Practical: HW 2 is due tonight at 11:59 PM
Office hour Tuesday 3:45-4:30 Serin 287 (Busch)
BEFORE CLASS:
ASK ME ABOUT PRELECTURE QUESTIONS
PLAY WITH GLASS, PLASTIC, WOOL TO GET
A REPULSIVE FORCE AT A DISTANCE

congratulations on 5/5 (as of 2:15) Abraham, Baldha, Cohen, Dias, Dormer, Gandhi, Geib, Hu, Huang, Jhaveri, Kanagala, Kershaw, Klecha, Lai, McKeown, Meer, Naphtali, Natarajan, Ning, Nonna, Parikh, P. Patel, Paul, Pugh, Rattan, Reyes, Rivera, Rondel, S. Shah, Song, Suresh, Toth, Uchil, Vidal, Yal, Zimmerman

2/6/2017 Phys 272
Chapter 17

Doppler effect for sound waves
Source S emits a wavecrest every $T = 1/f$ seconds.
The wavecrests move towards the detector with speed $v$.
Apparent frequency $f' = 1/T'$ where $T'$ is the time interval between arrival of consecutive wavecrests at the detector.

If source and detector are not moving, every wavecrest travels the same distance from S to D. Consecutive crests will arrive at intervals of $T$ and the apparent frequency is $1/T = f$. 

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If the source moves **towards** the detector, each wavecrest travels a **shorter** distance from S to D than the one before. The wavecrests will arrive at intervals of $T' < T$ and the apparent frequency is $1/T' = f' > f$.

For each wavecrest, the distance decreases by $v_S T$. $T' = T - v_S T/v = ((v-v_S)/v)T$ $f' = 1/T' = (v/(v-v_S))f$
If the source moves away from the detector, each wavecrest travels a longer distance from S to D than the one before. The wavecrests will arrive at intervals of $T' > T$ and the apparent frequency is $\frac{1}{T'} = f' < f$.

For each wavecrest, the distance increases by $v_S T$. 

\[
T' = T + \frac{v_S T}{v} = \left(\frac{v+v_S}{v}\right)T
\]

\[
f' = \frac{1}{T'} = \left(\frac{v}{v+v_S}\right)f
\]
If the detector moves away from the source each wavecrest travels a longer distance from S to D than the one before.
The wavecrests will arrive at intervals of $T' > T$ and the apparent frequency is $1/T' = f' < f$.

How does $f'$ depend on $v_D$?
When crest arrives, D is at $x_1$, travels at $v_D$.
Next crest starts at $x_1 - \lambda$, travels at $v$

$$x_1 + T' v_D = x_1 - \lambda + T' v \Rightarrow T' = \lambda/(v-v_D) \text{ and } f' = ((v-v_D)/v)f$$
If the detector moves towards the source, each wavecrest travels a shorter distance from S to D than the one before. The wavecrests will arrive at intervals of $T' < T$ and the apparent frequency is $1/T' = f'>f$.

$$f' = \left(\frac{v-v_D}{v}\right)f$$
If both the source and the detector are moving, the measured frequency is 

\[ F' = \left(\frac{v \pm v_D}{v \pm v_S}\right)f \]

- Important: source and detector speed is measured relative to the air (ie the medium in which the sound propagates).
- Word problems: identify the source and the detector
Transform to a reference frame in which the air is at rest then use the expression we found before.
If both the source and the detector are moving, the measured frequency is

\[ F' = \frac{(v +/- v_D)/(v +/- v_S)} f \]

- Important: source and detector speed is measured relative to the air (i.e., the medium in which the sound propagates).

- Word problems: identify the source and the detector
Example: A bat flies towards a cave at 50 m/s while emitting a 20 kHz screech. What frequency will it hear for the echo from the cave?
Example: A bat flies towards a cave at 50 m/s while emitting a 20 kHz screech. What frequency will it hear for the echo from the cave?

\[ f' = \frac{fv}{v - v_s} \]

\[ f'' = f'\left(\frac{v + v_D}{v}\right) \]

“Double Doppler effect”
Example: A bat flies towards a cave at 50 m/s while emitting a 20 kHz screech. What frequency will it hear for the echo from the cave?

Formula: \( f'' = \frac{(v+v_{bat})}{(v-v_{bat})}f \)

Answer: 26.8 kHz
I swing the Doppler ball in a circle around my head. We know what YOU hear. What do I hear?

(a) The same as you (alternating higher/lower)
(b) Constant frequency, same as the Doppler ball at rest.
(c) Constant frequency, higher than the Doppler ball at rest.
(d) Constant frequency, lower than the Doppler ball at rest.
I swing the Doppler ball in a circle around my head. We know what YOU hear. What do I hear?

(a) The same as you (alternating higher/lower)
(b) Constant frequency, same as the Doppler ball at rest.
(c) Constant frequency, higher than the Doppler ball at rest.
(d) Constant frequency, lower than the Doppler ball at rest.
Electricity and magnetism

Focus on fields as fundamental entities
Electric field $\vec{E}(\vec{r})$
Magnetic field $\vec{B}(\vec{r})$

First example of a unified theory
Electromagnetism

\[ \nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0} \]

\[ \nabla \cdot \mathbf{B} = 0 \]

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]

\[ \nabla \times \mathbf{B} = \mu_0 \mathbf{j} + \frac{1}{c^2} \frac{\partial \mathbf{E}}{\partial t}. \]

Maxwell’s equations:
fields \( \mathbf{E}(r) \) and \( \mathbf{B}(r) \), charge \( \rho(r) \), current \( \mathbf{j}(r) \)

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}). \]
Electromagnetism

\[ \oint \vec{E} \cdot d\vec{A} = q_{\text{enc}}/\varepsilon_0 \quad \oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \]

\[ \oint \vec{B} \cdot d\vec{A} = 0 \quad \oint \vec{B} \cdot d\vec{s} = \mu_0\varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0i_{\text{enc}} \]

Maxwell’s equations: fields, charge, current

\[ \mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) . \]
Electrostatics: HRW Chapter 21-25

\[ \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{enc}}}{\varepsilon_0} \quad \oint \vec{E} \cdot d\vec{s} = 0 \]

Maxwell’s equations: electric field & charge

\[ \vec{F} = q \vec{E} \]
A new force

plastic/glass rubbed with wool
A new force

Gravity \hspace{2cm} \text{new force}
Acts at a distance \hspace{1.5cm} \text{Acts at a distance}
Attractive \hspace{2.5cm} \text{Attractive AND repulsive}
very small \hspace{3cm} \text{easy to make large}
Proportional to mass \hspace{3cm} \text{proportional to charge}

Charge, like mass, is a scalar property of objects/particles.
Mass is positive
Charge can be positive or negative

Masses attract \hspace{2cm} \text{Like charges repel}
                  opposite charges attract
Force laws for two point particles

Law of gravity
Force on particle 2 due to particle 1 is directly towards particle 1
Magnitude depends on inverse square of separation

Law of electric force (Coulomb’s law)
Force on particle 2 due to particle 1 is along line connecting them
Magnitude depends on inverse square of separation
Towards particle 1 if \( q_1 q_2 < 0 \), away if \( q_1 q_2 > 0 \)

Unit of charge is Coulombs (C)
\[ k = 8.99 \times 10^9 \text{ N m}^2/\text{C}^2 \]
Force on particle 1 due to particle 2 satisfies Newton’s 3rd law
SUPERPOSITION: forces due to other particles add like vectors

\[ F = \frac{k q_1 q_2}{r^2} \]
What is the direction of the net force on the middle particle, if the particles on the x axis are equidistant from the origin?
Four particles with identical charges $q$ are arranged as shown below. In which of the three arrangements is the magnitude of the net electric force LARGEST?
Force exerted by a uniform shell

on a particle **outside** the shell

A uniform spherical shell of matter attracts a particle that is outside the shell as if all the shell’s mass were concentrated at its center.

A shell of uniform charge attracts or repels a charged particle that is outside the shell as if all the shell’s charge were concentrated at its center.

on a particle **inside** the shell

A uniform shell of matter exerts no net gravitational force on a particle located inside it.

If a charged particle is located inside a shell of uniform charge, there is no net electrostatic force on the particle from the shell.
Clicker: Three spherical shells with different radii but the same uniform charge $q$ are shown. Rank them according to the magnitude of the net electric force at $P$, greatest first.

(A) $a$, $b$, $c$
(B) $b$, $c$, $a$
(C) All equal
(D) $b$ equals $c$, then $a$
Clicker: Three spherical shells with different radii but the same uniform change $q$ are shown. Rank them according to the magnitude of the net electric force at $P$, greatest first.

(A) a, b, c  
(B) b, c, a  
(C) All equal  
(D) b equals c, then a
Can a charged object exert an electric force on a neutral object?

Let’s do the experiment

$+q$
Can there be an electric force between a charged object and a neutral object?

Object can have charged regions and still have net charge = 0
Simple example where net force is not zero

Let’s do the experiment at the other end
Materials are made out of charged particles:
Positively charged atomic nuclei
Negatively charged electrons

Nuclei move away from external positive charge
electrons move towards from external charge
External charge induces rearrangement of charges in an object

-qt +q

electrons

Atomic nuclei
Can there be an electric force between a charged object and a neutral object?

Induced charge rearrangement leads to a net force
Iclicker: what is the direction of the force for a negative external charge?

- $-q$

(A) towards the external charge
(B) away from the external charge
(C) the force is zero
(D) cannot determine without more information
Iclicker: what is the direction of the force for a negative external charge?

(A) towards the external charge
(B) away from the external charge
(C) the force is zero
(D) cannot determine without more information
DEMO: Force on a neutral 2x4

CHARGED OBJECTS AND SPARKS – gas station video
Gravity vs electric force

<table>
<thead>
<tr>
<th>Gravity</th>
<th>electric force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acts at a distance</td>
<td>Acts at a distance</td>
</tr>
<tr>
<td>Attractive</td>
<td>Attractive AND repulsive</td>
</tr>
<tr>
<td>Proportional to mass</td>
<td>proportional to charge</td>
</tr>
<tr>
<td>Central</td>
<td>central</td>
</tr>
<tr>
<td>Inverse square law</td>
<td>inverse square law</td>
</tr>
<tr>
<td>Mass is not conserved</td>
<td>charge is conserved</td>
</tr>
<tr>
<td>Mass is not quantized</td>
<td>charge is quantized in units of e</td>
</tr>
</tbody>
</table>

\[ e = 1.602 \times 10^{-19} \text{ C.} \]
21.5 Charge is Quantized

<table>
<thead>
<tr>
<th>Particle</th>
<th>Symbol</th>
<th>Charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>e or e−</td>
<td>−e</td>
</tr>
<tr>
<td>Proton</td>
<td>p</td>
<td>+e</td>
</tr>
<tr>
<td>Neutron</td>
<td>n</td>
<td>0</td>
</tr>
</tbody>
</table>

Elementary particles either carry no charge, or carry a single elementary charge.

\[ e = 1.602 \times 10^{-19} \text{ C.} \]
21.6 Charge is Conserved

In any process, the net electric charge stays constant!

**Example 1:** *Radioactive decay of nuclei,* in which a nucleus transforms into (becomes) a different type of nucleus.

\[ ^{238}\text{U} \rightarrow ^{234}\text{Th} + ^{4}\text{He}, \]

**Example 2:** An electron \( e^- \) (charge \(-e\)) and its antiparticle, the positron \( e^+ \) (charge \(+e\)), undergo an annihilation process, transforming into two gamma rays (high-energy light):

\[ e^- + e^+ \rightarrow \gamma + \gamma \quad \text{(annihilation).} \]

**Example 3:** A gamma ray transforms into an electron and a positron.

\[ \gamma \rightarrow e^- + e^+ \quad \text{(pair production).} \]