Studio Week 1
Electric Field

Picture credit: wikipedia.com.

Principles for Success

- **Treat everyone with respect.**
- **Learn by doing and questioning.**
- **Everything should make sense.**

Submitting to Gradescope

- This term, we will submit all activities to Gradescope
- After each activity, take a picture of your white board
  - Make sure it's neat and legible!
- At the end of class, upload your images to Gradescope
  - Include your group members!

Activity 1-1 – Field Generator

1. Suppose you have a proton in your physics lab. You would like to cause the proton to float suspended in the middle of the lab, and all you have is a single electric field generator. You can program this generator to make an electric field with any magnitude in any direction.
   a. Determine the settings of your electric field generator (*i.e.,* the *magnitude* and the *direction*) that will cause the proton to float.
   b. What would you need to change if you had an electron instead of a proton?

1-1 Field Generator

Wrap 2:25 at latest

Free Proton: $\oplus$ $\downarrow \vec{F}^g$

Need force here to get $F^{net}=0$ and float proton.

Floating Proton: $\oplus$

$\hat{y} \uparrow$

$\uparrow \vec{F}^E = \vec{E}q$ Force on a charge q in an electric field $\vec{E}$.

$\frac{N}{C}$

Forces have the same form!

$\downarrow \vec{F}^g = \vec{g}m$ Force on a mass m in a gravitational field $\vec{g}$.

$\frac{m}{s^2} = \frac{N}{kg}$

$$\vec{0} = \vec{F}^{net} = \vec{F}^E + \vec{F}^g$$
$$= \vec{E}q - mg\hat{y}$$
$$\vec{E}q = mg\hat{y}$$
$$\vec{E} = \frac{mg}{q}\hat{y}$$

If you choose a direction for $\vec{E}$ at this step, say $\vec{E} = E\hat{y}$, that is fine. If you end up finding a magnitude $E<0$ (negative, which you would get if $q<0$), then it just means you got the direction backward.

Proton

$m_p \approx 1.673 \times 10^{-27}\,kg$

$q_p \approx +1.602 \times 10^{-19}\,C$

Electron

$m_e = 9.109 \times 10^{-31}\,kg$

$q_e = -1.602 \times 10^{-19}\,C$

$\frac{m_p}{m_e} \approx 1836$

$e \approx 1.602 \times 10^{-19}\,C$

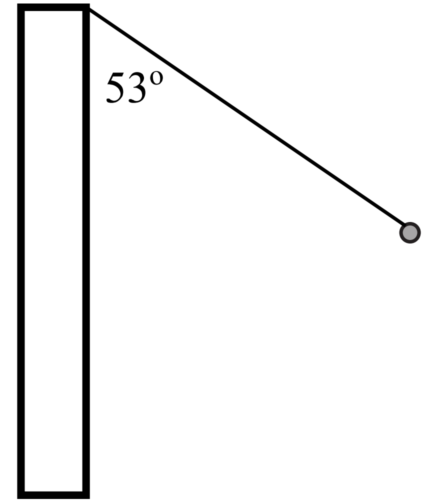
$$\vec{E} = \frac{m_p g}{e}\hat{y}$$ Points up

$$E \approx \frac{1.7 \times 10^{-27}\,kg \cdot 10\,\frac{m}{s^2}}{1.6 \times 10^{-19}\,C} \approx 10^{-7}\,\frac{N}{C}$$ Small magnitude

$$\vec{E} = -\frac{m_e g}{e}\hat{y}$$ Points down

$$E \approx \frac{10^{-30}\,kg \cdot 10\,\frac{m}{s^2}}{1.6 \times 10^{-19}\,C} = 6.25 \times 10^{-11}\,\frac{N}{C}$$ Even smaller! Less than 1000th the strength.

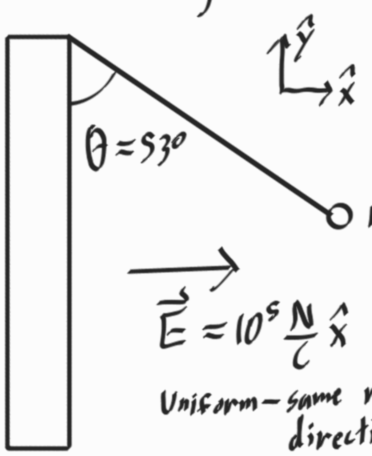
Activity 1-2 – Charged Ball



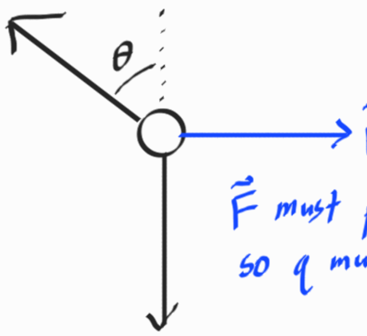
- An electrically charged ball with m = 0.06 kg hangs at the end of a string oriented θ = 53° outward from a wall.
- The wall produces a **uniform** electric field with magnitude $E = 10^5$ N/C that points away from the wall (to the right).
- Use the Real-world Context:
  1. Understand and Plan: Draw a free-body diagram!
  2. Solve the Problem: Determine a symbolic expression for the electric charge on the ball.
  3. Make Sense of your Answer: What do you expect to happen to q in the special case that $E = 0$? What about $\theta = 0$?

1-2 Charged Ball

start 2:35 Wrap 2:50



FBD: $\vec{F}^T = F^T(-\sin\theta\,\hat{x} + \cos\theta\,\hat{y}) = F^T_x\hat{x} + F^T_y\hat{y}$



$\vec{F}$ must point right, so q must be positive

Sensemaking Prep

$E \to 0$

If q were constant, $E \to 0$ would make $F^E \to 0$, so the ball would not be supported, and $\theta \to 0$.

But θ is constant, so we need to keep F^E constant. If E decreases, we need q to increase, so $q \to \infty$.

$\theta \to 0$

A ball hanging straight down is just held up by the tension. There is no net force in the horizontal direction, so $F^E \to 0$. For constant E, that means $q \to 0$.

$$\vec{0} = \vec{F}^{net} = \vec{F}^T + \vec{F}^g + \vec{F}^E$$

x: $0 = F^E_x + F^T_x$
$= Eq - F^T\sin\theta$
$F^T\sin\theta = Eq$

y: $0 = F^T_y + F^g_y$
$= F^T\cos\theta - mg$
$F^T\cos\theta = mg$

$$\tan\theta = \frac{\cancel{F^T}\sin\theta}{\cancel{F^T}\cos\theta} = \frac{Eq}{mg} \Rightarrow \boxed{q = \frac{mg}{E}\tan\theta}$$

$$= \frac{0.06\,\text{kg}\cdot 9.8\frac{m}{s^2}}{10^5\,N/C}\tan(53^\circ)$$
$$\approx 7.8\times10^{-6}\,C$$
$$\approx 4.87 \text{ trillion } e$$

Sensemaking Check

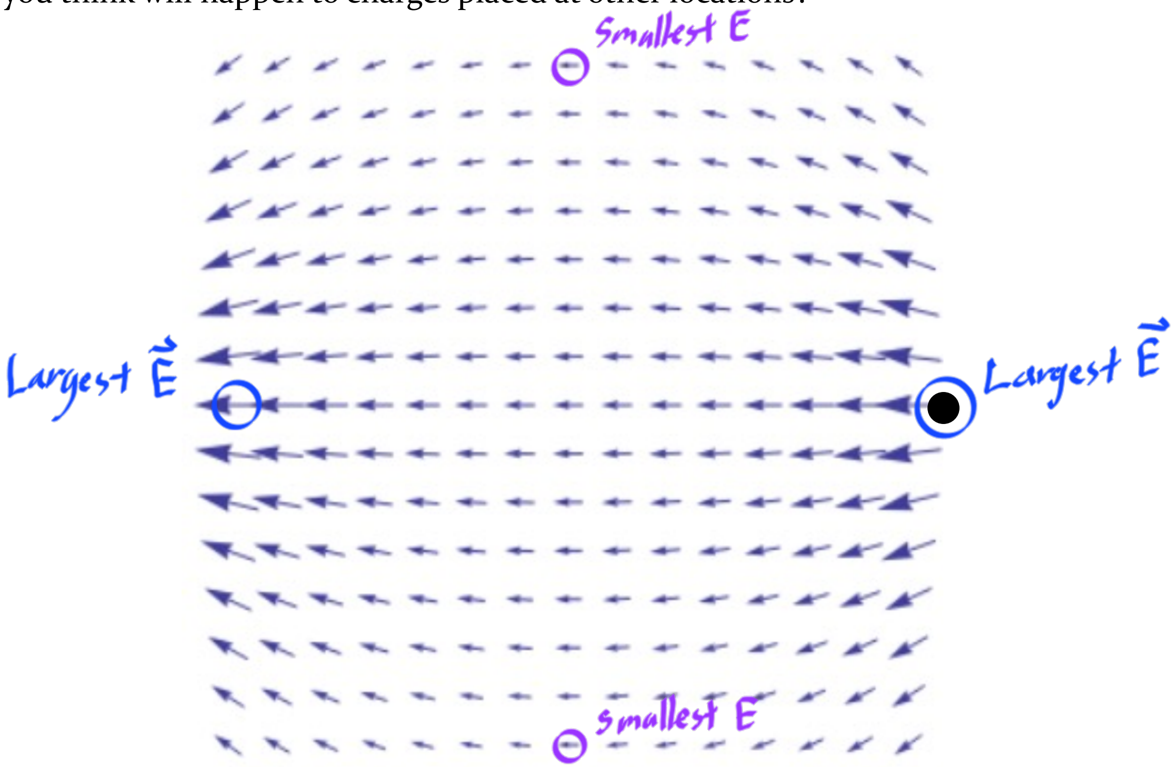
$E \to 0 \Rightarrow \frac{1}{E} \to \infty \Rightarrow q \to \infty$ ✓

$\theta \to 0 \Rightarrow \tan\theta \to 0 \Rightarrow q \to 0$ ✓

Activity 1-3

Shown below is an electric field vector map

1. Choose any point on the map and discuss the following
   a. How do you find the *direction* of the electric field at your chosen point?
   b. How do you find the *magnitude* of the electric field at your chosen point?
2. Identify one or more locations where the electric field is the largest.
3. Identify one or more locations where the electric field is the smallest.
   a. Is *E* zero anywhere on this map?
4. Suppose a positive point charge is located at the marked point. Describe what will happen to the charge over time.
   a. What do you think will happen to charges placed at other locations?



1-3 Electric Field Vector Map

start 3:10 Wrap 3:20

1a) Direction: The arrows point in the direction of $\vec{E}$ at the points they are located at.

1b) Magnitude: Longer arrows mean a stronger $\vec{E}$ field.

2) Largest $\vec{E}$ happens at the midpoints of the right and left sides (where the arrows are largest).

3) Smallest $\vec{E}$ happens at the midpoints of the top and bottom (where the arrows are smallest).

a) E is not zero anywhere (all marked points have an arrow of nonzero length).

<u>Note:</u> Points without an arrow still have $\vec{E}$, but we can't draw an arrow at every point. Unless the map is drawn very coarsely (omitting complicated small-scale features), the direction & magnitude is probably similar to that of the arrows around it.

4) At the marked point, $\vec{E}$ is large and points left, so the force on a positive charge will be strong and to the left, causing it to accelerate left.

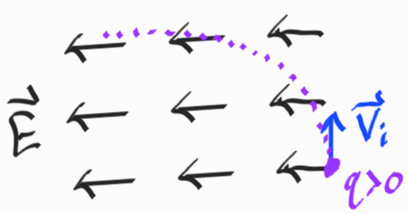
As it moves left, $\vec{E}$ still points left, but it gets smaller, so the charge will keep accelerating left, but at a lower rate.

Past the midpoint, $\vec{E}$ gets stronger, so the particle will keep accelerating left, now at an increasing rate.

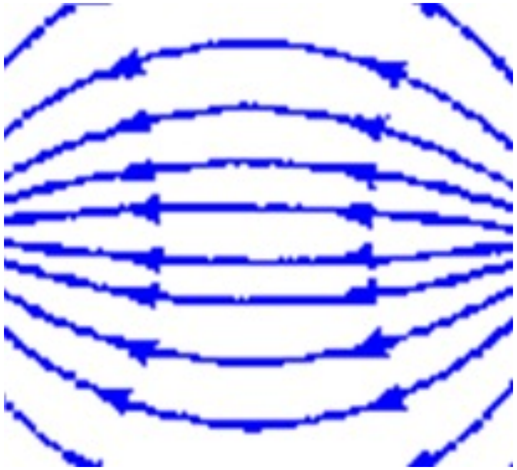
a) A charge at any location will accelerate in accordance with the direction of the arrows, because $\vec{F}^E = \vec{E}q$ (so positive charges accelerate in the direction an arrow points, and negative charges accelerate in the opposite direction).

A charge does <u>not</u> just "follow the arrows." It moves in the direction its velocity indicates, and the $\vec{F}^E$ arrow tells it how its velocity will change.

Example:



Electric Field Lines



Rules for Reading Electric Field Lines

- The arrows tell you the direction of the field
  - The electric field is tangent to the line (not curved!)
- The strength of the electric field is given by the density of the lines
  - Being on or off a line does not matter (the lines are imaginary)

Activity 1-4

Start 3:30 Wrap 3:40 Uploads 3:45

The electric field lines for two different systems are shown below.

1. For each system, determine which of the labeled point (if either) has an electric field with a greater magnitude

$E_P = E_Q$

The lines have the same density near P and Q.

It doesn't matter that P is not on a line. This is sort of like a zoomed out Google map, only showing the major roads—that doesn't mean they are the only roads.

$E_A > E_B$

The lines are closer together (higher density) near A than they are near B.