# E-7. DC Circuits

## Teaching Notes

### THE MAIN POINT

1. Understand the nature of electric currents.

2. Learn the relationship between voltage, current, and resistance in a DC circuit.

3. Analyze multi-loop circuits algebraically using Kirchhoff's Laws.

4. Understand energy dissipation in resistors.

### SAMPLE LESSON PLAN

Discussion Questions 1-3 ... 20 minutes in groups.
Mini-Lecture I ..................... 10 minutes. (Introduce V=IR and series/parallel resistor formulas.)
Problem 1 ............................. 15 minutes in groups, 10 minutes GSI-led discussion & boardwork.
Mini-Lecture II.................... 10 minutes. (Introduce loop rules and junction rules.)
Problem 3 ............................. 15 minutes in groups, 10 minutes GSI-led discussion & boardwork.
Problem 2 ............................. 20 minutes in groups.

### GENERAL TEACHING SUGGESTIONS

*The long view.* DC circuits *per se* are not usually given a lot of emphasis in Physics 7B. However, circuits considered more generally certainly *are* important to the course, and today's section on DC circuits is your first and best opportunity to help your students pick up the kind of basic understanding they will need from here on out.

*Circuit analysis.* The students will have to become proficient at analyzing circuits via loop rules and junction rules. Loop rules are especially important, since they will be the primary tools for analyzing circuits with time-dependent behavior (RC, LR).

Students are pretty good at multi-loop DC circuit analysis. (Many have studied the topic in high school.) But if you want to help the ones who are struggling, then my advice would be to *approach every circuit problem in the same way*. Apply the loop rules and the junction rules, and emphasize that the problem is now, in principle, finished. At this point, if the circuit is, in actuality, simple, (with only two loops for example), then go ahead and show how the answer might be obtained quickly. Your years of experience allow you to solve many circuits quickly at a glance, and to some extent you have a responsibility to share these insights with your class. Just don't let these ad hoc solutions take center stage.

*Heat dissipation in resistors.* This topic is more important than you might think. As the semester progresses, the concept of *energy storage* in electromagnetic fields will become increasingly important. In fact, energetics will ultimately emerge as a kind of ex post facto organizing principle for 7B, a motif recurring throughout our study of capacitance, inductance, RC circuits, LR circuits, AC circuits, and electromagnetic waves.

The worksheets have been constructed so that in all of these situations, the students will be able to “get hold” of the abstract notion of electromagnetic energy density by *watching that energy leak out* as heat through a resistor. (After all, this kind of heat energy is something we’ve all felt in everyday life, perhaps by touching a warm lamp cord for example.) For this to work, students have to become comfortable with resistive heating now.

## SAMPLE MINI-LECTURE AND BOARD SUMMARY

If the students have not yet heard a lecture on DC circuits, then you may have to introduce this material briefly with some mini-lectures, perhaps along the following lines. (These Mini-Lectures coordinate with the Sample Lesson Plan above.)

*Mini-Lecture I.* Your first job will be to motivate Ohm’s Law, V = IR, for a simple circuit consisting of a battery and a resistor in series. (Don’t introduce any multi-loop circuits yet.)

By the way, I find it helpful to explain Ohm’s Law in the form I = V/R. This is because, to me at least, it makes sense that “a large battery makes the current large, and a large resistance makes the current small.”

Your second job will be to motivate the rules for combining resistors in series and in parallel. Students have little trouble understanding what it means for resistors to be in series, but they occasionally stumble when it comes to identifying resistors in parallel. Recognize however that the students will learn this skill more from solving problems on their own than they will from any detailed definition you might write on the board. For now I would restrict my examples to the canonical situations where “you know it when you see it.”

*Mini-Lecture II.* Your next job will be to present the “loop rules” and “junction rules” for multi-loop circuits. In your discussion, refer back to Discussion Questions 2 and 3 as common-sense examples of the rules.

Make sure you clearly state the *sign conventions* used in the rules. By the way, it seems to minimize sign troubles if you express the junction rule as “current into a junction equals current out,” rather than the alternative, “the sum of currents into a junction is zero.” (In the first formulation, the arrows do *all* the work; in the second formulation you also have to introduce minus signs by hand.)

## REMARKS ON THE DISCUSSION QUESTIONS AND PROBLEMS

<u>*Discussion Question 1*</u>

This question has two goals. One is simply to make concrete the idea that current is the amount of charge passing a given point in a given time. The more important goal, however, is for students to come away with the ability to *visualize* current as charges in motion. Having a picture like this in mind makes many features of circuits easier to understand---the “junction rule” $i_{in} = i_{out}$, for example.

As a follow-up to part (c), you might ask how fast the electrons in the thin wire would have to be moving, in order for the currents to be equal.

As the students work on these Discussion Questions, keep a sharp lookout for those who are "formula hunting." Make the formula hunters put away their books, and get them to *think* about the situations.

*Discussion Question 2*

This question illustrates the "junction rule" principle of circuits in an extremely simple situation.

If you are following the Sample Lesson Plan above, then you will not have Mini-Lectured on the junction rule yet. The rationale here is that the situation described in this question is simple enough to analyze without formally introducing the junction rule. Later on, having answered a question like this one on the basis of common sense, the students should find the standard junction rule more intuitive.

By the way, in presenting such a simple situation, the idea is not simply to make the question easy; rather, the idea is to encourage the use of *common sense*, rather than equations. Indeed, as the students work on these Discussion Questions, keep a sharp lookout for those who are "formula hunting." Make the formula hunters put away their books, and get them to *think* about the situations.

*Discussion Question 3*

This question illustrates the "loop rule" principle of circuits in an extremely simple situation.

If you are following the Sample Lesson Plan above, then you will not have Mini-Lectured on the loop rule yet. The rationale here is that the situation described in this question is simple enough to analyze without formally introducing the loop rule. (The only fact you need is that the difference in potential between the leads of the voltmeter is independent of the path.) Later on, having answered a question like this from first principles---reinforcing ideas from electric potential in the process---the students should find the full-blown loop rule more intuitive.

By the way, in presenting such a simple situation, the idea is not simply to make the question easy; rather, the idea is to encourage the use of *common sense*, rather than equations. Indeed, as the students work on these Discussion Questions, keep a sharp lookout for those who are "formula hunting." Make the formula hunters put away their books, and get them to *think* about the situations.

*Problem 1*

Now is a good time to compare resistors and resistivity to thermal conductivity from way back in the beginning of the course! Ohm's law is essentially the same as the Heat Flow by Conduction law, with the electrical current taking the place of the heat flow [current is a 'charge flow'] and the voltage taking the place of the temperature difference [charges want to flow from higher to lower potentials; heat wants to flow from higher to lower temperature]. Using this analogy, we can read off how to get the resistance from the resistivity and geometric properties such as length and cross-section. Part (f) is more challenging, since it requires breaking the resistor up into concentric cylinders and integrating. It is probably best to leave this part as an excersize for the overzealous student.

<u>*Problem 2*</u>

This is a simple exercise in combining resistors in series and in parallel. Most students find this kind of thing amusing.

If you have not explicitly mentioned that batteries in series add, just wait and see if the students propose it on their own.

A good follow-up to this question would be to ask for the value of the current in the circuit.

<u>*Problem 3*</u>

This problem leads the students through a derivation of two basic power formulas: $P = i\mathcal{E}$ for the power delivered to the charge carriers by the battery, and $P = i^2R$ for the rate at which heat is dissipated by the resistor. Heat dissipation in resistors is an important topic for us, perhaps more important than you might think. (See the General Teaching Suggestions above, under *Heat dissipation in resistors*.)

Of the three problems on this worksheet, Problem 2 should probably be done last. See the Sample Lesson Plan above.

If you are running out of time when you get to this problem, consider making up a shorter problem on the spot. It certainly doesn't have to be a derivation of any kind; just something involving $P = i^2R$.

For that matter, consider doing the same thing if you have *extra* time after doing this problem.

<u>*Problem 4*</u>

In this problem, the students take a bird's-eye view of the process of solving a DC circuit. They count the number of distinct currents, determine how many equations they will need, and choose loops and junctions that could determine the currents. Finally, they set up the equations.

The question asks the students which loops and junctions they *can* choose to solve the circuit, but there didn't seem to be any convenient way to ask the students for a set of six loops and junctions that would *not* suffice to solve the circuit. You should probably pursue this in follow-up questions. For example, you might ask, "What would go wrong if I chose loops ABCD and junctions ab?"