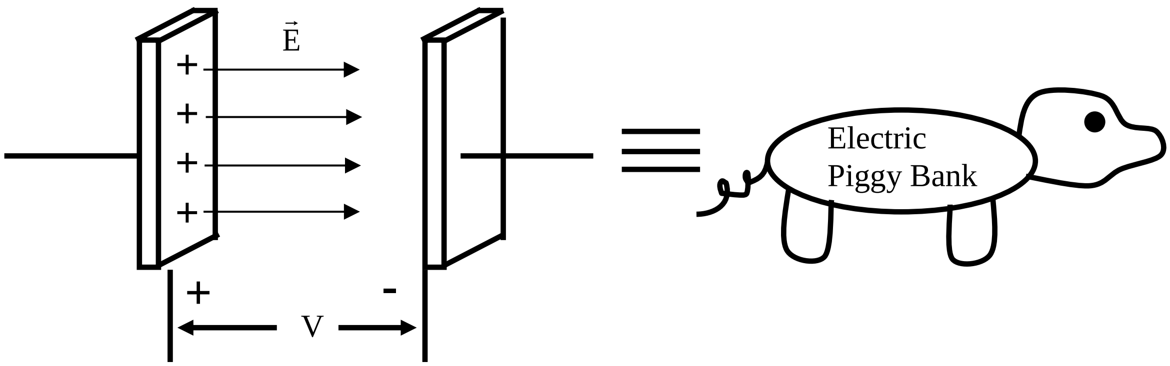
Capacitors and Dielectrics I

I. Capacitor

A. A capacitor is an electrical device that stores energy in an electric field created by the separation of charge between two conductors.



B. Definition of Capacitance

The **capacitance** of a capacitor is defined as the **ratio of the charge transferred** to one of the conductors of the capacitor **divided** by the **electric potential** between the conductors.

When thinking about capacitance, you should remember the phrase "**charge** **<u>CAPACITY</u>**"!!!

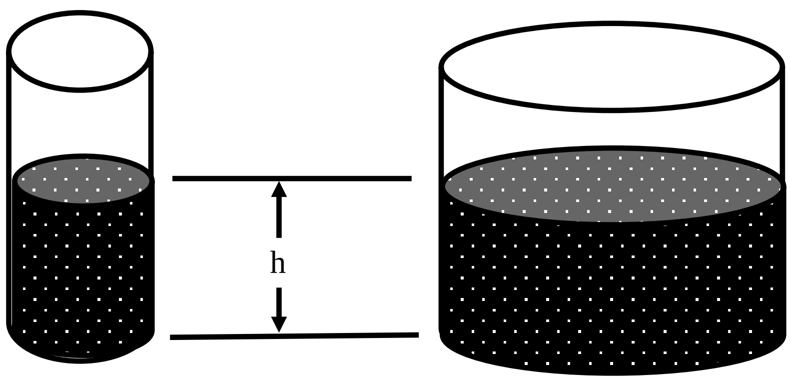
C. Units of Capacitance -

D. Factors Influencing Capacitance

1) **Geometry** of the capacitor

2) **Material** placed between the conductors of the capacitor.

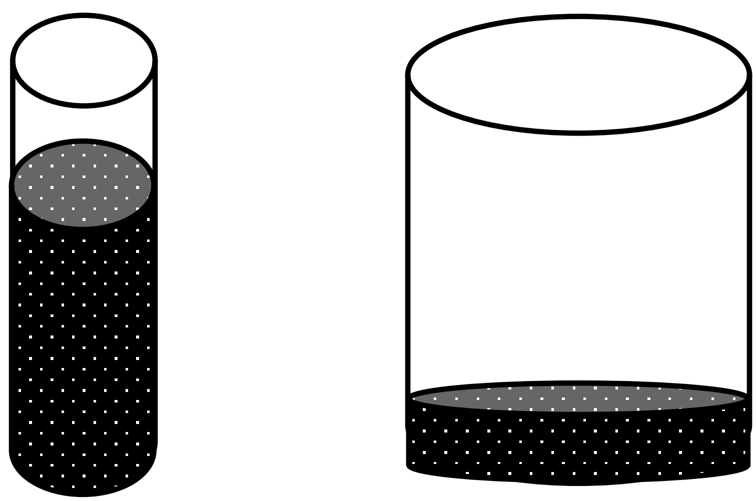
1. Geometry Effects (Water Analogy)



In our diagram, it is easy to see that the **wider glass** (largest area) **contains more water** when the <u>water</u> in both glasses is <u>at the same height</u>. By analogy, a **capacitor** whose conductor has a **larger surface area** can **hold more <u>charge</u> for a given electric potential difference**.

The water analogy can be useful in getting a handle on many concepts involving capacitors.

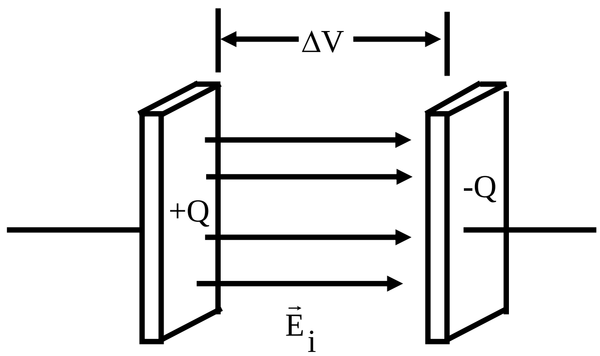
For instance, we could consider the problem of placing the same amount of charge upon two capacitors of different capacitance. The water analog of our problem is shown below:

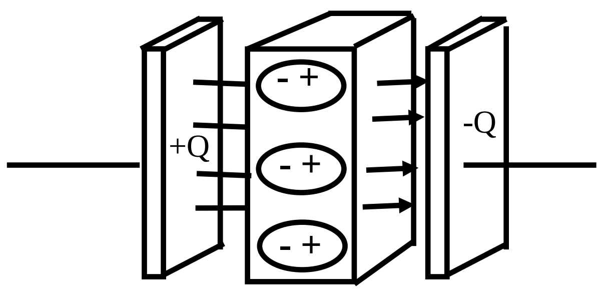


A smaller capacitor has a greater voltage for the same charge just as the water will have a greater depth in a smaller capacity water tank for the same amount of water.

Material Effects (Dielectrics)

In the diagram below, a charge of Q is transferred between the plates of a capacitor setting up an electric field, $\vec{E}_i$, and electric potential, ΔV, between the plates.





The initial electric field causes the dielectric to be

________________________. This produces an internal

__________________ __________________ that

_______________________ the initial electric field. Thus, the

resultant electric field is ________________________ than

the initial electric field.

Since the total electric field is ____________, the electrical

potential difference across the plates of the capacitor is also

_________________ since V = Ed.

Thus, more _______________ can be added to the capacitor

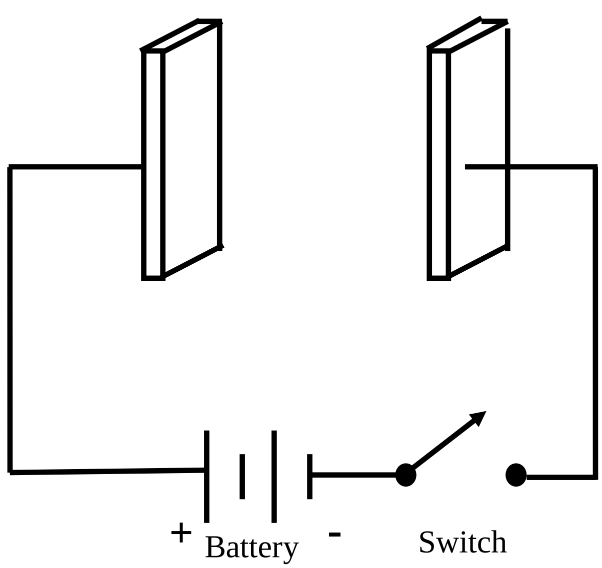
to ______________ the electrical potential difference back to

its original value. Therefore, the capacitor's capacitance has

______________________________.

II. Charging a Capacitor

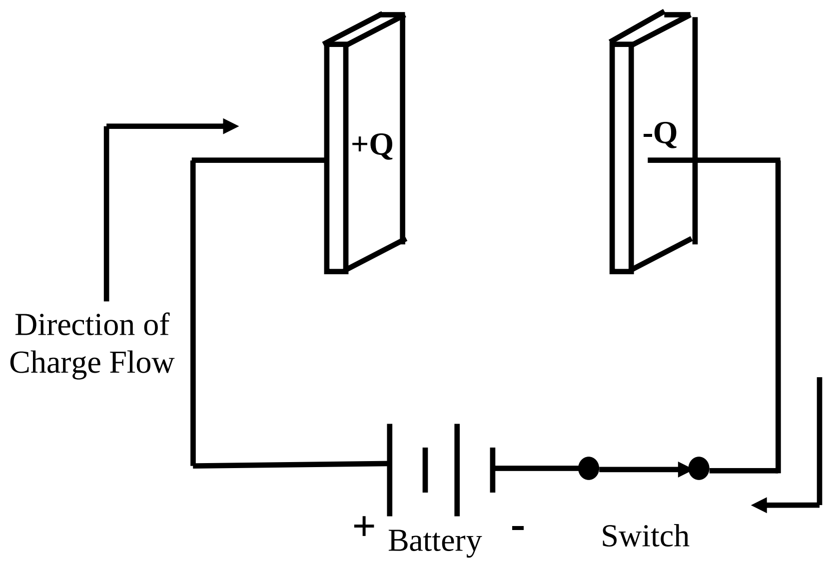
Two neutral plates are connected to a battery to form the electrical circuit shown below:



Since there is no net charge on either plate, there is no electric field between the plates and no electric potential energy stored.

A battery can be considered to be a **charge pump**. When the switch is closed, the battery will draw positive charge into the negative terminal and pump the positive charge out of the positive terminal. This is analogous to the flow of water using a water pump. It is important to understand that a battery doesn't create charge. It just transfers it from one place to another in the same way that a water pump transfers water.

Thus, an amount of charge +Q leaves the right plate traveling clockwise in the circuit and is placed on the left plate as shown below:



The **separation of charge** produces an electric field $\vec{E}$ between the plates. Thus, an electric potential difference exists across the plate and electric potential energy is stored in the system equal to work done by the battery in transferring the charge between the plates.

EXAMPLE: A battery transfers 2.00 μC of charge between the plates creating an electric potential difference of 4.00 v across the capacitor. What is the capacitance of the capacitor?

III. Parallel Plate Capacitor (Special Case)

The parallel plate capacitor is a special case of the capacitor that is highly useful. While a perfect parallel plate capacitor requires infinitely large plates, we can consider any capacitor with parallel plates to be approximately ideal (i.e. the field to be confined between the plates) if the sides of the plate are much greater than the distance between the plates.

The usefulness of an ideal parallel plate capacitor is that:

1) the equations are mathematically simple.

2) many practical devices employ them.

3) the electric field between the plates is constant.

A. Capacitance

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

where A is the plate area, d is the distance between the plates, and κ is the dielectric constant of the medium between the plates.

B. Electric Field – Electric Potential Relationship

The voltage drop between the plates is related to the magnitude of the electric field by:

$$\mathbf{V} = \mathbf{E} * \mathbf{d}$$

Proof of Capacitance Formula:

IV. Energy Stored in a Capacitor

U = Area =

Example: How much energy is stored in a 100 μf capacitor at 100 volts?

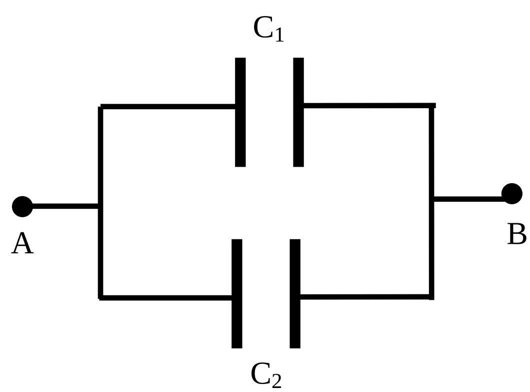
II. Parallel and Series Electric Circuits

A. Parallel –

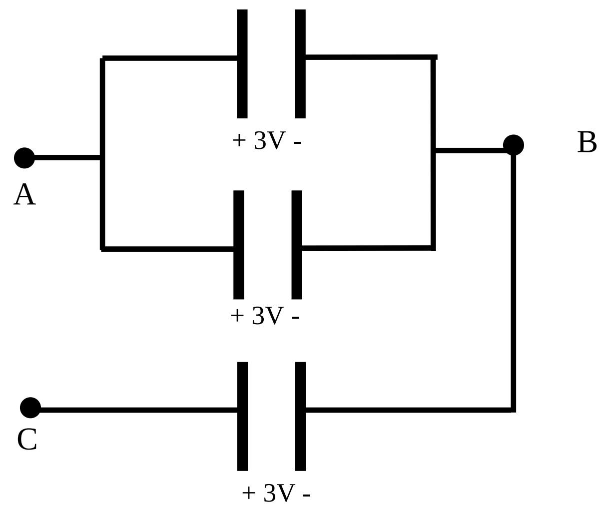
Two electrical circuit elements (example: two capacitors) are in parallel if and only if they both have the **SAME ELECTRICAL POTENTIAL DIFFERENCE**.

IMPORTANT: By the "same voltage" we mean that you must be able to simultaneously measure the voltage drop across both elements in a single measurement and not that the numerical values for the voltage drops are the same!!!

Example: If we place our voltmeter leads between points A and B, we will simultaneously measure the voltage drops across both capacitor 1 and capacitor 2. Thus, these capacitors are **in parallel**.



Example 2: In the drawing below, are the three capacitors in parallel?

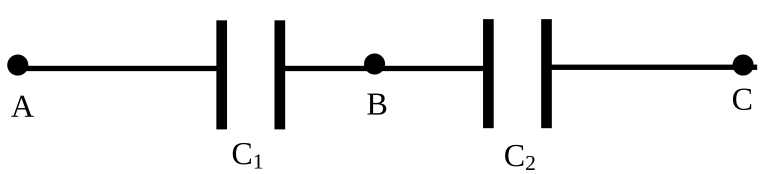


B. Series –

Two electrical circuit elements are in series if the <u>individual charges leaving the first</u> circuit element <u>**must**</u> <u>enter the second</u> element.

We will see later that this definition is the same as saying the same current flows through both elements. Thus, we must be able to **simultaneously measure the current in both elements with an ammeter.**

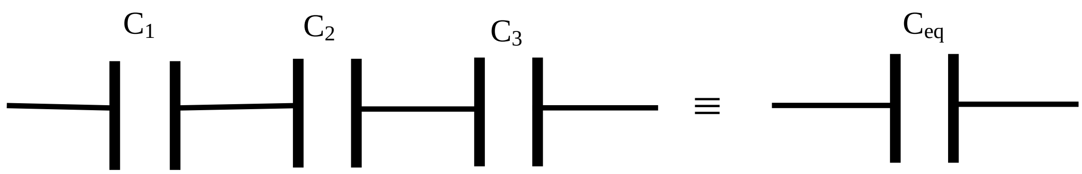
Example: The two capacitors below are in series.



C. Capacitors in Series and Parallel

Series - A group of capacitors in series are equivalent to a

single ______________capacitor determined by the formula:

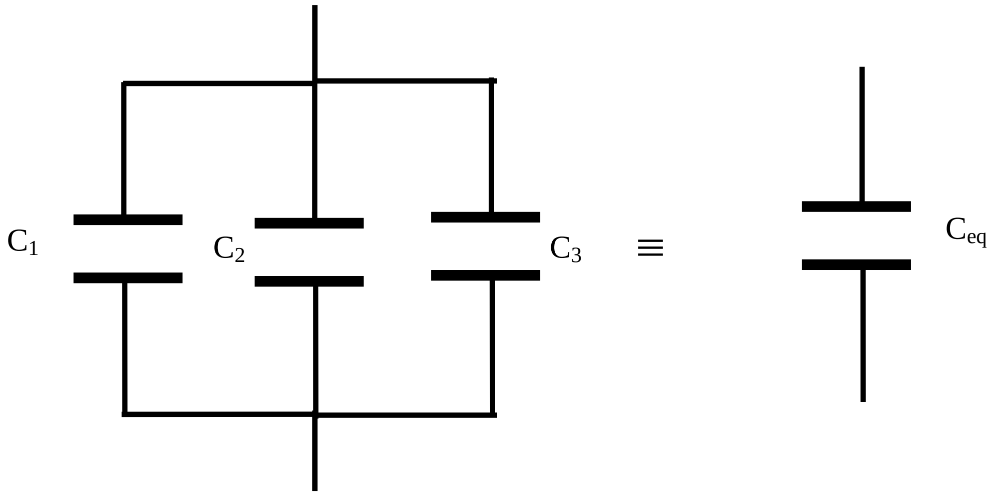


Note: Putting capacitor's in series is like making the space

between the plates _________________________ which makes the

capacitance ____________________.

Parallel - A group of capacitors in parallel are equivalent to a single ________________ capacitor determined by the formula:



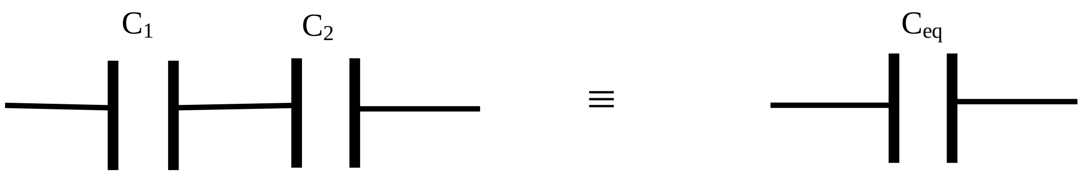
Note: Placing the capacitors in parallel is like

______________________ the plate area which

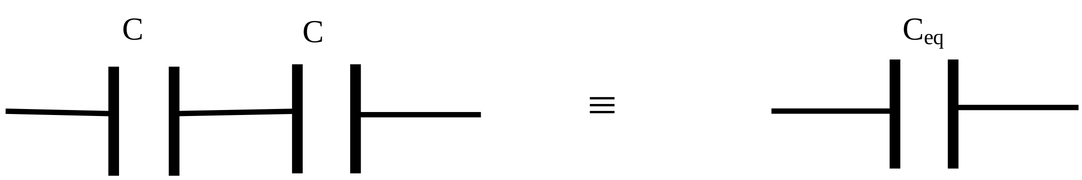
______________________ the capacitance.

Special Case – Two Capacitors in Series

The following formula is very convenient for simplifying circuits.



Special Case – "N" Equal Capacitor's in Parallel



EXAMPLE: What is the equivalent capacitance of the following circuit?