Welcome to Physics 122

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Content: Electricity & Magnetism

Format: Active Learning (Learn from Participation)

» PreLectures & Checkpoints (FlipIt Physics)
» Lectures (Presentations, demonstrations & clickers)
» Homework (Webassign)
» Tutorials (concepts in depth)
» Labs (hands-on interactions with the phenomena)
Web and Grading Policy

• Bookmark our Homepage (on canvas).
• Syllabus
  – Links to other aspects of course (FlipIt Physics, WebAssign, …)
  – PDFs of Lecture slides will be linked there after each lecture
  – Policy statements
  – Exam prep / follow-up items

• Grading Policy (just like 121). Grade is achievement based. Earn the points, get the grade. Many points are earned by just doing the work (HW, Clickers, FlipIt Physics, Lab work …)

1000 point system

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
<th>Points</th>
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<tbody>
<tr>
<td>Midterms (best 2 of 3)</td>
<td>35%</td>
<td>350</td>
</tr>
<tr>
<td>Final Exam</td>
<td>24%</td>
<td>240</td>
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<tr>
<td>Lab Section</td>
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<td>130</td>
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<tr>
<td>Tutorial Section</td>
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<tr>
<td>Lecture HW</td>
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<tr>
<td>FlipIt Physics</td>
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</tr>
<tr>
<td>Clickers</td>
<td>5%</td>
<td>50</td>
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PHYS 122 A: Electromagnetism

Instructor:

- Paul A. Wiggins (profw@uw.edu) (122A)
- Office hours: 3-4 PM Tuesday PAB409

Required course textbooks:

- Tipler-Mosca, "Physics for Scientists and Engineers", 6th edition (Custom edition for UW. However, some of you may find a cheaper/used copy of the standard version of the 6th edition and that is fine as well);
- McDermott and Shaffer "Tutorials in Introductory Physics, 2nd ed."
- PHYS 122 Lab Manual.

Recommended additional readings:

- The Feynman Lectures on Physics, Vol II, by Feynman, Leighton, Sands
- The Flying Circus of Physics, by Jearl Walker

Required Equipment/Packages:

- H-ITT Clicker (Not the same as biology and chemistry)
- FlipIt Physics (Course ID 1579089c)
- WebAssign
• “extended” deadline until Friday
The World According to Classical Mechanics (Physics 121)

- **Objects**
  - 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
E&M: It Wasn't That Easy

• Greeks
  - amber (fossil resin of pine trees) known as νλεκτρον (elektron). eg Plato (4th century BC) "wonderful attracting power of amber and the Heraclean stone"

• Gilbert (De Magnete .. 1600)
  - Electrical effects due to emission of a material effluvium.. no action at a distance

• DuFay (1733)
  - Two distinct electricities: vitreous and resinous
  - Like electricities repel; unlike electricities attract

• Franklin (1750)
  - One electrical fluid: excess ⇒ positive (vitreous) deficient ⇒ negative (resinous)
A scientific revolution...

- Physics in 1800s:
  - Electricity: Electric fish, lightning & static electricity.
  - Magnetism: Magnetite & the compass
  - Light (& other EM radiation)
... the great unification

- 1820: Electricity + Magnetism = Electromagnetism
- 1865: Electromagnetism + Light
- 1905: Newton → Special Relativity
Where Does Our Study Start?

• The Phenomena
  • Fur on rubber ⇒ rubber → negative
  • Silk on glass ⇒ glass → positive

• The Concept
  • Electric Charge
    • Attribute of body
    • Unlike charges attract
    • Like charges repel
Coulomb’s Law:

The force on a charge due to another charge is proportional to the product of the charges and inversely proportional to the separation squared.

\[ F \propto \frac{q_1 q_2}{r^2} \]

The force is always parallel to a line connecting the charges, but the direction depends on the signs of the charges:

- Opposite signs attract
- Like signs repel
Coulomb Law

\[ \vec{F}_{1,2} = \frac{k q_1 q_2}{r_{1,2}^2} \hat{r}_{1,2} \]

- \( \vec{F}_{1,2} \): Force applied by charge 1 on charge 2
- \( q_1, q_2 \): Charges of object 1 and 2
- \( k \): A physical constant
- \( \hat{r}_{1,2} \): Displacement vector connecting point 1 to 2
From FlipIt Physics...

The direction of the force.

There are two equations in the book, \((kq_1q_2/r^2)r\) and \((kq_1q_2)/(r^2)\). Which one do we use?

\[
\vec{F}_{1,2} = \frac{k q_1 q_2}{r_{1,2}^2} \hat{r}_{1,2}
\]
Coulomb Law

Charles-Augustin de Coulomb

\[ \vec{F}_{1,2} = \frac{k q_1 q_2}{r_{1,2}^2} \hat{r}_{1,2} \]

Examples:

If the charges have the same sign, the force by charge 1 on charge 2 would be in the direction of \( r_{12} \) (to the right).

If the charges have opposite sign, the force by charge 1 on charge 2 would be opposite the direction of \( r_{12} \) (left).

\[ k = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2 \]
Principle of Superposition

The net force on a charge of the sum of the forces

\[ \vec{F}_{i,\text{Net}} = \sum_{j \neq i} \vec{F}_{j,i} \]
The World According to Physics 122

- Things -- Bodies and Fields (E,B)
  - Specified by geometry and mass and charge
- Forces
  - Gravity: \( \vec{F} = -G \frac{m_1 m_2}{r^2} \hat{r} \)
  - Electromagnetic: \( \vec{F} = q \vec{E} + q \vec{v} \times \vec{B} \)
- Space and Time
  - Euclidean with Lorentz Invariance
    - “ordinary space” but can be really really fast...
The World According to Physics 122

• Bodies and Fields (E,B)
• Forces
• Space and Time

We’ll have fun with all of this stuff. See you next time!
Let’s start with a Clicker question

- A charged ball \( Q_1 \) is placed next to another charged ball \( Q_2 \) which is connected to a string. \( Q_2 \) comes to equilibrium at angle \( \theta \) as shown.

- From this observation, we can already learn something about the nature of the electrical force \( F_E \) exerted by \( Q_1 \) on \( Q_2 \).

- Example, what is the sign of each component of the force; ie, \( F_{Ex} \) and \( F_{Ey} \)?

1a:  
A) \( F_{Ex} < 0 \)  
B) \( F_{Ex} > 0 \)  
C) Cannot determine sign of \( F_{Ex} \) from this information

1b:  
A) \( F_{Ey} < 0 \)  
B) \( F_{Ey} > 0 \)  
C) Cannot determine sign of \( F_{Ey} \) from this information
A charged ball $Q_1$ is placed next to another charged ball $Q_2$ which is connected to a string. $Q_2$ comes to equilibrium at angle $\theta$ as shown.

1a: A) $F_{Ex} < 0$
   B) $F_{Ex} > 0$
   C) Cannot determine sign

Two forces act on $Q_2$
- its weight ($mg$)
- the tension ($T$) in the string

$T$ has an $x$-component; $mg$ does not.

Equilibrium: the net force on $Q_2$ must be zero

The electrical force ($F_E$) must at least have an $x$-component to cancel the $x$-component of the tension ($T$).

Therefore, B) $F_{Ex} > 0$
Now consider $F_{Ey}$.

1b: A) $F_{Ey} < 0$
B) $F_{Ey} > 0$
C) Cannot determine sign

$T$ and $mg$ have $y$-components of opposite sign, so at first glance it may look like we can say nothing about $F_{Ey}$. 
Now consider $F_{Ey}$

1b:  
A) $F_{Ey} < 0$  
B) $F_{Ey} > 0$  
C) Cannot determine sign

$T$ and $mg$ have y-components of opposite sign, so at first glance it may look like we can say nothing about $F_{Ey}$.

Remember that the Electrical Force has a positive x component...
Now consider $F_{Ey}$

1b:  
A) $F_{Ey} < 0$  
B) $F_{Ey} > 0$  
C) Cannot determine sign

$T$ and $mg$ have $y$-components of opposite sign, so at first glance it may look like we can say nothing about $F_{Ey}$.

Remember the Electrical Force has a positive $x$ component…

Assume, a *CENTRAL* force. It acts along the white line connecting the two charges

B) $F_{Ey} > 0$
Follow-up thoughts

Is this a reasonable assumption?

What if there was NO $F_{Ey}$ ???

Then, the only force $Q_2$ feels from $Q_1$ is to the right…$T_y$

and $mg$ balance

You could argue: C) Cannot determine the sign

Assumes, some preferred direction in space.

Not likely

But stay tuned. Non-Central Forces will invade our study soon!
A) “The Coulomb force is based on $k$ multiplied by $q \cdot Q$ divided by $r^2$. Therefore, $Q$ would exert a greater force than $q$ and since $Q$ and $q$ have the same signs, they repel each other.”

B) “due to Newton’s 3rd law, the forces acting on the charges will have the same magnitude, but opposite directions.”

C) “Since the charge on the right is ten times greater than the charge on the left it will exert a force that is 10 times greater than the other charge”
A charged ball $Q_1$ is fixed to a horizontal surface. Another charged ball $Q_2$ is brought near. It achieves equilibrium at a distance $d_{12}$ above $Q_1$.

$Q_1$ is replaced by $Q_3$, and $Q_2$ achieves equilibrium at $d_{23} (< d_{12})$.

Assume the electrical force is a Central Force, which ...

increases if the magnitude of one of the charges increases, and

increases if the distance between the charges is decreased.
2 Questions

A charged ball $Q_1$ is fixed to a horizontal surface. Another charged ball $Q_2$ is brought near $Q_1$. It achieves equilibrium at a distance $d_{12}$ above $Q_1$.

$Q_1$ is replaced by $Q_3$, and $Q_2$ achieves equilibrium at $d_{23}$ ($< d_{12}$).

1st: A) The charge of $Q_3$ has the same sign of 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 $Q_3$ & $Q_1$

2nd: 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 $Q_3$ & $Q_1$
Solution

A charged ball $Q_1$ is fixed to a horizontal surface. Another charged ball $Q_2$ is brought near. It achieves equilibrium at a distance $d_{12}$ above $Q_1$.

$Q_1$ is replaced by $Q_3$, and $Q_2$ achieves equilibrium at $d_{23}$ ($< d_{12}$)

- Force increases if the magnitude of one of the charges increases
- Force increases if the distance between the charges is decreased

1st:

A) The charge of $Q_3$ has the same sign of 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 $Q_3$ & $Q_1$

- Equilibrium $\rightarrow$ the total force on $Q_2$ must be zero.
- Only known force acting on $Q_2$ is its weight.
- The electrical force on $Q_2$ must be directed upward to cancel its weight.
- Therefore, the sign of $Q_3$ must be the SAME as the sign of $Q_1$
Solution

A charged ball $Q_1$ is fixed to a horizontal surface. Another charged ball $Q_2$ is brought near it. It achieves equilibrium at a distance $d_{12}$ above $Q_1$.

$Q_1$ is replaced by $Q_3$, and $Q_2$ achieves equilibrium at $d_{23}$ ($< d_{12}$).

- Force increases if the magnitude of one of the charges increases.
- Force increases if the distance between the charges is decreased.

2\textsuperscript{nd}:

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 $Q_3$ & $Q_1$

- The electrical force on $Q_2$ must be the same in both cases …
  \[ \rightarrow \] it just cancels the weight of $Q_2$.

- Since $d_{23} < d_{12}$ the charge of $Q_3$ must be SMALLER than the charge of $Q_1$ so that the total electrical force can be the same!!
In which Case is the magnitude of the net force on the center charge bigger?

A) Case 1

B) Case 2

C) They are the same

D) The answer depends on the sign of the charge in the center q

A) In case 2, the charges have the same signs so the net force is zero. On the other hands, in Case 1, the charges have different signs. Therefore the net force is not zero.

B) The magnitude of the net force on the center would be bigger for case two because both particle is positively charge, compared to the positive and negative which would attract to each other without q and have a net force of 0.

C) Newtons third law explains that all forces must be equal and opposite and therefore they are all the same.

D) Because if q is positive, it has a net force pointing down in case 1 and a net force of zero in case 2; if q is negative, it has a net force pointing up in case 1 and a net force of zero in case 2.
Four charged particles are placed on a circular ring with radius 3 m as shown below. A particle with charge $Q$ is placed in the center of the ring.

Which of the following statements best describes $F_x$, the x component of the net force on the charge at the origin?

A) $F_x > 0$  
B) $F_x = 0$  
C) $F_x < 0$
Four charged particles are placed on a circular ring with radius 3 m as shown below. A particle with charge $Q$ is placed in the center of the ring.

What is vertical force on $Q$?

A) $F_y > 0$  B) $F_y = 0$  C) $F_y < 0$

A) “The single 3q-charged particle has a greater Force on q in the y direction than the three q-charged particles.”

B) “Since net force is zero, $F_y = 0$”

C) “The 3q charge is stronger in the y direction compared to the three q charges because 2 of their forces are also directed in the x direction making their impact in the y direction less.”