PHYX 106 Lab

Experiment 3 — The Addition of Forces

Objective: To practice vector addition and to introduce you to the concept of force vectors.

Equipment: A force table: a circular table calibrated in degrees around the circle supported by a tripod base with leveling screws. Strings are attached to a ring in the center and then pass over low friction pulleys mounted at the edge of the table. Weight holders are attached to the ends of the strings.

Theory: Later in the course, we will study forces in great detail. For now, take it as a given that if an object is not accelerating, then the vector sum of all the forces acting on that object must be zero, and vice versa:

$$\mathbf{F_1} + \mathbf{F_2} + \mathbf{F_2} + \cdots = \mathbf{0} \text{ iff } \mathbf{a} = \mathbf{0}. \tag{1}$$

In this lab, the magnitude of the force due to each weighted string will be the mass of the weight multiplied by the acceleration due to gravity:

$$F = mg, \tag{2}$$

where g is the acceleration due to gravity at the Earth's surface:

$$g = 9.80665 \text{ m s}^{-2}. \tag{3}$$

The direction of $\mathbf{F}_i$ will be in the direction of the string, as measured by the force table.

The MKS unit of force is the Newton (N), where 1N = 1 kg m s^{-2}.

Procedure:

Part I: With the pin in place at the center of the table, place a mass of 0.200 kg at 0° and a mass of 0.400 kg at 60°. Be sure to include the mass of the weight holder in your calculation! By trial and error, determine the size and placement of a third mass which will center the ring on the table. It might be easier to get a first estimate of this quantity by first pulling on the string by hand.

When the ring is centered on the table, and you decide that the masses are roughly in balance, remove the pin and tap the ring a few times with your pen to see if it remains centered. (By tapping the ring, you overcome static friction in the pulleys.) Fine tune the weight and angle until the ring remains centered when tapped. **NOTE** that you can introduce systematic bias by tapping on the ring in the direction you want it to go! Tapping straight down is probably safest.

Once you are sure that you have a good choice for the magnitude and location of the third mass, add a gram or two more until the additional mass changes the position of the ring. Do the same by subtracting a gram or two. If the additional/less mass makes no apparent difference, then your measurements are uncertain by at least that amount! Estimate uncertainties in the angle regime by changing the location of the third mass by a degree or two in both directions, until it causes the ring to move. Record your measurement of the balancing mass and angle along with their uncertainties. Convert the mass to a force using Equation (2).

Question 1. Graphically represent the three force vectors in your lab notebook. Select an appropriate scale of centimeters to Newtons for the length of your vectors, and measure the angles with a protractor.

Question 2. Because the forces are all in balance, we expect from Equation 1 that $\mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3 = \mathbf{0}$, or in other words that

$$\mathbf{F}_1 + \mathbf{F}_2 = -\mathbf{F}_3. \tag{4}$$

Using ruler and protractor, graphically add $\mathbf{F}_1$ and $\mathbf{F}_2$. Measure the magnitude and angle of the resultant vector R and compare it with $-\mathbf{F}_3$.

Question 3. Add vectors $\mathbf{F}_1$ and $\mathbf{F}_2$ by resolving them into components and adding the x and y components separately to obtain the vector components of the resultant R_x and R_y. Use R_x and R_y to find the magnitude R and angle θ_R of $\mathbf{R}$ and compare your results to the measured magnitude and angle, F_3 and θ_3, of your balancing force. In the comparison, include a discussion of the uncertainties in the third force.

Part II. Draw 3 force vectors out of a hat (provided by the instructor). Call these forces $\mathbf{F}_1$ though $\mathbf{F}_3$. Resolve these vectors into components, and, using Equation (1), predict what force vector $\mathbf{F}_4$ will balance the other three. Before you conduct any further measurements, predict the mass, M_4, and angle, θ_4 required to balance the other forces at the force table. Write this down in PEN!

Go back to the force table. Place the pin back in, and set weights equivalent to the forces you picked out of the hat in the locations given. Check twice to make sure that you are placing the correct weights at the correct locations. Finally, place the weight M_4 at the location you think it should go and remove the pin.

Question 4. Did the ring balance? If not, figure out why not, and repeat the experiment until successful.

Estimate uncertainties in M_4 and θ_4 using the same methods as in Part 1.

Question 5. Add all four force vectors in this experiment, graphically or by components, and confirm that $\sum \mathbf{F}_i = 0$.