Physics 126

P. LeClair
OFFICIAL THINGS

• Dr. Patrick LeClair
  - leclair.homework@gmail.com
  - @pleclair on twitter
  - facebook/google+/etc
  - offices: 2050 Bevill, 323 Gallalee; lab: 1053 Bevill
  - 857-891-4267 (cell)

• Office hours:
  - MW 1-2pm, F 12-2pm in Gallalee 323
  - TuTh 1-3pm in Bevill 2050

• other times by appointment
OFFICIAL THINGS

Lecture/Lab:

• lecture in 329 Gallalee, labs in 112 Gallalee
• M-W 11-12:55

“Recitation”:

• F 11-11:55
• usually new material, but time spent on HW
**Misc. Format Issues**

- lecture and labs will be *somewhat* linked
- labs will mostly be ‘circuits’ and electronics
  - *practical* knowledge more than theory
  - will not bother with the traditional labs

- friday recitations: usually new material
- working in groups is encouraged *for homework*
**SOCIAL INTERACTION**

- we need you in groups of ~3 for labs to start with
- groups are not assigned ...
  - so long as they remain functional
  - even distribution of workload
Grading and so forth

- labs/exercises 15%
- homework 25%
  
given weekly via PDF
- quizzes
  
maybe. counts with HW
- 4 exams (15% each)
  
3 ‘hour’ exams
  
comprehensive (takehome) final
Homework

• new set every week, on course blog [pdf]
• problems due a week later (mostly)
• hard copy or email (e.g., scanned, cell pic) are OK
  Gallalee or Bevill mailbox
  at the start of class
• can collaborate - BUT turn in your own
• have to show your work to get credit.
1.

<table>
<thead>
<tr>
<th>Find / Given:</th>
<th>Sketch:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relevant equations:</th>
<th>Symbolic solution:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Numeric solution:</th>
<th>Double Check</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dimensions</td>
</tr>
<tr>
<td></td>
<td>Order-of-magnitude</td>
</tr>
</tbody>
</table>
QUizzes

• once and a while, there may be a quiz
• almost the same as current HW problems
• previous lecture’s material
• 5-10 min anticipated

• do the homework & reading, and it will be trivial
Labs / Exercises

- Labs will be very different...
  - Focus on learning how to build electronic stuff
  - Initially: focused labs to learn concepts & practice
  - Later: team project
- Inquiry-driven: usually no set procedure
- Some formal reports, mostly not
- Time is always critical...
  - Read carefully, work efficiently
STUFF YOU NEED

• textbook (Halliday & Resnick; get a used one)

• calculator

• paper & writing implement

• useful: flash drive, access to a computer you can install stuff on
USEFUL THINGS


For some material (e.g., optics and circuits) we will make use of supplemental online notes from PH102, which you can find there:

http://faculty.mint.ua.edu/~pleclair/ph102/Notes/

have the Feynman lectures in the undergrad lounge ...
SHOWING UP

• no make-up of in-class work or homework
  “acceptable” + documented gets you a BYE

• missing an exam is seriously bad.
  acceptable reason ... makeup or weight final

• lowest single lab, homework are dropped.

• Final is take-home, but you will have questions ...
  so stick around for a bit of finals week
INTERNETNS

• we have our own intertubes:
  - http://ph126.blogspot.com/
  - updated very often
  - comments allowed & encouraged
  - rss feed, integrated with twitter (#ua-ph126)

• google calendar (you can subscribe)

• Facebook group (find each other)
  - can add RSS feed of blog to facebook

• google+, it is the new shiny

• check blog & calendar before class
Quick advertisement:

Phy-EE double major

- Electrical and Computer Engineering majors need as few as 4 additional hours to complete a second major in Physics.
- This combination of fundamental and applied physics can be highly advantageous when the graduate enters the job market.
Today

- Vectors and vector functions

- Laws of E&M in brief

- Charge & electric forces in brief
Our friend the vector

• we will be doing terrible things with them this semester.

• vector = quantity requiring an arrow to represent
  – coordinate-free description
  – described by basis (unit) vectors of a coordinate system

• proper vectors are unchanged by coordinate transformations ...

Adding & subtracting vectors

• commutative, \( A+B = B+A \)
• associative, \( A + (B+C) = (A+B) + C \)
• subtracting = add negative (reverse direction)

• add head-tail geometrically (law of cosines)
• add by component (using unit vectors)
Geometrically:

\[ |\vec{a} + \vec{b}| = |\vec{a}| + |\vec{b}| - 2|\vec{a}||\vec{b}| \cos \theta \]

By components: first choose a basis/coordinate system

\[ \vec{a} = a_x \hat{x} + a_y \hat{y} \quad \vec{b} = b_x \hat{x} + b_y \hat{y} \]

\[ \vec{a} + \vec{b} = (a_x + b_x) \hat{x} + (a_y + b_y) \hat{y} \]

magnitude identical to geometric approach
Scalar multiplication

- Duh, the vector gets longer.
- By component:
  \[ c\vec{A} = ca_x\hat{x} + ca_y\hat{y} \]
- Geometrically: the arrow gets \( c \) times longer
- Distributive.
  \[ c \left( \vec{A} + \vec{B} \right) = c\vec{A} + c\vec{B} \]
Scalar ("dot") product

- product of vector A and the projection of B onto A
- scalar product of two vectors gives a scalar

\[ \mathbf{A} \cdot \mathbf{B} = a_x b_x + a_y b_y = |\mathbf{A}| |\mathbf{B}| \cos \theta_{AB} \]

- commutes, distributes

\[ \mathbf{A} \cdot \mathbf{B} = \mathbf{B} \cdot \mathbf{A} \quad \mathbf{A} \cdot (\mathbf{B} + \mathbf{C}) = \mathbf{A} \cdot \mathbf{B} + \mathbf{A} \cdot \mathbf{C} \]

- two vectors are perpendicular if and only if their scalar product is zero
Put another way, given two vectors, the angle between them can be found readily:

\[ \theta = \cos^{-1} \left( \frac{\mathbf{a} \cdot \mathbf{b}}{|\mathbf{a}| |\mathbf{b}|} \right) \]

Of course, this implies that if \( \mathbf{a} \) and \( \mathbf{b} \) are orthogonal (right angles), then

\[ \mathbf{a} \cdot \mathbf{b} = 0 \]

Moreover, two vectors are orthogonal (perpendicular) if and only if their dot product is zero, and they have non-zero length, providing a simple way to test for orthogonality. A few other properties are tabulated below, as well as the scalar product between unit vectors in different coordinate systems.

### Table 4: Algebraic properties of the scalar product

<table>
<thead>
<tr>
<th>Formula</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mathbf{a} \cdot \mathbf{b} = \mathbf{b} \cdot \mathbf{a} )</td>
<td>commutative</td>
</tr>
<tr>
<td>( \mathbf{a} \cdot (\mathbf{b} + \mathbf{c}) = \mathbf{a} \cdot \mathbf{b} + \mathbf{a} \cdot \mathbf{c} )</td>
<td>distributive</td>
</tr>
<tr>
<td>( \mathbf{a} \cdot (r\mathbf{b} + \mathbf{c}) = r(\mathbf{a} \cdot \mathbf{b}) + r(\mathbf{a} \cdot \mathbf{c}) )</td>
<td>bilinear</td>
</tr>
<tr>
<td>( (c_1 \mathbf{a}) \cdot (c_2 \mathbf{b}) = (c_1 c_2)(\mathbf{a} \cdot \mathbf{b}) )</td>
<td>multiplication by scalars</td>
</tr>
<tr>
<td>if ( \mathbf{a} \perp \mathbf{b} ), then ( \mathbf{a} \cdot \mathbf{b} = 0 )</td>
<td>orthogonality</td>
</tr>
</tbody>
</table>

### Table 5: Scalar products of unit vectors

<table>
<thead>
<tr>
<th>Cartesian</th>
<th>Spherical</th>
<th>Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{i} )</td>
<td>( \hat{\mathbf{r}} )</td>
<td>( \hat{R} )</td>
</tr>
<tr>
<td>( \hat{j} )</td>
<td>( \hat{\theta} )</td>
<td></td>
</tr>
<tr>
<td>( \hat{k} )</td>
<td>( \hat{\phi} )</td>
<td>( \hat{k} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \hat{i} )</td>
<td>( \sin \theta \cos \phi )</td>
<td>( \cos \theta \cos \phi )</td>
</tr>
<tr>
<td>( \hat{j} )</td>
<td>( \sin \theta \sin \phi )</td>
<td>( \cos \theta \sin \phi )</td>
</tr>
<tr>
<td>( \hat{k} )</td>
<td>( -\sin \phi )</td>
<td>( -\sin \phi )</td>
</tr>
</tbody>
</table>

Vector products:

The `cross` or vector product between these two vectors results in a pseudovector, also known as an `axial vector`.

An easy way to remember how to calculate the cross product of these two vectors, \( \mathbf{P} \), is by using the determinant of a matrix:

\[ \mathbf{P} = \begin{vmatrix} \mathbf{\hat{i}} & \mathbf{\hat{j}} & \mathbf{\hat{k}} \\ \mathbf{a}_x & \mathbf{b}_x & \mathbf{c}_x \\ \mathbf{a}_y & \mathbf{b}_y & \mathbf{c}_y \end{vmatrix} \]

Pseudovectors act just like real vectors, except they gain a sign change under improper rotation. See for example, the Wikipedia page `Pseudovector`. An improper rotation is an inversion followed by a normal (proper) rotation, just what we are doing when we switch between right- and left-handed coordinate systems. A proper rotation has no inversion step, just rotation.
vector ("cross") product

- product of vector A and B, gives 3rd vector perpendicular to A-B plane

\[ |\vec{A} \times \vec{B}| = |\vec{A}||\vec{B}| \sin \theta_{AB} \]
\[ \vec{A} \times \vec{B} = \vec{A}\vec{B} \sin \theta_{AB} \hat{n} \]

- Distributes, does **NOT** commute

\[ \vec{A} \times (\vec{B} \times \vec{C}) = (\vec{A} \times \vec{B}) + (\vec{A} \times \vec{C}) \]
\[ \vec{A} \times \vec{B} = - (\vec{B} \times \vec{A}) \]
familiarize yourself with these things later ...

<table>
<thead>
<tr>
<th>formula</th>
<th>relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \vec{a} \times \vec{b} = -\vec{b} \times \vec{a} )</td>
<td>anticommutative</td>
</tr>
<tr>
<td>( \vec{a} \times (\vec{b} + \vec{c}) = (\vec{a} \times \vec{b}) + (\vec{a} \times \vec{c}) )</td>
<td>distributive over addition</td>
</tr>
<tr>
<td>( (r\vec{a}) \times \vec{b} = \vec{a} \times (r\vec{b}) = r(\vec{a} \times \vec{b}) )</td>
<td>compatible with scalar multiplication</td>
</tr>
<tr>
<td>( \vec{a} \times (\vec{b} \times \vec{c}) + \vec{b} \times (\vec{c} \times \vec{a}) + \vec{c} \times (\vec{a} \times \vec{b}) = 0 )</td>
<td>not associative; obeys Jacobi identity</td>
</tr>
<tr>
<td>( \vec{a} \times (\vec{b} \times \vec{c}) = \vec{b}(\vec{a} \cdot \vec{c}) - \vec{c}(\vec{a} \cdot \vec{b}) )</td>
<td>triple vector product expansion</td>
</tr>
<tr>
<td>( (\vec{a} \times \vec{b}) \times \vec{c} = -\vec{c} \times (\vec{a} \times \vec{b}) = -\vec{a}(\vec{b} \cdot \vec{c}) + \vec{b}(\vec{a} \cdot \vec{c}) )</td>
<td>triple vector product expansion</td>
</tr>
<tr>
<td>( \vec{a} \cdot (\vec{b} \times \vec{c}) = \vec{b} \cdot (\vec{c} \times \vec{a}) = \vec{c} \cdot (\vec{a} \times \vec{b}) )</td>
<td>triple scalar product expansion†</td>
</tr>
<tr>
<td>(</td>
<td>\vec{a} \times \vec{b}</td>
</tr>
<tr>
<td>if ( \vec{a} \times \vec{b} = \vec{a} \times \vec{c} ) then ( \vec{b} = \vec{c} ) iff ( \vec{a} \cdot \vec{b} = \vec{a} \cdot \vec{c} )</td>
<td>lack of cancellation</td>
</tr>
</tbody>
</table>
vector ("‘cross’") product

• ‘perpendicular’ direction not unique!
  choice of ‘handedness’ or chirality. we pick RH.

\[
\begin{align*}
\hat{i} \times \hat{j} &= \hat{k} & -\hat{\mathbf{r}} &= \hat{\mathbf{c}} \times \hat{s} \\
\hat{j} \times \hat{k} &= \hat{i} & -\hat{s} &= \hat{\mathbf{r}} \times \hat{\mathbf{c}} \\
\hat{k} \times \hat{i} &= \hat{j} & -\hat{\mathbf{c}} &= \hat{s} \times \hat{\mathbf{r}}
\end{align*}
\]

cross products are not the same as their mirror images
Because of ‘handedness’ choice, cross products do not transform like true vectors under inversion.

- e.g., coordinate systems

\[ \hat{x} \times \hat{y} = \hat{z} \]

- cannot make RH into LH by proper rot.
- requires an inversion too (mirror flip)
- rotation + sign change required

- lack of invariance under improper rotation makes it a pseudovector or axial vector
- i.e., you need an axis of rotation to make sense of it.
- e.g., torque, magnetic field
• when we see cross products ...
  - somewhere, there is an axis of rotation
  - the problem is inherently 3D

• cross product of two ‘normal’ polar vectors = axial vector
  - polar = velocity, momentum, force
  - axial = torque, angular momentum, magnetic field

• axial vector = handedness = RH rule required
• axial vector doesn’t change properly in a mirror
  - e.g., angular momentum of car wheels reflected in a mirror

• if there is no change when reflected in a mirror ... polar!
(polar) \times (polar) = (axial)

\mathbf{r} \times \mathbf{p} = \mathbf{L} \quad \text{(angular momentum)}

(axial) \times (axial) = (axial)

\mathbf{\Omega} \times \mathbf{L} = \tau \quad \text{(gyroscope)}

(polar) \times (axial) = (polar)

\mathbf{v} \times \mathbf{B} = \mathbf{F} \quad \text{(magnetic force)}

(any) \cdot (any) = (scalar)

(polar) + (axial) = (neither) !!!
• cyclic permutation encodes chirality ...

\[ \mathbf{c} = \mathbf{a} \times \mathbf{b} \]

\[
\mathbf{c} = \begin{vmatrix}
\hat{i} & \hat{j} & \hat{k} \\
a_x & a_y & a_z \\
b_x & b_y & b_z
\end{vmatrix} = \begin{vmatrix}
a_y & a_z \\
b_y & b_z
\end{vmatrix} \hat{i} + \begin{vmatrix}
a_z & a_x \\
b_z & b_x
\end{vmatrix} \hat{j} + \begin{vmatrix}
a_x & a_y \\
b_x & b_y
\end{vmatrix} \hat{k}
\]

\[
= (a_y b_z - a_z b_y) \hat{i} + (a_z b_x - a_x b_z) \hat{j} + (a_x b_y - a_y b_x) \hat{k}
\]

• xyz, yzx, zxy = + \; \; \; \; yxz, xzy, zyx = -

• know and love this little trick

• note ... one can use the cross product to find the vector normal to a given plane

\[ \hat{n} = \frac{\mathbf{A} \times \mathbf{B}}{|\mathbf{A} \times \mathbf{B}|} \]
Vector triples ... key identities that will come up often.

\[ \mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = (\text{vec}) \cdot (\text{vec} \times \text{vec}) = \text{vec} \cdot \text{vec} = \text{scalar} \]

\[ \mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = \mathbf{B} \cdot (\mathbf{C} \times \mathbf{A}) = \mathbf{C} \cdot (\mathbf{A} \times \mathbf{B}) \]

cyclic permutation! break it, and pick up a minus sign

\[ \mathbf{A} \cdot (\mathbf{B} \times \mathbf{C}) = -\mathbf{B} \cdot (\mathbf{A} \times \mathbf{C}) \]

(also, the volume of a parallelepiped)
component form is nicely simple in matrix notation

\[
\vec{A} \cdot (\vec{B} \times \vec{C}) = 
\begin{vmatrix}
  a_x & a_y & a_z \\
  b_x & b_y & b_z \\
  c_x & c_y & c_z \\
\end{vmatrix} =
(a_x b_y c_z - a_x b_z c_y) + (a_y b_z c_x - a_y b_x c_z) + (a_z b_x c_y - a_z b_y c_x)
\]

\[
xyz, \ yzx, \ zxy = + \quad \text{yxz, xzy, zyx} = -
\]
distributes, associates, etc, and this works too:

\[
\vec{A} \cdot (\vec{B} \times \vec{C}) = (\vec{A} \times \vec{B}) \cdot \vec{C}
\]

this is nonsense though. why?

\[
(\vec{A} \cdot \vec{B}) \times \vec{C}
\]
vector triple

\[ \vec{A} \times (\vec{B} \times \vec{C}) = \vec{B} (\vec{A} \cdot \vec{C}) - \vec{C} (\vec{A} \cdot \vec{B}) \neq (\vec{A} \times \vec{B}) \times \vec{C} \]

vec scal vec scal

“BAC-CAB” rule
it will come up; this reduction formula is handy

a reminder that X does not commute
we remember how to define positions & directions
infinitesimal displacements along a path

\[(x, y, z) \rightarrow (x + dx, y + dy, z + dz)\]

described by a infinitesimal vector

\[d\vec{l} = dx \hat{x} + dy \hat{y} + dz \hat{z}\]

depends on coordinate system

\[d\vec{l} = dr \hat{r} + r \sin \theta \ d\theta \hat{\theta} + r \ dr \ d\theta \hat{\phi} \quad \text{(spherical)}\]
cartesian \( x, y, z \)
cylindrical \( R, \phi, z \)
spherical \( r, \theta, \phi \)
in E&M, we often have a SOURCE point and a FIELD point
we are interested in quantities depending on their separation

(where stuff is) \( \vec{r}' \) \( \vec{r} \) \( \vec{i} = \vec{r} - \vec{r}' \)

(where you are) \( \vec{r} \)

separation vector
(between you & stuff)

like in physics 1: the origin can be in an arbitrary place

you are interested in how far you are from stuff
\( r = \) from origin to you
\( r' = \) from origin to stuff
difference = from stuff to you!
we need two new concepts to deal with vector fields.

but only two!

(1) Flux

(2) Circulation
Flux?

basically, the net flow of a quantity through a region
e.g., liquid flux: liters/sec through a pipe of diameter $d$

Need to define a flow and a surface!

(Flux) = (average normal component)(surface area)

$$\Phi_{\text{water}} = (\rho \vec{v} \cdot \hat{n}) A$$

net flux through a closed region:
must be a source or sink inside!
Net flux through circle - more arrows leave than enter

\[ \vec{F} = \frac{\hat{r}}{r^2} \]
Area = \( A' = A \cos \theta \)

both surfaces have the same flux!
net ‘flow’ of a vector field out of a closed region

(a) all $S$ have same flux

(b) all have zero flux
all that enters leaves

net 'flow' of a vector field out of a closed region
Circulation?

Just what you think it is: is the field ‘swirling’ at all? Does it circulate?
Given some loop, is there net rotation?

E.g., stirred pot
there is no net flux
there is a circulation

circulation = (average tangential speed around a loop)(circumference)

pick a loop in the field, and find the average tangential velocity
if it is nonzero, the field circulates!
net CCW tangential velocity
angular velocity about z axis

\[ \vec{F}(x, y) = -y \hat{x} + x \hat{y} \]
E&M: all about flux and circulation of E & B

(flux of E through a closed surface) = $\frac{(\text{net charge inside})}{\varepsilon_o}$

(flux of B through any closed surface) = 0

given a curve C bounding a surface S:

(circulation of E around C) = $\frac{d}{dt}$ (flux of B through S)

$c^2$ (circulation of B around C) = $\frac{d}{dt}$ (flux of E through S) + $\frac{(\text{flux of electric current through S})}{\varepsilon_o}$
So how to do this quantitatively?

We need vector derivatives for that. Later.
The laws of classical physics, in brief

1. Motion

\[
\frac{d\vec{p}}{dt} = \vec{F}
\]

where

\[
\vec{p} = \frac{m\vec{v}}{\sqrt{1 - v^2/c^2}}
\]

Newton, with Einstein’s modification

2. Gravitation

\[
\vec{F} = -G \frac{m_1 m_2}{r^2} \hat{r}_{12}
\]
3. Conservation of charge

\[ \nabla \cdot \vec{j} = - \frac{d\rho}{dt} \]

(flux of current through closed surface) = - (rate of change of charge inside)

any conservation of stuff:

(\text{net flow of stuff out of a region}) = (\text{rate at which amount of stuff inside region changes})
4. Maxwell’s equations

\[ \nabla \cdot \vec{E} = \frac{\rho}{\varepsilon_r \varepsilon_0} \quad \text{(flux of E thru closed surface) = (charge inside)} \]

\[ \nabla \cdot \vec{B} = 0 \quad \text{(flux of B thru closed surface) = 0} \]

\[ \nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \quad \text{(circulating E) = (time varying B)} \]

\[ \text{(line integral of E around loop) = -(change of B flux through loop)} \]

\[ \epsilon_0 c^2 \nabla \times \vec{B} = \vec{j} + \varepsilon_r \frac{\partial \vec{E}}{\partial t} \]

\[ \text{(circulating B) = (time varying E)} \]

\[ \text{(integral of B around loop) = (current through loop) + (change of E flux through loop)} \]
4. Maxwell’s equations (alt)

\[ \mathbf{\nabla} \cdot \mathbf{E} = \frac{\rho}{\epsilon_r \epsilon_0} \]
Gauss: electric charge = source of electric fields

\[ \mathbf{\nabla} \cdot \mathbf{B} = 0 \]
There are no magnetic charges

\[ \mathbf{\nabla} \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]
Faraday: time-varying B makes a circulating E

\[ \epsilon_0 c^2 \mathbf{\nabla} \times \mathbf{B} = \mathbf{j} + \epsilon_r \frac{\partial \mathbf{E}}{\partial t} \]
Ampere: currents and time-varying E make B

5. Force law

\[ \mathbf{F} = q \mathbf{E} + q \mathbf{v} \times \mathbf{B} \]
And that’s all of it!

Of course, the solutions are tougher ... but we have a whole semester for that.
electrostatics

or, electric forces when nothing is moving.
Summarizing the properties of charge:

1. Charge is quantized in units of $|e| = 1.6 \times 10^{-19}$ C
2. Electrons carry one unit of negative charge, $-e$
3. Protons carry one unit positive charge, $+e$
4. Objects become charged by gaining or losing electrons, not protons
5. Electric charge is always conserved

**Table 3.1: Properties of electrons, protons, and neutrons**

<table>
<thead>
<tr>
<th>Particle</th>
<th>Charge [C]</th>
<th>$[e]$</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron ($e^-$)</td>
<td>$-1.60 \times 10^{-19}$</td>
<td>-1</td>
<td>$9.11 \times 10^{-31}$</td>
</tr>
<tr>
<td>proton ($p^+$)</td>
<td>$+1.60 \times 10^{-19}$</td>
<td>+1</td>
<td>$1.67 \times 10^{-27}$</td>
</tr>
<tr>
<td>neutron ($n^0$)</td>
<td>0</td>
<td>0</td>
<td>$1.67 \times 10^{-27}$</td>
</tr>
</tbody>
</table>
a) before

b) contact

c) after

charged rubber rod
“Little pieces of tissue paper (or light grains of sawdust) are attracted by a glass rod rubbed with a silk handkerchief (or by a piece of sealing wax or a rubber comb rubbed with flannel).”

- from a random 1902 science book
neutral metal sphere

b) charged rubber rod

d)
\begin{align*}
q_1 &\quad F \\
q_2 &\quad F
\end{align*}

\begin{align*}
+ &\quad \hat{r}_{12} \\
+ &\quad r_{12}
\end{align*}
2. Three point charges lie along the $x$ axis, as shown at left. A positive charge $q_1 = 15 \, \mu C$ is at $x = 2 \, m$, and a positive charge of $q_2 = 6 \, \mu C$ is at the origin. Where must a negative charge $q_3$ be placed on the $x$-axis **between the two positive charges** such that the resulting electric force on it is zero?
2. Three point charges lie along the \(x\) axis, as shown at left. A positive charge \(q_1 = 15 \, \mu C\) is at \(x = 2\, m\), and a positive charge of \(q_2 = 6 \, \mu C\) is at the origin. Where must a negative charge \(q_3\) be placed on the \(x\)-axis between the two positive charges such that the resulting electric force on it is zero?

\[
\sim 0.77\, m \text{ from } q_2
\]

or

\[
\sim 1.23\, m \text{ from } q_1
\]
equal charges

field: $A > B > C$
opposite charges
“dipole”

e.g.,
LiF & HF
unequal
like
unequal unlike
6. A circular ring of charge of radius has a total charge of uniformly distributed around it. The magnitude of the electric field at the center of the ring is:

\[ |E| = \frac{kq}{r^2} \]

\[ |E| = \frac{kq}{(R+r)^2} \]

\[ |E| = \frac{kq}{R^2} \]

\[ |E| = \frac{kq}{r^2} \]

\[ \text{none of these.} \]

7. Two isolated conducting spheres have a charge of \( q \) and \(-3q\), respectively. They are connected by a conducting wire, and after equilibrium is reached, the wire is removed such that both spheres are again isolated. What is the charge on each sphere?

\[ q, -3q \]

\[ -q, -2q \]

\[ 0, -2q \]

\[ -q, 0 \]

\[ -2q, q \]

8. An electric point charge \(+q\) is placed exactly at the center of a hollow conducting sphere of radius \( R \). Before placing the point charge, the conducting sphere had zero net charge. What is the magnitude of the electric field outside the conducting sphere at a distance \( r \) from the center of the conducting sphere?

\[ |E| = \frac{kq}{r^2} \]

\[ |E| = \frac{kq}{(R+r)^2} \]

\[ |E| = \frac{kq}{R^2} \]

\[ |E| = \frac{kq}{r^2} \]

\[ \text{none of these.} \]

9. Which set of electric field lines could represent the electric field near two charges of the same sign, but different magnitudes?

\[ \square \text{a} \]

\[ \square \text{b} \]

\[ \square \text{c} \]

\[ \square \text{d} \]
3.10 Questions

6. A circulator ring of charge of radius has a total charge of uniformly distributed around it.

The magnitude of the electric field at the center of the ring is:

\[ |E| = \frac{kq}{r^2} \]

7. Two isolated dielectric conductive spheres have a charge of \( q \) and \( -3q \), respectively. They are connected by a conducting wire, and after equilibrium is reached, the wire is removed such that both spheres are again isolated. What is the charge on each sphere?

\[ q, -3q \]

8. An electric charge of \( +q \) is placed exactly at the center of a hollow conducting sphere of radius \( R \). Before placing the point charge, the conducting sphere had zero net charge.

What is the magnitude of the electric field outside the conducting sphere at a distance \( r \) from the center of the conducting sphere?

\[ |E| = \begin{cases} \frac{kq}{r^2} & r > R \\ \frac{kq}{(R+r)^2} & r \leq R \end{cases} \]

9. Which set of electric field lines could represent the electric field near two charges of the same sign, but different magnitudes?

- a
- b
- c
- d

Dr. LeClair

PH102/Geophysical Physics I

[diagram with electric field lines]
10. Referring again to the figure above, which set of electric field lines could represent the electric field near two charges of opposite sign and different magnitudes?

- a
- b
- c
- d
10. Referring again to the figure above, which set of electric field lines could represent the electric field near two charges of *opposite sign* and *different magnitudes*?

- [ ] a
- [ ] b
- [ ] c
- [ ] d
both surfaces have the same flux!

Area = \( A' = A \cos \theta \)