# Physics 1502: Lecture 3
# Today's Agenda

- Announcements:
  - Lectures posted on: www.phys.uconn.edu/~rcote/
  - HW assignments, solutions etc.
- Homework #1:
  - On Masterphysics today: due next Friday
  - Go to masteringphysics.com and register
  - Course ID: MPCOTE33308
- Labs: Begin in two weeks
- No class Monday: Labor Day

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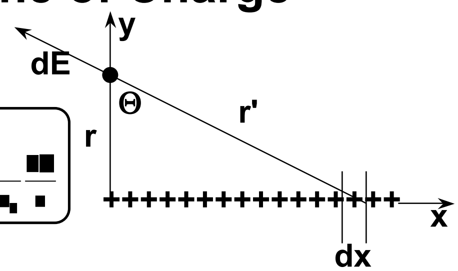
# Today's Topic :

- End of Chapter 20
  - Continuous charge distributions => integrate
  - Moving charges: Use Newton's law
- Chapter 21: Gauss's Law
  - Motivation & Definition
  - Coulomb's Law as a consequence of Gauss' Law
  - Charges on Insulators:
    - » Where are they?

## Infinite Line of Charge

- **Solution:**

[illegible]




**The Electric Field produced by an infinite line of charge is:**

- everywhere perpendicular to the line
- is proportional to the charge density
- decreases as 1/r.

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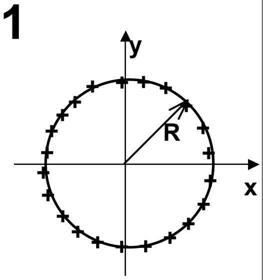
## Lecture 3, ACT 1

- **Consider a circular ring with a uniform charge distribution (λ charge per unit length) as shown. The total charge of this ring is +Q.**




- **The electric field at the origin is**

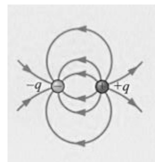
**(a)** zero **(b)** [illegible] **(c)** [illegible]

# Lecture 4

## Summary

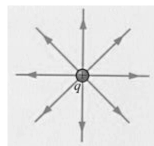
### Electric Field Distibutions

Dipole



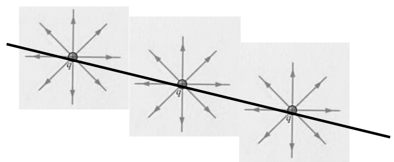
$\sim 1 / R^3$

Point Charge



$\sim 1 / R^2$

Infinite
Line of Charge



$\sim 1 / R$

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## Motion of Charged Particles in Electric Fields

- Remember our definition of the Electric Field,

[illegible]

- And remembering Physics 1501,

[illegible]

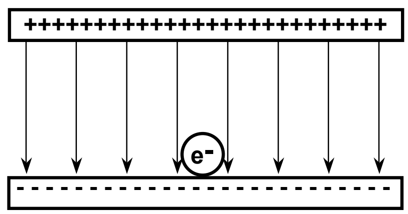
**Now consider particles moving in fields.**

**Note that for a charge moving in a constant field this is just like a particle moving near the earth's surface.**

| | |
|---|---|
| $a_x = 0$ | $a_y = \text{constant}$ |
| $v_x = v_{ox}$ | $v_y = v_{oy} + at$ |
| $x = x_o + v_{ox}t$ | $y = y_o + v_{oy}t + \frac{1}{2} at^2$ |

## Motion of Charged Particles in Electric Fields

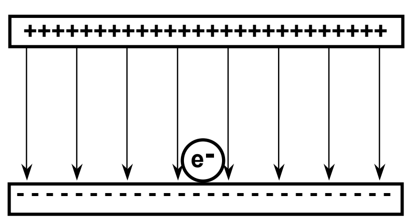
- **Consider the following set up,**




For an electron beginning at rest at the bottom plate, what will be its speed when it crashes into the top plate?

Spacing = 10 cm, E = 100 N/C, e = 1.6 x $10^{-19}$ C, m = 9.1 x $10^{-31}$ kg

## Motion of Charged Particles in Electric Fields




$v_o = 0$, $y_o = 0$

$v_f^2 - v_o^2 = 2a\Delta x$

Or,

[illegible]

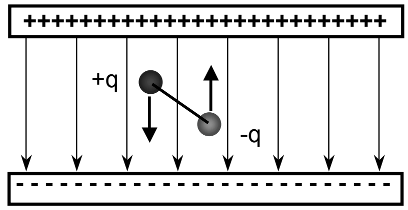
[illegible]

[illegible]

# Lecture 4

## Torque on a dipole

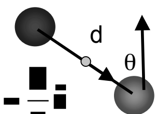
- Force on both charges
  - 2 different direction
  - Create a torque




- Recall: [illegible]
- And we have

[illegible]

[illegible]




[illegible]

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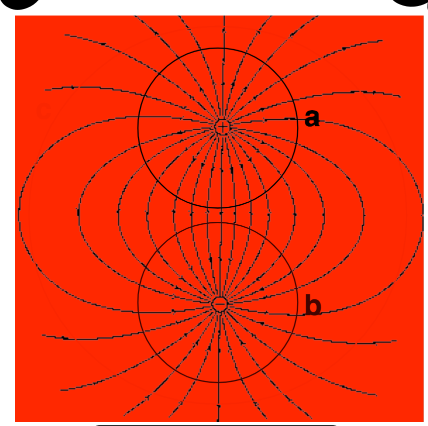
## Gauss' Law




$$\varepsilon_o \oint \vec{E} \bullet d\vec{S} = q$$

## Calculating Electric Fields

- Coulomb's Law
  - Force between two point charges
  - Can also be used to calculate E fields

**OR**

- Gauss' Law
  - Relationship between Electric Fields and charges
  - Uses the concept of Electric flux

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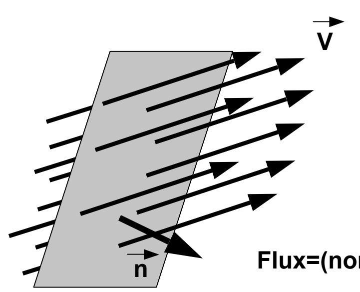
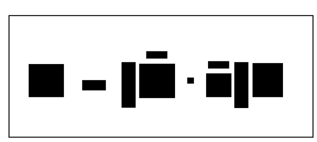
## Flux of a Vector Field



Flux=(normal component) (surface area)

## Electric Dipole
## Lines of Force

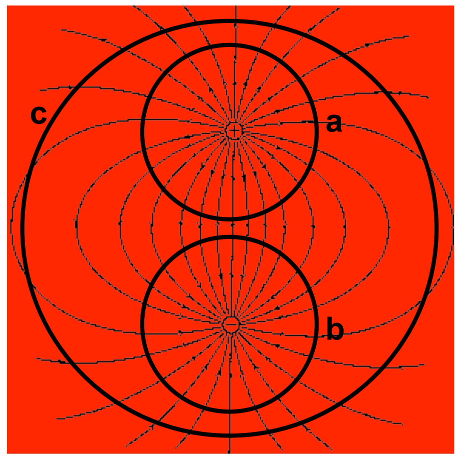
Consider imaginary spheres centered on :

a) +q (green)

b) -q (red)

c) midpoint (yellow)

- All lines leave a)
- All lines enter b)
- Equal amounts of leaving and entering lines for c)

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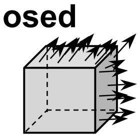
## Electric Flux

- Flux:

  Let's quantify previous discussion about field-line "counting"

  Define: electric flux $\Phi_E$ through the closed surface S

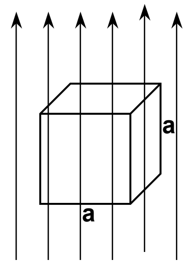
  $$\Phi_E \equiv \oint \vec{E} \bullet d\vec{S}$$



- What does this new quantity mean?
  - The integral is an integral over a CLOSED SURFACE
  - The result (the net electric flux) is a SCALAR quantity
  - $d\vec{S}$ is normal to the surface and points OUT

  ⇨ $\vec{E} \bullet d\vec{S}$ uses the component of E which is NORMAL to the SURFACE
  - Therefore, the electric flux through a closed surface is the sum of the normal components of the electric field all over the surface.
  - Pay attention to the direction of the normal component as it penetrates the surface…is it "out of" or "into" the surface?
  - "Out of is "+" "Into" is "-"

## Lecture 3, ACT 2




- Imagine a cube of side a positioned in a region of constant electric field, strength E, as shown.
  - Which of the following statements about the net electric flux $\Phi_E$ through the surface of this cube is true?

(a) $\Phi_E = 0$ (b) $\Phi_E = 2Ea^2$ (c) $\Phi_E = 6Ea^2$

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## Gauss' Law

Karl Friedrich Gauss
(1777-1855)

# Gauss' Law

- **Gauss' Law (a FUNDAMENTAL Law):**

  **The net electric flux through any closed surface is proportional to the charge enclosed by that surface.**

$$\varepsilon_0 \oint \vec{E} \bullet d\vec{S} = \varepsilon_0 \Phi = q_{enclosed}$$

- **How to Apply??**
  - The above eqn is TRUE always, but it doesn't look easy to use
  - It is very useful in finding E when the physical situation exhibits massive SYMMETRY
  - To solve the above eqn for E, you have to be able to CHOOSE a closed surface such that the integral is TRIVIAL
    - » Direction: surface must be chosen such that E is known to be either parallel or perpendicular to each piece of the surface
    - » Magnitude: surface must be chosen such that E has the same value at all points on the surface when E is perpendicular to the surface.
    - » Therefore: that allows you to bring E outside of the integral

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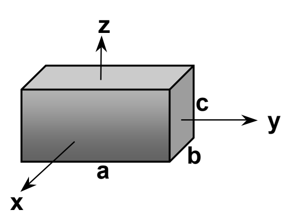
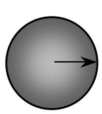
# Geometry and Surface Integrals

**If E is constant over a surface, and normal to it everywhere, we can take E outside the integral, leaving only a surface area**

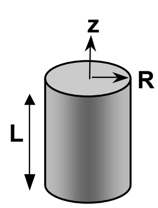
$$\oint \vec{E} \bullet d\vec{S} = E \oint dS$$




$$\oint dS = 2ac + 2bc + 2ab$$



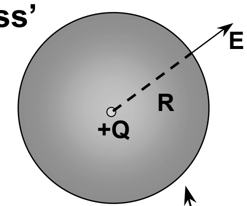
R $\oint dS = 4\pi R^2$




$$\oint dS = 2\pi R^2 + 2\pi RL$$

## Gauss $\Rightarrow$ Coulomb

- **We now illustrate this for the field of the point charge and prove that Gauss' Law implies Coulomb's Law.**




- **Symmetry $\Rightarrow$ E field of point charge is radial and spherically symmetric**
- **Draw a sphere of radius R centered on the charge.**

– **Why?**

**E normal to every point on surface**

$\Rightarrow \quad \vec{E} \bullet d\vec{S} = EdS$

**E has same value at every point on surface**

**$\Rightarrow$ can take E outside of the integral!**

- **Therefore,** $\oint \vec{E} \bullet d\vec{S} = \oint EdS = E\oint dS = 4\pi R^2 E$ **!**

– **Gauss' Law $\Rightarrow$** [illegible] $\Rightarrow$ [illegible]

**We are free to choose the surface in such problems…we call this a "Gaussian" surface**

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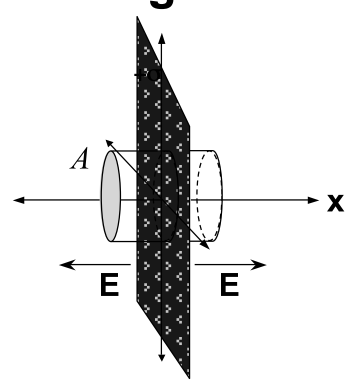
## Infinite sheet of charge

- **Symmetry:**

**direction of E = x-axis**



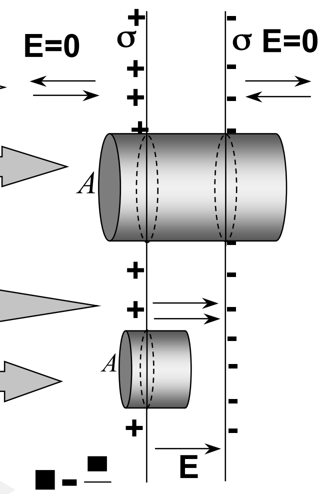

- **Therefore, CHOOSE Gaussian surface to be a cylinder whose axis is aligned with the x-axis.**
- **Apply Gauss' Law:**
  - **On the barrel,** $\oint \vec{E} \bullet d\vec{S} = 0$
  - **On the ends,** $\oint \vec{E} \bullet d\vec{S} = 2AE$
  - **The charge enclosed =** $\sigma A$

**Therefore, Gauss' Law** $\Rightarrow \varepsilon_0 \, (2EA) = \sigma A$ $\Rightarrow$ [illegible]

**Conclusion: An infinite plane sheet of charge creates a CONSTANT electric field .**

## Two Infinite Sheets

- Field outside the sheets must be zero. Two ways to see:
  - Superposition
  - Gaussian surface encloses zero charge
- Field inside sheets is NOT zero:
  - Superposition
  - Gaussian surface encloses non-zero chg




[illegible]

[illegible]

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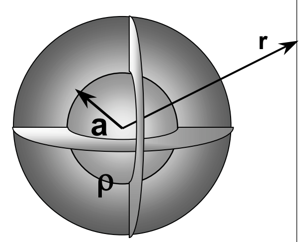
## Uniformly charged sphere

What is the magnitude of the electric field due to a <u>solid</u> sphere of radius a with uniform charge density ρ (C/m³)?



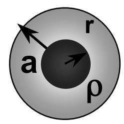

- Outside sphere: (r > a)
  - We have spherical symmetry centered on the center of the sphere of charge
  - Therefore, choose Gaussian surface = hollow sphere of radius r

[illegible] ⇒ Gauss' Law [illegible]

# Lecture 4

## Uniformly charged sphere

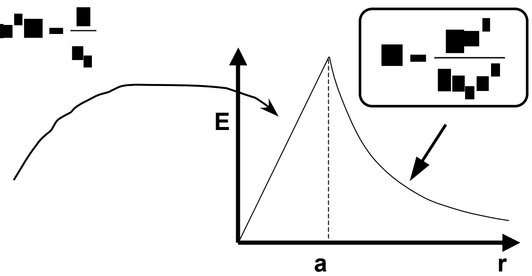
- **Inside sphere: (r < a)**
  - **We still have spherical symmetry centered on the center of the sphere of charge.**
  - **Therefore, choose Gaussian surface = sphere of radius r.**




**Gauss' Law**

**But,**

**Thus:**

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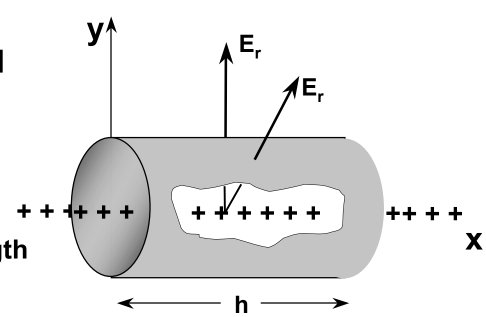
## Infinite Line of Charge

- **Symmetry ⇒ E field must be ⊥ to line and can only depend on distance from line**

- **Therefore, CHOOSE Gaussian surface to be a cylinder of radius r and length h aligned with the x-axis.**




- **Apply Gauss' Law:**
  - **On the ends,** $\vec{E} \bullet d\vec{S} = 0$
  - **On the barrel,** $\oint \vec{E} \bullet d\vec{S} = 2\pi r h E$ **AND** $q = \lambda h$ ⇒

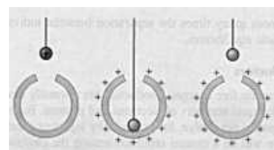
**NOTE: we have obtained here the same result as we did last lecture using Coulomb's Law. The symmetry makes today's derivation easier!**

# Conductors & Insulators

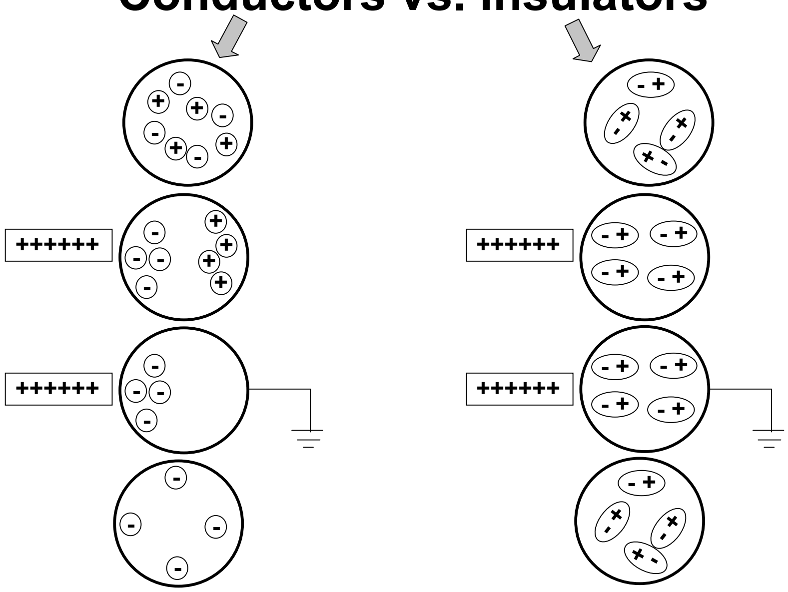
- Consider how charge is carried on macroscopic objects.
- We will make the simplifying assumption that there are only two kinds of objects in the world:
  - Insulators.. In these materials, once they are charged, the charges ARE NOT FREE TO MOVE. Plastics, glass, and other "bad conductors of electricity" are good examples of insulators.
  - Conductors.. In these materials, the charges ARE FREE TO MOVE. Metals are good examples of conductors.

- **How do the charges move in a conductor??**
  - **Hollow conducting sphere**

    **Charge the inside, all of this charge moves to the outside.**



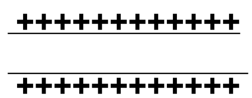
# Conductors vs. Insulators



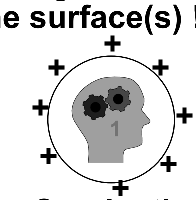
## Charges on a Conductor

- **Why do the charges always move to the surface of a conductor ?**
  - **Gauss' Law tells us!!**
  - **E = 0 inside a conductor when in equilibrium (electrostatics) !**
    - » **Why?**

      **If E ≠ 0, then charges would have forces on them and they would move !**
- **Therefore from Gauss' Law, the charge on a conductor must only reside on the surface(s) !**




**Infinite conducting plane**



**Conducting sphere**