

## Physics 200 Lab 3 Adding vector quantities

### Objectives:

- To get practice using several different methods of adding vectors.
- To understand how different forces act together to produce a combined, or net, force.
- To investigate conditions necessary for translational equilibrium.

### Overview:

Many quantities in physics can be described as vectors. One of the most important such quantities is force. That means that to obtain the total, or net, force acting on an object, we need to find the vector sum of all the individual forces acting on that object. The vector sum may be obtained by finding and adding components of the vectors involved, or by adding the vectors graphically. We will use both methods in this lab.

An important concept in physics and engineering is that of equilibrium. If an object has a constant velocity (acceleration = zero), it is said to be in translational equilibrium. (When we say translational motion we refer to an object moving from place to place without changing its orientation to distinguish from rotational motion where an object is not changing its location but may be spinning for example). A special case of translational equilibrium is an object at rest, which has a constant velocity of zero. For any object in equilibrium, all the individual forces acting on it add up to zero, so that the total (or net) force is equal to zero. Translational equilibrium gives us a way to find the sum of two (or more) forces. We apply the forces we wish to add, and find the single force that balances those other forces (that is, puts the object in translational equilibrium). This single balancing force is then equal and opposite to the sum of all the other forces.

You will use a circular force table which has a  $360^\circ$  scale marked on it. There is a small ring at the center of the table; this ring passes around a center peg. Several strings are tied to the ring so that forces can be applied to the ring. These forces are applied by passing the strings over pulleys attached to the rim of the table and hanging weights from the strings. The ring is balanced in translational equilibrium under the influence of these forces when it is suspended at rest without touching the center peg.



The force from the hanging masses is due to the Earth's gravitational force  $F_g$  on the masses. We'll see when we learn more about gravity that this force has a magnitude that can be calculated from  $F_g = m \cdot (9.8 \text{ m/s}^2)$ , where  $m$  is the mass in kg. The units associated with force are  $\text{kg} \cdot \text{m/s}^2$ , with  $1 \text{ kg} \cdot \text{m/s}^2 = 1 \text{ Newton}$  [abbreviated N].

Precautions:

- Press the pulley mounts firmly inward against the rim of the table before you tighten them in place.
- Sight along the strings and check that they all point to the center peg. If they don't, you should slide the point of attachment of the strings around on the ring until they do.
- To take friction in the pulleys into account when you take a force measurement, you should move the force probe slowly in and out radially (but without letting the ring hit the post) while taking your measurement and then select a range of data and use Analyze/Statistics to get the average and standard deviation of the force.
- When you use the force probe, make sure to pull with the force probe, hook, and string all in a straight line.

Accuracy is important in this experiment. If you are careful, you should be able to get good results (that is, your calculations and measurements should agree to within your measured uncertainty). Also, be sure to show your work for the calculations of the vector sums.

### **Investigation 1: Adding forces that are along the same line**

In this part of the lab, you'll apply two forces along the same line ("collinear forces") and find their sum.

**Prediction 1-1:** If you hang 160 g at  $0^\circ$  and 300 g at  $180^\circ$ , what will the force that balances them be? Show your work. Express the result as a magnitude (in N) and a direction (angle). What hanging mass (in grams) is required to produce this force?

1. Start Logger Pro and open the experiment file Measuring Force. Make sure the force probe is on the 10 N scale. Zero the force probe with nothing pulling or pushing on the hook and the force probe oriented horizontally.
2. Hang 160 g at  $0^\circ$  and 300 g at  $180^\circ$  (don't forget that the mass hangers have mass too!). Attach the hook of the force probe to a string and move the force probe to the angle at which it can balance the other two forces. Pull till the ring is supported only by the two strings with the hanging weights and the string with the force probe. Make sure that the strings are all parallel to

the top of the table, and that the ring is not touching the center peg. Record the angle and then click on Collect, and collect data for several seconds. Find the average and standard deviation of the force applied.

Angle:

Mean force:

Standard deviation:

Because of friction in the pulleys, there will be a range of angles for which the ring is still balanced (without touching the center peg). Find this range of angles by sliding the force probe to smaller and larger angles (always with the force probe and string pointing straight toward the center of the peg) and noting when the ring is no longer balanced.

Range of angles:

**Question 1-1:** Remembering that the balancing force should be equal and opposite to the sum of the original two vectors, does your prediction agree with the measured value (that is, within the error ranges)? Explain.

### **! Checkpoint 1**

#### **Investigation 2: Adding forces that are not along the same line**

**Prediction 2-1:** A 160 g mass is at  $0^\circ$  and a 300 g mass is at  $90^\circ$ , each exerting a force on the ring. Predict what single force will balance these two forces. Express the results as a magnitude and a direction (angle).

1. Now set the problem up on the force table (don't forget to include the mass of the hangers), and test your prediction by using the force probe to balance the first two forces. If the ring doesn't balance (without touching the center peg) when you test your prediction, ask for help. Again, obtain error ranges for the force (using the mean and standard deviation) and the angle (by moving the probe around).

Angle:

Mean force:

Standard deviation:

Angle range:

**Question 2-1:** Remembering that the balancing force should be equal and opposite to the sum of the original two vectors, does your prediction agree with the measured value (that is, within the error ranges)? Explain.

**Question 2-2:** Make a careful scale drawing, using a ruler and a protractor, of the force vectors involved when the ring is balanced. Show graphically how the forces add.

**! Checkpoint 2**

2. Keep the 160 g mass at  $0^\circ$  and move the 300 g mass to  $140^\circ$ . Now find experimentally the force (magnitude and angle) that balances those two forces, by moving the force probe to different angles.

Angle:

Mean:

Standard deviation:

Range of angles:

**Question 2-3:** Is the single force required to balance these forces the same as it was in part 1 of Investigation 2? Explain why your result makes sense.

**Question 2-4:** Calculate the vector sum of the forces in part 2 above and find the single force (magnitude and direction) that balances them. Compare to the measured value. Do the calculated and the measured values agree (within the measured uncertainty ranges)?

**Question 2-5:** Make a careful scale drawing, using a ruler and a protractor, of the force vectors involved when the ring is balanced. Show the vector addition graphically.

**! Checkpoint 3**

3. Now consider the sum of three forces: masses of 500 g at  $0^\circ$ , 300 g at  $180^\circ$ , and 200 g at  $50^\circ$ . Find the force that balances these experimentally (including the magnitude and angle ranges).

Angle:

Mean:

Standard deviation:

Range of angles:

**Question 2-6:** Calculate the vector sum of the three original vectors. Compare the measured and calculated values. Do they agree, within uncertainties?

**Question 2-7:** Make a sketch, to scale, of the force vectors involved when the ring is balanced. Show the vector addition graphically.

**Question 2-8:** What specific factors might cause discrepancies between your measured and calculated values? (Answer this question even if you had good agreement in all cases.) Please be more specific than “experimental error” or “human error.”

**! Checkpoint 4**