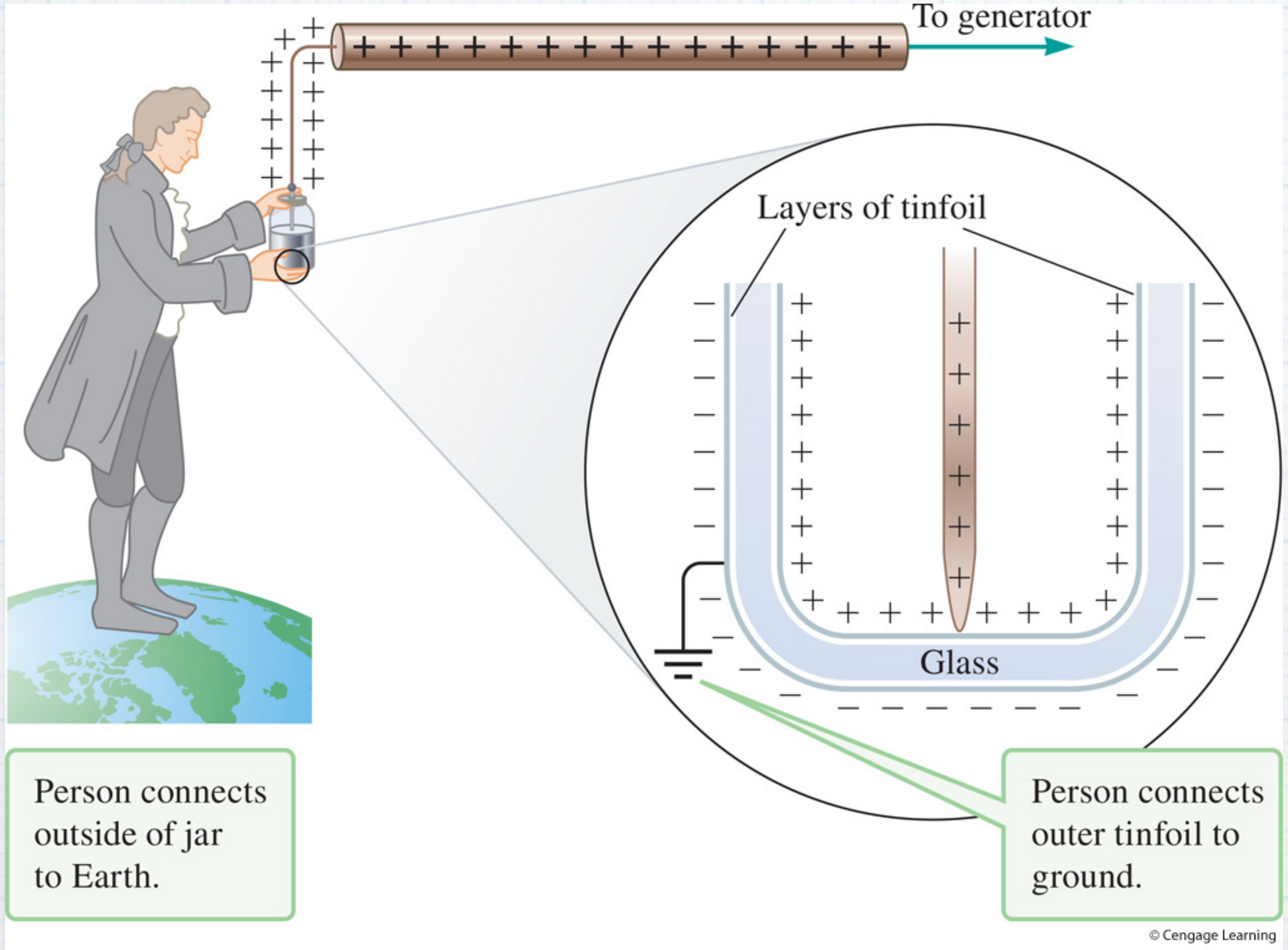
Batteries and Capacitors

I don't expect you to follow or be tested on any of the Gauss's Law stuff

Leyden Jars

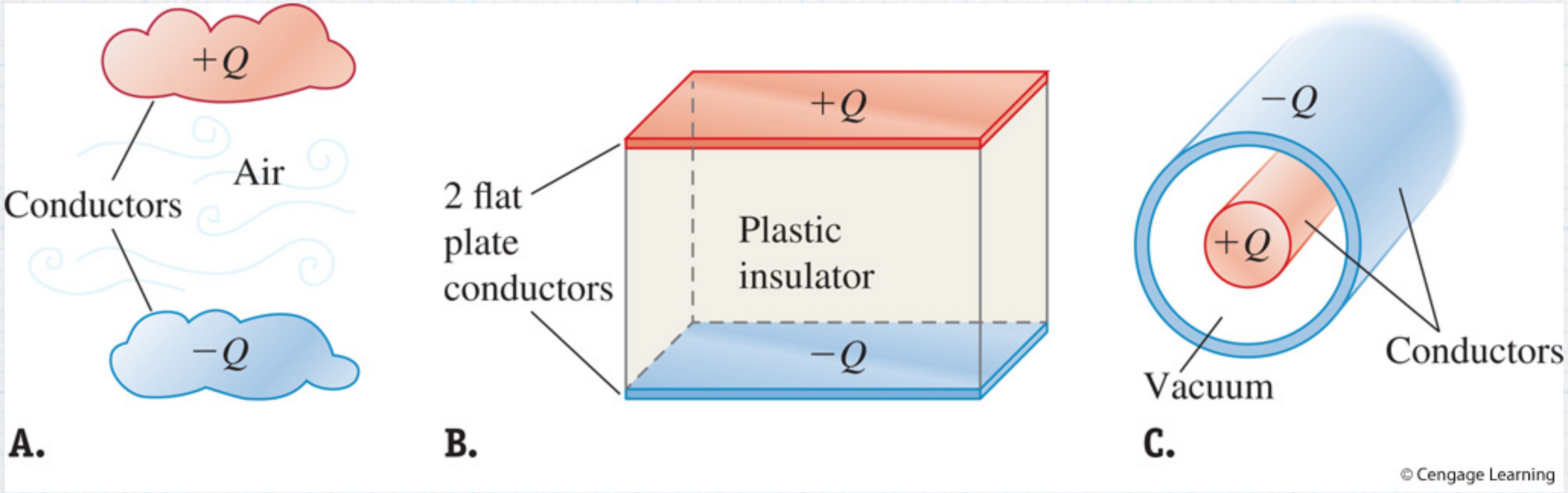



The Library Company of Philadelphia, Gift of Benjamin Franklin Bache, 1792.

dielectric strength of air 30 kV per centimeter

Capacitor

* Stores potential energy but generating charges on inner and outer plate
* Depends on geometry and materials in between plates

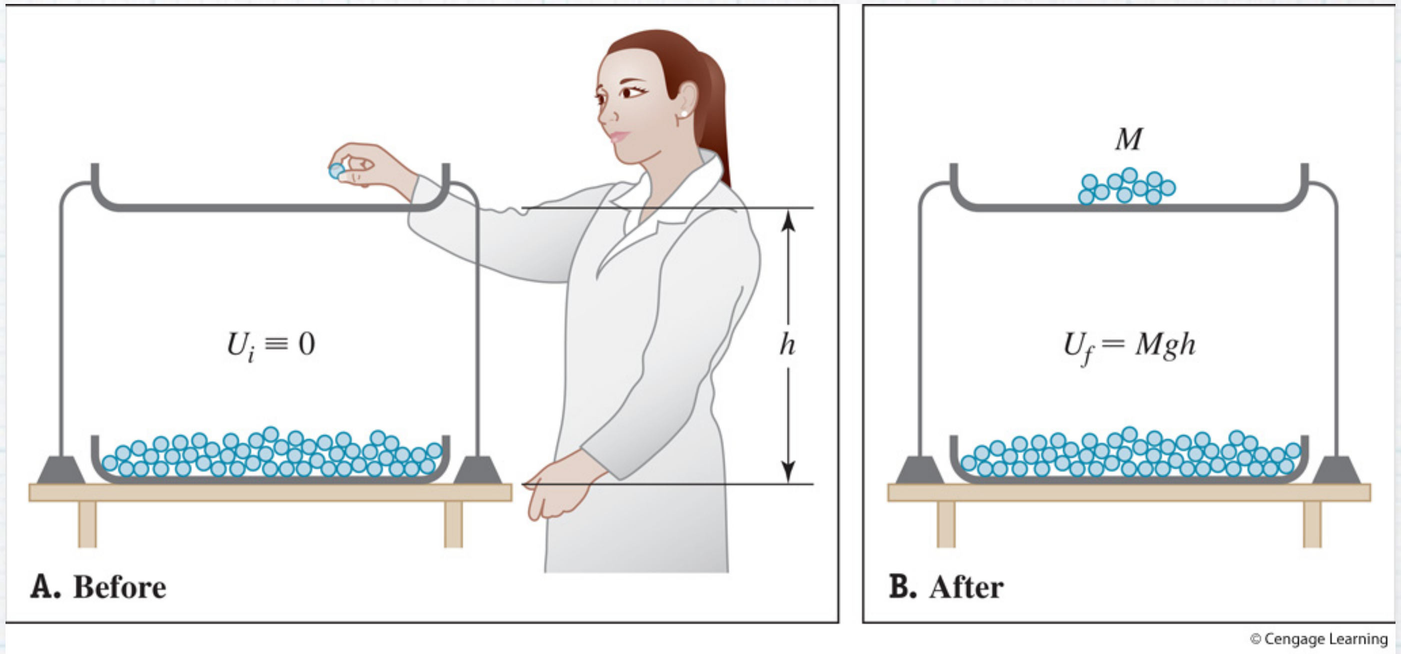


$$Q = C\Delta V$$

Farad = coulomb/volt

Energy Stored by a Capacitor

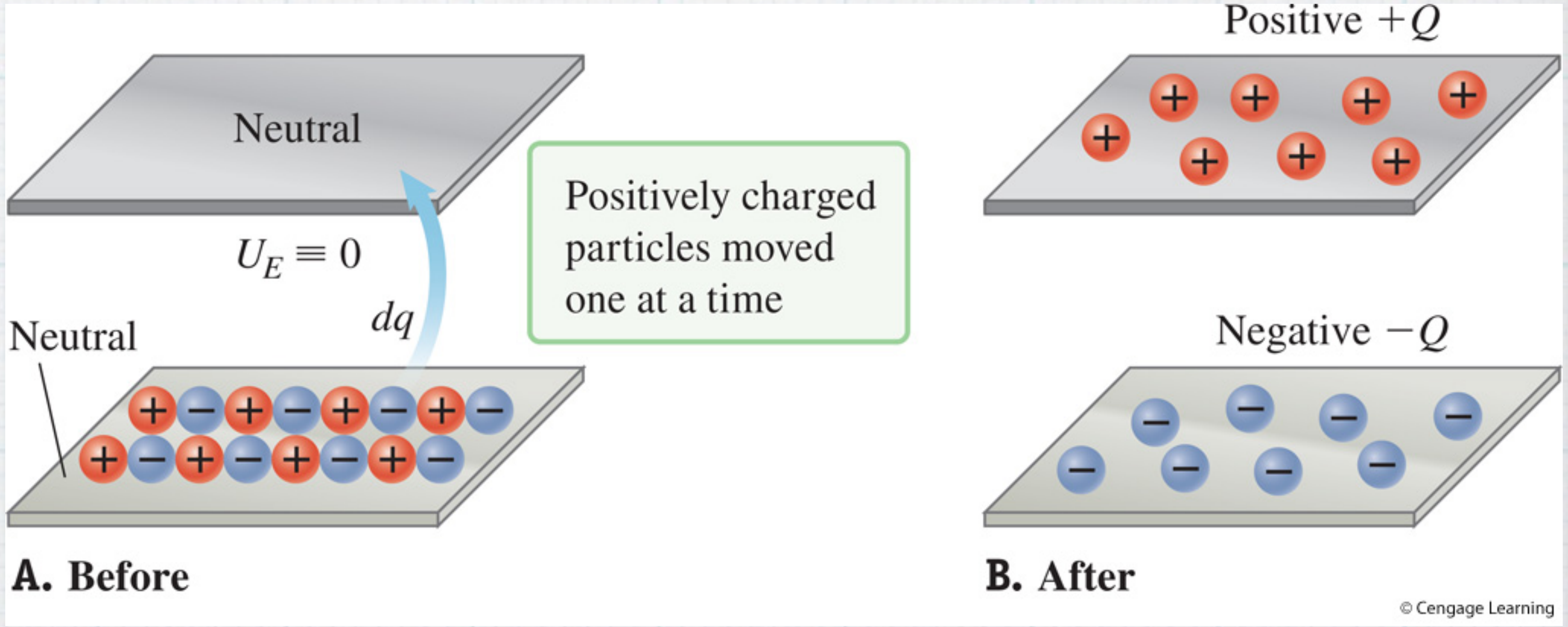
$$W = \sum_{i}^{N} m_i g h = Mgh$$



$$\int_0^{U_e} dU_e = \int_0^{Q} \Delta V\, dq$$

$$Q = C\Delta V$$

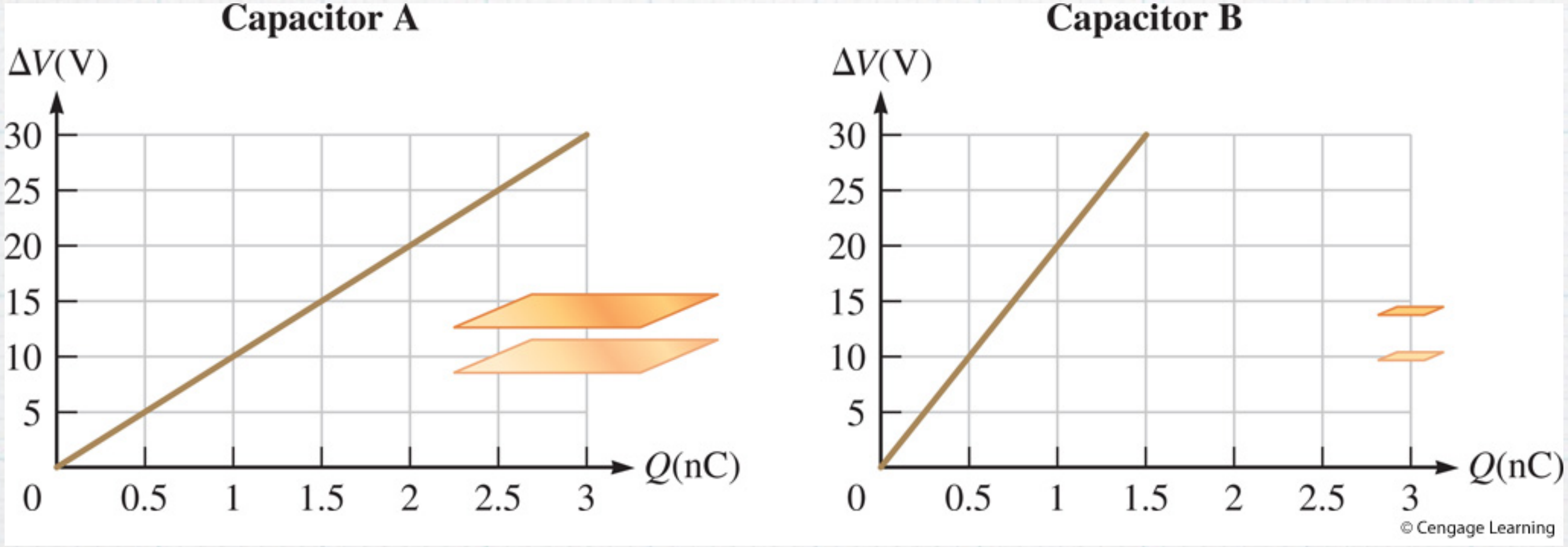
$$U_e = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}C(\Delta V)^2$$



Example

* Typical capacitors have capacitance between a few picofarads and microfarads
* A capacitor was used to launch a 90 gram metal ball 120 meters
* The potential difference in the capacitor was 1500 Volts
* What was the capacitance and charge?

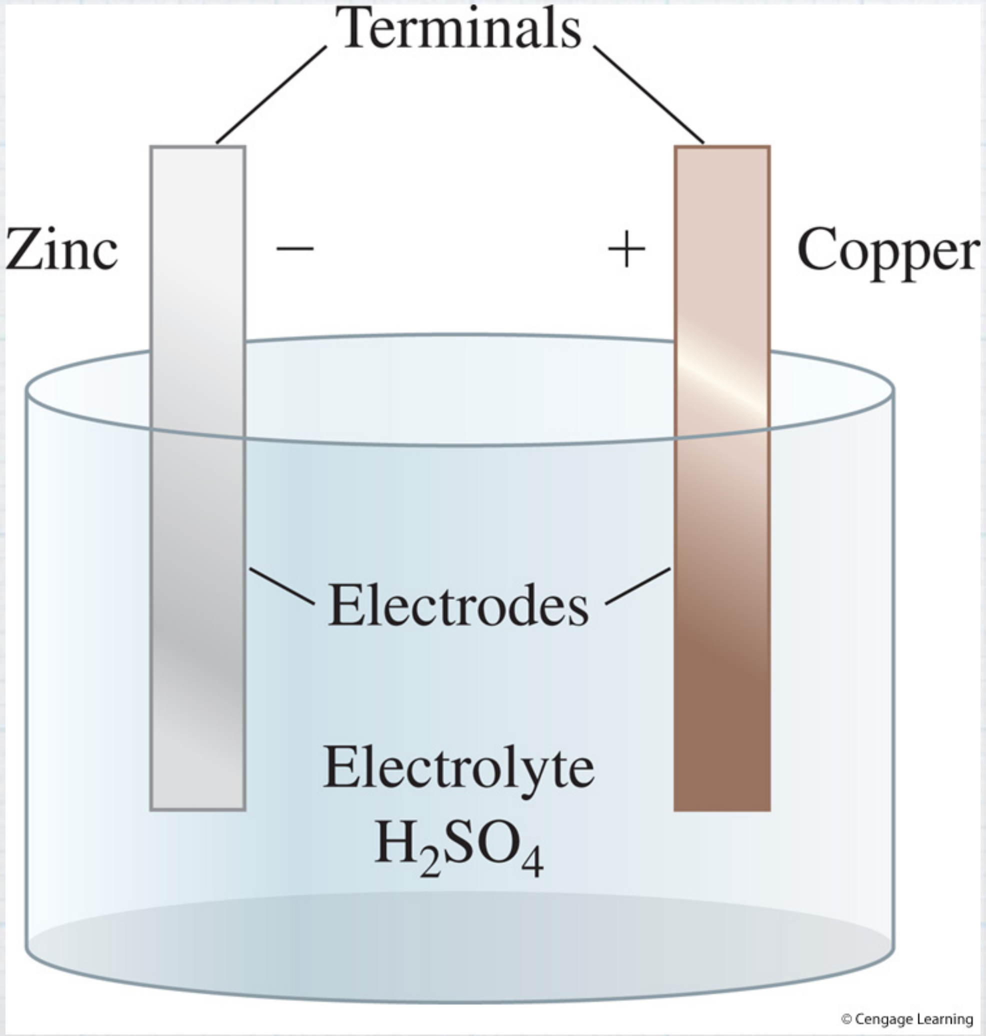
What's the Capacitance?

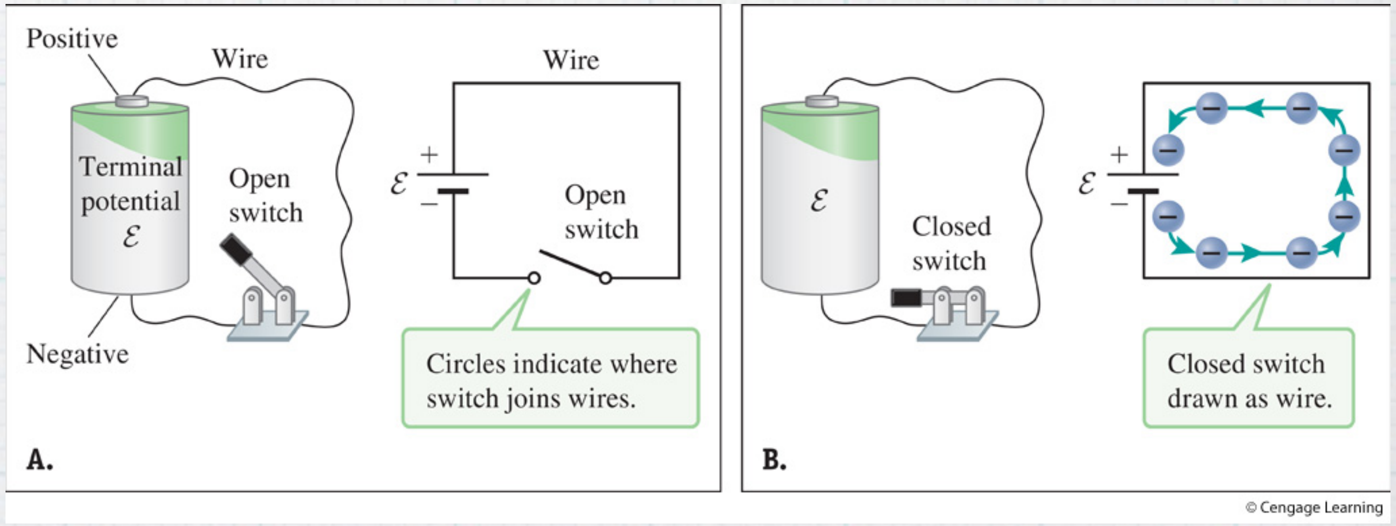


Batteries

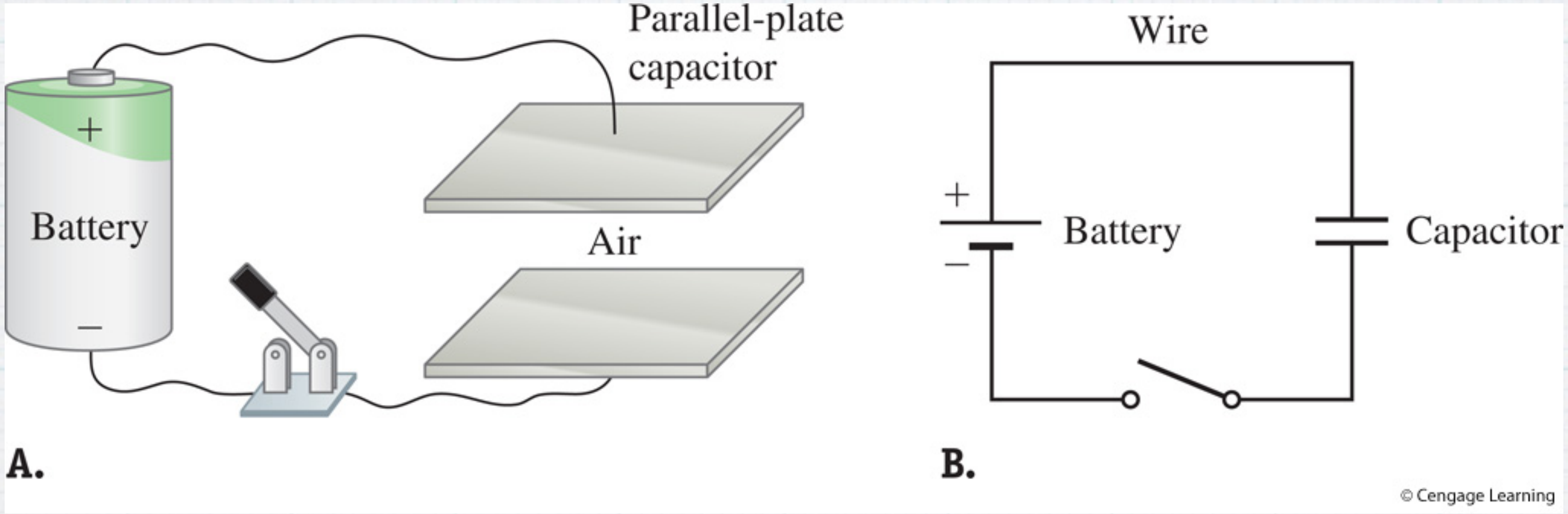
* Capacitors store charge resulting in a potential difference

* Batteries maintain a potential difference through chemical reactions





Charging a Capacitor



When the switch is closed the capacitor charges until there is an accumulation of +Q charge on the top plate and -Q on the bottom. The potential difference across the capacitor reaches the same value as the voltage of the battery

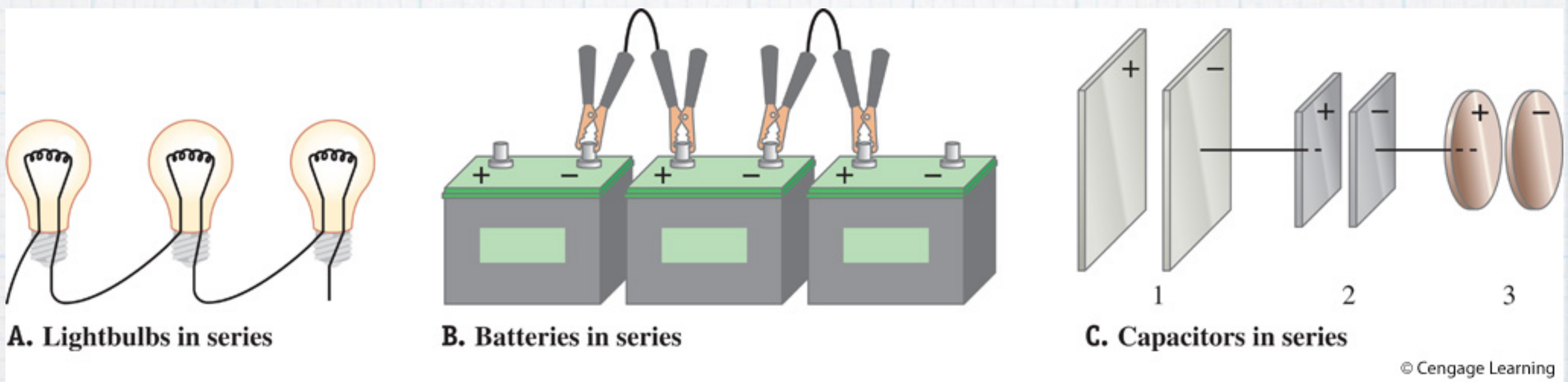
$$V_c = \xi \rightarrow Q = C\xi$$

Example

* How do the charge and potential energy in two capacitors compare when one has twice the capacitance of the other?

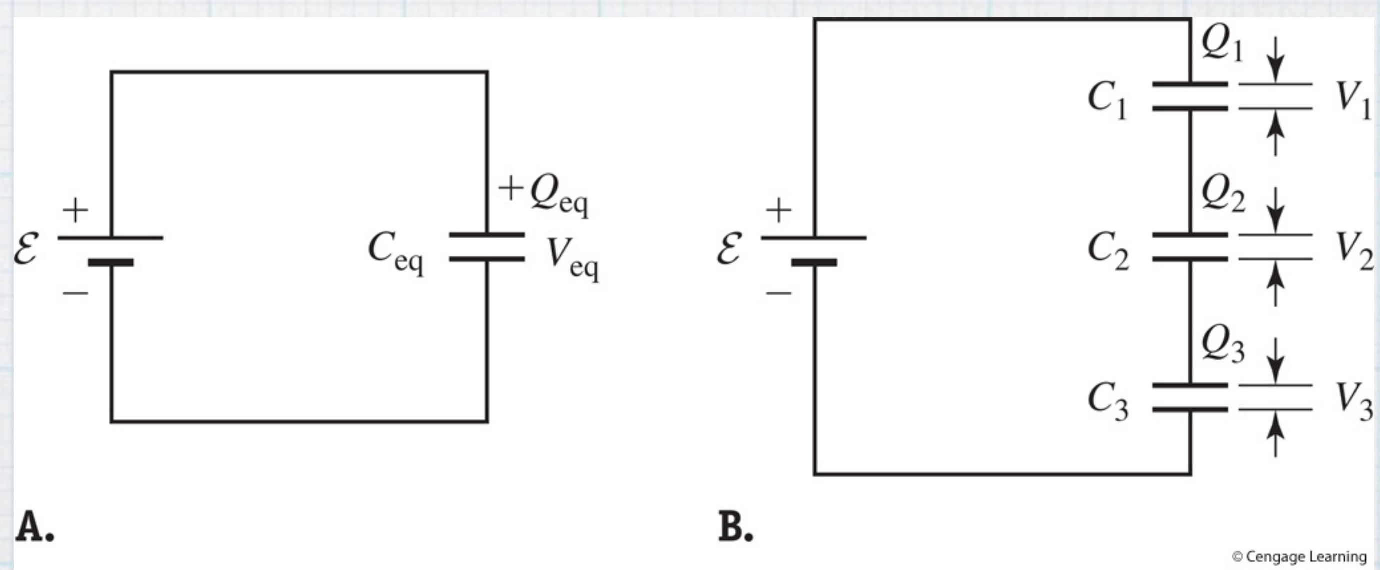
Capacitors in series

* The voltage supplied by the power source is all that matters.



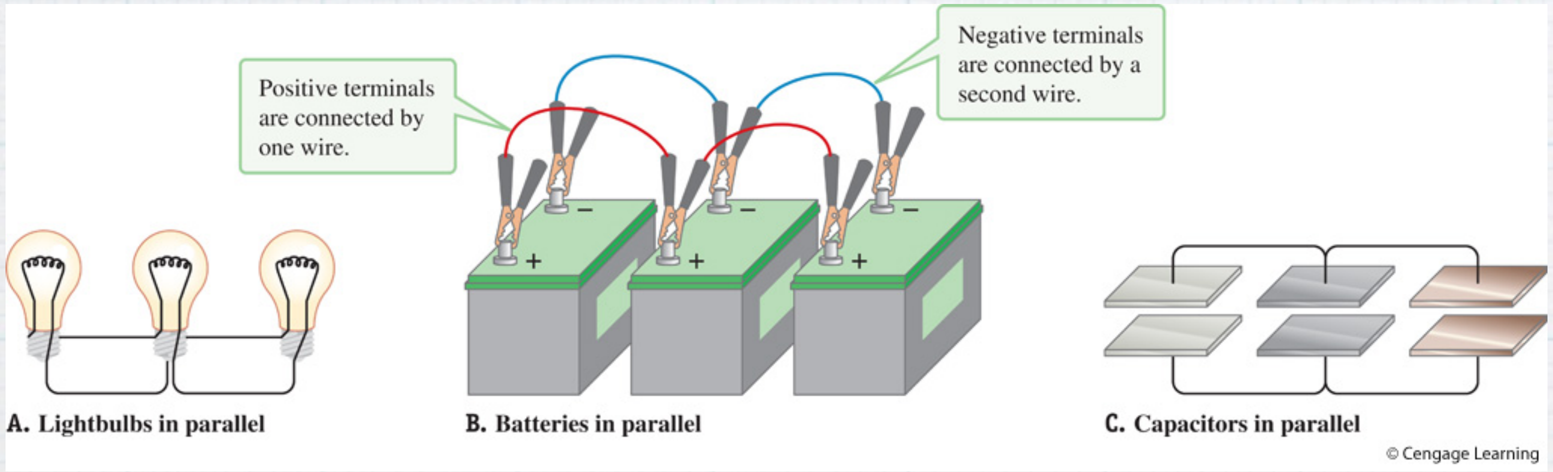
$$\frac{1}{C_{eq}} = \sum_{i}^{N} \frac{1}{C_i}$$

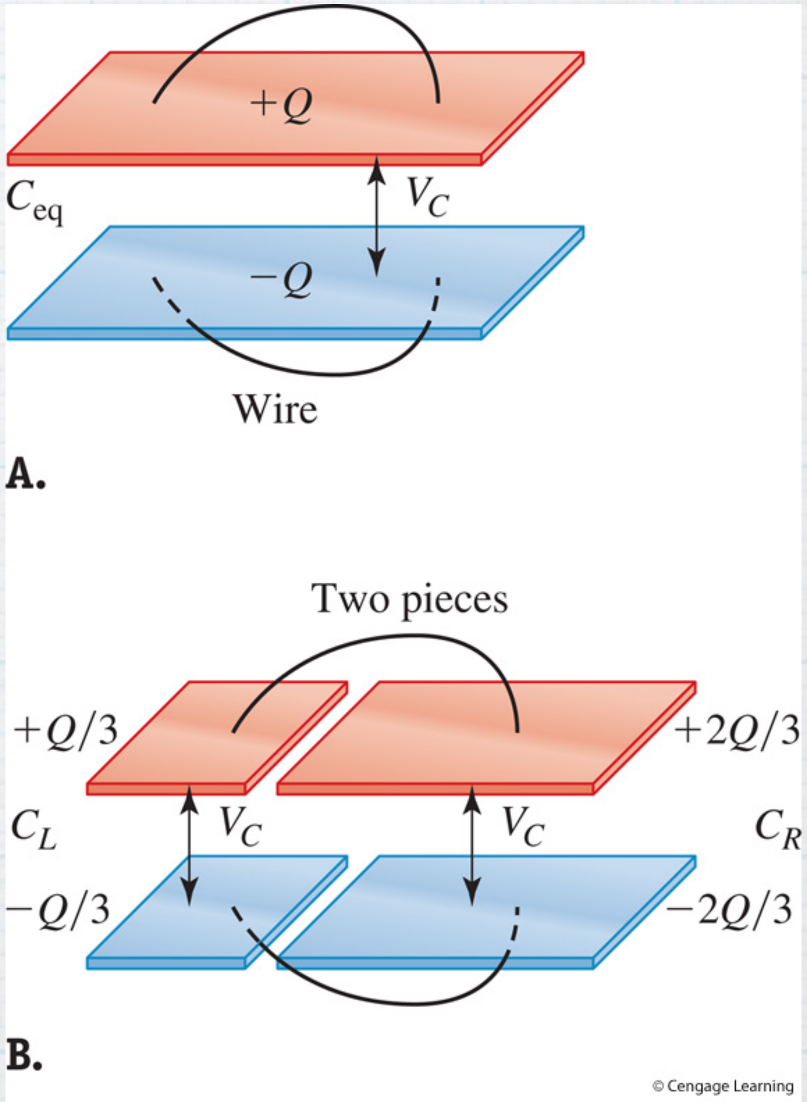
Smaller than individual capacitance



Capacitors in Parallel

* The total charge deposited on capacitors in parallel is the same, the potential difference between each capacitor is parallel is the potential of the power source

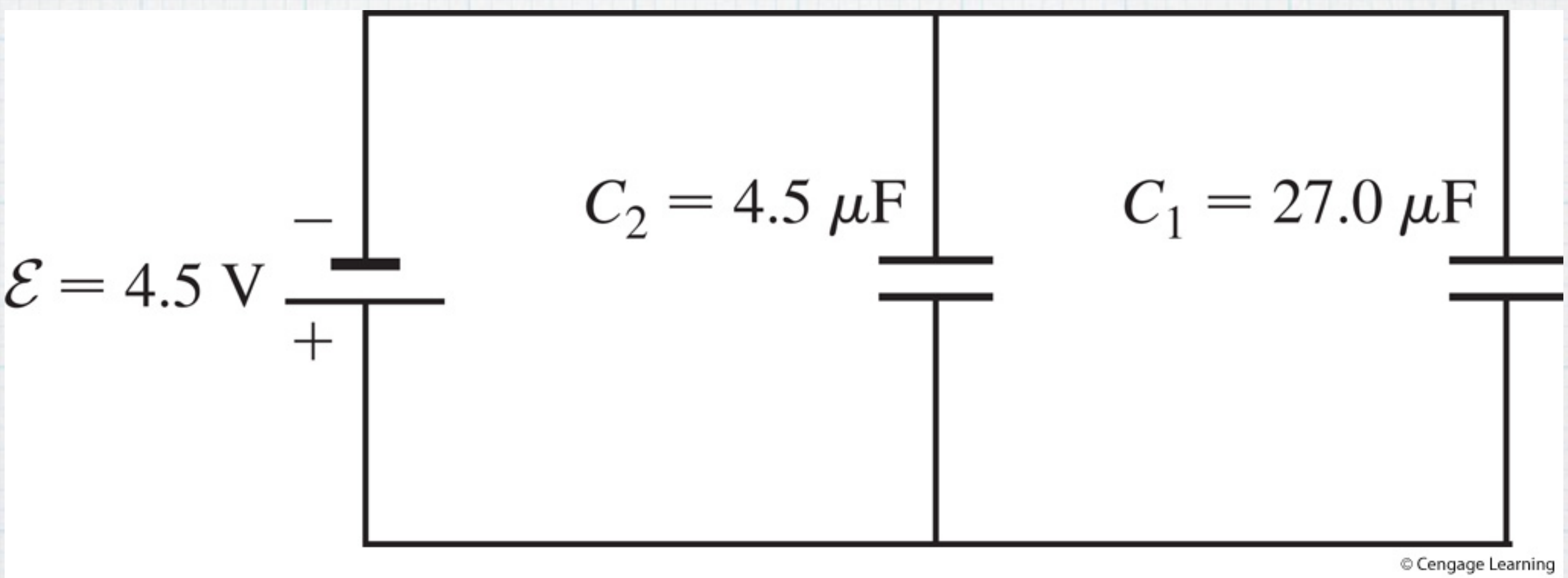


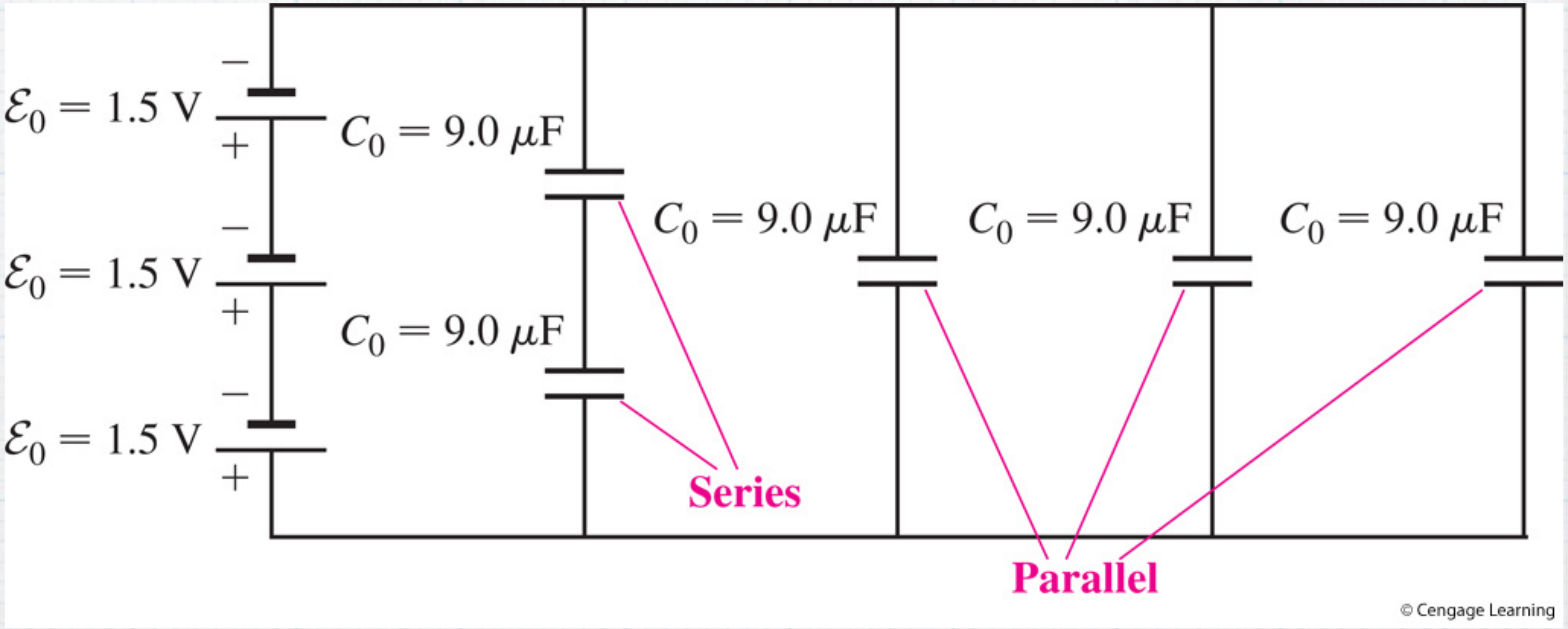


$$C_{eq} = \sum_{i}^{N} C_i$$

Example

we have 1.5 volt batteries and 9 micro farad capacitors
build the circuit below





$\mathcal{E}_0 = 1.5$ V
$\mathcal{E}_0 = 1.5$ V
$\mathcal{E}_0 = 1.5$ V
$C_0 = 9.0\ \mu$F
$C_0 = 9.0\ \mu$F
$C_0 = 9.0\ \mu$F
$C_0 = 9.0\ \mu$F
$C_0 = 9.0\ \mu$F
Series
Parallel
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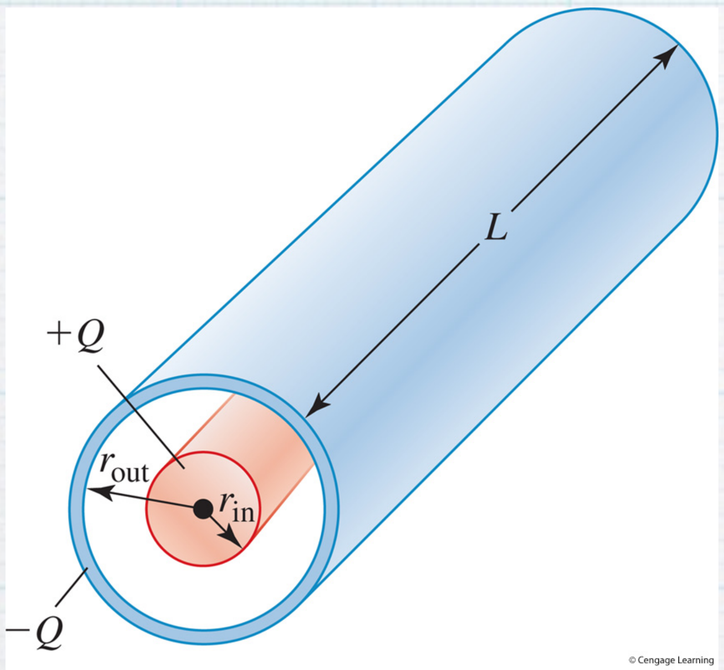
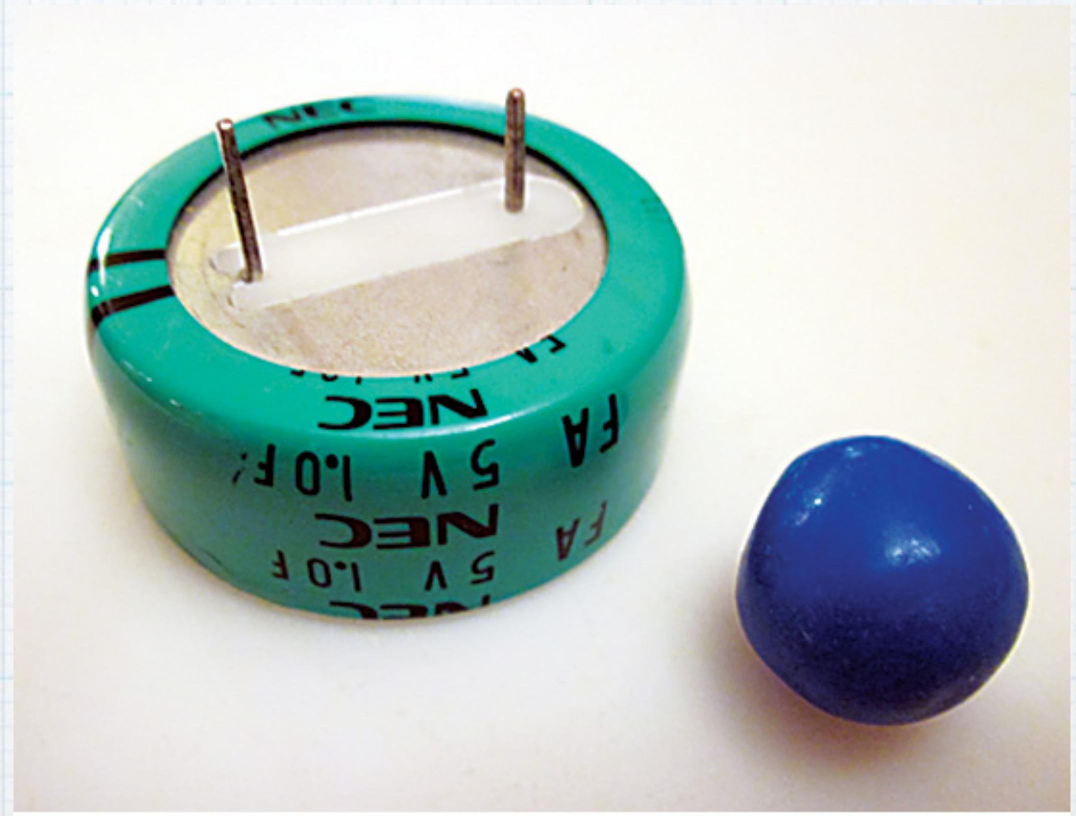
Cylindrical Capacitor





Debora Katz

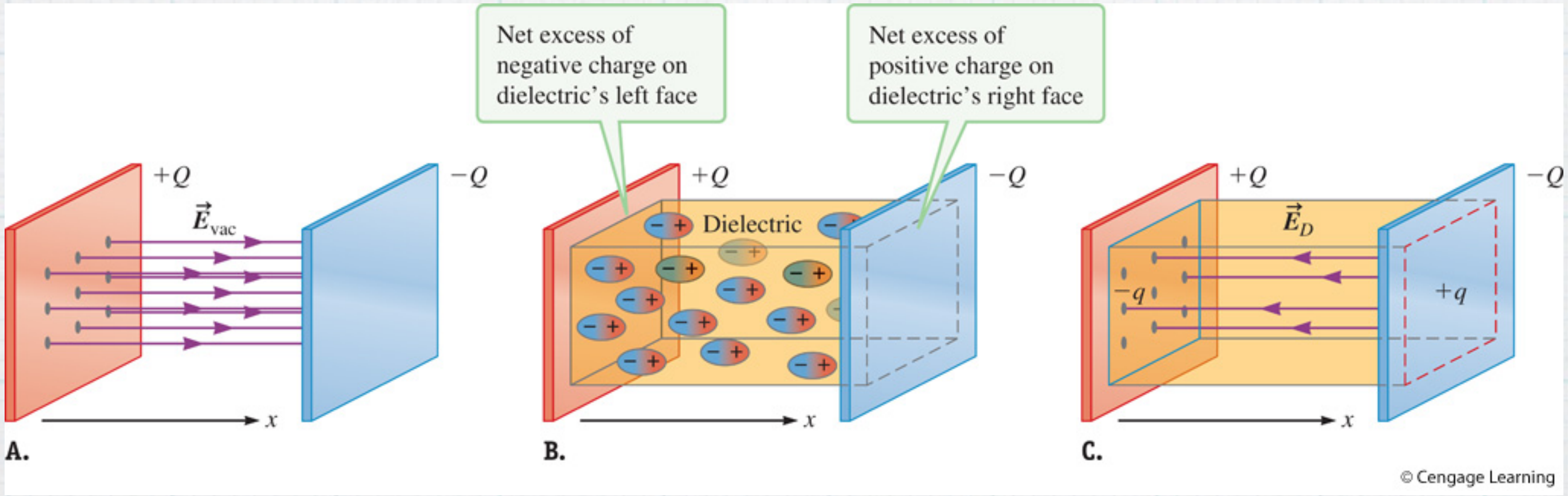
$$C = \frac{2\pi\epsilon_0 L}{ln(r_{out}/r_{in})}$$

How long must a capacitor be if C=1 Farad, R_{in} = 50 micro meters and R_{out} = 1.55mm?

6×10^{10}m?

Dielectrics

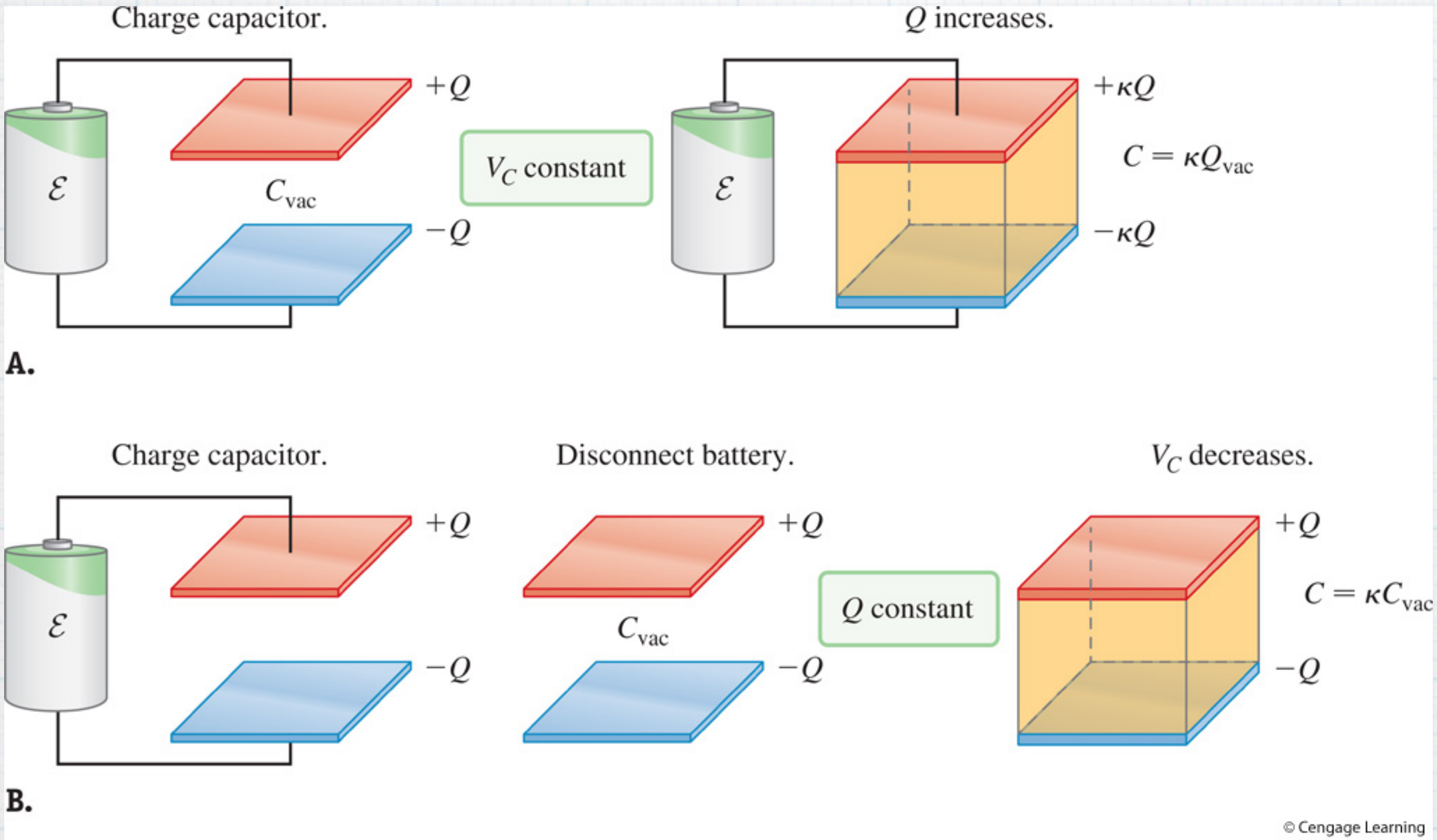
* Insulator that can maintain an electric field.
* More charge for less potential
* Dielectric constant kappa
* Dielectric strength - how much of an electrical field it can support before material becomes a conductor - Lightning



$$\vec{E}_c = \frac{1}{\kappa}\vec{E}_{vac} \rightarrow V_c = \frac{1}{\kappa}V_{vac}$$

$$C = \kappa C_{vac}$$

Energy Stored in a Dielectric Capacitor

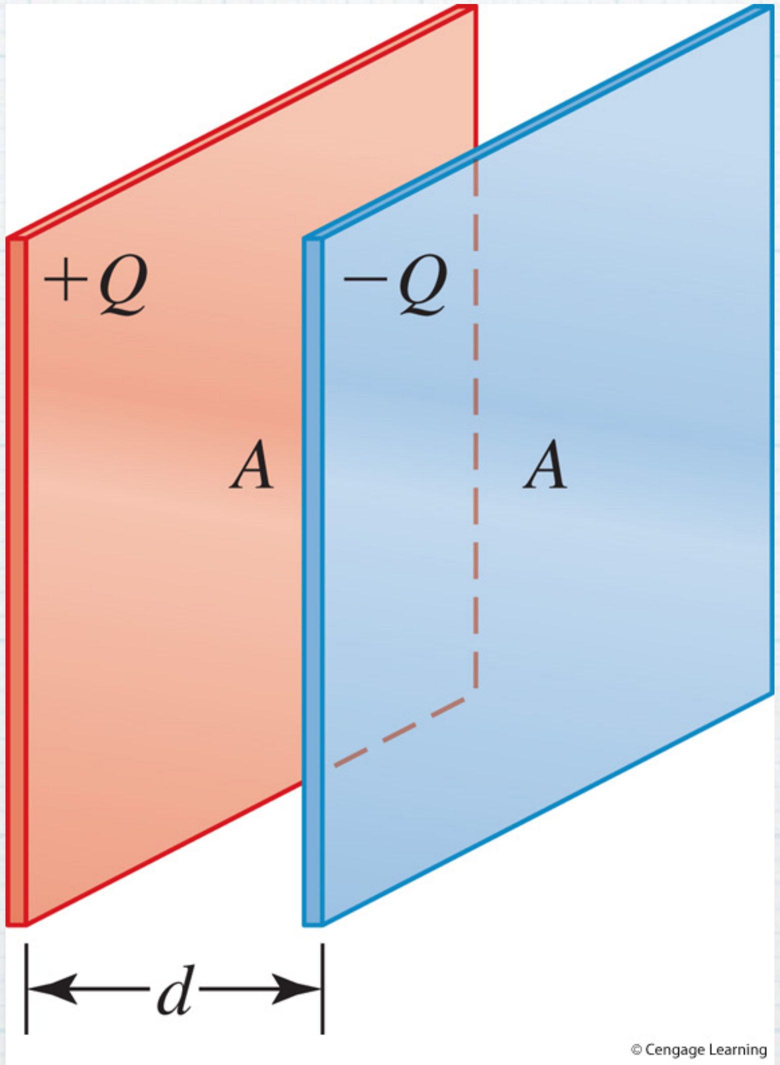


$$U = \kappa U_{vac}$$

$$U = \frac{U_{vac}}{\kappa}$$

Parallel plate with dielectric

$$C = \kappa \frac{\epsilon_0 A}{d}$$



Energy Density Parallel Plate

$$V_c = |\vec{E}|d$$

$$C = \frac{\kappa\epsilon_0 A}{d}$$

$$U_E = \frac{1}{2}CV_c^2 = \frac{1}{2}\kappa\epsilon_0|\vec{E}|^2(Ad)$$

$$u_E = \frac{U_E}{Ad} = \frac{1}{2}\kappa\epsilon_0|\vec{E}|^2$$

Example