Coulomb's Law – Problem-based Learning

Electric potential – Energy to accelerate a charged particle

TEACHER'S GUIDE

Sample solution:

The work done to move the positive test charge must be equal to the negative of the work done by the electric field. The change in voltage of the charge is defined as the work done against the electric field per unit charge. The difference in potential energy between infinity and the midway point is given by: $\Delta U = q\Delta V = k\frac{Qq}{d} - k\frac{2Qq}{d}$. This value is less than 0 so is negative.

The electric field created by the large positive charge will permeate all of space except for inside the conductor. The conductor's free electrons will move to create a surface charge that results in no electric field within the conductor. Thus, the test charge will continue to float through the conductor and towards the end with the large positive test charge. As it leaves the opposite end, it will suddenly be exposed to the large electric field and because like charges repel, it will be repelled away from the positive charge with a very large force and thus a very large acceleration. This means that ultimately the test charge will have a very high velocity and a very high kinetic energy. As we saw in the previous example, usually moving a charge closer to another charge requires doing work against the electric field to move the test charge near the large charge. If there had been no conductor, a large amount of work would need to be done to move the test charge close to the large positive charge. This would be stored as electric potential energy and once the test charge is released, would be converted into kinetic energy. However, in this situation the conductor reduces the work required to move the test charge into the vicinity. However, the test charge will ultimately speed away with a large kinetic energy. To gain this kinetic energy, something must lose energy, in this case the electric field does. Electric fields store energy and under these conditions it gives up energy to accelerate the test charge.

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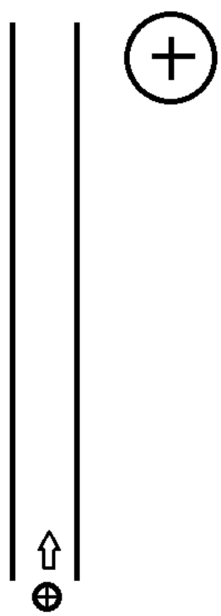
STUDENT INSTRUCTIONS

Two charges with charge -Q and 2Q are separated on the horizontal axis. What work must be done (positive or negative) to push a resting positively charged particle from infinity to halfway between them?

Now pretend that we have a hollow conducting pipe and we place a very large positive charge at one of the ends as shown in the diagram. A small positive test charge goes through the pipe towards the end with the large positive charge.



Describe the motion of the test charge as it moves through and out of the conducting pipe. Discuss the changes in energy – is the conservation of energy violated?

Suggested implementation:

The first question is rather simple and just to get students thinking about how work must be done to move a charge closer to another charge.

For the conductor and large positive charge question, ask students to draw in the electric field in the diagram. Students should note how there is no electric field inside the conductor. Ask how the electric field will affect the motion of the test charge as it moves through the conductor. Ask how it will affect the motion as the test charge exits the conductor.

Ask students to consider the energy of the test charge after it has been accelerated by the electric field after leaving the conductor. Is it large? How much work was needed to move the test charge through the conductor towards the large positive charge? Does this account for the large final kinetic energy of the test charge? If not, where does the energy come from to allow this change in kinetic energy? What could lose energy? Ask students what this situation tells them about electric fields. As a bonus, students can investigate the energy stored in an electric field.