Electric Fields -- Conceptual Solutions

1.) What does an electric field actually tell you? That is:

a.) Is it a vector? If so, what does its direction signify?

Solution: An electric field is a modified force field, so it's a vector. Its direction at a particular point in space is defined as the direction a *positive charge* would accelerate if placed in the field at that point.

b.) What does its magnitude tell you?

Solution: The magnitude of an electric field function, as defined at a particular point in space, tells you the amount of *force per unit charge* that is available at that point due to the presence of the *field-producing* charge. That is, if you know the magnitude of E at a point, a charge q placed at that point will experience a force $F = qE$.

c.) How might electric fields be used in everyday life?

Solution: Electric fields motivate charge to move. Need light? Flipping a switch provides an electric field which moves the charge in the filament of your light bulb, and voila . . . light. Need toast? Flipping a switch provides an electric field which moves charge through the heating coils of your toaster. Need to frappe´ something? Flipping a switch provides an electric field that moves charge through a coil producing a magnetic field that is required if your blender's motor is to work. None of that would happen without an electric field to feed electrical energy into your systems.

2.) An electric field is oriented toward the right.

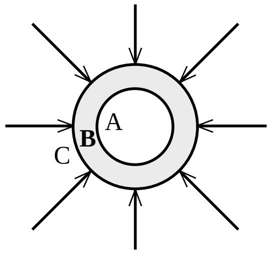
a.) What will an electron do if put in the field?

Solution: As positive charge moves *along* electric field lines (remember, the *direction* of an electric field line is defined as the direction a positive charge would accelerate if put in the field at the point of interest), a negative charge will move opposite the direction of the electric field lines.

b.) What will a proton do if put in the field at the same point as mentioned in *Part a*?

Solution: Protons and electrons have the same charge but different masses. When put in an electric field, the magnitude of the force each feels will be the same, but the directions will be opposite. Also, the accelerations will be different because the masses differ.

3.) To the right is a cut-away cross-section of a thick-skinned ball. Given the electric field lines as shown:



a.) Tell me everything you know about *area A*. Note that you may not know *why* your observations make sense, but at least make them.

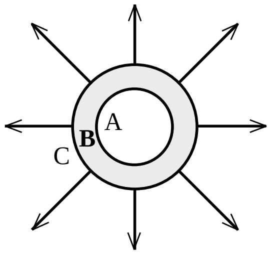
Solution: There are no electric field lines in *area A*, which is a hollow, so there is no electric field in that region.

b.) Tell me everything you know about *area B*.

Solution: There are no electric field lines in *area B*, so there is no electric field there. I can't tell from the information given whether the shell is made up of a conducting material (i.e., a metallically bonded material) or an insulating material (i.e., a covalently bonded material).

c.) Tell me everything you know about *area C*.

Solution: Now it's getting interesting. The electric field lines in *area C* are pointed inward toward the sphere's surface. Electric field lines *leave* positively charged surfaces (this makes sense as a *positive test charge*--the kind of charge that is used to define the direction of an electric field--would be repulsed by a positively charged surface, hence the electric field lines would *leave* that surface) and *enter* negatively charged surfaces. As the field lines in this case are entering the surface, you can bet that the surface is negatively charged. Again, there is nothing to let us know whether the shell is a conductor or an insulator.



4.) To the right is a cut-away cross-section of a thick-skinned ball. Given the electric field lines as shown:

a.) Tell me everything you know about *area A*. Note that you may not know *why* your observations make sense, but at least make them.

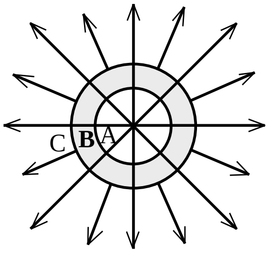
Solution: Again, there are no electric field lines in *area A*, which is hollow, so there is no electric field in that region.

b.) Tell me everything you know about *area B*.

Solution: There are no electric field lines in *area B*, so there is no electric field there. I can't tell whether it is a conducting material or an insulating material.

c.) Tell me everything you know about *area C*.

Solution: In this case, the electric field lines are *leaving* the surface, so the surface must be positively charged.



5.) To the right is a cut-away cross-section of a thick-skinned ball. Given the electric field lines as shown:

a.) Tell me everything you know about *area A*. Note that you may not know *why* your observations make sense, but at least make them.

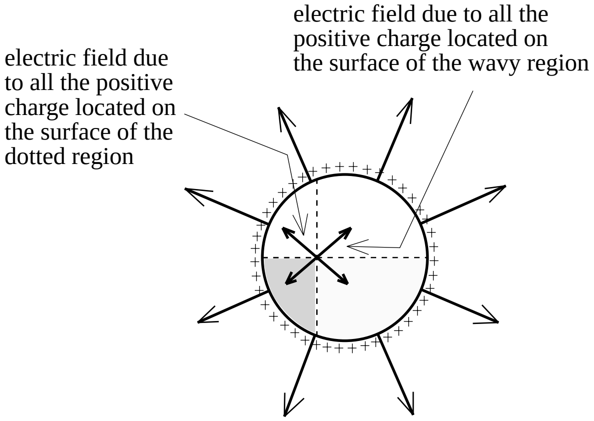
<u>Solution</u>: There are electric field lines that emanate outward from the center of the hollow. This suggests that there is a positive charge at the center of the hollow producing the outward electric field.

b.) Tell me everything you know about *area B*.

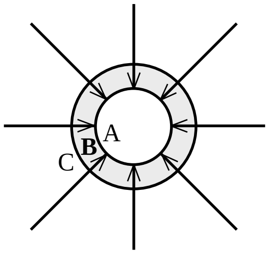
<u>Solution</u>: There is an outward electric field in this region. What is interesting, though, is what that says about the material. It *must be an insulator*--it can't be a conductor. The rationale behind this is as follows: As long as there is an electric field in a metallically bonded material (i.e., a conductor), electrons will move under the influence of that field (remember, electrons move in a direction that is *opposite* the direction of the electric field). If the solid portion of our spherical shell was a conductor, there would be valence electrons inside the metallically bonded region that continue to move within the structure until the net electric field inside that structure would be neutralized. That is, because charge in conductors *can* move around, they do so until the electric field in that region has been reduced to zero. Once accomplished, they stop moving. Put a little differently, the electric field inside ANY conductor in this kind of situation *must be zero*. In this case, there is a field in this region (the field lines show that), so the region *can't* be a conductor--it *must* be an insulator. What's more, because there doesn't seem to be a discontinuity between the field lines inside the hollow and inside the solid region, the electric field inside the shell must be due to the charge at the hollow's center and *not* due to additional charge shot through the insulating sphere.

c.) Tell me everything you know about *area C*.

<u>Solution</u>: There are more field lines outside the shell than inside the shell. This suggests that the field outside the shell is larger than the field inside the shell. How could this be? There must be additional positive charge on the outer surface of the shell. Now you might think that extra charge on the outside of the shell would increase the electric field *inside* the shell, too. It doesn't. To see why, consider the charged sphere to the right. The shell has been broken up into four sections. What is the electric field at the intersection of the regions? Because a point charge produces an electric field that is an inverse square function (i.e., related to the inverse of the square of the distance between the point charge and the point of interest), the electric field produced by the charge on the outside surface bounding the dotted region in the sketch will be equal in magnitude to the electric field produced by the charge on the outside surface bounding the wavy region. The same is true of the electric fields generated by the other two regions. When vectorially added together, the net field is found to be *zero*. Note: You have seen a situation like this before. The gravitational force on a mass that is located somewhere *inside a planet* is governed *only* by the mass inside the sphere upon which the mass rested at a given instant. The gravitational effect of the mass outside that sphere adds to zero. That happens because the gravitational force is an inverse square function. The same is the case here.) The only charge that will affect the intersection identified in the sketch above is charge *inside the sphere* upon which the point rests. As there is no charge inside that sphere in this case, there will



be no net electric field at that point. In short, charge on the outside of the shell will produce an electric field outside the shell, but it won't affect what's going on *inside* the shell.



6.) To the right is a cut-away cross-section of a thick-skinned ball. Given the electric field lines as shown:

a.) Tell me everything you know about *area A*. Note that you may not know *why* your observations make sense, but at least make them.

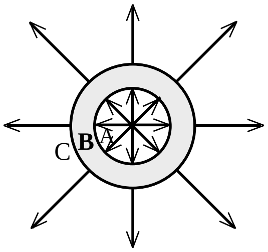
Solution: There are no electric field lines inside the hollow, so there must be no electric field *and* no charge inside the hollow.

b.) Tell me everything you know about *area B*.

Solution: There is an electric field inside the solid, and it is oriented inward. That means two things. First, the solid must be an insulator, not a conductor. Second, there must be negative charge (remember, electric field lines *enter* negative charge) on the *inside surface* of the shell.

c.) Tell me everything you know about *area C*.

Solution: Because the electric field lines outside the shell appear to be mere extensions of the electric field lines inside the shell, it is probable that the electric field found outside the shell is produced by the negative charge on the inside surface of the shell.



7.) To the right is a cut-away cross-section of a thick-skinned ball. Given the electric field lines as shown:

a.) Tell me everything you know about *area A*. Note that you may not know *why* your observations make sense, but at least make them.

Solution: There are outward directed field lines emanating from the center of the hollow, so there must be a positive charge Q at the center.

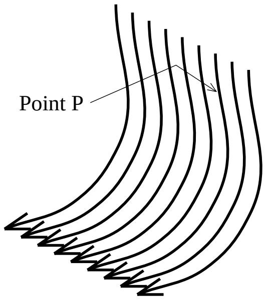
b.) Tell me everything you know about *area B*.

Solution: There are no electric field lines in the shell. If there had been no field lines *inside the hollow*, we would have no way of knowing whether the solid was a conductor or an insulator. Because there are field lines inside, we still don't know for sure if the shell is a conductor. How so? If the shell *was* a conductor, electrons in the shell would redistribute themselves so that $-Q$'s worth of charge would spread over the shell's inside surface. The field produced by this negative charge would superimpose on the field produced by Q at the hollow's center, and the net effect would be zero electric field in the conductor. If the material was an insulator, on the other hand, $-Q$'s worth of charge could have been placed on the shell's inside surface and the same net effect would be observed. In short, we can't tell what kind of material makes up the shell.

c.) Tell me everything you know about *area C*.

<u>Solution</u>: The field lines in this region mean there is an electric field. Where did it come from? It depends on whether the shell is an insulator or a conductor. If it is a conductor, the electrons that migrated to the inside surface of the shell would have left an equal amount of positive charge on the outside surface. That charge would produce an electric field comparable to the one shown. On the other hand, if the material was an insulator, then positive charge would have to have been placed on the outside surface. Either way, electric field lines exist outside the shell. That means there is an electric field in that region.

8.) An electric field is shown to the right.

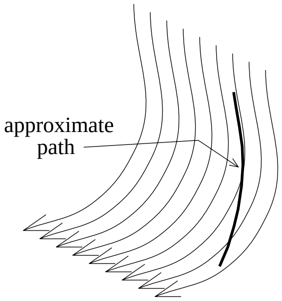


a.) In what direction will a positive charge accelerate if placed in the field at *Point P*?

<u>Solution</u>: It will accelerate along the electric field lines. At the point shown, that will be in the downward direction.

b.) Assume the positive charge *is* released at *Point P*. Draw a plausible path for the charge's motion after its release. Think about this. It isn't as simple as it may appear.

<u>Solution</u>: As the positive charge picks up speed, its momentum will carry it off-line. The electric field will still affect the charge, though, so the charge will curve leftward as it gets down into the region where the field lines angle leftward.



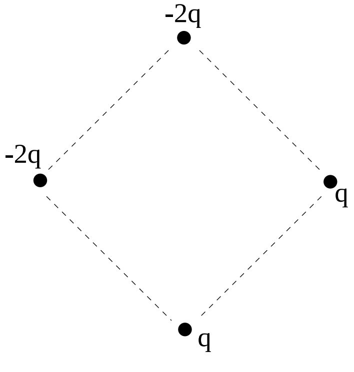
c.) What would be different in *Part a* if a negative charge had been placed at *Point P*?

<u>Solution</u>: Negative charges accelerate in a direction that is *opposite* the direction of electric field lines.

d.) Is there any region in which the magnitude of the electric field is a constant (at least to a good approximation)? If so, where on the sketch?

<u>Solution</u>: The field lines are approximately the same distance apart throughout the region (what changes is the direction). As such, the *magnitude* of the electric field is approximately constant *throughout the field*.

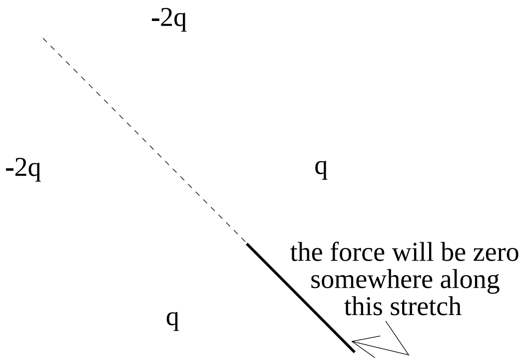
9.) Consider the charge configuration shown to the right. You would like to place a negative charge in the field so that its acceleration is zero.



a.) Ignoring gravity, where might that be possible?

<u>Solution</u>: Due to symmetry, the position will be somewhere along the line shown in the secondary sketch. Assuming the charge was -*Q*, it would be

repulsed by the *-2q's* and attracted to the *q's*. That eliminates the area inside the square where it will always be pulled upward and to the left. The area up and to the left is eliminated because the charge *-Q* would always be closer to the larger negative charges and, hence, the smaller positive charges would never be able to counteract the *-2Q* effects. That means *-Q* would have to be somewhere along the line to the bottom right.



b.) Assuming you found a point that fits the bill (there may be more than one, but take just one), what do you know about the electric field at that point?

Solution: If the net force is zero at the point of interest, that would mean the *force per unit charge* available at that point would be zero. In other words, the electric field would have to be zero at that point.