every charge.



21-6 The Electric Field

For a point charge:

$$E = \frac{F}{q} = \frac{kqQ/r^2}{q}$$

$$E = k\frac{Q}{r^2}; \qquad \text{[single point charge]}$$

or, in terms of ϵ_0 as in Eq. 21–2 $\left(k = 1/4\pi\epsilon_0\right)$:

$$E = \frac{1}{4\pi\epsilon_0}\frac{Q}{r^2}. \qquad \text{[single point charge]}$$

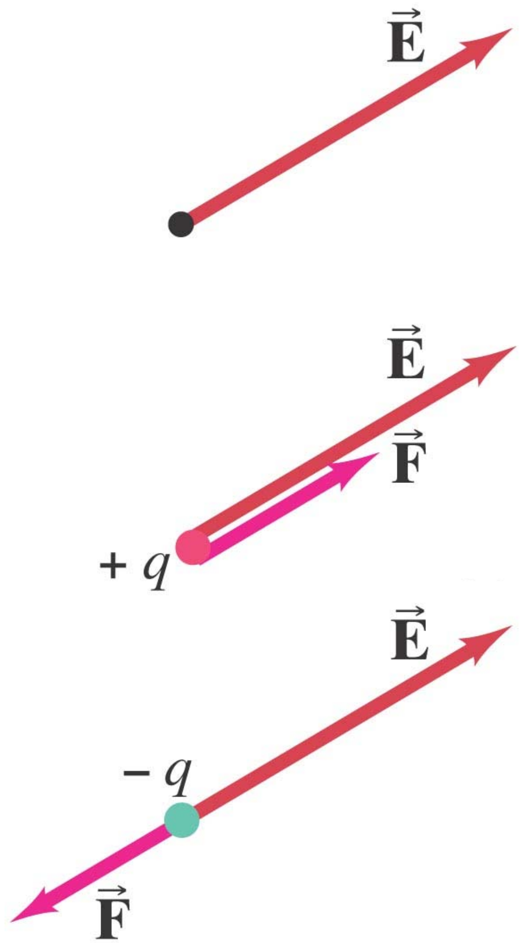
UNITS? F/q = Newton/Coulomb! =N/C

21-6 The Electric Field

Force on a point charge in an electric field:

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

i.e. E=F/q definition !

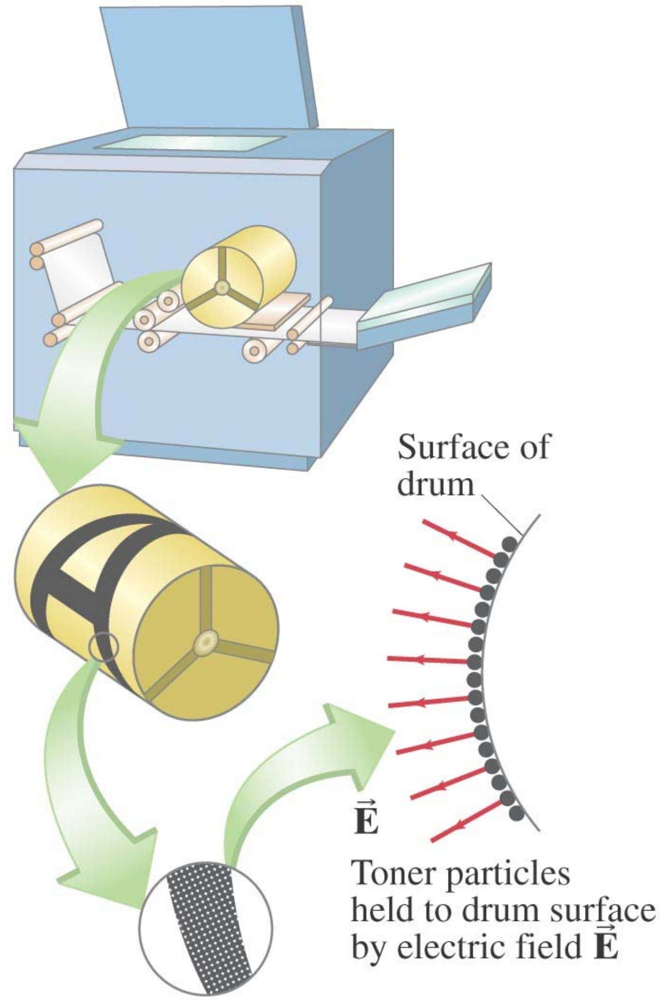


Note directions→

21-6 The Electric Field

Example 21-5: Photocopy machine.

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 dry toner (ink) 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 9.0 x 10^{-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. Solve the algebra!



$$F=qE=2mg$$

$$E=2mg/q=2mg/20e$$

$$=2\times9.0\times10^{-16}\times9.8/(20\times1.6\times10^{-19})$$

$$E = 5.5 \times 10^{3}\ N/C$$

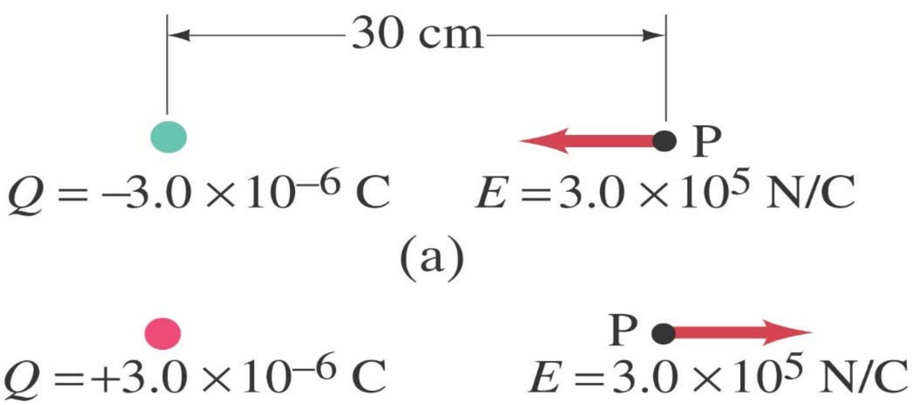
Example 21-6: Electric field of a single point charge. a.Calculate the magnitude and direction of the electric field at a point P which is 30 cm to the right of a point charge Q = -3.0 x 10^{-6} C. b. Same place but Q>0 SOLVE!

Sketch: Q----------r---------P

$E=kQ/r^2$ r= 30cm=0.3m, **Q = -3.0 x 10^{-6} C.**

E = 9x 10^9 x -3.0 x 10^{-6} =-3.0 x 10^5 N/Co

Minus just indicates attractive direction of + charge from P to Q and for b. its positive and away from Q



Example 21-7: *E* at a point between two charges.

Two point charges are separated by a distance of 10.0 cm. One has a charge of -25 μC and the other +50 μC. (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 (mass = 9.11 x 10^{-31} kg) is placed at rest at P and then released, what will be its initial acceleration (direction and magnitude)?

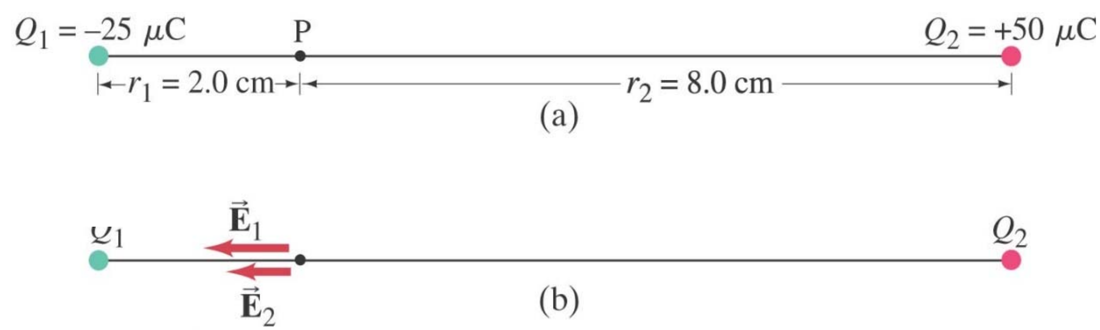
recall $E=kQ/r^2$ Both vectors in same direction so $E=E_1+E_2 = kQ_1/r_1^2 + kQ_2/r_2^2$

Text factors common k thus, $E= k(Q_1/r_1^2 + Q_2/r_2^2)$

$Q_1 = -25 \times 10^{-6}$ C $r_1 = 0.02\text{m} = 2 \times 10^{-2}$ m

$Q_2 = 50 \times 10^{-6}$ C $r_2 = 0.08\text{m} = 8 \times 10^{-2}$ m

$E=9\text{x}10^9(25\text{x}10^{-6}\text{ C} /(2\text{x}10^{-2})^2 + 50\text{x}10^{-6}/(8\text{x}10^{-2})^2 = 6.3 \times 10^8$ N/C

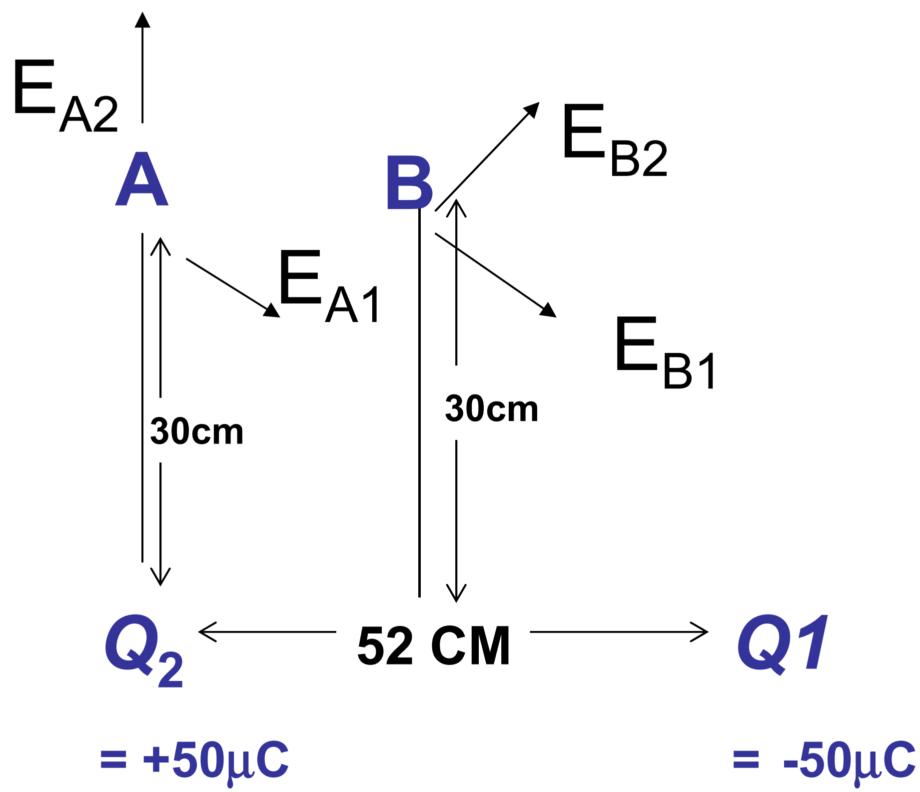


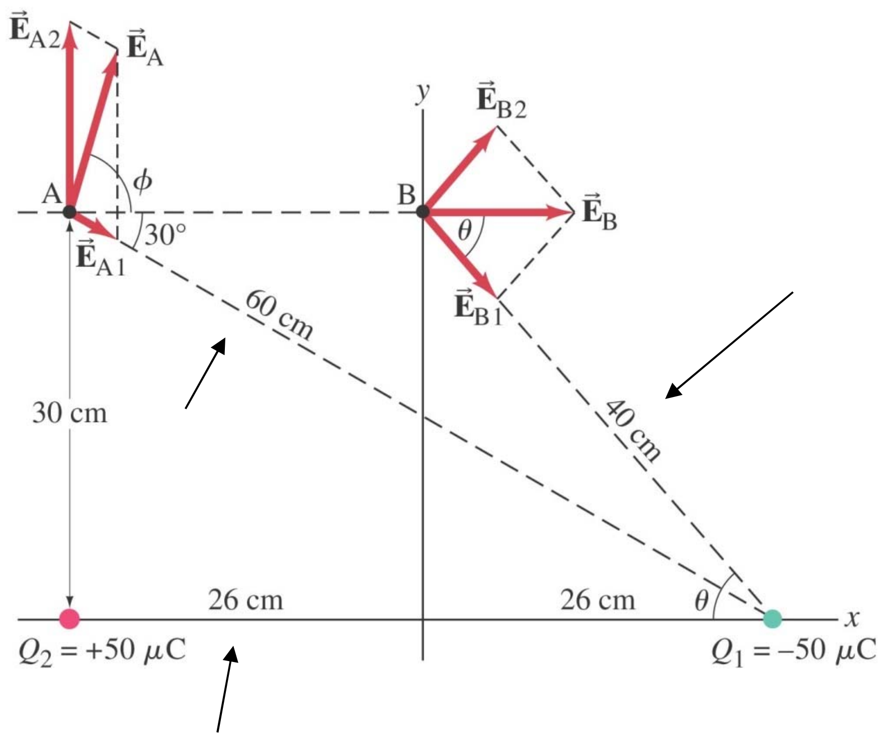
b. F =ma=qE →

$a=F/m=qE/m=eE/m_e = 1.6 \times 10^{-19}$ C x 6.3×10^8 N/C /9.11×10^{-31} kg

$a = 1.1 \times 10^{20}$ m / s^2

Example 21-8: $\vec{E}$ above two point charges. Calculate the total electric field (a) at point A and (b) at point B along midpoint in the figure due to both charges, Q_1 and Q_2. DRAW DIAGRAM at each point and note direction + charge would move in the field then solve things like distances not shown etc then SETUP ALGEBRA SOLUTION!

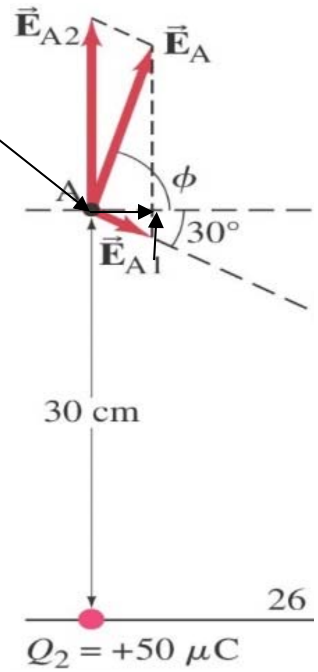




Example 21-8 SETUP ALGEBRA SOLUTION!

Once again we have a vector problem to solve and we need the components of the E vectors in the x and y directions which we will add to get the resultant E field at points A and B.

Point A first. E_{A2} = E_{A2y} no x component E_{A1} has two components



$E_{A2} = kQ_2/r_2^2 = 9\text{x } 10^9 \text{ x } 50 \text{ x } 10^{-6} /0.30)^2 = 1.25 \text{ x } 10^6$ N/C

$E_{A1} = kQ_1/r_2^2 = 9\text{x } 10^9 \text{ x } 50 \text{ x } 10^{-6} /0.60)^2 = 5.00 \text{ x } 10^6$ N/C

Sum of components at A

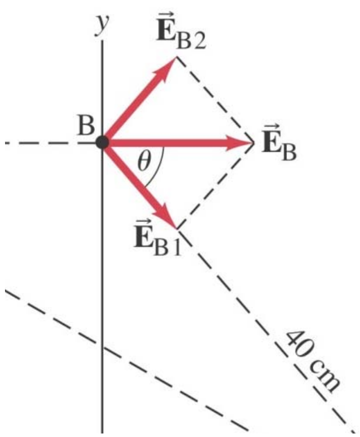
$E_{Ax} = E_{A1} \cos(30) = 1.1 \text{ x } 10^6$ N/C

$E_{Ay} = E_{A2} - E_{A1} \sin(30) = 4.4 \text{ x } 10^6$ N/C

Now resultant at A

$E_A = ((1.1)^2 + (4.4)^2)^{1/2} \text{ x } 10^{-6}$ N/C $= 4.5 \text{ x } 10^6$ N/C

$\tan\phi = 4.4/1/1 = 4.0\ \phi = \arctan(4) = 76^o$



Point B: note symmetry $E_{B2}=E_{B1}$ And E_{By}'s cancel here) **so** $E_B = 2E_{B1}\cos\theta$ and we note $\cos\theta = 26/30 = 0.65$

$E_{B1} = kQ/r^2 = 9\text{x } 10^9 \text{ x } 50 \text{ x } 10^{-6} /(0.40)^2 = 2.8 \text{ x } 10^6$ N/C

Hence, $E_B = 2 \text{ x } 2.8 \text{ x } 10^6 \text{ x } 0.65 = 3.6 \text{ x } 10^6$ N/C

HW

5. What are the magnitude and direction of the electric field at a distance of 2.50 m from a 90.0-nC charge?

6. Two point charges of +40.0 μC and -10.00 μC are separated by a distance of 10.0 cm. What is the intensity of electric field *E* midway between these two charges?

7. Three 3.0 μC charges are at the three corners of an square of side 0.50 m. The last corner is occupied by a -3.0 μC charge. Find the electric field at the center of the square

8. Q_1 = 5.0 C is at (0.30 m, 0); Q_2 = -2.0 C is at (0, 0.10 m); Q_3 = 5.0 C is at (0, 0). What is the magnitude and direction of the Electric field on the 5.0 C charge located at (0,0)? 2 D! MAG of E resultant &angle and do not use Coulombs law, E field equations only!

9. Four identical positive charges + q= 5uC are placed at the corners of a square of side L=10cm. Determine the magnitude and direction of the electric field due to them at the midpoint of one side of the square.   HINT symmetry helps

21-7 Electric Field Calculations for Continuous Charge Distributions

A continuous distribution of charge may be treated as a succession of infinitesimal (point) charges. The total field is then the integral of the infinitesimal fields due to each bit of charge: Magnitude of dE is

$$dE = \frac{1}{4\pi\epsilon_0}\frac{dQ}{r^2}. \longrightarrow \vec{\mathbf{E}} = \int d\vec{\mathbf{E}}.$$

Remember that the electric field is a vector; you will need a separate integral for each component.

A few words about dQ and charge density distribution Geometry

$$dE = \frac{1}{4\pi\epsilon_0}\frac{dQ}{r^2}.$$

Line density =λ= dQ/dl if uniform =Q/l
we use dQ= λdl in dE

Area density σ = dQ/dA if uniform= Q/A / Area
we use dQ= σdA in dE

Volume density ρ = dQ/dV if uniform = Q/V / Volume
we use dQ= ρdV in dE

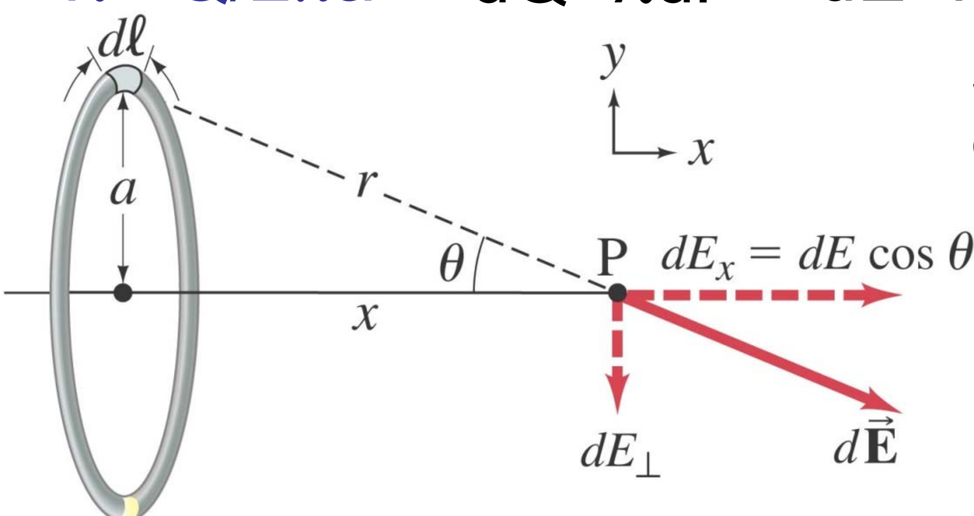
21-7 Electric Field Calculations for Continuous Charge Distributions

Example 21-9: A ring of charge.

A thin, ring-shaped object of radius *a* holds a total charge +*Q* distributed uniformly around it. Determine the electric field at a point P on its axis, a distance *x* from the center.

Let λ be the charge per unit length (C/m).

$\lambda = Q/2\pi a$ $\quad dQ=\lambda dl \quad dE=kdQ/r^2 = k\lambda dl/r^2$



Symmetry only x components of dE

$dE_x = dE\cos\theta$ $= k\lambda dl/r^2 \ \cos\theta$

$\cos\theta = x/r \quad r=(a^2+x^2)^{1/2}$

$$E = \int dE_x = k\lambda x / r^3 \int_0^{2\pi a} dl = k\lambda x 2\pi a / r^3$$

Additional representation of the ring Solution see text example 21-9

$$E = \int dE_x = k\lambda x / r^3 \int_0^{2\pi a} dl = k\lambda x 2\pi a / r^3$$

With $r=(x^2 + a^2)^{1/2}$ $k=1/4\pi\varepsilon_o$

Text has $E= (1/4\pi\varepsilon_o)\ \lambda x 2\pi a / (a^2+x^2)^{3/2}$

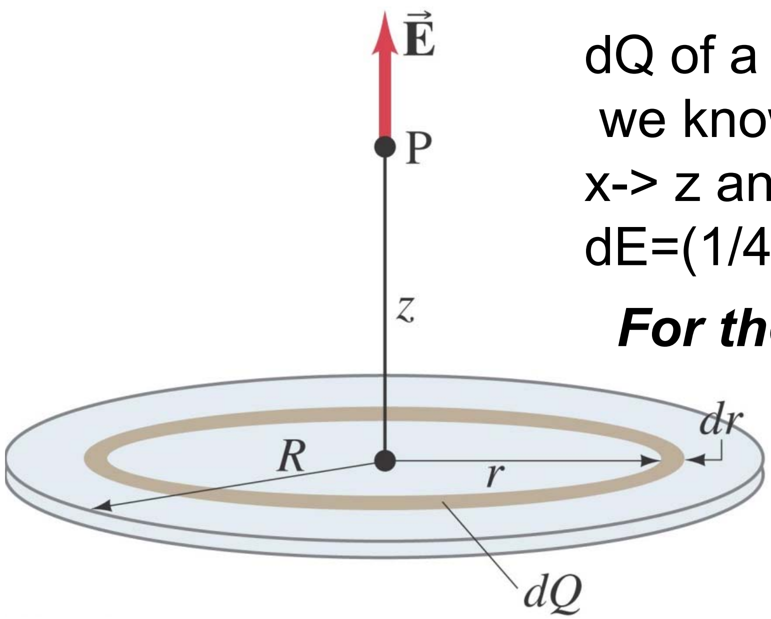
And since $\lambda = Q/2\pi a$ then

$E= (1/4\pi\varepsilon_o)\ Qx / (x^2 + a^2)^{3/2}$

21-7 Electric Field Calculations for Continuous Charge Distributions

Example 21-12: Uniformly charged disk.

Charge is distributed uniformly over a thin circular disk of radius *R*. The charge per unit area is $\sigma=Q/A=Q/\pi R^2$. we keep the σ symbol in this example and not use the latter relationship in the text (it could be used ok). Calculate the electric field at a point P on the axis of the disk, a distance *z* above its center. Important result from this example is applied to a device called a capacitor which is used to oscillate circuits



dQ of a ring is $\sigma 2\pi r dr$

we know the ring solution from the last example→

x-> z and Q-> dQ

$dE=(1/4\pi\varepsilon_o)\, z dQ/(z^2+r^2)^{3/2}$ (here z is x from before)

For the ring $\sigma=dQ/dA = dQ/2\pi r dr$

note def of dA here

Substitute for dQ above gives

$dE=(1/4\pi\varepsilon_o)\, z\sigma 2\pi r dr/(z^2+r^2)^{3/2}$

or $dE = z\sigma r dr / 2\varepsilon_o(z^2+r^2)^{3/2}$

Example 21-12: Uniformly charged disk -continued

Symmetry of the rings means and we reduced the problem to the variable r so we integrate the last Result i.e. The rings from 0 to R gives final form of E. Namely

$$E = \int dE = \frac{z\sigma}{2\varepsilon_o}\int_0^R \frac{rdr}{(z^2 + r^2)^{3/2}}$$

HW #10 YOU DO INTEGRAL TO GET THIS SOLUTION

$$E = \frac{\sigma}{2\varepsilon_o}\left[1 - \frac{z}{(z^2 + R^2)^{1/2}}\right]$$

at R very large to our position HENCE z small ie. We are very close to the disk, $E = \sigma/2\varepsilon_0$
IE. Solution when very close to infinite planes. See capacitors later..

21-7 Electric Field Calculations for Continuous Charge Distributions

In the previous example, if we are very close to the disk (that is, if $z \ll R$), the electric field is:

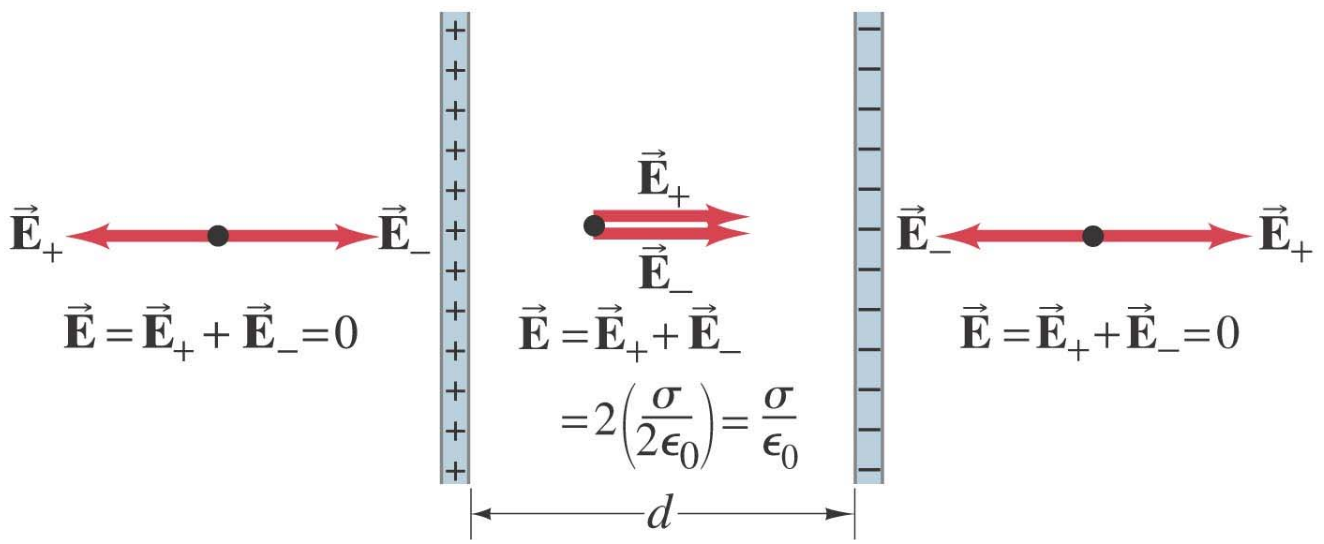
$$E = \frac{\sigma}{2\epsilon_0}. \qquad \text{[infinite plane]}$$

This is the field due to an infinite plane of charge. Its an area density for the surface

21-7 Electric Field Calculations for Continuous Charge Distributions

Example 21-13: Two parallel plates.

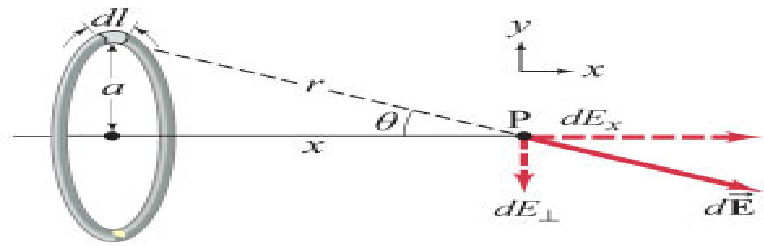
Determine the electric field between two large parallel plates or sheets, which are very thin and are separated by a distance d which is small compared to their height and width. One plate carries a uniform surface charge density σ and the other carries a uniform surface charge density $-\sigma$ as shown (the plates extend upward and downward beyond the part shown).



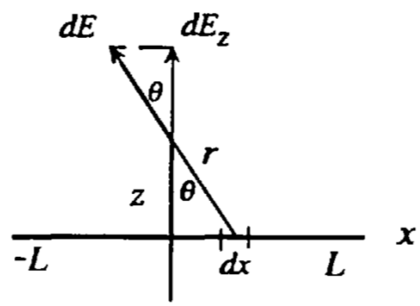
Hand in Homework

11. A thin, circular disk of radius R = 30 cm is oriented in the yz-plane with its center as the origin. The disk carries a total charge Q = +3 μC distributed uniformly over its surface. Calculate the magnitude of the electric field due to the disk at the point x = 15 cm along the x-axis. See fig below

12. At what position, *x*=*x*M , is the magnitude of the electric field along the axis of the ring a maximum?

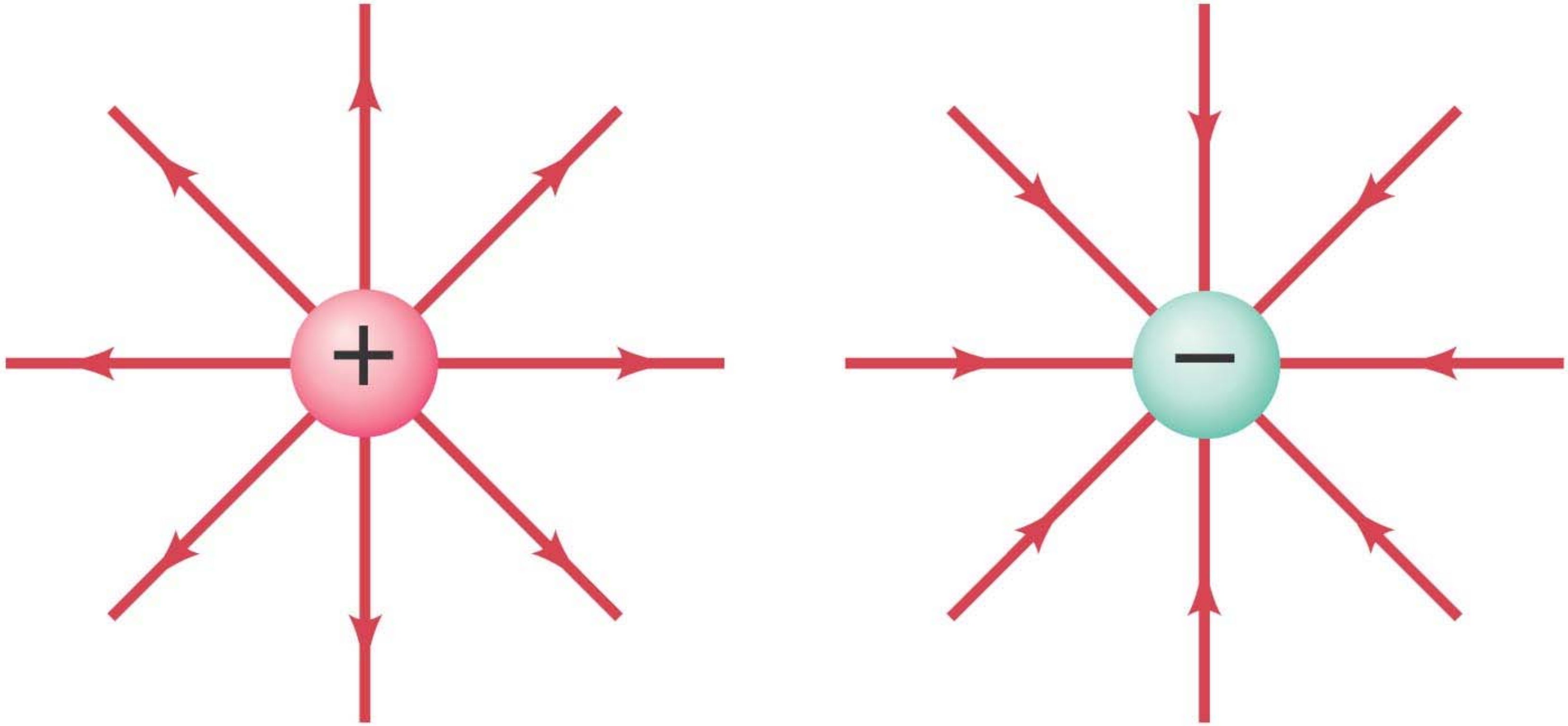


13. Charge is distributed uniformly, starting at the origin, along the positive semi-infinite x axis with a linear density. Determine the electric field at the point(0,0,z). Use symmetry and refer to the next figure for help. Assume $\lambda = Q/2L$ and get the answer in terms of Q,L and z



21-8 Field Lines-> a few words

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



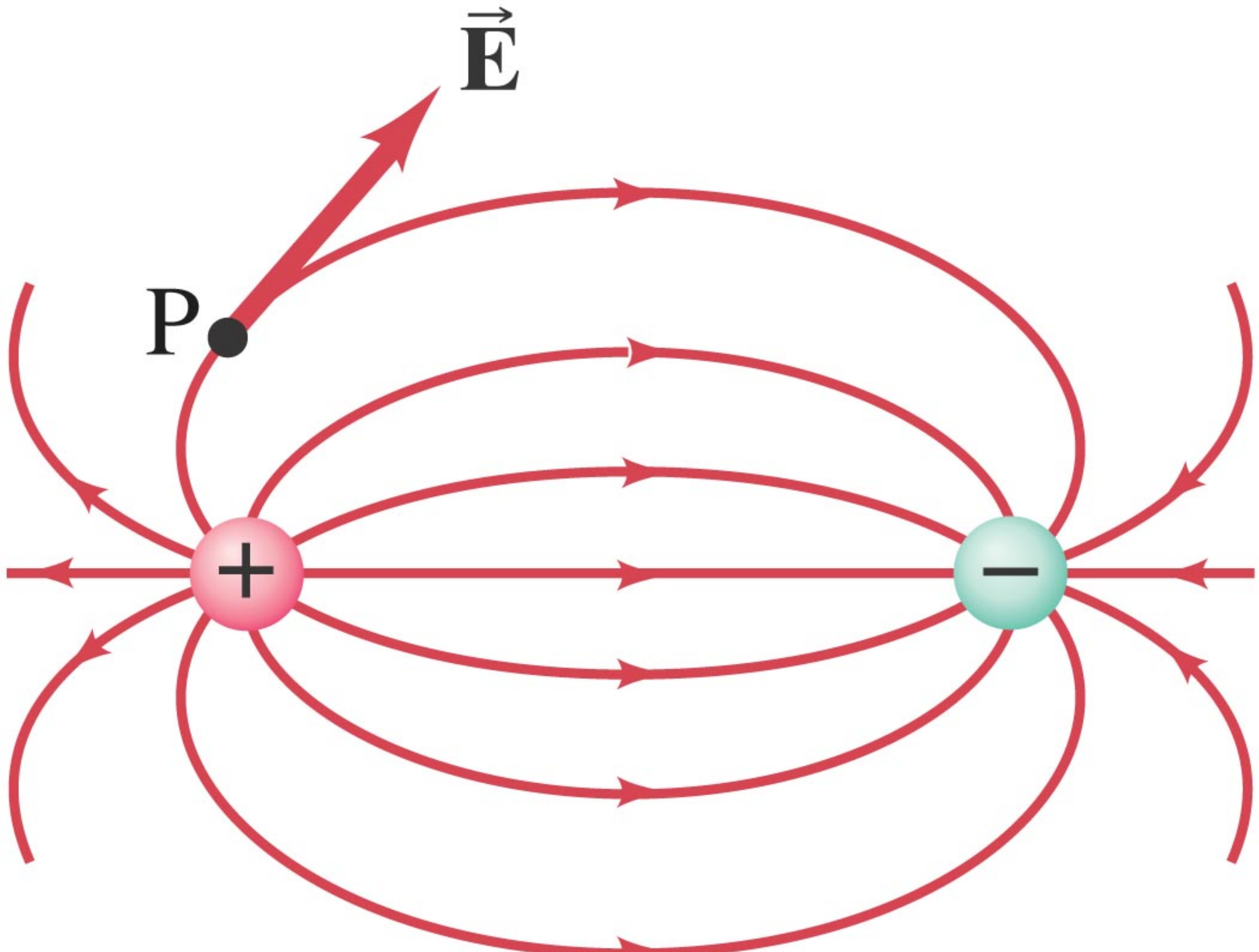
21-8 Field Lines

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

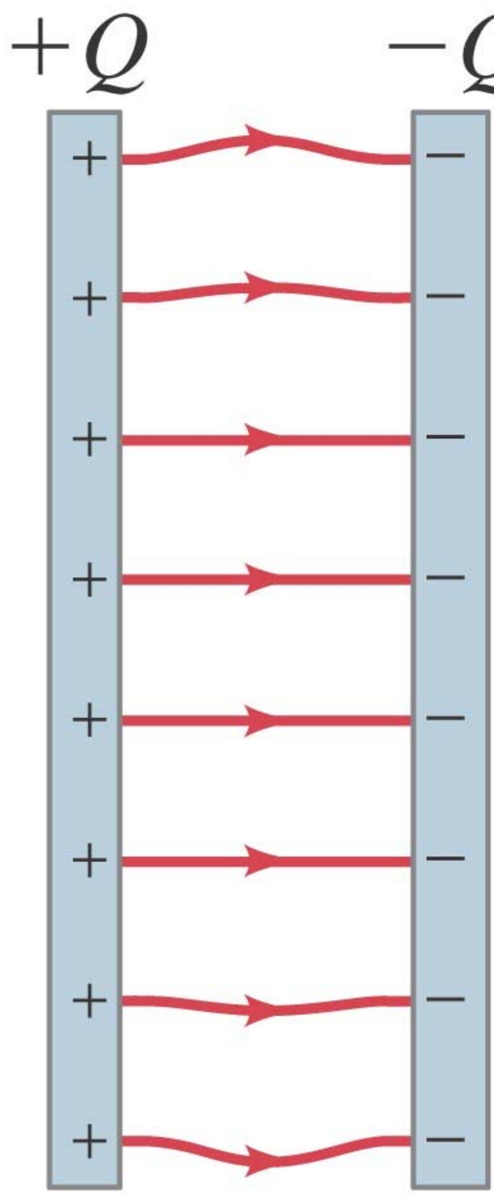
The electric field is stronger where the field lines are closer together.

21-8 Field Lines

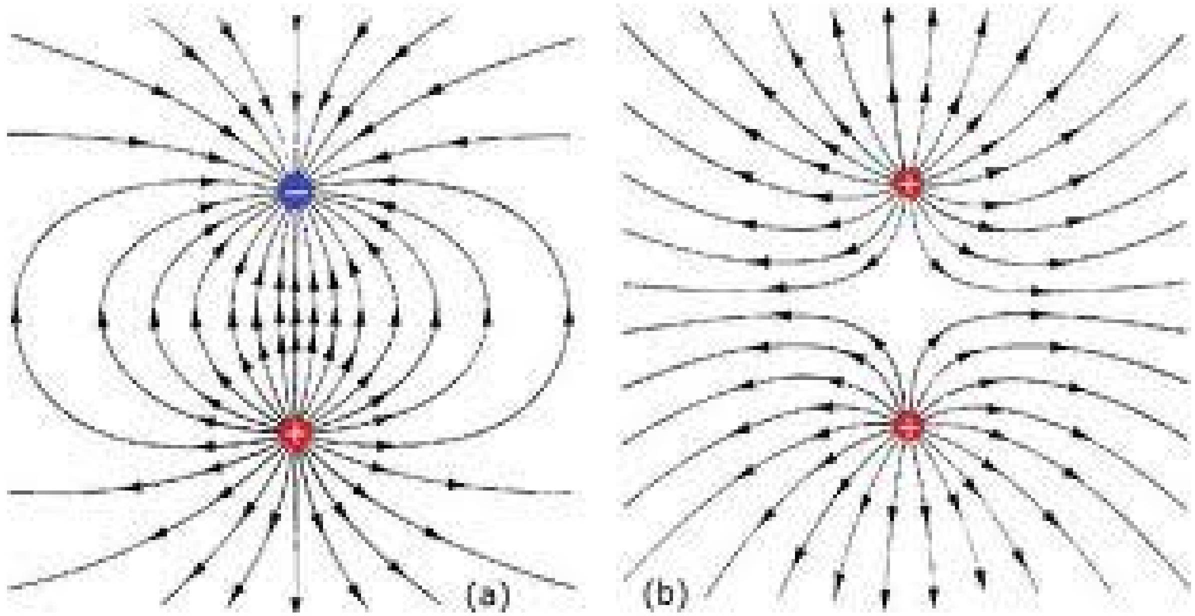
Electric dipole: two equal charges, opposite in sign:

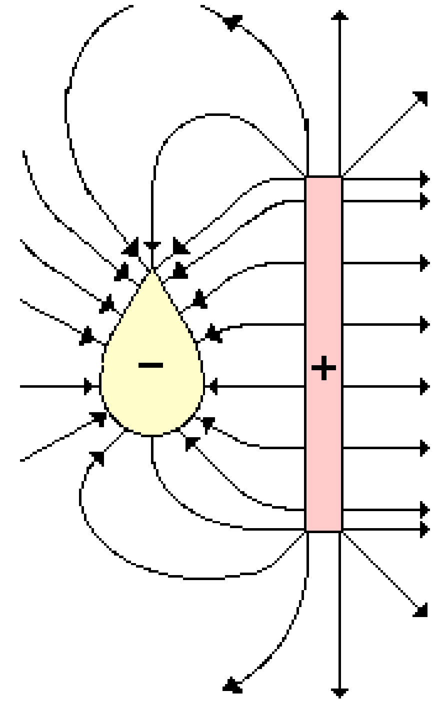


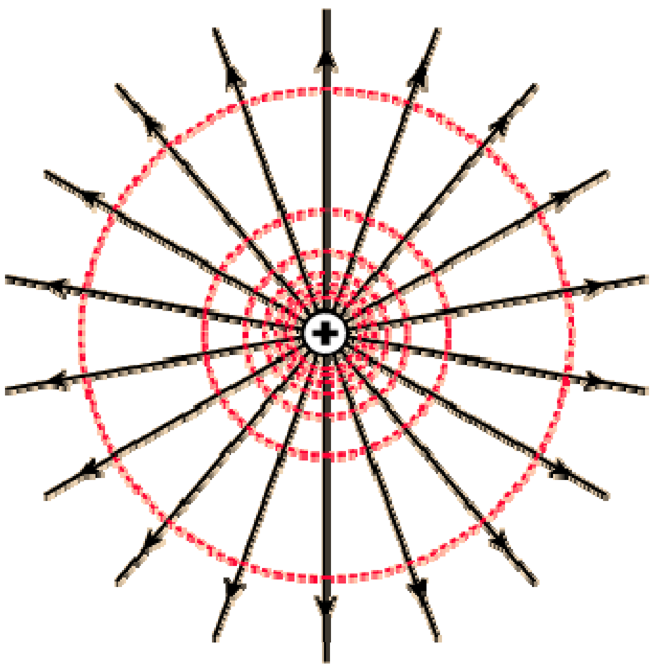
21-8 Field Lines

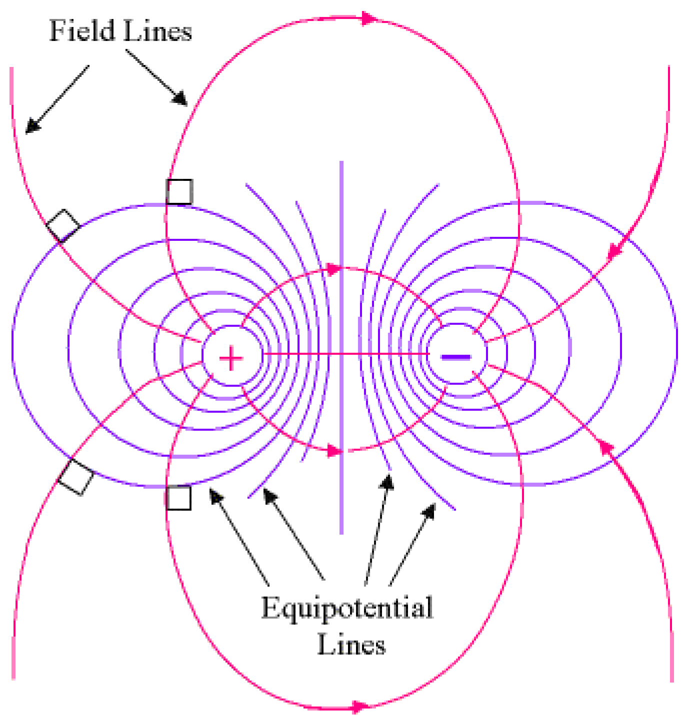


The electric field between two closely spaced, oppositely charged parallel plates is constant.


(a)
(b)






Field Lines
Equipotential Lines

21-8 Field Lines

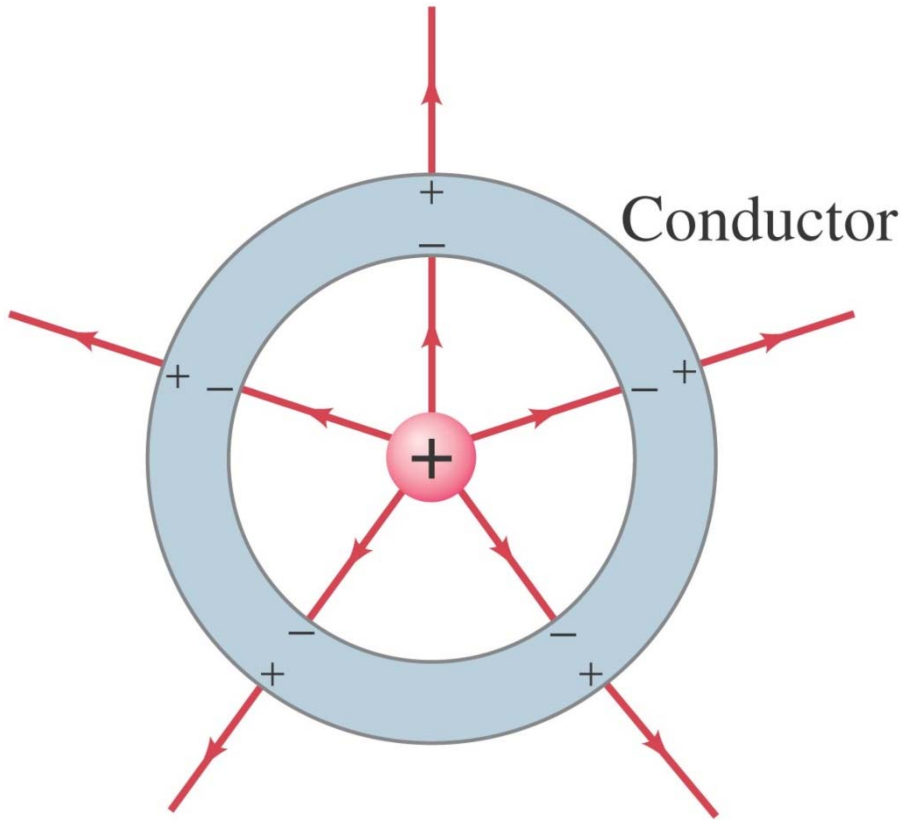
Summary of field lines:

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.

For the lab work field lines are perpendicular To Equipotential lines!

21-9 Electric Fields and Conductors

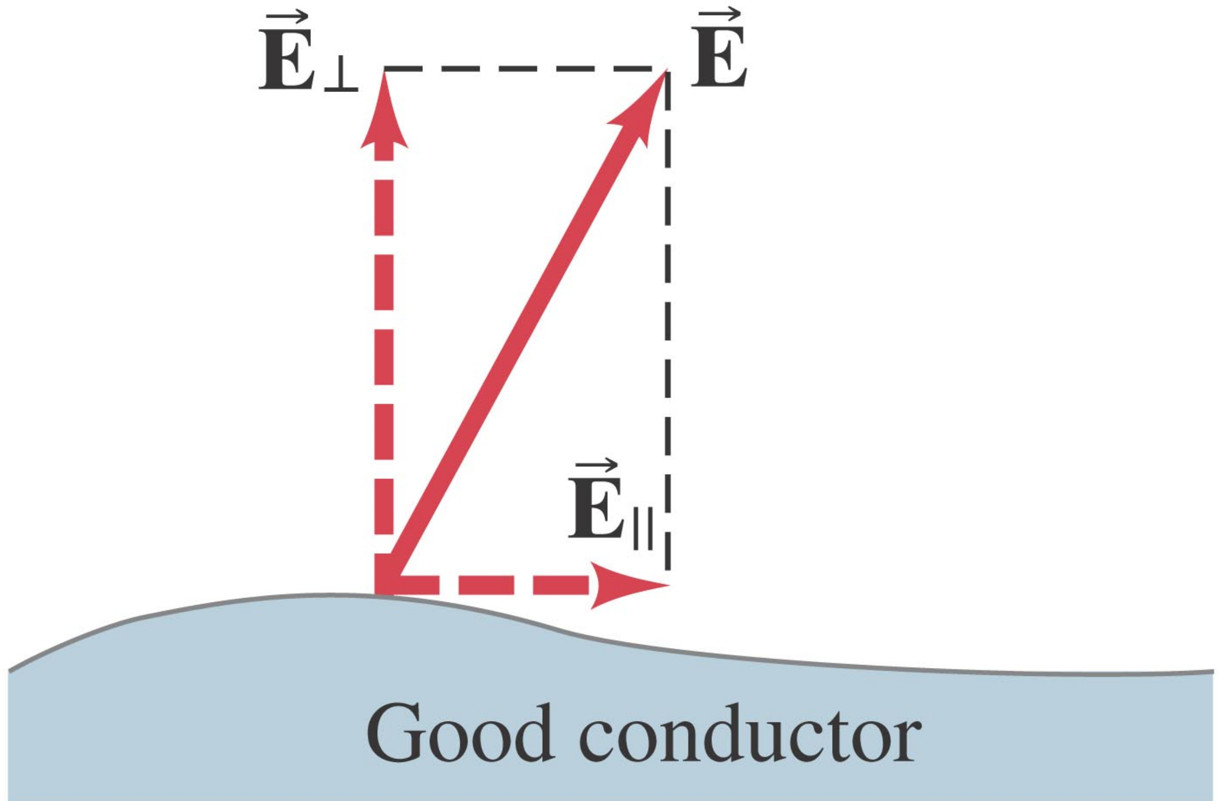
The static electric field inside a conductor is zero – if it were not, the charges would move.



The net charge on a conductor resides on its outer surface.

21-9 Electric Fields and Conductors

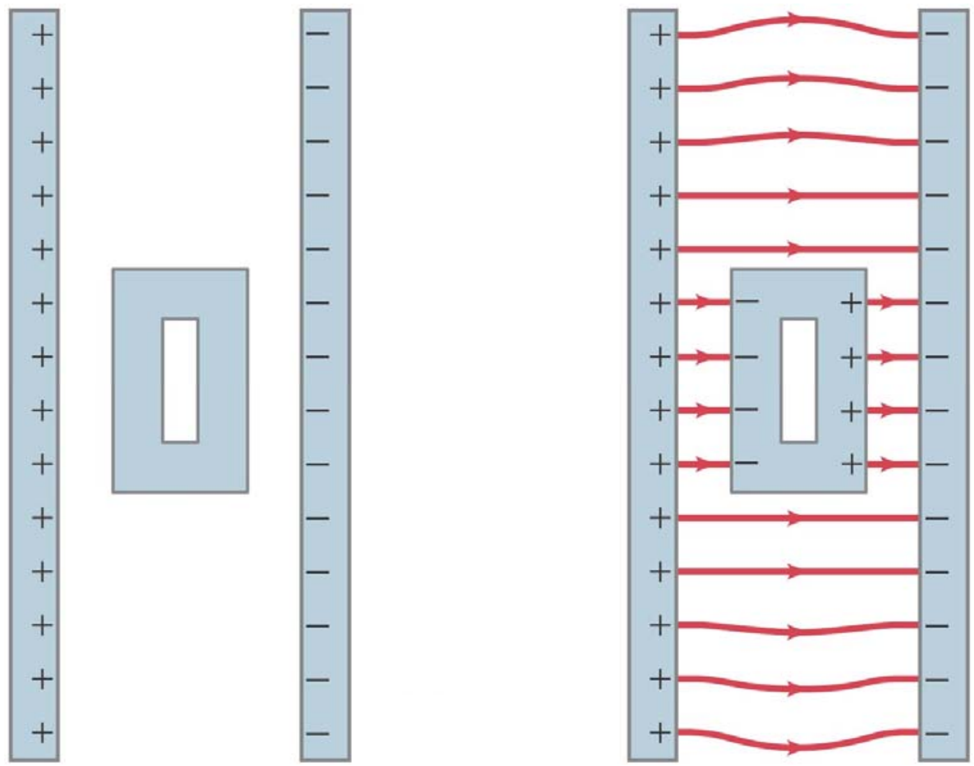
The electric field is perpendicular to the surface of a conductor – again, if it were not, charges would move.



21-9 Electric Fields and Conductors

Conceptual Example 21-14: Shielding, and safety in a storm.

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



Inside a car is a good idea in an electrical storm?

21-10 Motion of a Charged Particle in an Electric Field

The force on an object of charge q in an electric field $\vec{\mathbf{E}}$ is given by:

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

Therefore, if we know the mass and charge of a particle, we can describe its subsequent motion in an electric field.

i.e F=ma or a=qE/m =constant!

Recall constant “a” formulas

s=displacement (like x or y)

$v = v_o + at$

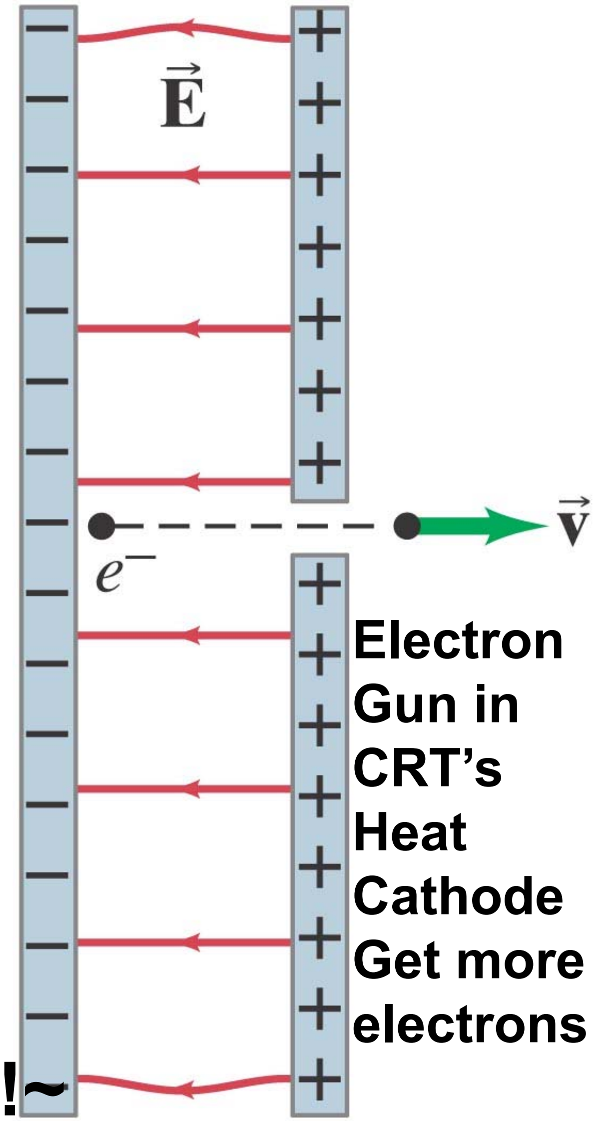
$s = v_o t + 1/2at^2$

$v^2 = v_o^2 + 2as$

F=ma =(circle->mv^2 /r

21-10 Motion of a Charged Particle in an Electric Field
Example 21-15: Electron accelerated by electric field

An electron (mass m = 9.11 x 10^{-31} kg) is accelerated in the uniform field (E = 2.0 x 10^4 N/C) between two parallel charged plates. The separation of the plates is 1.5 cm. The electron is accelerated from rest near the negative plate and passes through a tiny hole in the positive plate. (a) With what speed does it leave the hole? (b) Show that the gravitational force can be ignored. Assume the hole is so small that it does not affect the uniform field between the plates. SET UP ALGEBRAIC SOLUTION !



Electron Gun in CRT's
Heat Cathode
Get more electrons

(a) $F = m_e a = eE$ $a = eE/m_e$

$v^2 = v_0^2 + 2ax$ $v = (2ax)^{1/2}$

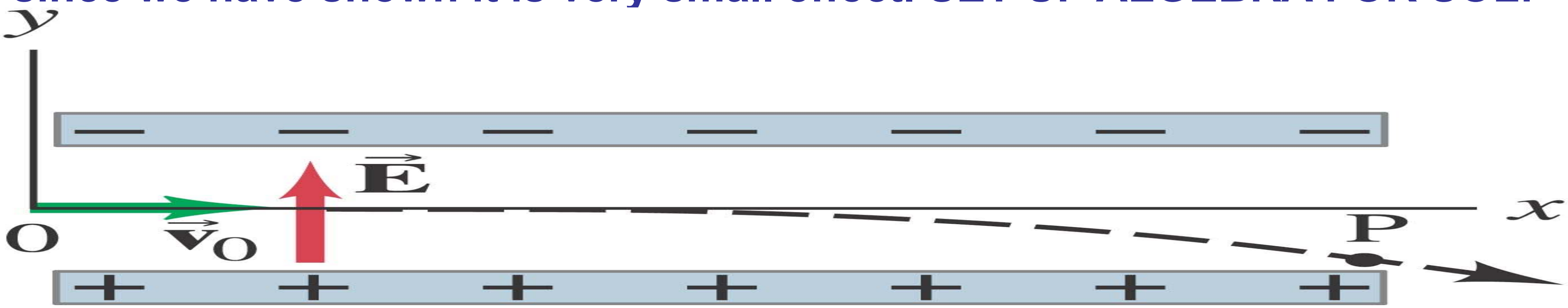
OR $v = (2eEx/m_e)^{1/2}$

(b) $eE/m_e g$ is very large

- see text for numbers for a and b!~

21-10 Motion of a Charged Particle in an Electric Field

Example 21-16: Electron moving perpendicular to $\vec{E}$ Suppose an electron traveling with speed v_0 = 1.0 x 10^7 m/s enters a uniform electric field , which is at right angles to v_0 as shown. Describe its motion by giving the equation of its path while in the electric field $\vec{E}$ Ignore gravity since we have shown it is very small effect. SET UP ALGEBRA FOR SOL!



2D motion→ apply $v=v_0+at$ & $s=v_0t+1/2at^2$ to x & y axis

in x direction :$v_x=v_0$ & $x=v_0t$

In y direction $y = 1/2a_yt^2$ $F=eE=m_ea_y$ -> $a_y = -eE/m_e$

$y= ½ a_y t^2$ since $a_y = -eE/m_e$ and $t=x/v_o$

$y = -eEx^2/2m_ev_0^2$ the equation of the parabola path

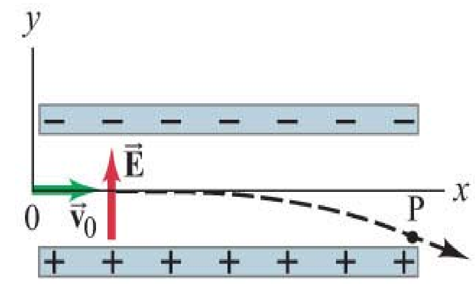
CRT!!

Hand in Homework

14. An electron with speed 2.50×10^7m/s is traveling parallel to a uniform electric field of magnitude 1.15×10^4N/C .
Part A. How far will the electron travel before it stops?
Part B. How much time will elapse before it returns to its starting point?

15. At what angle will the electrons leave the uniform electric field at the end of the parallel plates (point P in the figure to the right)? Assume the plates are 5.1cm long and $E = 4.7\times10^3$N/C . Ignore fringing of the field.

$V_o = 1.15 \times 10^7$ m/s

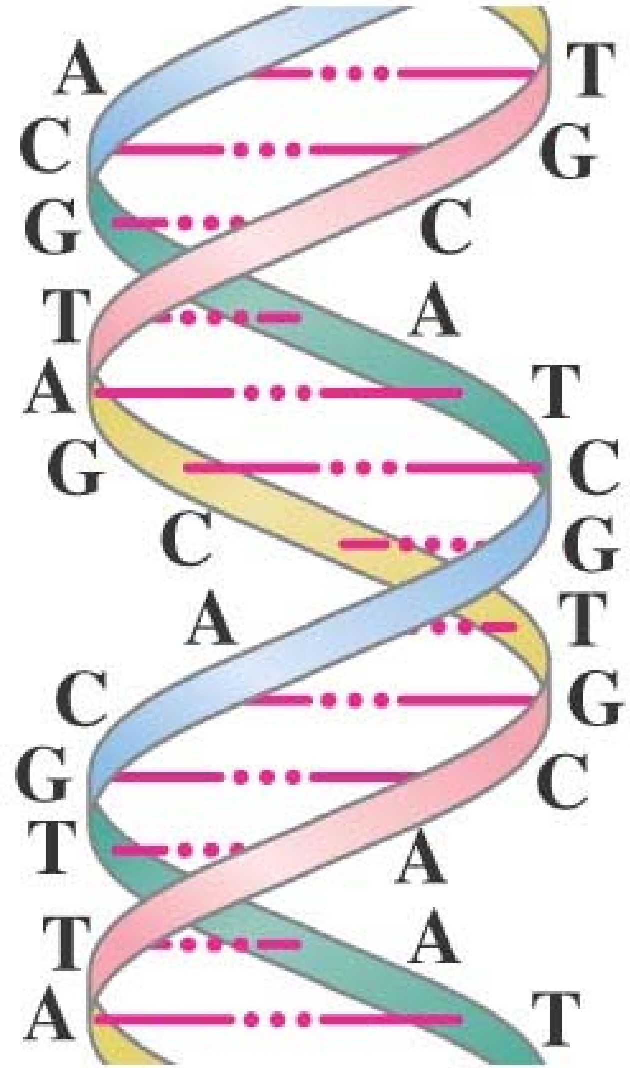


16. A uniform electric field is set up between two oppositely charged parallel plates. An electron (mass 9.11×10^{-31} kg) is released from rest at the negatively charged plate and strikes the positive plate a distance 1.5 cm away after 1.2×10^{-8} s. determine the speed of the electron when it strikes and the magnitude of the electric field it encountered.

21-12 Electric Forces in Molecular Biology; DNA

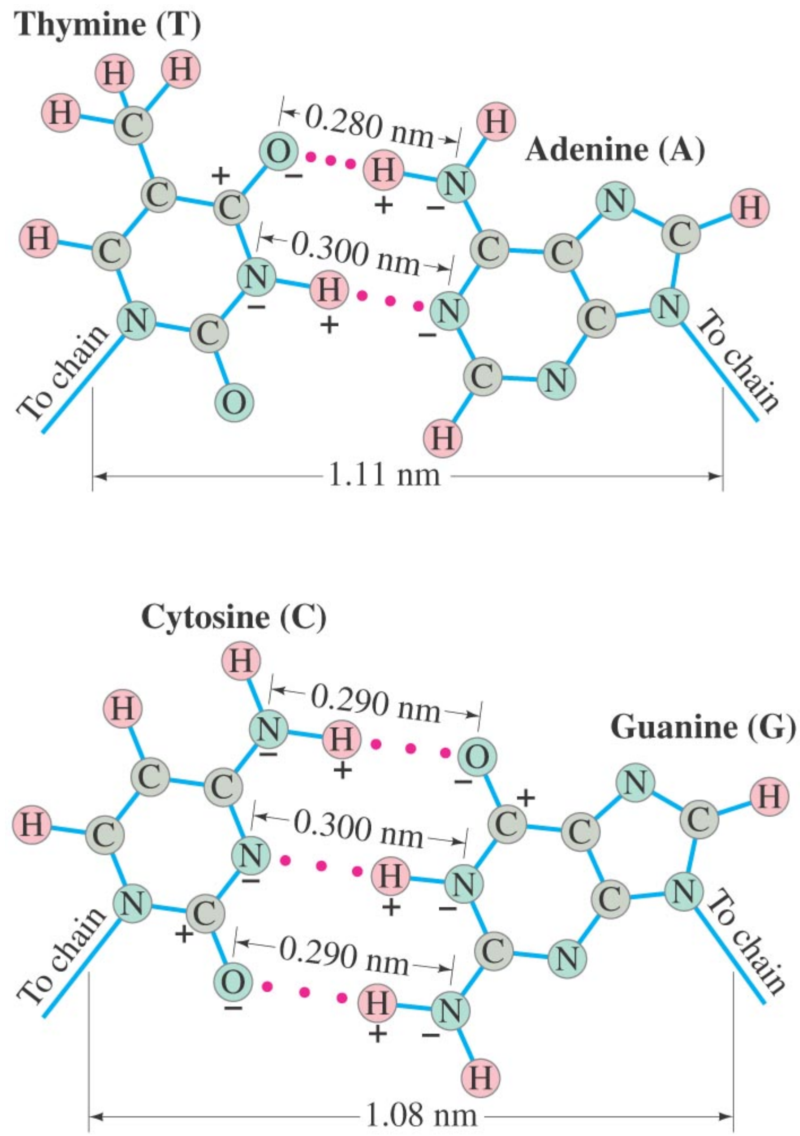
Molecular biology is the study of the structure and functioning of the living cell at the molecular level.

The DNA molecule is a double helix:



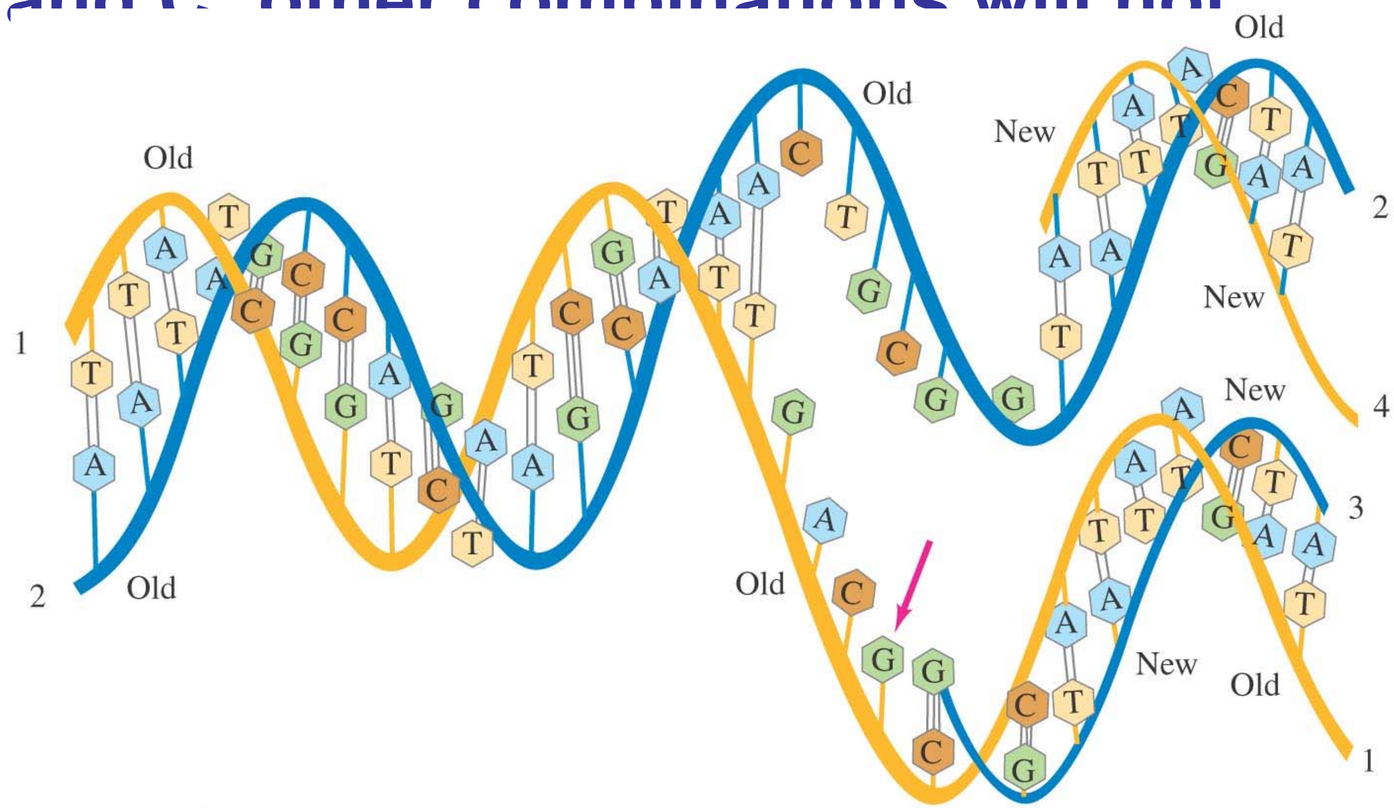
21-12 Electric Forces in Molecular Biology; DNA

The A-T and G-C nucleotide bases attract each other through electrostatic forces.



21-12 Electric Forces in Molecular Biology; DNA

Replication: DNA is in a "soup" of A, C, G, and T in the cell. During random collisions, A and T will be attracted to each other, as will G and C; other combinations will not.



21-13 Photocopy Machines and Computer Printers Use Electrostatics

Photocopy machine:

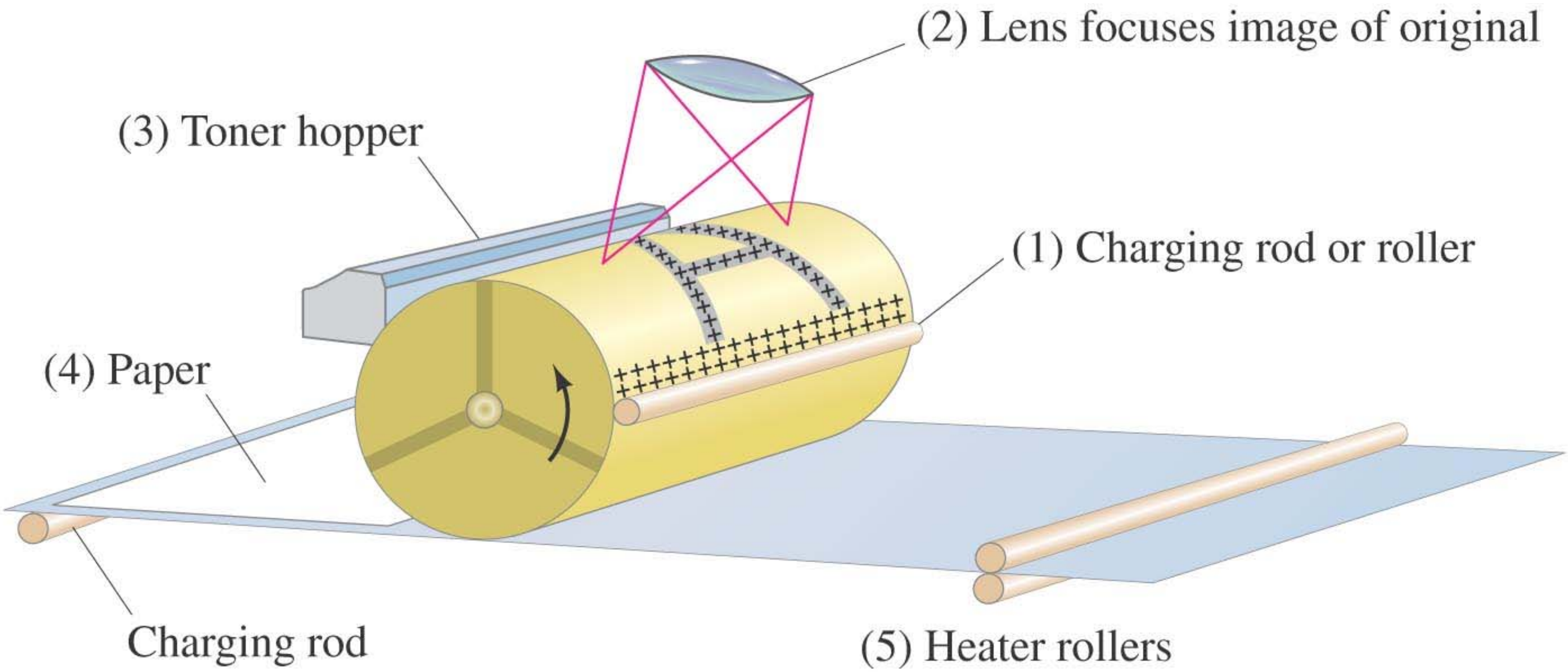
• drum is charged positively

• image is focused on drum

• only black areas stay charged and therefore attract toner particles

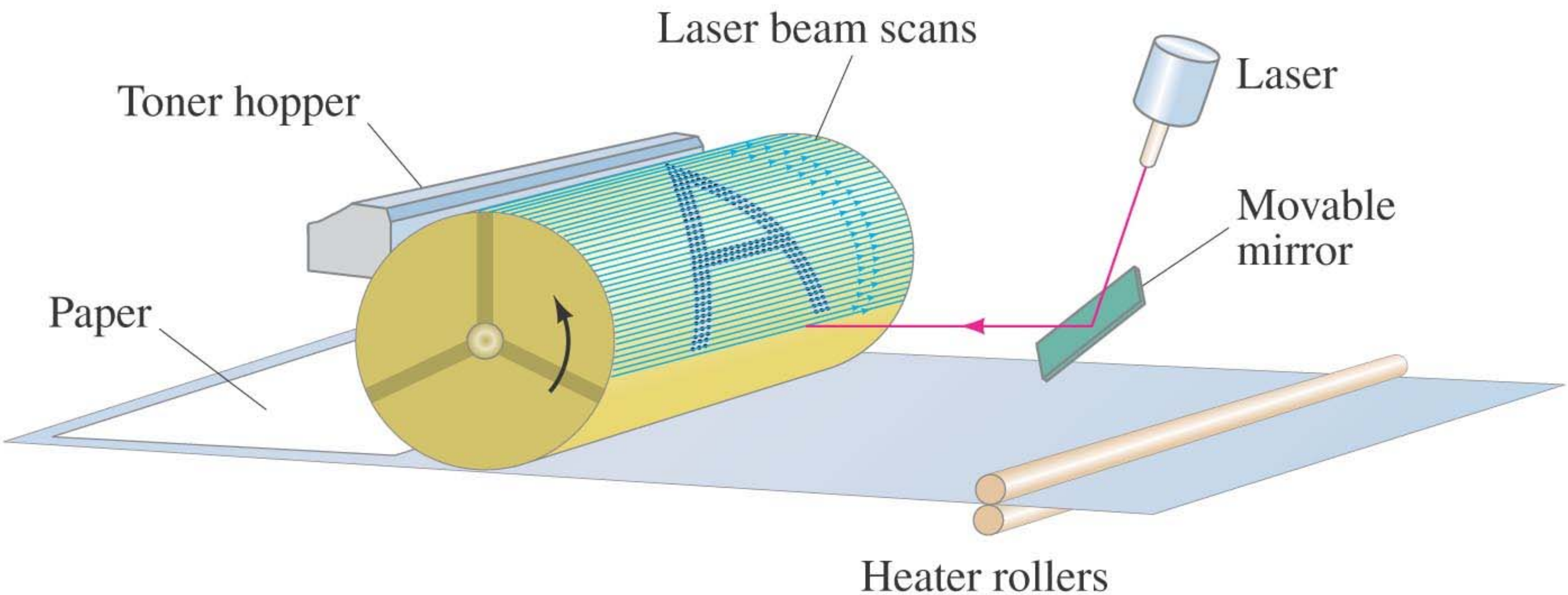
• image is transferred to paper and sealed by heat

21-13 Photocopy Machines and Computer Printers Use Electrostatics



21-13 Photocopy Machines and Computer Printers Use Electrostatics

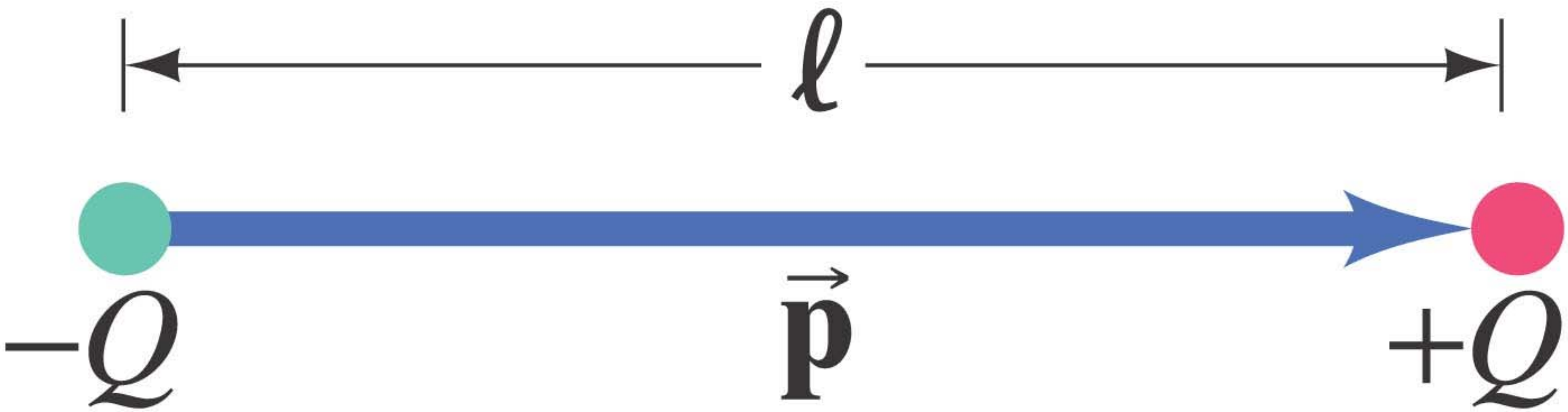
Laser printer is similar, except a computer controls the laser intensity to form the image on the drum.



SKIP NEXT SECTION

21-11 Electric Dipoles

An electric dipole consists of two charges Q, equal in magnitude and opposite in sign, separated by a distance ℓ. The dipole moment, $\vec{p} = Q\vec{\ell}$, points from the negative to the positive charge.

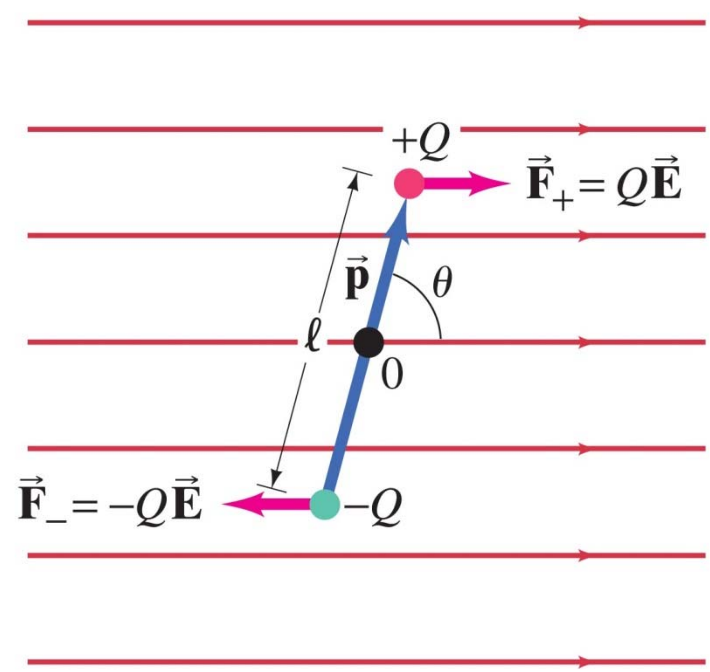


21-11 Electric Dipoles

An electric dipole in a uniform electric field will experience no net force, but it will, in general, experience a torque:

$$\tau = QE\frac{\ell}{2}\sin\theta + QE\frac{\ell}{2}\sin\theta = pE\sin\theta.$$

$$\vec{\boldsymbol{\tau}} = \vec{\mathbf{p}} \times \vec{\mathbf{E}}.$$

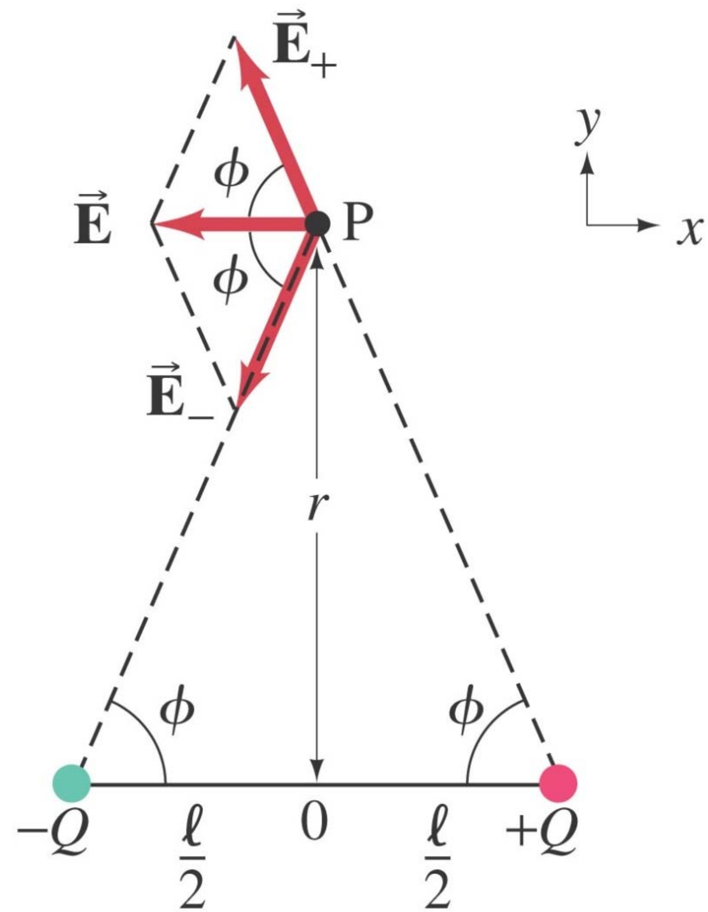


21-11 Electric Dipoles

The electric field created by a dipole is the sum of the fields created by the two charges; far from the dipole, the field shows a $1/r^3$ dependence:

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{\left(r^2 + \ell^2/4\right)^{\frac{3}{2}}}. \qquad \begin{bmatrix}\text{on perpendicular bisector} \\ \text{of dipole}\end{bmatrix}$$

$$E = \frac{1}{4\pi\epsilon_0}\frac{p}{r^3}. \qquad \begin{bmatrix}\text{on perpendicular bisector} \\ \text{of dipole; } r \gg \ell\end{bmatrix}$$



21-11 Electric Dipoles

Example 21-17: Dipole in a field.

The dipole moment of a water molecule is 6.1×10^{-30} C·m. A water molecule is placed in a uniform electric field with magnitude 2.0×10^{5} N/C. (a) What is the magnitude of the maximum torque that the field can exert on the molecule? (b) What is the potential energy when the torque is at its maximum? (c) In what position will the potential energy take on its greatest value? Why is this different than the position where the torque is maximum?