AP Physics C: Electricity and Magnetism

UNIT 2: CONDUCTORS, CAPACITORS, DIELECTRICS

Before You Begin

This study guide will guide you through each of the topics covered on the AP Physics C: Electricity and Magnetism exam, and cover core concepts, formulas, and other important info. However, it's important to note that there's a lot of prior knowledge required before starting on E&M.

Firstly, you're going to need a decent grasp of basic calculus. Both Physics C exams are **calculus-based**, rather than algebra-based, like Physics 1 and 2 are. You will need to know how to do basic integration and differentiation, as well as solve separable differential equations. It's not like Calculus BC: there won't be any integration by parts or anything, so don't fret about not being able to comprehend any super-advanced calculus concepts, because you won't need them here.

You should also have a decent grasp of regular high school curriculum-level physics concepts. If you've taken Physics 1 or 2, that works as well. The course and exam expand on some of the electricity and magnetism concepts covered there in greater detail, so if you already have a grasp of the basics, it'll really help you when trying to wrap your head around E&M concepts.

Also, something else of note: I will **BOLD** any variables in formulas that are vector quantities. That's how I'll be notating vectors in formulas in this study guide. Keep that in mind as you use this guide: some people bold variables instead, to mark them as vectors, but I'll be using the arrows.

With that being said, let's get started!

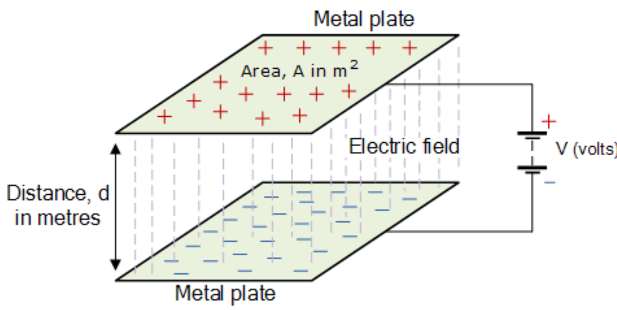
Conductors

This is a smaller part of the exam, and is usually some basic knowledge that you may know even before the exam.

Here are the basic facts to remember:

- The mutual repulsion of charges on the surface of a conductor will create a state of electrostatic equilibrium on the conductor. This mutual repulsion occurs as to decrease the full amount of repulsive forces.
  - This means that the conductor will have a uniform charge density for uniform shapes, and will have no electric field inside of the conductor, or in any cavity inside the conductor, irrespective of the shape of the conductor.
- Even if there's an external electric field, a conductor will not have any electric field within.
- You can induce charge on a conductor by bringing it near an electric field and connecting a ground to it.
- You can completely polarize a conductor in the presence of an electric field, because of the equipotential property in the presence of an external electric field.
- You can completely shield an area from an electric field by enclosing it in a conductor.

Capacitors



Picture Credit

A **capacitor** is a device that stores energy in a circuit. The simplest form of a capacitor is 2 closely spaced parallel plates. When you connect the plates to a battery, the battery transfers charges onto the plates until the voltage (potential difference) *V* is equal to the voltage across the battery. One plate will have charge +*Q* and the other will have charge -*Q*.

Remember that there is a uniform electric field between 2 parallel plates that is dependent on the charge density, which is dependent on *Q* and *A*.

$$E = \frac{\sigma}{\epsilon_0} = \frac{Q}{A\epsilon_0}$$

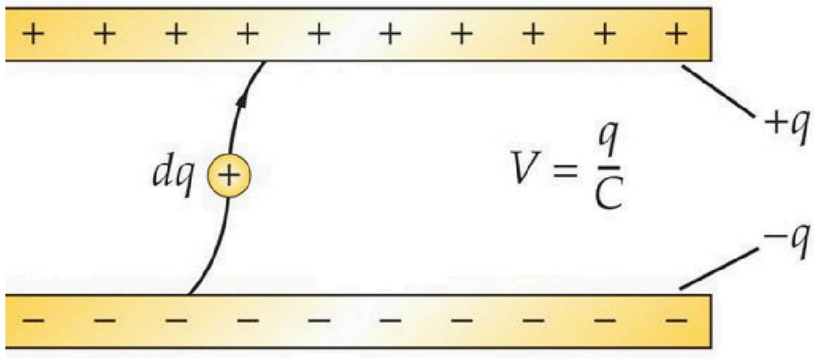
We also have the relationship between the electric field in the plates and the potential difference. When we substitute, we can find a new relationship between charge and voltage.

$$V = Ed = \frac{Qd}{A\epsilon_0} \longrightarrow Q = \left[\frac{A\epsilon_0}{d}\right] V$$

The relationship between *Q* and *V* is linear, with a constant called capacitance C, measured in farads (where 1 F = 1 C / V).

$$C = \frac{Q}{V}\ and\ for\ parallel\ plates, C = \frac{A\epsilon_0}{d}$$

Electric Energy Storage In Capacitors



Personal Photo

When charging a capacitor, imagine positive charges being moved from the negatively charged plate to the positively charged plate. When neither plate is initially charged, it doesn't take much work at all to move the first charge at all: however, as an electric field builds, the amount of work taken to move the charge increases.

The work to move infinitesimal charge dq across is dU, and is related to capacitance.

$$dU = V dq = \frac{q}{C} dq$$

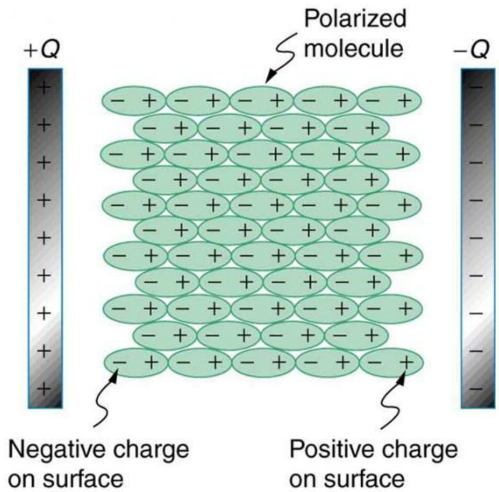
To fully charge the capacitor, you take an integral to add up all the infinitesimal bits of work.

$$U_c = \int dU = \int_0^Q \frac{q}{C} dq = \frac{1}{2}\frac{Q^2}{C}$$

$$U_c = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}QV = \frac{1}{2}CV^2$$

Dielectrics In Capacitors

Parallel plate capacitors are very common in everyday circuits. However, the vacuum in between the plates isn't very effective. Often, a non-conducting **dielectric** material is inserted between the plates. The electric field from the capacitor charging up polarizes the dielectric, and the polarization makes an electric field that opposes the field generated by the plates, which decreases effective voltage, which increases capacitance.



Picture Credit

If the electric field without dielectric is E_0, then E in the dielectric is reduced by κ, the **dielectric constant**.

$$\kappa = \frac{E_0}{E}$$

The capacitance is amplified by the dielectric constant as well:

$$C = \kappa C_0$$

Dielectric can also be seen as increasing the **effective permittivity**.

$$\epsilon = \kappa \epsilon_0$$