WELCOME!
Please grab a Handout from the back & look over pages 2-4.
Welcome to Physical Sciences 2

- What will we be learning this semester in PS2?

Mechanics: moving objects
Elasticity - tendons
Fluids - blood
Diffusion - chem. rxn in body

Force
impulse

Surface tension

Viscosity

1 μm
Pre-Reading for Class 1a: Vectors, Velocity, and Momentum

Read this while you wait... much of it may be review; we will cover it briefly in class.

- One of the most important concepts in PS2 is the concept of a vector. You can think of a vector as being like an arrow—something that has a direction, and a magnitude (or length). Here are a bunch of vectors, with various magnitudes and directions:

You can move a vector around on the page (or anywhere really) and it will always be the same vector—as long as it keeps the same magnitude and direction! Here are a bunch of vectors that are all identical:

Here are some vectors that all have the same magnitude but different directions:

And here are some vectors that all have the same direction but different magnitudes:

- We use vectors to represent physical quantities that require both a magnitude and a direction. For instance, we use vectors to describe the velocity of an object. In physics, the word "velocity" means both the speed and direction that an object is moving. So we need a vector to describe velocity:

  The magnitude of a velocity vector tells you the speed of an object: how fast is it going? (Note that the magnitude is always positive.)

  The direction of a velocity vector tells you the direction of motion: in what direction is it moving?

  Speed can be described using any convenient units, like miles per hour or meters per second. Direction can be specified in many ways—for instance, "north" or "east."
Physical Sciences 2: Class 1a

- One way to specify a vector is by using a coordinate system—typically, a set of $x$- and $y$-axes with a coordinate grid. Here is an example:

<table>
<thead>
<tr>
<th>A vector points from the tail to the head.</th>
</tr>
</thead>
<tbody>
<tr>
<td>To describe a vector, you need to tell me how long it is and in what direction it is pointing.</td>
</tr>
<tr>
<td>It's important to remember that the vector is the same no matter where it is: all four arrows drawn on this graph represent the same vector.</td>
</tr>
<tr>
<td>For this vector, going from the tail to the head means:</td>
</tr>
<tr>
<td>Move 5 steps in the $+x$ direction and 2 steps in the $-y$ direction</td>
</tr>
<tr>
<td>so the components are $(x, y) = (5, -2)$</td>
</tr>
<tr>
<td>Since it doesn't matter where you place a vector, if you place its tail at the origin of your coordinate system, then the coordinates of the head will be equal to the components of the vector: the head here is at coordinates $(5, -2)$</td>
</tr>
</tbody>
</table>

- In contrast to a vector, an ordinary number is called a scalar (pronounced SKAY-ler). We must distinguish vectors from scalars in our equations. If something is a vector, we will write it with a little arrow above it:

$$\vec{a} \text{ is a vector} \quad a \text{ is a scalar}$$

(In your textbook, vectors are distinguished by boldface type: $a$ is a vector.)

- Given a vector $\vec{v}$, we will use subscripts to indicate its components:

$$\text{For the vector } \vec{v}, \text{ the } x\text{-component is } v_x, \text{ and the } y\text{-component is } v_y.$$    

So in the example pictured above, the vector $\vec{v}$ has $v_x = 5$ and $v_y = -2$. Note that the components of a vector are ordinary scalars (numbers)!

- The magnitude of a vector can be found from its components using the Pythagorean theorem:

$$\text{The magnitude of } \vec{v} \text{ is written as } |\vec{v}|, \text{ and is equal to } \sqrt{v_x^2 + v_y^2}$$

- Since the magnitude of a vector is a scalar, we will often use $v$ (without an arrow!) to represent the magnitude $|v|$. So it is extremely important to use the arrow for vectors—if there’s no arrow, the letter alone means the magnitude of the vector!
Adding and Subtracting Vectors; Unit Vectors

• Suppose I tell you that $\vec{c} = \vec{a} + \vec{b}$. 

What does this mean mathematically?

Keeping in mind for any vector it's components can be written $\vec{v} = (v_x, v_y)$

$\vec{c} = (c_x, c_y) = (a_x + b_x, a_y + b_y)$

What does this mean graphically?
If one places the vectors $\vec{a}$ and $\vec{b}$ head to tail (no matter the order), then the vector from the free tail to the free head is the vector $\vec{c}$.

• Now suppose that $\vec{c} = \vec{a} - \vec{b}$.

What does this mean mathematically?

$\vec{c} = (c_x, c_y) = (a_x - b_x, a_y - b_y)$

What does this mean graphically?
If one places the vectors $\vec{a}$ and $\vec{b}$ tail to tail then the vector from the head of $\vec{b}$ to the head of $\vec{a}$ is vector $\vec{c}$.

• **Unit vectors** are very useful. Given any coordinate system, we can define:
  $\hat{x}$ : a vector that points in the $+x$ direction with unit length. It's equivalent to $(1,0)$.
  $\hat{y}$ : a vector that points in the $+y$ direction with unit length. It's equivalent to $(0,1)$.

So, for example a vector with components $\vec{a} = (-2, 3)$ is equal to $\vec{a} = -2\hat{x} + 3\hat{y}$.
Introduction

- Our course philosophy and approach to teaching:
  - We are all on the same team
  - Active learning in class

• Learning objectives: After this class, you will be able to...

1. Draw arrows (vectors) to represent quantities that have both magnitude and direction. Give examples of physical quantities that require a vector representation.

2. Describe a vector using its magnitude and angle with respect to an axis, or using its components in a coordinate system. Convert between these two representations.

3. Use vectors to determine the mean electrical axis of the heart from an EKG.

4. Add or subtract vectors graphically, and using components. Show how unit vectors can be used to construct a vector from its components.

5. Describe the position of an object using its position vector, and use vector subtraction to calculate the displacement vector.

6. Calculate the average velocity of an object, and compare average velocity with the instantaneous velocity.

7. Calculate the average speed of an object, and compare speed versus velocity.
Physical Sciences 2: Mechanics, Elasticity, Fluids, and Diffusion Harvard University, Fall 2019

Tu, Th 9:00–10:15am, Science Center B
Website: https://canvas.harvard.edu/courses/59512

Instructor: Dr. Greg Kestin (Science Ctr 201e) See course website for office hours

Preceptor: Dr. Dmitriy Beznosko (Science Ctr 117c) See course website for office hours

Head Staff:
Head Admin. TF: Bryan Janson - bryanjanson@gmail.com
Head Lab TF: Mingyue Chen - chen06@fas.harvard.edu
Head Section TF: Olivia Miller - omiller01@g.harvard.edu

Have questions?:
Administrative/Scheduling Questions PhysicalSciences23Harvard@gmail.com
Physics/Assignment Questions Help room or office hours
Email your TF (emails listed on course website)

For other issues email:
PhysicalSciences23Harvard@gmail.com
kestin@fas.harvard.edu
dbeznosko@fas.harvard.edu

Sectioning:
Please select your section and lab times on the Canvas course website. The deadline for requesting sections is NOON on Friday, Sept. 6. Any requests after that deadline will be considered on a space-available basis. For questions about sectioning, please contact Head TF Bryan Janson, bryanjanson@gmail.com.

Course Text:
Knight, Physics for Scientists and Engineers, 4th edition. ISBN: 978-0321752949. We consider this text to be recommended, not required. It is really just a reference.

Online Homework:
We will be using Sapling Learning for homework assignments and additional tutorials. Information to register and purchase a subscription will be posted on Canvas. One semester costs $42; a full year of access (for Physical Sciences 2 and 3) costs $64. If you earn 90% of the points on a sapling assignment, you will get full credit for that assignment.

Course Description:
An introduction to classical mechanics, with special emphasis on the motion in fluids of biological objects, from proteins to people. Topics covered include: momentum and energy conservation, kinematics, Newton's laws of motion, oscillations, elasticity, fluids, random walks, and diffusion. Examples and problem set questions will be drawn from the life sciences and medicine.

Placement Information:
PS 2 and 3 offer a calculus-based introduction to physics, with many examples and key topics drawn from the life sciences and medicine.

Examination Dates:
TBD (week of Sept. 30)  Midterm 1  time TBD
TBD (week of Nov. 11)  Midterm 2  time TBD

Course Grading:
Midterm Exam 1 15%  Note: There will be no makeup exams.
Midterm Exam 2 15%  If you miss one exam for a valid reason, your final exam score will be used in place of the missed exam.
Final Exam 30%  Note: Your lowest problem set will be dropped.
Problem Sets 15%  Note: Any missed labs will receive a grade of zero.
Laboratory 15%
Graded exams will be returned in discussion sections. Any concerns about grading errors must be noted in writing and submitted to your TF in person before leaving the classroom. Once an exam has left the classroom its grade will be considered final.

Course participation includes in-class activities, pre-class quizzes, and other activities designed to help you learn. We will tell you the correct answers for every problem, so you can earn full credit for every activity. If you earn 90% of the participation points you will get full credit for participation; anything less will be prorated accordingly.

**Prerequisites:**
Calculus at the level of Mathematics 1b (may be taken concurrently).

**Accessible Education:**
Any student receiving accommodations through the Accessible Education Office should present their AEO letter to the Head TF by Friday, Sept. 15. Failure to do so may prevent us from making appropriate arrangements for the first exam.

**Discussion Sections:**
Discussion sections (75 min.) meet on Thu. and Fri. starting Sept. 5; you will choose your section with the online sectioning program. For questions about sectioning, contact the Head TF, bryanjanson@gmail.com.

**Problem Sets:**
Problem sets will be posted on the Sapling website each Thursday and will be due the following Thursday before lecture (by 9:00am). The written portions of each assignment must be placed in the TF boxes outside Sci Ctr 108. Late problem sets will not be accepted, but we will drop your lowest problem set grade. Collaboration on problem sets is allowed, but you must acknowledge your collaborators, and you may not simply copy answers: the final write-up must be your own work. Collaboration on examinations is not allowed.

**Help Room:**
Teaching Fellows will be available to help with problem sets. The Physics Help Room is open in Science Center 106 on Tuesdays 6pm--10pm and in Science Center 102 on Wednesdays 4pm–10pm, starting the second week of the semester (see course site for added help room and office hours).

**Laboratory:**
Laboratory experiments are an integral part of the course: your understanding of lab will be tested on problem sets and on exams. Lab sessions meet in Sci Ctr 115 on Tues., Wed., and Thurs. from 1:30-4:15 and 6:00-8:45pm, and Fri. from 9am-noon during the weeks indicated on the schedule below (Note: not every week). You should sign up for a lab time using the online sectioning program. Attendance and participation is required. Questions about scheduling labs should be sent to the Head Lab TF, chen06@fas.harvard.edu.
Activity 1: Vectors, Angles, and Components

1. The arrow below represents the velocity vector (\( \vec{v} \)) of a baseball. The length of the arrow represents how fast the ball is moving (its speed), while the direction of the arrow represents the direction of the ball. Draw several other arrows representing (hint: see pre-reading):
   - (a) The same velocity vector
   - (b) The same speed, but different directions
   - (c) The same direction, but different speeds

   \[ \vec{v} \]

2. Another vector \( \vec{v} \) below is drawn on graph paper with coordinate axes (x and y). Draw the same vector so that its tail (the end without the arrow) is located at the origin of the coordinate system. Then estimate:
   - (a) The length of that vector (each square is one unit) 5.5
   - (b) The angle between that vector and the x-axis
   - (c) The angle between that vector and the y-axis

What is the most concise way you could describe this vector over the phone (i.e. without drawing anything)?

\[ \text{right 5 down 2} \]
\[ \text{length 5.5} \quad \beta = -120^\circ \quad \theta = -30^\circ \quad (\text{from x-axis}) \]

Draw a different vector on the graph somewhere, describe it to your classmates (without showing it!), and see if they can reconstruct the vector using only your description.
Activity 1 (continued)

3. For the same vector \( \vec{v} \) (drawn again below), determine the x-component and the y-component of the vector. Then calculate the magnitude of the vector (see pre-reading).

The x-component is: \( v_x = 5 \)

The y-component is: \( v_y = -2 \)

The magnitude is: \[ |\vec{v}| = \sqrt{v_x^2 + v_y^2} = \sqrt{5^2 + (-2)^2} = \sqrt{29} \approx 5.4 \]

\( \vec{v} \) in terms of unit vectors is: \( \vec{v} = 5 \hat{i} - 2 \hat{j} \)

4. **Bonus!** Given the rotated coordinate axes shown below, estimate the x- and y-components of the indicated velocity vector.

Scale: 1 m/s

\[ \vec{v} \approx (1.5, -1) \text{ m/s} \]
Vectors in Medicine

Vectors and components are crucial tools for analyzing EKG’s...

There are many signals (leads) recorded on an ECG. Let’s look at two:

Lead I:
\[ \text{(x-component)} \]

Lead aVF:
\[ \text{(y-component)} \]

The large “peak” on the ECG tells about the mean electrical axis of the heart.

When the heart contracts, an electrical signal propagates through the heart muscle. The mean electrical axis is a vector \( \mathbf{H} \) that points in the direction of this electrical signal.

The two leads shown above give the components of this vector \( \mathbf{H} \).

What is the direction of the mean electrical axis for the patient shown here?

Be careful about the direction of the \( y \)-axis (aVF)!
Position, Velocity, and Speed

1. The position vector $\vec{r}$ is a vector from the origin of the coordinate system to the location of the object. Draw position vectors for the initial position and final position of the ball.

2. The displacement $\Delta \vec{r}$ is the difference between the final and initial positions: $\Delta \vec{r} = \vec{r}_f - \vec{r}_i$. Draw the overall displacement vector between the two positions from question 1 above.

3. The average velocity $\langle \vec{v} \rangle$ during an interval is defined as: $\langle \vec{v} \rangle = \frac{\Delta \vec{r}}{\Delta t}$

   If this photograph was captured at 25 images per second, estimate the average velocity of the basketball during the duration of this image. (A basketball has a diameter of 23 cm.)

   $\langle \vec{v} \rangle = \frac{\Delta \vec{r}}{\Delta t} = \frac{(115 \text{ cm}, 8 \text{ cm})}{13.25 \text{ s}} = (22, 15) \text{ cm/s}$

4. The average speed $\langle v \rangle$ of an object is a scalar (not a vector!) defined as the total distance traveled divided by the total time. Estimate the average speed of the basketball during the duration of this image.

   $\langle v \rangle = \frac{\text{total dist (along path)}}{\Delta t} = \frac{238 \text{ cm}}{13.25 \text{ s}} = 457 \text{ cm/s}$

5. Bonus! The instantaneous velocity $\vec{v}$ at any time is defined as the average velocity over a very short time interval (strictly speaking, in the limit that the interval approaches zero). Draw some vectors on the image to represent the instantaneous velocity of the ball at various times.


Am I getting it?

- I’m going to start at the origin and walk 6 meters in the +x direction at a speed of 2 m/s. Then I’ll run back to where I started at a speed of 6 m/s.

1. What is my position vector \( \vec{r} \) after walking (before I turn around)? Choose all that are correct.
   
   a) \( \vec{r} = 6 \text{ m} \)  
   b) \( \vec{r} = (0 \text{ m}, 6 \text{ m}) \)  
   c) \( \vec{r} = (6 \text{ m}, 0 \text{ m}) \)  
   d) \( \vec{r} = (6 \text{ m})\hat{x} \)  
   e) \( \vec{r} = (6 \text{ m})\hat{x} + (0 \text{ m})\hat{y} \)  
   f) \( \vec{r} = 6\hat{x} \)  
   g) \( \vec{r} = 6\hat{x} + 0\hat{y} \)  

2. What is my average velocity \( \langle \vec{v} \rangle \) during the entire trip (walking and running back)? Choose all that are correct.
   
   a) \( \langle \vec{v} \rangle = 3 \text{ m/s} \)  
   b) \( \langle \vec{v} \rangle = 0 \text{ m/s} \)  
   c) \( \langle \vec{v} \rangle = (0 \text{ m/s})\hat{x} \)  
   d) \( \langle \vec{v} \rangle = (0 \text{ m/s}, 3 \text{ m/s}) \)  
   e) \( \langle \vec{v} \rangle = (0 \text{ m/s}, 0 \text{ m/s}) \)  
   f) \( \langle \vec{v} \rangle = 0 \text{ m/s} \)  

3. What is my average speed \( \langle v \rangle \) during the entire trip (walking and running back)? Choose all that are correct.
   
   a) \( \langle v \rangle = 3 \text{ m/s} \)  
   b) \( \langle v \rangle = 4 \text{ m/s} \)  
   c) \( \langle v \rangle = 0 \text{ m/s} \)  
   d) \( \langle v \rangle = (3 \text{ m/s}, 0 \text{ m/s}) \)  
   e) \( \langle v \rangle = 0 \)  

\[
\frac{12 \text{ m}}{4 \text{ s}} = 3 \text{ m/s}
\]

Bonus! For each of the following equations, write an equivalent equation (or equations!) involving the vector components. (x and y components will be sufficient)