Physics for Scientists & Engineers 2

Spring Semester 2005

Lecture 15

Review - Dielectrics

- Placing a dielectric between the plates of a capacitor increases the capacitance of the capacitor

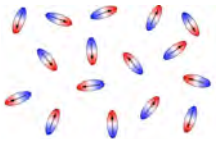
$$C = \kappa C_{air}$$

- Placing a dielectric between the plates of a parallel plate capacitor lowers the electric field

$$E = \frac{E_{air}}{\kappa} = \frac{q}{\kappa \varepsilon_0 A} = \frac{q}{\varepsilon A}$$

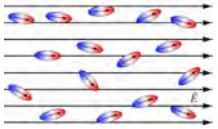
Microscopic Perspective on Dielectrics

- Let's consider what happens at the atomic and molecular level when a dielectric is placed in an electric field
- There are two types of dielectric materials
  - Polar dielectric
  - Non-polar dielectric
- Polar dielectric material is composed of molecules that have a permanent electric dipole moment due to their molecular structure
  - e.g., water molecules
- Normally the directions of electric dipoles are randomly distributed as shown below



Microscopic Perspective on Dielectrics (2)

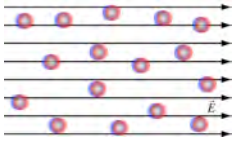
- When an electric field is applied to these polar molecules, they tend to align with the electric field



- Non-polar dielectric material is composed of atoms or molecules that have no electric dipole moment

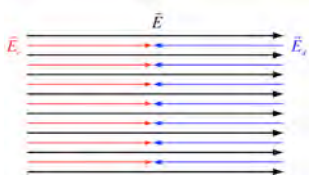
Microscopic Perspective on Dielectrics (3)

- These atoms or molecules can be induced to have a dipole moment under the influence of an external electric field
- This induction is caused by the opposite direction of the electric force on the negative and positive charges of the atom or molecule, which displaces the center of the relative charge distributions and produces an induced electric dipole moment



Microscopic Perspective on Dielectrics (4)

- In both the case of the polar and non-polar dielectric materials, the resulting aligned electric dipole moments tend to partially cancel the original electric field



- The electric field inside the capacitor then is the original field minus the induced field

$$\vec{E}_r = \vec{E} - \vec{E}_d$$

Example: Defibrillator

- An important application of capacitors is the portable automatic external defibrillator (AED)
- The AED is a device designed to shock the heart of a person that is in ventricular fibrillation
- A typical AED looks like this
- When a person's heart is in ventricular defibrillation, the heart is not beating in a regular pattern but is instead erratic and confused
- This condition must be treated within a few minutes
- AEDs located in public places allow quick treatment

Example: AED (2)

- An AED can be used to run a pulse of electrical current through the heart and possibly stimulate the heart to beat regularly
- Typically an AED is designed to automatically analyze the heartbeat of the person, determine if the person is in ventricular fibrillation, and administer an electrical pulse if required
- The (trained) operator of the AED must attach the electrodes of the AED to the chest of the patient and push the start button
- The AED will analyze the patient and do nothing if the patient is not in ventricular defibrillation
- If the AED determines that the patient is in ventricular fibrillation, the AED will ask the operator to press the button to shock the patient

Example: AED (3)

- Typically an AED delivers 150 J of electrical energy to the patient
- This energy is delivered to the patient by charging a capacitor with a special circuit from a low voltage battery
- This capacitor typically has a capacitance of 100 mF and is charged in 10 s.
- The power used during charging is
  - Power = Energy/time = 150 J/10 s = 15 W
    - Easily within the capacity of a simple battery
- The energy of the capacitor is then discharged in 10 ms
- The instantaneous power during the discharge is
  - Power = Energy/time = 150 J/10^{-3} s = 15,000 W
    - beyond the capability of a small, portable battery, but within the capabilities of a well designed capacitor

Example: AED (4)

- The energy stored in the capacitor is

$$U = \frac{1}{2}CV^2$$

- What is the voltage of the capacitor when charged?

$$V = \sqrt{\frac{2U}{C}} = \sqrt{\frac{2(150\ \text{J})}{100 \cdot 10^{-6}\ \text{F}}} = 1730\ \text{V}$$

- When the AED is commanded to deliver a shock, the capacitor is charged from a battery contained in the AED
- The capacitor is then discharged through the patient with a specific waveform to stimulate the heart to beat in a regular manner
- Most AEDs can perform this shock many times without recharging the battery.