PHYSICS NYB-10/11 Winter 2007

Lecture 4: Using and visualizing the electric field

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Review

Important points from last lectures:

- The magnitude of the electric force between two charged particle is $|\vec{F}_e| = k_e \frac{|q_1||q_2|}{r^2}$
- The force is repulsive for like charges and attractive for opposite charges
- The force is directed along the line joining the two particles
- The force from many charged particles is the sum of the forces from each of them

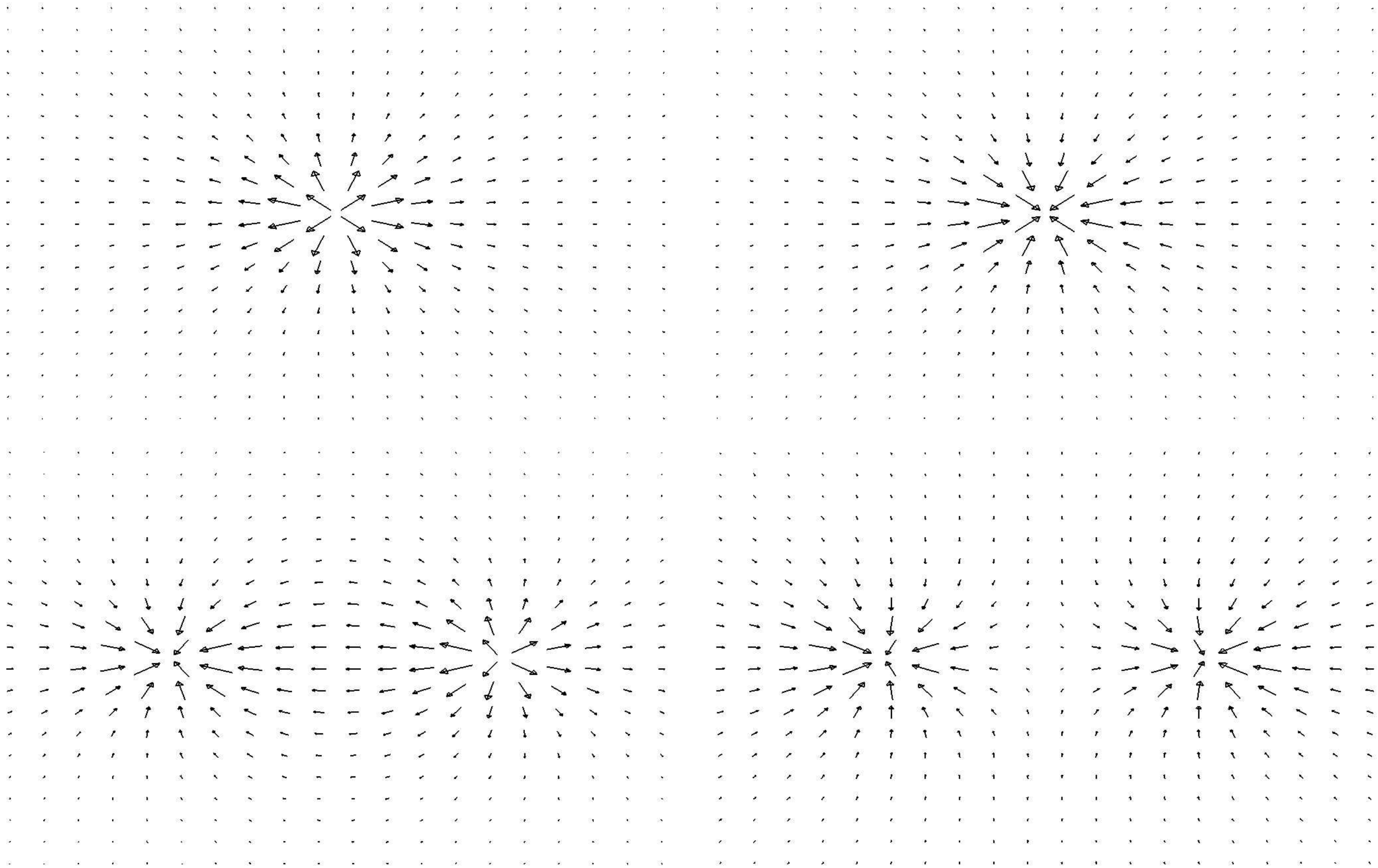
Review

Important points from last lectures:

- The reason there is an electric force is that a charge creates an electric field in space
- The electric field consists of a vector at every point in space
- A point charge q creates an **electric field** $\vec{E} = k_e \frac{q}{r^2}\hat{r}$
- The force on a particle of charge q_0 placed in an electric field $\vec{E}$ is $\vec{F}_e = q_0 \vec{E}$
- The field from many charged particles is the sum of the fields from each of them
- The electric field is physically real.

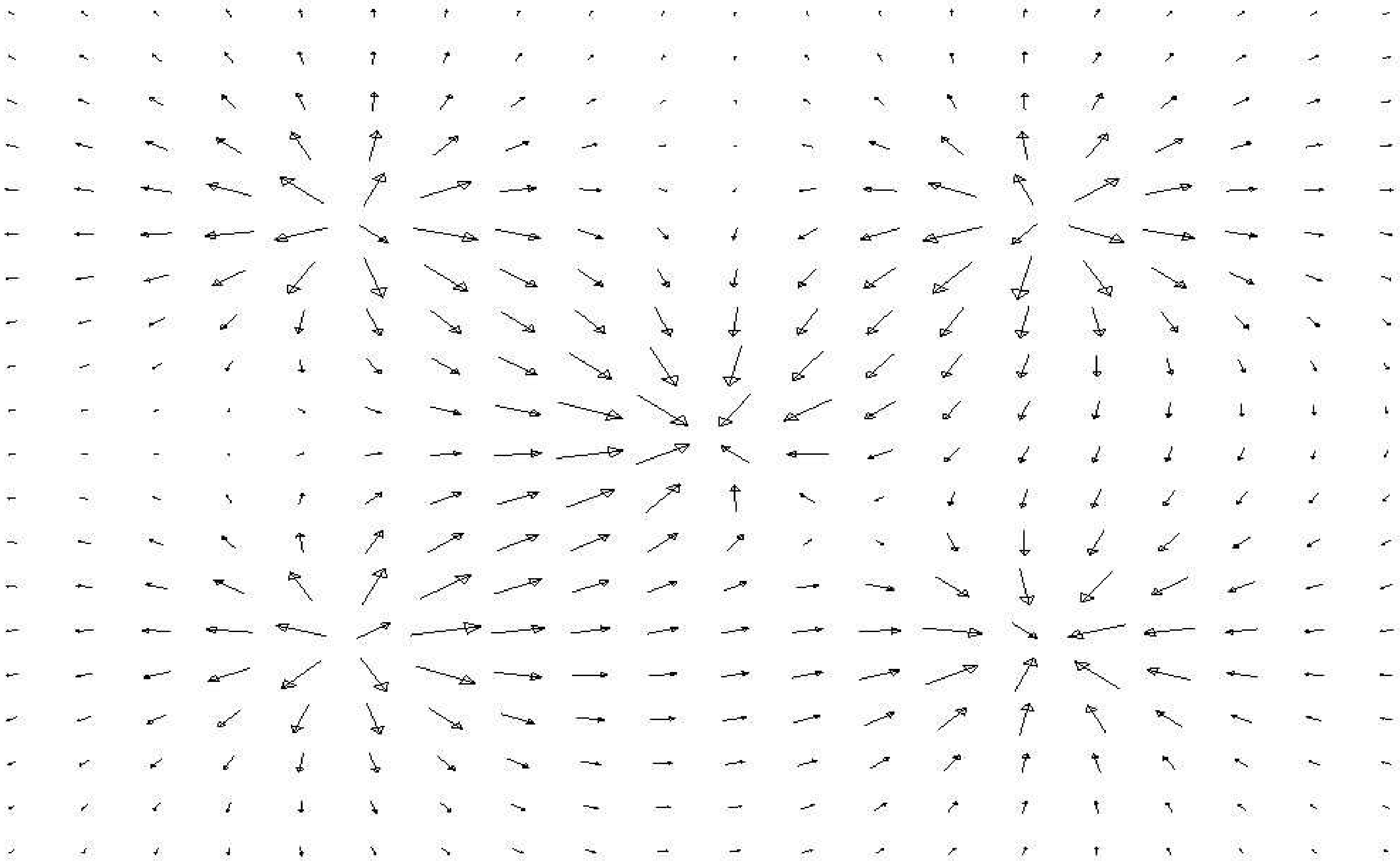
Review

Identify the charges.



From top left, clockwise: positive point charge, negative point charge, two negative point charges, one negative and one positive point charge.

Review



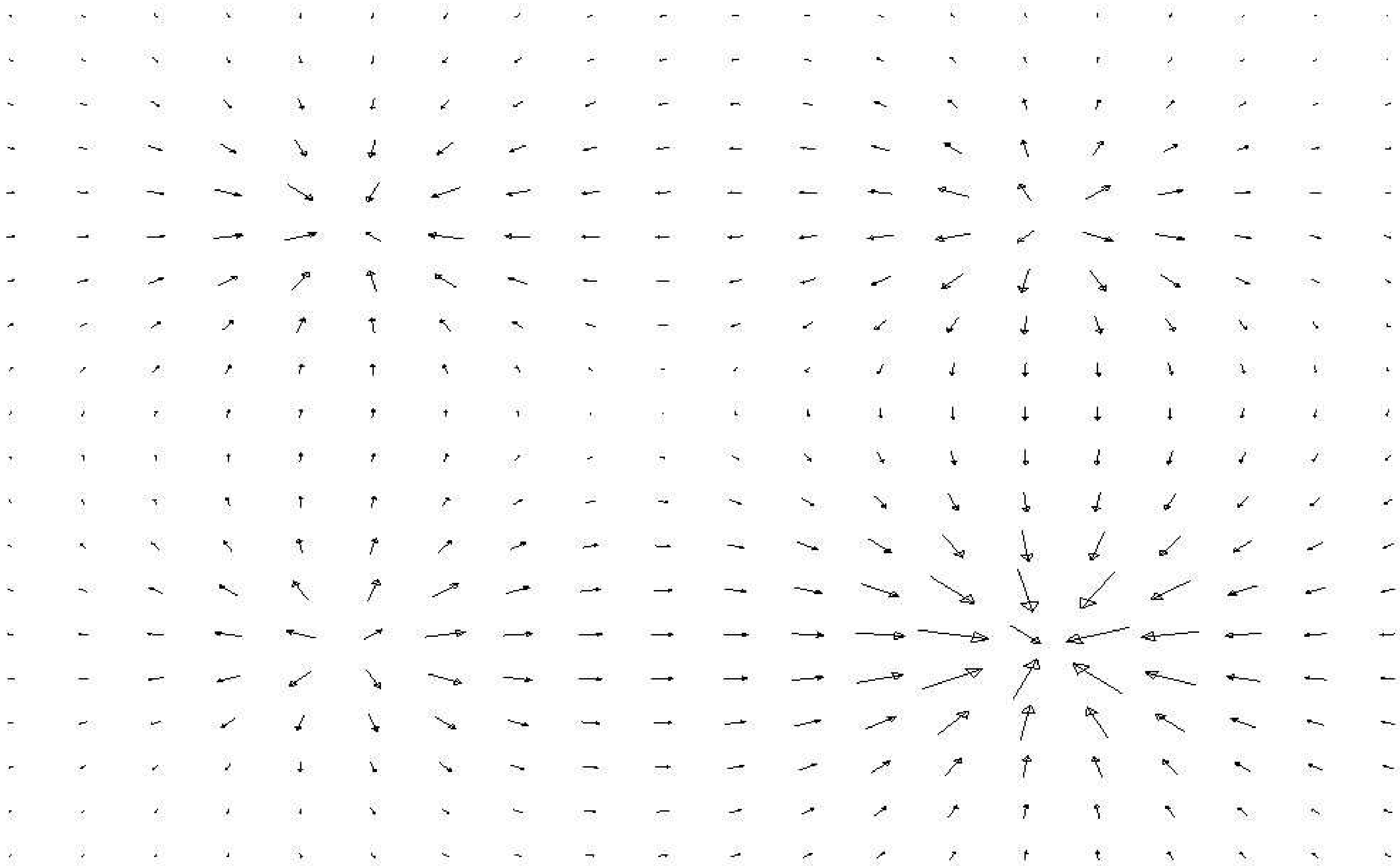
How many source charges are creating the electric field pictured here? What can you say about the sign of their charge and the magnitude of their charge?

Review

We can tell that there are five regions where the field vectors converge or diverge, so there are clearly five point charges here. The two at the top and the one at the bottom left have the electric field vectors pointing away from them, so are positive test charges. The other two have the electric field vectors pointing towards them and are therefore negative point charges.

We can tell all the point charges have the same magnitude, because the magnitude of the electric field vectors in the viscinity of each charge are the same.

Review



How many source charges are creating the electric field pictured here? What can you say about the sign of their charge and the magnitude of their charge?

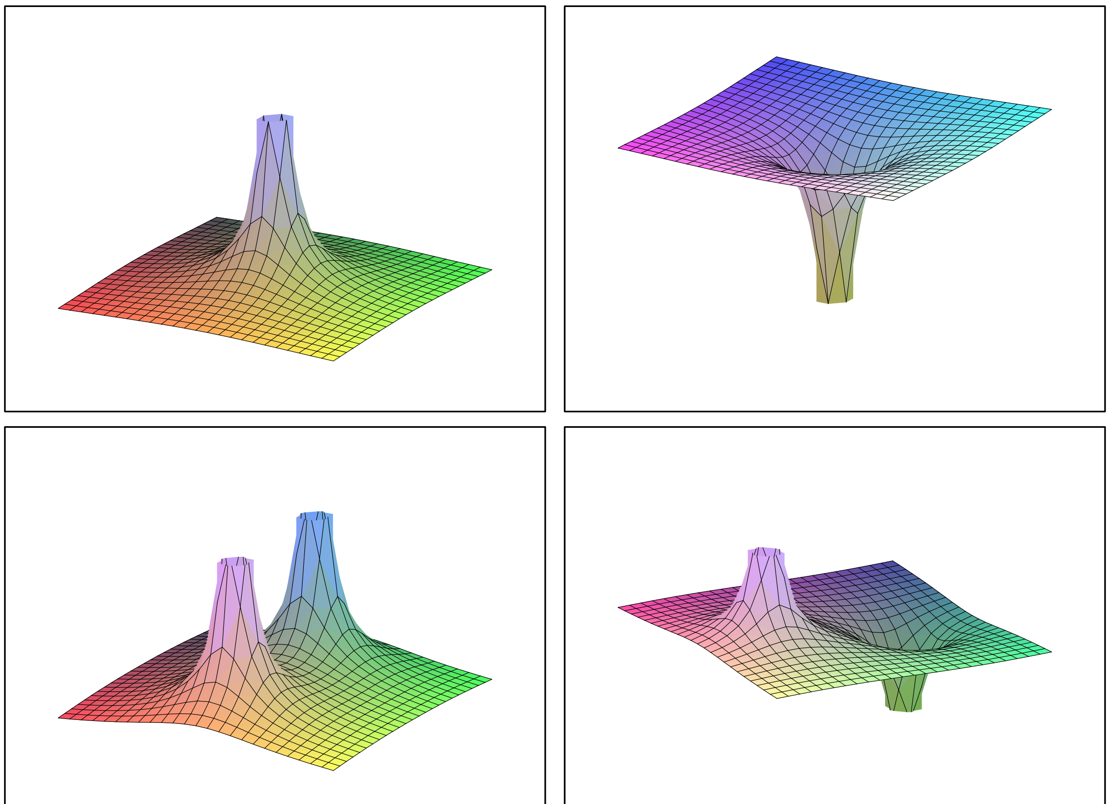
Review

We can tell that there are four regions where the field vectors converge or diverge, so there are clearly four point charges here. The top right and the the bottom left have the electric field vectors pointing away from them, so are positive test charges. The other two have the electric field vectors pointing towards them and are therefore negative point charges.

In this case, the bottom right charge has electric field vectors of larger magnitude than the three other charges in its viscinity. Therefore, we can conclude this source charge is greater than the other three.

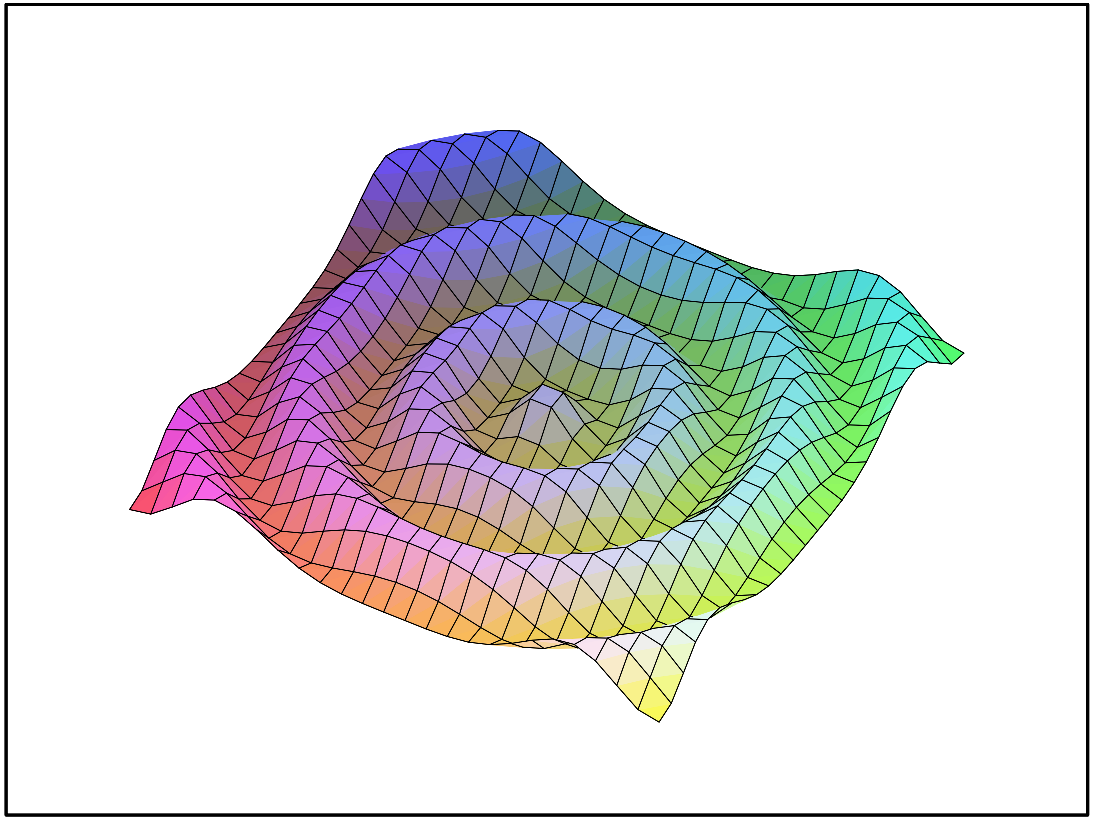
The concept of field

A useful analogy is to think of a surface, say a very steep mountain. Imagine putting a ball somewhere on this surface. It would feel a force pulling it down in the direction of steepest slope, with a magnitude proportional to the slope. The electric field indicates the direction of steepest slope, and its magnitude is proportional to the slope.



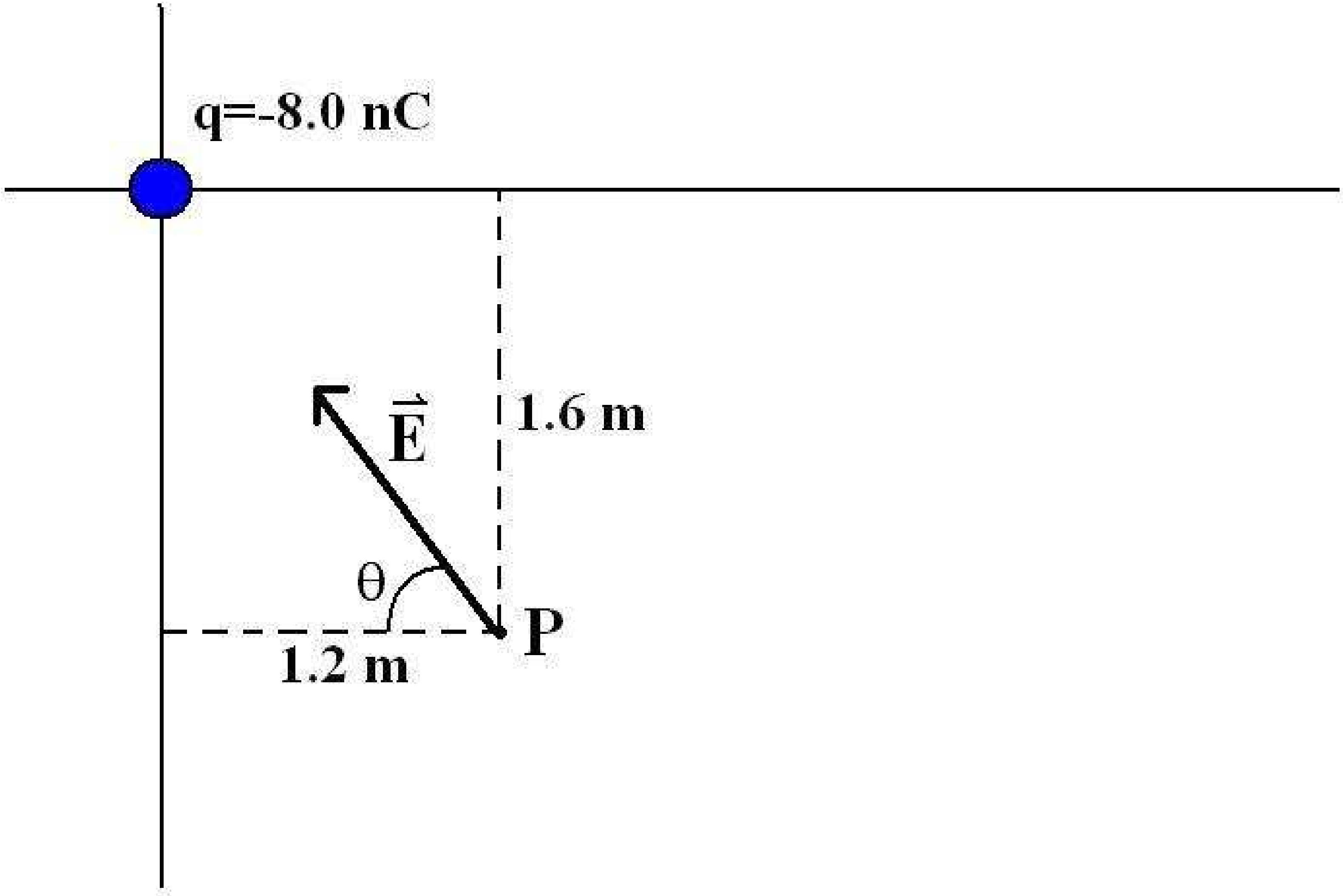
Light and the electric field

You learned in Physics NYC that light is an *electromagnetic wave*. When a charge is wiggled around, the electric field associated with it fluctuates, creating an electromagnetic wave, which is what light actually is: an oscillation in the electromagnetic field.



Examples

A point charge $q = -8.0$ nC is located at the origin. Find the electric field vector at the point $x = 1.2$ m, $y = -1.6$ m.



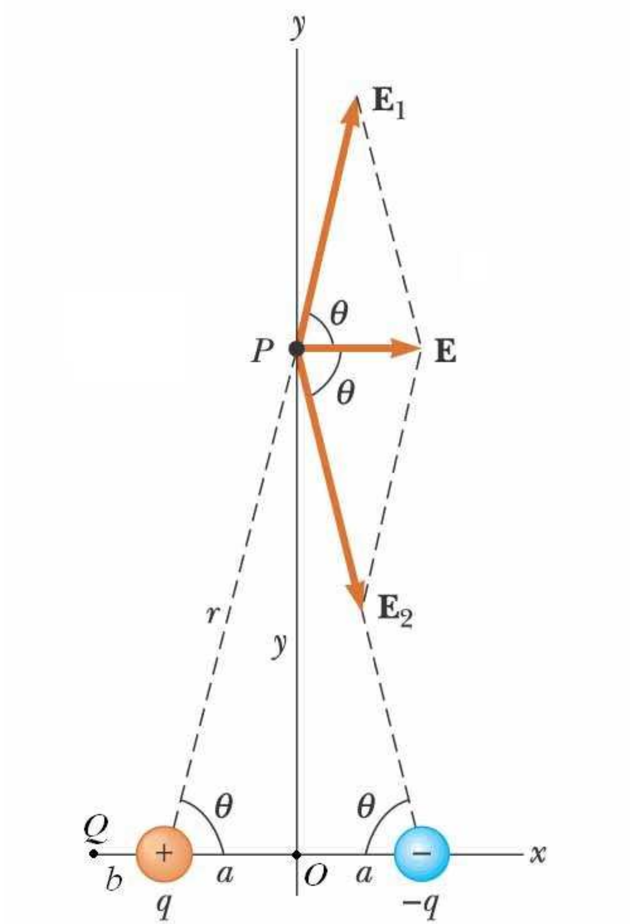
Examples

Since the charge is negative, the electric field will everywhere point directly towards it. The magnitude of the electric field vector will be $|\vec{E}| = k_e \frac{|q|}{r^2}$ where $r = \sqrt{(1.2)^2 + (-1.6)^2} = 2$ m. Plugging in numbers, we find that $|\vec{E}| = 17.98$ N/C.

We now want to find this vector's components. From the diagram, $\vec{E} = -|\vec{E}| \cos\theta \hat{i} + |\vec{E}| \sin\theta \hat{j}$. We find the angle through $\theta = \arctan\frac{1.6}{1.2} = 53.13^o$, which finally gives us $\vec{E} = (-10.79\hat{i} + 14.38\hat{j})$ N/C.

Examples

Question: What is the electric field of the configuration pictured below (called a *dipole*) at the points O, P, Q?



Examples

At point O, the field from the negative charge and the field from the positive charge are pointing in the positive x direction, and have the same magnitude, $|\vec{E}_{1,2}| = k_e \frac{|q|}{a^2}$. The net field is therefore $\vec{E} = 2k_e \frac{|q|}{a^2}\hat{i}$.

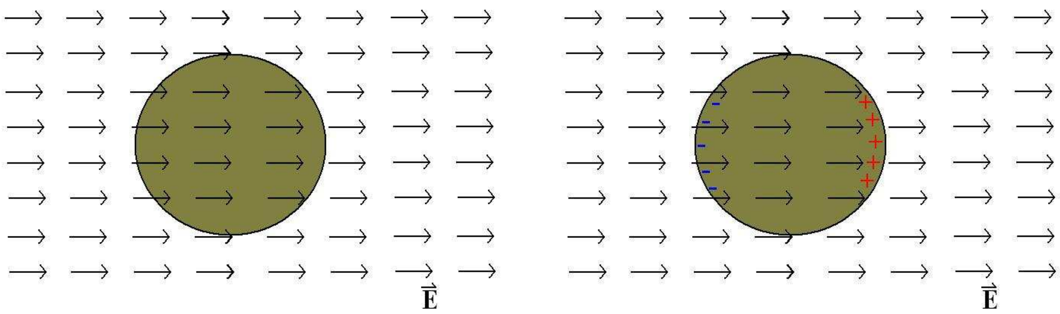
At point Q, the field from the positive charge is $\vec{E}_1 = -k_e \frac{q}{b^2}\hat{i}$ while the field from the negative charge is $\vec{E}_2 = k_e \frac{q}{(a+b)^2}\hat{i}$ so that the net field is $\vec{E}_Q = \vec{E}_1 + \vec{E}_2 = k_e q \left(\frac{1}{(a+b)^2} - \frac{1}{b^2} \right) \hat{i}$

Examples

At point P,

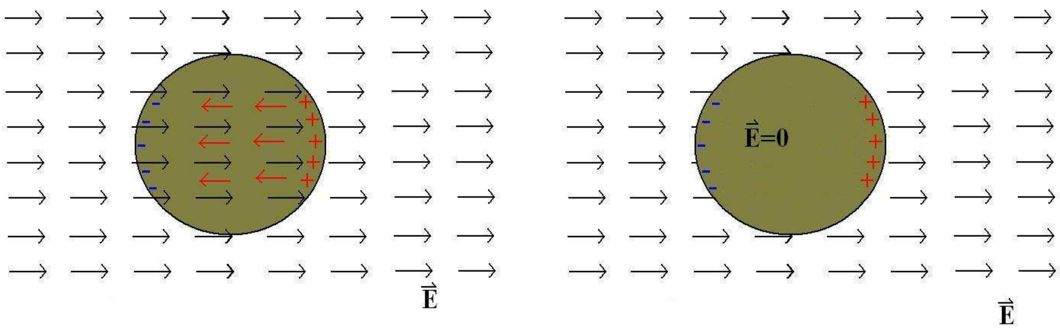
$$\begin{aligned}
\vec{E} &= \vec{E}_1 + \vec{E}_2 \\
E_y &= E_{1y} + E_{2y} = k_e \frac{q}{r^2} \sin\theta - k_e \frac{q}{r^2} \sin\theta = 0 \\
E_x &= E_{1x} + E_{2x} = k_e \frac{q}{r^2} \cos\theta + k_e \frac{q}{r^2} \cos\theta \\
&= 2k_e \frac{q}{a^2+y^2} \frac{a}{\sqrt{a^2+y^2}} \\
\vec{E} &= k_e \frac{2qa}{(y^2+a^2)^{3/2}} \hat{i}
\end{aligned}$$

Electric field inside conductors



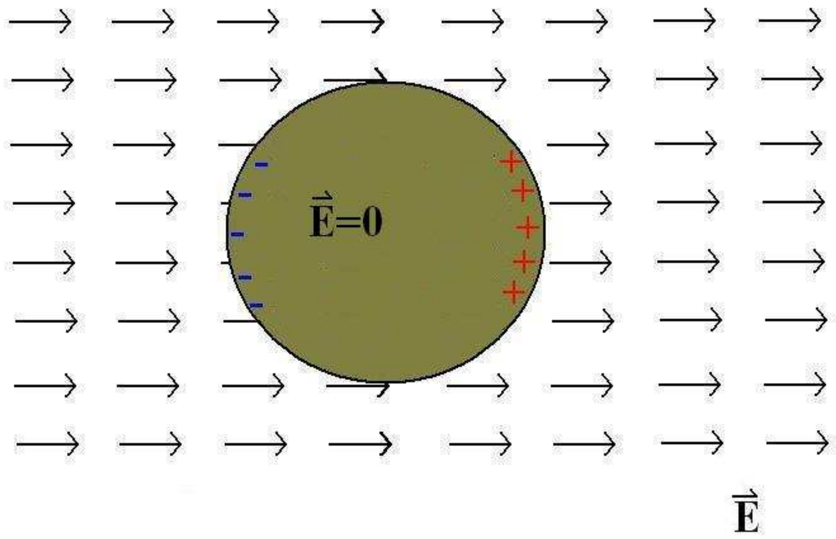
- Let's now think about what happens if we place a conductor inside an electric field.
- If an electric field is present, charges inside the conductor will feel a force $\vec{F} = q\vec{E}$.
- In a conductor, charges are free to move, so they will accelerate under the action of the force.

Electric field inside conductors



- But if we separate electric charges inside a conductor, they create their *own* electric field.
- This field is added to the initial one.
- Eventually, these two fields cancel, and the charges in the conductor no longer feel a force.
- *Electro-static equilibrium* has been reached.

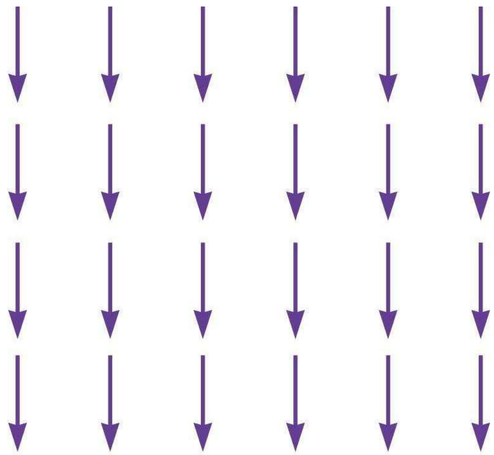
Electric field inside conductors



- So <u>the electric field in a conductor at electro-static equilibrium is zero!</u>
- Note that this is only true at electro-static equilibrium.
- Before equilibrium is achieved, the field is non-zero, and charges feel a force and move inside the conductor!

Uniform electric fields

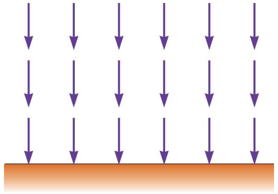
Did you notice that the field I drew previously had the following configuration?



- We notice two things:
  - The $\vec{E}$ vectors point in the same direction everywhere
  - The $\vec{E}$ vectors have the same magnitude everywhere
- This is called a *uniform electric field*.

Uniform electric fields

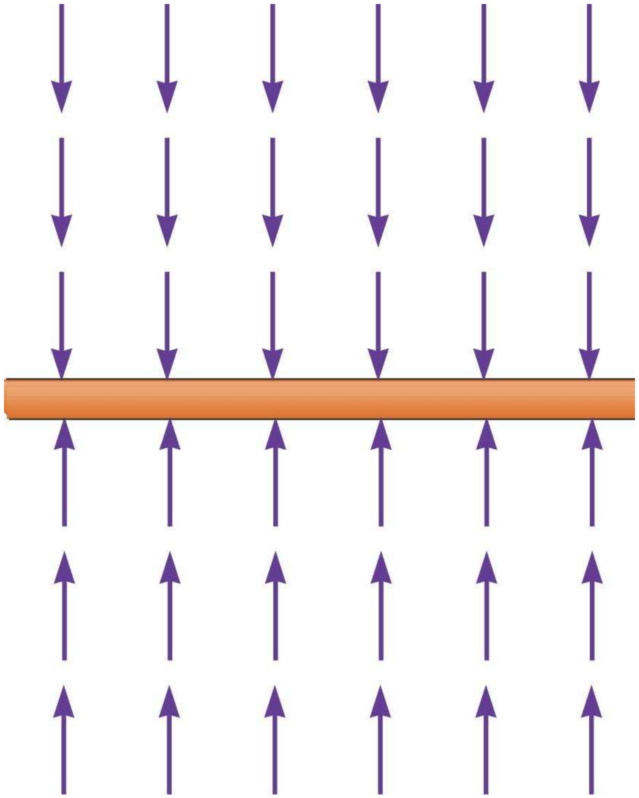
- How can we place charges in order to create a uniform electric field?
- An analogy might help; what uniform field do you all know?
- The gravitational field at the surface of the Earth is uniform!
  - it points straight down everywhere
  - it has a magnitude of 9.81 N/kg everywhere
- The mass is a large flat distribution (at least as seen from close-up)



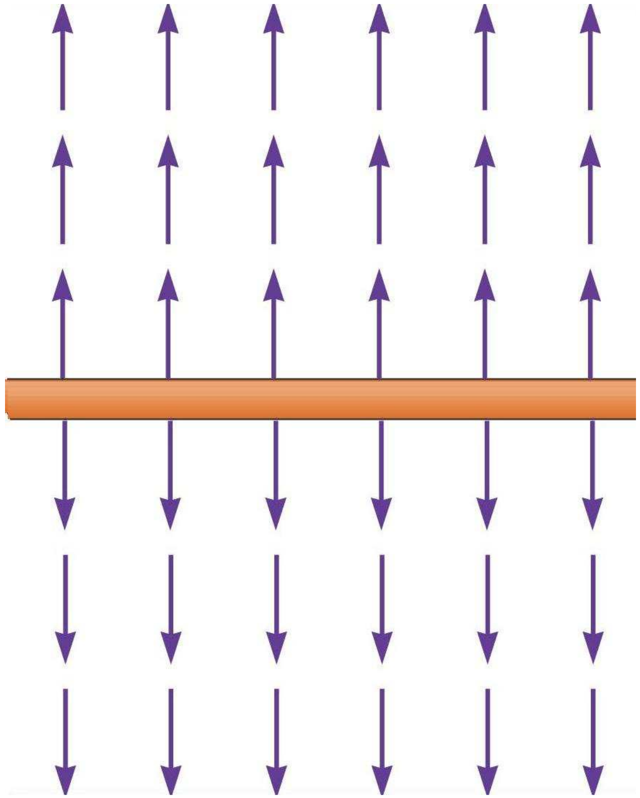
(b)

Uniform electric fields

A (infinitely) large sheet of charge creates a uniform electric field.



Negatively charged sheet



Positively charged sheet

Lightning

Why does this happen? The air always contains some free electrons. If there happens to be an electric field present (say because the storm clouds are charged), these electrons feel a force and accelerate.

Lightning

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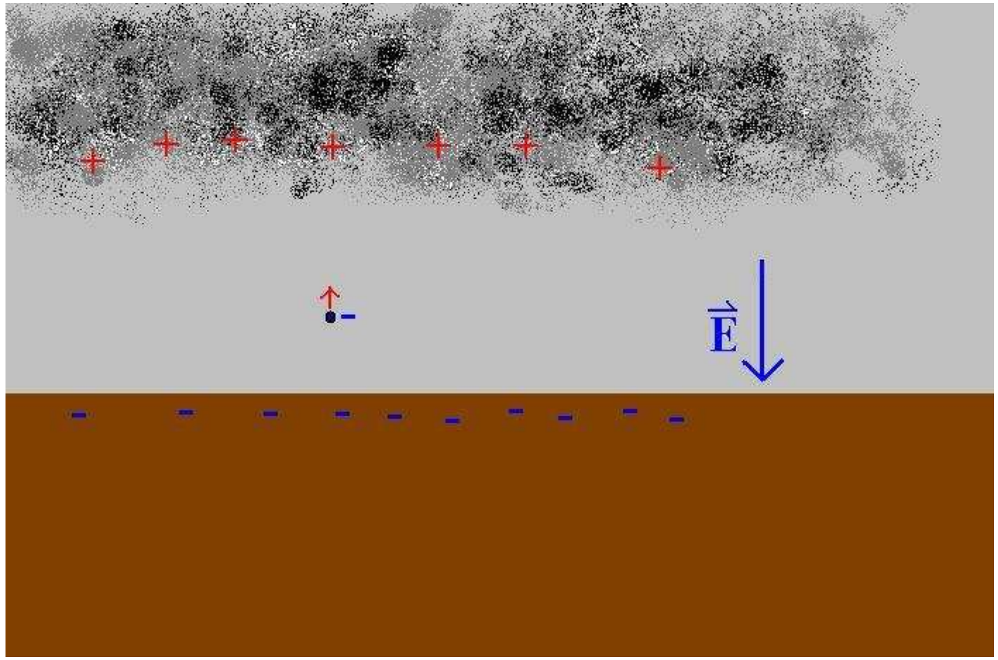

Lightning

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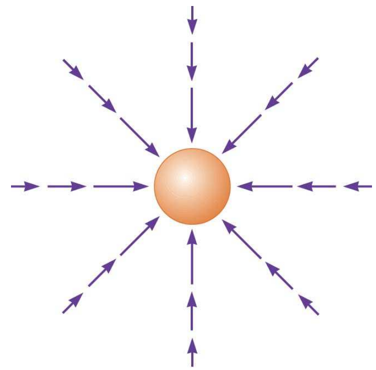
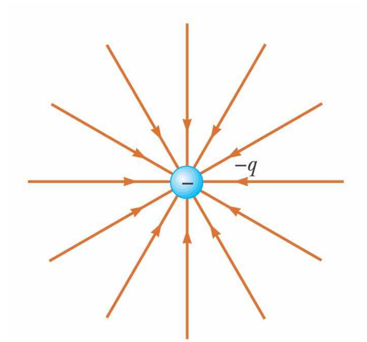
They reach high speeds and collide with air particles, knocking out other electrons which then accelerate and hit other air particles, knocking out even more electrons. This process is called *electro-static breakdown*. This large number of electrons moving is a large *current*. This is what shocks you if you are unlucky enough... The light comes from ions in the air capturing electrons and emitting light in the process.

Electric field lines

Consider the following electric field:



(a)



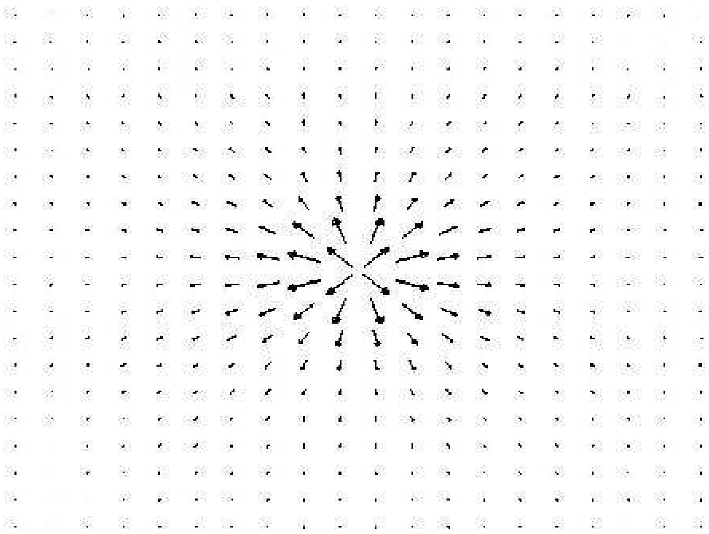
(b)

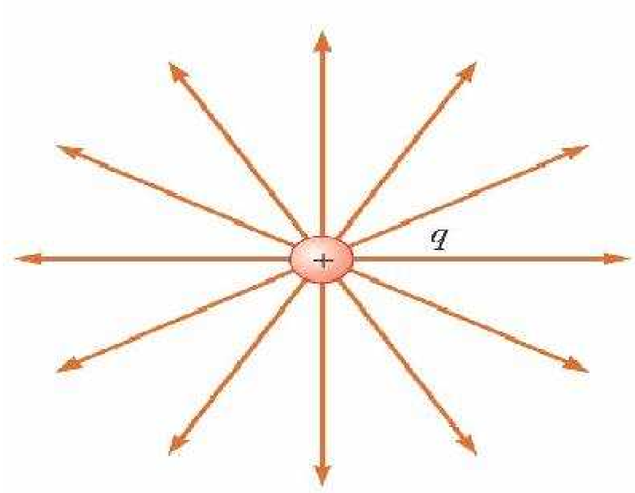
We can represent the same field using electric field *lines* instead

Information from electric field lines

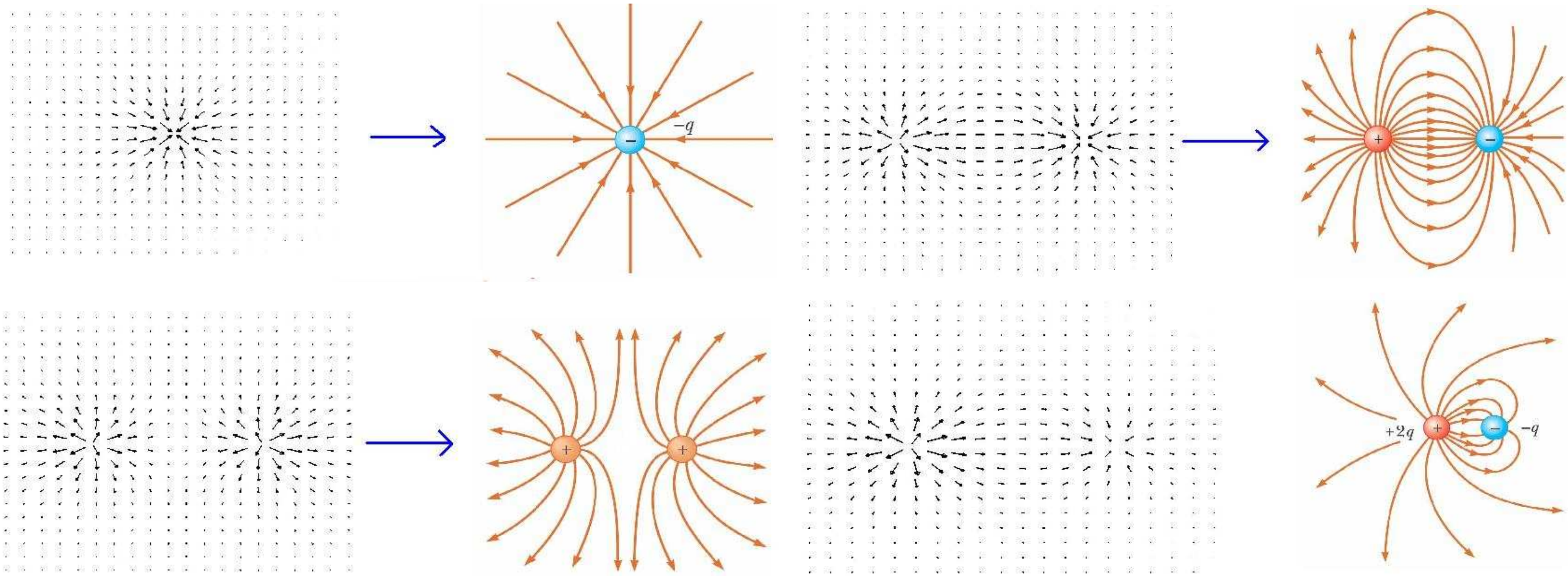
One piece of information we get from **fields lines** is the direction of the electric field.

The electric field is everywhere tangential to the field lines.





Electric field lines



Note that field lines can *never cross*! (Can you say why?)

The electric field only points in one direction at every point.

Electric field lines

Electric field lines are a convenient way to represent the electric field pictorially. In contrast to the electric field which is a *real physical entity*, electric field lines are *not real*.

- Electric field lines are parallel to the electric field vector at every point in space
- Electric field lines are directional, with an arrow pointing in the same direction as the electric field
- Field lines can only begin on a positive charge and end on a negative charge
- The force felt by a test charge at a point in space is tangential to the field line at that point
- FIELD LINES DO NOT REPRESENT THE MOTION OF PARTICLES IN A FIELD!!!

Information from electric field lines

Another piece of information we can get from field lines is the *strength of the electric field*.

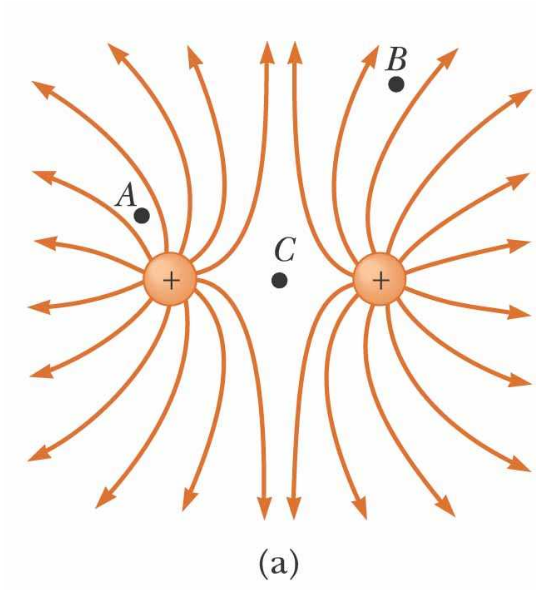
The magnitude of the electric field is proportional to the number of electric field lines passing through a surface perpendicular to them.

In other words, the larger the density of lines at a point, the stronger the electric field is at that point.

Information from electric field lines

In other words, the larger the density of lines at a point, the stronger the electric field is at that point.

Rank the magnitude of the electric field at points A, B and C.

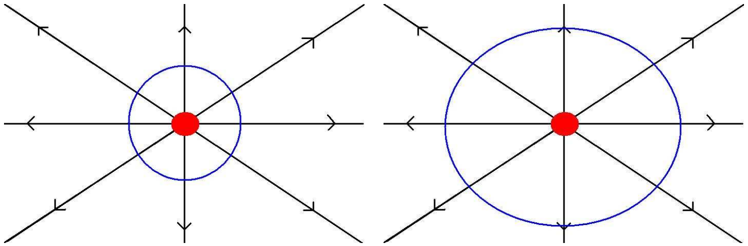


The field is stronger at A than at B and stronger at B than at C.

Information from electric field lines

The magnitude of the electric field is proportional to the number of electric field lines passing through a surface perpendicular to them.

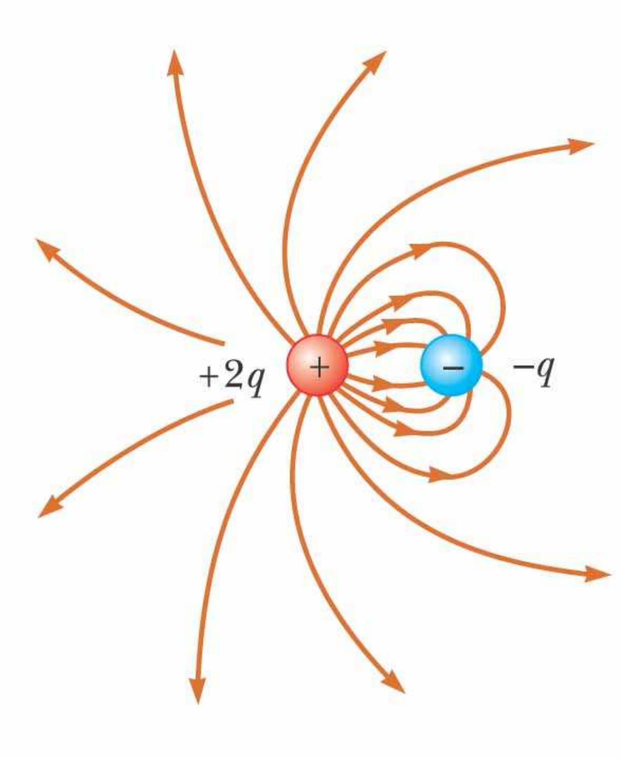
Let's check this for a sphere around a point charge:



The number of lines is constant, but the area of the sphere goes like r^2, and the lines per surface area go like $\frac{1}{r^2}$ which we know is the correct behaviour for the magnitude of the electric field.

Information from electric field lines

Another consequence of this is that *the number of field lines entering or leaving a charge is proportional to the magnitude of the charge*.



There are twice as many lines leaving $+2q$ as there are entering $-q$.

What to read for next lecture

- 23.7