The Electron Volt

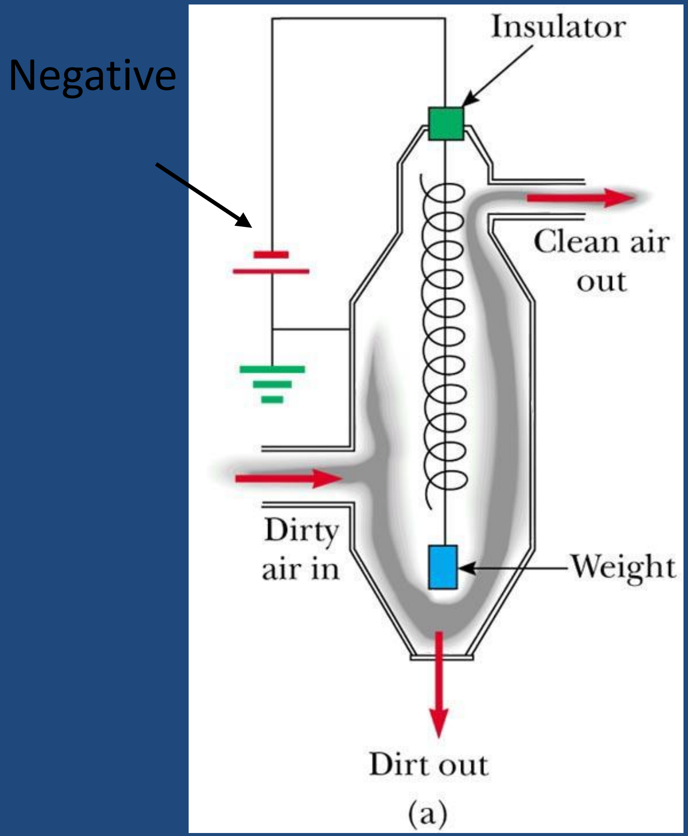
- The electron volt (eV) is defined as the energy that an electron (or proton) gains when accelerated through a potential difference of 1 V
  - Electrons in normal atoms have energies of 10's of eV
  - Excited electrons have energies of 1000's of eV
  - High energy gamma rays have energies of millions of eV
- 1 V=1 J/C $\rightarrow$ 1 eV = 1.6 x 10^{-19} J

Equipotential Surfaces

- An *equipotential surface* is a surface on which all points are at the same potential
  - No work is required to move a charge at a constant speed on an equipotential surface
  - The electric field at every point on an equipotential surface is perpendicular to the surface

Applications – Electrostatic Precipitator

- It is used to remove particulate matter from combustion gases
- Reduces air pollution
- Can eliminate approximately 90% by mass of the ash and dust from smoke



How does it work?

- High voltage (4-100 kV) is maintained between the coil wire and the grounded wall
- The electric field at the wire causes discharges, i.e., ions (charged oxygen atoms) are formed
- The negative ions and electrons move to the positively biased wall
- On their way the ions and electrons ionize dirt particles due to collisions
- Most of the dirt particles become negatively charged and are attracted to the wall as well – cleaning effect

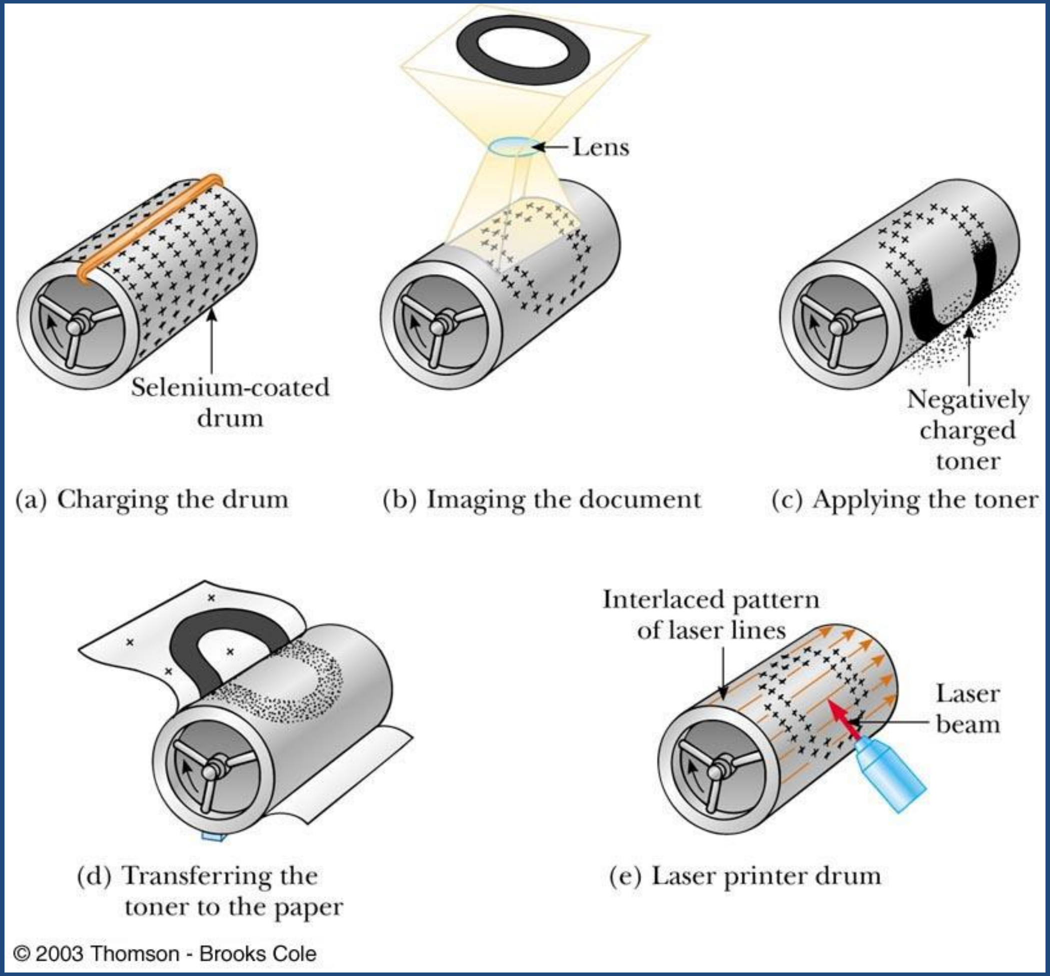
Electrostatic Air Cleaner

- Used in homes to relieve the discomfort of allergy sufferers
- It uses many of the same principles as the electrostatic precipitator

Application – Xerographic Copiers

- The process of xerography is used for making photocopies
- Uses photoconductive materials
  - A photoconductive material is a poor conductor of electricity in the dark but becomes a good electric conductor when exposed to light

The Xerographic Process



Application – Laser Printer

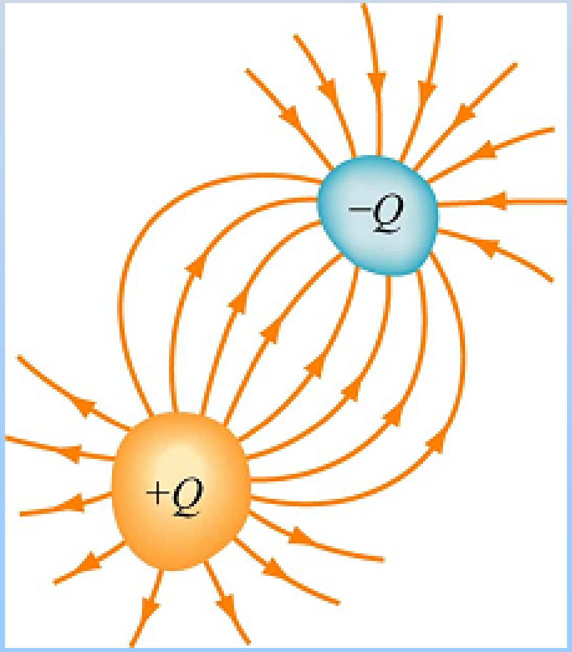
- The steps for producing a document on a laser printer is similar to the steps in the xerographic process
  - Steps a, c, and d are the same
  - The major difference is the way the image forms of the selenium-coated drum
    - A rotating mirror inside the printer causes the beam of the laser to sweep across the selenium-coated drum
    - The electrical signals form the desired letter in positive charges on the selenium-coated drum
    - Toner is applied and the process continues as in the xerographic process

Experiments to Verify Properties of Charges

- Millikan Oil-Drop Experiment
  - Measured the elementary charge, *e*
  - Found every charge had an integral multiples of *e*
    - $q = n e$

Capacitors: Store Electric Energy

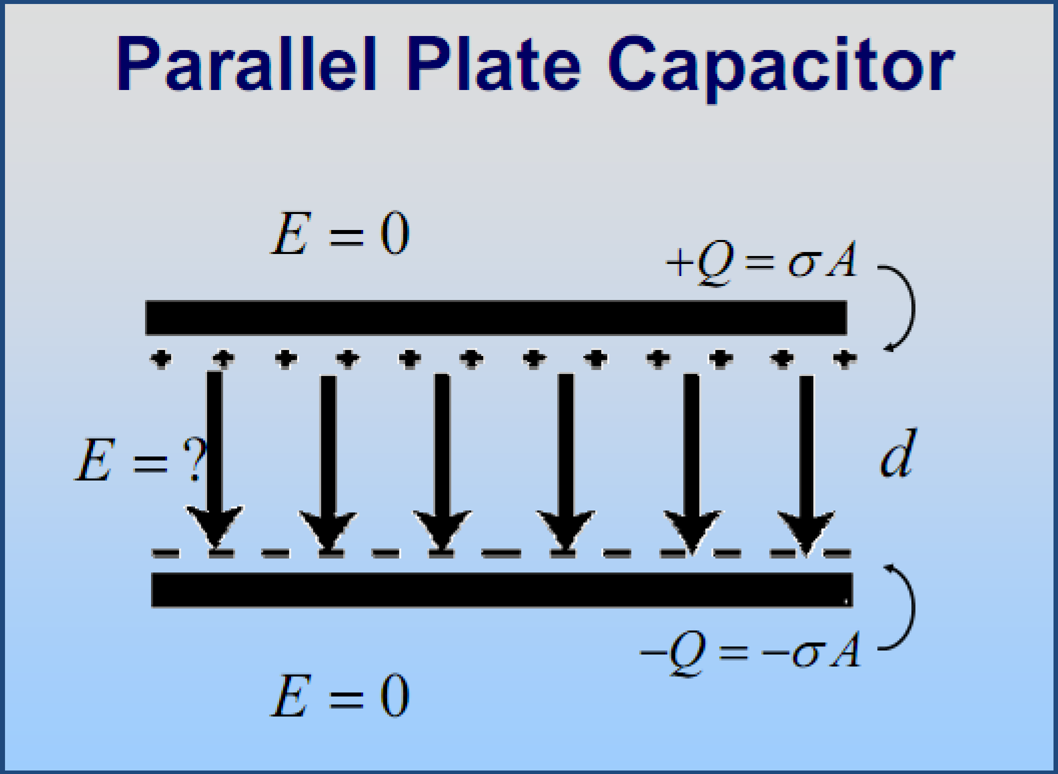
Capacitor: two isolated conductors with equal and opposite charges Q and potential difference ΔV between them.



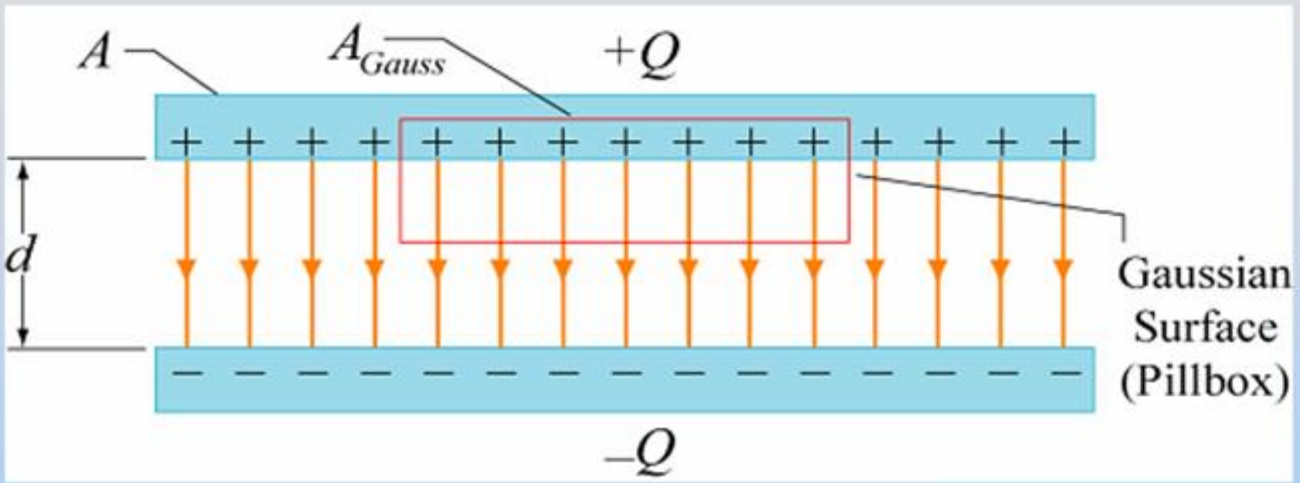
$$C = \frac{Q}{|\Delta V|}$$

Units: Coulombs/Volt or Farads

Parallel Plate Capacitor



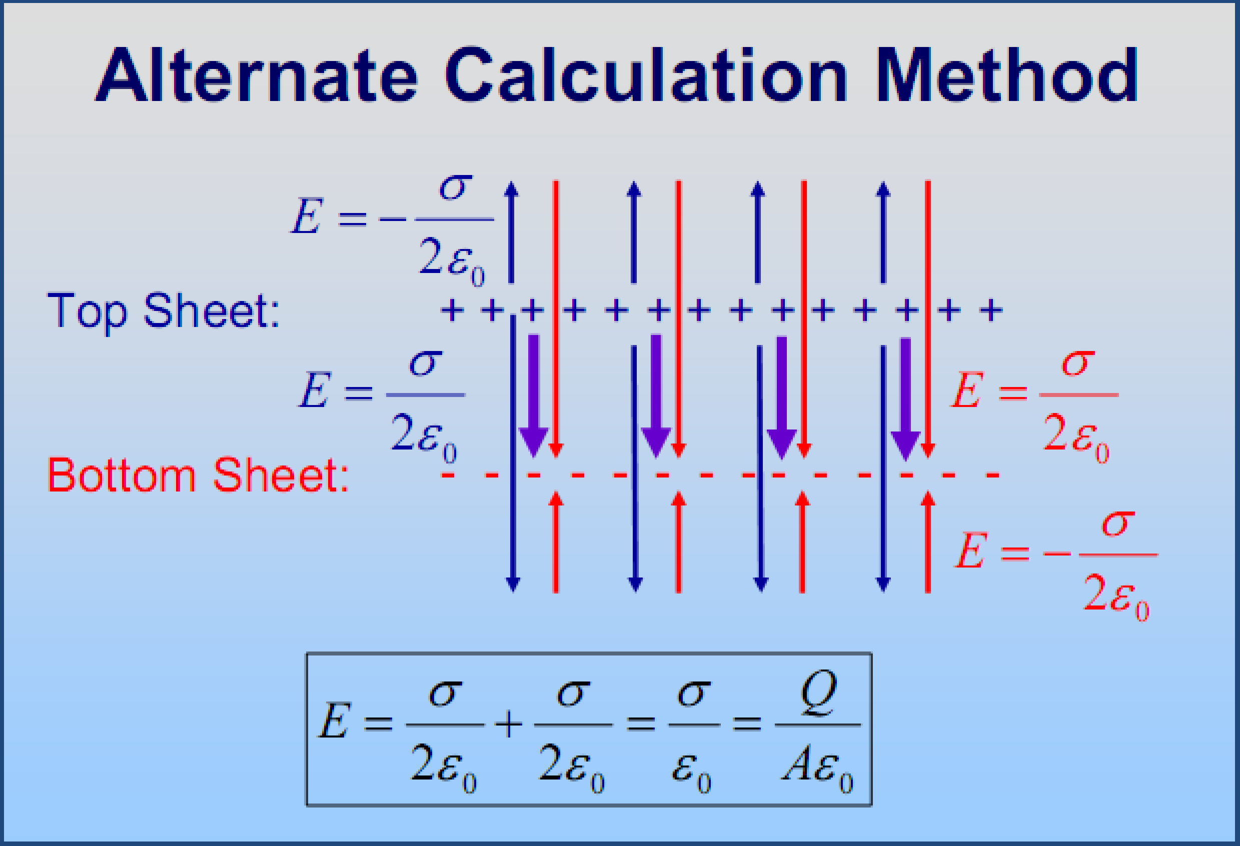
Calculating E (Gauss's Law)



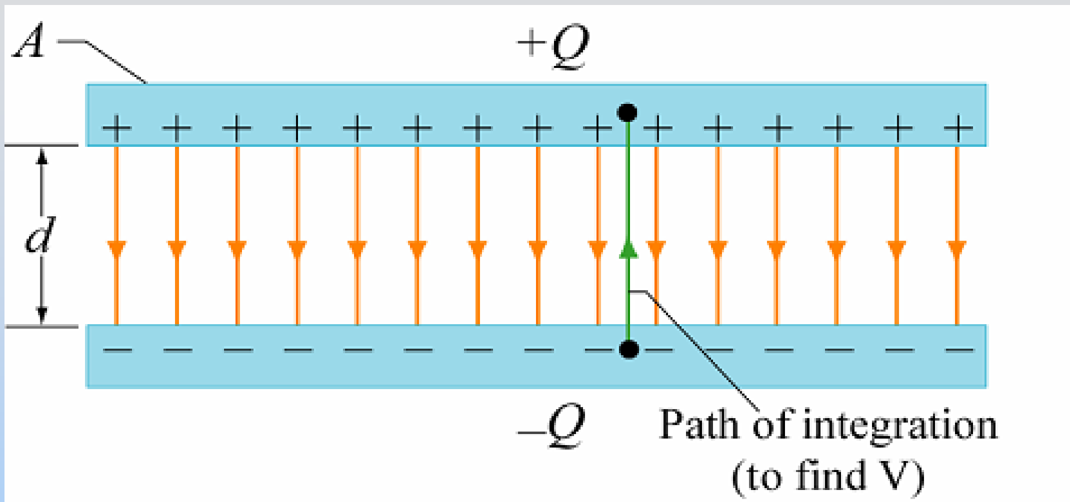
$$\oiint_S \vec{\mathbf{E}} \cdot d\vec{\mathbf{A}} = \frac{q_{in}}{\varepsilon_0} \qquad E\left(A_{Gauss}\right) = \frac{\sigma A_{Gauss}}{\varepsilon_0} \qquad \boxed{E = \frac{\sigma}{\varepsilon_0} = \frac{Q}{A\varepsilon_0}}$$

Note: We only "consider" a single sheet! Doesn't the other sheet matter?

Alternate Calculation Method



Parallel Plate Capacitor



$$\Delta V = -\int_{bottom}^{top} \vec{\mathbf{E}} \cdot d\vec{\mathbf{S}} = Ed = \frac{Q}{A\varepsilon_0} d$$

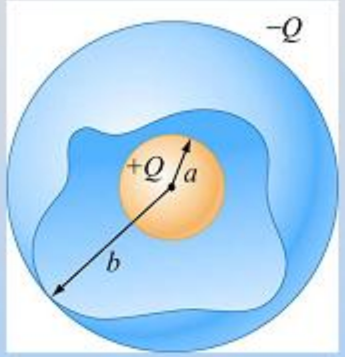
$$\boxed{C = \frac{Q}{|\Delta V|} = \frac{\varepsilon_0 A}{d}}$$

C depends only on geometric factors A and d

Spherical capacitor

Spherical Capacitor

Two concentric spherical shells of radii *a* and *b*



What is E?

Gauss's Law → E ≠ 0 only for $a < r < b$, where it looks like a point charge:

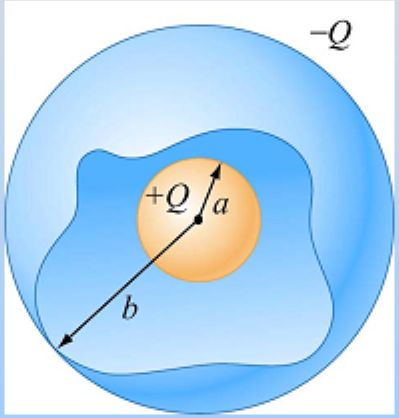
$$\vec{\mathbf{E}} = \frac{Q}{4\pi\varepsilon_0 r^2}\hat{\mathbf{r}}$$

Spherical capacitor

Spherical Capacitor

$$\Delta V = -\int_{inside}^{outside} \vec{\mathbf{E}} \cdot d\vec{\mathbf{S}} = -\int_a^b \frac{Q\hat{\mathbf{r}}}{4\pi\varepsilon_0 r^2} \cdot dr\,\hat{\mathbf{r}} = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{b} - \frac{1}{a}\right)$$

Is this positive or negative? Why?



$$C = \frac{Q}{|\Delta V|} = \frac{4\pi\varepsilon_0}{\left(a^{-1} - b^{-1}\right)}$$

For an isolated spherical conductor of radius *a:*

$$C = 4\pi\varepsilon_0 a$$

Capacitance of Earth

For an isolated spherical conductor of radius *a:*

$$C = 4\pi\varepsilon_0 a$$

$$\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{F/m} \qquad a = 6.4\times10^{6}\ \mathrm{m}$$

$$C = 7\times10^{-4}\ \mathrm{F} = 0.7\,\mathrm{mF}$$

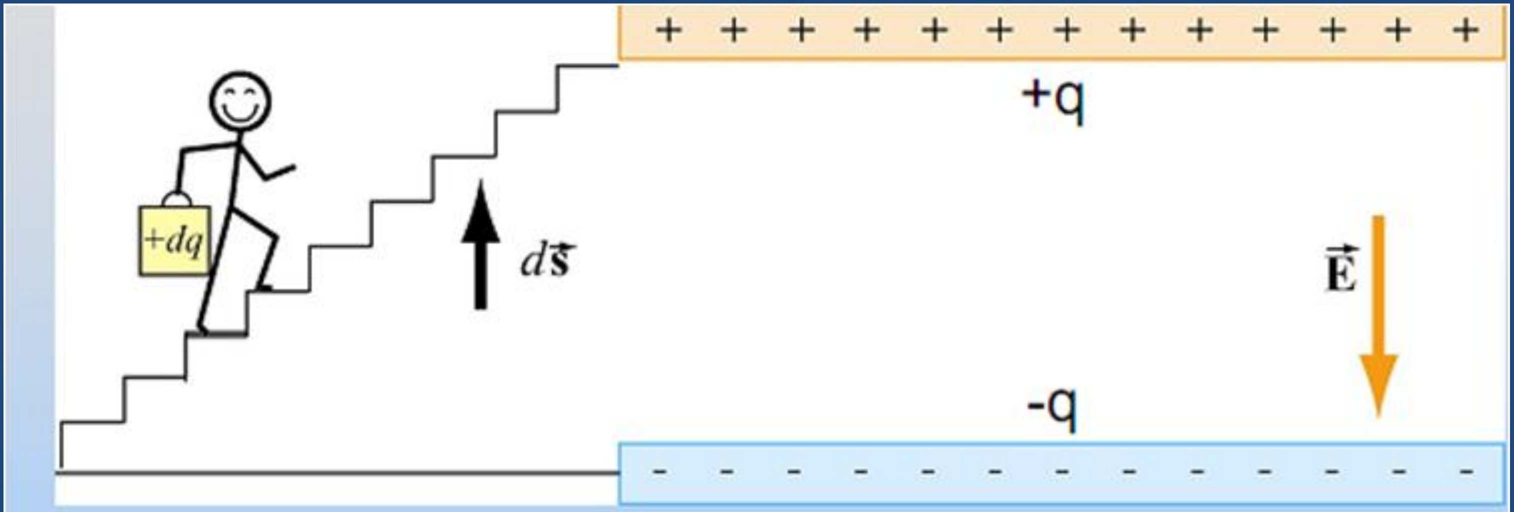
A Farad is REALLY BIG! We usually use pF (10^{-12}) or nF (10^{-9})

Farad Capacitor

How much charge?

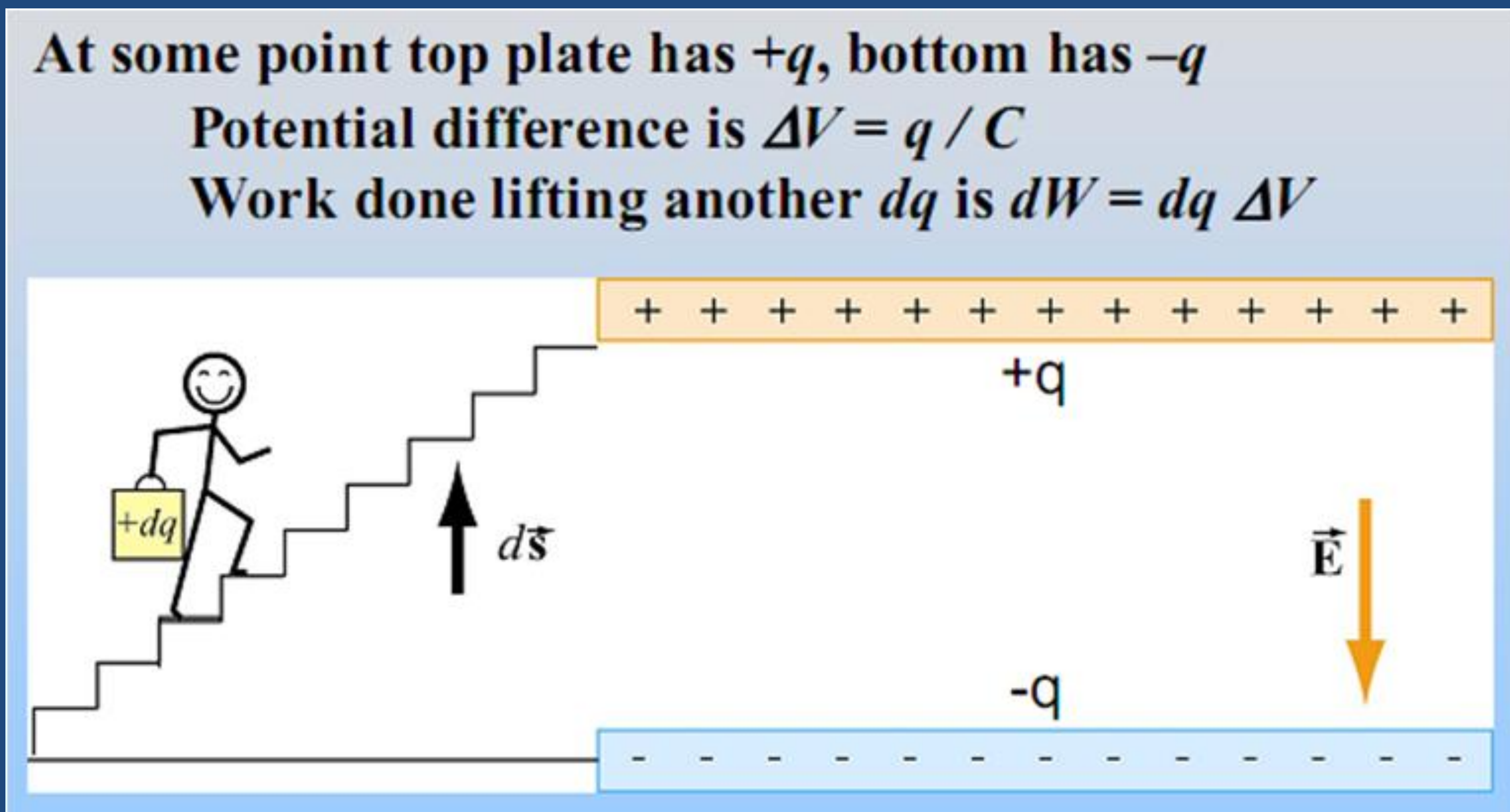
$$Q = C\left|\Delta V\right|$$
$$= (1\,\mathrm{F})(12\,\mathrm{V})$$
$$= 12\,\mathrm{C}$$

Energy To Charge Capacitor



1. **Capacitor starts uncharged.**
2. **Carry +*dq* from bottom to top.**
   Now top has charge q = +dq, bottom -dq
3. **Repeat**
4. **Finish when top has charge q = +Q, bottom -Q**

Work Done Charging Capacitor



The Work Done :

$$dW = dq\,\Delta V = dq\,\frac{q}{C} = \frac{1}{C}\,q\,dq$$

Total energy to charge to $q = Q$:

$$W = \int dW = \frac{1}{C}\int_0^Q q\,dq$$

$$= \frac{1}{C}\,\frac{Q^2}{2}$$

Energy Stored in capacitor

Energy Stored in Capacitor

Since $C = \frac{Q}{|\Delta V|}$

$$U = \frac{Q^2}{2C} = \frac{1}{2}Q|\Delta V| = \frac{1}{2}C|\Delta V|^2$$

Where is the energy stored???

Energy Stored in Capacitor

Parallel-plate capacitor: $C = \dfrac{\varepsilon_o A}{d}$ and $V = Ed$

$$U = \frac{1}{2}CV^2 = \frac{1}{2}\frac{\varepsilon_o A}{d}(Ed)^2 = \frac{\varepsilon_o E^2}{2} \times (Ad) = u_E \times (volume)$$

$$u_E = E \text{ field energy density} = \frac{\varepsilon_o E^2}{2}$$