Week 1

Coulomb's Law

SI Units

[Charge] = Coulombs (C)

[Distance] = meters (m)

[Force] = Newtons (N)

Constants

$e = -1.6\times10^{-19}\ \mathrm{C}$ Electron Charge

$$k = \frac{1}{4\pi\varepsilon_o} = 9\times10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}$$

Coulomb's Law

$$\boxed{\vec{F}_C = k\frac{q_1 q_2}{r^2}\hat{r}}$$

Gravitational Force

$$\boxed{\vec{F}_G = -G\frac{m_1 m_2}{r^2}\hat{r}}$$

SI Units

[Charge] = Coulombs (C)

[Distance] = meters (m)

[Force] = Newtons (N)

Constants

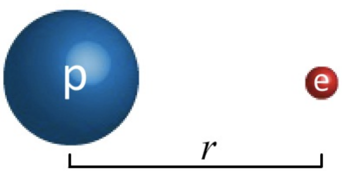
$e = -1.6\times10^{-19}\ \mathrm{C}$ Electron Charge

$$k = \frac{1}{4\pi\varepsilon_o} = 9\times10^{9}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}}$$

$$G = 6.67\times10^{-11}\ \frac{\mathrm{N\cdot m^2}}{\mathrm{kg}}$$

$m_e = 9.1\times10^{-31}\ \mathrm{kg}$ Electron Mass

$m_p = 1.6\times10^{-27}\ \mathrm{kg}$ Proton Mass



$$\boxed{\frac{F_C}{F_G} = \frac{k\,e^2}{G\,m_e m_p} \sim 10^{40}}$$

Force between protons and neutrons are stronger.

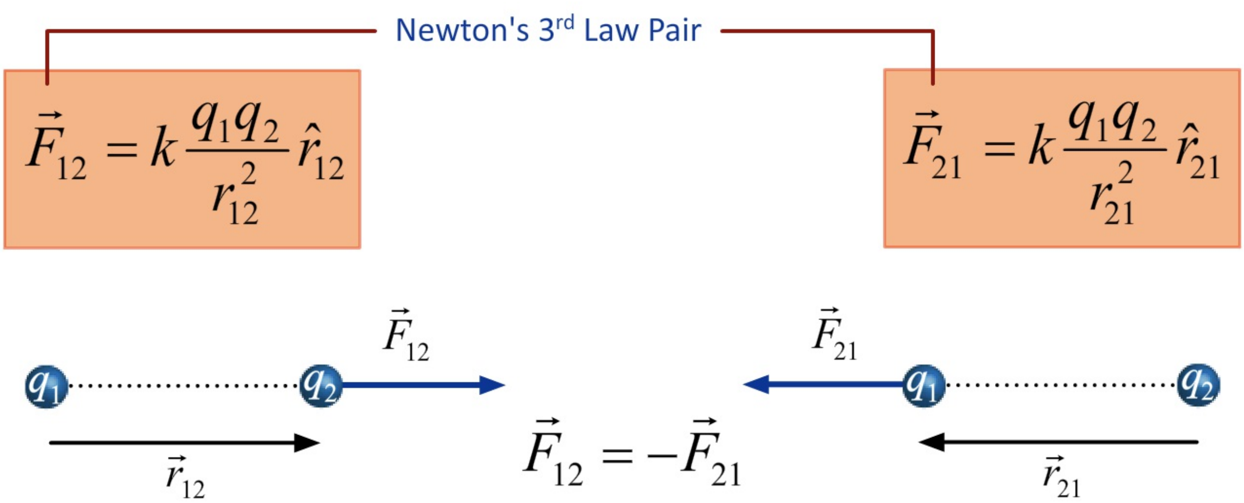
Questions

1. The nucleus of a Helium atom has a charge equal to twice the proton's charge. Let FN denote the magnitude of the force the Helium nucleus exerts on one of the electrons in a Helium atom, and let Fe denote the magnitude of the force one electron in the Helium atom exerts on the Helium nucleus.

Answer: F_N = F_e

Even though the charges are not the same, the magnitude of the forces must be equal. The dominant force between the nucleus and the electron is the Coulomb force and this force is proportional to the product of the charges. Therefore, the magnitudes of F_N and F_e must be equal since the order in the multiplication doesn't matter.

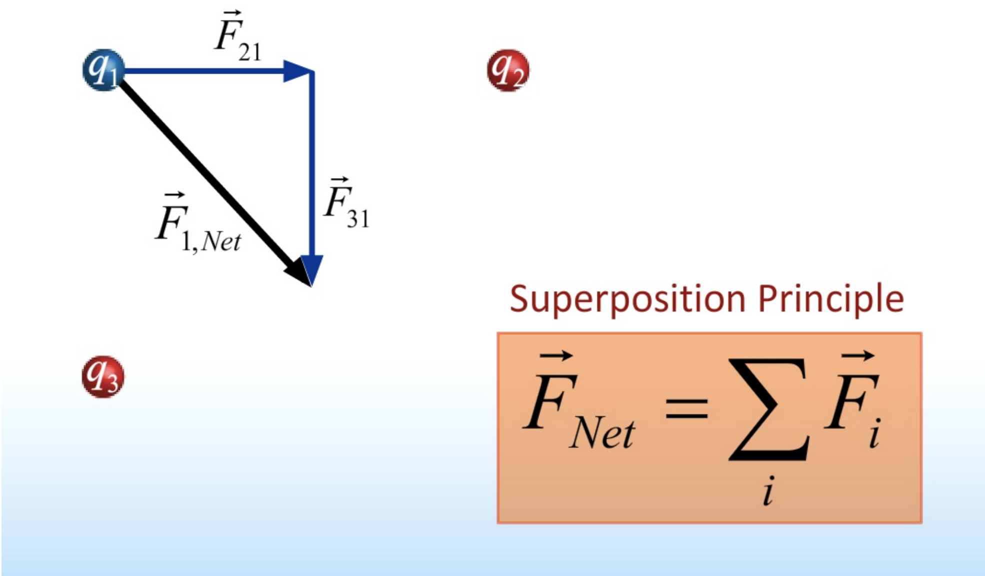
There is a more general reason that these forces must be equal, however: they comprise a Newton's third law interaction pair which means that their magnitudes are the same and their directions are opposite.



Superposition Principle

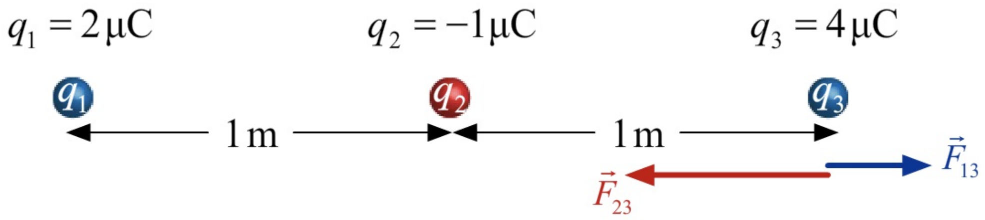
What if there are multiple negative charges, q2 and q3, exerting a force on positive charge q1?

$$\vec{F}_{1,Net} = \vec{F}_{21} + \vec{F}_{31}$$



You simply add the vectors (forces) to find the net force.

Example 1



Question: $\vec{F}_{3,Net} = ?$

$$\vec{F}_{3,Net} = \vec{F}_{13} + \vec{F}_{23}$$

Coulomb Force

$$\vec{F} = k\frac{q_1 q_2}{r^2}\hat{r}$$

$$\vec{F}_{13} = 9\times10^9 \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}} \frac{(2\,\mu\mathrm{C})(4\,\mu\mathrm{C})}{(2\,\mathrm{m})^2} = \boxed{0.018\ \mathrm{N}}$$

$$\vec{F}_{23} = 9\times10^9 \frac{\mathrm{N\cdot m^2}}{\mathrm{C^2}} \frac{(-1\,\mu\mathrm{C})(4\,\mu\mathrm{C})}{(1\,\mathrm{m})^2} = \boxed{-0.036\ \mathrm{N}}$$

To find F_3,Net, you calculate the sum of F_13 and F_23.

Example 2

What if we make this into a 2-D space, and place q2 below q3 at 90 degrees?

Then you would have to break this down into two parts, F_3, Net x and F_3 Net y

F_23x is trivial since you are only concerned about the force exerting on y-axis between q2 and q3, and F_13y is trivial since you are only concerned about the force exerting on x-axis between q1 and q3. Therefore, you can safely eliminate those two variables.

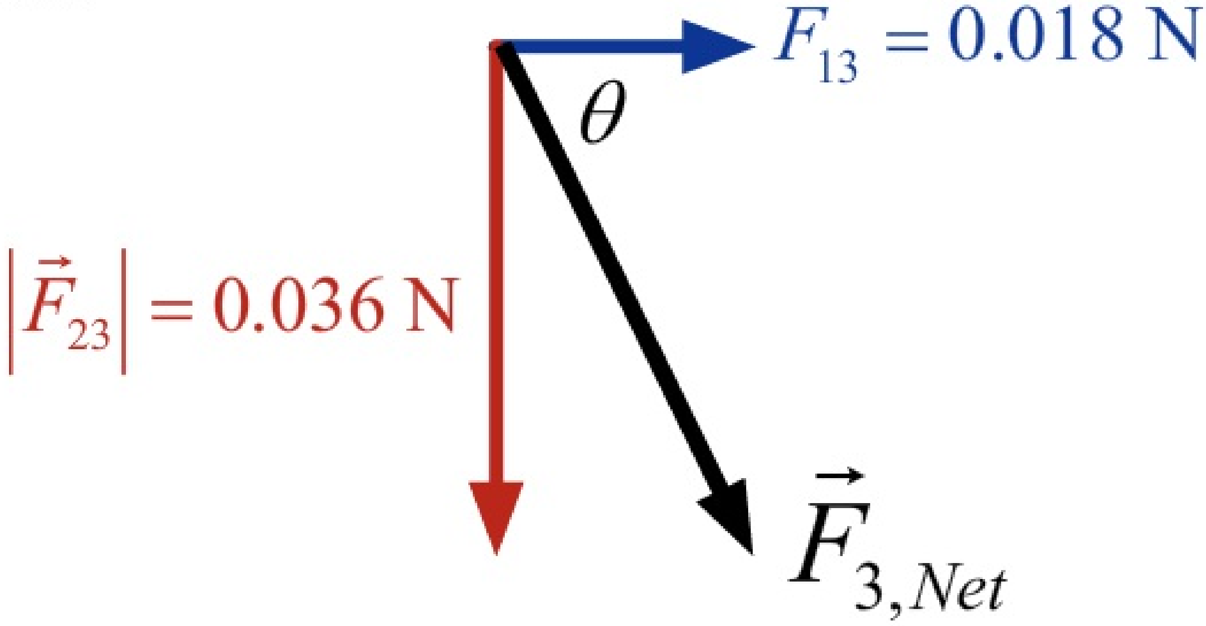
Since sum of vectors in 2-D requires using Pythagorean Theorem, you do

$$d_T = \sqrt{(d_{T_x})^2 + (d_{T_y})^2}$$

Pythagorean Theorem

$$\left|\vec{F}_{3,Net}\right| = \sqrt{(0.018\text{ N})^2 + (-0.036\text{ N})^2} = 0.040\text{ N}$$

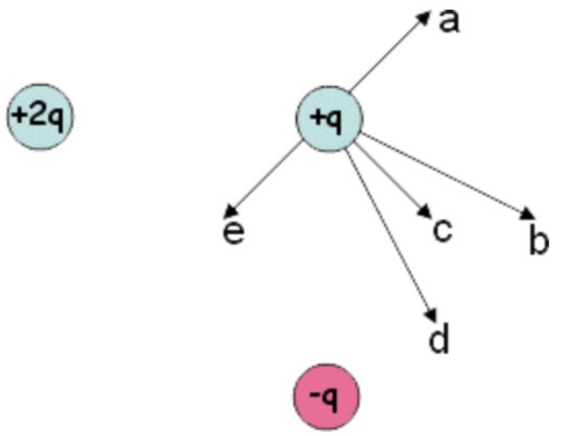
To find the direction of the vector, you use Trig.



$$\tan\theta = \frac{-0.036}{0.018} = -2$$

Questions

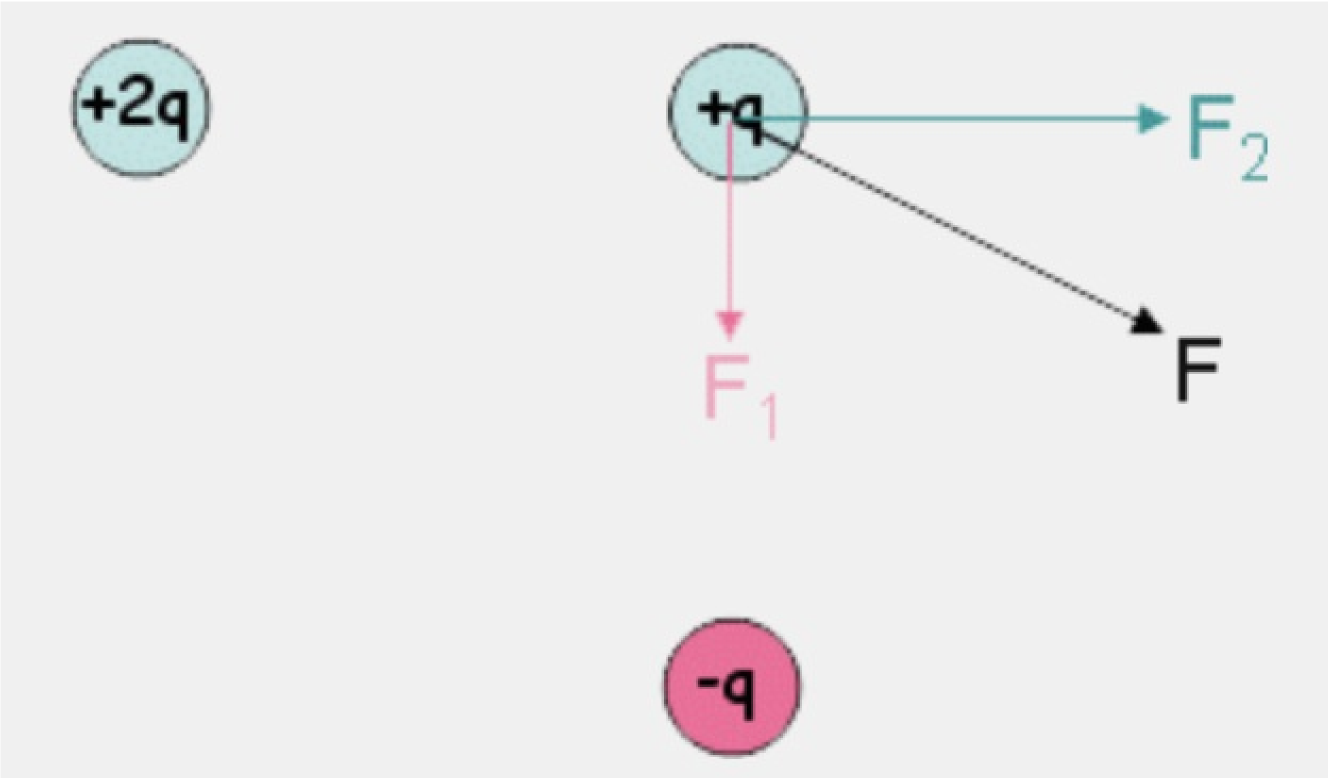
Three charges are fixed in place as shown below. The $+q$ charge is equidistant from the $+2q$ and $-q$ charges.



Which of the vectors shown most closely represents the total force on the $+q$ charge?

Answer: (b)

To find the total force on +q charge we need to add the force on it from the +2q charge (F2) and the force on it from the −q charge (F1) as shown in the diagram below.



Note that F2 is twice as long as F1 since the distances from +q to +2q and to –q are the same, but the magnitude of +2q is twice that of –q. F2 points to the right since +2q exerts a repulsive force on +q. F1 points down since –q exerts an attractive force on +q. The total force (F2) on +q is found by taking the vector sum as shown.