Lecture 9

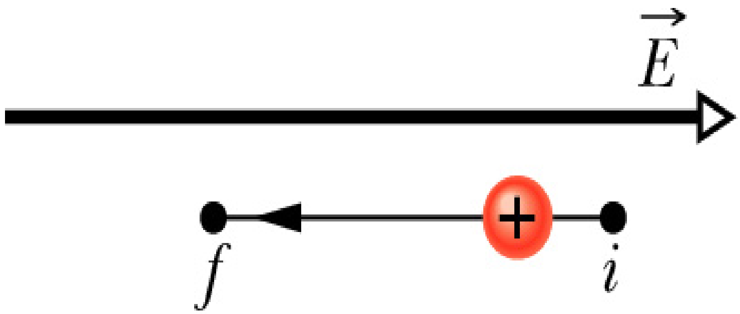
Chapter 25

Electric Potential

Problems

Electric Potential (41)

- Remember checkpoint #1 – A proton moves from point *i* to point *f* in a uniform *E* field.



$$W = \vec{F} \bullet \vec{d} = q\vec{E} \bullet \vec{d} = qEd\cos(180) = -qEd$$

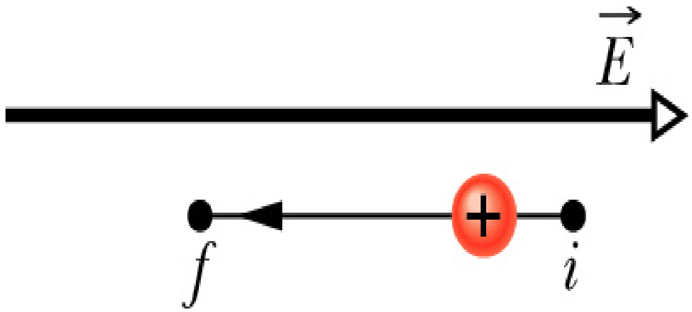
- Electric field does negative work so

$$\Delta U = -W = -(-qEd) = qEd$$

- Potential energy of proton increases

Electric Potential (42)

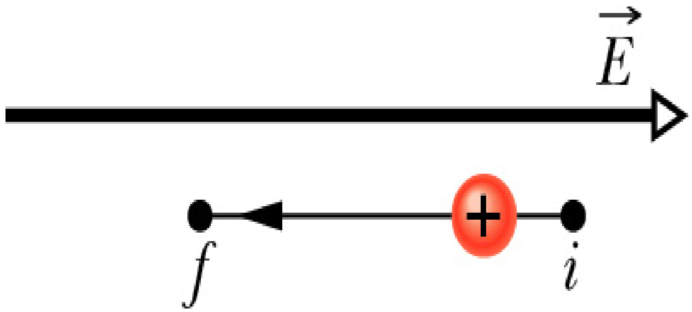
- Checkpoint #2 – Same diagram. proton from *i* to *f* in a field.



- A) Does our force do positive or negative work?
  - If we move a particle in an *E* field by applying a force we do work W_{app} and the *E* field does work *W* on it
  - Change in kinetic energy, *K*, is

$$\Delta K = K_f - K_i = W_{app} + W$$

Electric Potential (43)



- A) Does our force do positive negative work?
- If particle stationary before and move $\Delta K = 0$

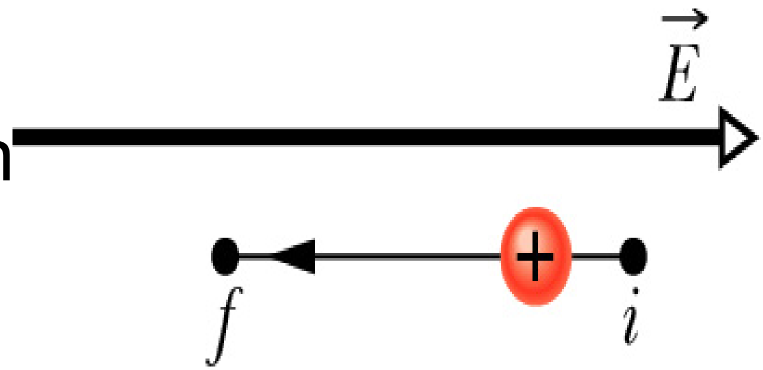
$$W_{app} = -W$$

- We want W_{app}
- From checkpoint #1 – Work done by *E* field was negative so our work must be

$$W_{app} = -(-qEd) = qEd$$ POSITIVE

Electric Potential (44)

- B) Does the proton move to point of higher or lower poten



$$\Delta V = -\frac{W}{q} = \frac{W_{app}}{q}$$

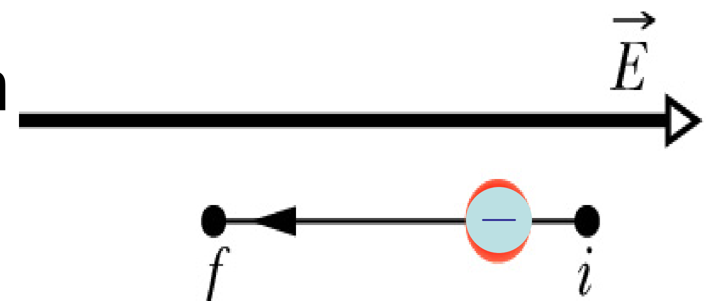
HIGHER

- Also, remember checkpoint #1 – potential energy, *U* , increased so *V* must be higher

$$\Delta V = \frac{\Delta U}{q}$$

Electric Potential (45)

- Replace proton with an electron



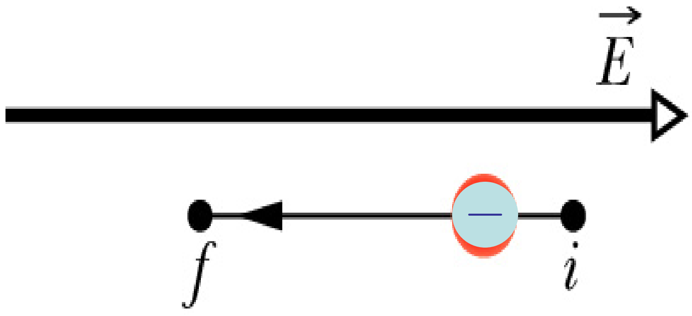
- A) Does our force do positive or negative work on the electron?

- Is it easy for us to move the electron from *i* to *f* ?
  - Remember *E* field lines point from positive to negative

EASY, so negative work

Electric Potential (46)

- Let's prove it



$$W_{app} = -W = -(\vec{F} \bullet \vec{d})$$

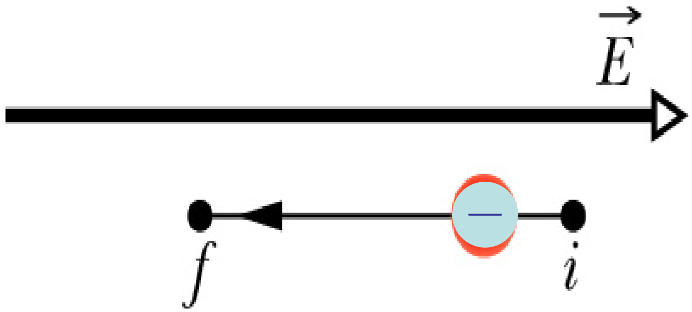
$$W_{app} = -qEd\cos(180) = qEd$$

- Why isn't this negative?
- Have to remember charge of particle. Electron is a $-q$ so

$$W_{app} = -qEd$$

Electric Potential (47)

- Does the electron's potential energy decrease or increase?



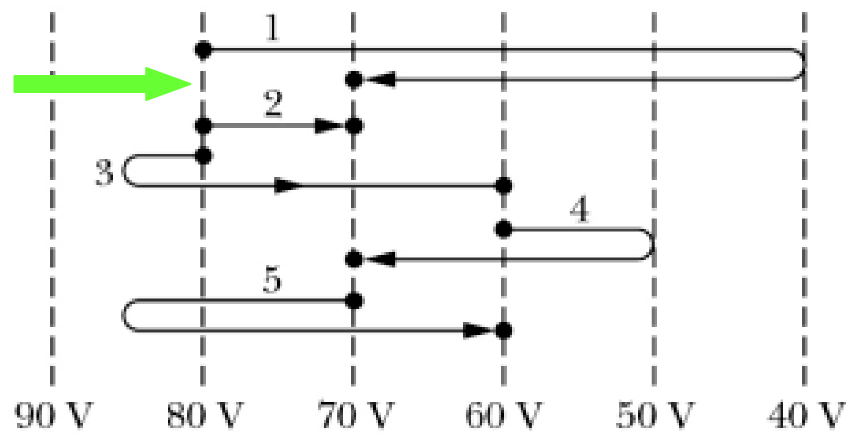
$$\Delta U = -W = W_{app}$$

$$W_{app} = -qEd$$

DECREASES

Electric Potential (48)

- Checkpoint #3 – An electron moves along 5 different paths between parallel equipotential surfaces
- a) What is the direction the *E* associated with surfaces?

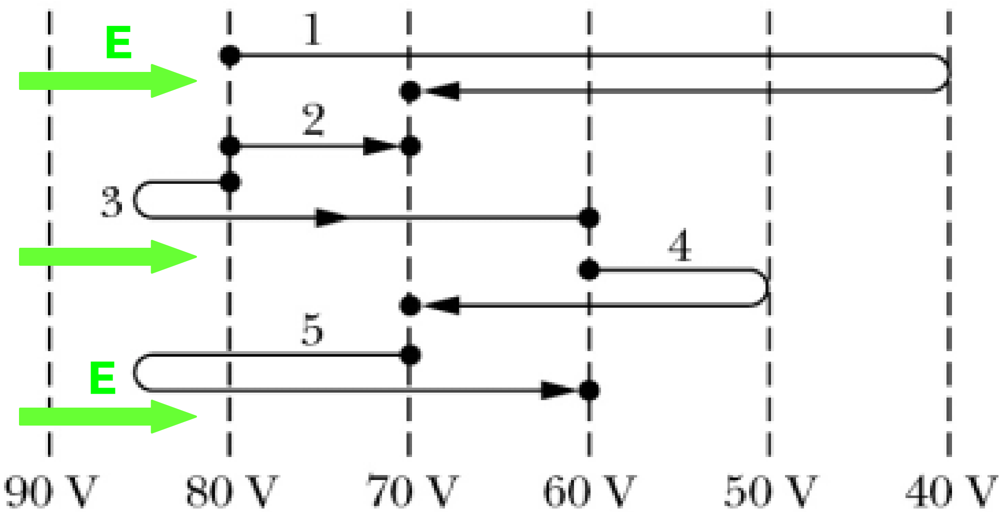


- Positive potentials which decrease going to the right

E is to the right

Electric Potential (49)

- Checkpoint #3 – b) For each path, is the work we do +, - or zero?



- Moving an electron
- What direction the electron go?

- Is it easy or hard for me to push it along the shown path?

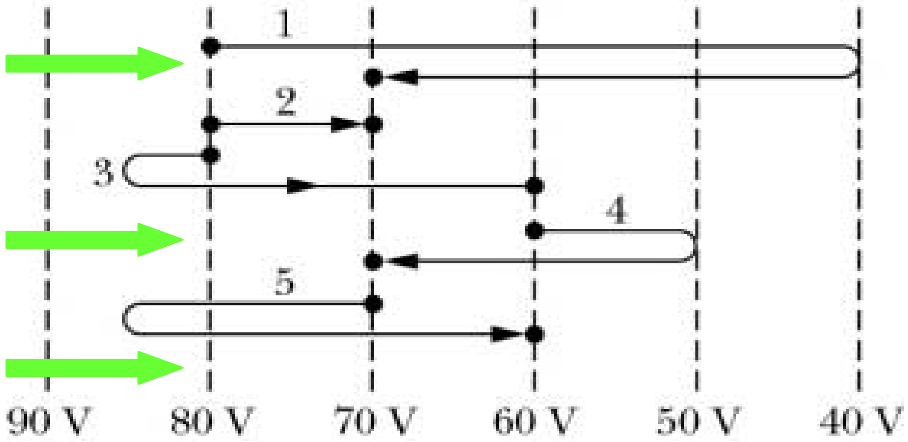
Paths 1,2,3 & 5 are +, 4 is -

Electric Potential (50)

- Checkpoint #3 – c) Rank the paths by amount of work we do (greatest first).

$$W_{app} = -W = q\Delta V$$

$$W_{app} = q(V_f - V_i)$$



- Electron gives $W_{Path1} = -q(70-80) = +10q$

3, then 1 & 2 & 5, last 4

Lecture 9

Chapter 26

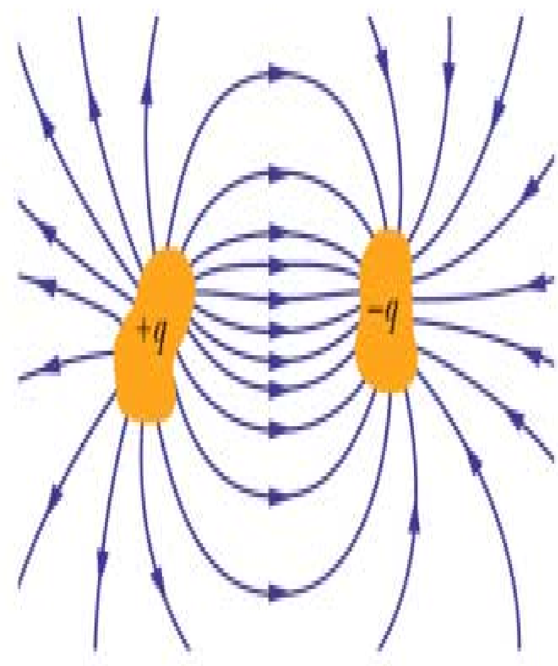
Capacitance

Capacitance (1)

- Capacitor – device used to store potential energy from an *E* field
- For 2 charged plates

$$V = Ed$$

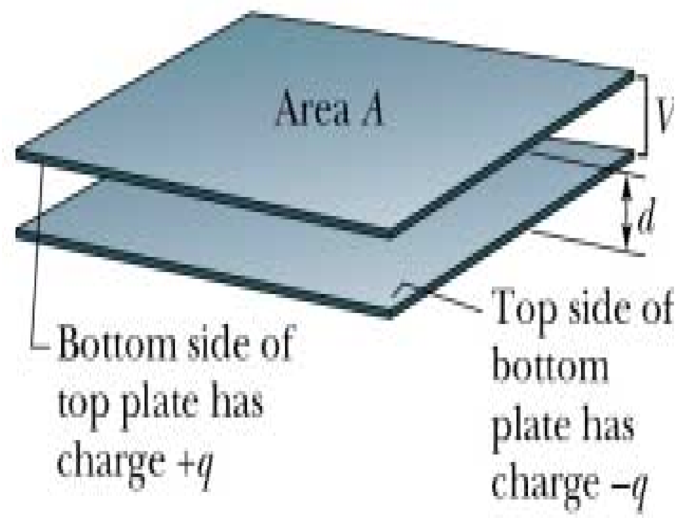
- A capacitor is formed from isolated conductors
- When capacitor is charged, plates have equal but opposite charges +*q* and -*q*



Capacitance (2)

- Capacitance is a proportionality constant relating q and V
  - q is absolute value of q on plates (it is not the total charge)
  - V is potential difference between plates

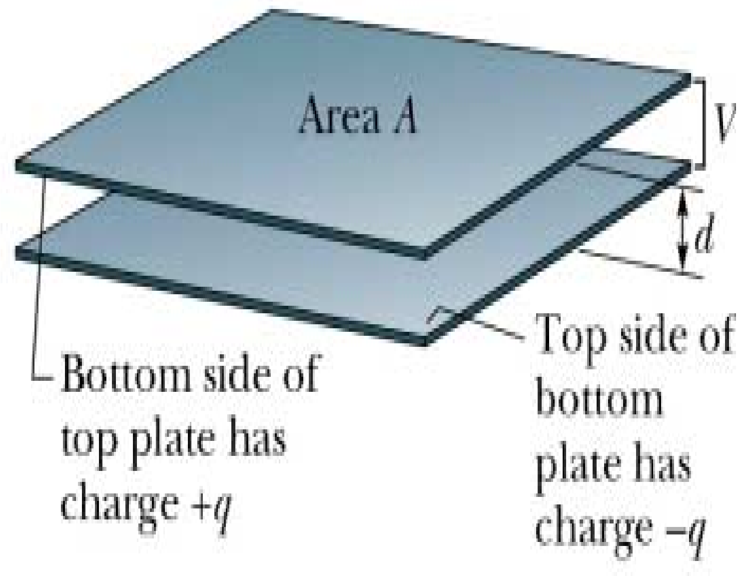
$$q = CV$$



- C depends only on geometry of plates, not on their q or V

Capacitance (3)

- Capacitance is measure of how much q is needed on plates to get V between them
  - Greater C, more q required

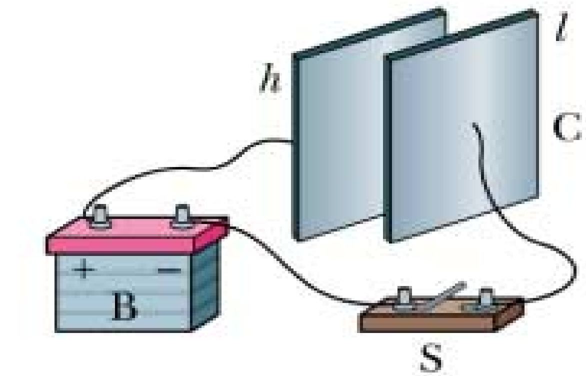


- SI unit is Farad

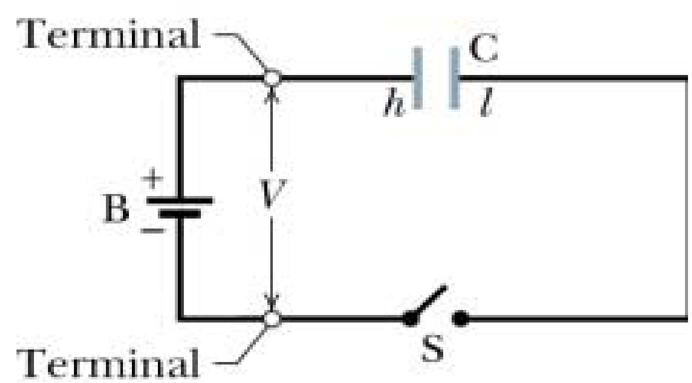
$$1F = 1C/V$$

Capacitance (4)

- Can charge a capacitor using a battery
- Battery – device maintains certain *V* between its terminals by internal electrochemical reactions
- Initially *V* on plates is 0
- Close switch, plates gradually charge up to *V* of battery through flow of electrons



(a)



(b)

Capacitance (5)

- Checkpoint #1 – Does the C of a capacitor increase, decrease or remain the same when
  - A) charge, q, on it is doubled
  - B) V across it is tripled

- Remember C of capacitor only depends on its geometry so C is the same for A and B

Capacitance (6)

- Calculate *C* of a capacitor from its geometry using steps:
- 1) Assume charge, *q*, on the plates
- 2) Find *E* between plates *q* and Gauss' law

$$\varepsilon_0 \oint \vec{E} \bullet d\vec{A} = q_{enc}$$

- 3) Find *V* from *E* using

$$\Delta V = -\int_i^f \vec{E} \bullet d\vec{s}$$

- 4) Get *C* using

$$C = \frac{q}{V}$$

Capacitance (7)

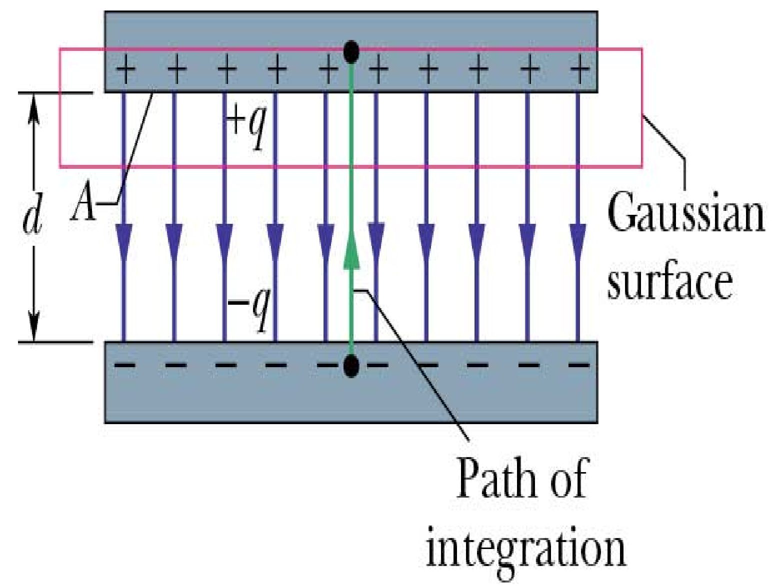
- Simplify Gauss' law

$$\varepsilon_0 \oint \vec{E} \bullet d\vec{A} = q_{enc}$$

- 1) Pick Gaussian surface to enclose charge on + plate and *E* and *dA* to be parallel

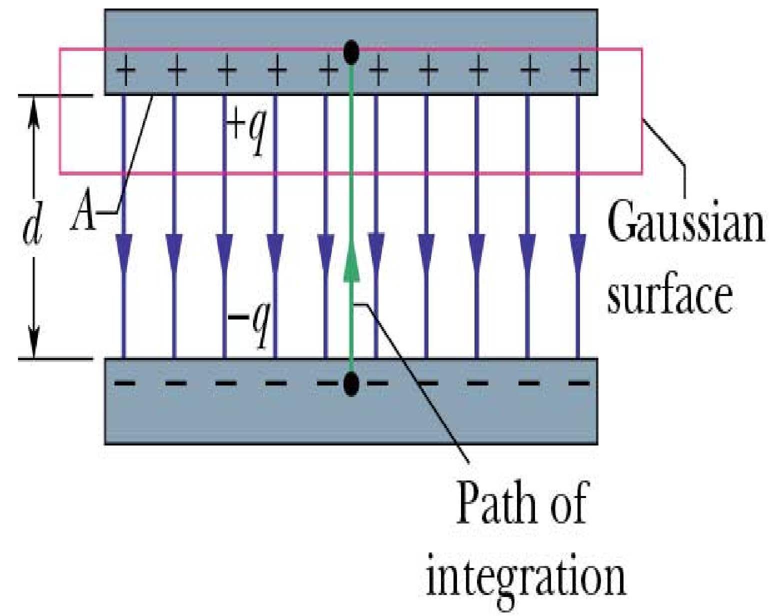
$$\vec{E} \bullet d\vec{A} = EA$$

$$q = \varepsilon_0 EA$$



Capacitance (8)

$$\Delta V = V_f - V_i = -\int_i^f \vec{E} \bullet d\vec{s}$$



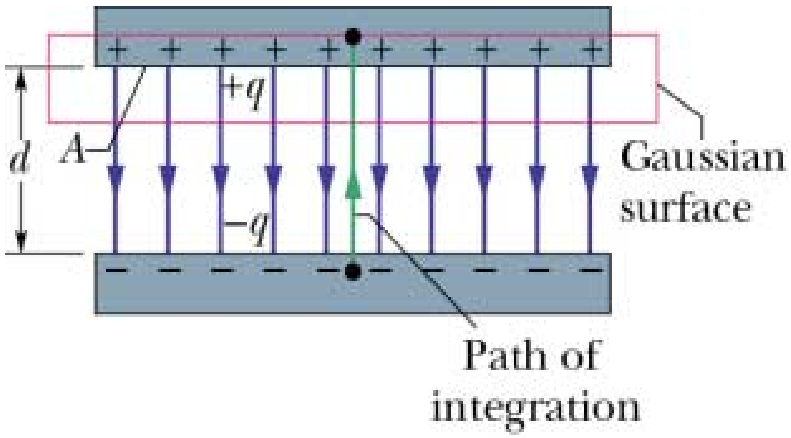
- 2) For *V* choose path follows *E* field line from – plate to + plate then *E* and *ds* are in opposite directions

$$\vec{E} \bullet d\vec{s} = -Eds$$

$$V = V_f - V_i = \int_-^+ Eds$$

Capacitance (9)

- Find *C* for parallel plate capacitor separated by *d*
  - E is constant between plates



$$V = \int_{-}^{+} E ds = E \int_{0}^{d} ds = Ed$$

  - *A* is area of plates

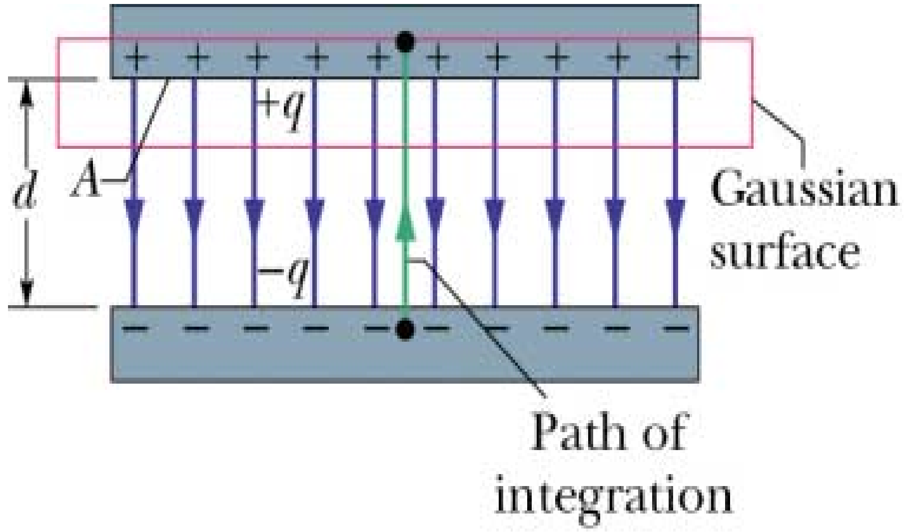
$$q = \varepsilon_0 EA$$

$$C = \frac{q}{V} = \frac{\varepsilon_0 EA}{Ed}$$

Capacitance (10)

- Parallel-plate capacitor

$$C = \frac{\varepsilon_0 A}{d}$$



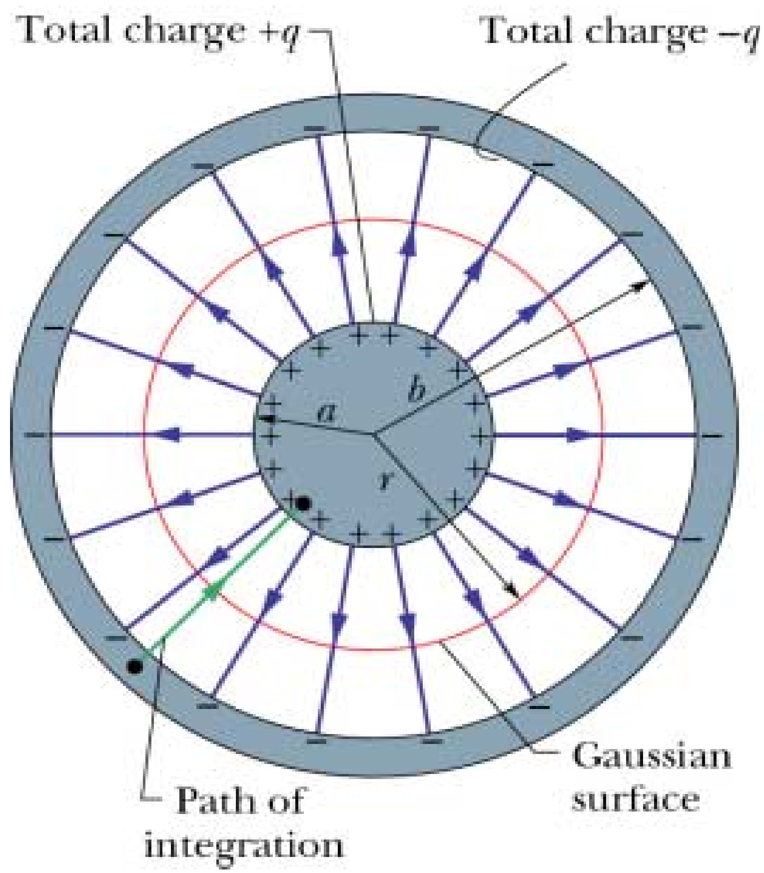
- Only depends on area *A* of plates and separation *d*
- *C* increases if increase *A* or decrease *d*

Capacitance (11)

- Spherical capacitor
- Gaussian sphere between shells, Gauss' law gives

$$q = \varepsilon_0 EA = \varepsilon_0 E(4\pi r^2)$$

$$E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2} = k\frac{q}{r^2}$$

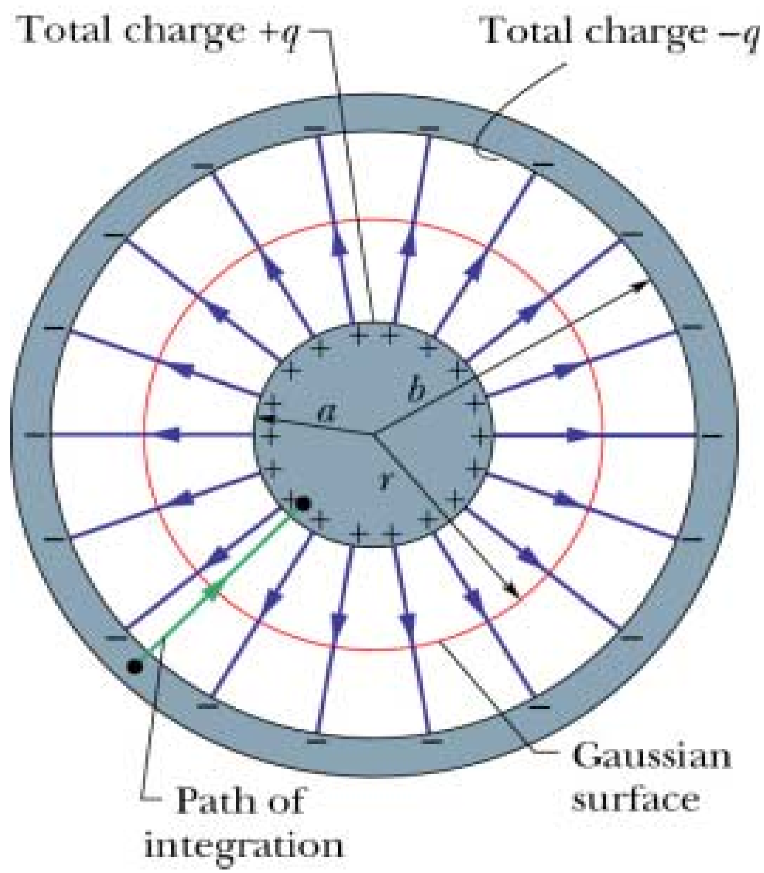


Capacitance (12)

- Substitute *E* into equation for *V* and replace *ds* with radial *dr*
  - – Integrate from – to + plate inward so

$$ds = -dr$$

$$V = \int_{-}^{+} E\,ds = -\frac{q}{4\pi\varepsilon_0}\int_b^a \frac{dr}{r^2}$$



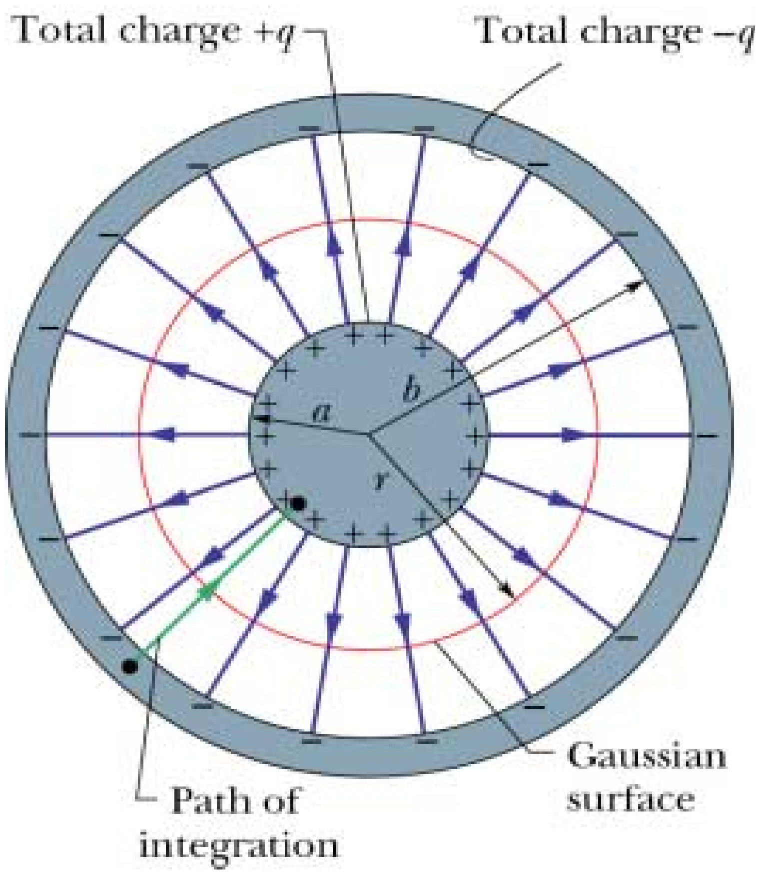
Capacitance (13)

- Solve for *V*

$$V = -\frac{q}{4\pi\varepsilon_0}\int_b^a \frac{dr}{r^2} = \frac{q}{4\pi\varepsilon_0}\left(\frac{1}{a}-\frac{1}{b}\right)$$

- Substitute into

$$C = \frac{q}{V} = \frac{q(4\pi\varepsilon_0)}{q\left(\frac{1}{a}-\frac{1}{b}\right)} = 4\pi\varepsilon_0\frac{ab}{b-a}$$



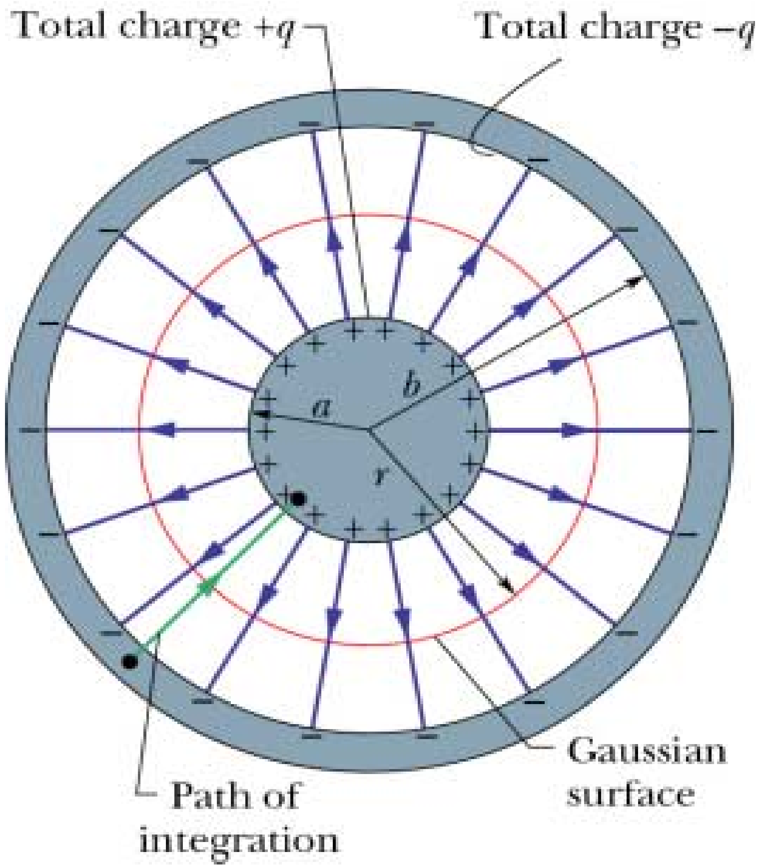
Capacitance (14)

- For spherical capacitor

$$C = 4\pi\varepsilon_0 \frac{ab}{b-a}$$

- Rewrite

$$C = 4\pi\varepsilon_0 \frac{a}{\left(1-\frac{a}{b}\right)}$$



Capacitance (15)

- Capacitance of isolated sphere
- Outer shell moves to ∞ then b→∞ and let radius a = R

$$C = 4\pi\varepsilon_0 R$$