

E-4. Conductors

Teaching Notes

THE MAIN POINT

1. Understand the various properties of conductors and explain their origin.
2. Learn some new uses for Gauss's Law.

SAMPLE LESSON PLAN

Discussion Question 2 10 minutes in groups, 5 minutes GSI-led discussion & boardwork.
Discussion Question 1 5 minutes in groups.
Discussion Question 3 10 minutes in groups.
Problem 2 15 minutes in groups, 10 minutes GSI-led discussion & boardwork.

GENERAL TEACHING SUGGESTIONS

Time management. Although the rules of conductors are commonly emphasized in Physics 7B, appearing on exams with some regularity, it must be admitted that this topic is “book-ended” by some more important material: Gauss's Law on the left, and electric potential soon to come on the right. Consequently, in any given semester the teaching staff may well decide to spend less than a full section on conductors. The Sample Lesson Plan above allows for this possibility, accounting as it does for less than an hour of section time.

Sophistication. When explaining the rules of conductors, keep things heuristic and pictorial. Forget uniqueness theorems and the like; at the level of 7B, it is better to paint vivid pictures of electrons sloshing around and so forth.

Gauss's Law. Quite apart from conductors themselves, an important goal of this worksheet is to continue the students' exposure to the flux integral as we introduce some new uses for Gauss's Law.

SAMPLE MINI-LECTURE AND BOARD SUMMARY

If your students have not yet heard a lecture on conductors, then you may want to use Discussion Question 2 to organize a Mini-Lecture. Start by explaining what a conductor is, making sure that your explanation incorporates the salient features that lead to the rules for conductors: *A perfect conductor contains an unlimited supply of completely free charges.*

(By the way, you might look at Griffiths, *Introduction to Electrodynamics*, Section 2.5.1, if you would like to refresh your memory as to the elementary version of all this.)

Having defined a conductor, you can then argue for the rules of conductors as stated on the worksheet. Make sure you take them in the given order: it makes the explanations a lot easier.

As always, when lecturing, keep an eye on the time, and try to get the students involved as much as possible.

REMARKS ON THE DISCUSSION QUESTIONS AND PROBLEMS

Discussion Question 1

You should probably not do this question first, unless everyone is already familiar with the rules of conductors. Discussion Question 2 would be a better place to start. (See the Sample Lesson Plan above.)

Discussion Question 2

The specific wording of the rules in this question is a response to some common misconceptions.

Within a conducting material, the electric field vanishes. Sometimes people just say, “Inside a conductor, the electric field vanishes.” But this plays into a common misconception, which is that the electric field is supposed to vanish everywhere within the outer boundary of a conductor. For example, in Problem 2, the field does not vanish at points within the large cavity. But there *is* a sense in which these points are “inside the conductor.” Hence the emphasis on the *material* in the above formulation.

Any net charge on a conductor must reside on a surface of the conductor. Sometimes people just say, “Any net charge on a conductor must reside on the surface of the conductor.” Again, this plays into a common misconception, which is that the excess charge will always migrate to the outer boundary of the conductor. Conductors can have several surfaces (as in the problems for this worksheet), and the indefinite article “a” calls attention to this fact. Similar comments hold for the last rule,

The electric field at a surface of a conductor is always perpendicular to the conducting surface.

This last rule could be restated as, *Any surface of a conductor is an equipotential surface.* But since the students will not have seen the electric potential yet in these worksheets, it is presumably best to keep this quiet for now. In the meantime, see Discussion Question 4 of Worksheet E-5 *Electric potential*.

Discussion Question 3

You should probably not do this question first, unless everyone is already familiar with the rules of conductors. Discussion Question 2 would be a better place to start. (See the Sample Lesson Plan above.)

Problem 1

Students seem to have a lot of trouble with part (a) of this problem. In fact, when I was a GSI for Physics 110A (E&M), the professor assigned this problem for homework, and a lot of my students got stuck on the first part of it.

It might appear that those who are getting the wrong answer simply have sign problems. But be on the lookout, because as I delved deeper into conversation with my 110A students, I realized that the real problem was much more profound: they had never really understood how to superpose two electric fields! (Worst of all, I had no one to blame but myself, since I was the 7B GSI for most of them....)

Problem 2

Problem 2 is similar to Problem 3, except that Problem 2 is broken into parts that spell out the reasoning. So if you're going to do one or the other in section, I would recommend that it be Problem 2. (See the Sample Lesson Plan above.) But point out that Problem 3 would make for good exam practice.

In part (c), the students determine that a charge $+Q$ resides on the inner surface of the large cavity. Then they are asked how this charge $+Q$ is distributed. Students have a difficult time with this, although many write down the correct answer simply because the idea of a *non-uniform* charge distribution doesn't occur to them.

If someone is having trouble on this, my suggestion would be to go ahead and tell them that the distribution is uniform. Mention something about the $-Q$ point charge pulling electrons out of the metal with equal strength in all directions, since it's in the center of the cavity. (For now we are conveniently ignoring the effect of the $+6Q$ charge distributed on the outer boundary of the conductor. But unless the student calls you on that, this would probably be better than appealing to the uniqueness property of solutions of Laplace's equation.)

Once you believe that the $+Q$ charge on the inner surface of the large cavity is distributed uniformly, then it is easy to decide how the $+6Q$ charge on the outer boundary will be distributed. This is because, outside the large cavity, the combined field of the $-Q$ point charge and the $+Q$ distribution vanishes. Hence the charges on the outer surface of the conductor feel no effects from the large cavity. Needless to say, they feel no effects from the small cavity either. In the absence of any such effects, a uniform distribution is clearly the charges' best option for minimizing their energy.

Thus parts (c) - (e) of Problem 2 lead naturally to the concept of shielding, which you should mention in summing up the problem. In the present context, shielding means that the various cavity surfaces act independently of one another, and independently of the outer surface as well.

Problem 3

Problem 3 is similar to Problem 2, except that in Problem 3 the students have to construct the arguments from scratch. If you're going to do one or the other in section, I would recommend that it be Problem 2. (See the Sample Lesson Plan above.) But point out that Problem 3 would make for good exam practice.