# PHYS 1444 – Section 002
# Lecture #9

*Monday, Oct. 2, 2017*

*Dr. Jaehoon Yu*

- Chapter 23 Electric Potential
  - V due to Charge Distributions
  - Equi-potential Lines and Surfaces
  - Electric Potential Due to Electric Dipole
  - Electrostatic Potential Energy
- Chapter 24 Capacitance etc..
  - Capacitors

Today's homework is homework #6, due 11pm, Monday, Oct. 9!!

# Announcements

- Bring out your special project #3 now
- Special colloquium 4pm tomorrow, Tuesday, Oct. 3 in SH103
  - Dr. Joseph Ngai of UTA Physics dept.

# Physics Department
# The University of Texas at Arlington
# COLLOQUIUM

## Realizing Novel Material Functionalities in Semiconductor-Crystalline Oxide Heterostructures


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Tuesday October 3, 2017
4:00 Room 103 Science Hall


Abstract

Developing materials that exhibit enhanced or novel functionalities is essential to address challenges faced in energy harvesting and information technology. Heterostructures comprised of materials exhibiting dissimilar yet complementary properties could lead to novel functionalities that cannot be achieved in the constituent materials alone. In this regard, monolithic heterostructures comprised of ionically bonded complex oxides and covalently bonded semiconductors (e.g. Si, Ge etc.) form an ideal complementary system to realize novel functionalities. I will discuss our recent efforts in electrically coupling multifunctional oxides to semiconductors through band-gap engineering, using epitaxial $SrZr_xTi_{1-x}O_3$ (SZTO) grown on Ge. Complex oxide thin films and heterostructures often exhibit surprising material behaviors not found in corresponding bulk samples. We have recently found that ultra-thin epitaxial films of SZTO exhibit relaxor behavior, characterized by a hysteretic polarization that can be exploited to modulate the surface potential of Ge. Strained films as thin as 5 nm corresponding to an equivalent-oxide-thickness of just 1.0 nm exhibit a ~ 2 V hysteretic window in the capacitance-voltage characteristics. The development of hysteretic metal-oxide-semiconductor capacitors with nanoscale gate thicknesses opens new vistas for nanoelectronic devices.



This work supported by NSF DMR-1508530



References: J. Moghadam et al. Nano Letters, DOI: 10.1021/acs.nanolett.7b02947
J. Moghadam et al., Adv. Mater. Interfaces 2, 1400497 (2015)
X. Shen et al., Appl. Phys. Lett. 106, 032903 (2015)

# 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

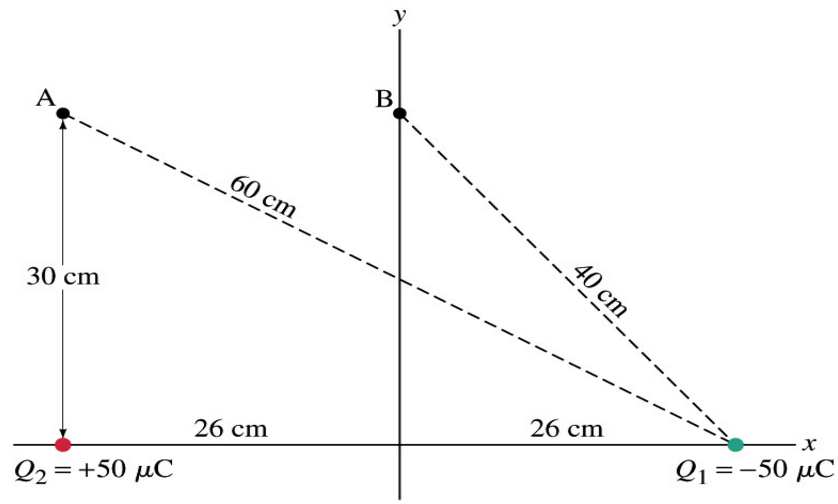
$$V_a = \sum_{i=1}^{n} V_{ia} = \sum_{i=1}^{n} \frac{Q_i}{4\pi\varepsilon_0}\frac{1}{r_{ia}}$$

- 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 $V_A = V_{1A} + V_{2A} = \sum \frac{Q_i}{4\pi\varepsilon_0} \frac{1}{r_{iA}} =$

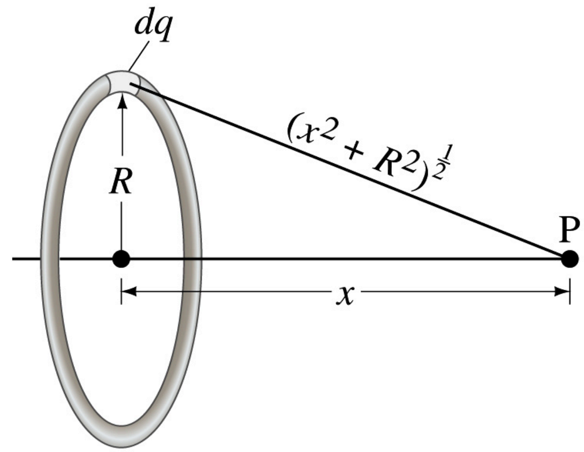
$$= \frac{1}{4\pi\varepsilon_0} \frac{Q_1}{r_{1A}} + \frac{1}{4\pi\varepsilon_0} \frac{Q_2}{r_{2A}} = \frac{1}{4\pi\varepsilon_0} \left( \frac{Q_1}{r_{1A}} + \frac{Q_2}{r_{2A}} \right)$$

$$= 9.0 \times 10^9 \left( \frac{-50 \times 10^{-6}}{0.60} + \frac{50 \times 10^{-6}}{0.30} \right) = 7.5 \times 10^5 V$$

(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?

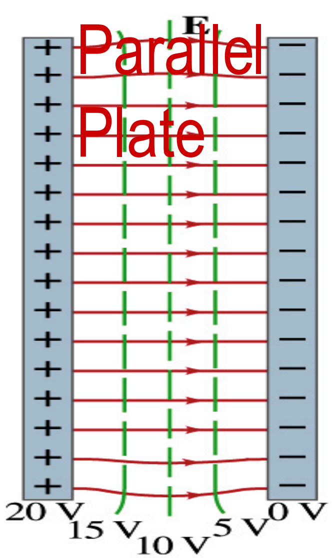
$$\frac{1}{4\pi\varepsilon_0\sqrt{x^2+R^2}}\int dq = \frac{Q}{4\pi\varepsilon_0\sqrt{x^2+R^2}}$$

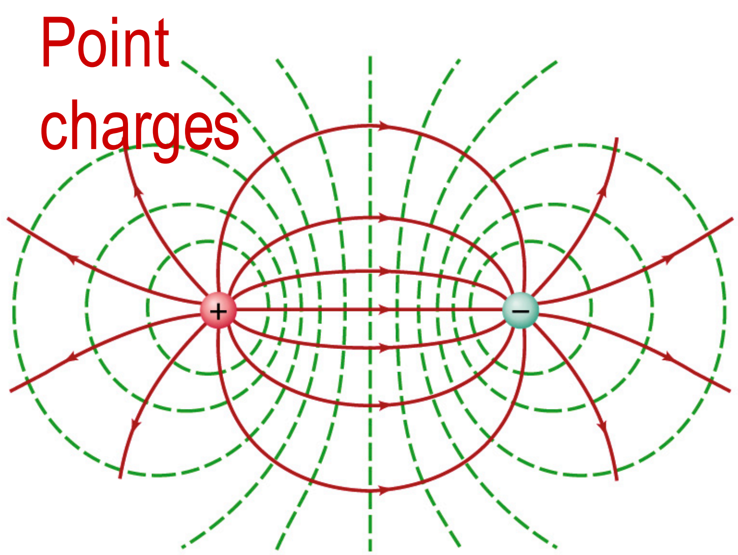
# Equi-potential Surfaces

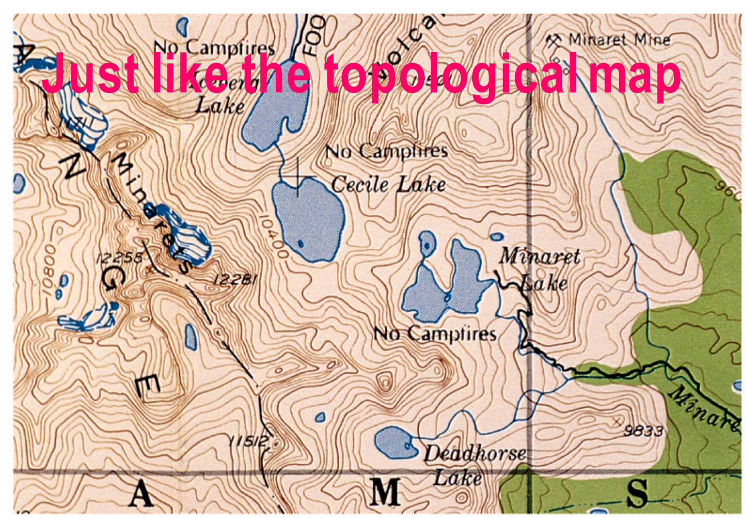
- Electric potential can be graphically shown using the equipotential lines in 2-D or the equipotential surfaces in 3-D
- Any two points on the equipotential surfaces (lines) are at the same potential
- What does this mean in terms of the potential difference?
  - The potential difference between the 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.

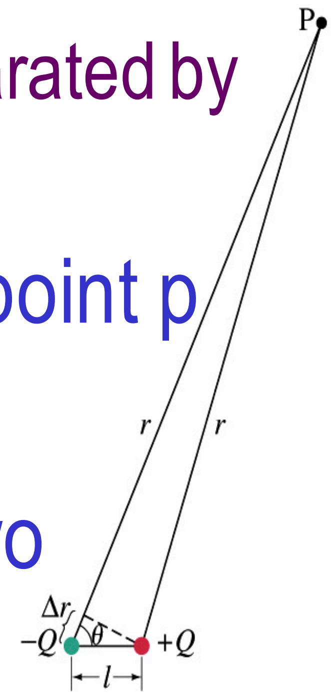


# Electric Potential due to Electric Dipoles

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




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

- Since Δr=$\ell$cosθ and if r>>$\ell$, r>>Δr, then r~r+Δr and

$$V = \frac{Q}{4\pi\varepsilon_0}\frac{l\cos\theta}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$

**V by a dipole at a distance r from the dipole**

$$V = \frac{1}{4\pi\varepsilon_0}\frac{p\cos\theta}{r^2}$$