

## Reese Ch. 18

(Sections 6-11 = pp. 813-825)

- Capacitors
- Series & Parallel Combinations of Capacitors
- Energy Storage in a Capacitor
- Electrostatics in Dielectrics (= Insulators)
- Use of Dielectrics in Capacitors
- Dielectric Breakdown

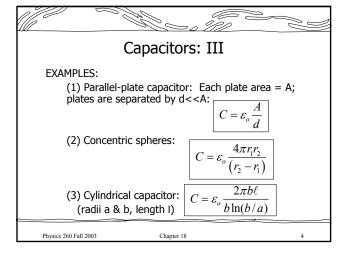
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Capacitors: I

- A capacitor is a circuit element that can store (separated) charge and electric potential energy.
- In most capacitors, the separated opposite electric charges are equal in magnitude.
- Ideally, once a capacitor is "charged" it can "hold its charge" indefinitely. Real capacitors "leak."
- The capacitance C of a capacitor is the ratio of the magnitude of separated charge to the (magnitude of the) potential difference:

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Capacitors: II NOTES: (1) The capacitance is positive by definition. (2) Capacitance unit = farad (F): 1 farad = 1 coulomb/voltIn a "vacuum capacitor" (one that is free of dielectric materials), the capacitance is determined by the size, shape, and separation of the plates. Physics 260 Fall 2003 Chapter 18



## Series and Parallel Combinations of Capacitors

 When capacitors are connected in parallel, they have the same voltage but the stored charge is the sum of the individual stored charges, so

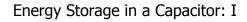
$$C_{\substack{equiv\\(parallel)}} = C_1 + C_2$$

 When capacitors are connected in series, they store equal charges, but the voltage across the assembly is the sum of individual voltages, so

$$C_{\substack{equiv\\(series)}} = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

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- If given the opportunity to "discharge," a charged capacitor can do a lot of work (wreak a lot of havoc!). Evidently a charged capacitor stores potential energy in the separated charges.
- Taking a completely discharged capacitor as the reference state and carefully calculating the work necessary to separate the charges, we find:

$$PE = \int_{0}^{Q} V(q) dq = \int_{0}^{Q} \frac{q}{C} dq = \frac{Q^{2}}{2C} = \frac{1}{2}CV^{2}$$

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## Energy Storage in a Capacitor: II

 It is possible to express the energy stored in a capacitor as a volume integral of electric energy density: (Why do it?)

$$PE = \int_{\substack{all \\ space}} \left(\frac{1}{2} \varepsilon_o \vec{E} \cdot \vec{E}\right) d(volume) \equiv \int_{\substack{all \\ space}} \left(\frac{1}{2} \varepsilon_o E^2\right) dV$$

 This is easily shown for a parallel-plate capacitor. (Try it!) It turns out to be a valid result for any vacuum capacitor.

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Electrostatics in Dielectrics (=Insulators)

- The vacuum equations that we have been using can also be applied in the presence of many dielectric materials provided that we replace  $\varepsilon_0$  by  $\varepsilon$ , the permittivity of the material. A dielectric material is often characterized by its dielectric constant  $\kappa$ :
- Notice that  $\kappa$  is dimensionless.

Some k values:

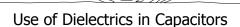
 $\kappa \equiv \frac{\varepsilon}{\varepsilon_o}$ 

Rubber: ~3; Pyrex: 5.6; H<sub>2</sub>O: 80

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- When a vacuum capacitor is "filled" with a dielectric material, its capacitance is multiplied by κ, implying more energy stored per volt.
- This is due to **polarization** of the dielectric, which produces a <u>bound-charge surface density</u> at each plate. Each bound-charge surface density is opposite in sign to the adjacent "free-charge surface densities":

$$\sigma_{bound} = -\left(\frac{\kappa - 1}{\kappa}\right)\sigma_{free}$$

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- If a dielectric material is subjected to a sufficiently strong electric field (typically a few million to a few hundred million volts per meter), the atoms and molecules in the material can lose their outer electrons.
- These liberated electrons can collide with other atoms and molecules, knocking loose still more electrons. The result is that the material temporarily becomes a conductor.
- **Lightning** is the meteorological dielectric breakdown of air.

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