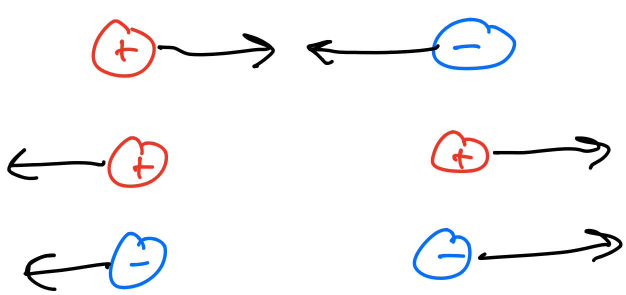
- What is charge?
    - Like mass, charge is a fundamental property of matter
    - *Unlike* mass, charge comes in two types
        - Positive and negative
    - Examples of charged particles?
    - What is the unit of charge?

Charge

- Property of matter
- Two types (+ and −)
- Charge of proton = e

$$e = 1.6 \times 10^{-19}\ C$$

- Smallest possible charge?
    - e
    - All charged objects have charges which are multiples of e
- Electric force
    - What happens when I bring two charges close to each other?
    - They experience a force
    - Either attract (like mass) or repel (new!)



$$|\vec{F}| \propto \,?$$

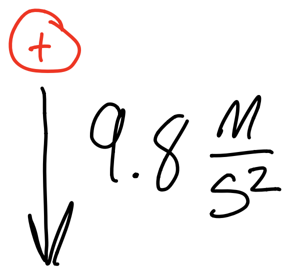
$$|\vec{F}| \propto q_1 q_2$$

$$|\vec{F}| \propto \frac{1}{r^2}$$

$$|\vec{F}| = \frac{k q_1 q_2}{r^2}, \quad k = \frac{1}{4\pi\epsilon_0},$$

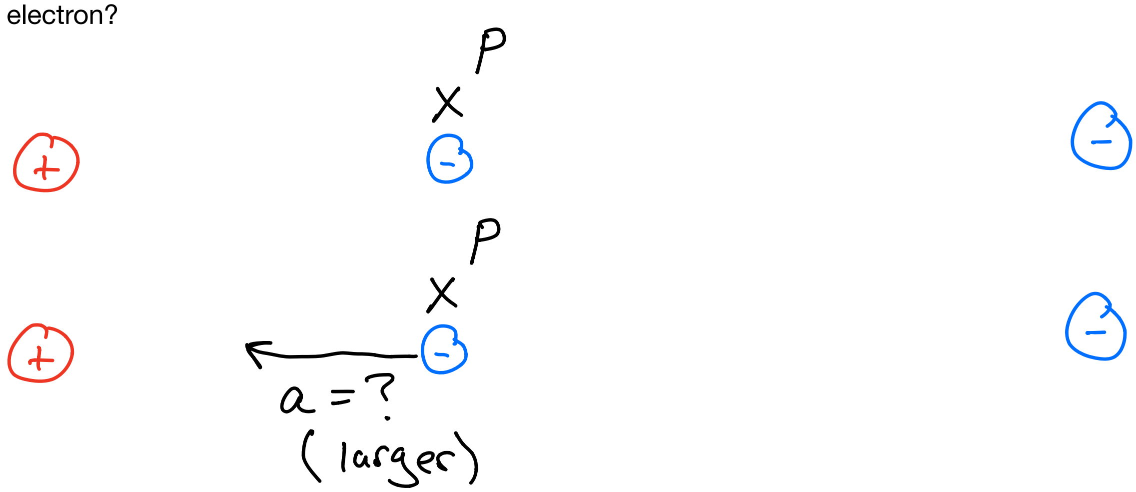
$$\epsilon_0 = 8.85 \times 10^{-12}\ \frac{C^2}{N \cdot m}$$

- A thought experiment
  - Suppose I'm holding a proton, I release it, and it accelerates directly downward at a = 9.8 m/s2
  - What do suppose the proton is interacting with?



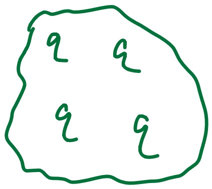
- Now I try the same thing over again, but this time the proton accelerates to the right at a=1x10^11 m/s^2
  - Is this likely to be a gravitational interaction?
  - What could cause this interaction? (Ask)
  - It's clearly electromagnetic right?

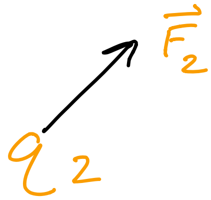
- What would you expect if I remove the proton, mark it's position, and then replace it with an electron?



- Clearly there is something going on at this particular point in space
  - Apparently, any charge we put there there will experience a force!
  - It's almost as if there is some mysterious force field there...
  - This property of space is what we will call the **Electric Field**
  - Think of it like a "virtual force", a force that is there just waiting for a charge to interact with

Electric Field





Define $\vec{E}_1$ such that

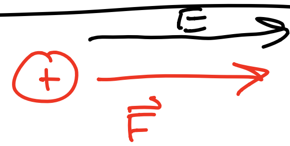
$$\vec{F}_2 = q_2 \vec{E}_1 \qquad \vec{E}_1 = \frac{\vec{F}_2}{q_2}$$

Force per unit charge

Properties of E field

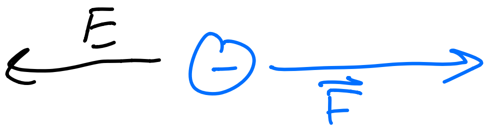
- vector
- property of a location in space $\vec{E}(x,y,z)$
- Exists at $\langle x,y,z \rangle$ even if there is no charge there
- created by other charges located elsewhere

Direction of E field



Force to the right
"q" is positive
therefore E is to the right

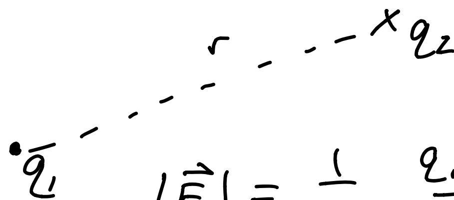
$$\vec{E} = \frac{\vec{F}}{q}$$



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

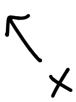
$q < 0 \Rightarrow \vec{F}$ is ←

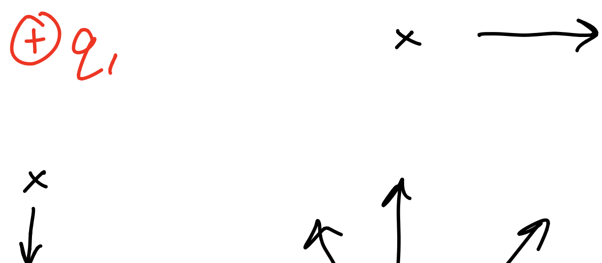
E Field of a Point Charge?

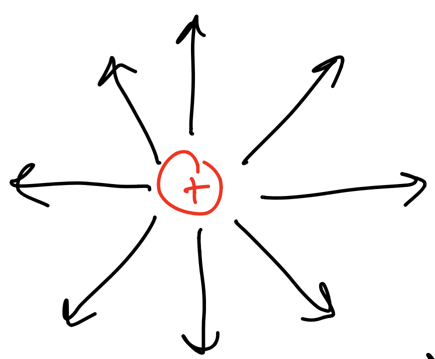


$$|\vec{F}| = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$|\vec{E}_1| = \frac{|\vec{F}_2|}{q_2} = \frac{1}{4\pi\epsilon_0} \frac{q_1}{r^2}$$



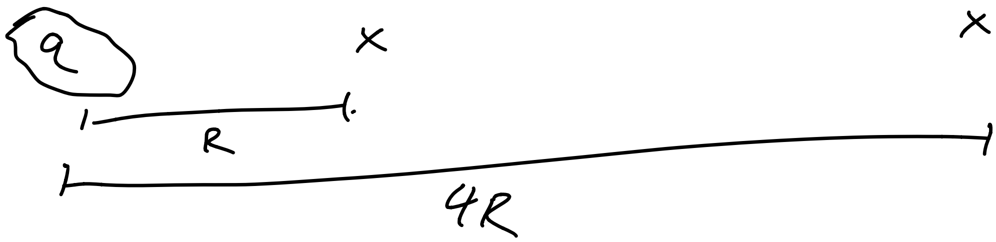




Field is "radial" ($\hat{r}$)

$$\vec{E}_1 = \frac{1}{4\pi\epsilon_0} \frac{q_1}{|\vec{r}|^2} \hat{r}$$

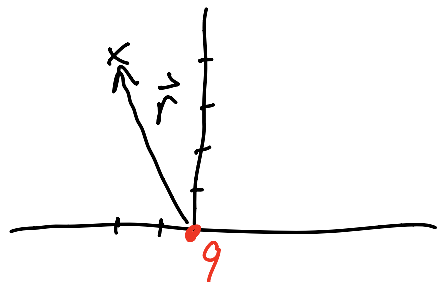
- If I move my measurement point 4x farther away, how does the field change?



Example:

We have a particle w/ charge $q = 6\mu C$

What is the field @ $\langle -0.2, 0.4, 0 \rangle m$?



$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{|\vec{r}|^2} \hat{r}$$

$$|\vec{r}| = \sqrt{0.2^2 + 0.4^2 + 0^2} = 0.45 \, m$$

$$\hat{r} = \frac{\vec{r}}{|\vec{r}|} = \left\langle \frac{-0.2}{.45}, \frac{0.4}{.45}, 0 \right\rangle$$

$$\hat{r} = \langle -0.44, 0.88, 0 \rangle$$

$$q = 6 \times 10^{-6} \, C$$

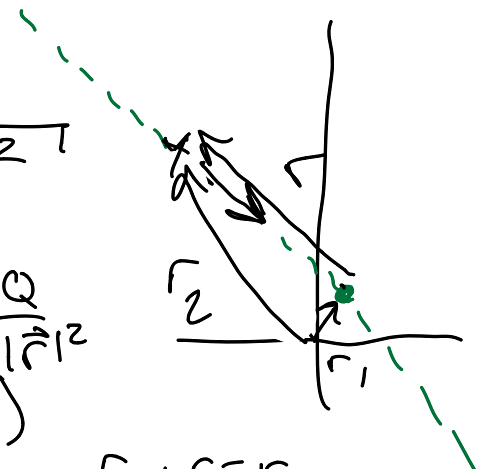
$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{6 \times 10^{-6}}{(0.45)^2} \langle -0.44, 0.88, 0 \rangle$$

Example

$\vec{E}$ field at $\langle -0.2, 0.1, 0 \rangle$ is $\langle 7.3\times10^3, -6.4\times10^3, 0\rangle \frac{N}{C}$.

$Q = -4\,nC$. Where is Q?

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{Q}{|\vec{r}|^2}\hat{r}$$



$$|\vec{E}| = \sqrt{(7.3\times10^3)^2 + (6.4\times10^3)^2}$$

$$= 9.7\times10^3 \frac{N}{C} = \frac{1}{4\pi\epsilon_0}\frac{Q}{|\vec{r}|^2}$$

$$|\vec{r}|^2 = \frac{1}{4\pi\epsilon_0}(4\times10^{-9})$$

$$r^2 = 35.97$$

$$r = 6.00$$

$$|\vec{r}| = 6.00$$

$r_1 + r = r_2$

$r = r_2 - r_1$

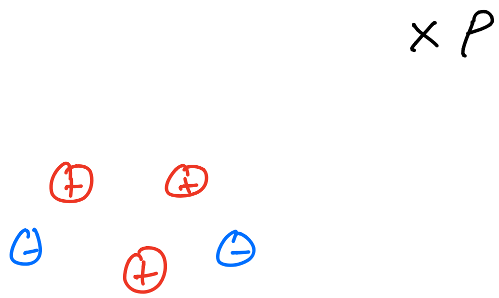
$r_1 = r_2 - r$

$\hat{r} = ?$ $\quad q < 0 \longrightarrow \hat{r} = -\hat{E}$

$$\hat{E} = \frac{\vec{E}}{|\vec{E}|} = \frac{1}{9.7\times10^3}\langle 7.3\times10^3, 6.4\times10^3\rangle$$

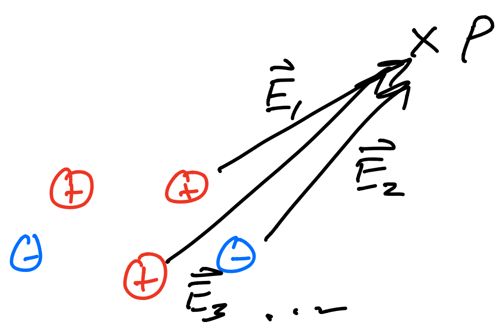
$$\hat{r} = -\hat{E}$$

- Superposition
  - How do we find the electric field of a collection of charges?



Superposition

Electric Field at a point in space is the vector sum of the individual field of all charged particles



$$\vec{E}_p = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots$$

We know the field of a point charge.

We know how to add vectors.

WE'RE DONE!