Physics 11A – Eiteneer

Lab: Forces in Equilibrium

Online version

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PURPOSE

To experimentally verify the vector nature of force.

INTRODUCTION

Newton's Laws assert that if a particle is in equilibrium then the total force on it must vanish, i.e. the vector sum of the applied forces must be equal to zero, $\sum_i \vec{F}_i = 0$.

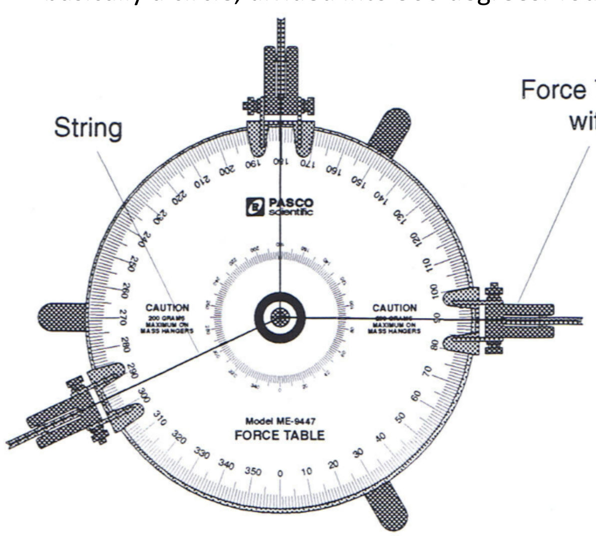
The purpose of this experiment is to test that assertion. The "particle" in question is a knot of string that is being pulled upon from three directions, as shown in the figure below. We will measure then tensions T_i in the three strings (i=1,2,3), and the angles θ_i at which the strings pull. From these quantities we compute the *x*- and *y*- components of the force vector applied to the knot by each string, denoted by F_{ix} and F_{iy}. These will then be added, forming the total $F_x = \sum_i F_{ix}$ and $F_y = \sum_i F_{iy}$, and the results compared with zero. If Newton's Laws are right, we should find that these two sums are equal to zero, within the uncertainty of the experiment.

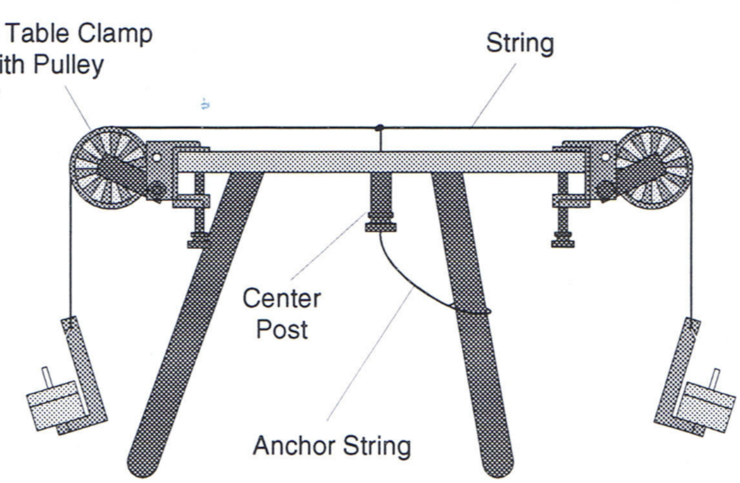
MATERIALS AND EQUIPMENT

Force table	Ruler
Hanging mass set	Plastic ring
3 super pulleys with clamps	Level
String or thread	Scale

PROCEDURE

1. The drawings below show the top view and the side view, respectively, of a sample set up. The force table is basically a circle, divided into 360 degrees. You will be using given angles and forces.





2. The goal of this lab is to create an equilibrium situation. We are going to tie three strings to a small plastic ring. These strings then pass through frictionless (virtually ideal) pulleys, and plastic hangers are attached to the other end of each string. Small masses are placed on the hangers until equilibrium is reached, as shown in the figures.
3. The forces in the setup (acting on the plastic ring) are effectively tension forces, even though we are going to be adjusting the masses of the handing weights. Thus, our forces will be measured in "grams" rather than newtons. This is called a "convenience unit" – units that can be directly read from the experiment. Rather than using unit conversions to convert the units for each measurement, we are going to save the conversion until the end (or not convert the units at all), thus eliminating a lot of "busywork." In this particular experiment, there is one more reason why the forces can be measured in grams. In one or two sentences, explain what that one reason is (besides the ease of using "convenience units."

The reason for us measuring the forces using grams besides the ease of having "convenience units" is that it helps keep our results and data accurate. Having to constantly convert units may skew our results a bit.

4. We are going to start with two known forces (masses), and determine the third force (mass) graphically, algebraically, and experimentally. The mass that is hanging on the string at 0° is 55 (counting the hanger itself). The mass that is hanging on the string at 160° is 105 g (counting the hanger). Assume all of these values are exact.
5. In order to create an equilibrium situation, the pulleys have to be adjusted so that the strings are as low as possible above the table but not touching the pulley clamp or the table. The strings also have to be parallel to the surface of the force table, which is also parallel to the floor.
6. We will call the force associated with the 50 gram disk/hanger as $\vec{F}_1$ and the force associated with the second disk/hanger as $\vec{F}_2$. We will call the third (unknown) force $\vec{F}_3$.
7. On the protractor template sheet (found on Canvas), draw vector arrows for $\vec{F}_1$ and $\vec{F}_2$. You will need a coordinate system and a scale conversion factor. Place the origin of the coordinate system at the center of the template with 0° as the +x-axis and use an appropriate scale. The scale must be chosen in such a way that your drawing fits completely within the protractor template. Make sure that the vectors you are drawing visually stand out, and not blend in with the protractor template.
8. Graphically add $\vec{F}_1$ and $\vec{F}_2$. Then draw the third force $\vec{F}_3$ in such a way that its tip is at the origin. Hint: you should have a triangle with one vertex at the origin. Don't forget to attach your graph when turning in this lab.
9. Now, add $\vec{F}_1$ and $\vec{F}_2$ algebraically, and thus determine $\vec{F}_3$ that would assure that the three forces add up to zero. In other words, use Newton's First Law, $\sum F_x = 0$ and $\sum F_y = 0$. Show all steps!

$\vec{F_1} = 55\hat{i} + 0\hat{j}$

$\vec{F_3} = \vec{F_1} + \vec{F_2}$

$\vec{F_2} = -98.66\hat{i} + 35.9\hat{j}$

$= (x_1\hat{i} + y_1\hat{j}) + (x_2\hat{i} + y_2\hat{j})$

$= x_1\hat{i} + x_2\hat{i} + y_1\hat{j} + y_2\hat{j}$

$= (55 - 98.66)\hat{i} + (0 + 35.9)\hat{j}$

$\boxed{\vec{F_3} = -43.66\hat{i} + 35.9\hat{j}}$

We take the negative of $\vec{F_3}$ because adding the sum of $-\vec{F_3}$ with all other vectors gets us 0!

$$\begin{array}{r} 55 \\ -98.66 \\ +43.66 \\ \hline 0 \end{array} \qquad \begin{array}{r} 0 \\ 35.9 \\ -35.9 \\ \hline 0 \end{array}$$

So, $\Sigma F_x = 0$ So, $\Sigma F_y = 0$

$\boxed{-\vec{F_3} = 43.66\hat{i} - 35.9\hat{j}}$

10. Once we have determined $\vec{F}_3$ graphically and algebraically, we need to do it experimentally. What that means in terms of physical setup, is that we are effectively figuring out 1) where the third pulley needs to be placed, and 2) how much mass we should place on its hanger so that the system is in equilibrium and the plastic ring is directly above the center of the table. Here is a hint: when the system is in equilibrium, you can gently nudge the plastic ring and see if it returns to the center position. If not, some adjustments need to be made to the magnitude and/or direction of the third force.

11. Look at the two photographs posted on Canvas, and determine the position (angle) of the third string. Record it here:
$\boldsymbol{\theta_3}$ = 320___________
The force (mass) was experimentally determined to be 57 g.

12. Using the **experimental value** for the magnitude and direction of $\vec{F_3}$, fill out the following table:

	x-component	y-component
F_1	55	0
F_2	-98.7	35.9
F_3	43.6	-36.2
Sum	-0.1	-0.3

13. Let's check to see how close our experimental values were to the calculated values. One convenient way to address the "goodness" of measurement is by percent error. Here, the calculation of percent error is modified to what's called a "percentage factor":

$$\text{percentage factor} = \frac{\left|\text{highest of the two } \left(\sum \text{F}\right) \text{ values}\right|}{\text{smallest magnitude of three forces}} \times 100\%$$

In this formula, the numerator is the absolute value of the highest value of the "sum" row of the table above, and the denominator is the smallest of the three forces. Look back at your table and the magnitudes of the three forces (masses). Hint: the first two forces were assumed to be exact, and the third one was found experimentally. Calculate percentage factor. Show all work.

percentage factor = $\frac{|-0.1|}{56} * 100\%$ = 0.178

14. Convert the magnitude of $\vec{F_3}$ to its newton equivalent. Show work.

F=m*a

Mass of $\vec{F_3}$ = 57g
1g = 0.001kg
57g = $\frac{57g}{1} * \frac{1kg}{1000g}$ = 0.057kg

F = 0.057kg * 9.8 $\frac{m}{s^2}$ = 0.5586 N

15. What is responsible for this error? What can be done to minimize the error in the future? Remember, there is no such thing as "human error"!

- Systematic Error for instrument drift: It is possible that the protractor used for the measurement may be stretched out in the process of printing it. Depending on the brand of printer or the type of paper being used to print it on, it is possible that the outcome is not to scale of an actual protractor. We can try solving this by formatting our prints properly and checking with a ruler next time.
- Instrument resolution (random): In this case, the limits of our results depend on what our force table can tell us. We can try solving this next time by using the null-difference method, which involves using instrumentation to measure the difference between similar quantities. One of those quantities will be accurate and adjustable. The adjustable quantity will be adjusted until the difference is completely

reduced to zero. Those quantities are then balanced and the unknown quantity is found by comparison with the reference sample.