Announcements:

When you register your Iclicker, use your RUID, not your NETID. If you have already registered with your NETID, please re-register!
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.
Two 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?

\[ F = 0 \]

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.
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 force that Charges #2 and #3 exert on Charge #1 is in

A. the +x direction.  
B. the −x direction.  
C. the +y direction.  
D. the −y direction.  
E. none of the above
Reasons to introduce electric (gravitational, magnetic, etc.) field:


Cure for the “action-at-a-distance” problem \( \Rightarrow \) charges generate “fields”, and these fields act upon other charges. The field perturbation travels in vacuum with the speed of light.

- The electromagnetic field is an objective reality, it possesses energy and momentum (Sun’s energy reaches us by means of electric and magnetic fields).
Electric Field

\[ \vec{F}_{q\rightarrow Q} = \frac{1}{4\pi \varepsilon_0} \frac{qQ}{(r_{qQ})^2} = Q \]

**Electric Field** \( \vec{E}(\vec{r}) \): the force per unit probe charge

magnitude (intensity) direction

**Units of the electric field:** \( \frac{N}{C} \)

(Intensity of) the gravitational field at Earth’s surface? Units?

\[ \vec{F}_{Q\rightarrow q}(\vec{r}) = q \vec{E}_Q(\vec{r}) \]

**the \( E \) field due to \( q \) at the location of \( Q \)**

\[ \vec{F}_{q\rightarrow Q} = \frac{1}{4\pi \varepsilon_0} \frac{qQ}{(r_{qQ})^2} = q \]

**the \( E \) field due to \( Q \) at the location of \( q \)**
If there are a few charges around, but no charge at the point $\vec{r}$, the electric field at point $\vec{r}$ is:

A. Zero

B. The electric force at the point $\vec{r}$.

C. The electric force that a particle of small charge $q$ and mass $m$ would experience, if it were placed at the point $\vec{r}$.

D. The electric force that a particle of small charge $q$ and mass $m$ would experience, if it were placed at the point $\vec{r}$, divided by $q$.

E. The electric force that a particle of small charge $q$ and mass $m$ would experience, if it were placed at the point $\vec{r}$, divided by $m$. 
Consider two charges: +Q (at the origin) and +q (at $\vec{r}$).

The force exerted by $Q$ on $q$: $\vec{F}_{Q\rightarrow q}(\vec{r}) = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2} \hat{r}$

The electric field due to $Q$ at the location $\vec{r}$:

$$\vec{E}_Q(\vec{r}) \equiv \frac{\vec{F}_{Q\rightarrow q}(\vec{r})}{q} = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$$

$\vec{E}$ is directed along $\hat{r}$ for $+Q$, along $-\hat{r}$ for $-Q$. 
Superposition Principle

The electric fields created by different charges do not interact with each other, the net field is the **vector** sum of the fields due to individual point charges:

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

- the field at the location \(\vec{r}\) due to all other charges

\[
\vec{F}_{net} = \sum_i \vec{F}_i
\]

- the force on a charge at the location \(\vec{r}\) due to all other charges
Consider four charges in a square (see the Figure). The electric field at the middle of the square, \( P \), is

\[
A. \quad k \frac{q}{2a^2} \\
B. \quad k \frac{q}{a^2} \\
C. \quad 2k \frac{q}{a^2} \\
D. \quad 4k \frac{q}{a^2} \\
E. \quad \text{zero}
\]
Electric field lines:
- direction of the field vector is tangential to the field line (curve);
- intensity of the field at a given point is proportional to the local density of field lines.

Density of lines: (relative) number of lines per unit area perpendicular to the lines.
Shown are the electric field lines, the charges that produced the electric field are not shown. Rank the magnitude of the electric field for the points labeled A through F.

\[ E_C \cong E_D > E_E > E_A > E_B > E_F \]
Electric Field Lines (cont’d)

For a point charge, $E(r) \propto \frac{1}{r^2} \implies$

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.

This picture resembles a laminar flow of some fluid from positive charges (“source”) to negative charges (“sink”), though there is no real displacement of matter in space.
Iclicker Question

Does this 2D plot do justice to a 3D electrostatic field?

Hint: the density of the field lines should be proportional to the intensity of the field.

A. Yes
B. No
C. Depends on the field strength.
D. Depends on the field direction.

In 2D, the density of lines $\propto 1/r$.

In 3D, the density of lines $\propto 1/r^2$.

Thus, this is just a “cartoon”, no true scientific value 😊.
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
How to Draw the Electric Field Lines

Convention:
- the electric field lines originate on positive charges;
- terminate on negative charges.

Field lines don’t form sharp bends (there is only one tangent line to a field “curve” at each point).
Electric Field of a Dipole

Dipoles: the second most important (after a point charge) configuration of charges.

2D plot of the field lines in the x-y plane

3D plot of the field intensity in the x-y plane
Conclusion

Electric Field: math. tool and phys. reality

Electric Field Lines

Iclicker Question

Which field line configuration correctly represents an electrostatic field?

A. Two tangent lines at \( \cdot \) O

B. Must be a charge at the intersection

C. The line forms a closed loop (OK in electrodynamics, forbidden in electrostatics)

D. Lines form sharp corners two tangent lines at bends

E. Straight lines belong to a solitary point charge, but the symmetry is broken