Physics 401: "**Electromagnetic Theory**" (Electrodynamics)

MWF 09:00 - Hebb 12 – **Jess H. Brewer** (jess@physics.ubc.ca)

http://musr.physics.ubc.ca/p401/

Everything is on the Website!

Schedule – Syllabus – Course Outline – Seminar Topics
Lectures – Assignments – Solutions – Old Exams
People Database – Surveys (feedback) – E&M Links

Please familiarize yourself with these.

The Plan for Today:

- Website tour:
  - **People Database**, Surveys (feedback) & **Schedule Conflicts**
  - **Syllabus** – Administrivia, Marks etc. - Tentative Course Outline
  - Seminars and some Typical Topics – External E&M Links
  - Lectures – ***Assignments*** – Solutions – Old Exams
- Grand Overview of Modern Physics (?)
- Review of Electrostatics & Magnetostatics
  - Electromagnetic **Forces** and **Fields**
  - Discrete & Continuous distributions of Charge & Current
  - Coulomb's (↔ Gauss') Law & Biot-Savart (↔ Ampère's) Law

My Schedule Conflicts (Add yours!)

as of 2005-12-29 Thu 12:19:14

Dept: PHYS **Course #** 401 **from** 2006-01-04 **to** 2006-01-13

Hour →			06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
course	↓ **Date**																
PHYS *401*	Wed 04 Jan 2006		1	1	1		Lecture										
PHYS *401*	Thu 05 Jan 2006												1	1	1	1	1
PHYS *401*	Fri 06 Jan 2006		1	1	1								1	1	1	1	1
PHYS *401*	Sat 07 Jan 2006												1	1	1	1	1
PHYS *401*	Sun 08 Jan 2006		1	1	1	1	1	1	1	1	1						
PHYS *401*	Mon 09 Jan 2006		1	1	1												
PHYS *401*	Tue 10 Jan 2006												1	1	1	1	1
PHYS *401*	Wed 11 Jan 2006		1	1	1												
PHYS *401*	Thu 12 Jan 2006												1	1	1	1	1
PHYS *401*	Fri 13 Jan 2006		1	1	1								1	1	1	1	1

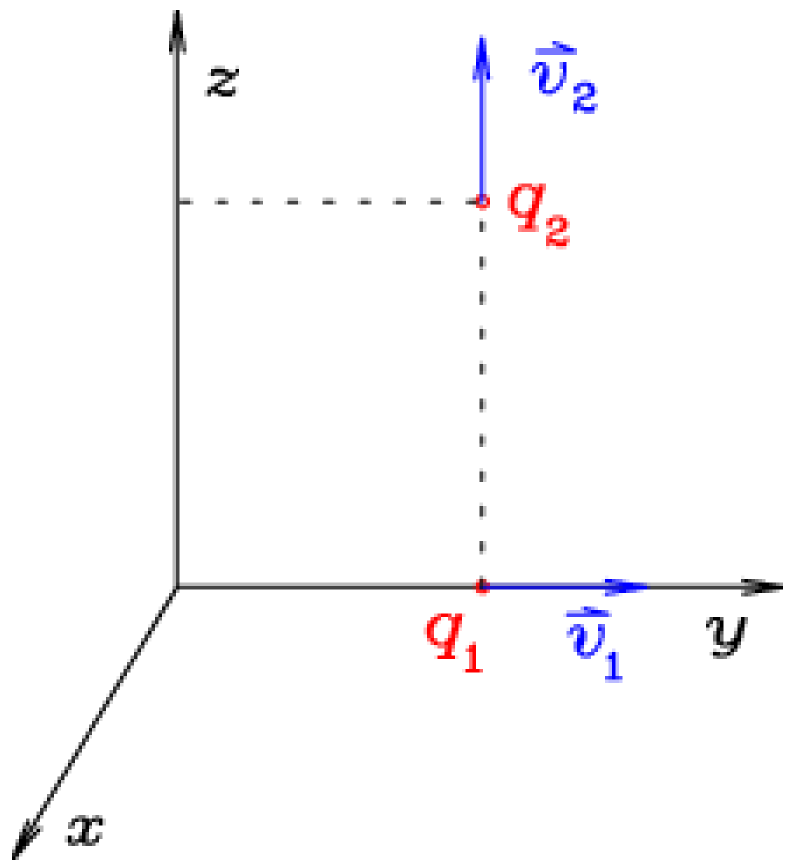
Click *checkboxes* by hours & dates for which you have *CONFLICTS*, then SUBMIT.

Don't hit **Reload**! It will resubmit the same data over again and corrupt the database.

Paradox in Classical E&M:

the **Lorentz force** appears to violate Newton's Third Law!

Calculate $\vec{F} = q\left(\vec{E} + \frac{\vec{v}}{c} \times \vec{B}\right)$ on each charged particle due to the fields caused by the other one. (Assume both charges are positive.)



Do you believe your answer?

Don't worry, we'll fix it up in P401 (eventually).

Intimations of 1905:

Static charges $\Rightarrow$ ***E*** field. *(Coulomb's Law)*

Moving charges $\Rightarrow$ ***B*** field. *(Ampère's Law)*

So viewing an ***E*** field from a moving reference frame changes it (partly) into a ***B*** field? **Yes!**

Changing (or moving, or moving through) a ***B*** field induces an ***E*** field. *(Faraday's Law)*

Changing (or moving, or moving through) an ***E*** field induces a ***B*** field. *(Maxwell's correction of Ampère's Law)*

So we get a **wave** propagating through vacuum at $c = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ without reference to any fixed coordinates? **Yes!**

Electrodynamics: where Modern Physics begins !

Static charges (Coulomb's Law): **Electric** Forces

(motion) → **Magnetic** Forces

the first **Unification:**

Four Forces: Gravity 10^{-40} | Weak 10^{-9} | Electromagnetic $\alpha = 1/137$ | **Strong** **1**

Electroweak (Std. Model)

Goal: **Grand Unification** (maybe by one of you?)

E&M Review

(what I hope you learned in PHYS 301/354 or equiv.)

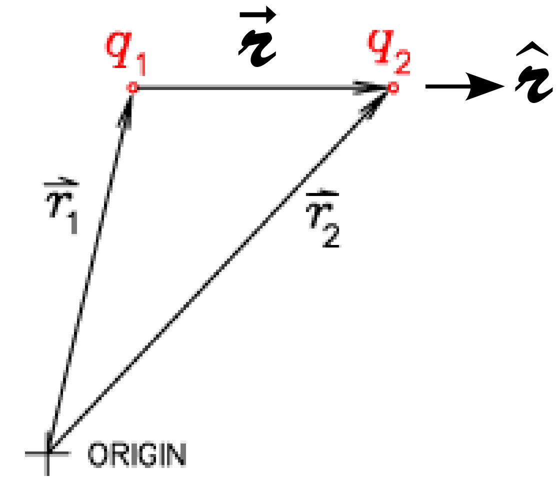
- Electric (magnetic) **forces** on (moving) electric charges
- Linear superposition of vector fields
- Electrostatic work & energy
- Electric field $\boldsymbol{E}$ & potential V: "toolbox" of techniques
- Conductors: boundary conditions for Laplace's equation
- Mastery of vector calculus and differential equations
- Magnetic fields due to steady currents $\boldsymbol{J}(\boldsymbol{r}')$
- Multipole expansions for arbitrary $\rho(\boldsymbol{r}')$ or $\boldsymbol{J}(\boldsymbol{r}')$
- **Materials** & dipoles: polarizability & magnetization
- Time-dependent fields & **Maxwell's equations**
- Electromagnetic **waves** carry energy & momentum.

PHYS 401 picks up here.

Direct Force Laws:

Electric force F_{12} **on** q_2 **due to** q_1**:**

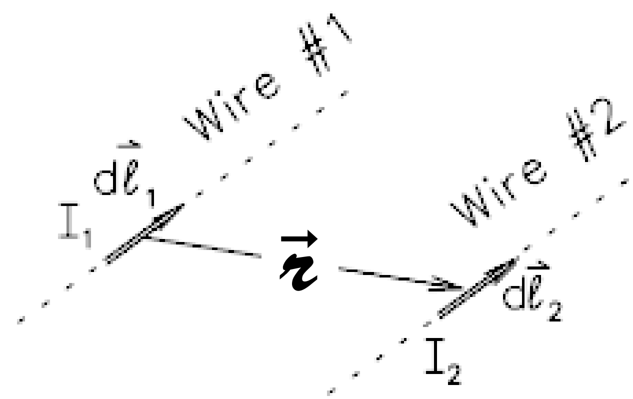
$$\vec{F}_{12} = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{\mathscr{r}^2}\,\hat{\mathscr{r}} \quad \text{where} \quad \vec{\mathscr{r}} \equiv \vec{r}_2 - \vec{r}_1$$



Magnetic force dF_{12} **on current element** $I_2 d\boldsymbol{\ell}_2$ **due to** $I_1 d\boldsymbol{\ell}_1$ **:**

$$\vec{F}_{12} = \frac{\mu_0}{4\pi}\frac{I_1 I_2}{\mathscr{r}^2}\, d\hat{\ell}_2 \times (d\hat{\boldsymbol{\ell}}_1 \times \hat{\mathscr{r}}\,)$$

(**Yuk!** This is why we invented **vector fields** in the first place!)



Fundamental Constants

Units: **SI** (mks or "engineering" units) used in Griffiths and P401.

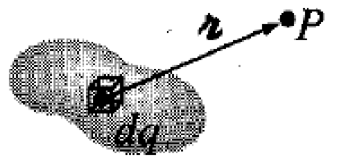
$$c \equiv 2.99792458 \text{ x } 10^8 \text{ m/s} = (\epsilon_0 \mu_0)^{-½}$$

$$k_M \equiv \mu_0 / 4\pi \equiv 10^{-7} \text{ N•A}^{-2} \qquad \mu_0 \equiv 4\pi \cdot 10^{-7} \text{ N•A}^{-2}$$

$$\epsilon_0 = 10^7 \text{ N•A}^{-2} / 4\pi c^2 = 8.8541878 \text{ x } 10^{-12} \text{ C}^2\text{•N}^{-1}\text{•m}^{-2}$$

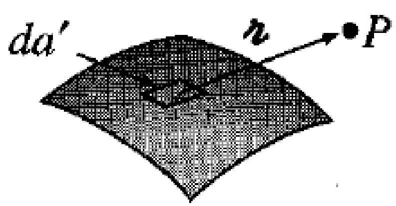
$$k_E \equiv 1/4\pi\epsilon_0 = c^2 \text{ x } k_M = 8.9875518 \text{ x } 10^9 \text{ V•m•C}^{-1}$$

Review: Discrete and Continuous Charge Distributions

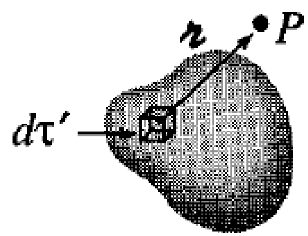


(a) Continuous distribution

(b) Line charge, λ



(c) Surface charge, σ



(d) Volume charge, ρ

Line Charge: λ= charge/length

dq= λ dl'

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\int \frac{\lambda(\vec{r}\,')\,dl'}{\mathscr{r}^2}\,\hat{\mathscr{r}}$$

Surface Charge: σ= charge/area

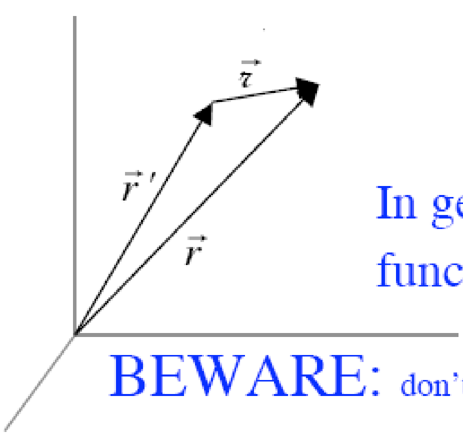
dq= σ da'

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\int \frac{\sigma(\vec{r}\,')\,da'}{\mathscr{r}^2}\,\hat{\mathscr{r}}$$

Volume Charge: ρ=charge/volume

dq= σ dτ'

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\varepsilon_0}\int \frac{\rho(\vec{r}\,')\,d\tau'}{\mathscr{r}^2}\,\hat{\mathscr{r}}$$



In general, λ, σ and ρ are functions of position

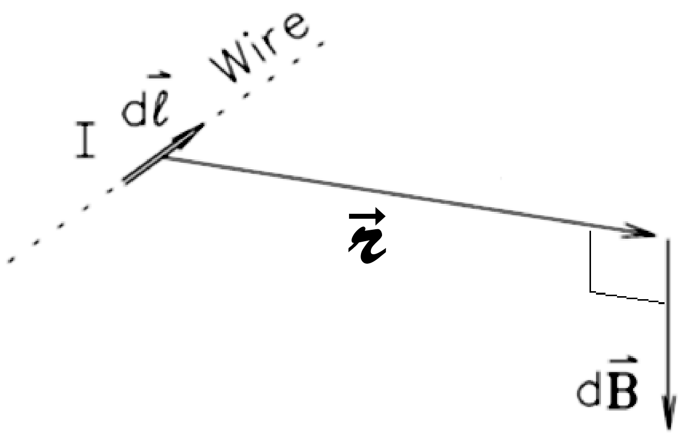
BEWARE: don't confuse field point and source point!

$\vec{\mathscr{r}} \neq \vec{r}$!!

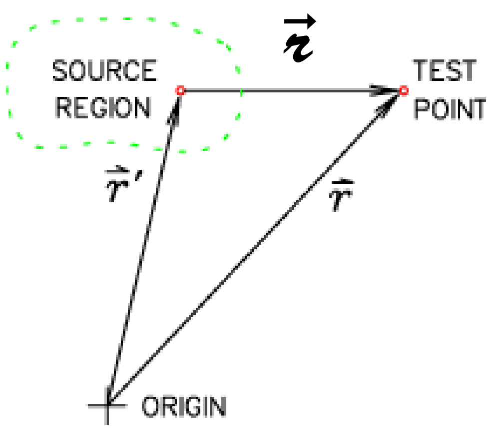
$$\vec{\mathscr{r}} = \vec{r} - \vec{r}\,' = (x - x')\hat{i} + (y - y')\hat{j} = (z - z')\hat{k}$$

Law of Biot & Savart

Magnetic field dB due to a current element $I d\ell$:



$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{\ell} \times \hat{\mathscr{r}}}{\mathscr{r}^2}$$



Magnetic field B due to a **continuous** current distribution:

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi} \iiint \frac{\vec{J}(\vec{r}\,') \times \hat{\mathscr{r}}}{\mathscr{r}^2}\, d\tau'$$

Coulomb ↔ Gauss & Biot-Savart ↔ Ampère

Coulomb's Law

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\epsilon_0} \iiint \frac{\rho(\vec{r}\,')\,\hat{\boldsymbol{\mathscr{r}}}}{\mathscr{r}^2}\, d\tau'$$

Law of Biot & Savart

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi} \iiint \frac{\vec{J}(\vec{r}\,') \times \hat{\boldsymbol{\mathscr{r}}}}{\mathscr{r}^2}\, d\tau'$$

div + simple vector calculus

div × . . .

curl + some hairy vector calculus

Gauss' Law

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_0} \qquad \vec{\nabla} \cdot \vec{B} = 0 \qquad \vec{\nabla} \times \vec{B} = \mu_0 \vec{J}$$

Gauss' Law

Stokes' theorem

Ampère's Law

$$\oiint \vec{E} \cdot d\vec{a} = \frac{1}{4\pi\epsilon_0} \iiint \rho\, d\tau = Q_{\text{encl}}$$

$$\oint \vec{B} \cdot d\vec{\ell} = \iint \vec{J} \cdot d\vec{a} = I_{\text{thr}}$$

(pre-Maxwell)