Announcement

EXAM I is MONDAY

8:00-9:30 PM –MONDAY SEPT. 24 in STEW 183

Material: Through Chapter 16 in the book.

8:00-10:00 PM -THURS SEP 16, Elliott Hall

Exam 1 - Monday, September 24, 8:00-9:30 PM in STEW 183

1. Absences must be excused in advance by filing an Absentee Report form in Rm 144 PHYS. See the syllabus on Blackboard Learn (BBL) at mycourses.purdue.edu . For emergencies, contact Prof. Carlson by email as soon as possible, ewcarlson@purdue.edu .

2. Students approved for separate test environments must contact Prof. Carlson as soon as possible for further instructions. ewcarlson@purdue.edu

3. You may NOT bring equations sheets, books, etc. It is a closed book exam. Necessary equations and constants will be provided. DO bring pencils and a calculator which cannot access the internet. Graphing Calculator is okay.

4. You must show your **Purdue Student ID card** when turning in your completed exam to your recitation TA.

5. The exam covers all assigned material in this course through Chapter 16 in the book, including lectures, labs, recitations, and homework.

8:00-10:00 PM -THURS SEP 16, Elliott Hall

Exam 1 - Thursday September 15, 8:00-10:00 PM PHYS Room 112

6. Mostly multiple choice questions + 1 hand graded question

7. Practice Exam + Solution coming soon to BBL

8. Exam scores will be uploaded to BBL

9. STUDY HARD AND GOOD LUCK!

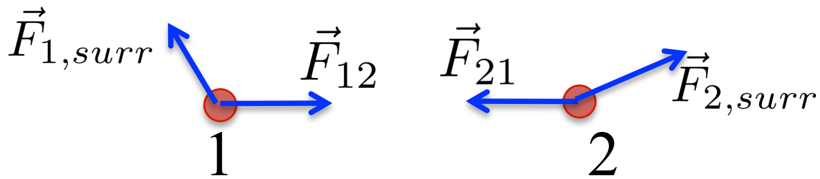
Last Time

- Review of potential energy
- Electric potential energy

Today

- Electric Potential (Voltage relative to infinite separation)
- Potential Difference and Electric Field
- Path Independence of Potential Difference

Last Time: Potential Energy



$$\Delta(E_1 + E_2) = \Delta K = W_{surr} + W_{internal}$$

Assuming rest mass does not change

$$\Delta K + \Delta U = W_{surr}$$

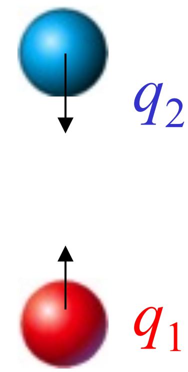
MULTIPARTICLE
ENERGY PRINCIPLE

$$\Rightarrow \boxed{\Delta U \equiv -W_{internal}}$$

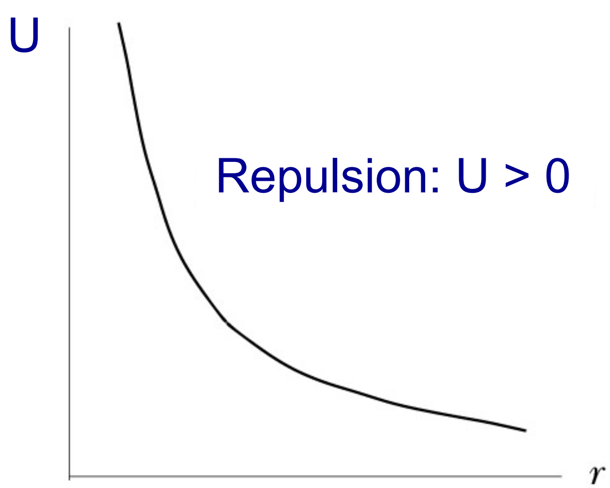
- Potential Energy = Interaction Energy
- Potential Energy **does not exist** for a single particle

Last Time: Potential Energy of Two Charges

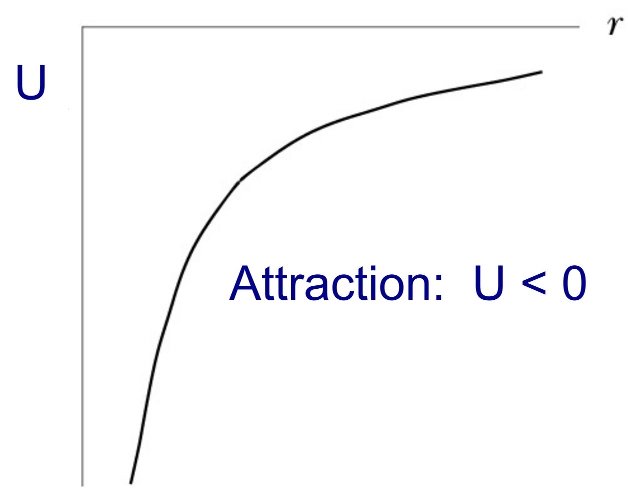
$$U = \frac{1}{4\pi\epsilon_o}\frac{q_1 q_1}{r_{12}}$$



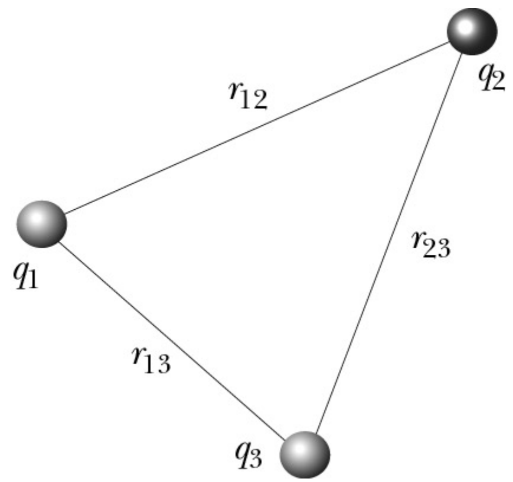
Like Charges:



Opposite Charges:



Potential Energy of Three Charges



Interaction between q_1 and q_2
is independent of q_3

There are three interacting pairs:

$U_{12}\,,\ U_{23},\ U_{31}$ Add them to get total

$$U = U_{12} + U_{23} + U_{31} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{12}} + \frac{1}{4\pi\varepsilon_0}\frac{q_2 q_3}{r_{23}} + \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{r_{13}}$$

THREE PARTICLES

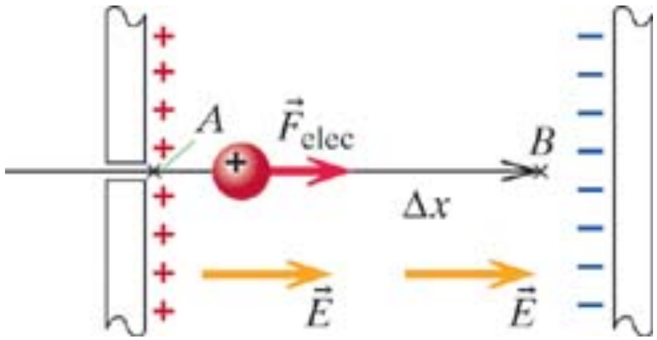
More than three particles?

$$U = \sum_{i<j} U_{ij} = \sum_{i<j} \frac{1}{4\pi\epsilon_o}\frac{q_i q_j}{r_{ij}}$$

MANY PARTICLES

Example

$$\vec{F} = q\vec{E} \qquad \Delta U = -W_{internal} \qquad W = \int \vec{F} \cdot d\vec{r}$$



The System = 2 charged plates + proton

$$\Delta x = x_B - x_A = 1 \text{ cm}$$

$|E| = 1 \text{ N/C}$ Uniform Electric Field

$$q = 1.6 \times 10^{-19}\text{C}$$

QUESTION: As proton moves from A to B, what is the change in potential energy of The System?

ANSWER:

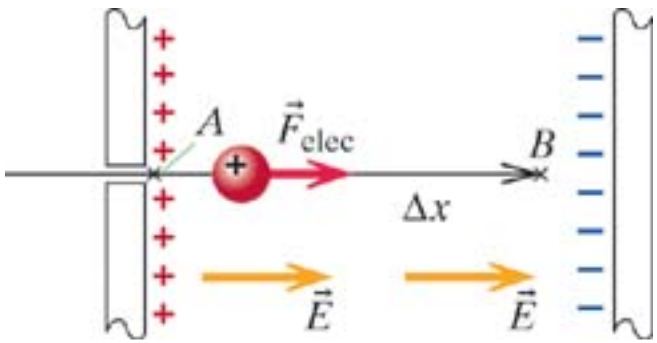
$$\Delta U = -W_{internal}$$

$$= -\int q\vec{E} \cdot d\vec{r} = -q \int E_x dx$$

$\boxed{\Delta U = -qE\Delta x}$ In a uniform field

Example

$$\vec{F} = q\vec{E} \qquad \Delta U = -W_{internal} \qquad W = \int \vec{F} \cdot d\vec{r}$$



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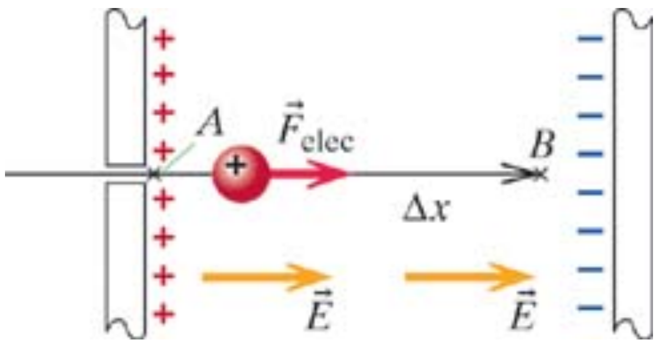
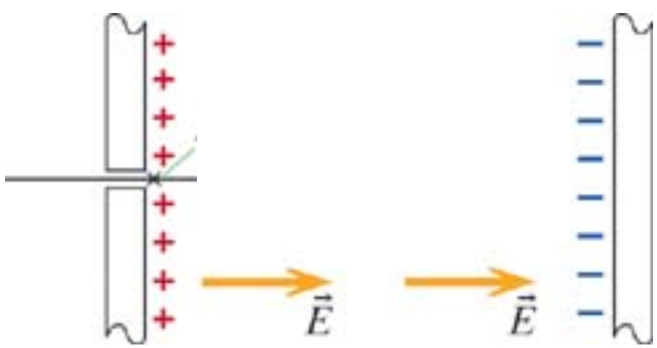
$$= -\int q\vec{E} \cdot d\vec{r} = -q\int E_x dx$$

$$\boxed{\Delta U = -qE\Delta x} = -1.6 \times 10^{-19} J$$

Electric Potential



With the "test charge" (proton)
in the capacitor, there is potential energy
between the proton and capacitor.



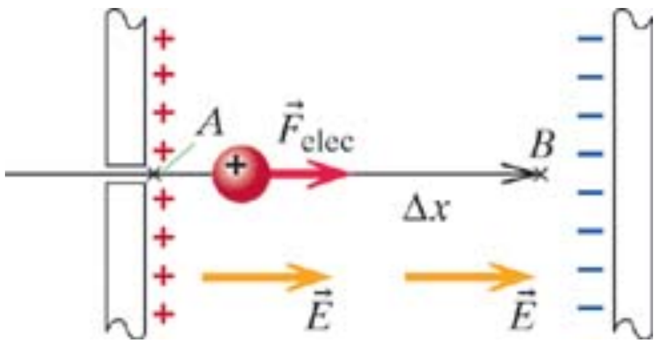
Remove the "test charge" (proton)

→ E-field due to plates is still present

ELECTRIC POTENTIAL
is "the potential" to have potential energy
if a test charge enters the system

Electric Potential

$\Delta U = -qE\Delta x$ (Uniform field) $\Delta U = -1.6 \times 10^{-19} J$



The System = 2 charged plates + proton

$\Delta x = x_B - x_A = 1 \text{ cm}$

$|E| = 1 \text{ N/C}$ Uniform Electric Field

$q = 1.6 \times 10^{-19}\text{C}$

Test Charge

$$\Delta U = q\underbrace{(-E\Delta x)}$$

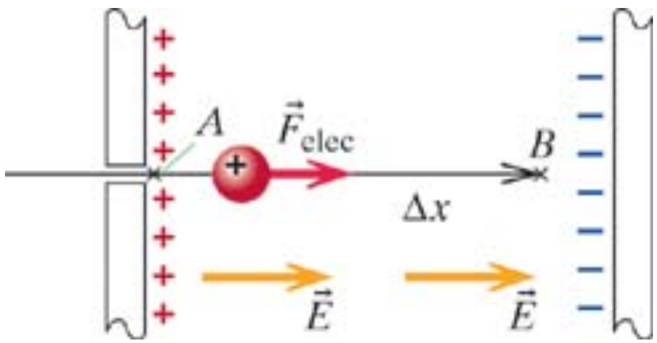
This part exists independent of the test charge.
It is "the potential" to have a potential energy difference

$$\Delta U \equiv q\underbrace{\Delta V}$$

This part is "The Potential Difference"

Electric Potential

$\Delta U = -qE\Delta x$ (Uniform field) $\Delta U = -1.6 \times 10^{-19} J$



The System = 2 charged plates + proton

$\Delta x = x_B - x_A = 1 \text{ cm}$

$|E| = 1 \text{ N/C}$ Uniform Electric Field

$q = 1.6 \times 10^{-19} \text{C}$

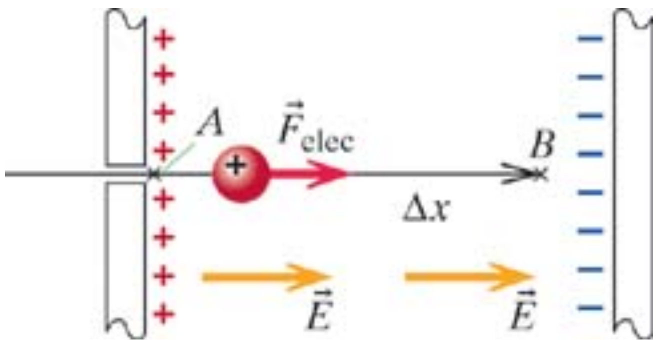
$$\Delta U = -qE\Delta x \equiv q\Delta V$$

V has units of "Volts" $V = \left[\text{Volt}\right] = \left[\frac{\text{Joule}}{\text{Coulomb}}\right]$

Units of Electric Field $|E| = \left[\frac{\text{Newton}}{\text{Coulomb}}\right] = \left[\frac{\text{Volt}}{\text{Meter}}\right]$

Electric Potential

$\Delta U = -qE\Delta x$ (Uniform field) $\Delta U = -1.6 \times 10^{-19} J$



The System = 2 charged plates + proton

$\Delta x = x_B - x_A = 1 \text{ cm}$

$|E| = 1 \text{ N/C}$ Uniform Electric Field

$q = 1.6 \times 10^{-19} \text{C}$

$$\Delta U = -qE\Delta x \equiv q\Delta V$$

In this example, the change in Electric Potential is:

$$\Delta V \equiv V_f - V_i = V_B - V_A = \frac{\Delta U}{q}$$

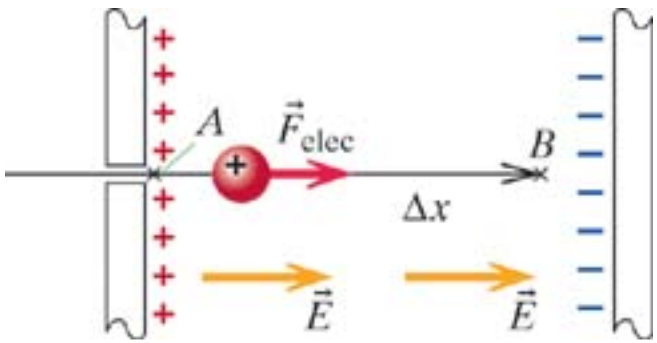
$$= \frac{-1.6 \times 10^{-19} J}{1.6 \times 10^{-19} C} = -1 \text{ Volt}$$

Which is larger, V_A or V_B?

Positive charges move toward **lower voltages**, like water running down a hill.

What's an eV?

$\Delta U = -qE\Delta x$ (Uniform field) $\Delta U = -1.6 \times 10^{-19} J$



The System = 2 charged plates + proton

$\Delta x = x_B - x_A = 1 \text{ cm}$

$|E| = 1 \text{ N/C}$ Uniform Electric Field

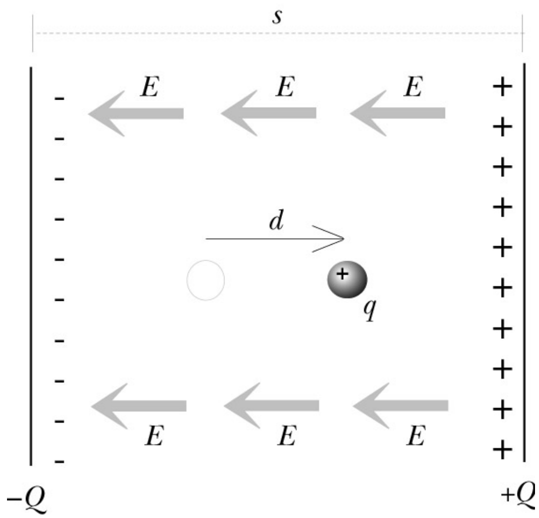
$q = 1.6 \times 10^{-19}\text{C} = -e$

$$\Delta U = -qE\Delta x \equiv q\Delta V$$

An electron-Volt (eV) is the energy required to move q=1e through 1V.

The proton lost $\boxed{1.6 \times 10^{-19}\text{J} = 1\text{eV}}$ of energy in this example.

iClicker



A system consists of a proton inside of a capacitor. The proton moves from left to right as shown at a constant speed due to the action of an external agent.

Which of the following statements is true?

A) The system's potential energy is unchanged and the external agent does no work on the system.

B) The system's potential energy decreases and the external agent does work $W > 0$ on the system.

C) The system's potential energy decreases and the external agent does work $W < 0$ on the system.

D) The system's potential energy increases and the external agent does work $W > 0$ on the system.

Potential Difference: The Full Story

Uniform E-Field, E||x: $\Delta U = -qE\Delta x \equiv q\Delta V$

$\Rightarrow \Delta V = -E\Delta x$ for uniform E||x

For a uniform E-field pointing in any direction:

$$\Delta V = -(E_x\Delta x + E_y\Delta y + E_z\Delta z) \equiv -\vec{E}\cdot\Delta\vec{x}$$

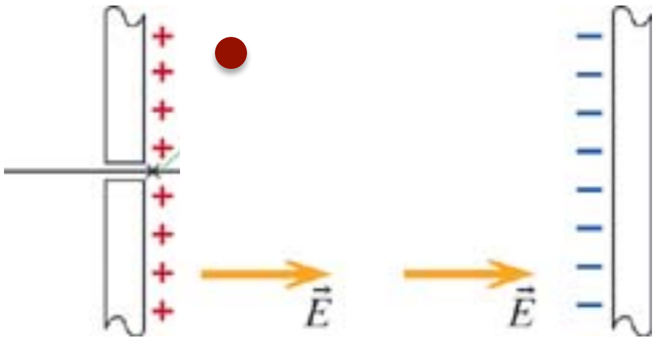
If E is *not* uniform, but varies in space:

$$\boxed{\Delta V = -\int_i^f \vec{E}\cdot d\vec{l}}$$

POTENTIAL DIFFERENCE
IN NONUNIFORM E-FIELD

Potential Difference: Path Independence

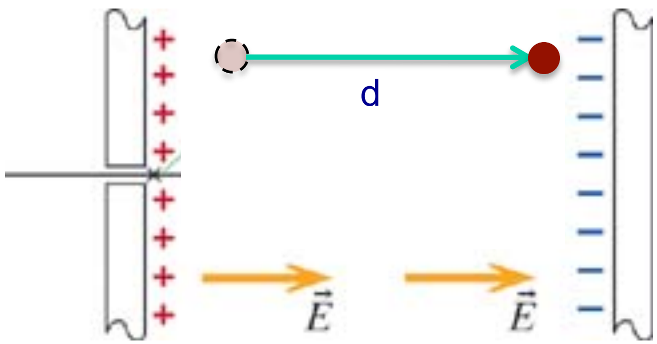
Uniform E-Field: $$\Delta V = -(E_x \Delta x + E_y \Delta y + E_z \Delta z)$$



Uniform E-Field
in a Capacitor

Potential Difference: Path Independence

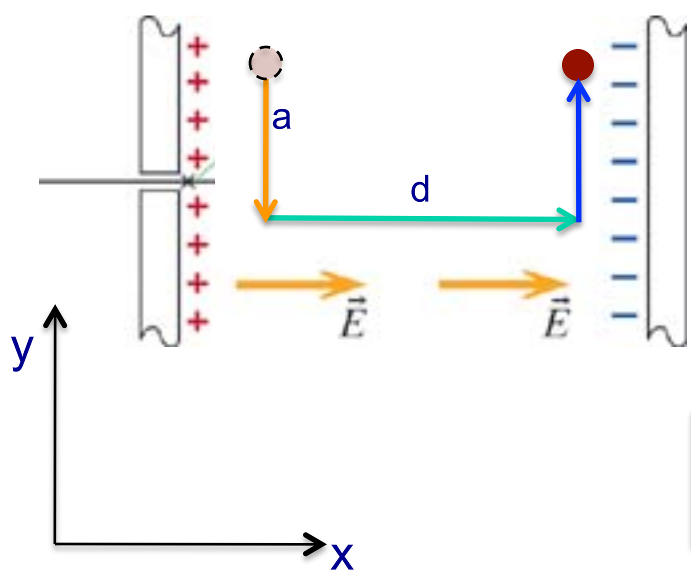
Uniform E-Field: $\Delta V = -(E_x \Delta x + E_y \Delta y + E_z \Delta z)$



Uniform E-Field
in a Capacitor

Particle moves a distance d to the right.

$$\Delta V = -E_x d$$



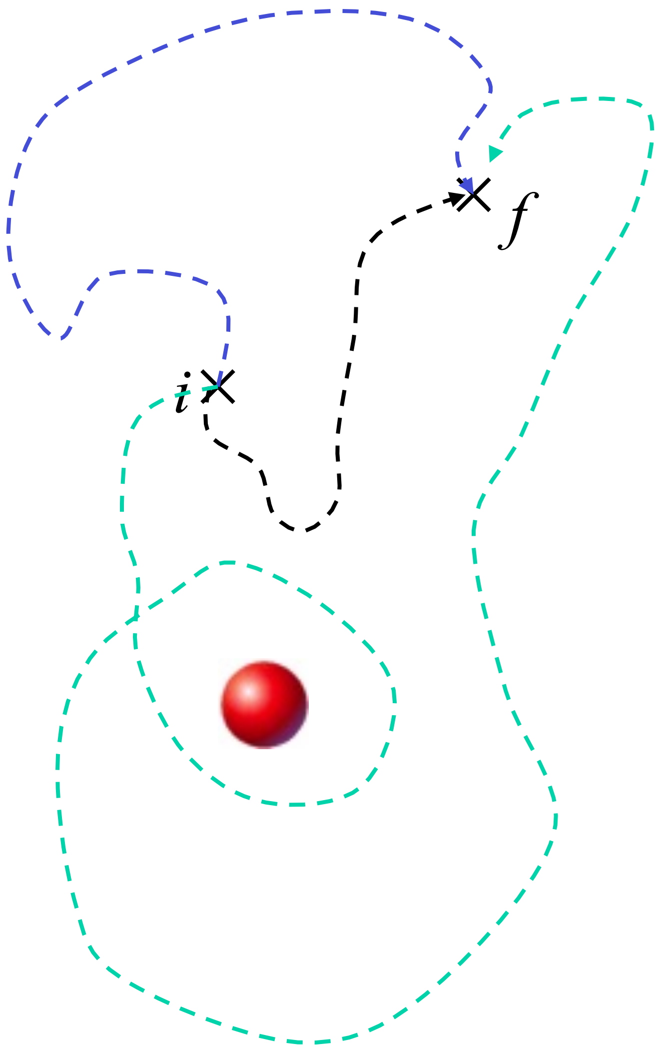
Part 1: $\Delta V = -E_y \Delta y = E_y a \quad = 0$

Part 2: $\Delta V = -E_x d$

Part 3: $\Delta V = -E_y \Delta y = -E_y a = 0$

Total ΔV is Independent of the Path taken

Potential Difference: Path Independence



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

$$\Delta V = V_f - V_i \qquad V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

Path independence principle:

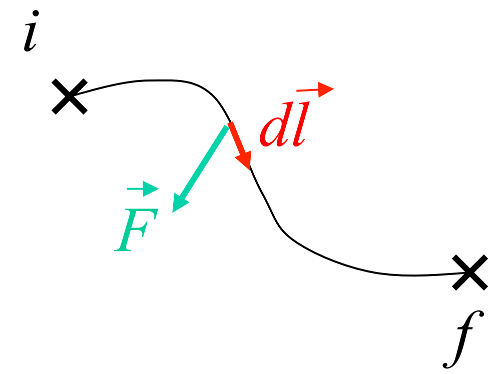
ΔV between two points does not depend on integration path

Today

- Electric Potential (Voltage relative to infinite separation)
- Potential Difference and Electric Field
- Path Independence of Potential Difference

Potential Difference and Electric Field

$$\Delta U = -W_{\text{int}} = -\int_i^f \vec{F} \bullet d\vec{l}$$



$$\Delta\left(\frac{U}{q}\right) = -\int_i^f \left(\frac{\vec{F}}{q}\right) \bullet d\vec{l}$$

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

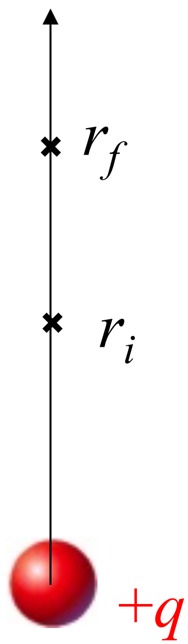
$$\boxed{V_f - V_i = -\int_i^f \vec{E} \bullet d\vec{l}}$$

For very short path: $\Delta V = -\vec{E} \bullet \Delta\vec{l}$

Example: $E = 3 \cdot 10^6$ N/C, $\Delta l = 1$ mm:

$$\Delta V = -\left(3 \times 10^6 \text{ N/C}\right)\left(0.001 \text{ m}\right) = -3000 \text{ V}$$

Example: Different Paths near Point Charge



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

1. Along straight radial path:

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

$$\Delta V = -\int_{r_i}^{r_f} \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\hat{r} \bullet \hat{r}\, dr$$

Origin at +q

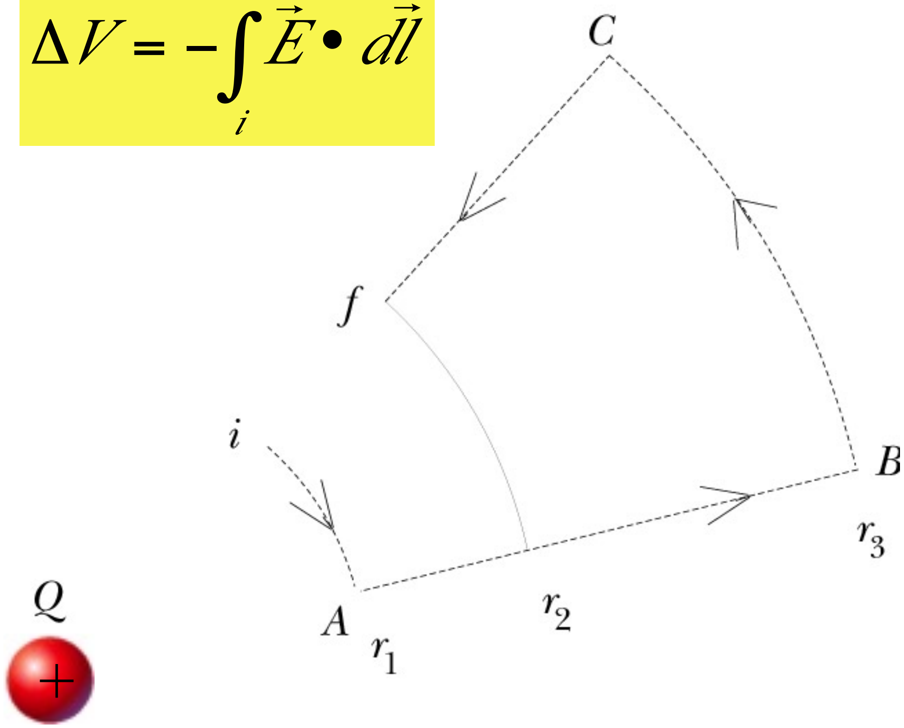
$$\Delta V = -\frac{1}{4\pi\varepsilon_0} q \int_{r_i}^{r_f} \frac{1}{r^2} dr$$

$$\Delta V = -\frac{1}{4\pi\varepsilon_0} q \left[-\frac{1}{r}\right]_{r_i}^{r_f}$$

$$\boxed{\Delta V = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_f} - \frac{1}{r_i}\right] = V_f - V_i}$$

Example: Different Paths near Point Charge

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



2. Special case

iA: $\Delta V_{iA} = 0$

AB: $\Delta V_{AB} = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_3} - \frac{1}{r_1} \right]$

BC: $\Delta V_{BC} = 0$

Cf: $\Delta V_{Cf} = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_2} - \frac{1}{r_3} \right]$

$$\Delta V_{iABCf} = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_3} - \frac{1}{r_1} + \frac{1}{r_2} - \frac{1}{r_3} \right] = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_2} - \frac{1}{r_1} \right] = \Delta V_{if}$$

Example: Different Paths near Point Charge

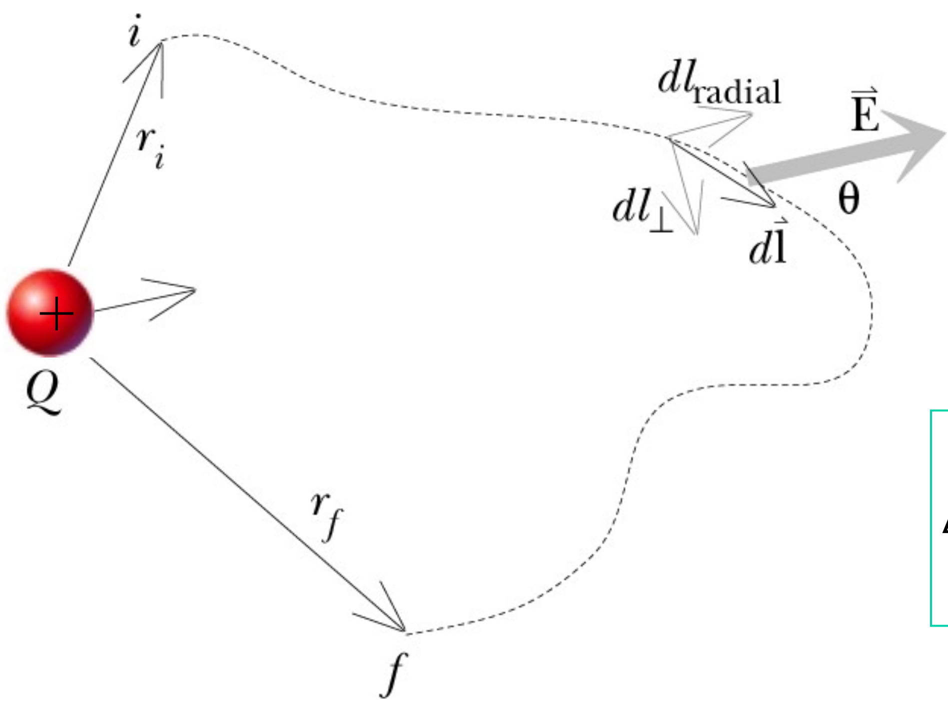
$$\Delta V = -\int_i^f \vec{E} \bullet d\vec{l}$$

3. Arbitrary path

$$\vec{E} \bullet d\vec{l} = E\,dl\cos\theta$$

$$\vec{E} \bullet d\vec{l} = E\,dl_{radial}$$

$$\Delta V = -\int_i^f E\,dl_{radial}$$



$$\Delta V = \frac{1}{4\pi\varepsilon_0} q \left[\frac{1}{r_f} - \frac{1}{r_i} \right] = V_f - V_i$$