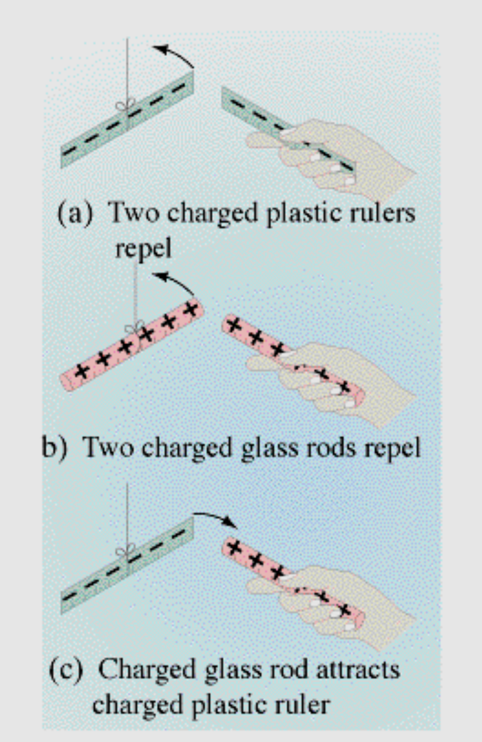
Chapter 21

Electric Charge and Electric Field

- Electric charge
- Conductors and insulators
- Coulomb's Law
- Electric Fields

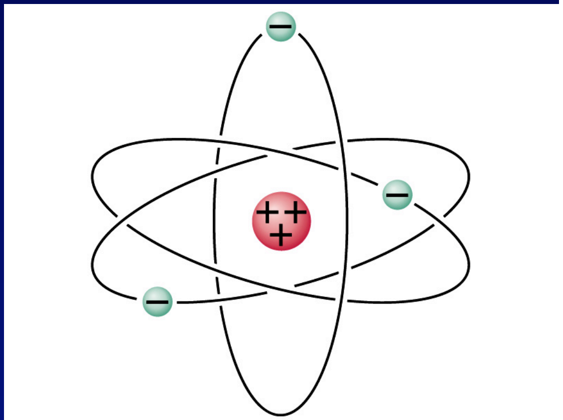
Electric Charge

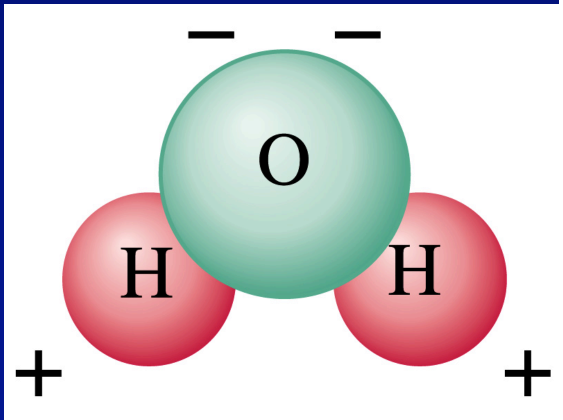


- There are **two** kinds of charge:
  - positive (+) and negative (–)
  - like charges repel
  - unlike charges attract
- Charge is **conserved**
  - The net amount of electric charge produced in any process is zero.
  - Charge can be transferred from one place to another.
- Charge comes in "packages" (quantized)
  - discrete amounts of smallest charge: *electron*

Electric Charge is Quantized

- Elementary charge: $e = 1.602 \times 10^{-19}$ C
- Any charge is an integer multiple of e.
  - Q (proton) = e
  - Q (electron) = -e
  - Q (typical) has about 10^{+12} of e. (seems continuous)
  - Objects that carry a positive charge has a deficit of electrons
  - Objects that carry a negative charge has an excess f electrons





- Most atoms and molecules are charge neutral.
  - Q (lithium atom) = 0
  - Q (water molecule) = 0
  - Charged-atoms or molecules are called Ions.
- Unit: 1 Coulomb = $6.24 \times 10^{+18}$ e.
  - Typical charge is $\mu C = 10^{-6}$ C.

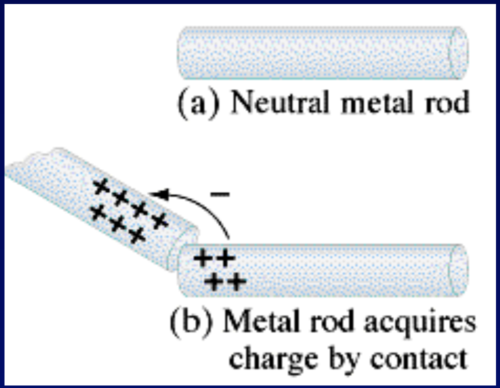
Types of Materials

- **Insulators**: charges cannot move freely
  - glass, rubber, plastic
- **Conductors**: charges can move freely
  - metals
- **Semiconductors**: impurities alter electrical properties
  - silicon, germanium
- **Superconductors**: infinite conductivity at low temp.

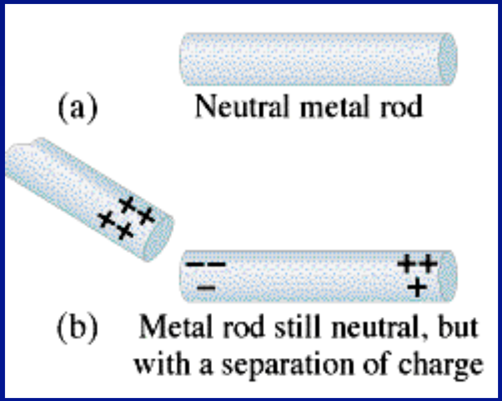
Material	Conductivity
silver	10^{8}
iron	10^{7}
germanium	10^{0}
silicon	10^{-3}
rubber	10^{-13}

Methods of Charging

- Charging by **contact**
  - direct transfer

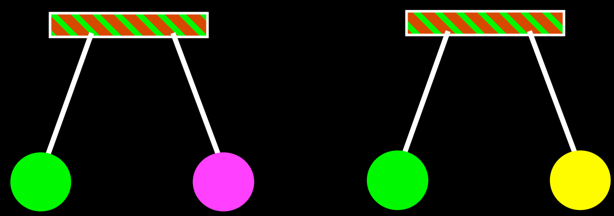


- Charging by **induction**
  - no contact
  - Can happen to both conductors and insulators
  - separation of charge is called **polarization**



ConcepTest 21.1 Electric Charge

- From the two separate tests, what can you conclude about the charges?



(1) have opposite charges

(2) have the same charge

(3) all have the same charge

(4) one ball must be neutral (no charge)

Coulomb's Law

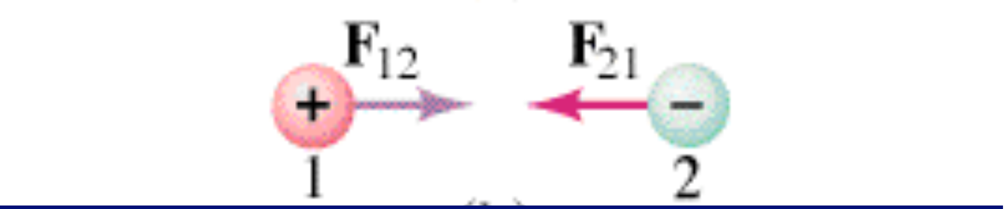
New Topic

Coulomb's Law

- Electric force is a field force (acts at a distance)

$$F = k\frac{Q_1 Q_2}{r^2}$$

k = 9 x 10^9 N m^2/C^2



The unit for charge is ***Coulomb (C)***

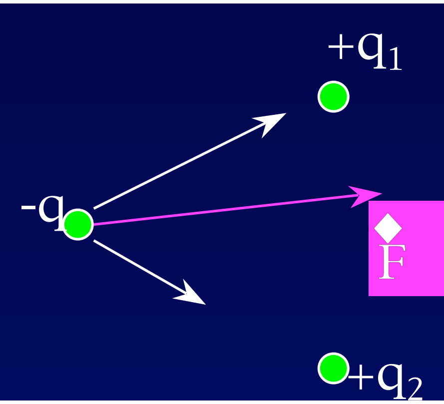
The smallest charge: *e = 1.6 x 10^{-19} C.*

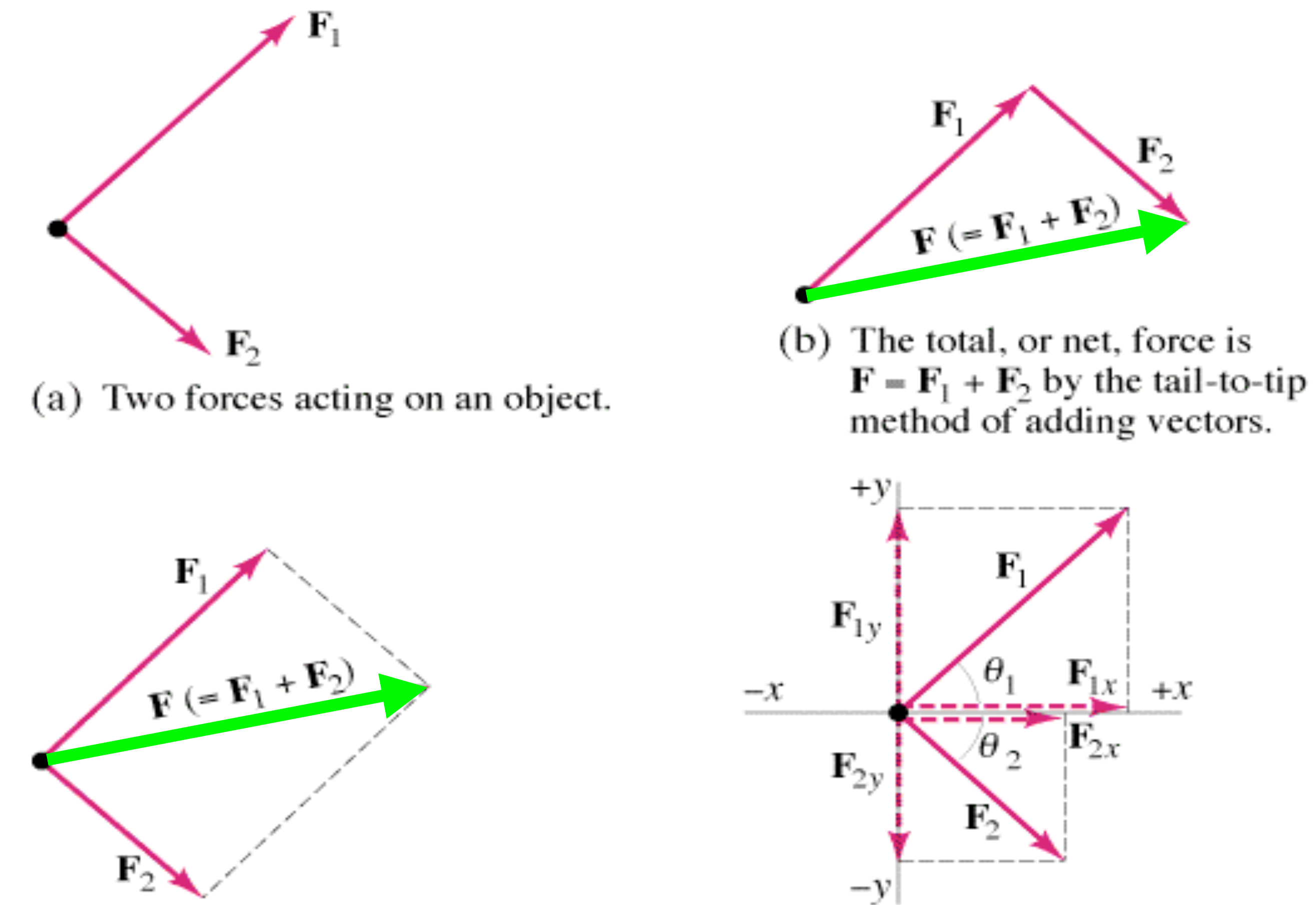
Two 1-C charges separated by 1 m has Coulomb force of 9x10^9 N!

- Note similarity in form to gravitational force: $F_g = G\frac{M_1 M_2}{r^2}$

Coulomb's Law: multiple charges

- If there are several charges, the net force on any one of them is the vector sum of the individual forces due to all the others.
  - Superposition principle





(a) Two forces acting on an object.

(b) The total, or net, force is $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$ by the tail-to-tip method of adding vectors.

(c) $\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$ by the parallelogram method.

(d) $\mathbf{F}_1$ and $\mathbf{F}_2$ resolved into their x and y components.

ConcepTest 21.2 Coulomb's Law

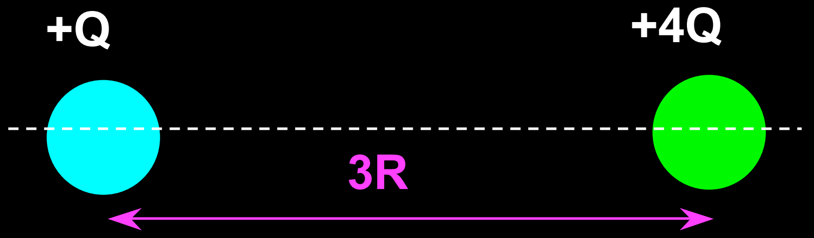
- Two balls with charges +Q and +4Q are fixed at a separation distance of 3R. Is it possible to place another charged ball Q_0 on the line between the two charges such that the net force on Q_0 will be zero?

(1) yes, but only if Q_0 is positive

(2) yes, but only if Q_0 is negative

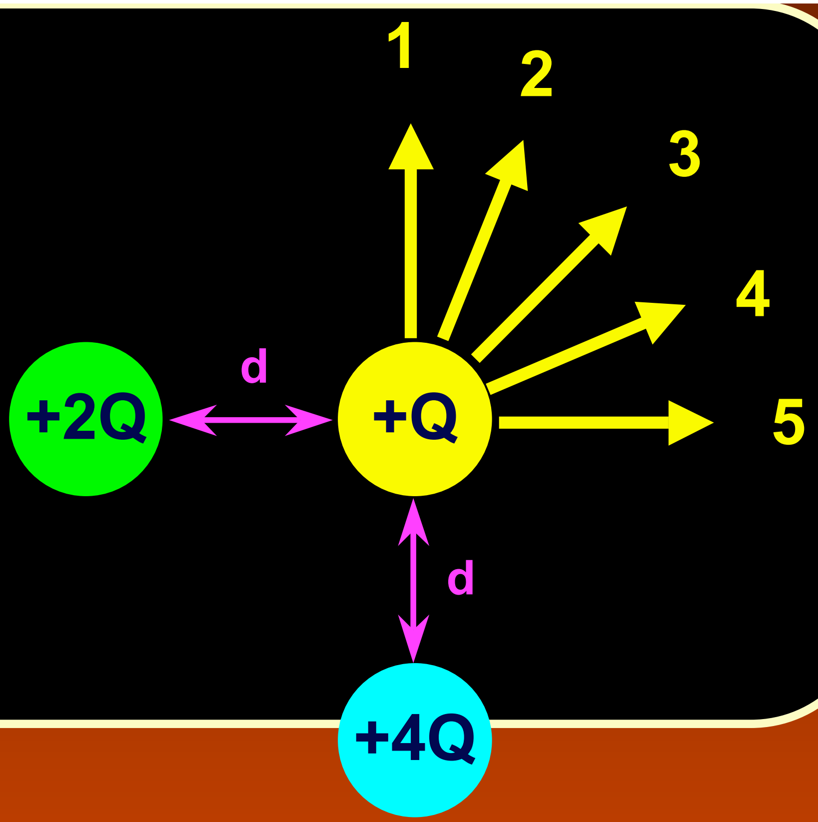
(3) yes, independent of the sign (or value) of Q_0

(4) no, the net force can never be zero



ConcepTest 21.3
Coulomb's Law

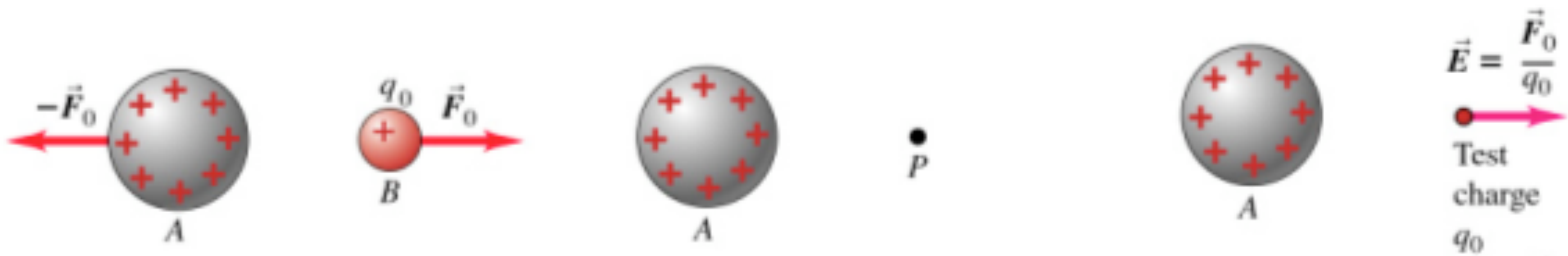
- **Which of the arrows best represents the direction of the net force on charge +Q due to the other two charges?**



Electric Field

New Topic

The Concept of Electric Field



(a) How does charged body A exert a force on charged body B?

(b) Remove body B and label its former position as P

(c) Body A sets up an electric field $\vec{E}$ at point P: $\vec{E}$ is the force per unit charge exerted by A on a test charge at P

Move around a small test charge and see what electric force it feels!

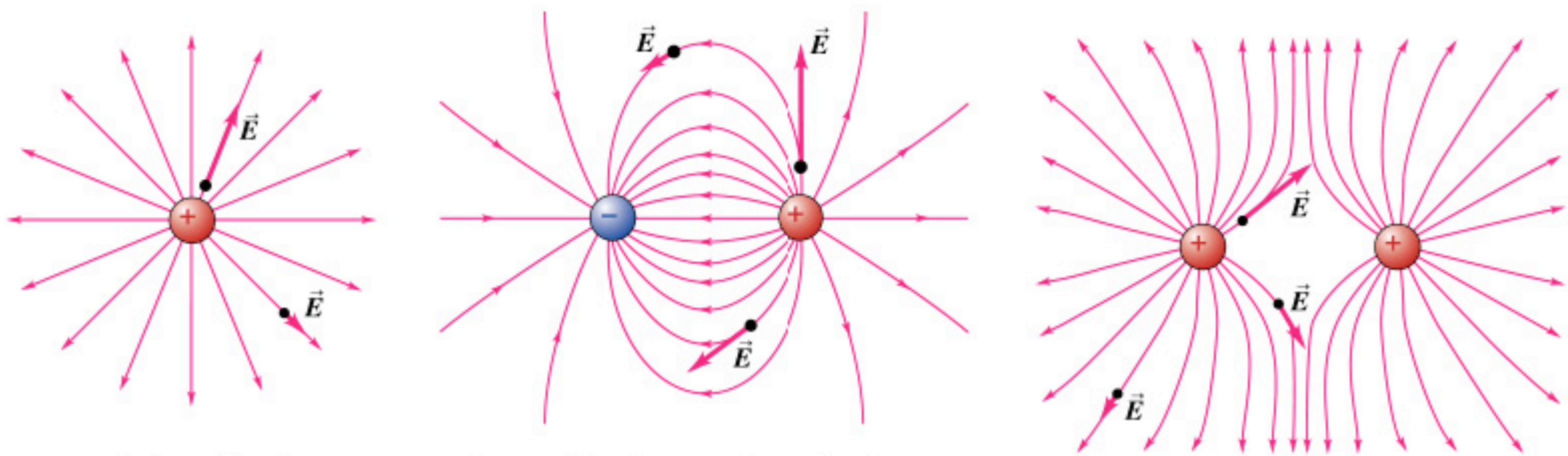
Definition of the Electric Field:

$$\vec{E} = \frac{\vec{F}}{q_0}$$

- **Since *F* is a vector, *E* is a vector**
  - ***field direction* = direction of force on a small *positive* "test" charge**

Field Lines: visualizing E fields

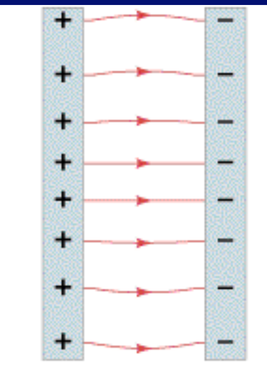
- Lines start on positive charges and end on negative charges
- Number of lines leaving/entering $\longrightarrow$ amount of charge
- Tangent of line $\longrightarrow$ direction of E
- Density of lines $\longrightarrow$ magnitude of E
- Field lines never cross. Otherwise, there would be multiple field values at a given point, which is not physical.



(a) A single positive charge (compare Figure 21.16)

(b) A positive charge and a negative charge of equal magnitude (an electric dipole)

(c) Two equal positive charges



(d)

Electric field of a point charge

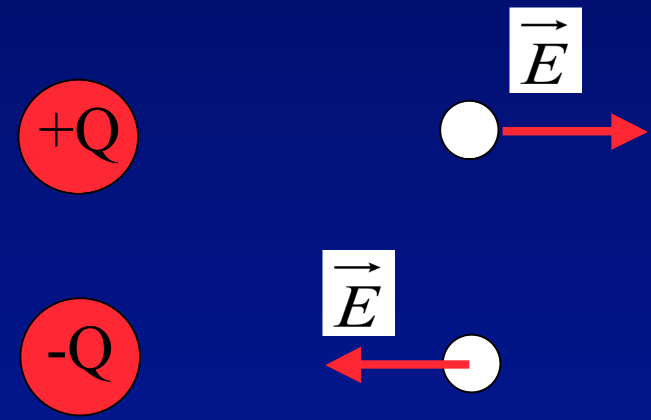
- **Coulomb's law:**

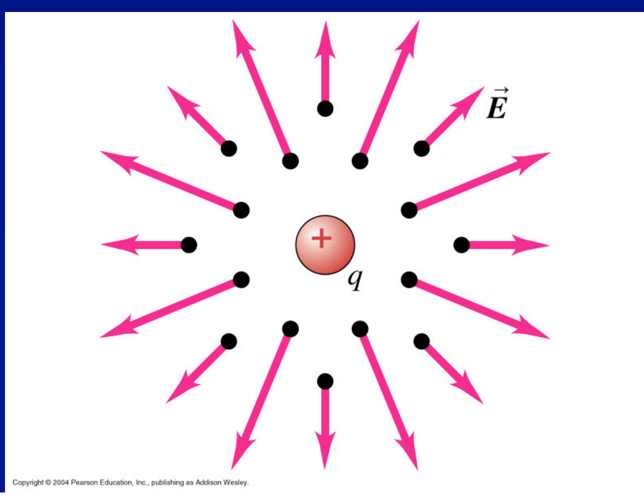
$$F = k\frac{Qq_0}{r^2}$$

- **What about direction?**

- **Electric field:**

$$E = k\frac{Q}{r^2}$$





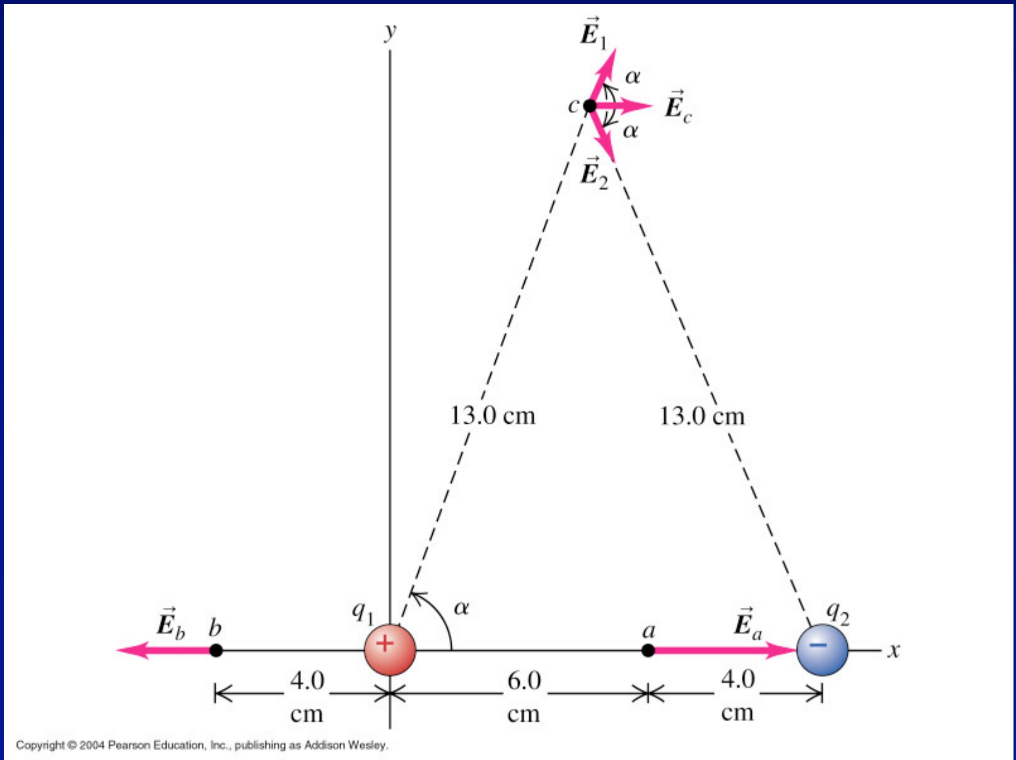
Example: What is the electric field at a point which is 30 cm away from a point charge q=+3μC ?

What about multiple point charges?

- Superposition principle
  - The field at a given point is a vector sum of the electric field caused by each charge individually.

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \cdots$$

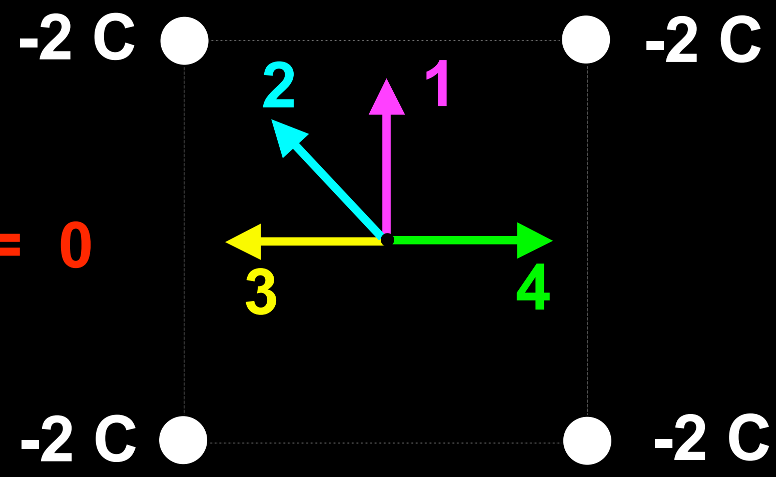
- Example: electric dipole
  - Point charges q_1=+12nC and q_2=-12nC are placed 10 cm apart. This combination of two charges with equal magnitude and opposite sign is called an electric dipole.
  - Compute the electric field at points a, b, and c.



ConcepTest 21.4 Electric Fields

- **Four equal charges sit at the for corners of a square. What is the electric field at the center of the square?**

5) E = 0



ConcepTest 21.5 Electric Fields

- Two charges are fixed along the x-axis. They produce an electric field E directed along the negative y-axis at the indicated point. Which of the following is true?

(1) charges are equal and positive

(2) charges are equal and negative

(3) charges are equal and opposite

(4) charges are equal, but sign is undetermined

(5) charges cannot be equal