Wed. 9/9 Thurs 9/10 Fri. 9/11	*(C 13)* **Advertisement, 1.1.1-.1.2, 1.1.4, 1.3.1; 2.1.1-.1.3** The Electric Field**; T1** Simple Plots *(C 15)* **2.1.4** Continuous Charge Distributions	
Mon. 9/14 Wed. 9/16 Thurs 9/17	*(C 21.1-.5,.8)* **1.2, 2.2.1-.2.2** Gauss & Div, **T2** Numerical Quadrature *(C 21.1-.5,.8)* **2.2.2** Gauss & Div	 HW1

Equipment

- Ipod
- Vandergraff generator
- Aluminum ball on a string
- Syllabus
- Computational tutorial
- My schedule
- Whiteboards

Welcome – to Electricity and Magnetism, Phys 332

- **Today**
    - Usual 1st-Day-of-Class logistics
    - Actually getting started on the course material
    - Working on Simulation/Computational skills

LOGISTICS

- **Introduce Course**
    - **Where it fits in the curriculum.** In the great helix that is physics education, this is your second college-level pass through Electricity and Magnetism; if you go to physics or astronomy graduate school, you'll pass through yet again.
        - **Phys 232:** In your first pass, Phys 232, you got a firm
            - **conceptual** understanding
            - and a beginning at the **quantitative** modeling (both Analytical and Computational.)
        - **Phys 332:** Naturally that's grown a little dusty over the years, but hopefully it'll come back to you as we review (and I encourage you to look back at your intro text).
            - This time around, the largest emphasis will be on the **quantitative** modeling, but hopefully this revisit will also deepen your conceptual understanding.
            - We'll cover a little over half of the text.
    - **Demand.** I expect you all know what you're in for with an upper-level, theoretical physics course – it will be mathematically and conceptually demanding at times; I'd expect more frequently than Classical Mechanics but less frequently than Quantum.
    - **Syllabus:** hand-out
        - **Office Hours:** Hand-out survey sheet. Mark times that work for you. As you probably know, If I'm not in class or about to go to class, any time is fair game, whether it's officially my office hour or not.
        - **Texts:**
            - **Griffith's.** To the extent that anyone *likes* a text, Griffith's text tends to be a favorite; I hope you enjoy it. This is a brand-new edition, so while I expect all

the old Errata have been rectified, we'll have to keep our eyes out for new ones.

- **Policies and Expectations**
  - **General.** You're Jr's & Sr's – you know what it takes to do well in Physics, and you know how to identify and get what you need. So I'm structuring this course to support independently driven work.
  - **Reading.** As always, you'll get the most out of our time together if you've read and thought about the material beforehand. Thus…
  - **Discussion Prep.** By 8a.m. each lecture, have contributed to the Google Moderator site for the course.
    - You'll need a Google account to log in.
    - Ask questions, make requests / suggestions for what we do today.
    - If you see a question/suggestion up there that resonates with you (you've got the same question or request), you can vote it up. This way I know the difference between a question that just one person has (and maybe I should just communicate with that one person, outside of class) and a question that lots of folks have (and I should really address in class.)

- **Homework:** (hand-out) Here's what I anticipate assigning
  - 50% of your grade
    - 40% for problem sets
    - 10% for discussion prep
  - **Clarity.** I expect homework that clearly communicates your work, not just scratch work or results. Using proper notation is very important because it is impossible for me to distinguish between sloppy notation and lack of understanding (you should learn to communicate clearly!).
    - for *vectors*, use "arrow notation" ($\vec{E}$), instead boldface (**E**) like the textbook
    - *components* of vectors should be labeled with subscripts (E_x, E_y, E_z), but *not* arrows
    - *unit vectors* should also be used correctly ($\vec{E} = E_x\hat{x} + E_y\hat{y} + E_z\hat{z}$).
    - *scalars* (including *magnitudes* of vectors, like $E = \left|\vec{E}\right|$) should *not* be labeled as vectors
    - the *del operator* ($\vec{\nabla}$) is a vector operator so it should be labeled as a vector

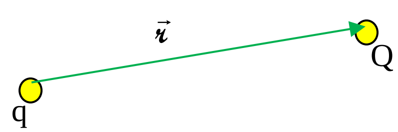
  - **Collaboration.** you guys will be each other's best resources in this class. I strongly encourage you to work together. Compare homework- it's much better for you to catch your mistake and correct it and understand than for me to catch it and grade it. Of course, what you do turn in must be your own (not a facsimile of the work of someone else who understands it better.)
  - **Computation.** All but one week, the homework requires computational work. The syllabus gives instructions for installing the necessary programs on your own machine (they're free); alternatively, they're available on this room's machines.

- **Exams:**
  - Three, non-cumulative, at 16.6% each, for 50%.
- **Schedule:**
  - **First section**: *Static charge* densities and *static electric* fields (and corresponding scalar electric potential)
  - **Second section:** *Static current* densities and *static magnetic* fields (and corresponding vector potential)
  - **Third section:** *time-varying charge and current* densities and their electric and magnetic fields.
  - **Note: Wed 2nd of Oct –** Summer Research Presentations. We coerced folks who did research this past summer to share their experiences with the rest of the department.

ACTUALLY GETTING STARTED ON THE COURSE MATERIAL

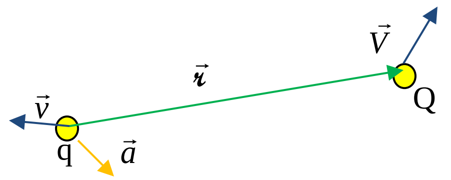
- **Tools for Studying Nature.**
  - Fundamentally, Physics is the study of motion and interactions. These are quite tangible; we experience them every day. Of course, English is too vague a language to contemplate as precisely as we'd like, so we define mathematical quantities to represent motion (momentum, kinetic energy) and interaction (force, work). It's worth emphasizing that motion and interaction are *facts of nature* while momentum and force are *conceptual/mathematical tools* – terribly useful, but defined, not discovered, and not altogether indispensable. If you took Quantum, you could have gone a whole semester without uttering "force", if you took Classical, you know the alternative tool of Lagrangians can just as soundly link motion and interaction.
  - I point this out because we're going to be spending an awful lot of time this semester talking about fields, which are themselves conceptual offshoots of forces – modeling not quite interactions, but the potential for interactions. Like Newton and Forces, the work of Coulomb and Faraday didn't so much lead to the "discovery" electric and magnetic fields as it did the "definition" of them.
  - I leave it to you to, over the course of the semester, ponder the philosophical question of "what distinguishes a defined 'concept' from a discovered 'object'?"
- **Electricity & Magnetism**
- **Overview.** The basic story in classical E & M is really, really simple.
  - There's some property, let's call it "charge" that comes in two flavors, let's say "+" and "-". Two particles with the same type of charge repel each other and two with opposite types attract. *All* of classical electrodynamics boils down to this.
  - Mathematically, if both charges are happily sitting around, in terms of forces, we'd model the interaction is simply as

$$\vec{F}_{Q\leftarrow q} = \frac{qQ}{4\pi\varepsilon_o}\frac{\vec{\mathscr{r}}}{\mathscr{r}^3} \quad \left(\text{note: } \frac{\vec{\mathscr{r}}}{\mathscr{r}^3} = \frac{\hat{\mathscr{r}}}{\mathscr{r}^2}\right)$$



- Of course, when particles are in motion, there are relativistic effects – what *they* "see" differs from what *we* "see" according to how they're moving. Allowing for this effect of motion, here's the force one charge, q, exerts on another one, Q.
- $$\vec{F}_{Q\leftarrow q} = \frac{qQ}{4\pi\varepsilon_o}\frac{\mathscr{r}}{(\vec{\mathscr{r}}\cdot\vec{u})^3}\left\{\left[(c^2 - v^2)\vec{u} + \vec{\mathscr{r}}\times(\vec{u}\times\vec{a})\right] + \frac{\vec{V}}{c}\times\left[\hat{\mathscr{r}}\times\left[(c^2 - v^2)\vec{u} + \vec{\mathscr{r}}\times(\vec{u}\times\vec{a})\right]\right]\right\}$$

  (10.74)



$\vec{u} \equiv c\hat{\mathscr{r}} - \vec{v}$

- True though that may be, as Bob the Builder says, 'you need the right tool for the job' if you want to make the job easy; this usually *isn't* the right tool. In fact, of this semester will be about *avoiding* using this tool, and we'll go to great lengths. It will be a few months before we find our way back to it. As Griffiths remarks when his text arrives at this equation "the entire theory of classical electrodynamics is contained in that equation…but you see why I preferred to start out with Coulomb's law."
- We start with a static charge distribution.

  - **Coulomb's Electric Force Law**:

    $$\vec{F}_{Q\leftarrow q} = \frac{1}{4\pi\varepsilon_o}\frac{qQ}{\mathscr{r}^2}\hat{\mathscr{r}}$$

$$\varepsilon_o = 8.85\times10^{-12}\frac{C^2}{N\cdot m^2}$$

so

$\frac{1}{4\pi\varepsilon_o} = 8.99 \times 10^9$ N m^2/C^2

- This is the force that holds atoms together, holds molecules together, holds you together and keeps you from falling through your chair. *Why* nature works this way, or *what* charge is, in some deeper sense, are open questions. So far any answers that may be posed generate still other questions.
- That there are two opposite flavors of charge, conveniently mathematically handled with + and – sings, means that this is can be attractive or repulsive depending on the 'flavors' involved.

The Electric Field

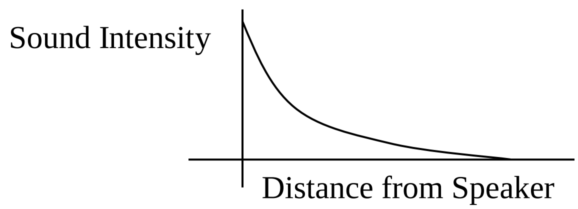
- **Action at a Distance**
  - The concept of a field gets a lot of use in Physics. We generally use it to help conceptualize at-a-distance interactions like gravitational and electrical ones. In these cases, objects pull or push on each other, without 'touching'; in fact, the Sun pulls on the Earth gravitationally though they sit 1.5×10^{11}m apart. Unfortunately, a remote

interaction is a bit hard to picture, and thus hard to conceptualize. In fact, they have a physical shortcoming of suggesting instantaneity. A Field, as a continuous intermediary, has the potential to rectify these problems.

- **Conceptual analogy of Sound**

Cue sound

  - Here's an analogy. There are speakers playing. There are ears hearing. In between, there's a perturbation of air that we physicists tend to call 'sound.' Though you're hearing the music at your specific location in space, you recognize that there is sound all through this room, even at places you are not, and if you went to those places, you'd hear it. *If* you went near the speaker, you'd hear it louder, *if* you went out the door, you'd hear it quieter. You can visualize where the sound is strongest and where it is weakest. What you're visualizing is a *sound field.*



Cut sound

  - Analogously, if we had a big electric charge here on the head of the Vandergraf Generator, without having to actually bring in another charge to feel its influence, you know it *would* feel it stronger nearby and weaker far away, you can visualize how the big electric charge conditions the space around it to interact with another charge. That's the *electric field*.

- **Apply Sound model to Action-at-a-distance**
  - If other action-at-a-distance situations had a *medium* like sound does, then, we could conceptualize the processes much like sound – a source driving a medium all around it, and a sensor somewhere getting buffeted by that medium.
  - **Gravitational Example:** For example, we would not picture the Sun 1.5×10^{11}m away invisibly tugging on the Earth, we would picture all space filled with some medium and the Sun disturbing it, like a speaker head disturbs the air, and the Earth being dragged by the medium's response. In fact, the picture would be much like the sun being a drain in a giant bathtub, as the water rushes toward the drain, it carries the Rubber Ducky of the Earth with it. Though there is no material medium performing this task, it's useful to *imagine* one. That imaginary breeze is called the **Gravitation Field** in classical models of gravitation.
  - **Electrical Example:**
    - **Demo: Vander Graff Generator and tin foil ball.**
      - Show the ball and the paper 'hair' being pushed out by electric interaction of charge on them with charge on Vander Graff.
    - Rather than thinking of the charge on the dome of the Vander Graff Generator as remotely pushing on the charge on the tinfoil ball, we can picture all space filled with some medium that mediates the interaction. The Dome's charge creates something like a wind that blows radially outward, the tinfoil ball is

caught in that breeze and so pushed out. We picture this breeze to exist everywhere around the dome, independent of where the ball is. That breeze is the **Electric Field**.

Definition.

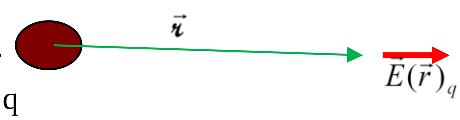
- This is a useful picture, but we can make it even more useful by making a precise mathematical definition**.** In our picture, the breeze is responsible for pushing the ball. Where we put the ball in the breeze should determine how big a force the ball feels. The mathematical description of the field should then tell us something like what the *force would be if we put our charged particle somewhere.*
  - $\vec{E}(r) \equiv \frac{\vec{F}(r)_{Q\leftarrow q}}{Q}$ The Electric Field at a point in space is the electric force a particle there with charge Q would feel, divided by its charge.
  - **Units:** N/Coul. (it has no special name of its own)

Point sources.

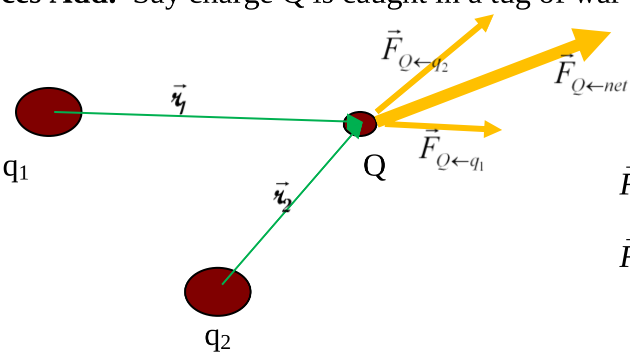
- So, returning to our point sources, the field *of charge q* at the location where Q happens to be is

$\vec{E}_q = \frac{1}{4\pi\varepsilon_o}\frac{q}{\mathscr{r}^2}\hat{\mathscr{r}}$ Whether Q is there

or not.



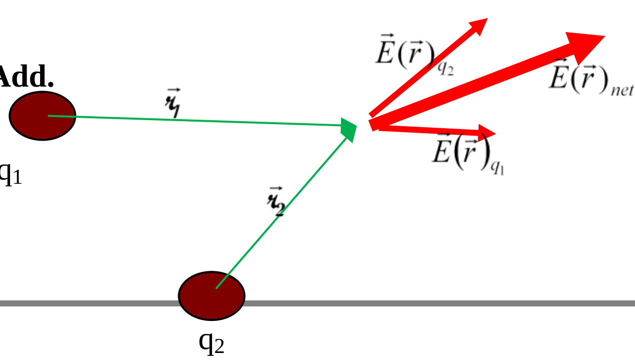
- **Superposition.**
  - Your intuition about fields inherits some of your intuition about forces. For example, forces, and hence fields, add like the vectors they are.
  - **Forces Add.** Say charge Q is caught in a tug of war between charges q_1 and q_2.



$$\vec{F}_{Q\leftarrow net} = \vec{F}_{Q\leftarrow q1} + \vec{F}_{Q\leftarrow q2}\cdots$$

$$\vec{F}_{Q\leftarrow net} = \frac{1}{4\pi\varepsilon_o}\frac{q_1 Q}{\mathscr{r}_1^2}\hat{\mathscr{r}}_1 + \frac{1}{4\pi\varepsilon_o}\frac{q_2 Q}{\mathscr{r}_2^2}\hat{\mathscr{r}}_2 + \ldots$$

  - **Fields Add.**



$$\vec{E}(\vec{r})_{net} = \vec{E}(\vec{r})_{q1} + \vec{E}(\vec{r})_{q2} \cdots$$

$$\vec{E}(\vec{r})_{net} = \tfrac{1}{4\pi\varepsilon_o}\frac{q_1}{\mathscr{r}_1^{\,2}}\hat{\mathscr{r}}_1 + \tfrac{1}{4\pi\varepsilon_o}\frac{q_2}{\mathscr{r}_2^{\,2}}\hat{\mathscr{r}}_2 + \ldots$$

Whiteboards

Exercises:

Problem 2.2

(a) Find the electric field (magnitude and direction) a distance *z* above the midpoint between two equal charges, *q*, a distanc *d* apart. Check that your result is consistent with what you'd expect when $z>>d$.

(b) Repeat part (a), only this time make the right-hand charge $-q$ instead of $+q$.

Problem 2.1

(a) Twelve equal charges, *q*, are situated at the corners of a regular 12-sided polygon (for instance, one on each numeral of a clock face). What is the net force on a test charge Q at the center?

(b) Suppose *one* of the 12 *q*'s is removed (the one at "6 o'clock"). What is the force on Q? Explain your reasoning carefully.

MATH Tools

Del Operator, Divergence, and Curl –

We didn't use it today, but very soon, and for much of the semester, you're going to be using the Del Operator. So we'll do a little review today. I expect that different folks have spent different amounts of time with the Del operator. All of you should have met it in Phys 232. Those of you who have had Phys 331 have gotten a little bit of practice with it. If you took Calc IV (Vector Calc), you should have gotten a good deal of practice with it.

The *del operator* is a vector operator – it has no value until applied to something:

$$\vec{\nabla} = \hat{x}\frac{\partial}{\partial x} + \hat{y}\frac{\partial}{\partial y} + \hat{z}\frac{\partial}{\partial z}$$

[*Gradient* – a derivative of a scalar that results in a vector, which is relate to the direction in which the function changes most quickly]

$$\vec{\nabla}T = \frac{\partial T}{\partial x}\hat{x} + \frac{\partial T}{\partial y}\hat{y} + \frac{\partial T}{\partial z}\hat{z}$$

Divergence – a derivative of a vector that results in a scalar, which is related to how much a vector field "diverges" from a point

$$\vec{\nabla}\cdot\vec{v}=\frac{\partial v_x}{\partial x}+\frac{\partial v_y}{\partial y}+\frac{\partial v_z}{\partial z}$$

Curl – a derivative of a vector that results in a vector, which is related to how much a vector field "curls around" a point

$$\vec{\nabla}\times\vec{v}=\begin{vmatrix}\hat{x} & \hat{y} & \hat{z}\\ \partial/\partial x & \partial/\partial y & \partial/\partial z\\ v_x & v_y & v_z\end{vmatrix}=\hat{x}\left(\frac{\partial v_z}{\partial y}-\frac{\partial v_y}{\partial z}\right)+\ldots$$

Whiteboard

Exercises:

1.15 ab – find the divergences of the following vector functions

(a) $\vec{v}_a=x^2\hat{x}+3xz^2\hat{y}-2xz\,\hat{z}$

$$\vec{\nabla}\cdot\vec{v}_a=\frac{\partial}{\partial x}\left(x^2\right)+\frac{\partial}{\partial y}\left(3xz^2\right)+\frac{\partial}{\partial z}-\left(2xz\right)=2x+0-2x=0$$

(b) $\vec{v}_b=xy\,\hat{x}+2yz\,\hat{y}+3zx\,\hat{z}$

$$\vec{\nabla}\cdot\vec{v}_b=\frac{\partial}{\partial x}\left(xy\right)+\frac{\partial}{\partial y}\left(2yz\right)+\frac{\partial}{\partial z}\left(3zx\right)=y+2z+3x$$

Note that the answers are scalar functions!

1.18 ab – find the curls of the functions above

(a)

$$\vec{\nabla}\times\vec{v}_a=\begin{vmatrix}\hat{x} & \hat{y} & \hat{z}\\ \partial/\partial x & \partial/\partial y & \partial/\partial z\\ x^2 & 3xz^2 & -2xz\end{vmatrix}=\hat{x}\left(0-6xz\right)+\hat{y}\left(0+2z\right)+\hat{z}\left(3z^2-0\right)=-6xz\,\hat{x}+2z\,\hat{y}+3z^2\,\hat{z}$$

(b)

$$\vec{\nabla}\times\vec{v}_b=\begin{vmatrix}\hat{x} & \hat{y} & \hat{z}\\ \partial/\partial x & \partial/\partial y & \partial/\partial z\\ xy & 2yz & 3zx\end{vmatrix}=\hat{x}\left(0-2y\right)+\hat{y}\left(0-3z\right)+\hat{z}\left(0-x\right)=-2y\,\hat{x}-3z\,\hat{y}-x\,\hat{z}$$

Note that the answers are vector functions!

Computational Tutorial – Simple Plots using Python

Have students go through the handout & try the exercise at the end

There is a problem that requires a plot in HW #1

Friday

Don't forget your Discussion Prep for Friday – 9a.m.

Preview

For Friday, you'll read about calculating electric fields for charge distributions. I strongly urge you to ignore Eqs. 2.6-2.8. It is better to start with a diagram and the summation equation (Eq. 2.4) when setting up an integral! Notice that is what is done in Example 2.1.

Should start working on HW #1 – we will finish all of the material for that on Monday (but most of it on Friday)