PHYS 1441 – Section 002
Lecture #8

Wednesday, Sept. 26, 2018

Dr. Jaehoon Yu

- Chapter 23 Electric Potential
  - Electric Potential due to Point Charges
  - Shape of the Electric Potential
  - V due to Charge Distributions
  - Equi-potential Lines and Surfaces
  - Electric Potential Due to Electric Dipole
  - Electrostatic Potential Energy

Announcements

- Quiz #2
  - Coming Monday, Oct. 1, at the beginning of the class
  - Covers CH22.1 through what we cover in class today (CH23.8?)
  - Bring your calculator but DO NOT input formula into it!
    - Cell phones or any types of computers cannot replace a calculator!
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of **handwritten** formulae and values of constants for the quiz
  - No derivations, word definitions or solutions of any problems!
  - No additional formulae or values of constants will be provided!
- Mid-term results
  - Class average: 59.3/98
    - Equivalent to 60/100
  - Top score: 96/98
- Colloquium today
  - Dr. Amir Shamoradi of UTA Physics

Physic Department
The University of Texas at Arlington
<u>COLLOQUIUM</u>

Uncertainty Quantification in Scientific Inference

Amir Shahmoradi
The University of Texas at Arlington

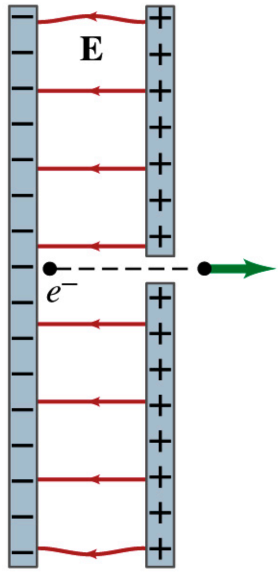
Wednesday September 26, 2018
4:00 p.m. Room 100 Science Hall

Abstract

For centuries, scientific methodology has been founded on the two classical pillars of science: observation and theory. Over the past 50 years, however, technological breakthroughs have given rise to computational and data sciences as the third pillar of science: a new means of acquiring knowledge through predictive computing, computer simulations, and data-driven discovery. In this pedagogical talk, I will review the connections between the three cornerstones of quantitative science: the collection of experimental data, the formation of hypotheses/theories, and the use of computer simulations, mathematical modeling, and data mining techniques to make the most accurate predictions and decisions. Examples will focus on the topics and projects that my computational data science lab is currently undertaking and involved.

Refreshments will be served at 3:30 in 106 SH

Reminder: Special Project #3



- **Particle Accelerator**. A charged particle of mass **M** with charge **-Q** is accelerated in the uniform field **E** between two parallel charged plates whose separation is **D** as shown in the figure on the right. The charged particle is accelerated from an initial speed $\mathbf{v_0}$ near the negative plate and passes through a tiny hole in the positive plate.
  – Derive the formula for the electric field E to accelerate the charged particle to a fraction f of the speed of light c. Express E in terms of **M, Q, D,** f**, c** and $\mathbf{v_0}$.
  – (a) Using the Coulomb force and kinematic equations. (8 points)
  – (b) Using the work-kinetic energy theorem. (8 points)
  – (c) Using the formula above, evaluate the strength of the electric field E to accelerate an electron from 0.1% of the speed of light to 90% of the speed of light. You need to look up and write down the relevant constants, such as mass of the electron, charge of the electron and the speed of light. (5 points)
- Must be handwritten and not copied from anyone else!
- Due beginning of the class Monday, Oct. 1

Electric Potential and Electric Field

- The effect of the charge distribution can be described in terms of electric field or electric potential.
  - What kind of quantities are the electric field and the electric potential?
    - Electric Field: Vector
    - Electric Potential: Scalar
  - Since electric potential is a scalar quantity, it is often easier to handle.
- Well other than the above, how are these two quantities related?

Electric Potential and Electric Field

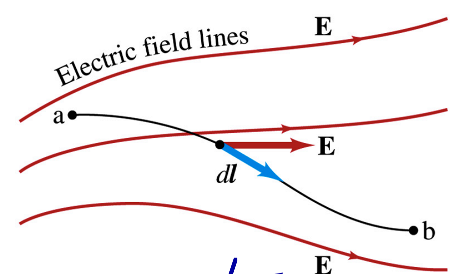
- **Potential energy** change is expressed in terms of a conservative force (point ***a*** at the higher potential)

$$U_b - U_a = -\vec{F}\cdot\vec{D} = -W_C$$

- For the electrical case, we are more interested in the **potential** difference:

$$V_{ba} = V_b - V_a = \frac{U_b - U_a}{q} = -\frac{\vec{F}}{q}\cdot\vec{D} = -\vec{E}\cdot\vec{D} = -ED\cos\theta$$

  - This formula can be used to determine V_{ba} when the electric field is given.



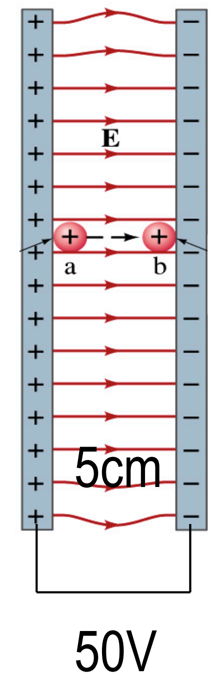
- When the field is uniform

$$V_b - V_a = -\vec{E}\cdot\vec{D} = -ED\cos\theta = -Ed \quad \text{so} \quad E = -V_{ba}/d$$

What does "-"sign mean? The direction of E is along that of decreasing potential.

Unit of the electric field in terms of potential? V/m Can you derive this from N/C?

Example



Uniform electric field obtained from voltage: Two parallel plates are charged to a voltage of 50V. If the separation between the plates is 5.0cm, calculate the magnitude of the electric field between them, ignoring any fringe effect.

What is the relationship between electric field and the potential for a uniform field?

$$\boxed{V = Ed}$$

Solving for E

$$E = \frac{V}{d} = \frac{50V}{5.0cm} = \frac{50V}{5\times 10^{-2}m} = 1000V/m$$

Which direction is the field? Direction of decreasing potential!

Electric Potential due to Point Charges

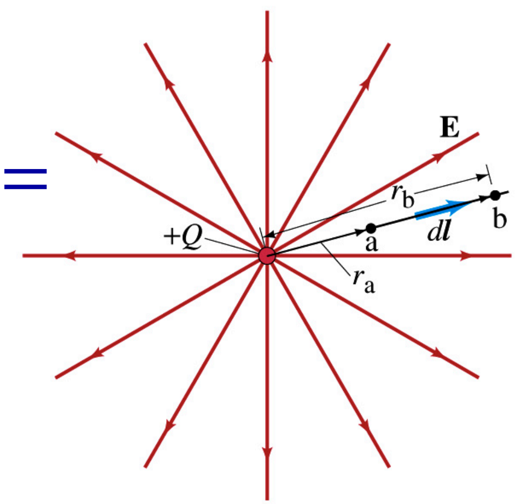
- What is the electric field by a single point charge Q at a distance r?

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

- Electric potential due to the field E for moving from point r_a to r_b in radial direction away from the charge Q is

$$V_b - V_a = -\int_{r_a}^{r_b} \vec{E}\cdot d\vec{l} = -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{\hat{r}}{r^2}\cdot\hat{r}\,dr =$$

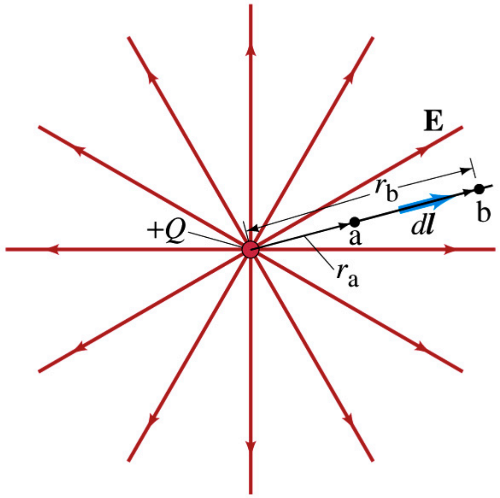
$$= -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{1}{r^2}dr = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_b} - \frac{1}{r_a}\right)$$



Electric Potential due to Point Charges

- Since only the differences in potential have physical meaning, we can choose $V_b = 0$ at $r_b = \infty$.
- The electrical potential V at a distance r from a single point charge Q is

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$



- So the absolute potential by a single point charge can be thought of **<u>the potential difference by a single point charge between r and infinity</u>**

Properties of the Electric Potential

- What are the differences between the electric potential and the electric field?
  - Electric potential

    $$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

    - Electric potential energy per unit charge
    - Inversely proportional to the distance
    - Simply add the potential by each of the source charges to obtain the total potential due to multiple charges, since potential is a scalar quantity
  - Electric field

    $$\left|\vec{E}\right| = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r^2}$$

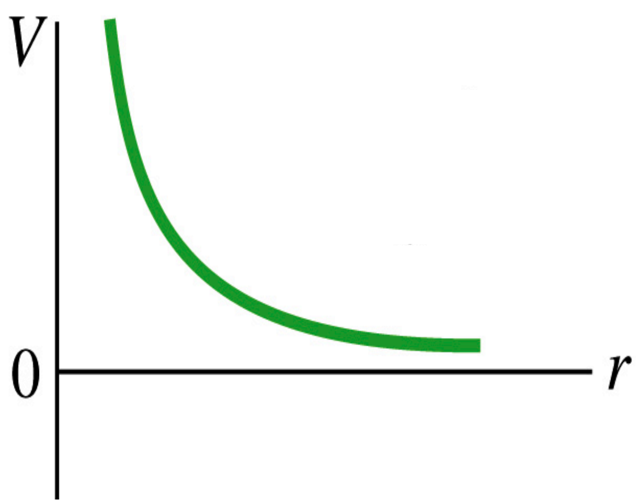
    - Electric force per unit charge
    - Inversely proportional to the **square** of the distance
    - Need vector sums to obtain the total field due to multiple source charges
- Potential due to a positive charge is a large positive near the charge and decreases towards 0 at large distance.
- Potential due to a negative charge is a large negative near the charge and increases towards 0 at large distance.

Shape of the Electric Potential

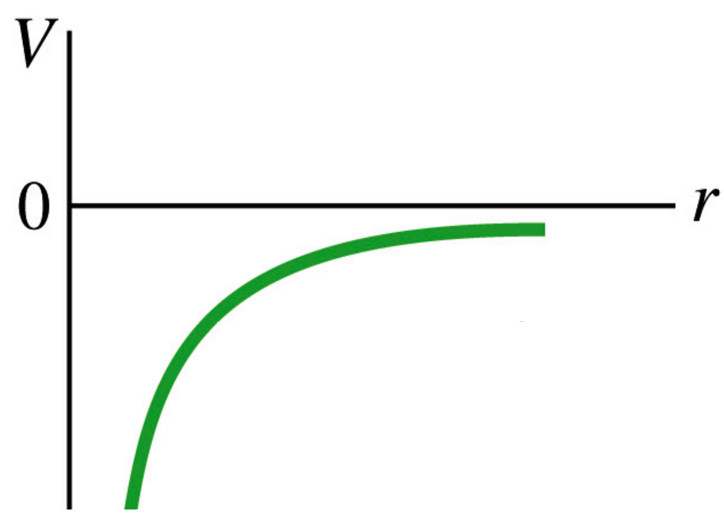
- So, how does the electric potential look like as a function of distance?
  - What is the formula for the potential by a single charge?

$$V = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$$

Positive Charge



Negative Charge



Uniformly charged sphere would have the potential the same as a single point charge.

What does this mean? **Uniformly charged sphere behaves like all the charge is on the single point in the center.**

Example 23 – 6

Work to bring two positive charges close together: What is minimum work required by an external force to bring the charge q=3.00μC from a great distance away (r=∞) to a point 0.500m from a charge Q=20.0 μC?

What is the work done by the electric field in terms of potential energy and potential?

$$W = -qV_{ba} = -\frac{q}{4\pi\varepsilon_0}\left(\frac{Q}{r_b} - \frac{Q}{r_a}\right)$$

Since $r_b = 0.500m, r_a = \infty$ we obtain

$$W = -\frac{q}{4\pi\varepsilon_0}\left(\frac{Q}{r_b} - 0\right) = -\frac{q}{4\pi\varepsilon_0}\frac{Q}{r_b} = -\frac{\left(8.99\times10^{9} N\cdot m^2/C^2\right)\cdot\left(3.00\times10^{-6}C\right)\left(20.00\times10^{-6}C\right)}{0.500m} = -1.08J$$

Electric force does negative work. In other words, the external force must do +1.08J of work to bring the 3.00μC charge from infinity to 0.500m to the charge 20.0μC.

Electric Potential by Charge Distributions

- Let's consider a case of n individual point charges in a given space and V=0 at r=∞.
- Then the potential V_{ia} due to the charge Q_i at point a, distance r_{ia} from Q_i is

$$V_{ia} = \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- Thus the total potential V_a by all n point charges is

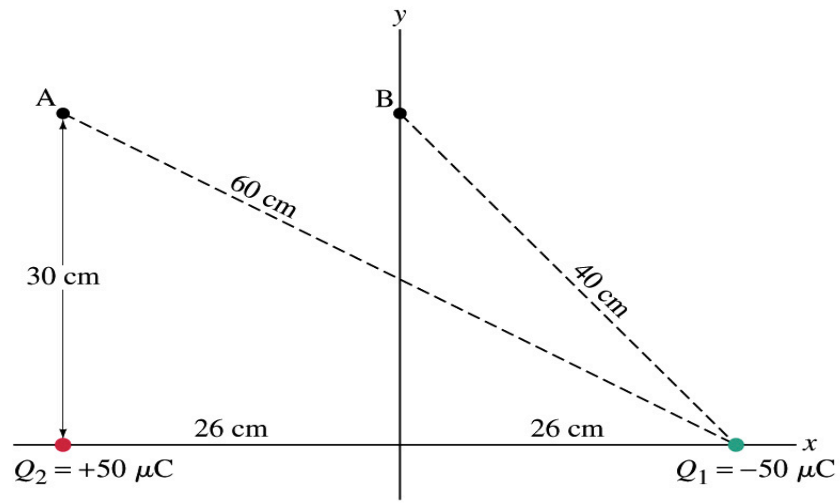
$$V_a = \sum_{i=1}^{n} V_{ia} = \sum_{i=1}^{n} \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- For a continuous charge distribution, we obtain

$$V = \frac{1}{4\pi\varepsilon_0}\int\frac{dq}{r}$$

Example

- **Potential due to two charges**: Calculate the electric potential (a) at point A in the figure due to the two charges shown, and (b) at point B.



- Electric potential is a scalar quantity, so one adds the potential by each of the source charge, as if they are numbers.

(a) potential at A is $V_A = V_{1A} + V_{2A} = \sum \frac{Q_i}{4\pi\varepsilon_0} \frac{1}{r_{iA}} =$

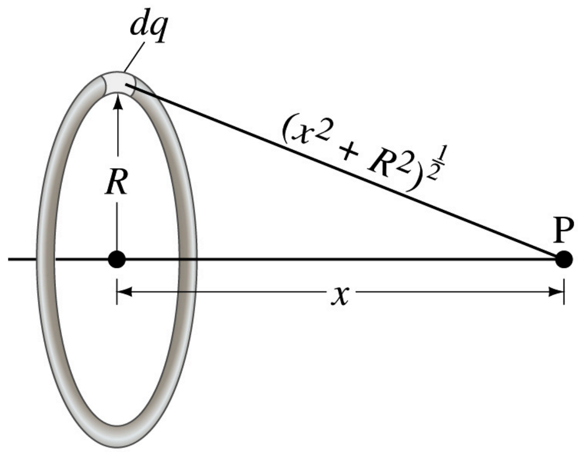
$$= \frac{1}{4\pi\varepsilon_0}\frac{Q_1}{r_{1A}} + \frac{1}{4\pi\varepsilon_0}\frac{Q_2}{r_{2A}} = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q_1}{r_{1A}} + \frac{Q_2}{r_{2A}}\right)$$

$$= 9.0\times10^9\left(\frac{-50\times10^{-6}}{0.60} + \frac{50\times10^{-6}}{0.30}\right) = 7.5\times10^5 V$$

(b) How about potential at B?

Example 23 – 8

- **Potential due to a ring of charge**: A thin circular ring of radius R carries a uniformly distributed charge Q. Determine the electric potential at a point P on the axis of the ring a distance x from its center.



- Each point on the ring is at the same distance from the point P. What is the distance?

$$r = \sqrt{R^2 + x^2}$$

- So the potential at P is

$$V = \frac{1}{4\pi\varepsilon_0}\int \frac{dq}{r} = \frac{1}{4\pi\varepsilon_0 r}\int dq =$$

What's this?

$$\frac{1}{4\pi\varepsilon_0\sqrt{x^2 + R^2}}\int dq = \frac{Q}{4\pi\varepsilon_0\sqrt{x^2 + R^2}}$$