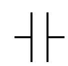
Capacitance & Capacitors (Bogart, page 285)

- **Capacitance** is a measure of a component's ability to store charge.
- A **capacitor** is a device specially designed to have a certain amount of capacitance.
- This ability to store charge means that capacitors can be **dangerous**. Some common electronic devices, such as televisions, contain **large capacitors that can hold a deadly charge long after the device has been turned off and unplugged**. Just as you should always assume that a firearm is loaded, you should always assume that a capacitor is charged.

Capacitor Application: A Camera Flash

- A simple, everyday use of capacitors is in the flash unit for a camera. You need a large charge in a very short time to light up the camera's flash bulb. The camera's battery cannot provide such a large charge in such a short time. So the charge from the battery is gradually stored in a capacitor, and when the capacitor is fully charged, the camera lets you know that it's ready to take a flash picture.

Schematic Symbol, and Appearance



- Here's the **schematic symbol** for a standard capacitor:
  Often, one of the lines in this symbol is drawn slightly curved, so that people won't confuse it with the symbol for a voltage source. Our textbook draws it with a curved line (for example, see the diagram on page 287).
- While most resistors look more or less the same, capacitors come in many different types of package. Here are a few examples of what they may look like.

Parallel-Plate Capacitor (Bogart, p. 285)

- Most capacitors are parallel-plate capacitors, which means that they consist of two parallel pieces of conducting material separated by an insulator.
- The insulator between the plates is called the **dielectric**.

Charging a Capacitor (Bogart, p. 286)

- When a capacitor is connected across a voltage source, charge flows between the source and the capacitor's plates until the voltage across the capacitor is equal to the source voltage.
- In this process, the plate connected to the voltage source's negative terminal becomes negatively charged, and the other plate becomes positively charged.

Units of Capacitance (Bogart, p. 287)

- Capacitance is abbreviated *C*.
- The unit of capacitance is the **farad** (F).
- Typical capacitors found in electronics equipment are in the microfarad (µF) or picofarad (pF) range. Recall that **micro-** means 10^{-6} and that **pico-** means 10^{-12}.
- You may also remember that **nano-** means 10^{-9} . **But** for some reason, we usually don't measure capacitors in nanofarads, even in cases where that might make the most sense. For instance, if a capacitance is equal to 1×10^{-9} F (or 0.000000001 farads), you might think that you'd write that as 1 nF. But in fact, most people would write this as either 1000 pF or 0.001 µF. This is strange and confusing, but you just have to get used to it.

Charge per Voltage (Bogart, p. 287)

- As a mathematical quantity, capacitance is defined to be **the ratio of the charge stored by a capacitor to the voltage across it**:

  $$C = Q \div V$$ (Equation 9.1 in the book)

  where capacitance (***C***) is in farads, charge (***Q***) is in coulombs, and voltage (***V***) is in volts.

- We'll use this basic formula frequently in analyzing capacitor circuits.

Capacitor Ratings (Bogart, p. 293)

- Commercially available capacitors have several important specifications:
    - **nominal value** and **tolerance**
    - **dc working voltage**
    - **leakage resistance**
- Read on for discussion of these specifications.

Nominal Value & Tolerance (Bogart, p. 293)

- Capacitors are available in a wide range of nominal values, from 1 picofarad to several farads.
- A specific capacitor's actual value is subject to the manufacturer's **tolerance specification**. Typical capacitor tolerances range from ±5% to ±20%.

DC Working Voltage (DCWV) (Bogart, pp. 293-294)

- The **DCWV** is the maximum voltage at which a capacitor is designed to operate continuously.
- Usually, the higher the capacitance value, the lower the DCWV.
- Typical values of DCWV are a few volts for very large capacitors to several thousand volts for small capacitors.

Leakage Resistance (Bogart, p. 294)

- An ideal capacitor would have infinite resistance, with absolutely no current flowing between the plates.
- In reality, a capacitor's resistance is finite, resulting in a small **leakage current** between the plates.
- Typical values of **leakage resistance** are 1 MΩ to 100,000 MΩ or more. This is large enough that, from a practical standpoint, we can often pretend that the resistance is infinite.

Capacitor Types (Bogart, pp. 294-299)

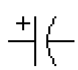
- Capacitors are often classified by the materials used for the dielectric.
- Some types are **air**, **paper**, **plastic film**, **mica**, **ceramic**, **electrolyte**, and **tantalum**.
- Each type has its own advantages and disadvantages; see pages 295-299 of the textbook.
- Often you can tell a capacitor's type by the appearance of the package. For example,

  ceramic capacitors typically look like this: 

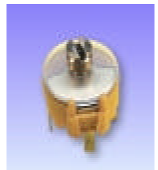
  Here's a typical plastic-film capacitor: 

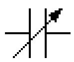
  Here's how electrolytic capacitors usually look: 

Electrolytic Capacitors (Bogart, p. 298)

- Of the different types of capacitors just mentioned, one in particular deserves special discussion: electrolytic capacitors, which are available in very large values, up to 100,000 µF and above.
- Unlike most capacitors, they are polarized: one side must remain positive with respect to the other. Therefore you must insert them in the proper direction. Inserting them backwards can result in injury to you or in damage to equipment.
- In this photo of an electrolytic cap, notice that it has little arrows with negative signs pointing to one end: 
  The lead that the arrows are pointing to is the negative lead.
- Also, the schematic symbol for an electrolytic cap has a positive sign to tell you which way to hook up the capacitor: 

Variable Capacitors (Bogart, p. 295)

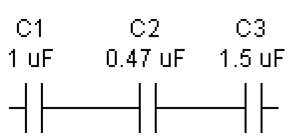
- **Variable capacitors** are also available. These contain a knob or screw that lets you adjust the capacitor's capacitance. 
- The schematic symbol has an arrow to show that the component's value can be adjusted:



Stray Capacitance (Bogart, pp. 299-300)

- **Stray capacitance** exists between any two conductors that are separated by an insulator, such as two wires separated by air. This means that a circuit may contain some capacitance even if there's no capacitor in the circuit.
- Stray capacitance is usually small (a few pF), and you can usually ignore it, but it can have undesirable effects in high-frequency ac circuits.

Capacitors in Series (Bogart, p. 302)



- To find the total equivalent capacitance of capacitors in series, use the **reciprocal formula**:

$$C_T = 1 \div (1 \div C_1 + 1 \div C_2 + \ldots + 1 \div C_n) \quad \text{(Equation 9.13)}$$

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- So **capacitors in series combine like resistors in parallel**.

Charge on Capacitors in Series (Bogart, pp. 300-301)

- In a series circuit, each capacitor has the same charge, regardless of the individual capacitance values. In symbols, $\boldsymbol{Q_1 = Q_2 = Q_3 = \ldots}$
- We call this charge Q_T. It's given by:

$$Q_T = C_T E$$

where E is the source voltage.

- Note: this equation is basically a rearranged version of the equation that we saw earlier:

$$C = Q \div V$$

The only difference is that we're using E instead of V for the voltage, and we've added "T" subscripts to show that we're talking about **total** capacitance and **total** charge. Do you agree that, once you've made these changes, basic algebra lets you derive the one equation from the other?

Voltage on Capacitors in Series (Bogart, p. 303)

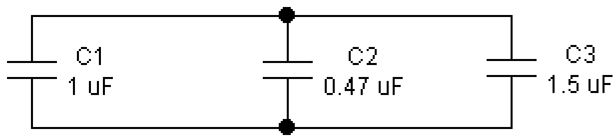
- Once you know the charge on each capacitor in a series circuit, find the voltage drops by using the equation:

$$V = Q \div C$$

for each capacitor.

- Again, this is just a rearranged version of our basic formula. Right?

Capacitors in Parallel (Bogart, p. 304)



- The total equivalent capacitance of capacitors in parallel is equal to the sum of the individual capacitances:

$$C_T = C_1 + C_2 + \ \dots + C_n \qquad \text{(Equation 9.19)}$$

- So **capacitors in parallel combine like resistors in series**.

Charge and Voltage on Capacitors in Parallel (Bogart, p. 304)

- Parallel-connected capacitors have the same **voltage**.
- To find the **charge** on each capacitor, use

$$Q = VC$$

Once again, this is not a new equation, just a rearranged version of our basic equation for capacitors.

- For capacitors in parallel, the total charge delivered by the source equals the sum of the charges on the individual capacitors.

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Series-Parallel Capacitors (Bogart, p. 305)

- For series-parallel capacitor circuits, the strategy is very similar to the strategy that you learned in EET 150 for series-parallel resistor circuits:
    1. Combine series capacitors and parallel capacitors to obtain progressively simpler equivalent circuits.
    2. Then work backwards, using $C = Q \div V$ and remembering that **series-connected capacitors have the same charge** and **parallel-connected capacitors have the same voltage**.
