Daniel Citron
Lesson Plan: Capacitors

Context
This lesson plan is intended for a single 50-minute discussion section of Physics 2217 – Introduction to Electricity and Magnetism (Honors). The course consists of freshman students who are interested in pursuing physics as a major.

For this course, discussion section classrooms have a set of 4-5 hexagonal tables around which up to 6 students may sit comfortably. This seating arrangement is ideal for allowing students to work alone or in small groups. The instructor can walk around the classroom and observe students as they work, answer questions on the fly, and discuss the material with students individually or in small groups. Lecture is kept to a minimum so that students get as much time as possible practicing solving archetypal physics problems and improving their problem-solving abilities.

The lesson plan is designed to include more material than students are usually expected to finish during one class period. A few students will answer all of the questions given, but most will not. The students who work at a slower pace will be encouraged to continue working on this set of practice problems after the discussion section ends in order to guide their preparations for solving the week's homework set. The given practice problems are structured such that all learning objectives may be completed by solving and discussing the very first part of the problem – further problems only elaborate upon the concepts from the early part.

Prerequisites
This lesson comes one week after learning about how ideal conductors add constraints to electrostatic fields and electric potential. Students should already be familiar with basic techniques for relating charge density, electric potential, and electric fields, such as how to apply Gauss's Law.

Learning Objectives
After this lesson, students will be able to
   • Relate capacitance to fundamental electrostatic quantities: charge, electric field, and electric potential
   • Calculate the capacitance of conductors arranged in parallel-plate geometry
   • Calculate the energy stored in capacitors

Teaching methods:
   • Short introductory lecture – review what a capacitor is, how we can characterize capacitors using electrostatics
   • Small group problem solving – students divide into groups of 1-6 and work on the assigned practice problems. As they work, the instructor observes and discusses their progress on each problem.
   • Short concluding lecture – poll the class on their final answers to each practice problem, and explain briefly how the instructor would have approached and solved each problem

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Practice Problems
1. Consider a parallel plate capacitor with square plate area $S = D^2$ and a distance d between the two plates. Assume that the separation distance is very small, such that $d \ll D$, meaning that we can ignore the effects of the edges. The voltage difference between the two plates is V.
    a. What can we assume to be true about the magnitude and direction of the electric field between the two plates?
    b. Using your answer to part a, find the magnitude of the electric field between the two plates
    c. Using Gauss's Law, find the magnitude and direction of the electric field everywhere *outside* the two plates.
    d. Using Gauss's Law, find the charge density on each of the plates that would create the electric field you found in part b.
    e. Calculate the capacitance of this capacitor.
2. Use the same parallel plate capacitor from question 1.
    a. How much energy does it store? Can you write your answer in terms of the capacitance and the voltage?
    b. Suppose I then decrease the gap between the two plates to $d/2$ - how does the stored energy change? Is the change positive or negative- in other words, is it easy or difficult to change the separation distance this way?
3. Use the same parallel plate capacitor from question 1. Now imagine that we slightly tilt one of the plates such that the separation on one edge is $d+a$ and the separation at the other edge is $d-a$. The voltage difference V is held constant.
    a. Which electrostatic quantities calculated in problem 1 change? Which do not?
    b. Solve for the electric field between the two plates as a function of position
    $$[-D/2 < x < D/2]$$
    c. Solve for the charge stored on each plate as a function of position
    d. Find the new capacitance
    e. Find the energy stored in this new capacitor – have we increased or decreased the total energy?

Evaluation
Evaluation is informal. The instructor will discuss the material with students and observe their work in person. By talking to individual students about their problem solving process, the instructor will have a small sample of how well a few individual students understand the material. By polling different groups at the end of class, the instructor will have a general idea of how much the class understood overall.

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Detailed Outline:
    0. Before discussion section begins, the instructor draws a diagram of a parallel plate capacitor and writes all practice problems on the board
    1. Short introductory lecture (~5 minutes)
        a. Define capacitance
        b. Discuss diagram of capacitor, emphasizing these elements
            i. Voltage difference between two plates
            ii. Electric field between two plates
            iii. Charge accumulating on each plate
            iv. Relate diagram back to the definition of capacitance given
        c. Posit that capacitors contain energy
            i. Poll class: where might the energy be found?
            ii. Show youtube clip: capacitor discharge explodes watermelon
    2. Problem solving in small groups (~40 minutes)
        a. Present practice problems to groups
        b. Give the groups some time to form and decide on how to approach various problems
        c. Walk around to each group and listen in on what they're discussing
        d. Answer any questions that arise
        e. Depending on how many groups are having difficulty, can announce hints to the class, or explain what the instructor would do first
    3. Conclusion (~5 minutes)
        a. Poll class for answers, being careful to compare answers across different groups rather than revealing the correct answer immediately
        b. Confirm the correct solutions to each problem
            i. If students got the questions mostly correct (usually the case), give brief overview for how to solve each problem. Emphasize how the problems solved here connect to skills that
            ii. If students mostly did not arrive at the correct answer, review the diagram of the elements of a capacitor and walk through step by step how to answer question 1. Emphasize that students who did not arrive at this answer should return to this problem later.