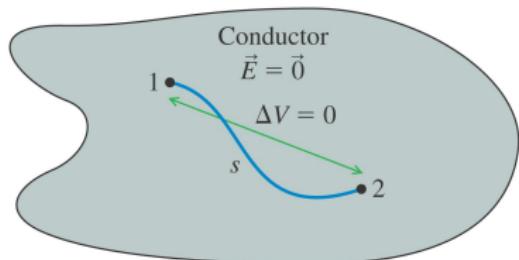


A Conductor in Electrostatic Equilibrium (30.4)

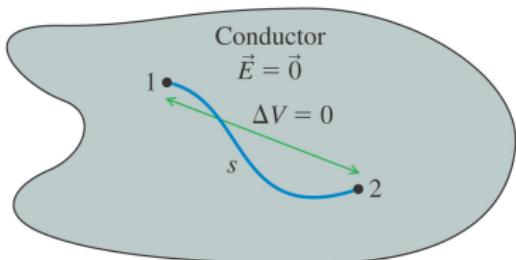
- We have already learned that electric field is zero everywhere inside a conductor.



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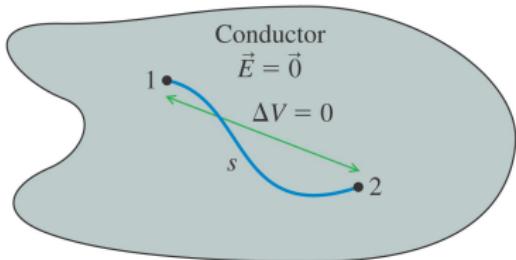
- We have already learned that electric field is zero everywhere inside a conductor.
- That also means that the potential difference between any two points in a conductor is zero.



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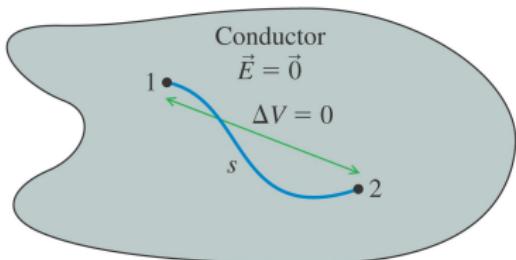
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- In electrostatic equilibrium the entire conductor is at one potential.



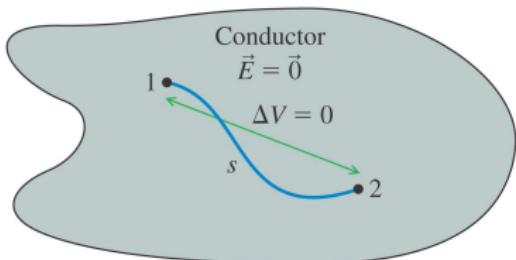
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- So, there is no \vec{E} inside but there is \vec{E} outside, what happens at the surface??
- The surface is an equipotential surface - \vec{E} must be perpendicular to it!

A Conductor in Electrostatic Equilibrium

1. All excess charge is on the surface.

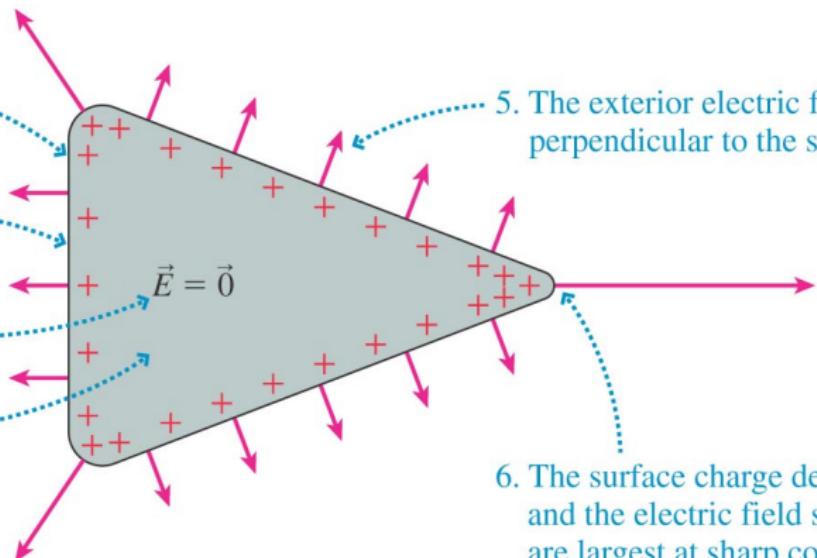
2. The surface is an equipotential.

3. The electric field inside is zero.

4. The interior is all at the same potential.

5. The exterior electric field is perpendicular to the surface.

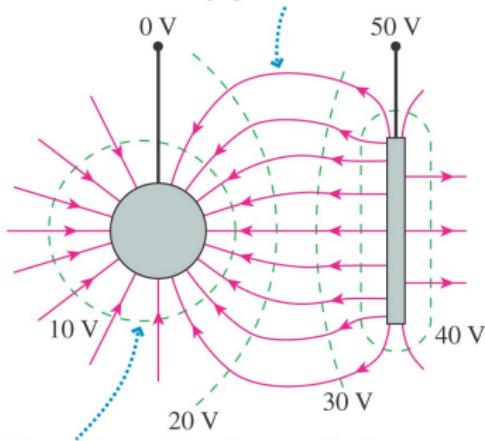
6. The surface charge density and the electric field strength are largest at sharp corners.



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A Conductor in Electrostatic Equilibrium

The field lines are perpendicular to the equipotential surfaces.



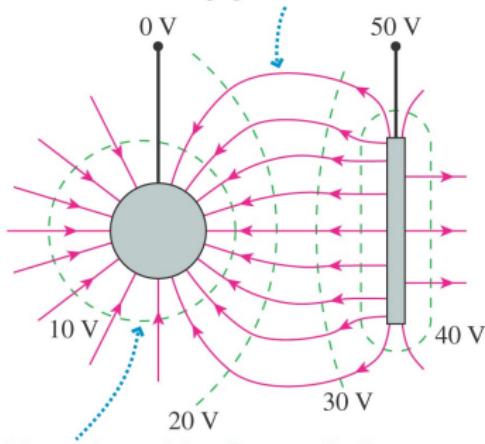
The equipotential surfaces gradually change from the shape of one electrode to that of the other.

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- The field and potential between two conductors then needs to have a funny shape.

A Conductor in Electrostatic Equilibrium

The field lines are perpendicular to the equipotential surfaces.



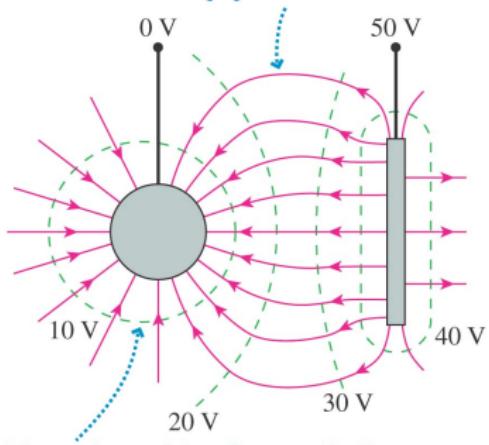
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A Conductor in Electrostatic Equilibrium

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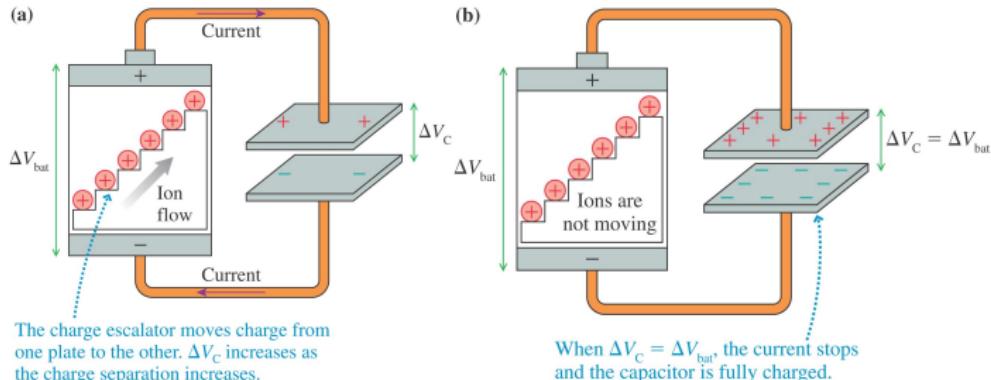


The equipotential surfaces gradually change from the shape of one electrode to that of the other.

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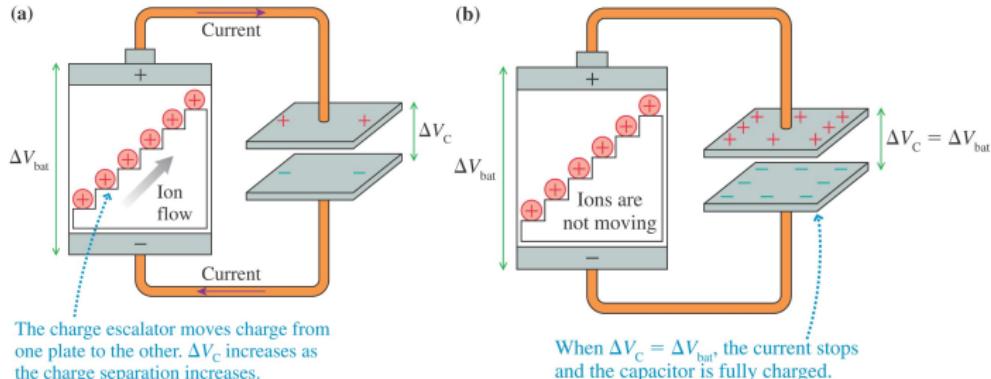
- The field and potential between two conductors then needs to have a funny shape.
- The field must be perpendicular to each conductor surface, no matter what shapes those conductors have.
- An equipotential surface close to an electrode must roughly match the shape of the electrode.

Capacitance and Capacitors (30.5)



- We have been using capacitors a lot without defining **capacitance** or describing how to charge-up these devices.

Capacitance and Capacitors (30.5)



- We have been using capacitors a lot without defining **capacitance** or describing how to charge-up these devices.
- A battery will create a potential difference across a capacitor which is equal to the potential difference in the battery.

Capacitance and Capacitors

- We know that the potential difference in a capacitor is related to its electric field by $\Delta V_C = Ed$ and the electric field is

$$E = \frac{Q}{\epsilon_0 A}$$

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- The unit of capacitance is the **farad** (F).

$$1 \text{ farad} = 1 \frac{\text{coulomb}}{\text{volt}} = 1 \frac{\text{C}}{\text{V}}$$

Charging a Capacitor (Example 30.6)

Example 30.6 - Charging a Capacitor

The spacing between the plates of a $1\mu F$ capacitor is 0.050mm. (a) What is the surface area of the plates? (b) How much charge is on the plates if this capacitor is attached to a 1.5V battery?

- The area is

$$A = \frac{dC}{\epsilon_0} = 5.65 \text{ m}^2$$

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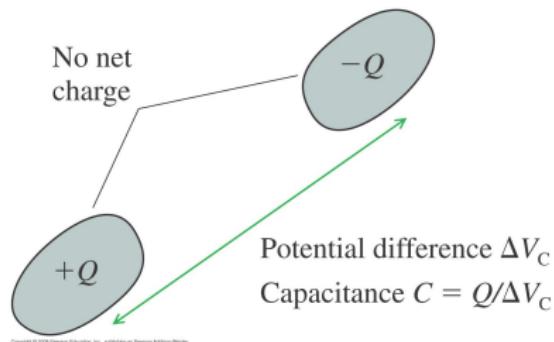
- The area is

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- The charge is

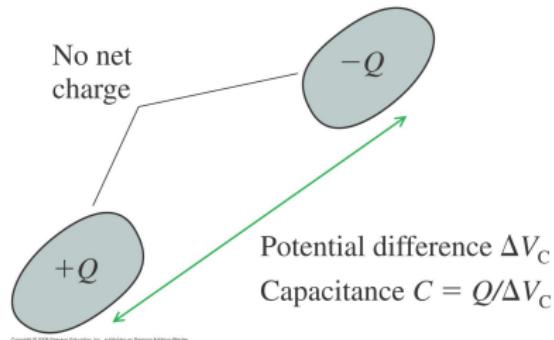
$$Q = C\Delta V_C = 1.5 \times 10^{-6} \text{ C} = 1.5 \mu\text{C}$$

Forming a Capacitor (30-22)



- We have been drawing our capacitors as parallel plates since those are the most useful ones. However, any two electrodes will form a capacitor.

Forming a Capacitor (30-22)

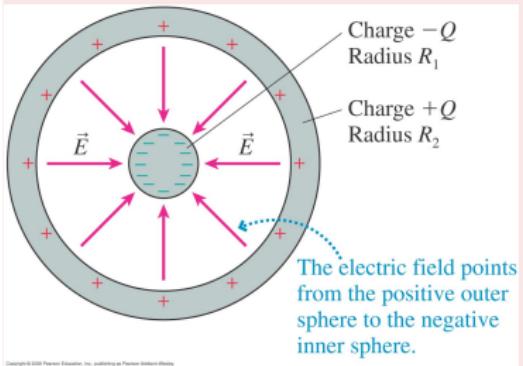


- We have been drawing our capacitors as parallel plates since those are the most useful ones. However, any two electrodes will form a capacitor.
- The capacitance is

$$C = \frac{Q}{\Delta V_C}$$

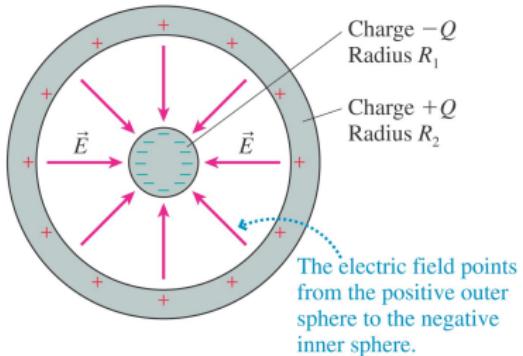
A Spherical Capacitor (Example 30.7)

Example 30.7



A metal sphere of radius R_1 is inside and concentric with a hollow metal sphere of radius R_2 . What is the capacitance of this spherical capacitor?

A Spherical Capacitor (Example 30.7)

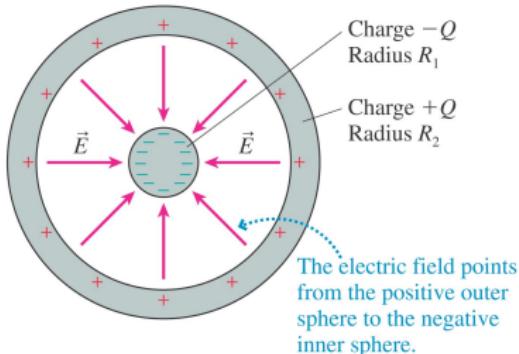


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- The potential difference between the two spheres is

$$\Delta V = V_f - V_i = - \int_{S_i}^{S_f} E_s ds$$

A Spherical Capacitor (Example 30.7)



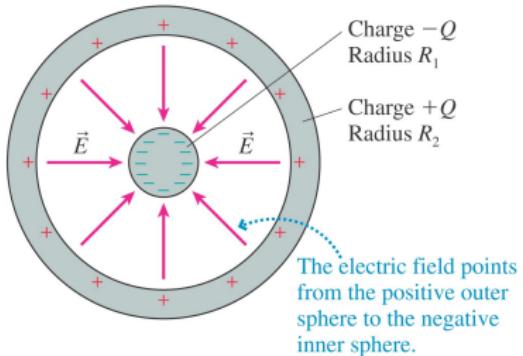
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- The potential difference between the two spheres is

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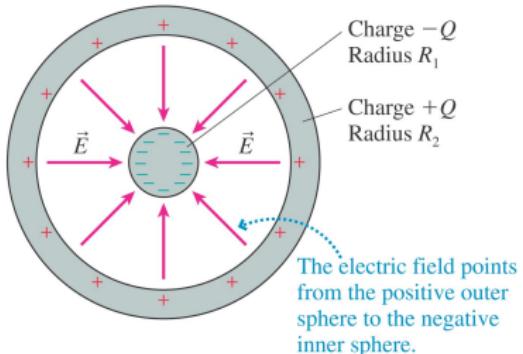
$$\Delta V = V_f - V_i = - \int_{s_i}^{s_f} E_s ds$$

- The electric field contribution from the outer sphere is zero.

- Integrate on a radial line from $s_i = R_1$ to $s_f = R_2$. The field component points inward, so is negative.

$$\Delta V_C = - \int_{R_1}^{R_2} \left(\frac{-Q}{4\pi\epsilon_0 s^2} \right) ds = \frac{Q}{4\pi\epsilon_0} \int_{R_1}^{R_2} \frac{ds}{s^2} = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

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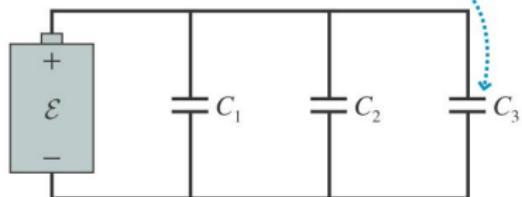
$$\Delta V_C = - \int_{R_1}^{R_2} \left(\frac{-Q}{4\pi\epsilon_0 s^2} \right) ds = \frac{Q}{4\pi\epsilon_0} \int_{R_1}^{R_2} \frac{ds}{s^2} = \frac{Q}{4\pi\epsilon_0} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

- Capacitance is then

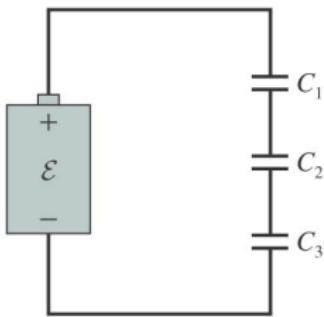
$$C = 4\pi\epsilon_0 \left(\frac{1}{R_1} - \frac{1}{R_2} \right)^{-1}$$

Combinations of Capacitors

The circuit symbol for a capacitor is two parallel lines.



Parallel capacitors are joined top to top and bottom to bottom.



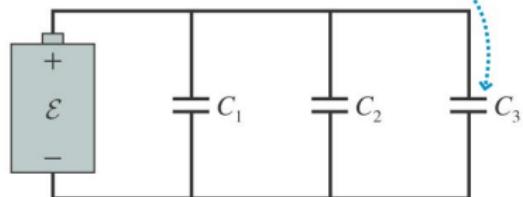
Series capacitors are joined end to end in a row.

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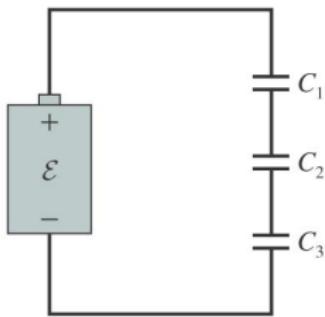
- We can join capacitors together in **parallel** or in **series**.

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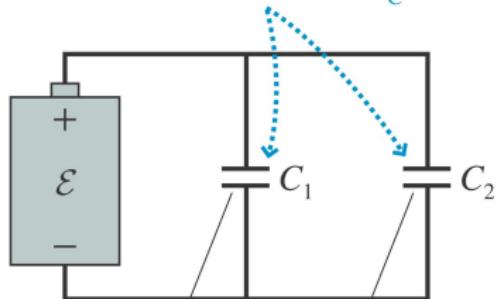
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- We can join capacitors together in **parallel** or in **series**.
- In either case we will learn to replace a system of capacitors with a single **equivalent capacitor**.

Parallel Capacitors

(a)

Parallel capacitors have the same ΔV_C .

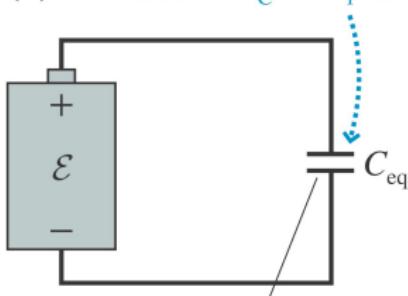


$$Q_1 = C_1 \Delta V_C \quad Q_2 = C_2 \Delta V_C$$

- The two top electrodes are connected by a conducting wire, so form a single conductor in equilibrium.

(b)

Same ΔV_C as C_1 and C_2



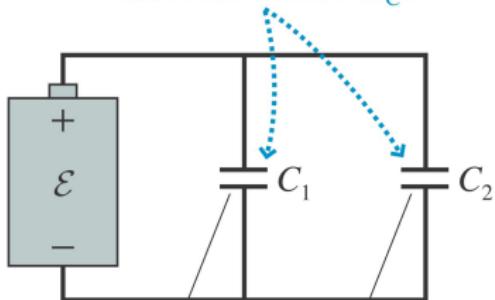
$$Q = Q_1 + Q_2$$

Same total charge as C_1 and C_2

Parallel Capacitors

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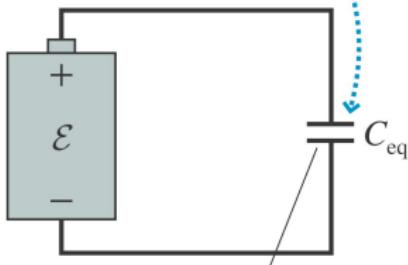


$$Q_1 = C_1 \Delta V_C \quad Q_2 = C_2 \Delta V_C$$

- The two top electrodes are connected by a conducting wire, so form a single conductor in equilibrium.
- The two top electrodes are therefore at the same potential. Two or more capacitors connected in parallel all have the same potential difference between electrodes.

(b)

Same ΔV_C as C_1 and C_2



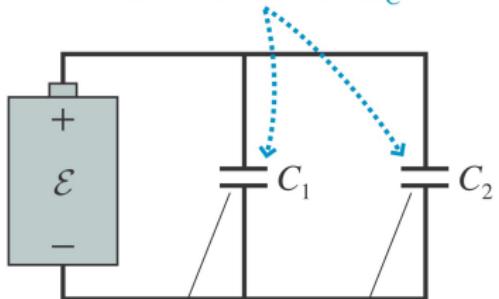
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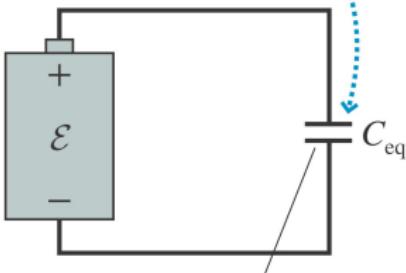
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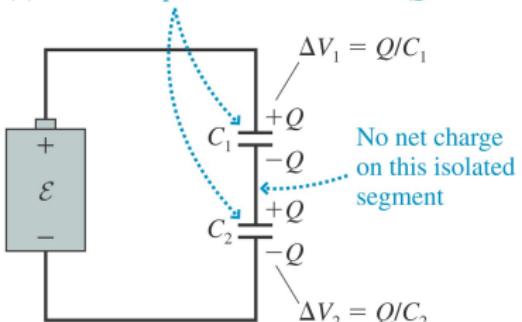
- The two top electrodes are connected by a conducting wire, so form a single conductor in equilibrium.
- The two top electrodes are therefore at the same potential. Two or more capacitors connected in parallel all have the same potential difference between electrodes.
- The battery has to do the work to move $Q = Q_1 + Q_2$ to the top plates. So, the equivalent capacitance is

$$C_{eq} = \frac{Q_1 + Q_2}{\Delta V_C} = C_1 + C_2$$

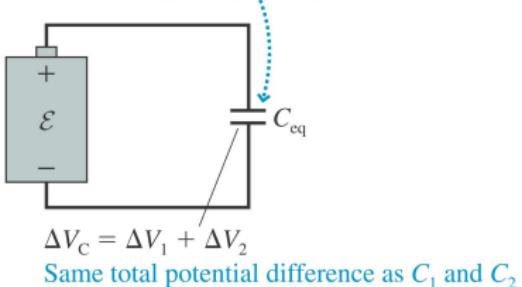
Just sum the capacitances!

Series Capacitors

(a) Series capacitors have the same Q .



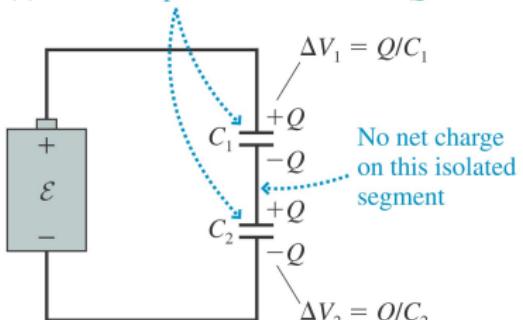
(b) Same Q as C_1 and C_2



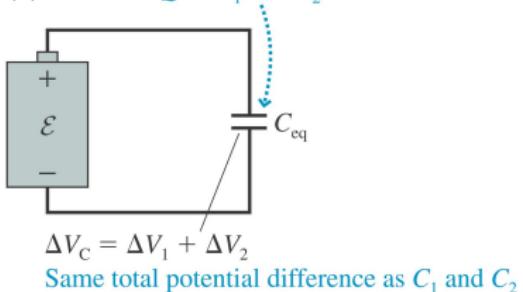
- The battery sees only the top plate of the first capacitor and the bottom plate of the second one. It cannot add or remove charge from the others.

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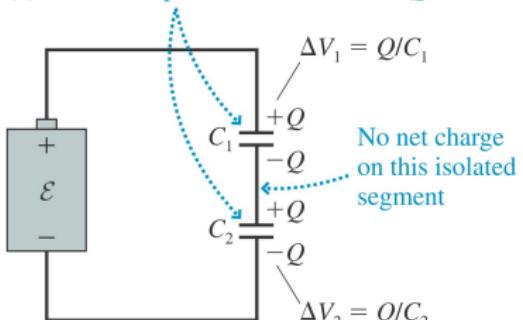
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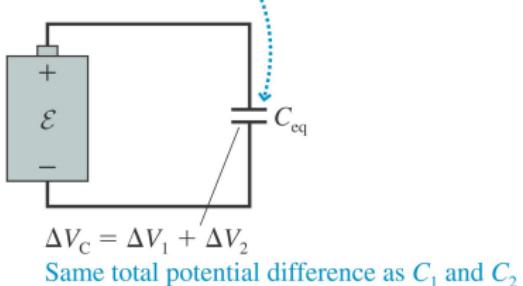
- The battery sees only the top plate of the first capacitor and the bottom plate of the second one. It cannot add or remove charge from the others.
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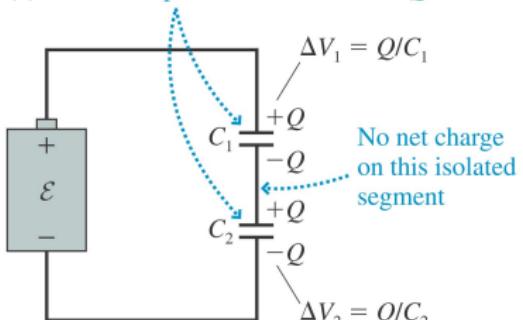
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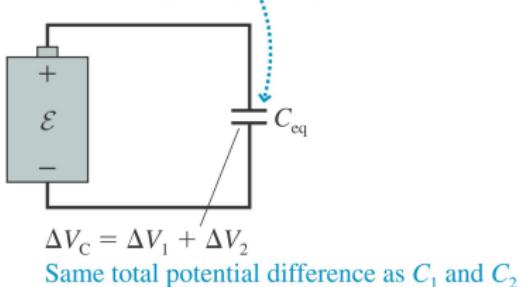
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- The potential difference across both capacitors is $\Delta V_C = \Delta V_1 + \Delta V_2$.

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(b) Same Q as C_1 and C_2

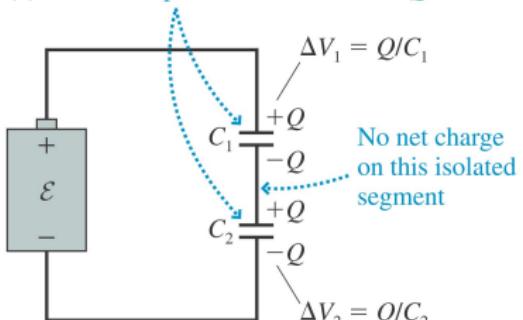


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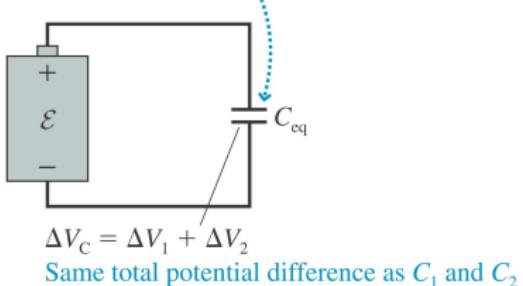
$$C = \frac{Q}{\Delta V_C} = \frac{Q}{\Delta V_1 + \Delta V_2}$$

Series Capacitors

(a) Series capacitors have the same Q .



(b) Same Q as C_1 and C_2

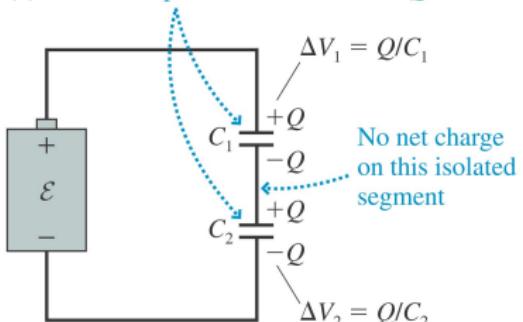


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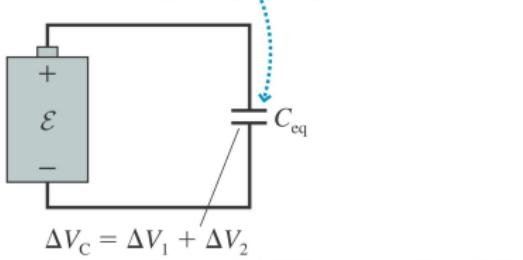
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Series Capacitors

(a) Series capacitors have the same Q .



(b) Same Q as C_1 and C_2



Same total potential difference as C_1 and C_2

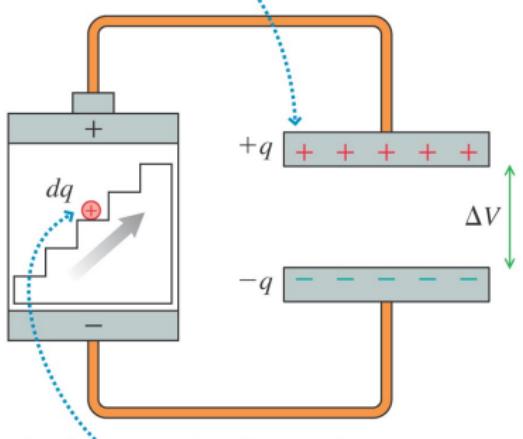
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$$C = \frac{Q}{\Delta V_C} = \frac{Q}{\Delta V_1 + \Delta V_2}$$
$$\frac{1}{C} = \frac{\Delta V_1}{Q} + \frac{\Delta V_2}{Q} = \frac{1}{C_1} + \frac{1}{C_2}$$

The Energy Stored in a Capacitor (30.6)

- Charging a capacitor uses energy from the battery. Energy is conserved, therefore it “goes” somewhere.

The instantaneous charge on the plates is $\pm q$.

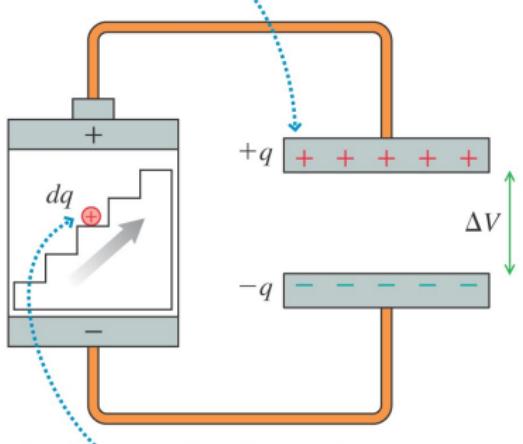


The charge escalator does work $dq \Delta V$ to move charge dq from the negative plate to the positive plate.

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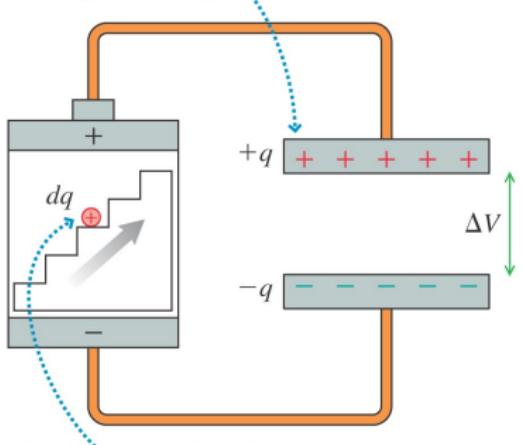
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- Charging a capacitor uses energy from the battery. Energy is conserved, therefore it “goes” somewhere.
- As the battery uses energy, the potential energy stored in the capacitor increases

$$dU = dq \Delta V = \frac{q dq}{C}$$

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- Integrating over all of the charging time gives

$$U_C = \frac{1}{C} \int_0^Q q dq = \frac{Q^2}{2C} = \frac{C(\Delta V)^2}{2}$$

The Energy Stored in a Capacitor

- The energy stored is proportional to the square of the potential difference - reminds me of a spring $U = \frac{1}{2}k\Delta x^2$

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- What is the power dissipated if that energy is released in $10\mu\text{s}$?

$$P = \frac{\Delta E}{\Delta t} = 2.5 \text{ MW}$$

that's "megawatts".