Electrostatics

Course- PHY 2105 / PHY 105

Lecture 13

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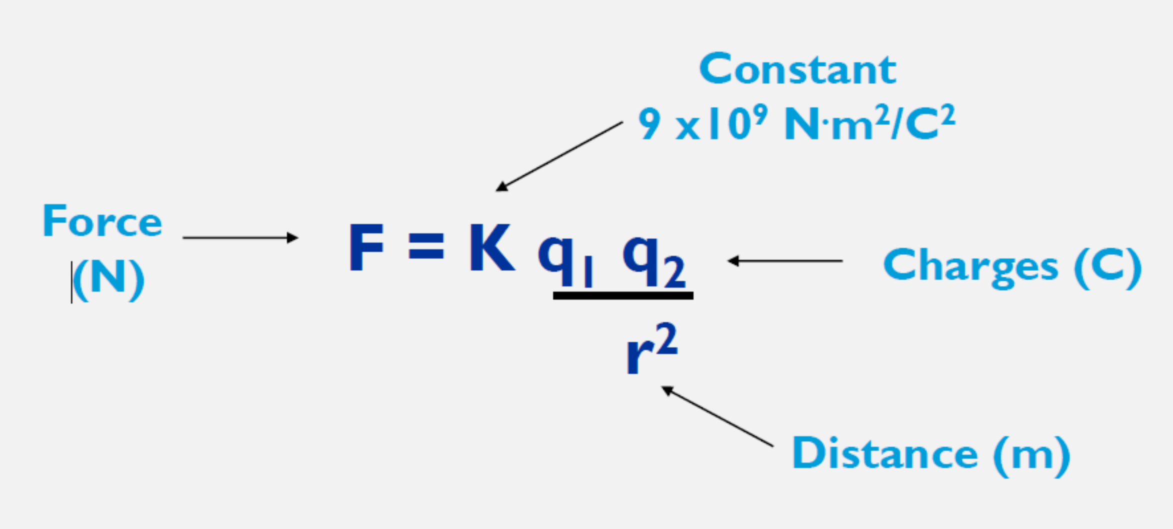
Coulomb's Law

The electrostatic force between two charged object is directly proportional to the product of the amount of charges and inversely proportional to the square of the distance between them



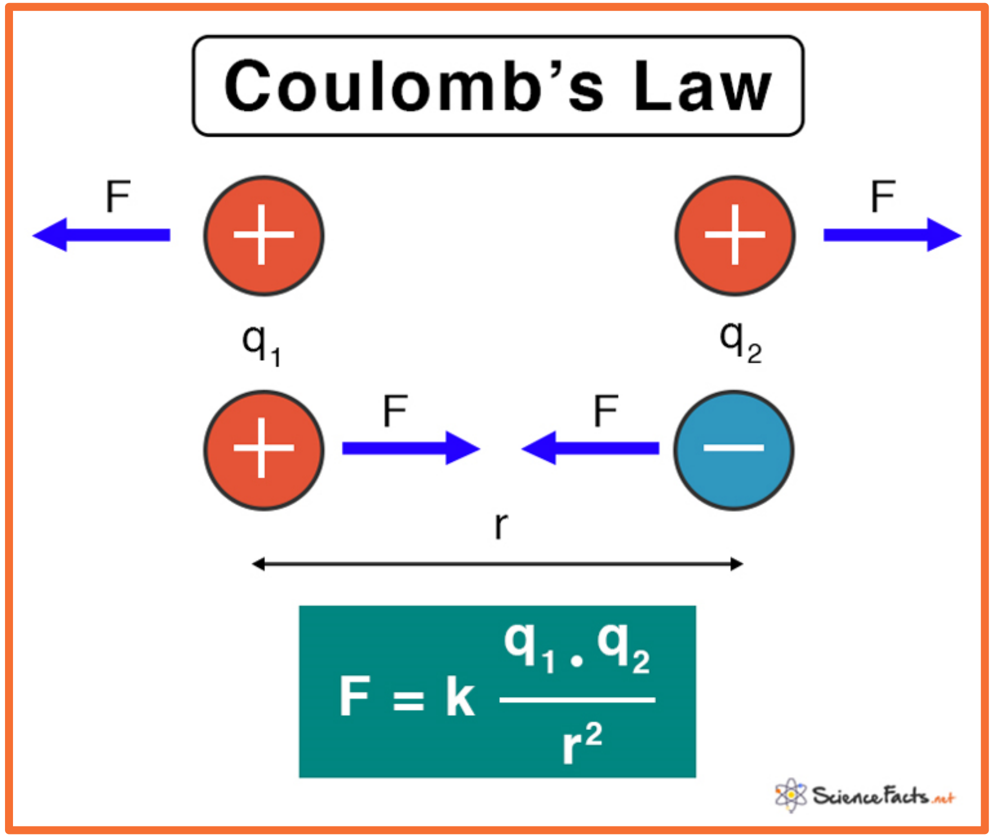
$$k = \frac{1}{4\pi\varepsilon_0}$$

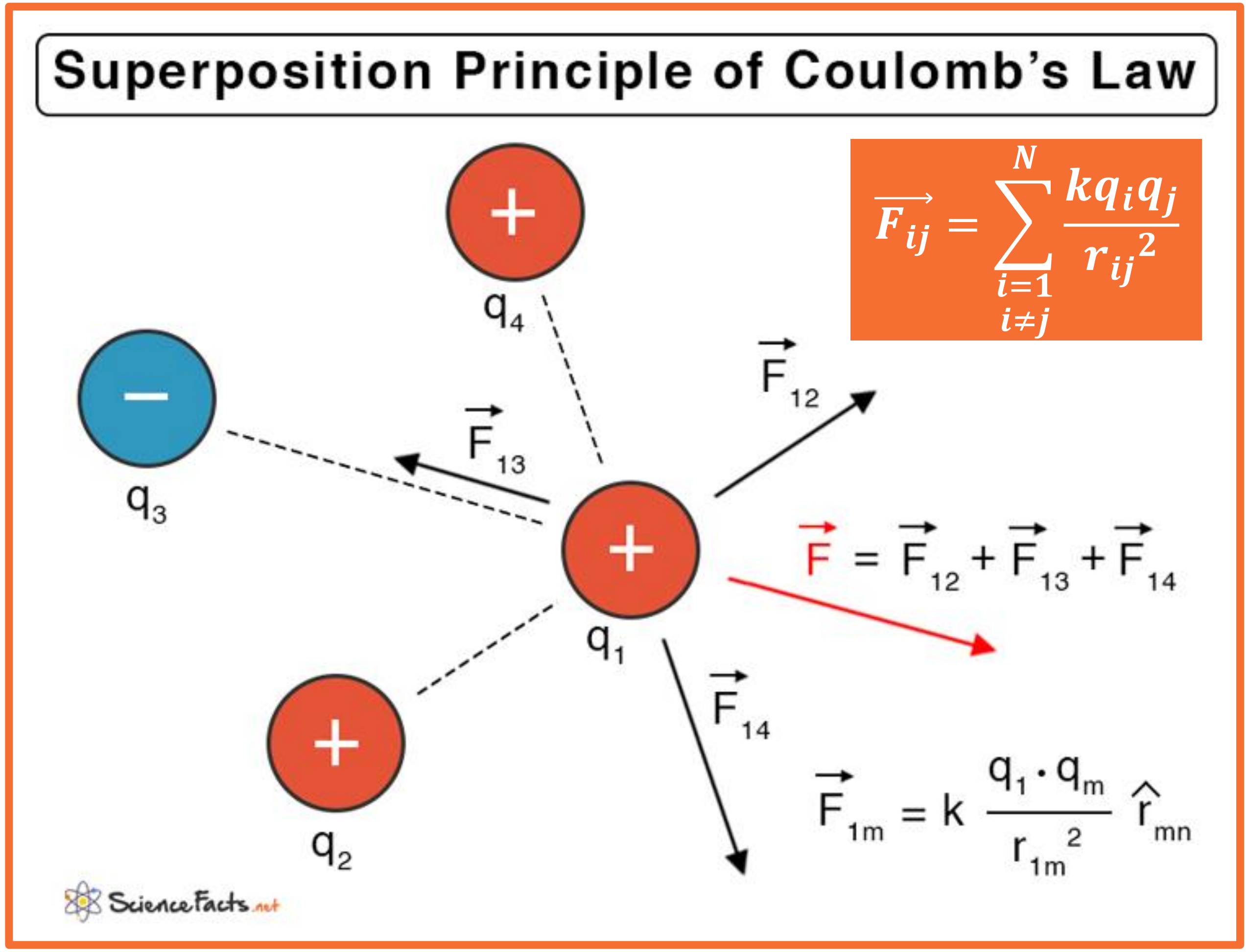
- *Experimental law*
- *Valid for point charges only*
- *Obeys Inverse Square Law*
- *Valid for only charges at rest*

$$Electrostatic\ constant, k = 9 \times 10^{9}\ \frac{Nm^2}{C^2}$$

$$Permittivity\ constant, \varepsilon_0 = 8.854 \times 10^{-12}\ \frac{C^2}{Nm^2}$$

Coulomb’s Law: Superposition





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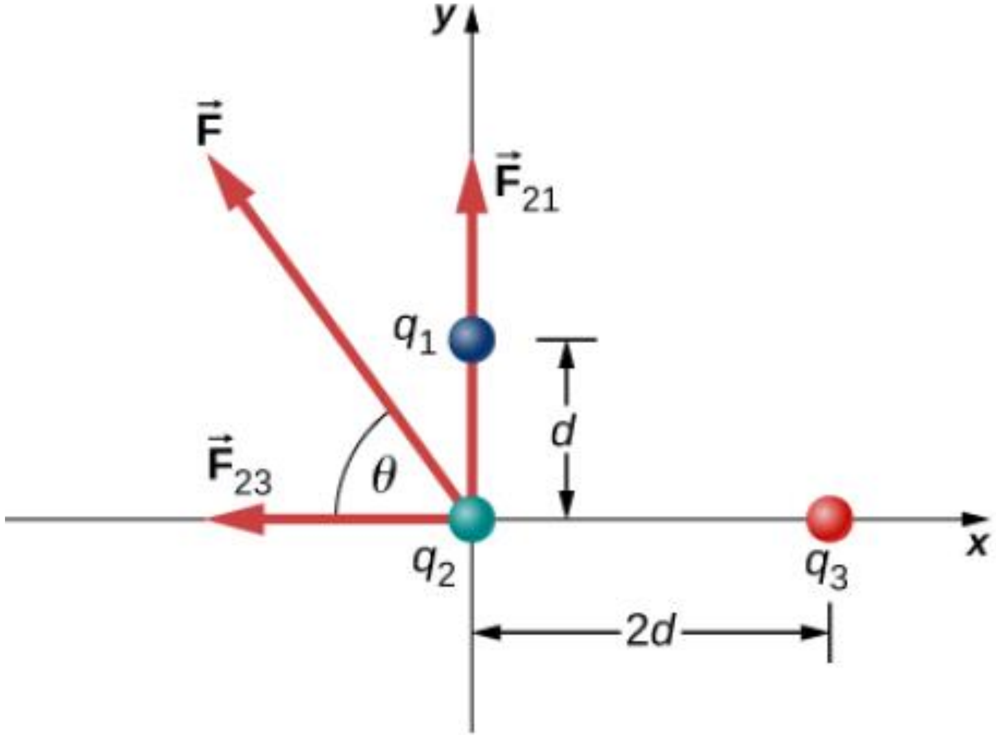
Example 11.4

The charges q1 and q2 are fixed in place; q3 is free to move. Given q1=2e, q2=-3e, and q3=-5e, and d= 200nm, what is the net force on the middle charge q2?



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$$F = \sqrt{F_x^2 + F_y^2}$$

$$\begin{aligned} F_x &= -F_{23} = -\frac{1}{4\pi\varepsilon_0}\frac{q_2 q_3}{r_{23}^2} \\ &= -\left(8.99 \times 10^9\,\frac{\mathrm{N{\cdot}m^2}}{\mathrm{C^2}}\right)\frac{\left(4.806\times10^{-19}\ \mathrm{C}\right)\left(8.01\times10^{-19}\ \mathrm{C}\right)}{\left(4.00\times10^{-7}\ \mathrm{m}\right)^2} \\ &= -2.16 \times 10^{-14}\ \mathrm{N} \end{aligned}$$

$$\begin{aligned} F_y &= F_{21} = \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_1}{r_{21}^2} \\ &= \left(8.99 \times 10^9\,\frac{\mathrm{N{\cdot}m^2}}{\mathrm{C^2}}\right)\frac{\left(4.806\times10^{-19}\ \mathrm{C}\right)\left(3.204\times10^{-19}\ \mathrm{C}\right)}{\left(2.00\times10^{-7}\ \mathrm{m}\right)^2} \\ &= 3.46 \times 10^{-14}\ \mathrm{N}. \end{aligned}$$

We find that

F= 4.08x10^-14 N at angle -58°

$$F = \sqrt{F_x^2 + F_y^2} = 4.08 \times 10^{-14}\ \mathrm{N}$$

at an angle of

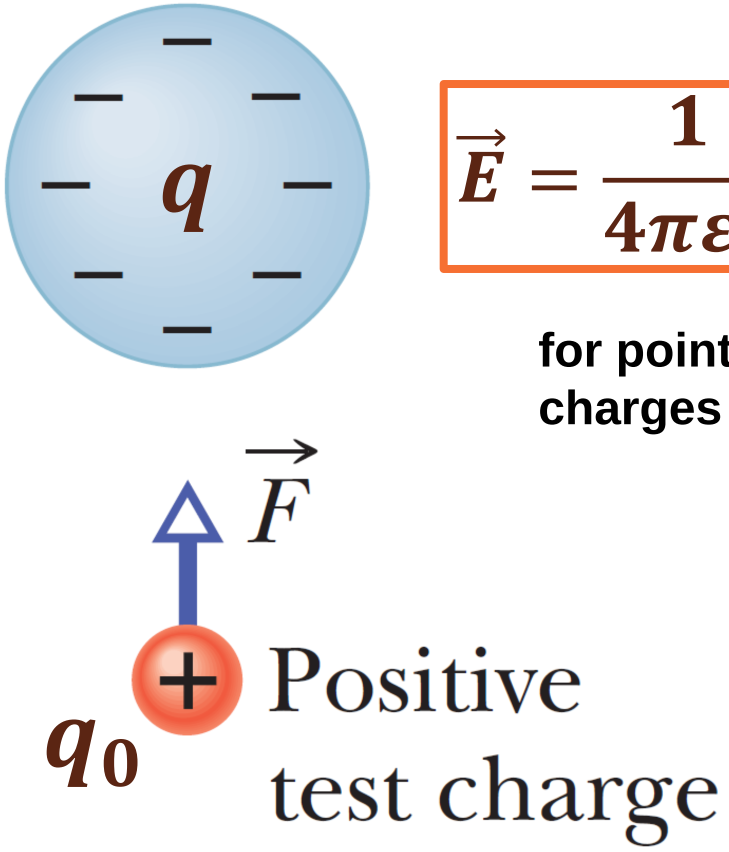
$$\phi = \tan^{-1}\left(\frac{F_y}{F_x}\right) = \tan^{-1}\left(\frac{3.46 \times 10^{-14}\ \mathrm{N}}{-2.16 \times 10^{-14}\ \mathrm{N}}\right) = -58^\circ,$$

that is, 58° above the $-x$-axis, as shown in the diagram.

Electric Field

$$\boxed{F = q_0 E}$$

A charge has an effect on its surroundings. The area where it has an effect is generally called an *Electric field.* If any other charge enters that area, it feels an electrostatic Coulomb force.



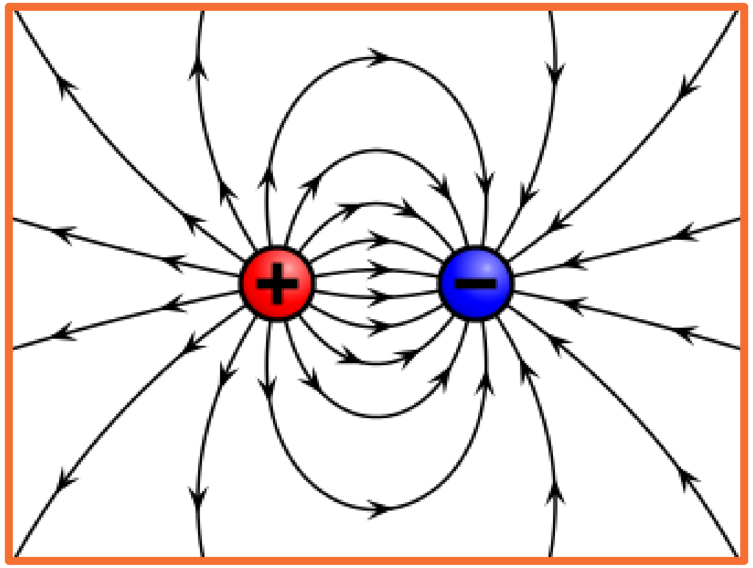
$$\boxed{\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\,\hat{r}}$$

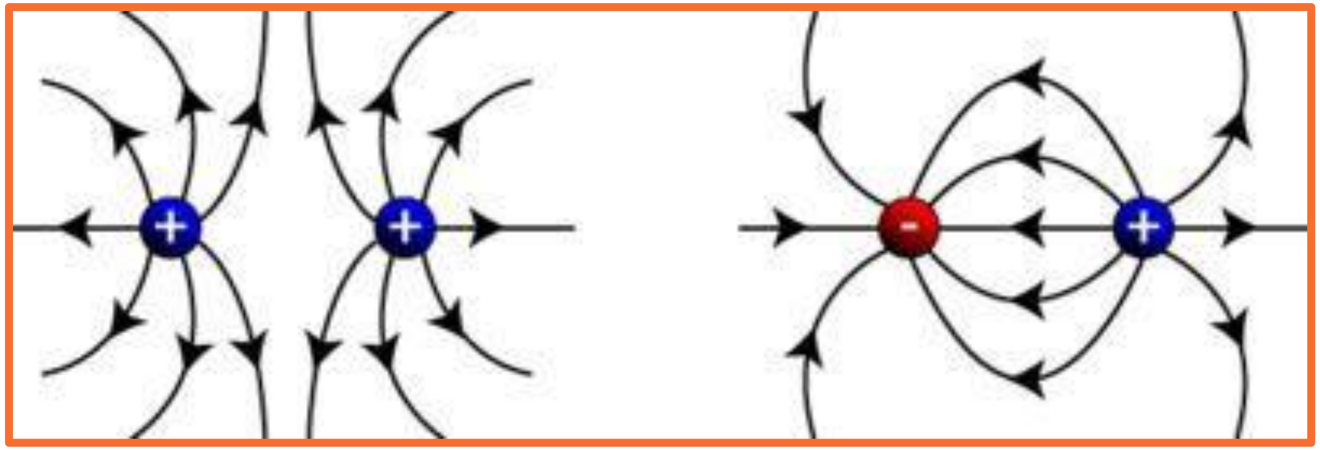
for point test charges only

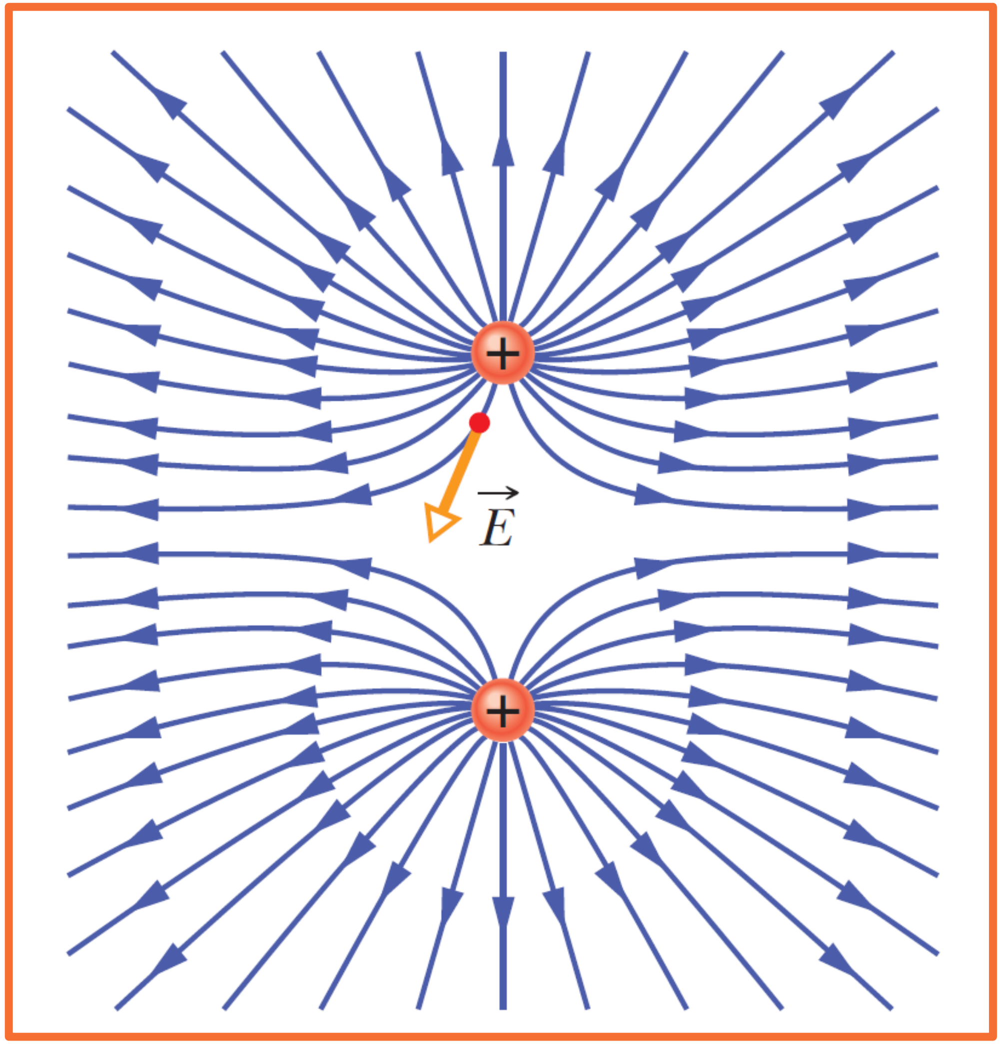
The electric force on a charged body is exerted by the electric field created by *other* charged bodies.

Field Lines

$$E = \frac{1}{4\pi\varepsilon_0}\frac{|q|}{r^2}$$

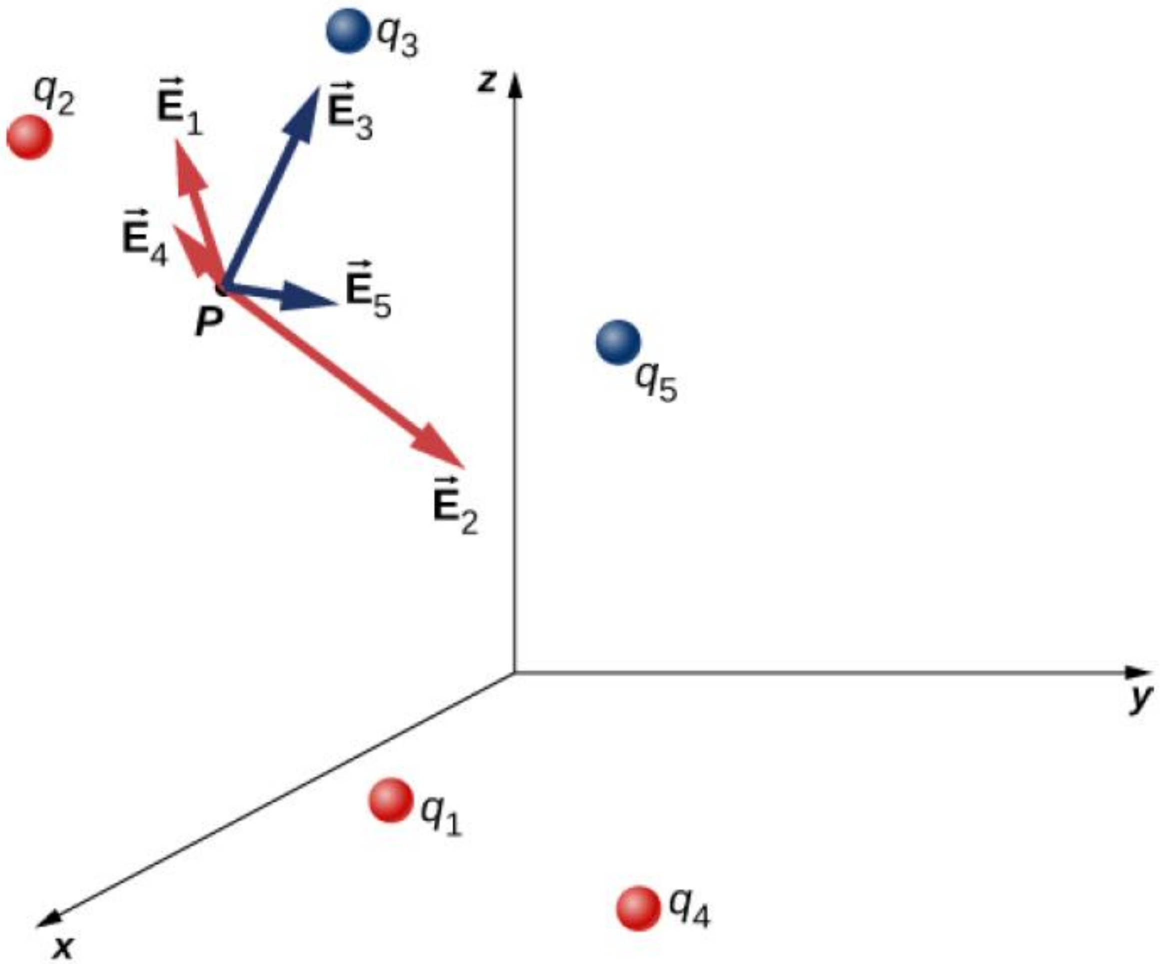






Superposition of Electric field

$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{N}\frac{q_i}{r_i^2}\,\hat{r}$$



- ❑ Treat electric field as a vector quantity
- ❑ q is source charge
- ❑ The test charge is positive

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Electric field due to a dipole

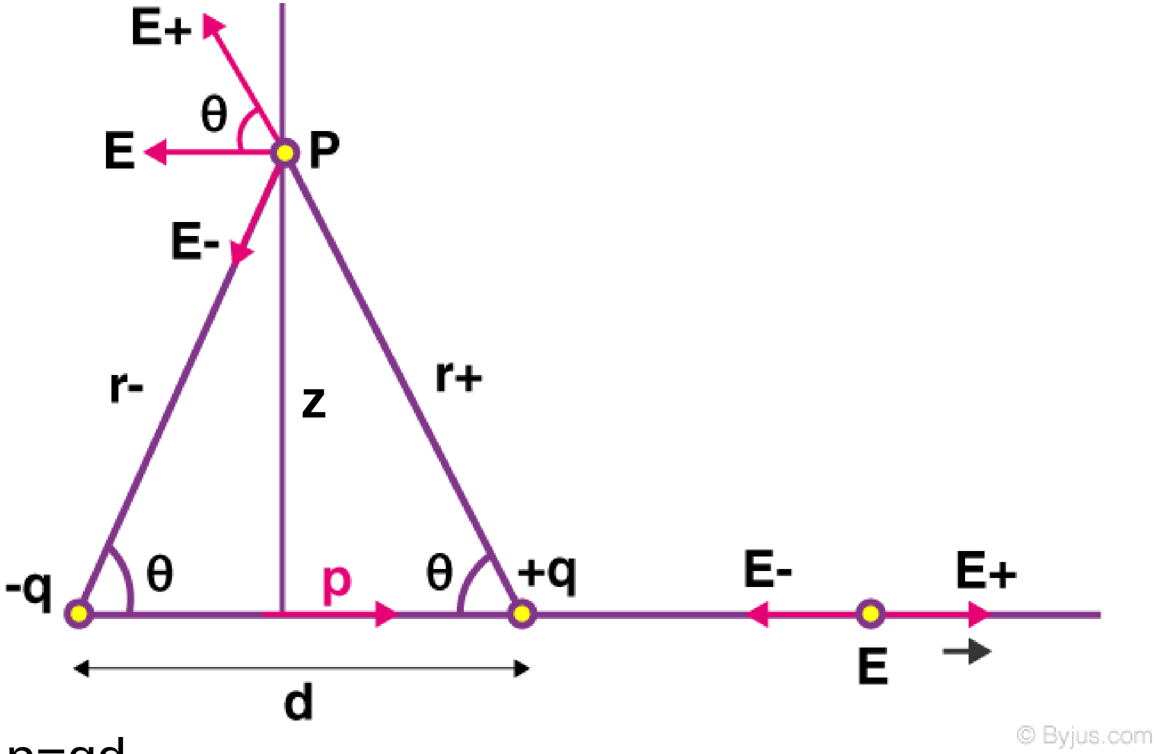
Pairs of point charges with equal magnitude and opposite sign are called *electric dipoles*

At any point

$$E = \frac{1}{4\pi\varepsilon_0}\frac{p}{z^3}$$

Along the dipole axis

$$E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{z^3}$$



Where, dipole moment, p=qd

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Electric Field in Nature

Sharks and the "Sixth Sense"

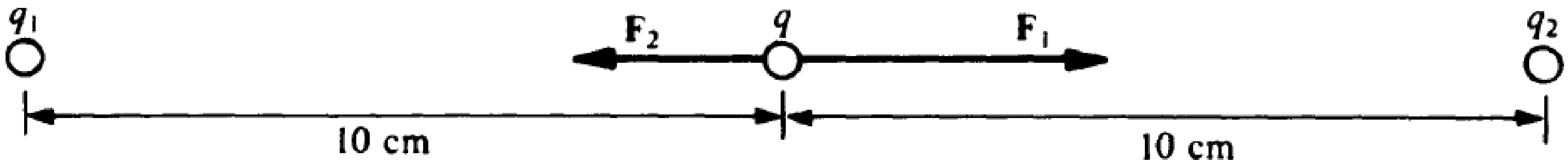
Sharks have the ability to locate prey that are completely hidden beneath the sand at the bottom of the ocean. They do this by **sensing the weak electric fields produced by muscle contractions** in their prey.

Sharks derive their sensitivity to electric fields (a "sixth sense") from jelly-filled canals in their bodies. These canals end in pores on the shark's skin (shown in this photograph). An electric field as weak as 5x10^-7 N/C causes charge flow within the canals and triggers a signal in the shark's nervous system.

Because the shark has canals with different orientations, it can measure different components of the electric-field vector and hence determine the direction of the field

Example 13.1

A test charge of $+1 \times 10^{-6}$ C is placed halfway between a charge of $+5 \times 10^{-6}$ and a charge of $+3 \times 10^{-6}$ C that are 20 cm apart (Fig. 23-2). Find the magnitude and direction of the force on the test charge.



The force exerted on the test charge q by the charge q_1 is

$$F_1 = \frac{kqq_1}{r_1^2} = \frac{(9 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1 \times 10^{-6}\ \mathrm{C})(5 \times 10^{-6}\ \mathrm{C})}{(0.1\ \mathrm{m})^2} = +4.5\ \mathrm{N}$$

This force is taken to be positive because it acts to the right. The force exerted by the charge q_2 on q is

$$F_2 = \frac{kqq_2}{r_2^2} = \frac{(9 \times 10^9\ \mathrm{N \cdot m^2/C^2})(1 \times 10^{-6}\ \mathrm{C})(3 \times 10^{-6}\ \mathrm{C})}{(0.1\ \mathrm{m})^2} = -2.7\ \mathrm{N}$$

This force is taken to be negative because it acts to the left. The net force on the test charge q is

$$F = F_1 + F_2 = +4.5\ \mathrm{N} - 2.7\ \mathrm{N} = +1.8\ \mathrm{N}$$

and it acts to the right, that is, toward the $+3 \times 10^{-6}$ C charge.

Example 13.2

A charge of -2x10^-9 C is placed between two metallic plates, and receives an electrostatic force of 10^-4 N. What is the quantity of the electric field between the plates?

Example 13.3

The electric field in a certain neon sign is 5000 V/m. (*a*) What force does this field exert on a neon ion of mass 3.3×10^{-26} kg and charge $+e$? (*b*) What is the acceleration of the ion?

(*a*) The force on the neon ion is

$$F = qE = eE = (1.6 \times 10^{-19}\ \text{C})(5 \times 10^{3}\ \text{V/m}) = 8 \times 10^{-16}\ \text{N}$$

(*b*) According to the second law of motion $F = ma$, and so here

$$a = \frac{F}{m} = \frac{8 \times 10^{-16}\ \text{N}}{3.3 \times 10^{-26}\ \text{kg}} = 2.4 \times 10^{10}\ \text{m/s}^2$$

Example 13.4

How strong electric field is required to exert a force on a proton equal to its weight at sea level? m(p) = 1.67x10^-24 g

The electric force on the proton is $F = eE$, and its weight is mg. Hence $eE = mg$, and

$$E = \frac{mg}{e} = \frac{(1.67 \times 10^{-27}\ \mathrm{kg})(9.8\ \mathrm{m/s^2})}{1.6 \times 10^{-19}\ \mathrm{C}} = 1.02 \times 10^{-7}\ \mathrm{V/m}$$

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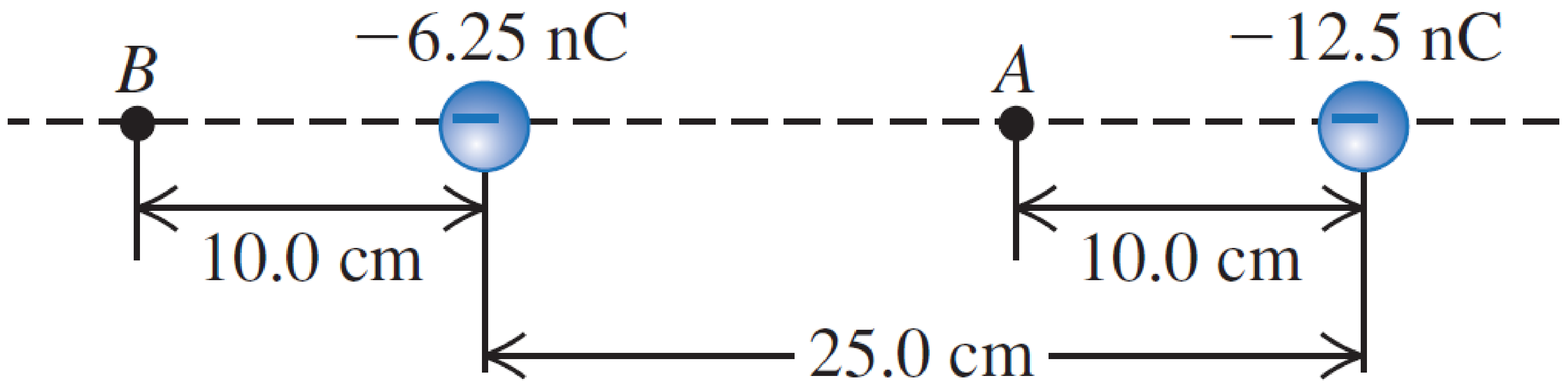
Example 13.5

Two point charges are separated by 25 cm. Find the net electric field these charges produce at (a) point A and (b) point B.
(c) What would be the magnitude and direction of the electric force this combination of charges would produce on a proton at point A?



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