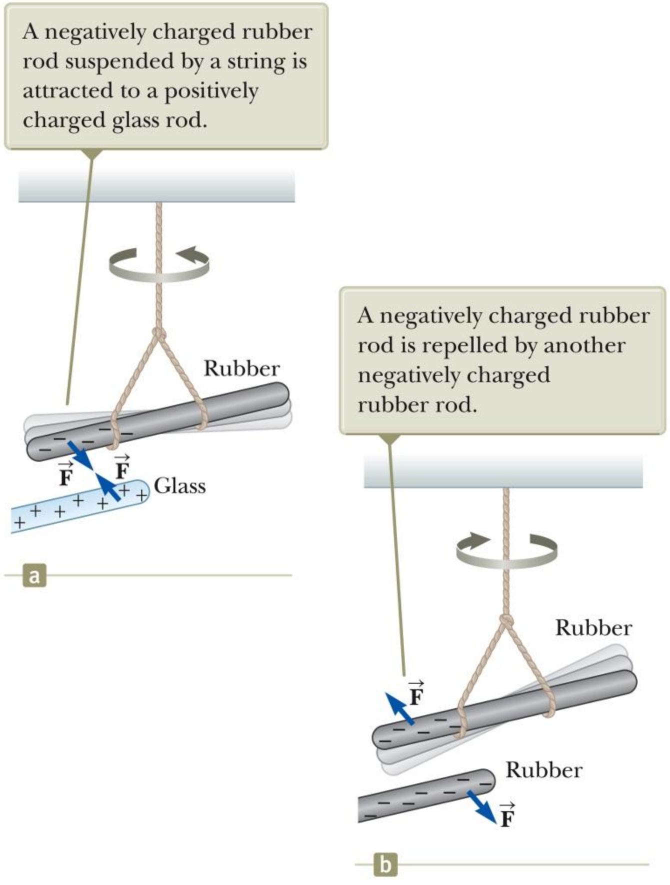
# Electric Fields

- Sources of electric fields – Charges
- Properties of charges
- Interaction of charges – Electric forces
- Electric fields
- Motion of charges in electric fields

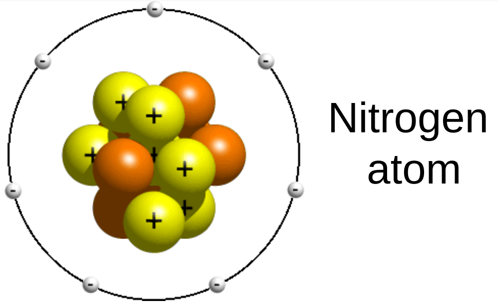
# Electrical Charges

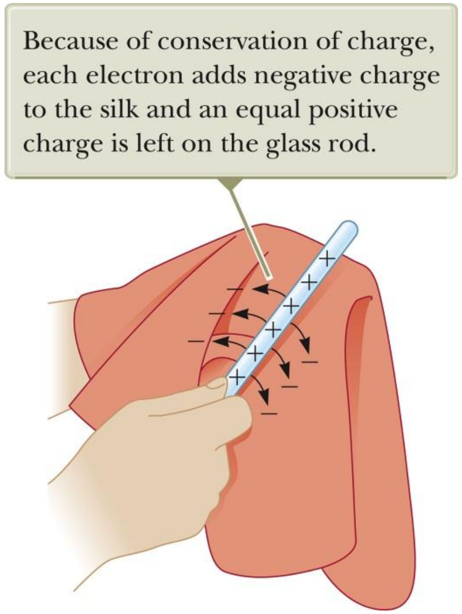
- Charge is carried by electrons and protons.
- Can be positive or negative.
- Like charges repel, opposite charges attract.
- Total charge in a system is conserved.
- Charges come in discrete quantities.
- Charges  are measured in Coulombs (C).
- Usually denoted by q.



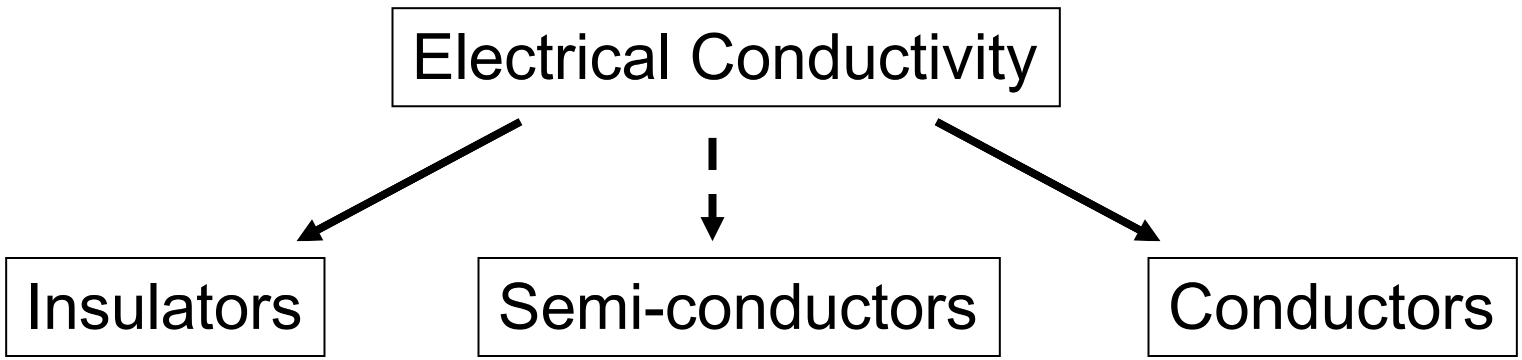
# What Carries Charge?

- Smallest unit of charge is:
  - $e = 1.6 \times 10^{-19}$ C
- 1 electron : -1 e
- 1 proton : +1 e
- 1 neutron : 0 e
- Most matter is naturally neutral.
- Charging can be accomplished by rubbing (thermal agitation).
- We can consider Earth to be an infinite source of charge - grounding



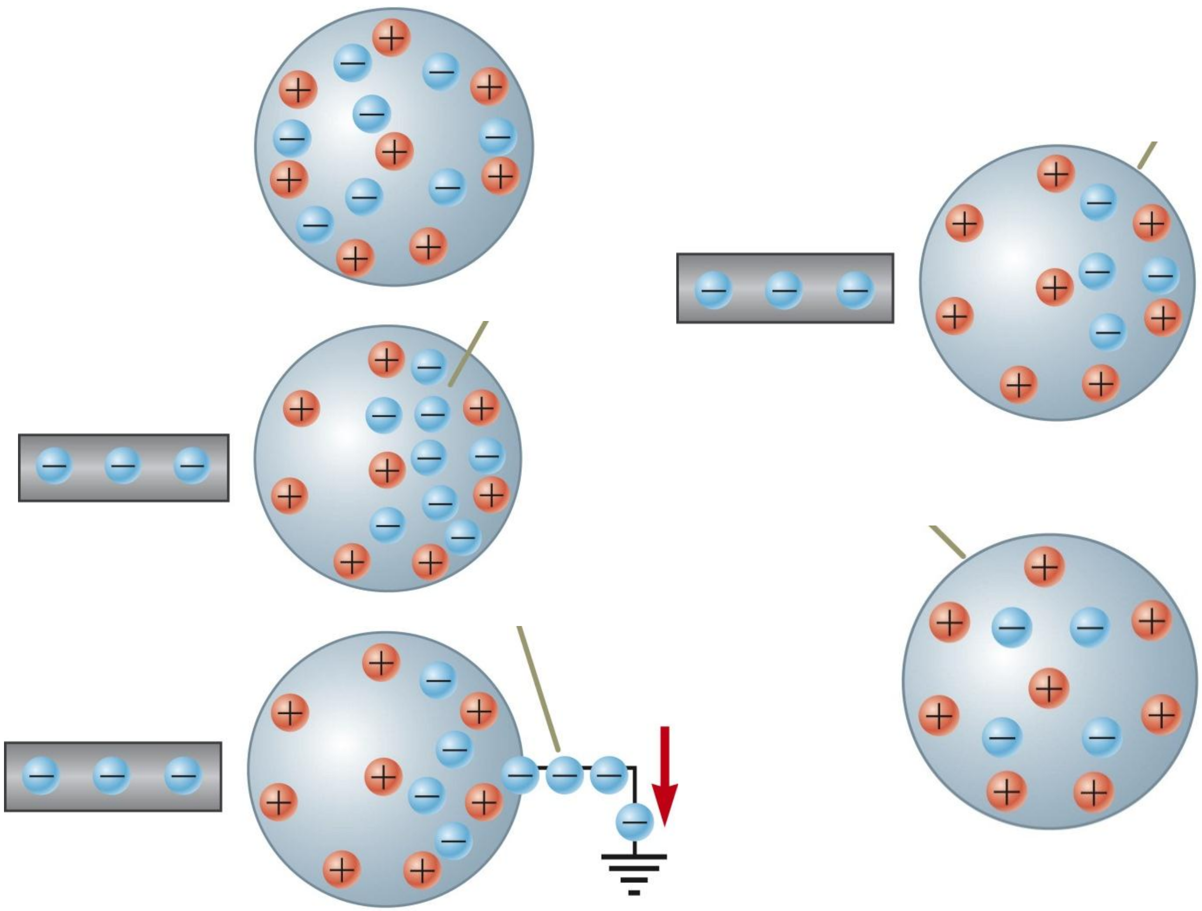



# Insulators and Conductors

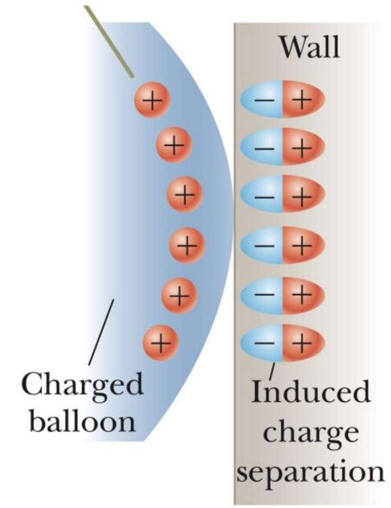



| Insulators | Semi-conductors | Conductors |
|---|---|---|
| No movement of charges within the object | Limited number of free carriers | Free movement of charges |
| Wood, plastics, glass | Silicon, Germanium | Metals (Cu, Ag, Al) |

# Charging by Induction



INDUCTION
(conductor)




INDUCTION
(insulator)

# Concept Question

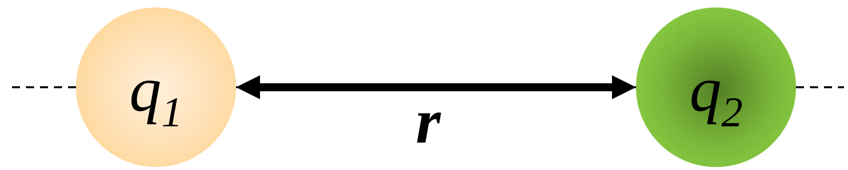
Three pith balls are suspended from thin threads. Various objects are then rubbed against other objects (nylon against silk, glass against polyester, etc.) and each of the pith balls is charged by touching them with one of these objects. It is found that pith balls 1 and 2 repel each other and that pith balls 2 and 3 repel each other. From this we can conclude that

1. 1 and 3 carry charges of opposite sign.
2. 1 and 3 carry charges of equal sign.
3. all three carry the charges of the same sign.
4. one of the objects carries no charge.
5. we need to do more experiments to determine the sign of the charges.

# Electrostatic Force

- The electrostatic force between charges follows an inverse-square law (like gravity).
- The force can be attractive or repulsive (unlike gravity).
- As with other forces it is a vector quantity.
- The superposition principle applies.

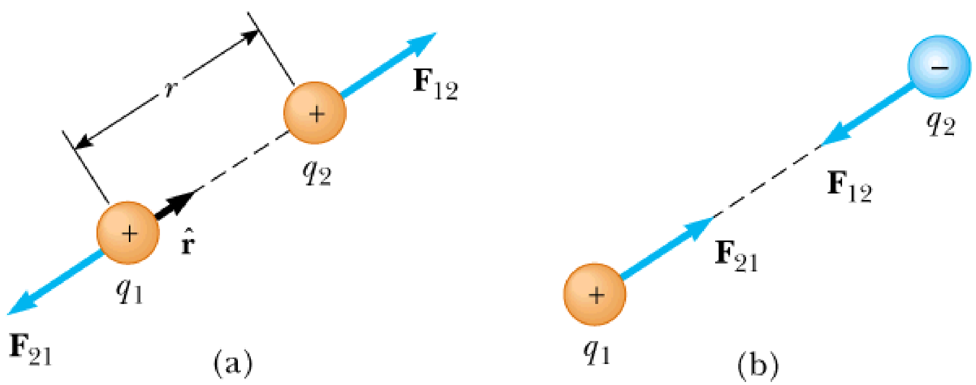
# Coulomb's Law




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

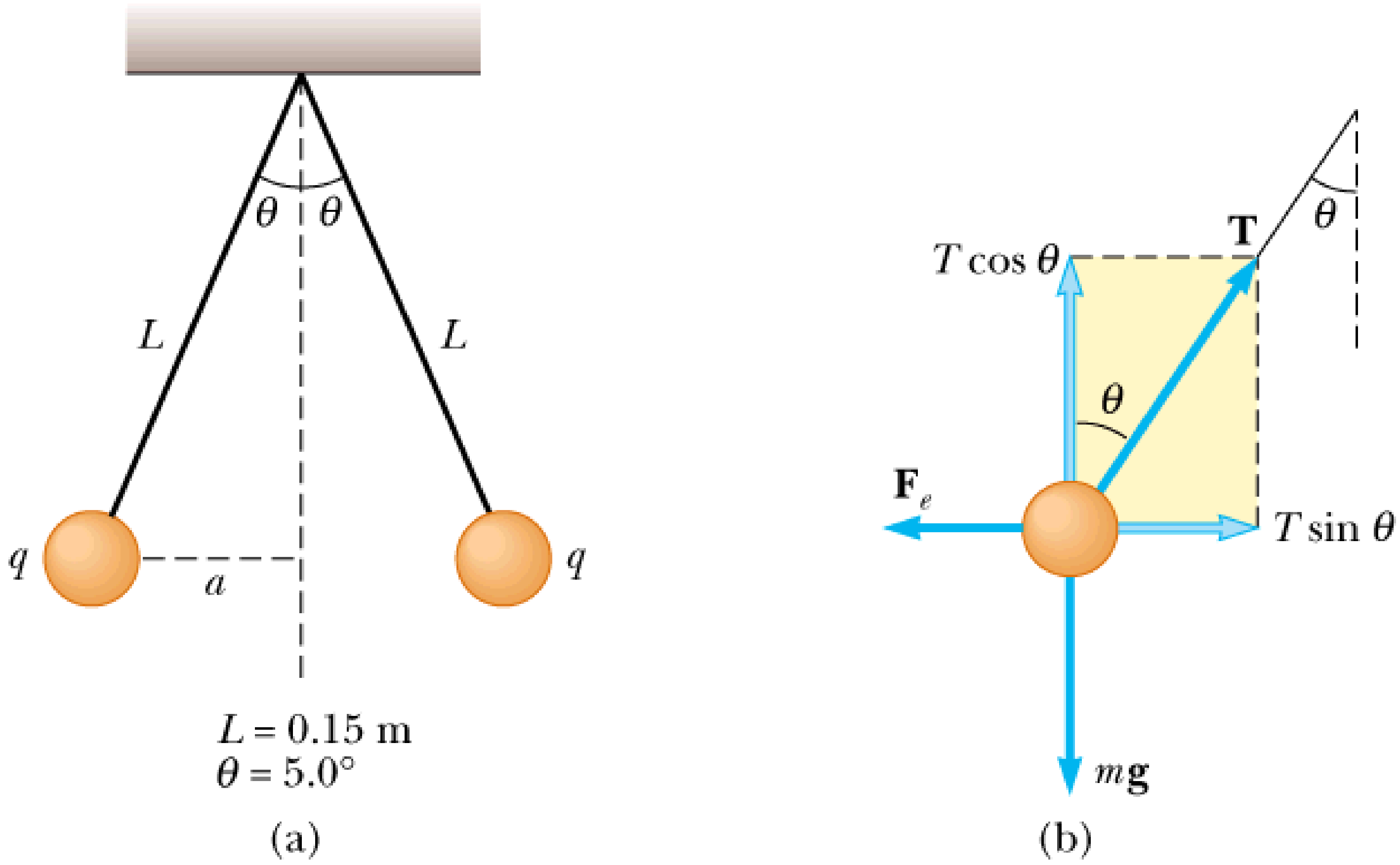
$$k_e = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \ \mathrm{N.m^2/C^2}$$

$$\varepsilon_0 = 8.85 \times 10^{-12} \ \mathrm{C^2/N.m^2}$$



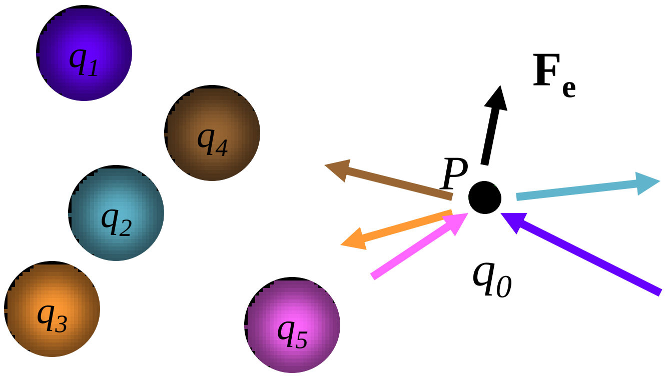

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}$$

# Charged Spheres



# Electric Field

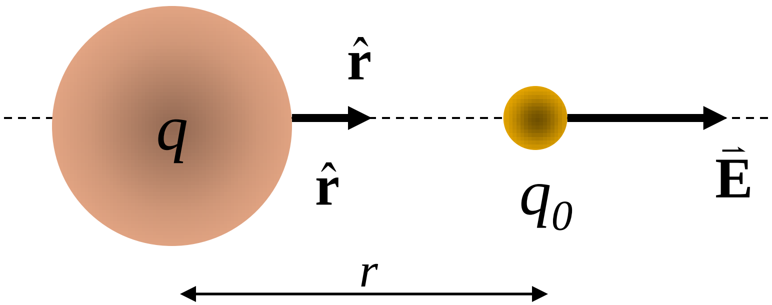
- Field forces can act without physical contact (like gravity).
- To find the **field** created by a group of charges, calculate the total force acting on a small test charge.
- Then divide the force by the charge of the test particle.
- So the units are of electric force per unit charge (*N/C*)
- Of course the electric field is also a vector quantity.




$$\vec{\mathbf{F}}_{\mathbf{e}} = \sum_i \vec{\mathbf{F}}_i \longrightarrow \vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}_{\mathbf{e}}}{q_0}$$

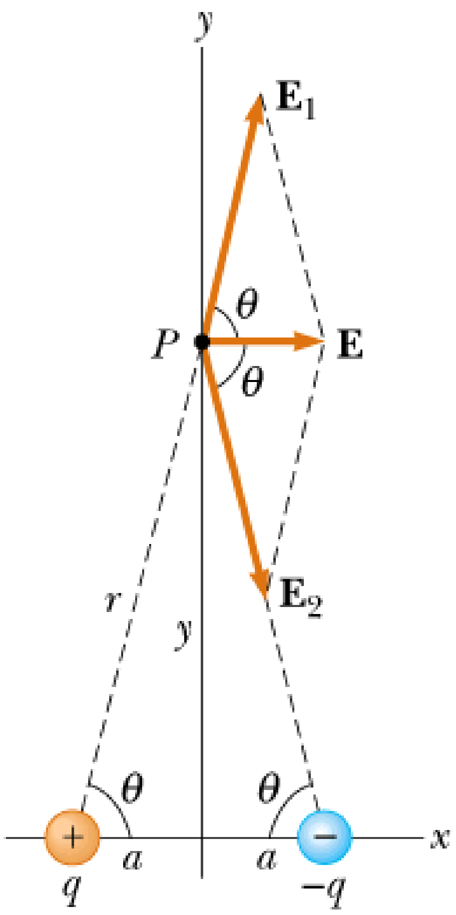
$$\vec{\mathbf{F}}_{\mathbf{e}} = q\vec{\mathbf{E}}$$

# Electric Field of a Point Charge




$$\vec{\mathbf{E}} = \frac{\vec{\mathbf{F}}_{\mathbf{e}}}{q_0} = k_e \frac{q}{r^2}\hat{\mathbf{r}}$$

# The Electric Dipole



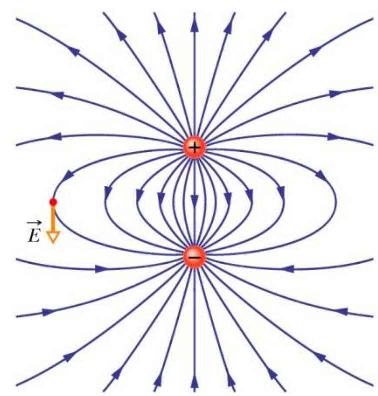

$$E = k_e \frac{2qa}{(y^2 + a^2)^{3/2}}$$

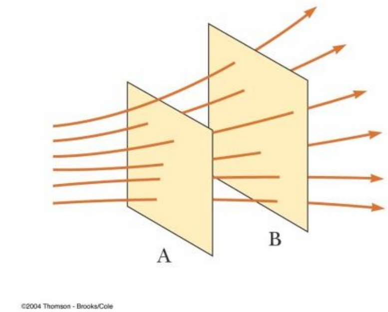
$$E = k_e \frac{2qa}{y^3} \qquad y >> a$$

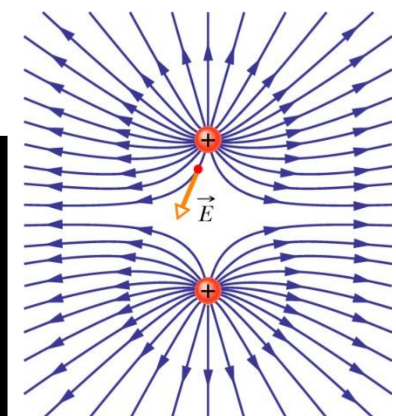
What is the electric force on a test charge, $q_0$, at $P$?

# Electric Field Lines

- A way to visualize field patterns over space.
- The e-field is tangent to the field lines at each point and along the direction of the field arrow.
- The density of the lines is proportional to the magnitude of the e-field.
- Field lines start from positive charges an end at negative ones.
- Field lines can not cross.

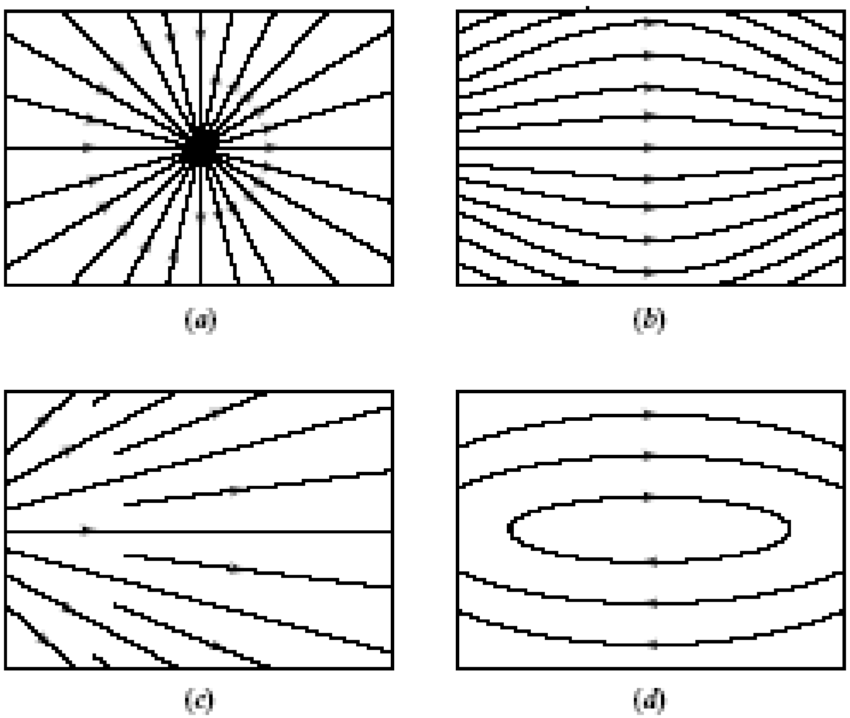


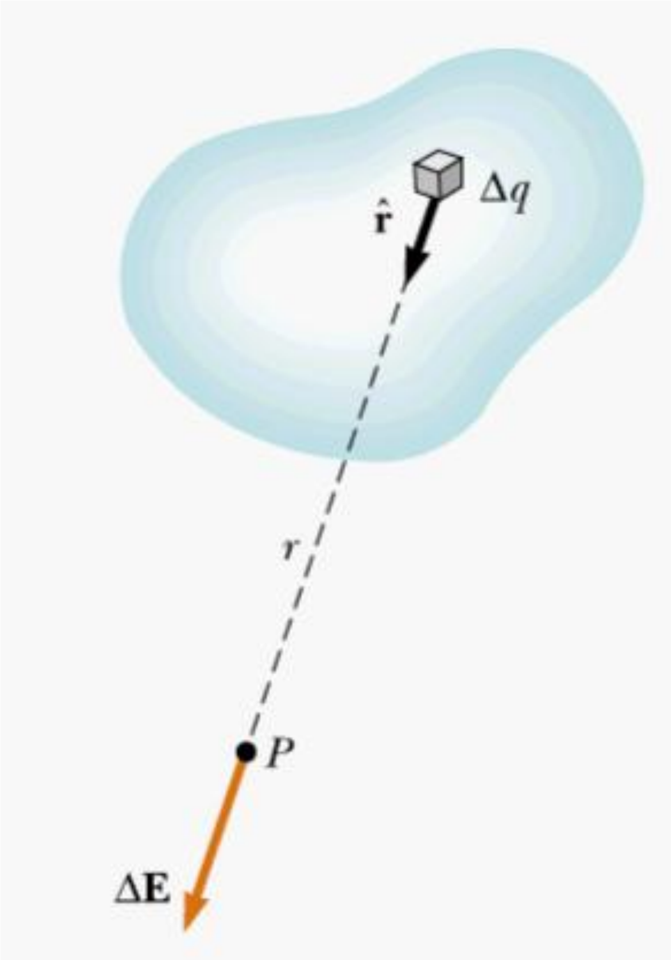
# Concept Question

Consider the four field patterns shown. Assuming there are no charges in the regions shown, which of the patterns represent(s) a possible electrostatic field:




1. (*a*)
2. (*b*)
3. (*b*) and (*d*)
4. (*a*) and (*c*)
5. (*b*) and (*c*)
6. some other combination
7. None of the above.

# Continuous Charge Distributions




$$\Delta\vec{\mathbf{E}} = k_e \frac{\Delta q}{r^2}\hat{\mathbf{r}}$$ Field at P due to Δq

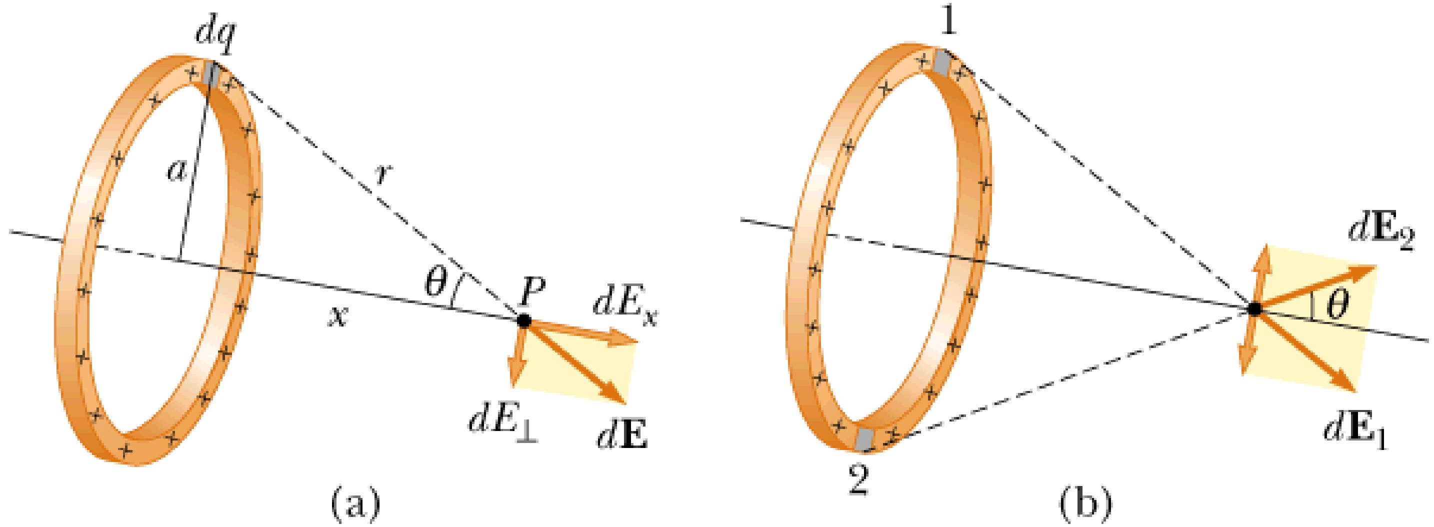
$$\vec{\mathbf{E}} \approx k_e \sum_i \frac{\Delta q_i}{r_i^{\,2}}\hat{\mathbf{r}}_i$$

$$\vec{\mathbf{E}} = k_e \int \frac{dq}{r^2}\hat{\mathbf{r}}$$ Total field at P

For uniform charge distributions:

$$\rho = \frac{Q}{V}(C/m^3) \quad \sigma = \frac{Q}{A}(C/m^2) \quad \lambda = \frac{Q}{l}(C/m)$$

# Uniformly Charged Ring




$$\mathbf{d\vec{E}} = k_e \frac{dq}{r^2}\hat{\mathbf{r}}$$

$$dE_x = dE\cos\theta \qquad dE_\perp = 0$$

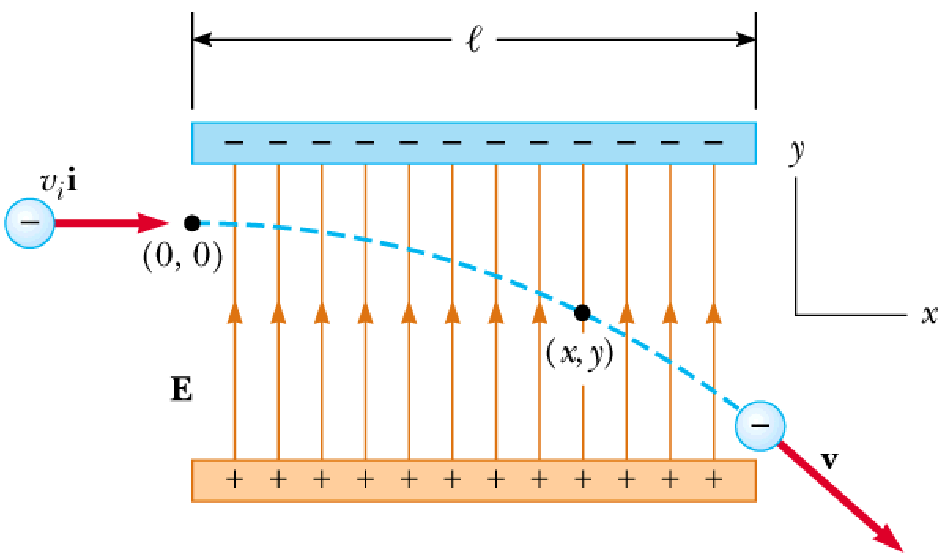
$$dE_x = dE\cos\theta = k_e\left(\frac{dq}{r^2}\right)\frac{x}{r} = \frac{k_e x}{(x^2+a^2)^{3/2}}dq$$

$$E_x = \int \frac{k_e x}{(x^2+a^2)^{3/2}}dq = \frac{k_e x}{(x^2+a^2)^{3/2}}\int dq$$

$$E_x = \frac{k_e x}{(x^2+a^2)^{3/2}}Q$$

# Motion in a Uniform E-Field

| E-Field | Force | Acceleration |
|---|---|---|
| $\vec{\mathbf{E}}$ | $\vec{\mathbf{F}} = q\vec{\mathbf{E}}$ | $\vec{\mathbf{a}} = \dfrac{\vec{\mathbf{F}}}{m} = \dfrac{q\vec{\mathbf{E}}}{m}$ |




$$v_x = v_i = \text{constant}$$

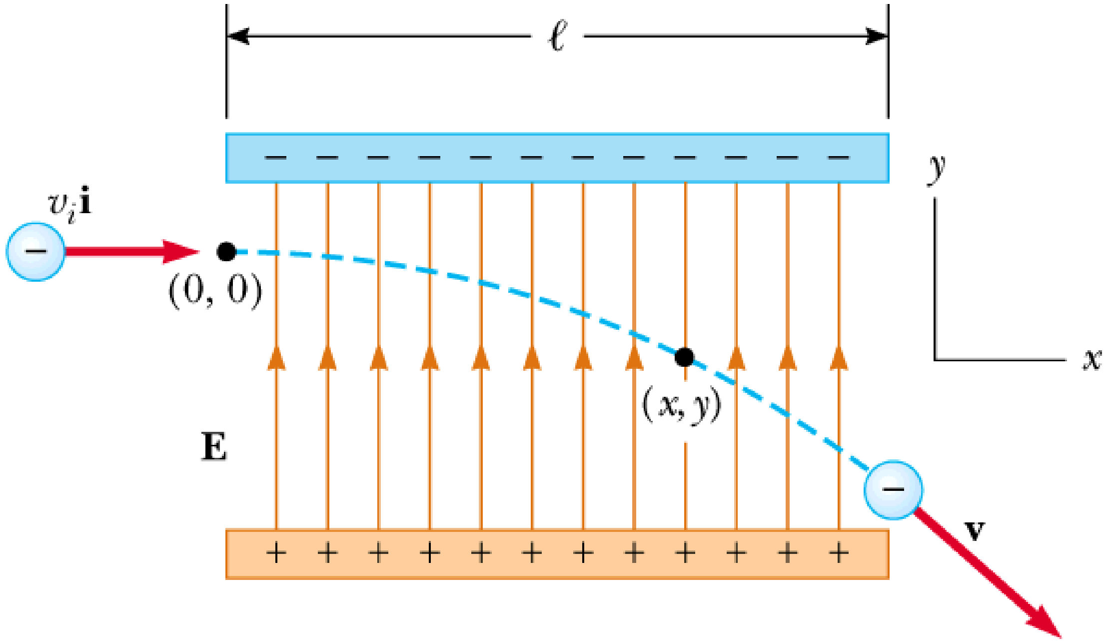
$$v_y = a_y t = -\frac{eE}{m} t$$

$$x(t) = v_x t$$

$$y(t) = \frac{1}{2} a t^2 = \frac{1}{2} \frac{eE}{m} t^2$$

$$y(t) = \frac{1}{2} \frac{eE}{m} \left( \frac{x}{v_x} \right)^2$$

# Example 23.10




$v_i$ = 3 x $10^6$ m/s
$E$ = 200 N/C
$l$ = 0.1 m

$a$ = ?
$T$ = ?
$y$ = ?

# Summary

- Charges can be negative or positive.
- Charge is discrete, conserved.
- Like charges repel, opposites attract.
- Electrostatic force obeys Coulomb's Law.
- Electric Field is force per unit charge.
- Field lines help us visualize field direction and strength.
- Charges are the sources of the e-field.

# For Next Class

- Reading Assignment
  - Chapter 24 - Gauss' Law
- WebAssign: Assignment 1