

## Forces in Equilibrium

Fall 2004

### Introduction

The purpose of this experiment is to see how close the *vector* sum of the measured forces on an object at rest is to the expected value of zero:

$$\sum \vec{F} = 0$$

*Note: Each person will create their own vector map. You will be graded on the precision and neatness of your drawing and calculations: take care!*

### Experiment

- Four forces are applied to a bracket by strings that pass over pulleys and support hanging masses. *The weight of each mass equals the force applied to the bracket.* Be sure each string passes straight over each pulley.
- Create a data table in your report as below (*note that  $F_{scaled} = F \times Scale$* ):

Data Table				Scale: 3 cm = 1 N				
Force	mass, m (kg)	F = mg (N)	F <sub>scaled</sub> (cm)	F <sub>x</sub> (cm)	F <sub>y</sub> (cm)	F <sub>x</sub> (N)	F <sub>y</sub> (N)	
$\vec{F}_1$	—	—	—	—	—	—	—	
$\vec{F}_2$	—	—	—	—	—	—	—	
$\vec{F}_3$	—	—	—	—	—	—	—	
$\vec{F}_4$	—	—	—	—	—	—	—	
$\langle \vec{F} \rangle \Rightarrow$			$\sum \vec{F} \Rightarrow$					

**Important: If You Wish To Pass This Lab, Sharpen Your Pencil To A Fine Point Now!!**

- Slide a clean sheet of graph paper under the bracket, grid side *down*. Align the paper so that the string creating the largest force is *directly* along the long axis of the page. Looking straight down with one eye (to minimize parallax effects), *carefully* locate the position of each string by marking three widely separated points under it. The orientation of each string indicates the direction of the force it applies to the bracket.
- For each of the four forces draw a *faint* line that best fits the dots. *Lightly* draw an arrow to indicate the direction of each force. Label the forces as indicated in the table above (label all vectors appropriately).

5. Enter the mass suspended from each string in your data table (*remember to include the mass of each hanger*). From these masses, calculate the magnitude of each force.
6. Use a scale factor of  $3\text{ cm} = 1\text{ N}$  to represent these forces as *lengths*. Record this scale on your vector map, and use it to calculate the scaled length of each force,  $F_{\text{scaled}}$ .

## Analysis

7. One of the forces is larger than the other three. Using the  $F_{\text{scaled}}$  value for this force, draw a **darkened** vector to its scaled length (it should originate somewhere near the right or left edge of the page – *not* the top or bottom – at the intersection of two grid lines. *Think* about the direction the rest of your vectors will take).

### a) Graphical Addition of Vectors:

Translate a second vector so that its tail meets the head of the first vector. Your instructor will show you how to do this using two triangles (you may find it helpful to tape your vector map to the table). Darken this vector to its scaled length. Add the third, then the fourth vector graphically by translation.

We'll call the resultant vector, from the tail of the first vector to the head of the last, the *closure error* (**Note:** *Don't* draw a vector for the closure error; leave it as a gap!). Measure the length of the resultant vector (if its length is zero, congratulations!), convert it to a force using your scale, and record in your report. Express your "Graphical" sum of forces error as a percentage of the average magnitude of the four forces as follows:

$$\text{Sum of Forces Error (Graphical)} = \frac{\text{Closure Error (N)}}{\text{Average of the Four Forces}} \times 100\%$$

### b) Addition of Vector Components:

Label the  $x$  and  $y$ -axes on the vector map, and graphically resolve each force into its  $x$  and  $y$  components: lightly draw dashed lines for the components, and *be sure to label them and indicate their direction*.

Measure the components with a ruler and record their values in the table. *Watch your signs!* Use your scale to convert them to force components. Calculate and record the sums of the  $x$  and  $y$  force components in the table, then calculate the "Component" sum of forces error as a percentage of the average magnitude of the four forces (the error for the  $x$  components is shown; *do the same for the  $y$ -components!*):

$$\text{Sum of Forces Error (X-Component)} = \frac{\sum F_x (\text{N})}{\text{Average of the Four Forces}} \times 100\%$$

## Discussion

- Restate your results. Compare your results with those predicted by Newton's 2<sup>nd</sup> law.
- Discuss possible causes of error.