AP Physics - Electric Fields

The earth is surrounded by a gravity field. Any object with mass will have a force exerted on it by the earth's gravity (and it will exert an equal force on the earth – third law, natch). This is fairly simple to picture in one's mind. You have the earth pulling things down with the force of gravity, but because the force of gravity is so weak, we don't have to worry about the force of gravity between objects that are in the earth's gravity field.

This is not true for electric charges. If you have a group of them, the forces they exert on each other are significant and we can't ignore them. It would be like having 3 or 4 planets scattered around in a volume a thousand times smaller than the solar system. They would all exert tremendously large forces on each other. Because of this we have to treat electric forces between charges way different than how we treat gravitational forces between masses.

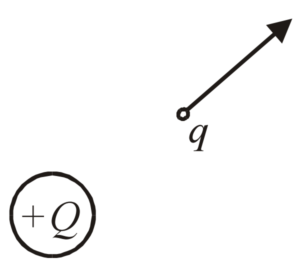
Electric Lines of Force: An electric field exists around any charged object in space. A second charged object brought into this field will experience a force according to Coulomb's law. Of course this is also true for gravity. Objects with gravity are surrounded by a gravity field. The thing is that gravity fields aren't very useful (because gravity is pretty simple), but electric fields are.

The electric field $\boldsymbol{E}$ is a vector quantity. It has both magnitude and direction. The direction of the field is the direction a small ***positive*** charge would be subject to.

In the drawings below, $\boldsymbol{Q}$ represents the charge causing the field. $\boldsymbol{q}$ represents a small test charge. In this first case, Q is positive and the test charge is positive.

In the example above, a positive charge $\boldsymbol{Q}$ exerts a force on a small positive test charge $\boldsymbol{q}$. The direction of the force is away from $\boldsymbol{Q}$.

If we move the test charge to a new location, the force exerted on it will have a new direction, but it will still be away from $\boldsymbol{Q}$.



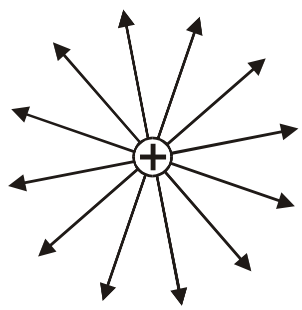
We can represent the field and the direction of the forces it will exert by drawing in lines that show how the forces would be directed. We call these ***electric lines of force***.

Electric lines of force* $\equiv$ *lines drawn so that a tangent to the line shows the direction of the electric force.

1. The number of lines per unit area is proportional to the strength of the field.

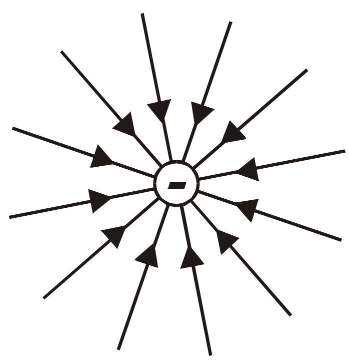
2. Where ***E*** (the electric field strength) is large, the lines will be close together. Where ***E*** is small, the lines will be far apart.

The electric field around a single point ***positive*** charge would look like this:



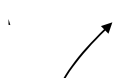
The direction of the arrows is the direction of the force that would be exerted on a positive test charge placed at that point. The lines show that any positive charge in the field would experience a force that wold be directed directly away from the positive charge in the center.

The lines of force around a ***negative*** charge would look like this:

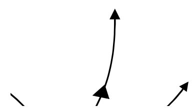


Note: the direction is towards the source of the field. This is because a positive test charge would be attracted to the negative charge in the center.

Here are electric lines of force between two positive charges:



Lines of force between two unlike charges:



Field Intensity: The field intensity is a measure of the strength of an electric field. It is represented by the symbol ***E***.

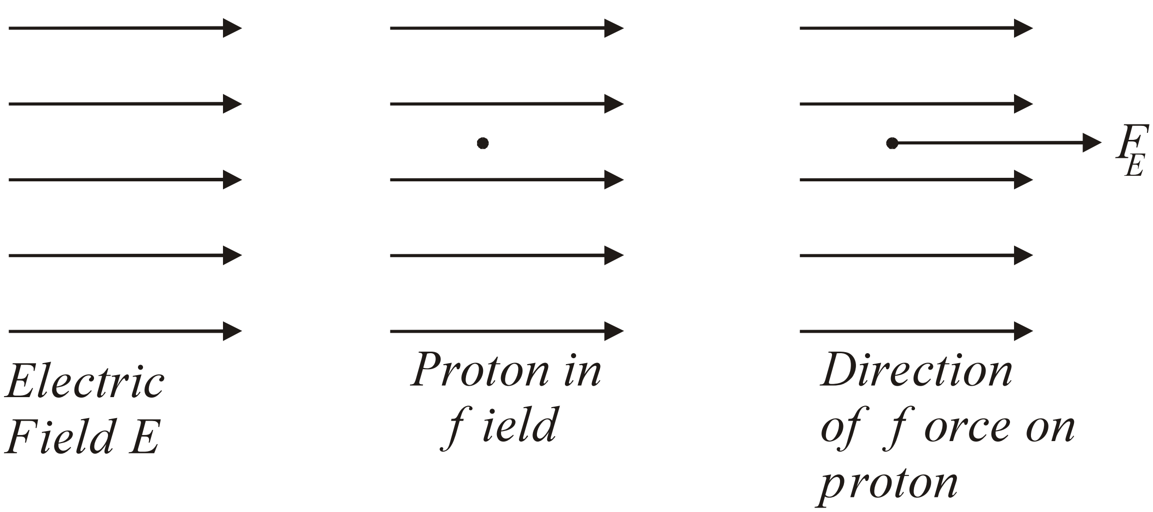
$$E = \frac{F}{q}$$

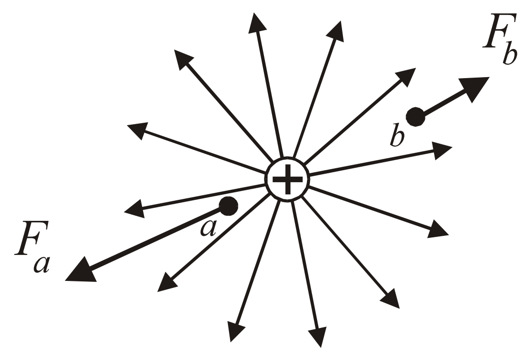
Here, ***E*** represents field intensity, ***F*** represents the force in Newtons acting on a test charge q_0, which is a test charge that is being acted upon. This charge, q_0, ***is not the charge that has set up the field***! q_0 ***is a test charge that is in the field made by Q (which is some other charge)!***

The unit for the field intensity is a $\frac{Newton}{Coulomb}$ or N/C.

Electric lines of force are very useful to figure out what sort of forces will act on charges in a given electric field.

You can quickly determine the direction of a force acting on a charged particle due to an electric field. In the above example (in the drawing) there is a uniform electric field ***E***. A proton will experience an electric force from the field, F_E as shown in the drawing below.





An electric field surrounds a positive charge. Two small positive test charges are placed in the field; one at point ***a*** and the other at point ***b***. We can determine the direction of the forces acting on the test charges and also determine their relative magnitudes. The force on the particle at ***a*** will be greater than the force at ***b*** because the lines of force are closer together where ***a*** is located. Closer lines of force means a bigger force.

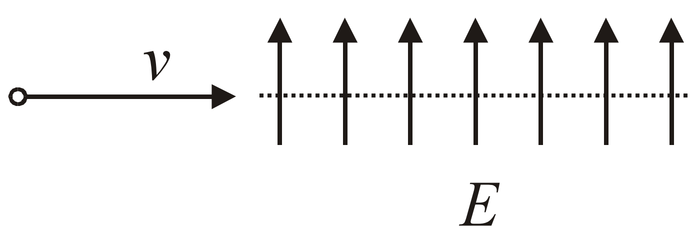
- An electric field has a field intensity of 2.0×10^4 N/C. If the force acting on a test charge is 6.2 N, what is the magnitude of the test charge?

This is a simple plug and chug problem.

$$E = \frac{F}{q} \qquad q = \frac{F}{E} = \frac{6.2\ \cancel{N}}{2.0\, x\, 10^4\ \frac{\cancel{N}}{C}} = \boxed{3.1\, x\, 10^{-4} C}$$

Once we can find forces, we can use Newton's laws to calculate all sorts of wondrous things. Like velocity or acceleration!

- An electron travelling at 2.3×10^5 m/s with a direction as shown in the drawing enters a uniform 280 N/C electric field. (a) Analyzing the electric lines of force, what is the direction of the force acting on the particle? (b) What is the magnitude of the force? (c) What is the acceleration acting on the electron? (d) If the electron travels a distance of 3.0 mm in the field, what is the distance it will be deflected from its original path?



(a) The direction of the force will be down. The arrows on the lines of force show the direction of a force acting on a positive test charge. Since the electron has a negative charge, the force will be in the opposite direction.

(b) We know the charge of an electron, so we can figure out the force acting on it.

$$E = \frac{F}{q} \qquad F = Eq \quad = 280\frac{N}{\cancel{C}}\left(1.6\,x\,10^{-19}\,\cancel{C}\right) = \quad 448\,x\,10^{-19}\,N \quad = \quad \boxed{4.5\,x\,10^{-17}\,N}$$

(c) We can use the second law to find the acceleration. We'll need the mass of the electron, but we can look that up.

$$F = ma \qquad a = \frac{F}{m} \quad = 4.5\,x\,10^{-17}\,\frac{\cancel{kg} \cdot m}{s^2}\left(\frac{1}{9.11\,x\,10^{-31}\,\cancel{kg}}\right)$$

$$a = 0.494\,x\,10^{14}\,\frac{m}{s^2} \quad = \quad \boxed{4.9\,x\,10^{13}\,\frac{m}{s^2}}$$

(d) The electron is moving horizontally at a constant velocity. It will be accelerated downward by an electromagnetic force and also by gravity. Looking at the acceleration from the electric field, we can see that the acceleration from gravity is way way smaller, so we can ignore gravity - it is totally insignificant. (Hey, what is a lousy 9.8 m/s^2 compared with 10^{13} m/s^2?)

We need to figure out the length of time it will be accelerated. It is moving through a field – this is ***when*** it will be accelerated – a distance of 3.0 mm. We know the horizontal speed, so we can find the time to travel that distance.

$$x = vt \quad t = \frac{x}{v} \quad = 0.0030\,\cancel{m}\left(\frac{1}{2.3\,x\,10^{5}\,\frac{\cancel{m}}{s}}\right) \quad = \quad 0.0013\,x\,10^{-5}\,s \quad = \quad 1.3\,x\,10^{-8}\,s$$

Armed with the time, we can find the distance it will be displaced.

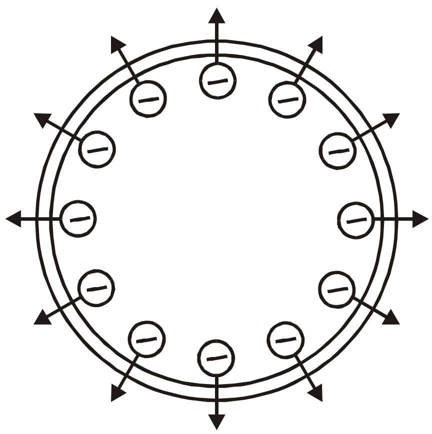
$$y = \frac{1}{2}at^2 \quad = \frac{1}{2}\left(3.2\,x\,10^{13}\,\frac{m}{\cancel{s^2}}\right)\left(1.3\,x\,10^{-8}\,\cancel{s}\right)^2 \quad = \quad \boxed{2.1\,x\,10^{-3}\,m \quad or \quad 2.1\,mm}$$

So the electron will be deflected downwards a distance of 2.1 mm as it travels through the field.

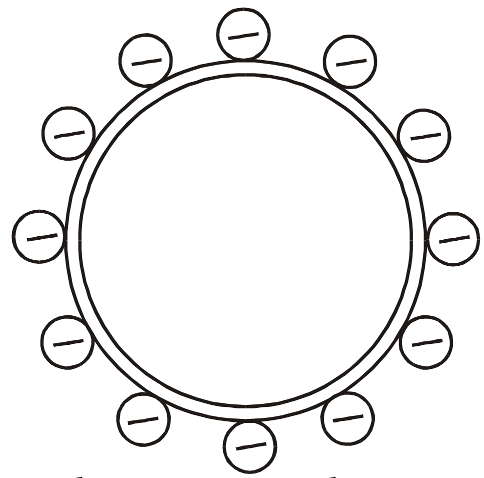
This problem looked really horrible, even the Physics Kahuna must admit this, but it actually turned out to be quite simple. Other than the $E = \frac{F}{q}$ equation, the problem dealt with a force, an acceleration, a constant velocity over a given distance, and a displacement caused by a force. All of which is stuff you've done before.

Electric Fields and Objects: The electric charge on an object, such as a conductive sphere, say for example, always is on the outside of the object. It is on the outer surface. Why is this so?

Well, it’s very fundamental. The free electrons repel each other. This means that they try to get as far away from one another as they possibly can. In order to do this, they collect on the outside surface and spread out. If they were on the inside, they would be closer together, so they don’t do that.



Electrons repel each other to the outside



Electrons end up on the outer surface