Resolution of Forces with the Force Tables Simulation

revised 2020

In this lab, you will experiment with forces and the conditions for equilibrium. Later in the lecture course, we will discuss the conditions for equilibrium. For now, you may assume that a system is in equilibrium if the following is true:

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

You should notice that **F** has an arrow over it indicating that this is a vector equation. Most specifically, this means that the sum of the $\hat{x}, \hat{y}, \text{and} \hat{z}$ components of the forces acting at a point must be equal to zero if the system is in static equilibrium. Why did I put the vector sign over the zero? This is to indicate that this is the zero vector:

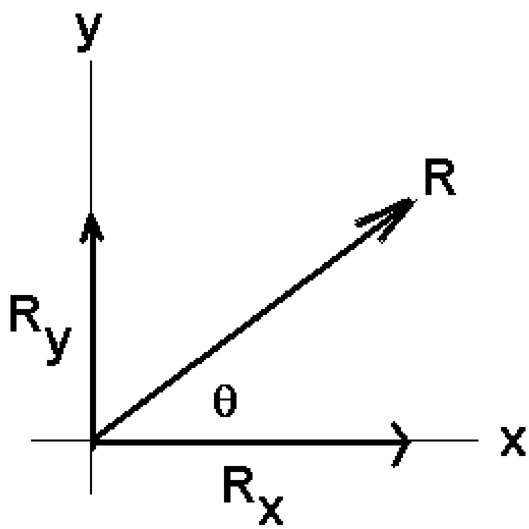
$$\vec{0} = 0\hat{x} + 0\hat{y} + 0\hat{z} \quad .$$

Mathematically, this was included to assure that I did not equate a scalar to a vector. Notice here, that I use two notations for unit vectors to help familiarize you with multiple notation schemes.

In today's lab, you will be dealing with forces generated by the action of the Earth's gravitational field acting upon a mass. This force is commonly called weight and in the SI system of units, we have force specified in units of Newtons (N). **Notice that this is not in kg or g since these are units of mass, not weight.**

Resolution of vector components

One of the most important keys to your success in physics lies with developing an ability to resolve vectors into components. This is done by simple application of trigonometry. As an example, consider the vector shown below:



READ THIS! You will need to use this!

The components of $\vec{R}$ are $R_x = \vec{R}\cdot\hat{x} = |\vec{R}|\cos(\theta)$ and $R_y = \vec{R}\cdot\hat{y} = |\vec{R}|\sin(\theta)$ where $\vec{R} = R_x\hat{x} + R_y\hat{y}$. You must become proficient with these types of vector calculations in order to have success with physics! Note: $|\vec{R}| = \sqrt{\vec{R}\cdot\vec{R}} = \sqrt{R_x^2 + R_y^2}$. You will notice that I have used "dot product" notation here. You must be able to use this vector operation in physics

Example for calculation of a force

Suppose your total weight on one string is 55 g. How many Newtons of force is this? Assuming the acceleration due to gravity in the SI system of units is given by:

$$\vec{g} = 9.8\frac{m}{s^2}(-\hat{z}) = -9.8\frac{m}{s^2}\hat{z}$$

we then find the gravitational force (or weight) by:

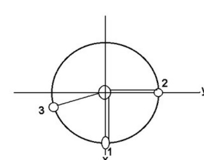
$$\vec{F} = m\vec{g} = (55\,g)\left(1\frac{kg}{1000\,g}\right)\left(9.8\frac{m}{s^2}\right)(-\hat{z}) = -0.539\frac{m}{s^2}\hat{z} = -0.539\,N\hat{z}$$

$$|\vec{F}| = \sqrt{\vec{F}\cdot\vec{F}} = \sqrt{(-0.539\,N\hat{z})\,x\,(-0.539\,N\hat{z})} = 0.539\,N$$

You should notice how careful I have been to show that the direction of this acceleration is downward. **When I write g without a vector symbol, you should interpret this to be the magnitude of g** and has the SI value of $g = 9.8\frac{m}{s^2}$.

Note about the sketches: draw them on a piece of paper. You do not need to construct electronic sketches to include with your lab report but you may construct electronic images if you desire. I do actually want you to draw the vector diagrams that your spreadsheet is showing and include them in your lab report.

For each of these experiments I want you to sketch vector diagrams on paper and include each sketch in your lab report, correctly associated with the experiment you are doing. **You can sketch this by looking at the spreadsheet.**



Experiment 1. Place one pulley at 0^0 and place the second pulley at 90^0. Place a 50 g mass on each of these two pulleys. Rotate the third pulley, varying its mass until the key ring is centered. Note that I am purposely not showing the correct position of force #3. **You should draw a circle, representing the situation with all masses and angles recorded on your picture.** You may want to save each spreadsheet with a different name for each of the experiments.

Experiment 2. Leave the first mass at 0^0. Place 70 g total on holder #1, 125 g total on holder #2. Change the angle for holder #2 to be at 110^0. Vary the mass and angle of holder #3 until equilibrium is established. **Save your spreadsheet with a new name.**

Experiment 3. Leave the first mass at 0^0 . Place 100 g total on holder #1, 50 g total on holder #2. Leave the angle for holder #2 at 110^0. Vary the mass and angle of holder #3 until equilibrium is established. Record your results in the table below and **make a sketch of your system as before. Save your spreadsheet with a new name.**

Experiment 4. Leave the first mass at 0^0 . Place 50 g total on for the first mass. For the second mass, place 50 g total for the second mass. Choose an angle for the second holder that is different than angles that have been used (but not 0 or 180). This choice is up to you. Vary the mass and angle of holder #3 until equilibrium is established. Record your results in the table below and **make a sketch of your system as before. Save your spreadsheet with a new name.**

The analysis

Your analysis will consist of observations made during the four experiments and interpretation of your drawings and calculations. You should report how far away from equilibrium your set-up actually was. You should also include details about how you established equilibrium.

The Conclusion

State and explain the condition for equilibrium. When you found the sum of all forces acting on the ring, you probably did not come up with exactly zero. Why not? Compare the results of experiment 2 and experiment 3 and experiment 4 to decide if the error would be greater or smaller if you used larger masses.

Spreadsheet Calculations

Here is an important note: the spreadsheets for these labs are designed to help you through the sometimes complex calculations ... they act like little teaching assistants. However, if you do not learn how they work, you are not using the spreadsheets properly. Thus you are required to learn how the spreadsheet calculations work!

Reading across row 2, we have: input mass (g) and input angle(degrees). The magnitude of the weight in Newtons is $|\vec{F}|=m|\vec{g}|=m(9.8)\mathrm{N}$ Since the mass is in g, you will need to convert it to kg by:

$$m[kg]=m[g]x\frac{1\,kg}{1000\,g}\quad .$$

You will notice that I do this automatically in the calculation.

The X component is given by:

$$F_x=\vec{F}\cdot\hat{x}=|\vec{F}||\hat{x}|\cos(\theta)=mg\cos(\theta)\Rightarrow F_x=|\vec{F}_x|=mg\cos(\theta)$$

The Y component is given by:

$$F_y=\vec{F}\cdot\hat{y}=|\vec{F}||\hat{y}|\cos(90-\theta)=mg\sin(\theta)\Rightarrow \vec{F}_y=|\vec{F}|\hat{y}=mg\sin(\theta)\hat{y}$$

Notice that the spreadsheet calculates angles using radians, rather than degrees. The conversion between radians and degrees is

$$\theta[\text{degrees}]x\frac{2\pi[\text{"rad"}]}{360[\text{degrees}]}=\theta[\text{"rad"}]$$

If you do not understand the difference between degrees and radians, you should review trigonometry. **It is absolutely essential that you understand the difference.** This will be extremely important throughout physics.

The sum of the components of a force is given by:

$$\sum F_x=\sum_{i=1}^{3}\vec{F}_i\cdot\hat{x}=F_{1,x}+F_{2,x}+F_{3,x}\quad .$$

The sum of the magnitudes of the forces is less useful in general but we use it here as a method of comparison. This is given by adding the magnitudes of the individual forces.

The percent deviation is given by an unusual formula here. We can not compare to the expected value of zero. Instead we compare to the total force. Thus we have:

$$\%\text{deviation}=\frac{\sum F_x}{|\sum \vec{F}|}\ \text{ or }\ \frac{\sum F_y}{|\sum \vec{F}|}\quad .$$

Equipment required: (for in lab experiment)

This is what would be done for the in class lab experiment. Since we are remote, you can look at these and I can show you the demonstration in the lab lecture only.

1 3B Scientific Force Table (assembled)
3 pulleys
Hangers with centering ring
1 Mass Kit
You may assume the masses are correctly marked and are close enough to be accepted to within other experimental errors during this lab.
Each mass kit **will** contain the following masses **before** and **after** the lab:

Hanger	1x3 (each weighs 50 g)
5 g mass	2x3
10 g mass	2x3
20 g mass	2x3
50 g mass	2x3

Examine your equipment. If you are the first day of the week in lab, you may need to assemble the force table at the beginning of your experiment. If you are in the last day of the week for this lab lab, you may need to disassemble your force table at the end of your lab. Regardless of which day you are in, you will need to make sure all the weights are returned to the boxes provided in an ordered way after your lab.

Place one of the pulleys on the 0 mark so that it will stay.