PHYS 1444 – Section 003
Lecture #9

Tuesday, Sept. 20, 2011

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

Today's homework is homework #5, due 10pm, Tuesday, Sept. 27!!

Announcements

- Quiz Results
  - Class Average: 45.1/70
    - Equivalent to: 64.4/100
    - How did you do last time: 45.6/100
  - Top score: 66/70
- Reading assignments
  - CH23.9
- First Term Exam
  - Non comprehensive
  - 12:30 – 2:00, Thursday, Sept. 29 in SH103
  - Covers CH21.1 through what we learn on this Thursday, Sept. 22, plus Appendices A and B on pages A1 – A7
  - There will be a review session Tuesday, Sept. 27, in the class
  - Bring your own sets of problems to go through in the session
- Colloquium this week
  - Our own Dr. Cuntz

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Studies of Extrasolar Planets and Astrobiology

Dr. Manfred Cuntz

Department of Physics

The University of Texas at Arlington

4:00 pm Wednesday September 21, 2011 room 101 SH

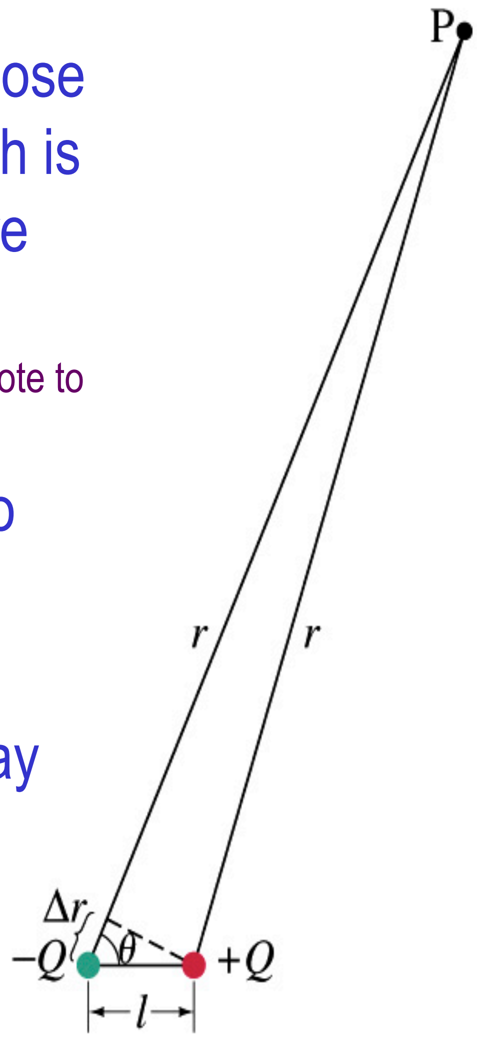
Abstract:

So far more than 650 planets have been identified outside the Solar Systems commonly referred to as extrasolar planets. They encompass Jupiter-type gas planets as well as a growing number of super-Earth planets. It is the purpose of my talk to highlight various advances made in this field with emphasis on studies pursued at UTA. They include work about orbital stability of theoretical and observed star-planet systems as well as contributions to astrobiology, including studies of planets in stellar habitable zones and the computation of planetary geodynamic models.

Refreshments will be served at 3:30p.m in the Physics Library

Special Project #3

- Derive the formula for the potential due to a dipole whose magnitude of dipole moment is p = Qℓ at point P which is r away from the +Q of the dipole as shown in the figure on the right. (10 points)
  - You must show your work in a lot more detail than page 14 of this lecture note to obtain any credit.
- Evaluate the moment of a dipole which consists of two charges of 3e and -3e and are 1 nm away from each other. (5 points)
- Evaluate the potential due to this dipole at r=1μm away and the angle θ=25 degrees. (5 points)
- Be sure to write down proper units.
- Due is beginning of the class Tuesday, Oct. 4!.



Electric Potential due to Point Charges

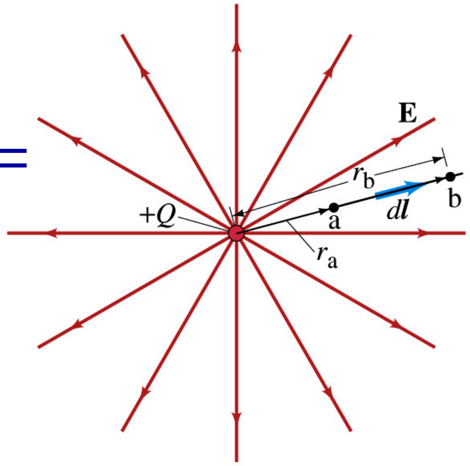
- What is the electric field by a single point charge Q at a distance r?

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

- 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

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

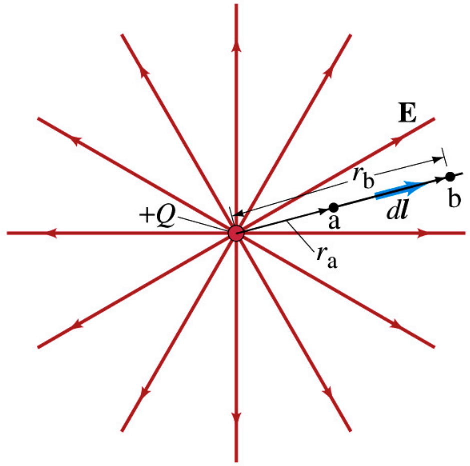
$$= -\frac{Q}{4\pi\varepsilon_0}\int_{r_a}^{r_b}\frac{1}{r^2}dr = \frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r_b}-\frac{1}{r_a}\right)$$



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 **the potential difference by a single point charge between r and infinity**

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 charges to obtain the total potential from multiple charges, since potential is a scalar quantity
  - Electric field

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

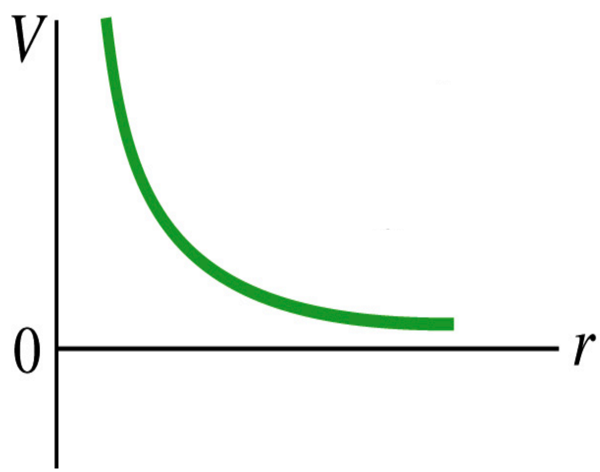
    - Electric force per unit charge
    - Inversely proportional to the square of the distance
    - Need vector sums to obtain the total field from multiple charges
- Potential for the positive charge is larger near the charge and decreases towards 0 at large distance.
- Potential for the negative charge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

Shape of the Electric Potential

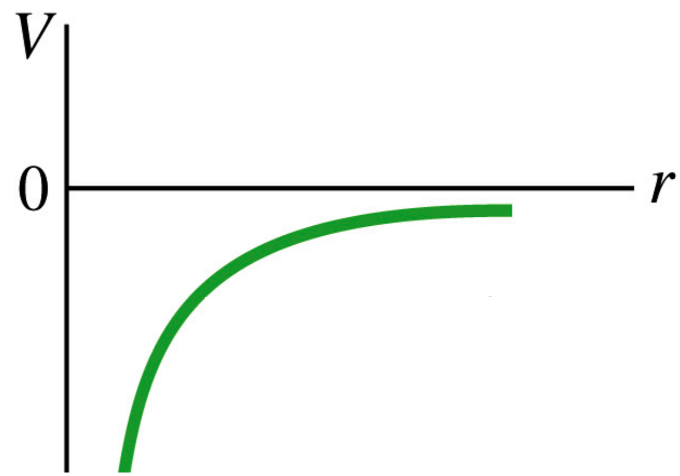
- So, how does the electric potential look like as a function of distance?
  - What is the formula for the potential by a single charge?

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

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 minimum work is required by an external force to bring a 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 work +1.08J to bring the charge 3.00μC 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 a point a, distance r_{ia} from Q_i is

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

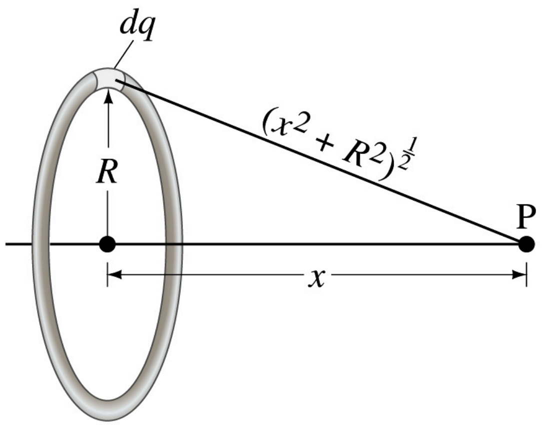
- Thus the total potential V_a by all n point charges is

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

- For a continuous charge distribution, we obtain

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

Example 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?

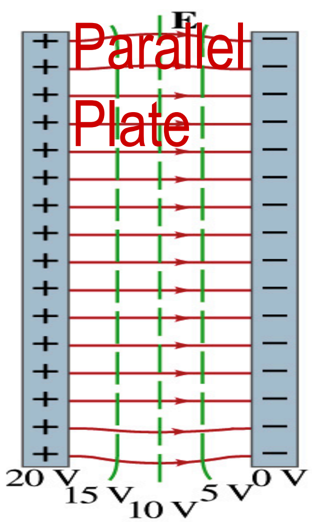
$$\frac{1}{4\pi\varepsilon_0\sqrt{x^2+R^2}}\int dq = \frac{Q}{4\pi\varepsilon_0\sqrt{x^2+R^2}}$$

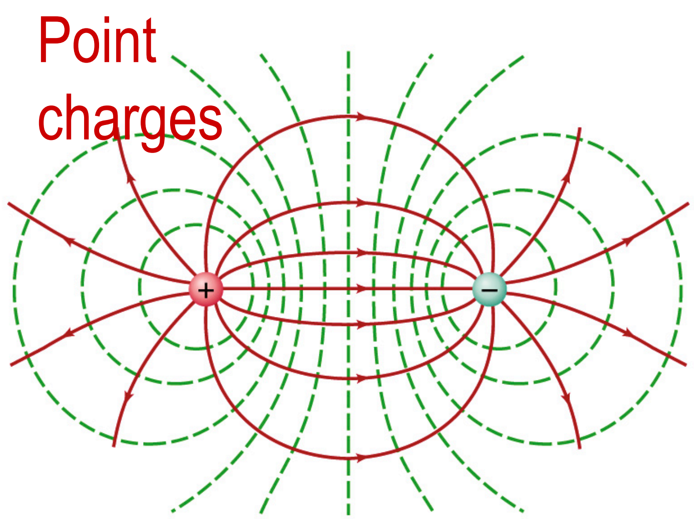
Equi-potential Surfaces

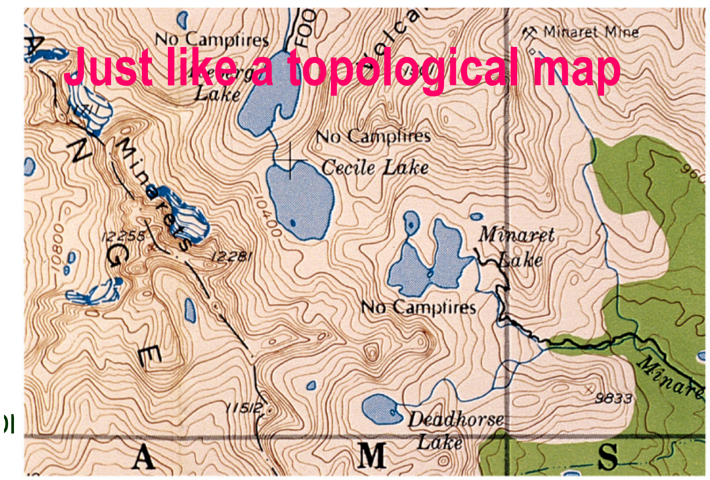
- Electric potential can be graphically shown using the equipotential lines in 2-D or the equipotential surfaces in 3-D
- Any two points on the equipotential surfaces (lines) are on the same potential
- What does this mean in terms of the potential difference?
  - The potential difference between two points on an equipotential surface is 0.
- How about the potential energy difference?
  - Also 0.
- What does this mean in terms of the work to move a charge along the surface between these two points?
  - No work is necessary to move a charge between these two points.

Equi-potential Surfaces

- An equipotential surface (line) must be perpendicular to the electric field. Why?
  - If there are any parallel components to the electric field, it would require work to move a charge along the surface.
- Since the equipotential surface (line) is perpendicular to the electric field, we can draw these surfaces or lines easily.
- Since there can be no electric field within a conductor in a static case, the entire volume of a conductor must be at the same potential.
- So the electric field must be perpendicular to the conductor surface.

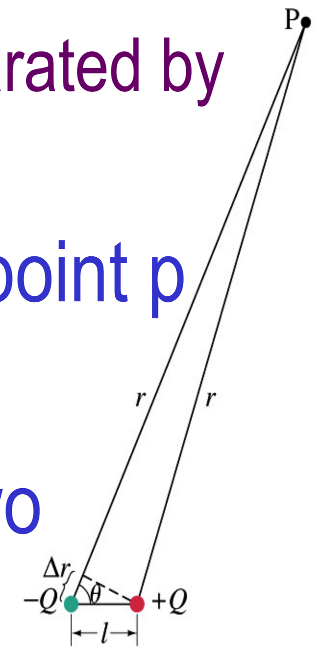






Electric Potential due to Electric Dipoles

- What is an electric dipole?
  - Two equal point charge Q of opposite signs separated by a distance ℓ and behaves like one entity: P=Qℓ



- For the electric potential due to a dipole at a point p
  - We take V=0 at r=∞
- The simple sum of the potential at p by the two charges is

$$V=\sum\frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}=\frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r}+\frac{(-Q)}{r+\Delta r}\right)=\frac{Q}{4\pi\varepsilon_0}\left(\frac{1}{r}-\frac{1}{r+\Delta r}\right)=\frac{Q}{4\pi\varepsilon_0}\frac{\Delta r}{r+\Delta r}$$

- Since Δr=ℓcosθ and if r>>ℓ, r>>Δr, thus r~r+Δr and

$$V=\frac{Q}{4\pi\varepsilon_0}\frac{l\cos\theta}{r}=\frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r}$$

V by a dipole at a distance r from the dipole

$$V=\frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r}$$