



Recitation 4

...

It's ~electric~



Review: What you've done

Temperature
of universe

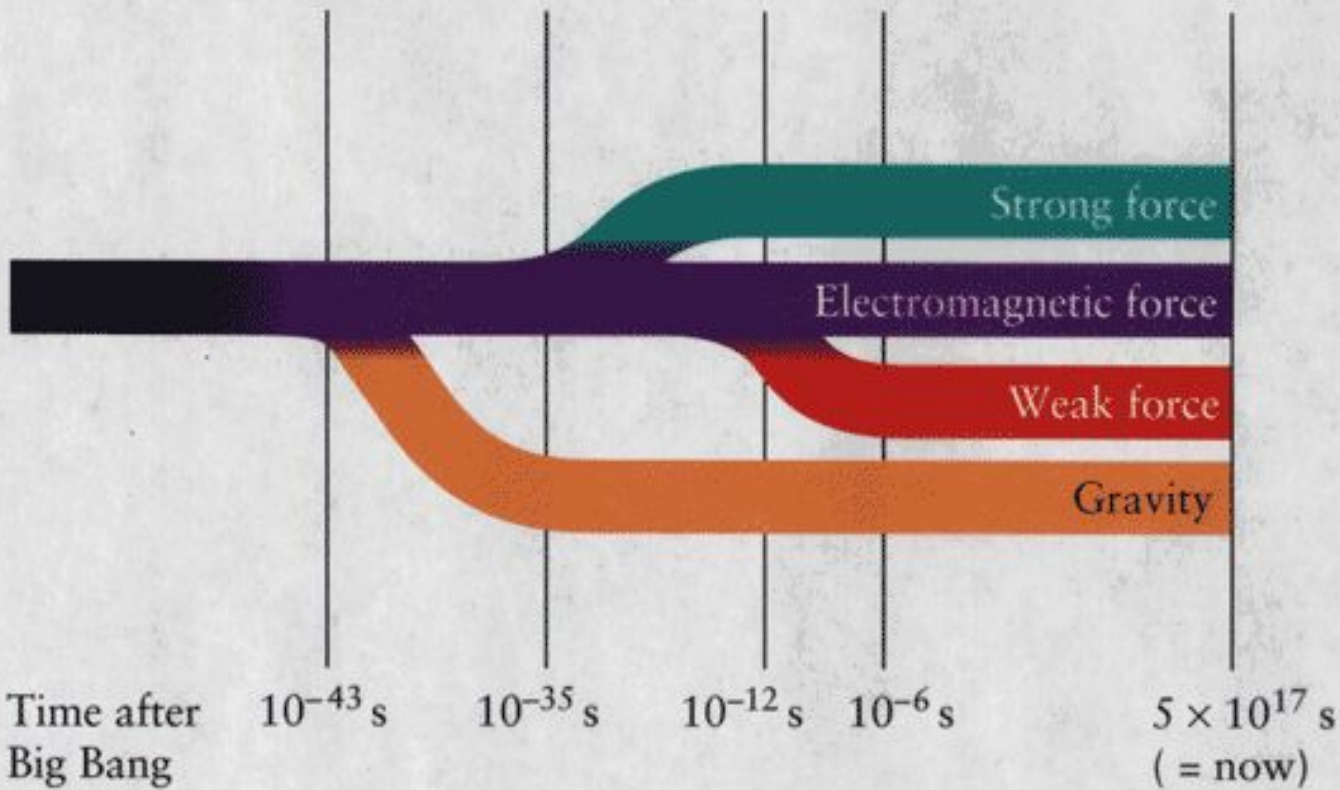
10^{32} K

10^{27} K

10^{15} K

10^{13} K

3K



Time after
Big Bang

10^{-43} s

10^{-35} s

10^{-12} s

10^{-6} s

5×10^{17} s
(= now)

Strong force

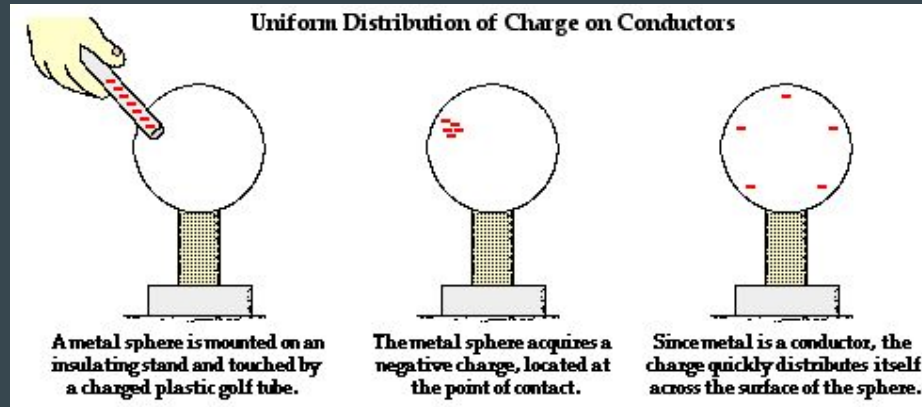
Electromagnetic force

Weak force

Gravity

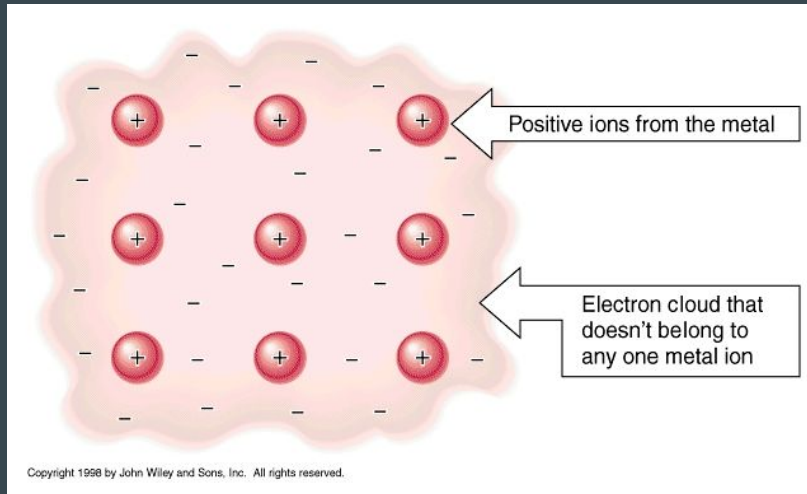
Properties of matter

- Charge is an *intrinsic* property
- Comes in quantized bundles of $\pm 1.602 \times 10^{-19}$ C (we call this e)
- Protons have a charge of positive e , electrons have a charge of negative e , neutrons are neutral
- Charge can transfer from one object to another



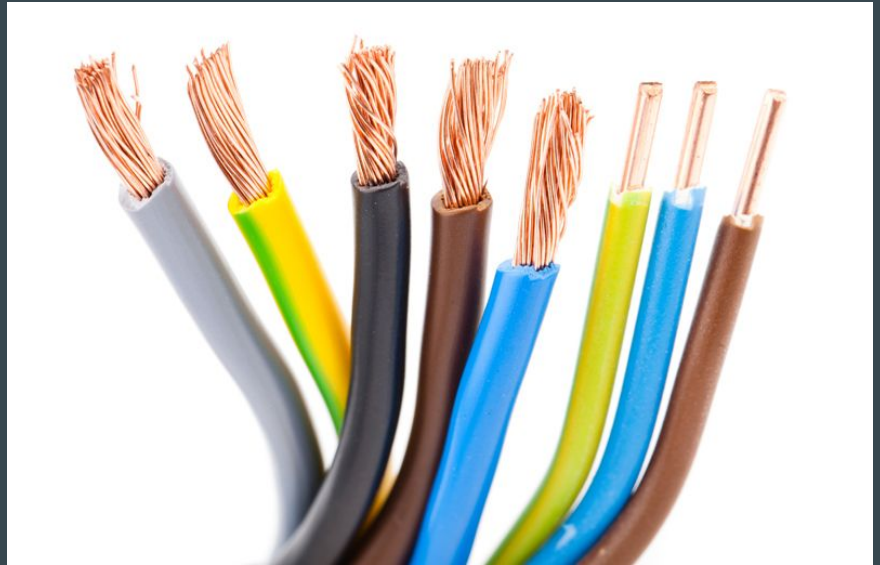
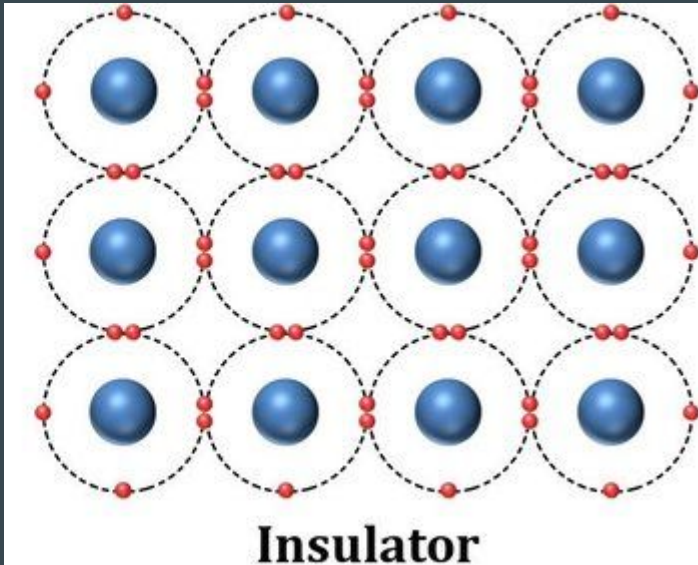
Conductors

- Usually some type of metal like copper
- Electrons easily move around in a conductor
- Electrons are not bound to any one atom
- Still confined to the metal (they stay within the conductor)



Insulators

- Electrons are bound to an atom
- Difficult for current to travel through
- May have some free electrons, but not very many



Lichtenberg Figures

- If the current is large enough, it will travel through the insulator and branch out creating a cool, fractal pattern



Coulomb's Law - Model in Words

$$|F_{21}| = |F_{12}| = \frac{k|q_1||q_2|}{|\Delta\vec{r}_{12}|^2}$$

Electric force
of particle 2 on 1



Electric force
of particle
1 on 2



Charge 1



Charge 2



$$|\vec{F}_{21}^E| = |\vec{F}_{12}^E| = \frac{k |q_1| |q_2|}{|\Delta\vec{r}_{12}|^2}$$

Distance between
 q_1 and q_2



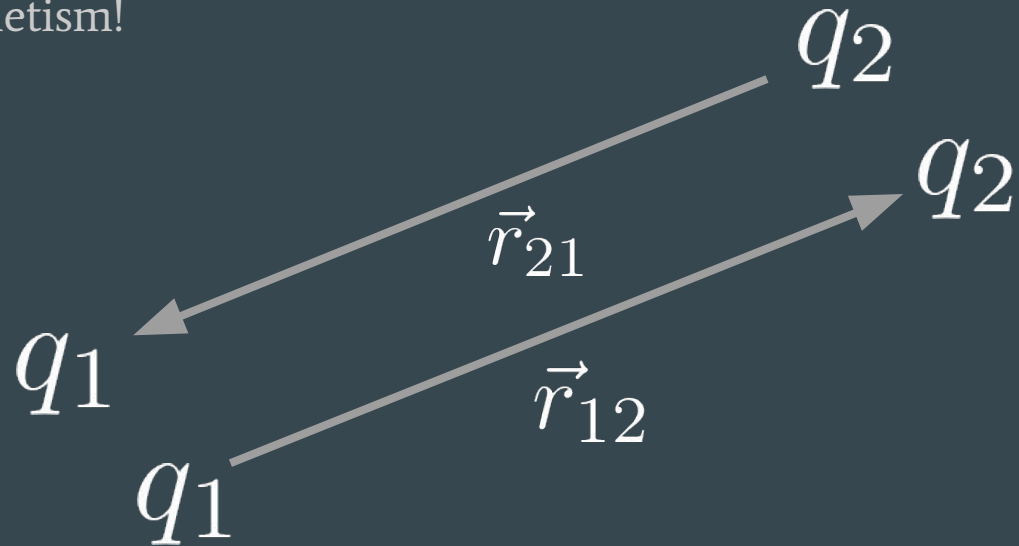
$$*k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

In words: The magnitude of the **electric force of particle 2 on 1** is equal to the magnitude of the **electric force of 1 on 2** which is equal to the **constant k** times the magnitude of q_1 , times the magnitude of q_2 , divided by the **absolute distance between q_1 and q_2** squared

Vectors - they're back!

- Distance and a magnitude
- Written as $\langle x \text{ component}, y \text{ component} \rangle$
- Bars around a quantity are a magnitude $|\mathbf{r}|$ of the vector
- Used a lot in electricity and magnetism!

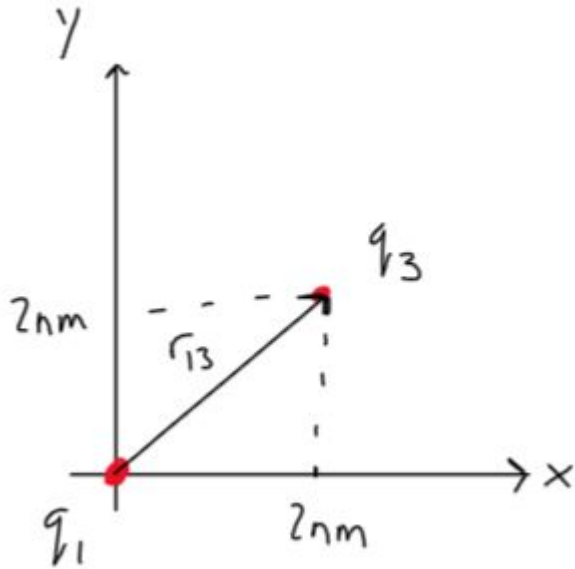
$$|\vec{r}_{21}| = |\vec{r}_{12}|$$



Practicing Coulomb's Law

(3) A point charge with charge $q_1 = -1.8nC$ is located at the origin. A point charge with charge $q_2 = 3.6nC$ is located a distance $r_{12} = 6nm$ away. A point charge with charge $q_3 = 5nC$ is located at a position $r_3 = \langle 2, 2 \rangle nm$. What is the magnitude of the coulomb force from charge 1 on charge 3?

1. Visualize the problem

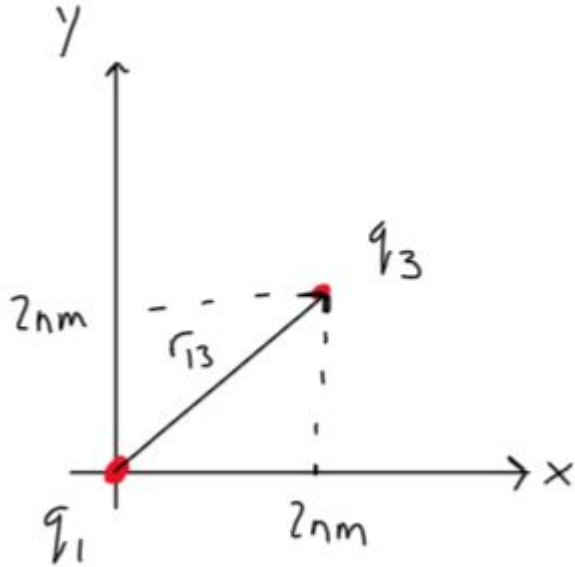


2. Find the vector $\Delta\vec{r}_{13}$

$$\begin{aligned}\Delta\vec{r}_{13} &= \langle 2, 2 \rangle - \langle 0, 0 \rangle \\ &= \langle 2, 2 \rangle\end{aligned}$$

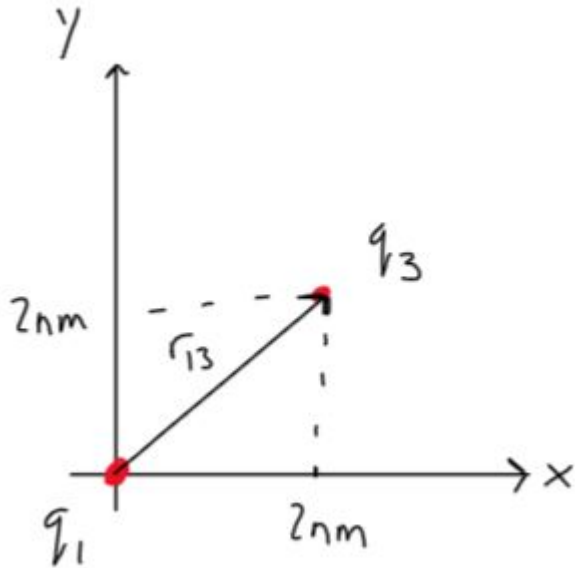
(3) A point charge with charge $q_1 = -1.8\text{nC}$ is located at the origin. A point charge with charge $q_2 = 3.6\text{nC}$ is located a distance $r_{12} = 6\text{nm}$ away. A point charge with charge $q_3 = 5\text{nC}$ is located at a position $r_3 = \langle 2, 2 \rangle \text{nm}$. What is the magnitude of the coulomb force from charge 1 on charge 3?

3. Find the magnitude of the vector $|\Delta\vec{r}_{13}|$



$$\begin{aligned} |\Delta\vec{r}_{13}| &= \sqrt{2^2 + 2^2} \\ &= \sqrt{8} \\ &= 2\sqrt{2} \text{ nm} \end{aligned}$$

(3) A point charge with charge $q_1 = -1.8nC$ is located at the origin. A point charge with charge $q_2 = 3.6nC$ is located a distance $r_{12} = 6nm$ away. A point charge with charge $q_3 = 5nC$ is located at a position $r_3 = \langle 2, 2 \rangle nm$. What is the magnitude of the coulomb force from charge 1 on charge 3?



4. Calculate the magnitude of the force

$$|\vec{F}_{13}| = k \frac{|q_1| |q_2|}{|\Delta \vec{r}_{13}|^2}$$

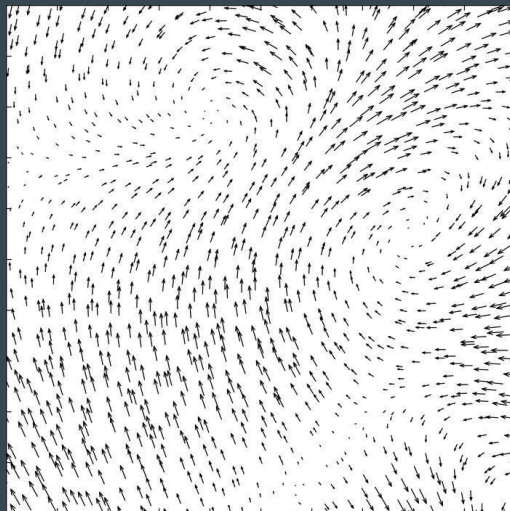
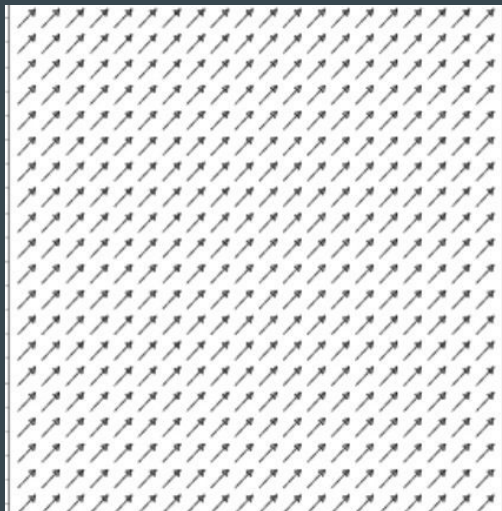
$$|\vec{F}_{13}| = k \frac{(1.8 \cdot 10^{-9} C)(5 \cdot 10^{-9} C)}{((2\sqrt{2}) \cdot 10^{-9} m)^2}$$

$$|\vec{F}_{13}| = 10.1 \cdot 10^9 N$$

$$= 10.1 GN$$

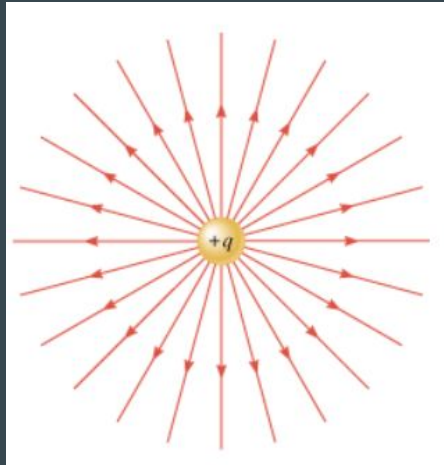
Fields

- A vector field (each point has a magnitude and a direction)
- Tells you what the field is at each point
- Fields can be uniform or non-uniform
- Follow the same superposition rules
- Mathematical tool *and* a real thing (they store energy!)



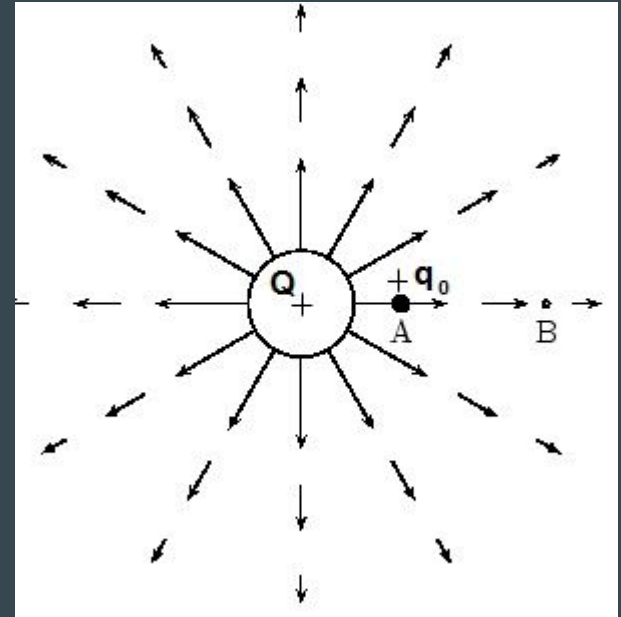
Field Lines

- Tell us the direction of the force from the electric field
- Density of the field lines tell us about the magnitude
- Arrows tell us about the direction
- What would the field lines for a negative charge be?



Electric Field

- Every charge creates an electric field
- A particle's own field doesn't exert any forces on that particle
- We can find out how that field affects other charges
- https://phet.colorado.edu/sims/html/charges-and-fields/latest/charges-and-fields_en.html



Electric Field from a Point Charge

$$\vec{E}(\vec{r}) = k \frac{q}{|\Delta\vec{r}|^2} \hat{r}$$

Electric Field from a Point Charge

$$\vec{E}_q(\vec{r}_p) = \frac{kq}{|\Delta\vec{r}|^2} \Delta\hat{r}$$

$$*k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

In words: The **electric field** from charge **q**, at point **p**, is equal to the **Coulomb's constant** multiplied by the **charge** divided by the square of the **change in position vector pointing from q to p**, multiplied by the **delta r hat** direction.

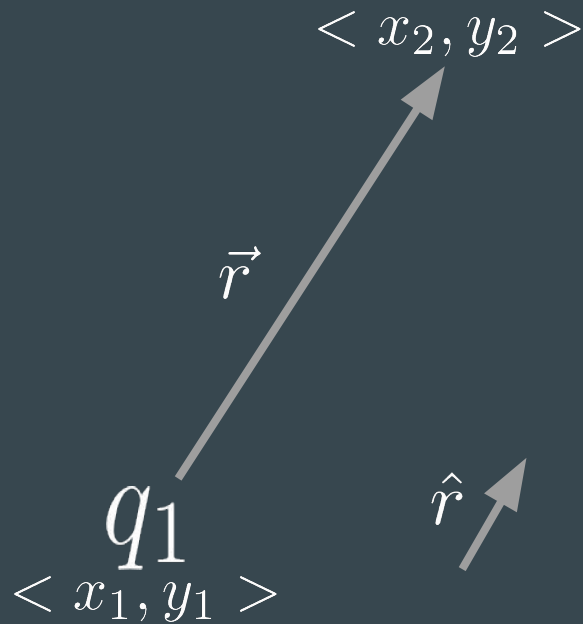
Breaking It Down

$$\vec{E}(\vec{r}) = k \frac{q}{|\Delta \vec{r}|^2} \hat{r}$$

$$|\Delta \vec{r}| = \sqrt{\Delta x^2 + \Delta y^2}$$

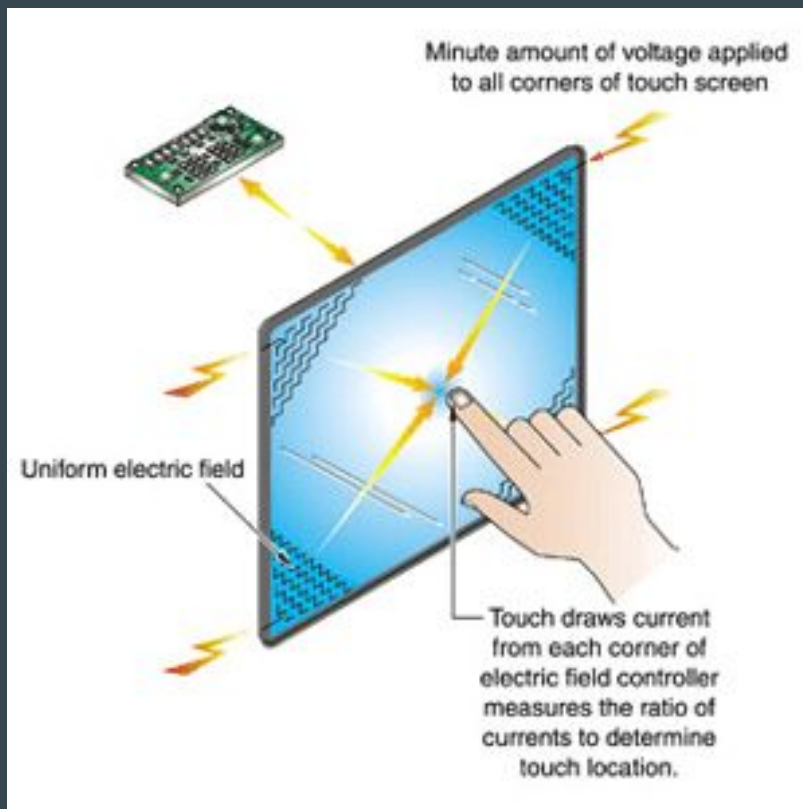
$$\hat{r} = \left\langle \frac{\Delta x}{|\Delta r|}, \frac{\Delta y}{|\Delta r|} \right\rangle$$

$$\vec{r} = |\Delta r| \hat{r}$$



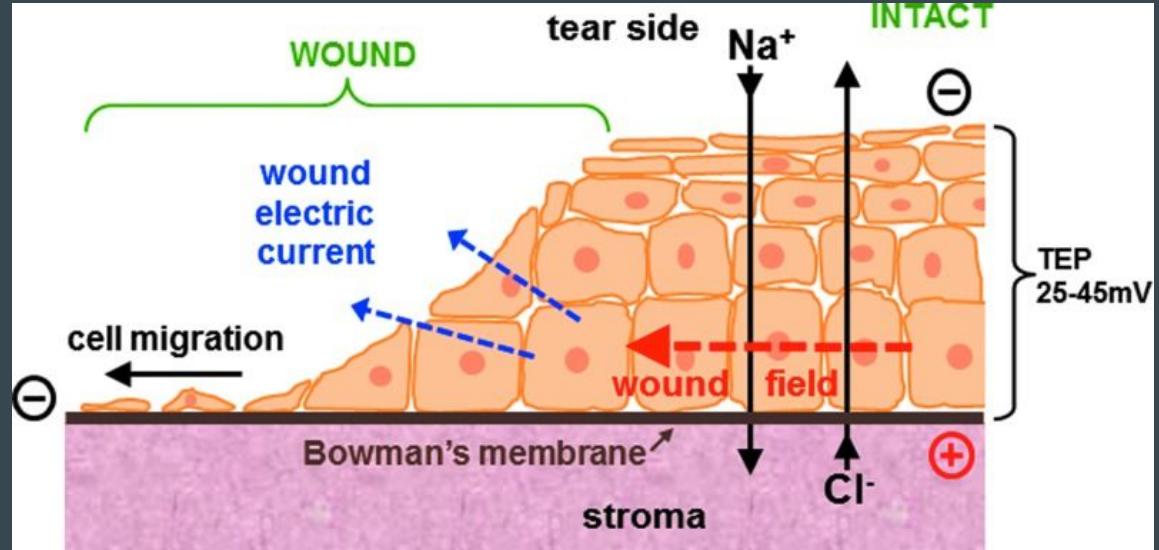
**Electric fields are cool and
let us do a lot of things**

It's how touch screens work!



It's helps wounds heal

- Transepithelial Potential (TEP)
- Na^+ goes one way, Cl^- the other to create an electric field
- Field orients toward the wound and causes epithelial cells to move toward the wound, helping it heal



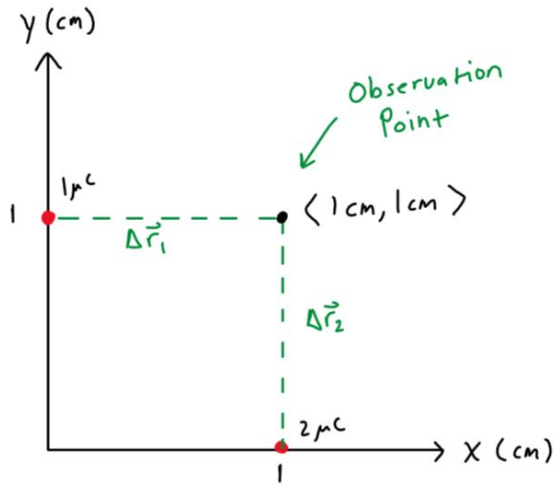
Putting it to Practice

S18 Midterm 2, Question 1

1. (6 points) One charge of $2 \mu\text{C}$ is placed at $(x,y) = (1 \text{ cm}, 0 \text{ cm})$, another charge of $1 \mu\text{C}$ is placed at $(x,y) = (0 \text{ cm}, 1 \text{ cm})$.

a) What is the electric field at $(x,y) = (1 \text{ cm}, 1 \text{ cm})$?

1. Visualize the problem



2. Find the distance between charges $|\Delta \vec{r}_1|$

$$\begin{aligned}\Delta \vec{r}_1 &= \vec{r}_{\text{obs}} - \vec{r}_1 \\ &= \langle 1 \text{ cm}, 1 \text{ cm} \rangle - \langle 0 \text{ cm}, 1 \text{ cm} \rangle \\ &= \langle 1 \text{ cm}, 0 \text{ cm} \rangle\end{aligned}$$
$$|\Delta \vec{r}_1| = \sqrt{(0.01 \text{ m})^2 + (0 \text{ m})^2}$$
$$|\Delta r_1| = 0.01 \text{ m}$$

3. Find the direction of the field \hat{r}

$$\hat{r} = \left\langle \frac{1 \text{ cm}}{1 \text{ cm}}, \frac{0 \text{ cm}}{1 \text{ cm}} \right\rangle$$

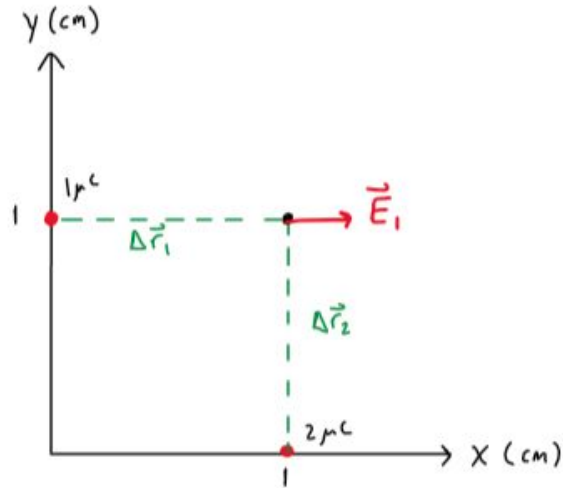
$$\hat{r} = \langle 1, 0 \rangle$$

$$|\hat{r}| = 1 \quad \checkmark$$

S18 Midterm 2, Question 1

1. (6 points) One charge of $2 \mu\text{C}$ is placed at $(x,y) = (1 \text{ cm}, 0 \text{ cm})$, another charge of $1 \mu\text{C}$ is placed at $(x,y) = (0 \text{ cm}, 1 \text{ cm})$.

a) What is the electric field at $(x,y) = (1 \text{ cm}, 1 \text{ cm})$?



$$|\Delta r_1| = 0.01 \text{ m}$$

$$\hat{r} = \langle 1, 0 \rangle$$

4. Calculate the field E_1

$$\vec{E}_1 = k \frac{q}{|\Delta r_1|^2} \hat{r}$$

$$\vec{E}_1 = k \frac{q}{(0.01 \text{ m})^2} \langle 1, 0 \rangle$$

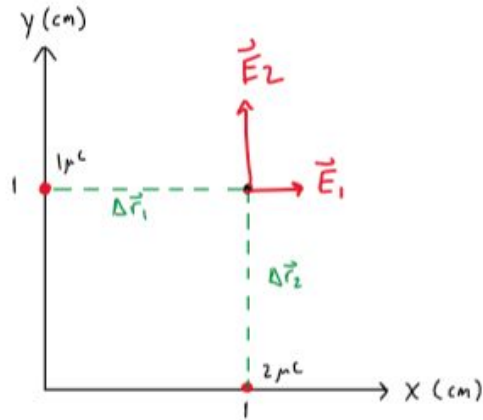
$$= \frac{(8.99 \cdot 10^9 \text{ Nm}^2/\text{C}^2)(1 \cdot 10^{-6} \text{ C})}{(0.01 \text{ m})^2} \langle 1, 0 \rangle$$

$$= \langle 9 \cdot 10^7 \text{ N/C}, 0 \text{ N/C} \rangle$$

S18 Midterm 2, Question 1

1. (6 points) One charge of $2 \mu\text{C}$ is placed at $(x,y) = (1 \text{ cm}, 0 \text{ cm})$, another charge of $1 \mu\text{C}$ is placed at $(x,y) = (0 \text{ cm}, 1 \text{ cm})$.

a) What is the electric field at $(x,y) = (1 \text{ cm}, 1 \text{ cm})$? *S. Find the field E_2*



$$\begin{aligned}\Delta \vec{r}_2 &= \langle 1 \text{ cm}, 1 \text{ cm} \rangle - \langle 1 \text{ cm}, 0 \text{ cm} \rangle \\ &= \langle 0 \text{ cm}, 1 \text{ cm} \rangle\end{aligned}$$

$$\begin{aligned}\hat{r} &= \left\langle \frac{0 \text{ m}}{0.01 \text{ m}}, \frac{0.01 \text{ m}}{0.01 \text{ m}} \right\rangle \\ &= \langle 0, 1 \rangle\end{aligned}$$

$$\begin{aligned}|\Delta \vec{r}_2| &= \sqrt{(0 \text{ m})^2 + (0.01 \text{ m})^2} \\ &= 0.01 \text{ m}\end{aligned}$$

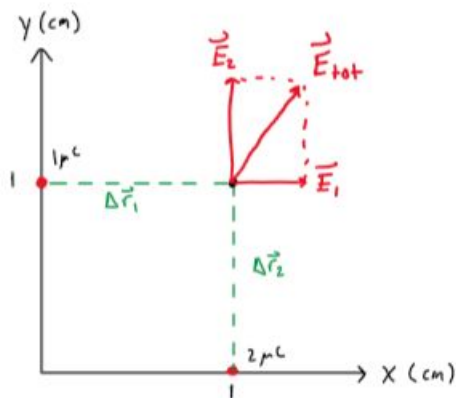
$$\vec{E}_2 = \frac{(8.99 \cdot 10^9)(2 \cdot 10^{-6} \text{ C})}{(0.01 \text{ m})^2} \langle 0, 1 \rangle$$

$$\vec{E}_2 = \langle 0 \text{ N/C}, 1.8 \cdot 10^8 \text{ N/C} \rangle$$

S18 Midterm 2, Question 1

1. (6 points) One charge of $2 \mu\text{C}$ is placed at $(x,y) = (1 \text{ cm}, 0 \text{ cm})$, another charge of $1 \mu\text{C}$ is placed at $(x,y) = (0 \text{ cm}, 1 \text{ cm})$.

a) What is the electric field at $(x,y) = (1 \text{ cm}, 1 \text{ cm})$?



$$\vec{E}_1 = \langle 9 \cdot 10^7 \text{ N/C}, 0 \text{ N/C} \rangle$$

$$\vec{E}_2 = \langle 0 \text{ N/C}, 1.8 \cdot 10^8 \text{ N/C} \rangle$$

6. Calculate the total electric field at the point

$$\vec{E}_{\text{tot}} = \vec{E}_1 + \vec{E}_2$$

$$= \langle 9 \cdot 10^7 \text{ N/C}, 0 \text{ N/C} \rangle + \langle 0 \text{ N/C}, 1.8 \cdot 10^8 \text{ N/C} \rangle$$

$$= \langle 9 \cdot 10^7 \text{ N/C}, 1.8 \cdot 10^8 \text{ N/C} \rangle$$

↳ x-comp.

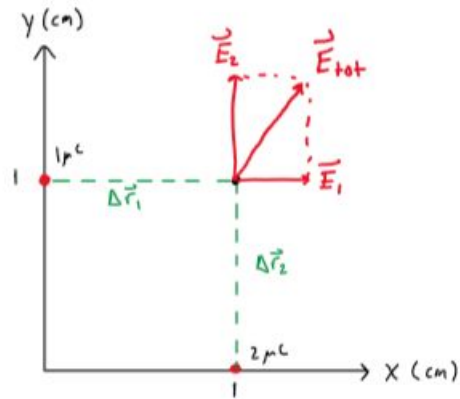
↳ y-comp.

S18 Midterm 2, Question 1

1. (6 points) One charge of $2 \mu\text{C}$ is placed at $(x,y) = (1 \text{ cm}, 0 \text{ cm})$, another charge of $1 \mu\text{C}$ is placed at $(x,y) = (0 \text{ cm}, 1 \text{ cm})$.

a) What is the electric field at $(x,y) = (1 \text{ cm}, 1 \text{ cm})$?

b) What is the magnitude of the electric field?



The magnitude of the electric field is then

$$\begin{aligned} |\vec{E}_{\text{tot}}| &= \sqrt{(9 \cdot 10^7 \text{ N/C})^2 + (1.8 \cdot 10^8 \text{ N/C})^2} \\ &= 2.01 \cdot 10^8 \text{ N/C} \end{aligned}$$

S18 Midterm 2, Question 3

3. A +1 C charge is placed at the origin. A -2 C charge is placed on the x-axis, 30 cm to the right of the origin. Which of the following statements are true?

- a) Other than $x = \pm\infty$, there are no locations on the x axis where the electric field magnitude is zero.
- b) Other than $x = \pm\infty$, there is only one location on the x axis where the electric field magnitude is zero.
- c) In addition to $x = \pm\infty$, there is more than one location on the x axis where the electric field magnitude is zero.
- d) The electric field is zero at a point between the two charges.
- e) Other than $x = -\infty$, the electric field is zero at one point to the left of both charges.
- f) Other than $x = \infty$, the electric field is zero at one point to the right of both charges.
- g) The electric potential energy of the -2 C charge is greater than the electric potential energy of the +1 C charge.

S18 Midterm 2, Question 4

4. Which of the following situations correctly depict the force on a negative charge placed at the black dot? (+ and - charges have equal magnitudes, ++ implies twice the charge)

- a)
- b)
- c)
- d)
- e)
- f)

