# Physics 1502

*Fall 2009*

**Electricity and Magnetism**
**plus Optics and Modern Physics**

**Instructor: Robin Côté**

## Course Info

- Course has several components:
  - **Lecture: (me talking, demos and** Active **learning).**
  - **Homework Sets: problems from the book.**
  - **Tests: two midterms and a final.**
    - » **Questions on tests will look like those we do in the rest of the class; in homework and during lectures.**
    - » **No surprises**
  - **Office hours: to answer additional questions**
  - **Labs: (group exploration of physical phenomena).**

## How to do well in the course ?

- **FINAL GRADE WILL BE MADE OF:**
  - » **2 Midterms 30%**
  - » **Final Exam 25%**
  - » **Homeworks 20%**
  - » **Labs 25%**

- **Remember:**
  - if you miss 1 HW (out of ~10 given during the semester), you miss 2% of the final score !
  - if you miss more than one LAB => incomplete

## Announcements

- **Most of the info about the class will be posted on:**
  - **www.phys.uconn.edu/~rcote**
    - » **lecture notes (.ppt and .pdf formats)**
    - » **homework assignments and solutions**
    - » **exams and solutions**
    - » **Syllabus**
  - **Follow the link to 1502**

- **Labs** start during the week of Sept. 14.

# Announcements

- **Homeworks will be posted on Mastering Physics**

**[www.masteringphysics.com](http://www.masteringphysics.com)**

**Register for MasteringPhysics**

**Course ID: MPCOTE33308**

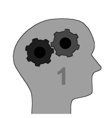
- HW will be due usually Fri. mornings (8:00 am)
- No Late HW accepted

HELP:

- **Become familiar with the *Physics Resource Center* for help with problem sets. Room P201, time posted on the door.**

# Format of Lectures

- **Roughly 2/3 of the time in class devoted to presentation of material by instructor**
- **InterACTive periods during lectures where students work together on problems**

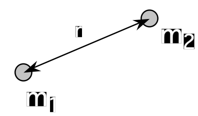



**an "ACT"**

- **Occasional demos to illustrate key concepts**

## The World According to Physics 1501

- Things
  - Specified by geometry and mass
- Forces
  - Gravity: $F = G\frac{m_1 m_2}{r^2}$

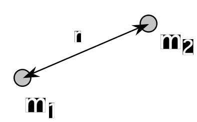



  - Others: Tension, Normal, Friction
- Space and Time
  - Euclidean with Galilean Invariance
    - "ordinary" 3D space; "slow" velocities

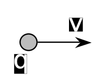
## The World According to Physics 1502



- Things -- Bodies and Fields (E,B)
  - Specified by geometry and mass and charge
- Forces
  - Gravity: $F = G\frac{m_1 m_2}{r^2}$



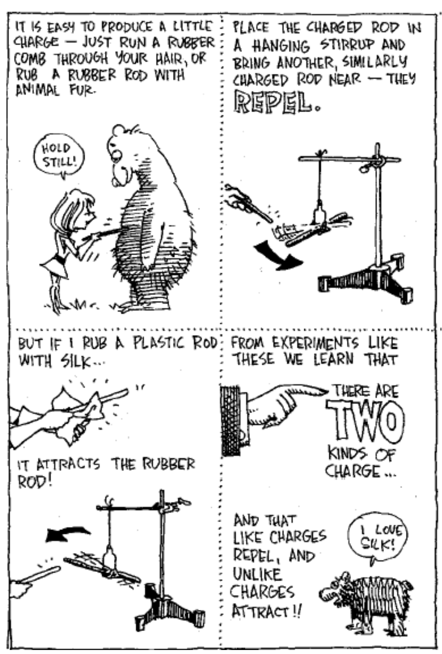

  - Electromagnetic: $F = qE + qv \times B$

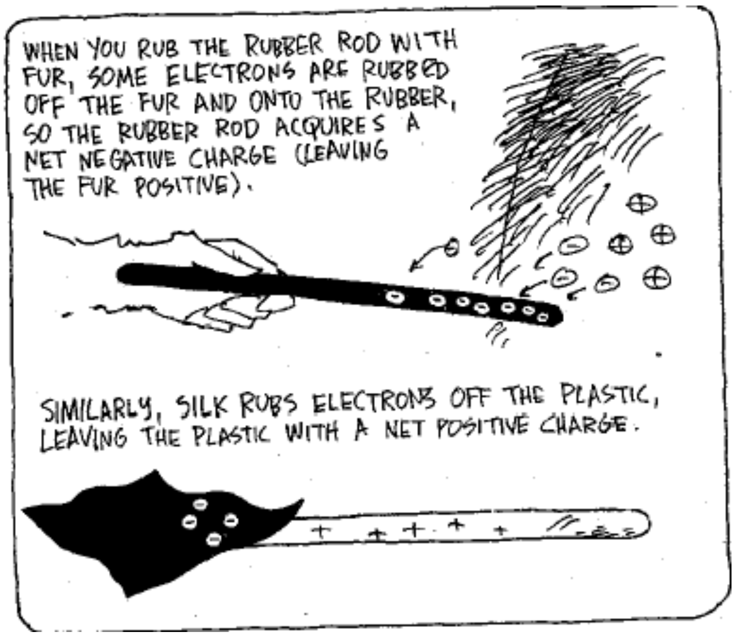



- Space and Time
  - Euclidean with Lorentz Invariance
    - "ordinary space" but can be really really fast...

## Where Does Our Study Start?

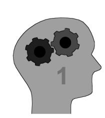
- The Phenomena
  - Silk on glass ⇒ glass → positive
  - Fur on rubber ⇒ rubber → negative
- The Concept
  - Electric Charge
    - Attribute of body
    - Unlike charges attract
    - Like charges repel






## The Force of an Electric Charge

- Assume that the electrical force between two charged objects acts along the line joining the centers of the charges (a Central Force).
- It increases if the magnitude of one of the charges increases.
- It increases if the distance between the charges is decreased, i.e. the charges get closer



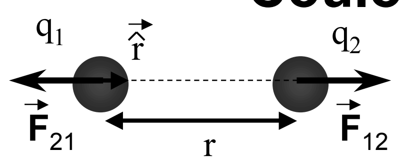
# The Force of an Electric Charge

Charles Coulomb (1736-1806)

**The electric force between two charged particles:**

- **is inversely proportional to the square of the distance between particles;**
- **increases if the magnitude of the charges increases;**
- **is attractive if the charges are of opposite sign and repulsive if the charges have the same sign.**

# What We Call Coulomb's Law




$$\vec{F}_{12} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{r}$$

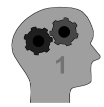
**SI Units:**

- **r in meters**
- **q in Coulombs**
- **F in Newtons**

$$\Rightarrow \frac{1}{4\pi\varepsilon_0} = 8.987\ 10^9\ \mathrm{N\ m^2/C^2}$$

**We call this group of constants "k" as in: $F = k\, q_1 q_2/r^2$**

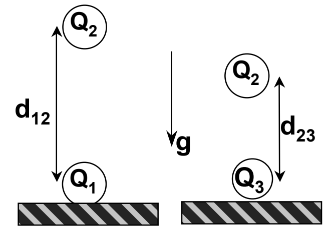
- **This force has same spatial dependence as gravitational force, BUT there is NO mention of mass here!!**
- **The strength of the FORCE between two objects is determined by the charge of the two objects.**



# Chapter 20, ACT 1

- A charged ball $Q_1$ is fixed to a horizontal surface as shown. When another charged ball $Q_2$ is brought near, it achieves an equilibrium position at a distance $d_{12}$ directly above $Q_1$.

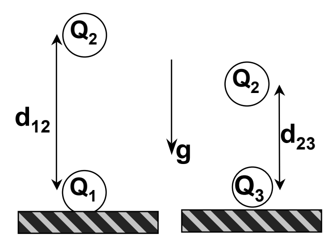
- When $Q_1$ is replaced by a different charged ball $Q_3$ , $Q_2$ achieves an equilibrium position at distance $d_{23}$ ($< d_{12}$) directly above $Q_3$.




1: A) The charge of $Q_3$ has the same sign as the charge of $Q_1$
B) The charge of $Q_3$ has the opposite sign as the charge of $Q_1$
C) Cannot determine the relative signs of the charges of $Q_3$ & $Q_1$

# Chapter 20, ACT 2

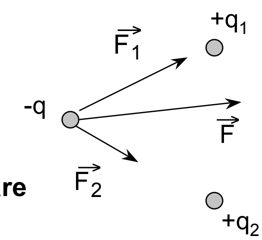
- A charged ball $Q_1$ is fixed to a horizontal surface as shown. When another charged ball $Q_2$ is brought near, it achieves an equilibrium position at a distance $d_{12}$ directly above $Q_1$.
- When $Q_1$ is replaced by a different charged ball $Q_3$ , $Q_2$ achieves an equilibrium position at distance $d_{23}$ ($< d_{12}$) directly above $Q_3$.




2: A) The magnitude of charge $Q_3$ < the magnitude of charge $Q_1$
B) The magnitude of charge $Q_3$ > the magnitude of charge $Q_1$
C) Cannot determine relative magnitudes of charges of $Q_3$ & $Q_1$

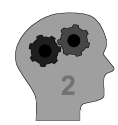
# What happens when you consider more than two charges?

- If $q_1$ were the only other charge, we would know the force on q due to $q_1$ .
- If $q_2$ were the only other charge, we would know the force on q due to $q_2$ .



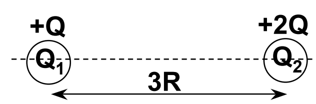

- What is the force on q when both $q_1$ and $q_2$ are present??
  - The answer: just as in mechanics, we have the **Law of Superposition:**
    - The TOTAL FORCE on the object is just the VECTOR SUM of the individual forces.

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

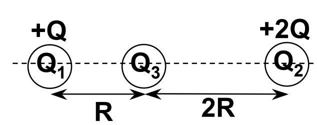



# Chapter 20, ACT 3

- Two balls, one with charge $Q_1$ = +Q and the other with charge $Q_2$ = +2Q, are held fixed at a separation d = 3R as shown.




- Another ball with (non-zero) charge $Q_3$ is introduced in between $Q_1$ and $Q_2$ at a distance = R from $Q_1$ .



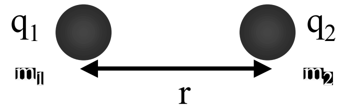

- Which of the following statements is true?

(a) The force on $Q_3$ can be zero if $Q_3$ is positive.

(b) The force on $Q_3$ can be zero if $Q_3$ is negative.

(c) The force on $Q_3$ can never be zero, no matter what the charge $Q_3$ is.

# Force Comparison Electrical vs Gravitational




$$F_{elec} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

$$F_{grav} = G\frac{m_1 m_2}{r^2}$$

$$\Rightarrow \quad \frac{F_{elec}}{F_{grav}} = \frac{q_1 q_2}{m_1 m_2}\,\frac{\frac{1}{4\pi\varepsilon_0}}{G}$$

For a proton,

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

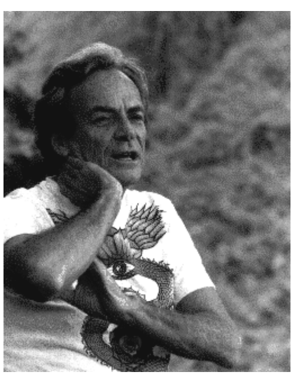
$m = 1.67 \times 10^{-27}$ kg

$G = 6.7\ 10^{-11}$ N $m^2/kg^2$

$\Rightarrow$ [illegible]

Note: smallest charge seen in nature *!*

# How Strong is the Electrical Force? Really?



Richard Feynman (1918-1988)

- Nobel Prize for QED
- Educator Extraordinaire

For more info, check:
The Character of Physical Law
Surely You're Joking, Mr. Feynman
What Do You Care What Other People Think?

http://www.mindspring.com/~madpickl/feyn.htm

## Richard Feynman, The Feynman Lectures:

"If you were standing at arm's length from someone and each of you had *one percent* more electrons than protons, the repelling force would be incredible. How great? Enough to lift the Empire State Building? No! To lift Mount Everest? No! The repulsion would be enough to lift a "weight" equal to that of the entire earth! "

# Should we believe this?

- How many electrons in a person?
  - What do we assume is the chemical composition of a person?

    Simplify: assume water (molecular weight = 18)
  - What then is the number of electrons/gram in a person?

$$\frac{6 \times 10^{23} \text{ molecules/mole}}{18 \text{ g/mole}} \times 10 \text{ e}^-\text{/molecule} = 3.3 \times 10^{23} \text{ e}^-\text{/g}$$

  - So, how many electrons in a person?

Assume mass = 80 kg ⇨ $3.3 \times 10^{23} \text{ e}^-\text{/g} \times 80 \text{ kg} = \boxed{2.6 \times 10^{28} \text{ e}^-}$

- How much charge is 1% of electrons in a person?

$$1\% \times 2.6 \times 10^{28} \text{ e}^- \times 1.6 \times 10^{-19} \text{ C/e}^- = \boxed{4.2 \times 10^{7} \text{ C}}$$

# Should we believe this?

- What is the force between 2 people an arm's length apart if they each had an excess of 1% electrons?

$$F = (9 \times 10^{9} \text{ N-m}^2\text{/C}^2) \times \left(\frac{4.2 \times 10^{7} \text{ C}}{0.75 \text{ m}}\right)^2$$

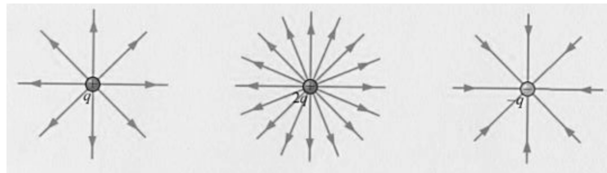
$$\boxed{F = 2.8 \times 10^{25} \text{ N}}$$

- What is the weight of the earth?

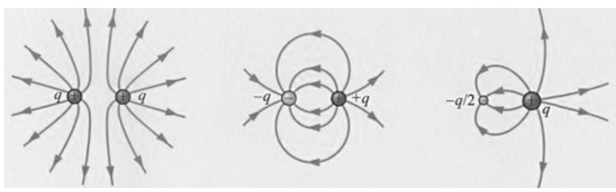
$$W_{earth} = 6 \times 10^{24} \text{ kg} \times 9.8 \text{ m/s}^2$$

$$\boxed{W_{earth} = 5.9 \times 10^{25} \text{ N}}$$

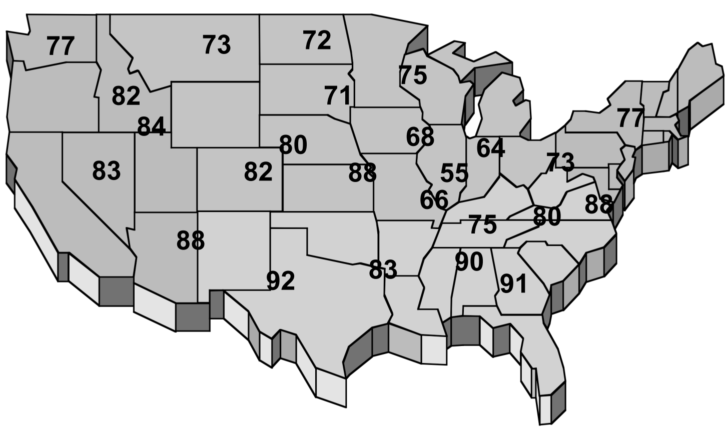
- Yes, that's INCREDIBLE!!




# Electric Fields




## Fields of all kinds...

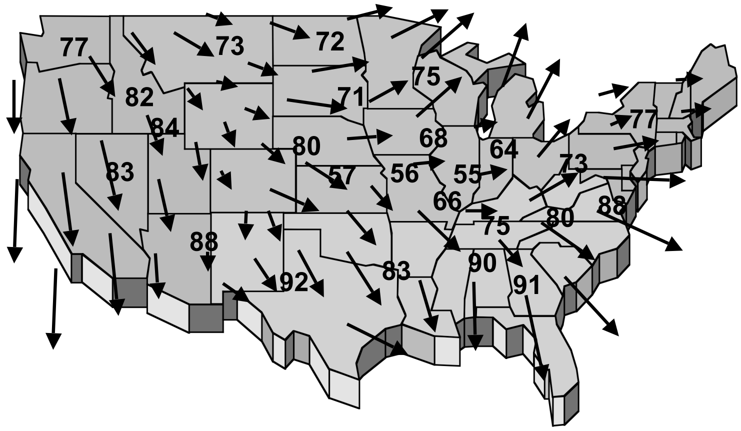



**These isolated Temperatures make up a Scalar Field**

**(you learn only the temperature at a place you choose)**

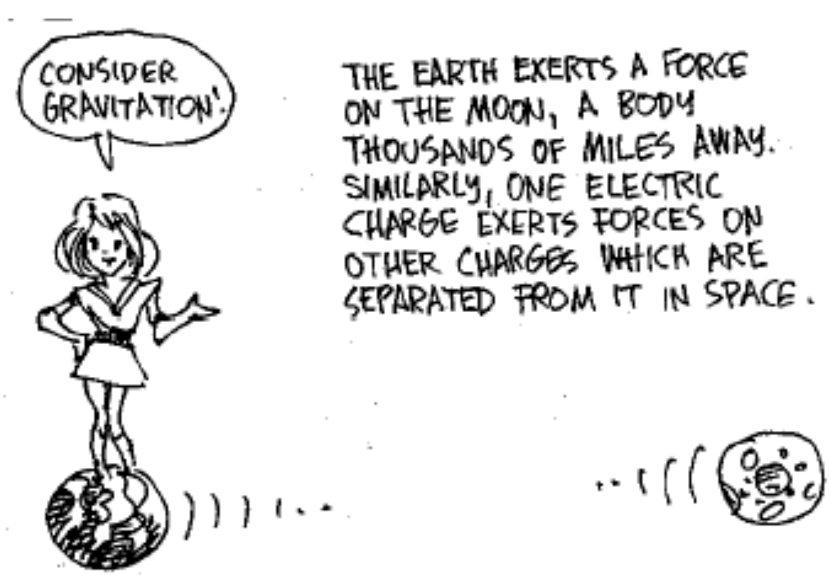
# Fields of all kinds...

**It may be more interesting to know which way the wind is blowing …**




**That would require a VECTOR field.**

**(you learn how fast the wind is blowing,
AND in what direction)**



# Electric Fields

**The force, F, on any charge q due to some collection of charges is always proportional to q:**

$$\vec{F} = \frac{q}{4\pi\epsilon_0}\sum \frac{q_i}{r_i^2}\hat{r}_i$$

**Introducing the Electric Field:**

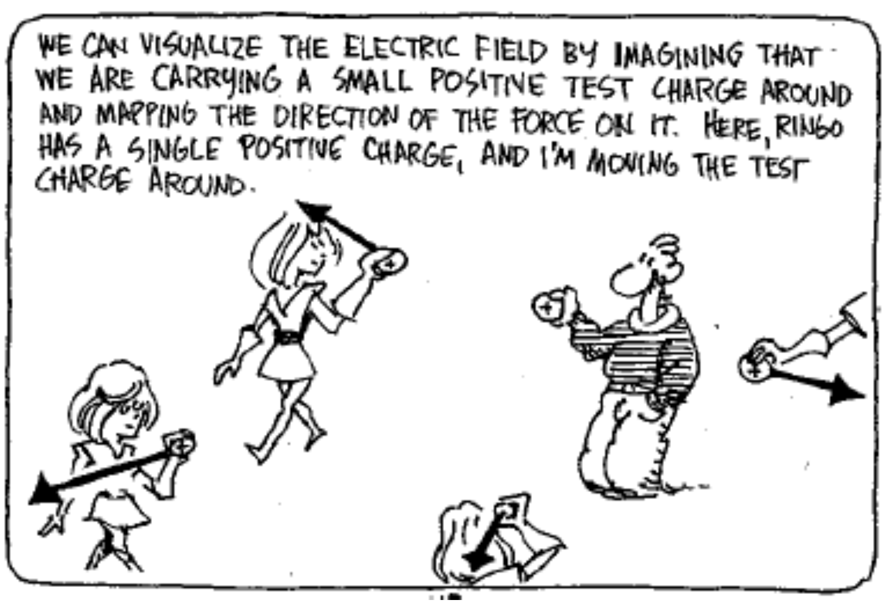
$$\vec{E} = \frac{\vec{F}}{q}$$

**a quantity, which is independent of that charge q, and depends only upon its position relative to the collection of charges.**

***A FIELD is something that can be defined anywhere in space***

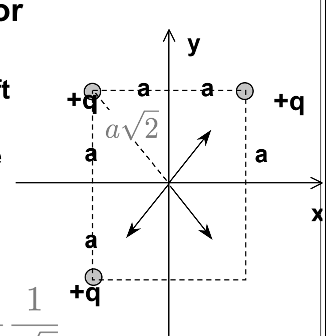
**it can be a scalar field (e.g., a Temperature Field)**

**it can be a vector field (as we have for the Electric Field)**



# Example

- What is the electric field at the origin for this collection of charges?
  - The fields from the top right and bottom left cancel at the origin!!
  - The total field is then just the field from the top left charge, which points away from the top left charge as shown.
  - The components of the field are then:

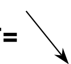
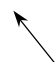



$$E_x = \frac{1}{4\pi\epsilon_0}\frac{q}{2a^2}\frac{1}{\sqrt{2}} \qquad E_y = -\frac{1}{4\pi\epsilon_0}\frac{q}{2a^2}\frac{1}{\sqrt{2}}$$

**If a charge Q were placed at the origin, the force on this charge would be:**

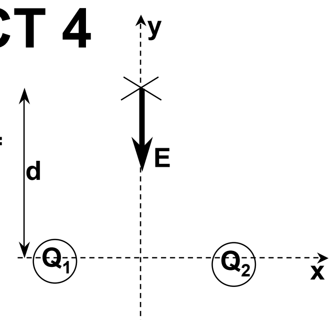
$$F_x = QE_x = \frac{1}{4\pi\epsilon_0}\frac{Qq}{2\sqrt{2}a^2}$$

$$F_y = QE_y = -\frac{1}{4\pi\epsilon_0}\frac{Qq}{2\sqrt{2}a^2}$$

**Note:**
**if Q>0, F=** 
**if Q<0, F=** 

# Chapter 20, ACT 4

- Two charges, $Q_1$ and $Q_2$ , fixed along the x-axis as shown, produce an electric field E at a point (x,y) = (0,d) which is directed along the negative y-axis.
  - Which of the following statements is true?




**(a)** Both charges $Q_1$ and $Q_2$ must be positive.

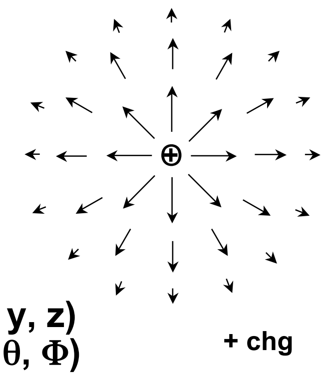
**(b)** Both charges $Q_1$ and $Q_2$ must be negative.

**(c)** The charges $Q_1$ and $Q_2$ must have opposite signs.

## How Can We Visualize the E Field?

- **Vector Maps:**

  **arrow length indicates vector magnitude**




- **Graphs:**

  **$E_x$, $E_y$, $E_z$ as a function of (x, y, z)**
  **$E_r$, $E_\theta$, $E_\Phi$ as a function of (r, $\theta$, $\Phi$)**