PHSY221 Lab 2 – Vectors

Labs are done individually this week.

Each student will submit their own lab report.

You may work with a lab partner, but you will have different given values.

Pre-Lab is on last page of the Manual and must be compled and submitted at the beginning of your lab session.

Instructional Goals:

Goals:

- Hands-on practice using vectors:
  - Converting between magnitude and direction to component vectors and vice-versa.
  - Vector addition.
- Introduction to weight as a force.

What You Turn In:

- Turn in the Pre-Lab portion of this lab within the first five minutes of your lab start time.
- A complete apparatus sketch, description and procedure. Your data table and calculations and accompanying diagrams.

Background Reading:

Background reading for this lab can be found in textbook.

Equipment provided by the on-site lab:

- Force Table with four pulleys
- Small ring with four attached strings
- Four weight hangers
- Set of masses
- Protractors
- Paper to draw vectors

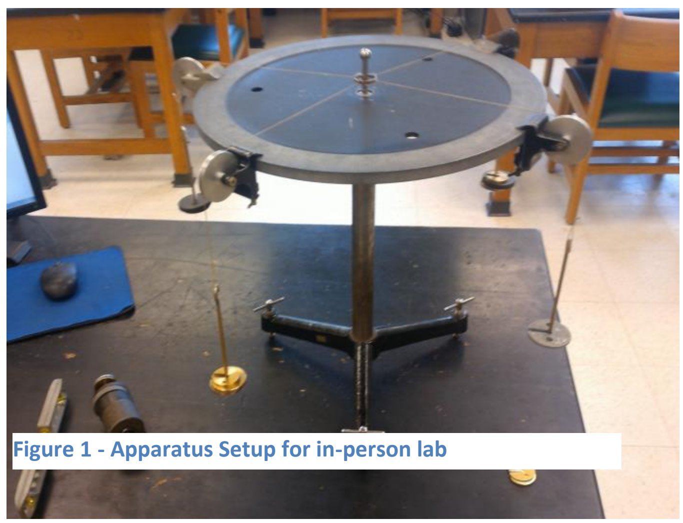


Figure 1 - Apparatus Setup for in-person lab

Equipment provided by the student:

- PC/Mac with Internet connection and Zoom
- Ruler, Protractor
- Pen, Calculator

Background:

When describing physical quantities, we use different mathematical structures. The first is a scalar. A scalar is simply a quantity with units. Examples of this are mass (SI unit – kilogram), temperature (SI unit – Kelvin), time (SI unit – second), etc.

Another way to describe a physical quantity is by using a vector. A vector is a scalar associated with a direction. An example is displacement, which is distance and the direction associated with it. Think of where the door is relative to where you are now. The door is some distance away (a scalar value) and in a particular direction. If someone were to ask you how to get to the Trabant Student Center from the front door of Sharp Lab, a complete description would not be distance or direction only, but the distance and direction. In fact, it may be a series of distances and directions added together.

This is a unique point. Any place in space can be represented as a vector displacement from any other point. As an example, where is the front of Brown Lab from the front of Sharp Lab? It is approximately at 174 m, 80° South of East.

Note that measuring angles with a compass is different than we typically use in physics. Zero degrees (0°) is due North, rather than in the positive x – direction on a Cartesian plane (***East is not 0° in navigation***). Headings are also measured positively in the clockwise direction, rather than counterclockwise.

Looking at the map, it is easy to see that we cannot walk directly to our destination on the straight line if we must keep off the grass. This is the displacement vector (Figure 2), so we must take another route.

Let us ask Google® maps (Figure 3) to provide us a walking route by specifying the front a spot in fron of the Green side door of Sharp Lab as our starting point and the a point in front of Brown Lab as our end.

Now you need to give a direction and a distance, this is known as a displacement. Two possible routes are shown and the distacnes and directions[1] for each leg are below:

1. Head south	go 87 m	1. Head south	go 168 m
2. Turn 45° left	go 62 m	2. Turn 45° left	go 44 m
3. Turn 45° right	go 39 m		
Total Distance	188m	Total Distance	212 m

Total displacement: 174 m in a direction 80° S of E.

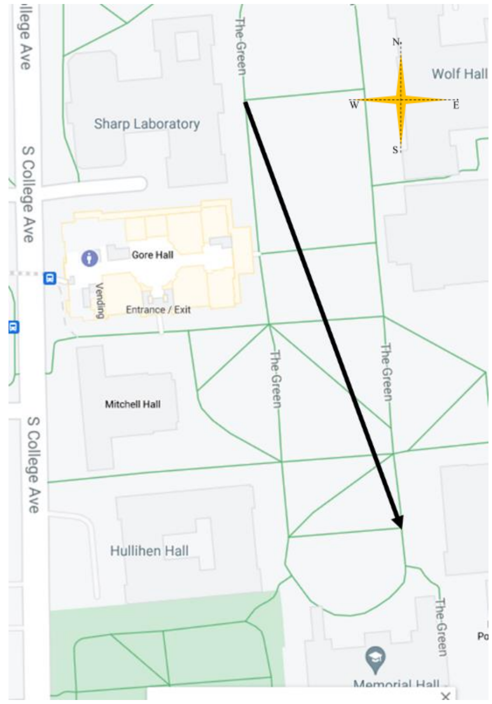


Figure 2 - Google map showing the straight-line displacement from Sharp

Notice how each of these is a direction and distance. We have displacement vectors. Each displacement vector is laid out such that the "tail" is at the "head" of the previous. In this way, we add the vectors; the resulting vector is the single displacement vector.

There are many possible routes, from Sharp Lab to Brown Lab but when all the vectors in any particular route between two particular points are added the result must *always* be the same displacement vector.

The total distance is different, but the ***displacement*** is the same.

In this lab you will sum a set of force vectors to find the *net* force vector.

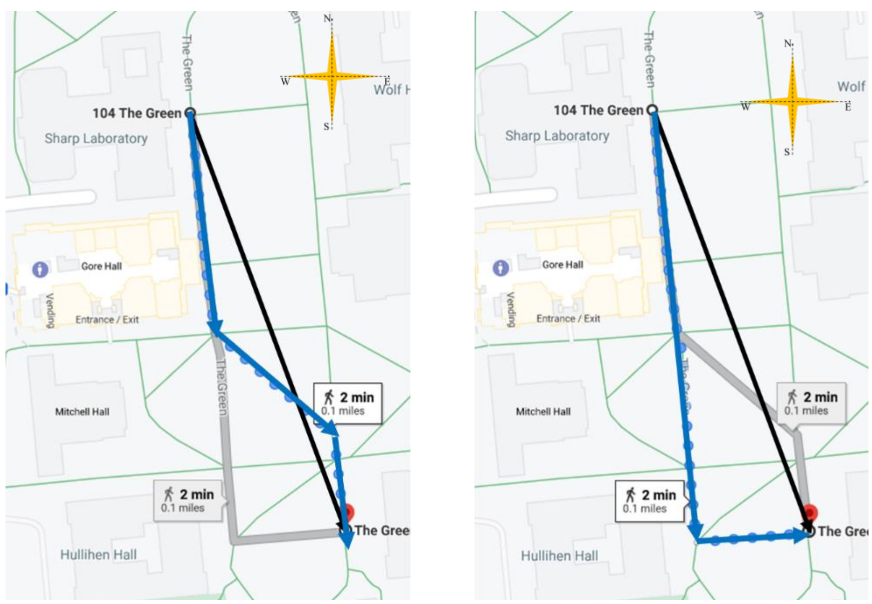


Figure 3 – Two different walking routes consisting of several vectors each that add to the total displacement.

[1] For demonstration purposes, let us take the paths to be laid out in an East-West and North-South fashion. In reality it is rotated about 5° CCW.

To balance the system to have a *zero* net force, you will take the negative of the *net* force vector and create it on the table using one of the strings and hangers to verify your results.

Even if you have not gotten to weight in your lecture yet, we will apply some simple results:

1. A force is something that pushes or pulls on an object.
2. If there is a net force, the object will move in that direction according to Newton's second law, $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$.
3. Force is a vector, as is acceleration. The mass of the object affected by this force, m, is a scalar value.

Thus, if there is no net force, then there is no acceleration. If the central ring is at rest then the forces pulling on the ring are balanced (i.e., no net force), then it will stay balanced and not touch the center post.

Note that the unit of force in the *SI* system is the Newton. One Newton is equivalent to one kilogram-meter per second squared:

$$1\,\mathrm{N} = 1\frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s}^2}$$

When calculating the force provided by each string to be the mass of the hanger plus any (masses on the hanger) multiplied by the acceleration it would have due to gravity if left free to fall. In other words,

$$F_g = mg$$

The direction of the force is always downward, but when a strings passing over a pulley, the direction of that force changes. So each string will pull with a force of *mg*. Don't forget the mass of the hanger and to convert to kilograms!

Useful vector relations:

A detailed explanation is in the accompanying lab introduction video (See Canvas for the link).

We will draw the vectors as given in each section with the angle of 0° being along the +*x*-axis and 90° being along the +*y* axis. With this *definition* we can relate the components of a vector to its *magnitude* and *direction*. Let us take a vector, $\vec{\mathbf{A}}$, we will denote its magnitude as, A, and its direction counter-clockwise from the $+x$-axis as θ.

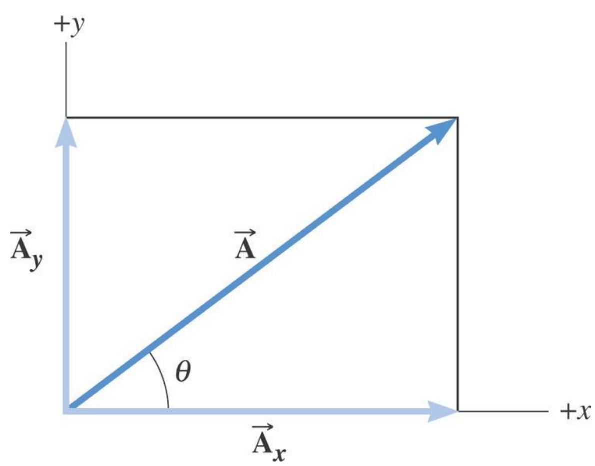


Figure 4 - Components of a vector

If we know the direction and magnitude of a vector, its components are,

$$A_x = A\cos\theta \qquad A_y = A\sin\theta$$

If we know the components, the magnitude and directon of the vector are

$$A = \sqrt{A_x^2 + A_y^2} \qquad \theta = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$

Due to the limited nature of the inverse tangent function, your calculator will only return values between –90° and +90°. You must use your knowledge of what *quadrant* the vector lies within to determine its *actual* value $\left(0° \le \theta < 360°\right)$. To the right is a handy chart of how to determine this.

A_x	A_y	What to do with the number your calculator returns
+	+	Nothing
–	+	Add 180°
–	–	Add 180°
+	–	Add 360°

While you could memorize this, it's best to understand why this is the case and use that knowledge as needed. During the lab, your drawings should show that this table provides the correct angles CCW with respect to the positive x-axis.

Before You Begin:

Make a sketch of your experimental apparatus in your lab notebook (to include in your report). This does not have to be an artistic masterpiece, but it should clearly show how the apparatus works and each part of the apparatus should be clearly labeled.

You will be solving the vector problems given, and then use the device to check them. Your TAs will be able to help troubleshoot if you encounter difficulty. It may take some time to get to your group, so after asking a TA for help, begin the next problem.

Refer to the lab introduction video (https://drive.google.com/open?id=0B8xoUMuFYFHnWWJfcThuUFUxS28) to see how the appartus works and what you need to do. **NOTE:** You must be logged into google with your udel.edu account in order to view the video.

NO CREDIT WILL BE GIVEN WITHOUT ALL SUPPORTING WORK SHOWN!

Before you begin, make sure you read the entire lab manual including the description of what will be due after the lab is completed!

Experimental Procedure and Analysis:

The grayed text is for the in-person lab. It is given here for reference only.

For each section, your TA will provide your group with a list of weights to be hung and the direction from center which they should go. Using graph paper (or plain if you do not have graph paper). Draw the vectors as given in each section with the angle of 0° being along the +*x*-axis and 90° being along the +*y* axis.

When the force vectors are balanced, the ring can be set such that it will not touch the center post (see digram in Figure 2):

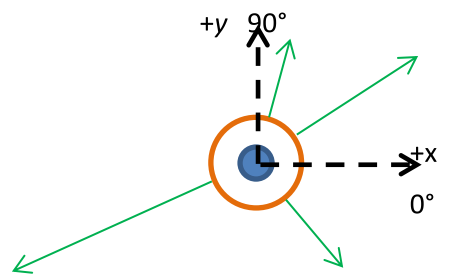


Figure 5 - Balanced force vectors leading to the ring being centered on the post.

A. *Two Strings:*

1. "Common Sense" should give you the force vector (and hanger mass) that needs to balance the single vector you have been given. Write down what you think it should be.
2. Decompose your given vector into components along the *x* and *y* axes.
3. To get the vector that will balance the net force, find the inverse of these components (i.e. multiply each component by –1).
4. Convert back the vector from (3) back into direction and magnitude.
5. Find the mass needed on the hanger to produce this force.
6. Position the unused pulley at the appropriate angle, hang the string over the pulley with the correct weights.
7. Does the center ring touch the post?
   a. If not record the result and proceed.

   b. If the ring touches the post, make sure the strings pull *radially* away from the ring. If it still touches the post, double check your calculations and try again.

   c. If your calculations are correct, you can vary the mass and position of the pulley *slightly* to get the ring to not touch the post. Record your actual values.

8. If you wish, you may ask your TA to confirm your solution.

B. Three Strings.

1. "Common Sense" may no longer give you what the resulting balancing force vector should be. Make an "educated guess as to what you think it should be. At least provide a small range of direction and magnitudes.
2. Decompose your given vectors into components along the *x* and *y* axes. Then sum to find the *net force*.
3. Follow steps (3) through (8) as in part (A).

C. Four Strings.

1. It should now be quite difficult to "intuit" the correct direction and magnitude of the vector that will "balance" the forces you have been given. Make your best estimate anyway.
2. Once again, decompose your given vectors into components along the *x* and *y* axes. Then sum to find the *net force*.
3. Follow steps (3) through (8) as in part (A).

D. Rotational Invariance.

1. Take the setup from part (**B**) above and *rotate* all the vectors by the same number of degrees in the same direction as provided by your lab instructor.
2. Once again, decompose your given vectors into components along the **NEW** *x* and *y* axes. Then sum to find the *net force*.
3. Does this match the resultant vector in the new reference frame?

Make sure you have the data to turn in the following items due after the lab (i.e. this week's lab report):

- You must also turn in a lab report **procedure section**. This section should have the following format.
  a. A clear heading as the laboratory procedure.
  b. A complete description of where to find the basic procedure for this lab. For example, "The protocol followed in this lab came from "PHYS221 Lab 2 Manual – Vectors, from Fall 2021."
  c. A clear and concise listing of any deviations from the standard protocol.
  d. Any apparatus parameters not specified in the laboratory must be clearly documented and if appropriate appear on the sketch.
- It should include tables of the magnitude, direction, components of each vector in each setup.
- You need to include an **Analysis section**. It should include the answers to any questions posed here in the manual. You may combine the data and analysis for each portion of the lab. All

calculated values **MUST** include the formula(e) by which they were calculated (e.g. any and all values in the tables that was not directly measured).

- Discuss the importance of finding the net force on an object.
- Discuss the importance of the results observed in part (*D*).
- Was either part (*B*) or part (*D*) easier to calculate? Why?
- It is complicated to quantify the instrument error in measurements in this lab due to its nature using angles, so for once we will not make use of error analysis. However, it can be done and were you to produce publishable results, you would need to calculate them!

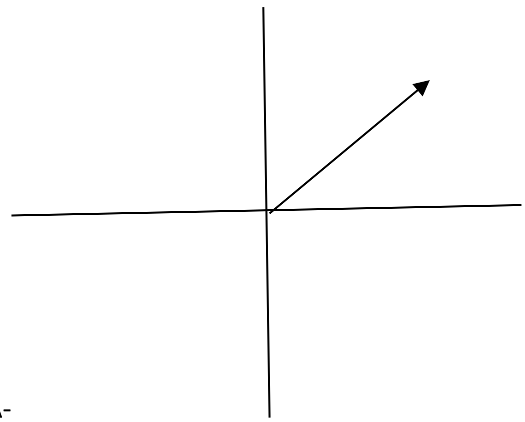
Make sure you include your names, instructor's name and the course with lab section number on your document!

Name____ Lab Section_________________

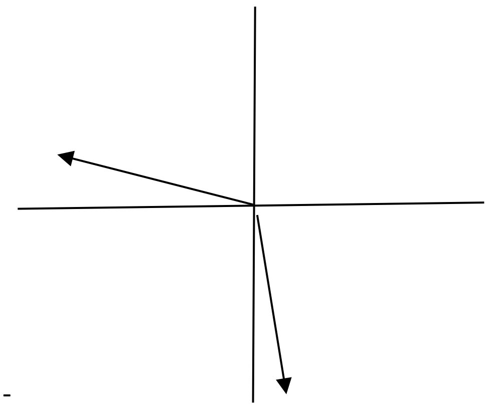
Pre Lab Questions

(due in Canvas by the beginning of your lab session)

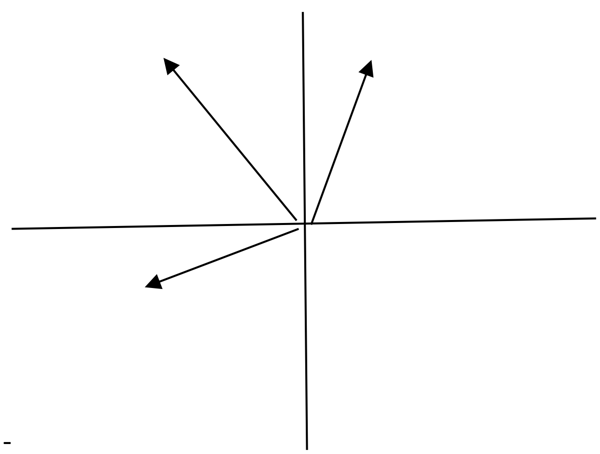
1. Consider the following vector configurations. Draw where you think the balancing vector (i.e. the vector that would balance all the forces) should be placed and briefly explain your answer.



A-



B -



C -

2. Why is distance insufficient to determine an object's location relative to another object?

(conintued on next page)

3. Distance and displacement are important terms to know when working with vectors. Define distance. Define displacement. Also consider the following example:

   During baseball practice, a player hits a very high ball then runs in a straight line to catch it. Which had a greater displacement? Which travelled a greater distance?