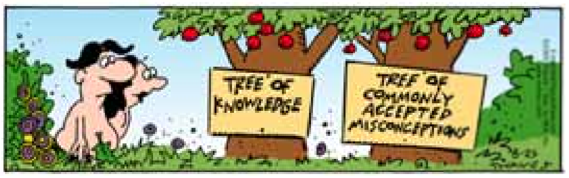
April 29, 2011 Physics 122 Prof. E. F. Redish

- **Theme Music:** **Rustcycle**
  Capacitance
- **Cartoon:** **Bob Thaves**
  Frank & Ernest



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Outline

- Electric Circuits Examples
- The Capacitor
  - Example
  - Charging
  - Capacitor Equations

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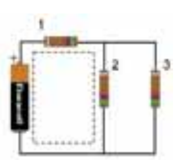
Sample Problem

- The circuit diagram shown at the right contains a 1.5 Volt battery and three identical 50 Ω resistors. Find the current in and voltage drop across each of the resistors.



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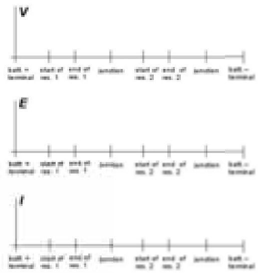
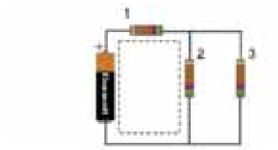
Sample Problem

- Track the voltage and electric field a test charge would measure as it followed the indicated loop through the circuit. Show the current one would measure as one went around that loop.





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Capacitance

- What we see in the previous problem is the reflection of an explicit assumption we have made in our discussion of circuits so far:
  - that there is no charge build up anywhere in the circuit.
- But there are possibilities to build up small non-neutral regions of charge if they are carefully matched.

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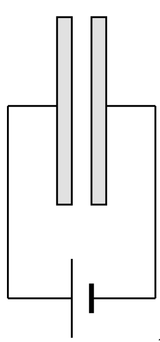
The Capacitor

- Suppose we hook two parallel conducting plates up to a battery. What happens?



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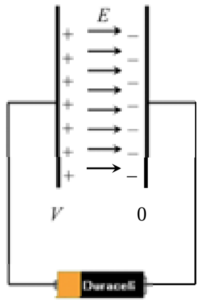
Storing electrical energy: The capacitor

- Two parallel metal plates of area *A* separated by a distance *d*.
- Connect the plates to the two sides of a battery.



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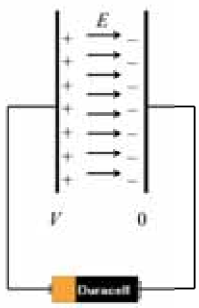
Charging a capacitor

- What is the potential difference between the plates?
- What is the field around the plates?
- How much charge is on each plate?



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Capacitor Equations

$$\Delta V = E\Delta x = Ed$$

$$E = 4\pi k_C \sigma = 4\pi k_C \frac{Q}{A} \quad \Rightarrow \quad Q = \left(\frac{A}{4\pi k_C}\right)E$$

$$Q = \left(\frac{A}{4\pi k_C d}\right)\Delta V$$

$4\pi k_c$ is often written as "$1/\varepsilon_0$"

$$Q = C\Delta V$$

What does this "Q" stand for?

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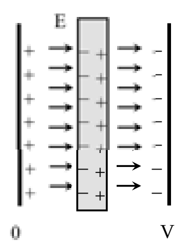
Dielectrics

- In electrical systems, we want to store as large a charge separation as we can, but creating potential differences is expensive. We would like to find ways of reducing ΔV while keeping Q the same.
- In biological systems, we often have charge separations, but the are almost always separated by spaces containing fluids – not by empty space.
- It turns out that the answer to the first problem is provided by the second observation.

Consider what happens with a conductor

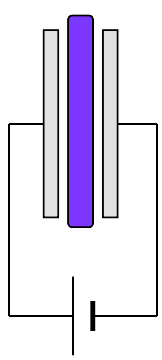
- The potential difference is produced by adding up $E\ \Delta s$.
- If we can reduce E along the path, we can reduce ΔV.
- Inside a static conductor, there can be no E field. (Why not?)
- What happens if we put a conducting sheet between the plates?



Conductors

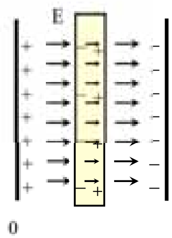
- Putting a conductor inside a capacitor eliminates the electric field inside the conductor.
- The distance, d', used to calculate the ΔV is only the place where there is an E field, so putting the conductor in reduces the ΔV for a given charge.

$$C = \frac{1}{4\pi k_C} \frac{A}{d'}$$



Consider what happens with an insulator

- We know that charges separate even with an insulator.
- This reduces the field inside the material, just not to 0.
- The field reduction factor is defined to be *k*.



$$E_{\text{inside material}} = \frac{1}{\kappa} E_{\text{if no material were there}}$$

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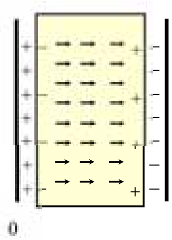
Capacitors filled with an insulating material

$$E = \frac{1}{\kappa}\frac{\sigma}{\varepsilon_0}$$

$$E = \frac{Q}{\kappa\varepsilon_0 A}$$

$$\Delta V = Ed = \left(\frac{d}{\kappa\varepsilon_0 A}\right)Q$$

$$C = \kappa\frac{\varepsilon_0 A}{d}$$



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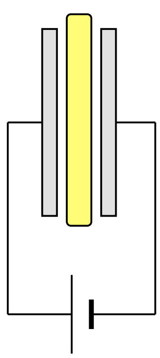
Dielectrics

- If a non-conductor is put between the plates, there is still some polarization reducing the field so the voltage required for a given charge is reduced, i.e., *C* is increased.
- The factor (assuming the space between the plates is filled) is called the dielectric constant, .

$$C = \kappa\frac{1}{4\pi k_C}\frac{A}{d}$$



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