Electrostatics Challenge Questions

Physics

1. A point in space has a voltage of 4.5 V. Will a charged particle accelerate at that location? Explain how you know – or if you don't know, explain what additional information would help you determine the answer.

2. A point in space has a voltage of 8.9 V. What does that number tell you? Be as specific as possible, but limit your answer to implications that will always be true, regardless of any other information (such as what is creating the electric field, what types of charges might be placed in that spot, etc.)

3. When you calculate the net electric field in a location due to the presence of more than one large charge (Q), it is generally not helpful to include the sign of the charges in the equation for electric field. Why not? Specifically, what does the sign of a charge tell you about the direction of the electric field, and what does the sign of a charge NOT tell you about the direction of the electric field?

4. In contrast to question number 3, when you calculate the voltage (electrical potential) at a point in space – whether it's due to the presence of one or more large charges – it is critical for you to include the sign of the Q's that are creating the electric field. Why?

5. Spherical objects that are resting on curved surfaces in the earth's gravitational field behave in predictable ways. The slope of the surface that the object is on will determine whether or not it will accelerate, how quickly it will accelerate, and in which direction. The height of the object above the ground determines how much kinetic energy it would have if it accelerated all the way to the ground. Changing the height of an object requires work to be done to the object if it is being raised in height, or will result in the object having kinetic energy if it is allowed to roll to a lower height on its own. (For this example, imagine that the object is so small that there is no energy necessary to cause it to rotate.) Using your understanding of electrical potential and electric field, create an analogy that relates the behavior of objects on curved surfaces in the earth's gravitational field to the behavior of a charged particles in varying electric fields. (To start with imagine that we are only looking at the behavior of positively charged particles in electric fields; once you have that figured out, you can extend your analogy to negatively charged particles in the same electric fields.)

Answers:

1. You don't know whether the particle will accelerate. In order to find out, you would need to know how the voltages are different at points in space immediately next to the

point we are considering. If there are lower voltages present, a positively charged particle would accelerate towards the lowest of those voltages. If there are higher voltages present, a negatively charged particle would accelerate towards the highest of those voltages. You can imagine other scenarios – what would you expect to see if the point were surrounded by higher or lower voltages in all directions?

2. The only thing that number can tell you is that it would take 8.9 joules of work to move a +1 Coulomb charged particle to that position from an infinite distance away (or that a -1 Coulomb charged particle would have that much kinetic energy if allowed to accelerate to that point, starting from rest, from an infinite distance away).

3. The sign of the charge has nothing to do with whether the direction of an E-field will be positive or negative with respect to a certain linear frame of reference. The E-field created by a positive charge radiates outward from that charge in all directions (if you set a standard frame of reference, you'll see that depending on which point you're looking at, the direction of the electric field can be positive or negative in the x- and y-dimensions, and can in fact be pointing at any angle). For a negative charge, the E-field radiates INWARD in all directions. So the positive and negative directions that would be associated with the E-field equation would tell you "outward" (a positive number) or "inward" (a negative number). Those directions are irrelevant in a standard frame of reference. So instead, it's easier to just leave the signs out of the equation and use pictures to determine when to add, subtract, or use vector math to combine E-field components.

4. Voltage isn't a vector. The signs you get for voltage don't indicate direction; instead, they tell you whether the voltage from a charge at a location is above or below the electrical potential of a point an infinite distance away. The equations for voltage are derived using the conventional standard of zero volts at an infinite distance, so the signs those equations produce are meaningful within that standard. In other words, a negative charge really does create negative voltage: the locations nearest a negative charge have less electrical potential than locations farther away (a positively charged particle within the E-field created by a negative charge has less electrical potential as it gets closer to the negative charge, just as an object in the earth's gravitational field has less gravitational potential energy as it moves closer to the ground).

5. Electric field is like slope – greater electric fields will result in greater acceleration just like greater slopes will result in greater accelerations. Since positive charges always accelerate towards lower voltages, you can imagine that voltage (electrical potential) is like height: positive charges will always accelerate "downhill" from higher voltages to lower voltages. The more the voltage changes from one point to another, the steeper the "slope" is in that region (i.e., there is a stronger electric field). The voltage difference

between two locations determines how much work it will take to move a particle between those locations (like pushing an object uphill) or how much kinetic energy a particle can acquire if it accelerates on its own between those locations (like letting an object roll downhill). See the illustration below for one way to think about this analogy. The analogy works exactly the same way for negatively charged particles – except these particles will accelerate "uphill", from lower to higher voltages!