Structures
Activity 1 - Vectors

Introduction

One of the most important concepts in physics is that of vector quantities, including their visualization and their mathematical manipulation. The purpose of this activity is to give you some practice in the addition of vector quantities, using both experimental and analytical techniques. There are many physical quantities that are described mathematically as vectors including displacement, velocity, acceleration, and force. In this activity, we will work with forces as our example of a vector quantity.

Remember that vector quantities, like force, have both a magnitude (for example 100 lbs.) and a direction (for example 30° north of east). The condition for static equilibrium (a body at rest will remain at rest) is that the vector sum of the forces acting on the body is zero. In other words, all of the forces acting on the body are balanced.

In general, there may be many forces acting on an object and they may be oriented at many different angles with respect to some set of coordinate axes centered on the object. In this case, the condition for static equilibrium is that the sum of the x-components of each force acting on the object must be zero and independently, the sum of the y-components of each force acting on the object must also be zero. Therefore, some components must be positive and some must be negative such that their sum is zero. Stated analytically, the total forces must balance:

$$\vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ... = 0$$

Equivalently, the x-components must balance:

$$\vec{F}_{1x} + \vec{F}_{2x} + \vec{F}_{3x} + ... = 0,$$

and the y-components must balance:

$$\vec{F}_{1y} + \vec{F}_{2y} + \vec{F}_{3y} + ... = 0$$

Experiment

What You Will Need

- 3 spring scales
- 3 ring stands
- 1 washer with three strings attached
- Protractor
- Some heavy masses

Experiment 1

For the first part of this activity, you will set up two forces at a right angle (90°) to each other and then determine the force needed to balance them. If you push two tables together, you should have enough room to set up your experiment. Slide the loop of each spring scale over the post of each ring stand and spread them out in a circle. Hook the three pieces of string that are attached to the washer to the hangers on the three spring scales. Place a protractor underneath the washer and set up two of the ring stands so that their strings are at a right angle to each other and so that the washer lies loosely over the center of the protractor.
1. Make a prediction: In order to balance all three forces, at what angle must you place the third string if you set up forces of equal magnitude in the first two strings?

2. Set up your third ring stand at the angle you predicted in number 1. Have at least one person working each of the ring stands and gently slide the stands backward (stretching the strings) until you get a reading on the spring scales, being careful to keep the strings at the angles you set up previously. Keep adjusting the positions of the stands until the force reading on the scales at the 90° angle to each other is 4 Newtons each and the force from the third stand balances these two. How do you know if the forces are balanced?

3. Once your team is confident that you have set up your forces correctly, draw a diagram showing your results. (Draw a set of coordinate axes where the origin is the position of the washer and draw your forces on this diagram. Make sure you label each force with its magnitude, in Newtons, and its direction as an angle from the positive x-axis).

Analysis

4. We will now determine the balancing force in Experiment 1 using mathematical techniques. Remember that you started Experiment 1 by setting up two forces of equal magnitude at a right angle to each other.
   a. What is the x-component of the force needed to balance the system?

   b. What is the y-component of the force needed to balance the system?

   c. Using the Pythagorean theorem, determine the magnitude of the balancing force.

   d. Using trigonometry, determine the angle of the balancing force.

   e. Do these results agree with the results you obtained during the experiment? If not, why?
Experiment 2

Now set up your ring stands so that you have a force of 2 Newtons at an angle of 30° from the positive x-axis and a force of 4 Newtons at an angle of 150° angle from the positive x-axis. Using the same technique as you used in Experiment 1, set up the third ring stand so that its force balances the first two forces. Record your results below by drawing a vector diagram showing the magnitude and direction (angle) of all three forces.

Analysis

5. In Experiment 2, you set up two forces of equal magnitude at 30° and 150°.

   a. Using trigonometry, determine the x-components of each of these forces and state their directions (positive x-axis or negative x-axis).

   b. Using trigonometry, determine the y-components of each of these forces and state their directions (positive y-axis or negative y-axis).

   c. What are the total x and y components of the balancing force?

   d. Determine the magnitude of the balancing force.

   e. Determine the direction (angle from the positive x-axis) of the balancing force.

   f. Do these results agree with the results you obtained during the experiment? If not, why?
**Experiment 3**

For this part of the activity, choose a magnitude and a direction for the first two forces. Set up two of your stands and their scales at the angles you chose. Adjust the third stand until it balances the first two forces. Record your results below by drawing a vector diagram showing the magnitude and direction (angle) of all three forces.

**Analysis**

6. In Experiment 2, you set up two forces of equal magnitude at 30° and 210°.
   
   a. Using trigonometry, determine the x-components of each of these forces and state their directions (positive x-axis or negative x-axis).

   b. Using trigonometry, determine the y-components of each of these forces and state their directions (positive y-axis or negative y-axis).

   c. What are the total x and y components of the balancing force?

   d. Determine the magnitude of the balancing force.

   e. Determine the direction (angle from the positive x-axis) of the balancing force.

   f. Do these results agree with the results you obtained during the experiment? If not, why?