Investigating student ability to apply basic electrostatic concepts to conductors

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1. Introduction

In teaching electrostatics and electrodynamics, it is necessary to introduce abstract ideas such as electric fields and electric potential difference before discussion of circuits can take place. The Physics Education Group at the University of Washington is investigating student ability to apply electrostatic concepts to systems involving conductors, in preparation to developing curriculum to bridge the standard instructional approaches to electrostatics and electric circuits.

2. Context and methods

Questions were administered to 500+ calculus-based introductory physics students, all of whom had received all the relevant lecture instruction.

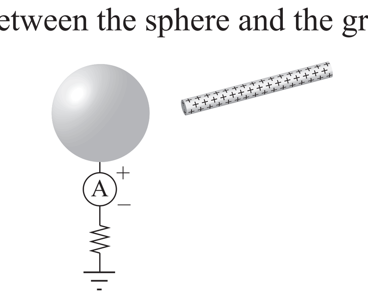
Questions were asked on on-line pretests, and as written and multiple-choice midterm and final exam questions.

Specific examples are described in the following sections.

3. Student tendency to calculate potential based on net charge

About 60% of introductory students used the net charge on an object to calculate potential differences around it, instead of the definition, $\Delta V = -W_{elec}/q_{test}$:

Question: when a positively charged rod is brought near a grounded sphere, the ammeter is observed to deflect. While it is deflected, what is the potential difference between the sphere and the ground?



Answer: positive.

"Electrons accumulate in the conducting sphere, so while this is occuring the potential in the sphere is negative, and the potential at ground is zero."

Only 15% of students correctly stated the potential difference was positive, most of whom used the direction of conventional current to determine their answer.

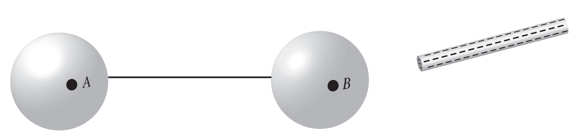
Interestingly, a few of the students who incorrectly (5-10%) explicitly stated that after a long time the potential difference would be zero, since charge would no longer flow from ground to the sphere. This contradicts their original answer, since after a long time the sphere is still negative.

In addition, all students who attempted to use net charge to determine the potential difference neglected to consider the charged rod, only considering the system of the sphere and the ground. Students also tended to consider only the system under question, instead of the entire system, in several other questions about potential.

4. Student tendency to not draw on prior experience when examining a new problem

60% of students could correctly predict that an extended conductor would have the same potential at all points.

Question: What is the potential difference between points A and B on the two spheres?

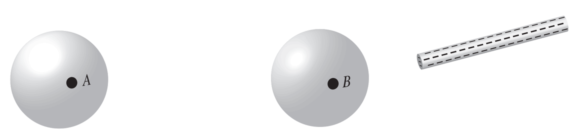


Answer: zero, since the two spheres are part of the same connected conductor, which is an equipotential.

"Within a conductor, there is no electric field and thus no electric potential difference."

However, if the wire is removed, the percentage of correct responses dropped to 25%:

Question: What is the potential difference between points A and B on the two spheres? (No charges flow as a result of the wire being removed.)



Answer: zero, since the two spheres had the same potential before the wire was removed, and no charges have moved.

"Electric potential on the right sphere is greater because the right sphere is positive and the left one is negative."

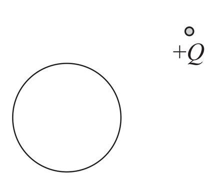
[student correctly answered the first question]

Half of the students who had correctly answered with the wire in place changed their answer, and argued based on the net charges on the spheres. Only 10% of students referenced the fact that the charge distribution was the same as before.

5. Difficulty relating charge distributions to potential differences

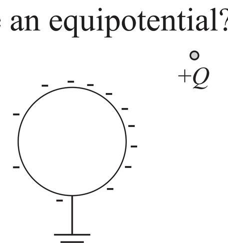
Students had no difficulty with determining charge distributions, but had significant difficulty in determining if the surface of an object was an equipotential based on its charge distribution.

Question: Draw the charge distribution on a neutral metal sphere when a positive point charge is place nect to it.



95% of students drew a qualitatively correct diagram.

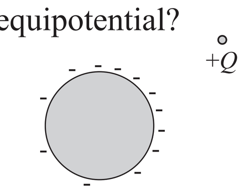
Question: Is the surface of the grounded metal sphere an equipotential?



35% of students correctly said the sphere is a conductor, so the surface is an equipotential.

40% said it is not because charge can flow to or from the sphere.

Question: The metal sphere is replaced with an insulating sphere with the same charge distribution. Is the surface of the sphere an equipotential?



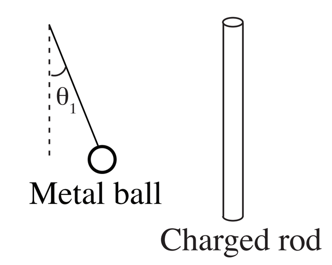
10% correct said yes, since the charge distribution is the same as on the conducting sphere.

70% stated insulators can only be equipotentials with uniform charge distribution.

6. Spontaneous charging by induction in electric fields

A significant fraction of students (up to 40%) believe that charge can appear on a conductor in the presence of an external electric field:

Question: A student observes a neutral metal ball being attracted to a charged rod. Explain this observation.

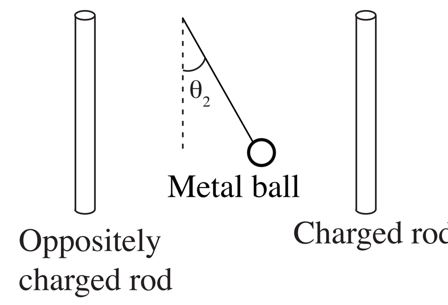


90% of students correctly explian that the rod will polarize the ball, so the ball will be attracted, but 10% think the ball becomes charged:

"The pith ball is attracted to the charged rod because the pith ball desires the charges on the rod and becomes inductively charged toward the rod."

An oppositely charged rod is now placed on the opposite side of the ball, and the fraction of students using spontaneous charging rises to 40%:

Question: The deflection increases when an oppositely charged rod is added. Explain why.



"The metal ball might have gained a charge [...] so the oppositely charged rod being alike to the ball repels it even farther."

In the last part of the question, students are asked what would happen to the deflection of the ball if the ball was grounded. 30% of students argued that the deflection would decrease, since grounding would remove the charge on the ball; most of these students also used spontaneous charging in the second question.

7. Summary

A number of reasoning patterns and difficulties emerge when asking introductory students to think about electric potential and charge distributions:

Students often calculate potential difference based on the net charge on an object, instead of using the work done by the electric field. This makes it difficult for students to make the connection to voltage differences in circuits.

Students have a high tendency to only consider properties of the objects in question, instead of considering the entire system.

The belief that charge can appear and disappear from conductors in the presence of external charges is widely prevalent, and can be seen in a wide variety of contexts.

Students struggle with the conceptual application of electrostatics ideas, even in relatively simple contexts. The development of curricula designed to address these difficulties and help students make the connection with voltage in electric circuits may significantly increase student understanding of electrostatics and electric circuits.