Last Lecture: Coulomb’s Law:
Consider two point-like charges of the same mass: #1 has charge $+q$, and #2 has charge $Q = +10q$. You hang them from threads near each other. The angle between the thread supporting #1 and the vertical is $\alpha_1$, the angle between the thread supporting #2 and the vertical is $\alpha_2$.

Choose the statement with which you agree:

A. $\alpha_1 > \alpha_2$

B. $\alpha_1 < \alpha_2$

C. $\alpha_1 = \alpha_2$

D. You need to know the mass to answer the question.
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\[
F = \frac{1}{4\pi \varepsilon_0} \frac{q_1 q_2}{r^2}
\]

\begin{align*}
\text{X-components:} & \quad F_{1 \to 2} = F_{2 \to 1} \quad \text{Newton's 3\textsuperscript{d} Law} \\
\text{Y-components:} & \quad m_1 g = m_2 g = mg
\end{align*}
Electric field

At any point in space, we can define a vector (the “electric field”) as the force on a test charge, divided by the test charge:

\[ \vec{E} = \frac{\vec{F}_0}{q_0} \]

\( \vec{E} \) is the force per unit charge exerted by \( A \) on a test charge at \( P \).
Electric field does not depend on test charge

The force on a positive test charge $q_0$ points in the direction of the electric field.

The force on a negative test charge $q_0$ points opposite to the electric field.
A point charge $q$ produces an electric field at all points in space.

The field strength decreases with increasing distance.

The field produced by a positive point charge points away from the charge.

The field produced by a negative point charge points toward the charge.
The electric field of a point charge

• Using a unit vector that points away from the origin, we can write a vector equation that gives both the magnitude and the direction of the electric field:

\[ \vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \hat{r} \]

\[ F_{q\rightarrow Q} = \frac{1}{4\pi\varepsilon_0} \frac{qQ}{r^2} = Q \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} = QE_q(r) \]
Two nonzero charges are placed a certain distance apart. The probe charge is at some point on a line connecting the charges but *not* between them. The force exerted on the probe charge is 0. What is the *most general* thing we can say about the charges?

A. The same sign and magnitude.
B. Opposite signs but the same magnitude.
C. The same sign but must have different magnitudes.
D. Opposite signs but must have different magnitudes.
E. Zero magnitude necessarily for both of them.
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Superposition of electric fields

- The total electric field at a point is the vector sum of the fields due to all the charges present.

\[ \vec{E}(\vec{r}) = \sum_i \vec{E}_i(\vec{r}) \]

The electric field at location \( \vec{r} \) due to all other charges:
**Electric field lines**

- An **electric field line** is an imaginary line or curve whose tangent at any point is the direction of the electric field vector at that point.
Electric field lines of a point charge

- Electric field lines show the \textit{direction} of the electric field at each point.

- The spacing of field lines gives a general idea of the \textit{magnitude} of the electric field at each point.
Electric field lines of a dipole

• Field lines point away from + charges and toward – charges.

• At any point, the electric field has a unique direction, so field lines never intersect.
The magnitude of the electric field at a given point is proportional to the density of field lines at that point:

\[
\text{Density of lines} = \text{number of lines per unit area}\text{ perpendicular to the lines.}
\]
For a point charge, \( E(r) \propto \frac{1}{r^2} \)  \( \Rightarrow \)

the density of lines \( \propto \frac{1}{r^2} \).

The area of a sphere centered at the charge \( \propto r^2 \).

Thus, **the total number** of lines is fixed: they don’t “vanish into thin air”, must be terminated either at another (negative) charge or continue to infinity.
Three point charges are fixed at the vertices of an equilateral triangle as shown. All three charges have the same magnitude, but charges #1 and #2 are positive (+q) and charge #3 is negative (−q).

The net electric filed produced by charges #2 and #3 at the position of the probe charge #1 points in

A. the +x direction.  
B. the −x direction.  
C. the +y direction.  
D. the −y direction.  
E. none of the above
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B. the −x direction.  
C. the +y direction.  
D. the −y direction.  
E. none of the above
1. Charge separation by friction.

2. The girl acquires a charge distributed across her surface.

3. Like charges on individual hairs repel each other and force the hairs to stand away from each other and the girl’s head.

4. Girl’s hairs (roughly) follow the field lines.
Demonstration: Van de Graaff Generator

Robert J. Van de Graaff
1901-1967

1) hollow metal sphere
2) upper collecting electrode
3) upper roller (for example an acrylic glass)
4) side of the belt with positive charges
5) opposite side of the belt with negative charges
6) lower roller (metal)
7) lower electrode (ground)
8) spherical device with negative charges, used to discharge the main sphere
9) spark between the electrodes
Electric polarization – redistribution of charges within a neutral object by an external electric field. As a result, a neutral object acquires a dipole moment.

Dielectric Materials:

Induced/built-in dipoles

Electric field → orientation of dipoles

For example, water molecules are dipoles.
Dipoles in an Electric Field

- In a uniform electric field, the net force on a dipole is zero.
- There is a **torque** that tends to align the dipole with the field:
  \[ \vec{\tau} = \vec{p} \times \vec{E} \]  
  (\(\vec{p}\) directed from – to +)

- In a non-uniform field, aligned dipoles are attracted into the region of stronger field.