General Physics I Lab (PHYS-2011)
Experiment MEAS-3:
The Force Table: TRIG REVIEW & VECTORS

Objective:

Physics makes use of scalar and vector quantities to describe the world around us. After we discuss the distinction between scalar and vector physical quantities, we will focus on the representation and the combination of vector quantities. This will include a brief review of the necessary trigonometry.

Today's experiment is designed to provide you with experience in vector addition using graphical, experimental and analytical methods.

Scalars and Vectors

A **scalar** quantity has magnitude but no directional information. Meanwhile, a **vector** has both magnitude and directional information.

Examples of scalar quantities include mass m, temperature T, and the Universal Gravitational Constant G. Examples of vectors include velocity $\vec{v}$, acceleration $\vec{a}$, and force $\vec{F}$. We distinguish vector velocity $\vec{v}$, which is expressed with a magnitude and direction, from scalar speed v, which is expressed with a magnitude only. See the following list of measurements for additional examples:

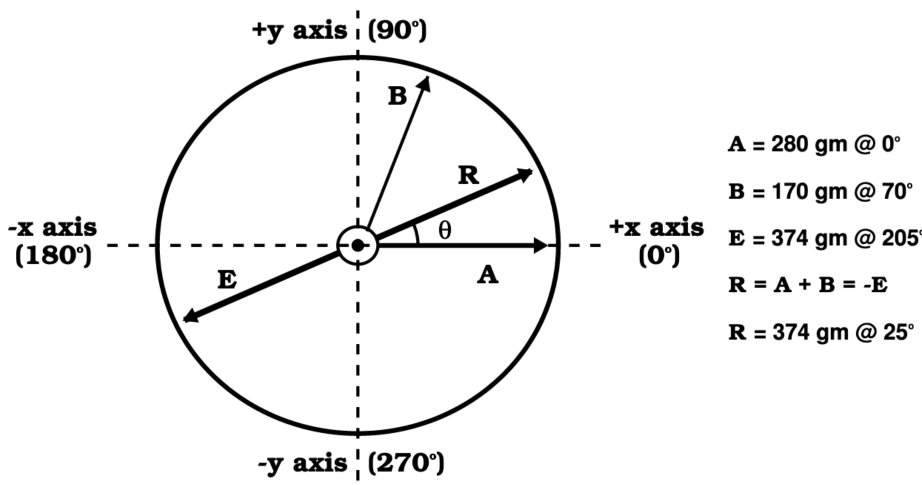
- 4 kg and 600 K are scalars.
- 420 km/s is a scalar (i.e., speed).
- 420 km/s to the NW (northwest) is a vector(i.e., velocity).
- 420 km/s NW is not equal to 420 km/s SE (southeast)!
- Note that textbooks and lab manuals can represent a vector with either an arrow over the variable letter (e.g.,$\vec{A}$), or indicate a vector with a boldface letter (e.g., $\boldsymbol{A}$). In these Lab Experiments for the General Physics Laboratory courses (PHYS-2011 and PHYS-2021), vectors will be indicated with an arrow over the variable letter.

Arithmetic for scalars and vectors are handled differently with respect to each other. In both cases, adding or subtracting such quantities only makes sense if the quantities describe the same property and are in consistent units. Adding or subtracting vectors must account properly for directions. We will describe vector arithmetic after a brief mathematical review.

The Force Table

A force table can be used to determine the sum of two or more vectors and the difference between two vectors. See figure of force table below.

Weights (masses) that represent the magnitude of a given vector are placed on a force table in the proper direction by adjusting the angle of the individual pulleys containing the given weights. Let's associate these weights with vectors $\vec{A}$ and $\vec{B}$. Then the equilibrium weight $\vec{E}$ is determined by trial and error by adjusting the amount of weight on the pulley and the angle placement of the pulley.



The final equilibrium weight vector will be achieved when the central axis of the force table is directly in the center of the center ring to which the pulley strings are attached.Then the **resultant vector** $\vec{R}$ of the addition of vectors $\vec{A}$ and $\vec{B}$ will be the opposite vector to vector $\vec{E}$ as shown in the following figure.

Example: Analytical and Graphical Analysis - 2 Vectors

Find $\vec{R} = \vec{A} + \vec{B}$, Given the vectors: $\vec{A} = 150$ gm @ $50°$ and $\vec{B} = 200$ gm @ $150°$ Determine where the Equivalent vector $\vec{E}$ needs to go on the Force Table and how big it needs to be to allow the plastic ring in the middle to not touch the pin sticking up out of the center of the Force Table.

Analytical Analysis

1. For starters, let's break them down into components using trig. This gives us:

$$\vec{A_x} = 150\ cos\ 50° = 96 \text{ gm} \quad \text{and} \quad \vec{A_y} = 150\ sin\ 50° = 115 \text{ gm}$$

$$\vec{B_x} = 200\ cos\ 150° = -173 \text{ gm} \quad \text{and} \quad \vec{B_y} = 200\ sin\ 150° = 100 \text{ gm}$$

2. Next, we want to sum everything up in the x-direction and sum everything up in the y-direction to get the total resultant vector $\vec{R}$. *Pay close attention to sign convention.* Up/right = positive. Down/Left = negative.

$$R_x = A_x + B_x = 96 - 173 = -77 \text{ gm} \quad \text{and} \quad R_y = A_y + B_y = 115 + 100 = 215 \text{ gm}$$

$$\vec{R} = \sqrt{(R_x)^2 + (R_y)^2} = \sqrt{(77)^2 + (215)^2} = 228 \text{ gm}$$

The vector components ($\vec{R_x}$, $\vec{R_y}$) as well as the resultant vector, $\vec{R}$ is shown in the Figure at the bottom left of the page.

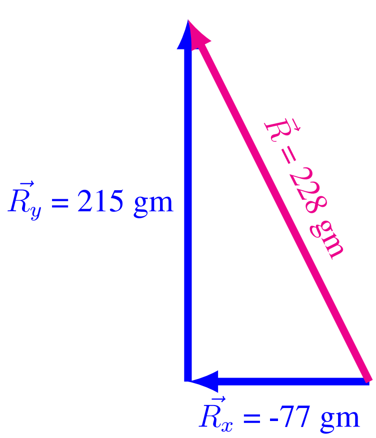
3. Now we want to solve for the angle:

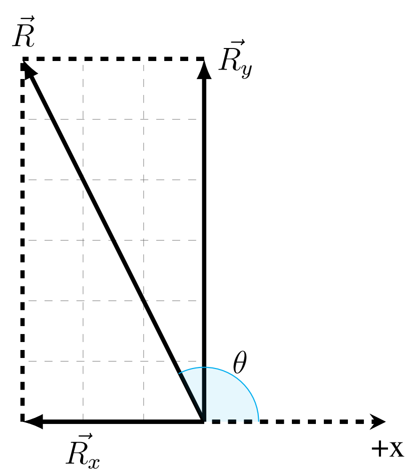
$$\theta = \tan^{-1}\left(\frac{R_y}{R_x}\right) = \tan^{-1}\left(\frac{215}{-77}\right) = -70° \text{ or } (-70° + 180°) = 110°$$

Note: Both angles are mathematically valid. From the drawing, $110°$ makes sense.

4. So the Equilibrium vector, $\vec{E}$ must be exactly opposite of this resultant vector. Add $180°$ to $110°$. This yields:

$$\vec{E} = 228 \text{ gm @ } 290°$$



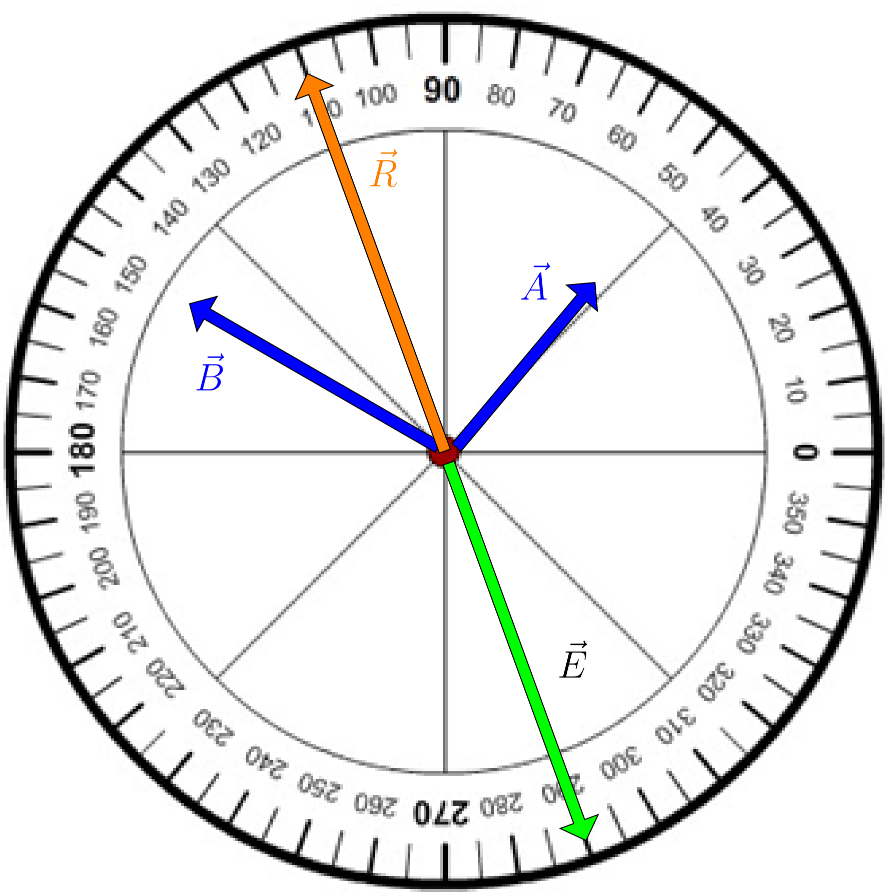


Graphical Analysis

1. Below we have an example Force Table showing 150 gm hung at the $50°$ degree mark on the force table and 200 gm hung at the $150°$ degree mark. Recall that on the force table you can imagine an x-axis going from $0°$ - $180°$ and then a y-axis going from $90°$ to $270°$.

2. There is a plastic ring in the center of the force table and the two masses (blue arrows below), are hung from the edge of the force table. Now since we are not doing this using an actual Force Table experimentally, we have to imagine the dark red circle in the middle of the Force Table diagram is designed this way. When the masses are hung over the edge of the Force Table, they exert a force in the string and that force is applied to the plastic ring at the center of the Force Table.

3. The goal for this lab is to analytically and graphically determine what the equilibrium mass $\vec{E}$ is and where to place it so that this plastic ring in the middle does not touch the pin sticking up in the center of the Force Table. To do this graphically, we can construct the vector components ($\vec{R_x}$, $\vec{R_y}$) with the resultant vector, $\vec{R}$ like the one in the Figure at the bottom left on page 2. Then using these results we know where to draw each vector on the diagram below at a length roughly proportionate to its magnitude.



$\vec{A}$ = 150 gm @ $50°$

$\vec{B}$ = 200 gm @ $150°$

$\vec{R} = \vec{A} + \vec{B} = -\vec{E}$

$\vec{R}$ = 228 gm @ $110°$

$\vec{E}$ = 228 gm @ $290°$