LAKE FOREST COLLEGE
Department of Physics

PHYS 114 **Experiment 2: The vector nature of forces** Fall 2024

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Preliminary Instructions
As you did last week, create a Teams folder for you and your lab partner. Save a copy of these instructions for each student to that folder. Include your name in the filename. Save one copy of the *Excel* template with both your and your partner's name included in the filename.

Experimental purpose of today's experiment
Test whether the total force acting on a knot of strings is zero when the knot is at rest.

Pedagogical purpose of today's experiment
Practice adding vectors both graphically and component-wise.

Background
From everyday experience, you have some idea about what a force is—a push or a pull on an object. The SI unit of force is the newton (N). Later in the course we will establish the idea that an object in equilibrium (in this case, an object at rest) must have zero net force on it. Today's experiment will test this prediction.

We claim that forces obey the rules of vector addition: $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$. You will study the force of strings pulling on a knot. Each string runs over a pulley and is attached to a weight (of known mass). If the weight is not accelerating, then the magnitude of the force that the string exerts is $\left|\vec{F}\right| = mg$ (where $g = 9.81\,\text{m/s}^2$ is a constant), the direction of the force is along the string, away from the knot. (If the mass is in kilograms and the constant g is in meters per second squared, then the force is in units of Newtons.) By moving the pulleys and using various combinations of weights, you will put the knot into equilibrium. By examining the magnitude and direction of the known forces, you will calculate the magnitude and direction of the net force acting on the knot. The prediction is that this net force will be zero.

Procedural outline:

1. Hang three different masses of 300 g, 400 g, and 500 g from the three strings. Move the position of the pulleys so that the knot is in equilibrium. You may increase or decrease the masses to help achieve equilibrium of the knot in a convenient position (not too close to the edge of the table.) Masses can be "daisy-chained" using the hook on the bottom of the mass.

2. Adjust the angle of each pulley so that the string is aligned with the groove in the pulley. Adjust the height of each pulley, so that the string is very close to the table, but not touching the table.

3. When you achieve equilibrium, take pictures of your setup and **paste your pictures here**. **Include figure captions.** Take at least one picture from above, clearly showing the three strings pulling on the knot. Take at least one additional picture from the side showing one of the strings going over the pulley to the hanging mass. After pasting the pictures into this report, use Word's insert shapes features (arrows and textboxes) to draw labels on top of the pictures. Label the following pieces.
    - The three strings (let $\vec{F}_1$ correspond to the 300 g mass, $\vec{F}_2$ to the 400 g mass, and $\vec{F}_3$ to the 500 g mass).
    - The knot joining the string together.
    - The pulley(s)
    - The hanging mass(es)

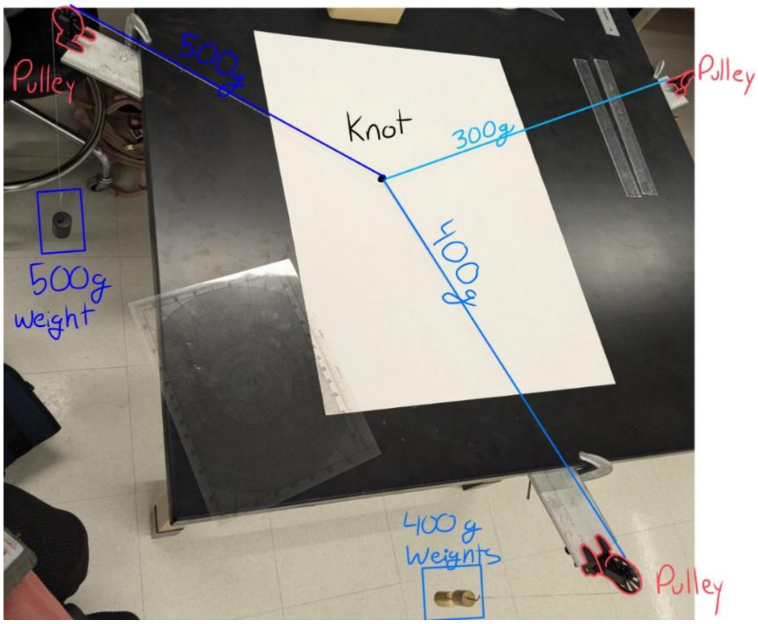

Figure 1. View of setup from above. The pulleys are outlined in red and the knot is marked by a black dot. Lightest blue represents the lightest weight at 300g, medium blue represents 400g, and the darkest blue represents the heaviest weight at 500g. 300g weights are out of view of the picture. The weights hanging from the pulleys counterbalance to hold the knot in equilibrium above the paper.

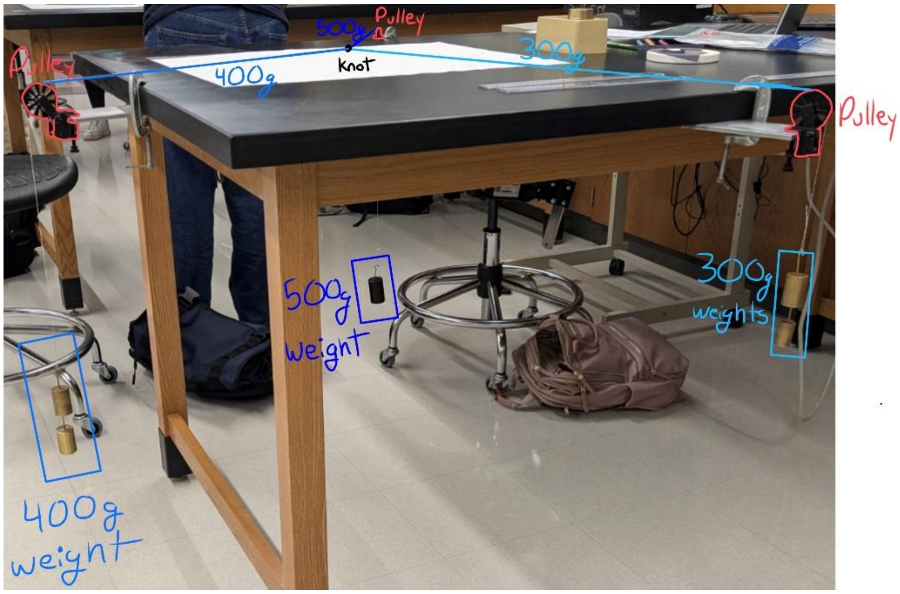

Figure 2. View of setup from the side. Pulleys are outlined in red, and the knot is marked by the black dot. Lightest blue represents the lightest weight at 300g, medium blue represents 400g, and the darkest blue represents the heaviest weight at 500g. The 500g weight is hanging off the opposite side of the table.

Part 1: Graphical vector addition

4. Tape a large sheet of paper under the strings with the knot near the center. Carefully and lightly draw the directions of the strings directly onto the paper.

5. Remove and weigh the masses. Record the masses in your *Excel* table in units of kg.

6. Use an *Excel* formula to compute the magnitude of the three forces. Each time that you create an equation in *Excel* like this, you should write the formula for that equation (with variables, not numbers or cell labels) by hand on a sheet of paper. After finishing your *Excel* table, you will scan and paste this sheet of formulas into your report.

7. Choose a scale factor of 4.0 cm/N that relates the magnitude of each force in Newtons to the length of its arrow in cm. This scale is large enough that the force vectors are large when drawn on the paper, but small enough that the graphical addition of the forces will fit on the paper. Record this scale factor in the *Excel* table.

8. Use an *Excel* formula to calculate the length of each arrow in cm.

9. Using your sheet on which the string directions have been drawn, draw force vectors (arrows) of the appropriate length onto the three string directions. Label the forces $\vec{F}_1$, $\vec{F}_2$, and $\vec{F}_3$.

10. Use a set of parallels and a ruler to add the known forces geometrically (tip to tail) to find $\vec{F}_{\text{net}} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3$. Use this order and proceed counterclockwise. Label the sum as $\vec{F}_{\text{net}}$. Note: $\vec{F}_{\text{net}}$ is predicted to be $\vec{0}$. Experimentally, it is the small arrow going form the tail of $\vec{F}_1$ to the tip of $\vec{F}_3$. Measure its length with a ruler: this is the "measured net force arrow length." Calculate the corresponding force magnitude in Newtons using the same scale factor as before. In this step, you must *divide* the measured arrow length by the scale factor.

11. Calculate the ratio of $\left|\vec{F}_{\text{net}}\right|$ to the magnitude of the force ($\vec{F}_1$, $\vec{F}_2$, or $\vec{F}_3$) with largest magnitude. This is a measure of how closely the forces summed to zero.

12. **Paste a picture of your vector addition diagram here**. **Include a caption.**

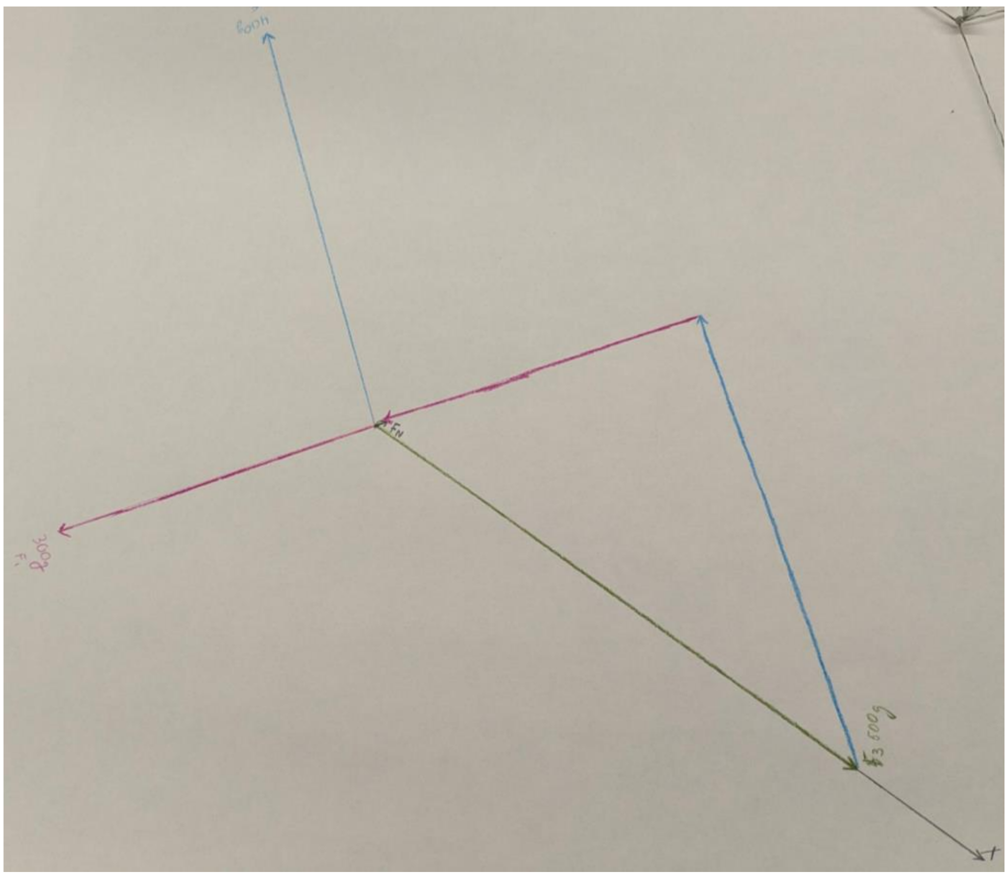

Figure 3. Vector Diagram. The vector from the 300g weight (F_1) is drawn in pink and has a magnitude of 11.8cm. The vector from the 400g weight (F_2) is drawn in blue and has a magnitude of 15.7cm. The vector from the 500g weight (F_3) is drawn in green and has a magnitude of 19.6cm. The x-axis extends from vector F_3.

13. **Paste part 1 of your *Excel* table here. Also paste a scan of your sheet of your hand-written equations that were used in this part of the *Excel* table. Include table and picture captions.**

g (m/s^2)	9.81
scale factor (cm/N)	4.00

String	Mass (kg)	Force (N)	Arrow length (cm)
1	0.30	2.94	11.8
2	0.40	3.92	15.7
3	0.50	4.91	19.6

Measured net force arrow length (cm)	0.5
Net force magnitude (N)	0.1
Net force magnitude / largest individual force magnitude	0.02

Table 1. Graphical Vector Addition.

Force = Mass · g
Arrow Length = Mass · scale factor
Net Force = Net Force Arrow / scale factor

Figure 4. Graphical vector addition equations. Force is in units newtons (N), mass is in units kilograms (kg), and arrow length is in units centimeters (cm). g is a constant at 9.81m/s^2 and the scale factor is a constant of 4.00cm/N

14. **Write a brief analysis of your results for part 1 here**. Comment on how well your results match the prediction of zero total force. You do not need to calculate uncertainties, so you do not need a ratio test. Comment on reasons why your net force might be different from zero.

The results were very close to the predicted net force of 0, however, the last vector fell just short of reaching the origin. The paper, rulers, and string shifted very easily as they were worked with which created a lot of opportunity for errors to form which may explain why the net force is not 0.

Part 2: Component vector addition

15. Let the positive *x*-axis of a rectangular coordinate system be in the direction of the 500 g mass. Draw the *x* and *y* axes on your paper. Measure angles of the other two forces relative to these axes. **Clearly indicate on your diagram and in words here which angles you measured.** (For example, you may say that the angle of the direction of force $\vec{F}_2$ was measured above the positive *x* axis.) The protractor sheet permits angles to be measured to about 0.5 degree. Record these angles in part 2 of your *Excel* sheet.

16. Paste a picture of your diagram with the labeled angles here. Include a caption.

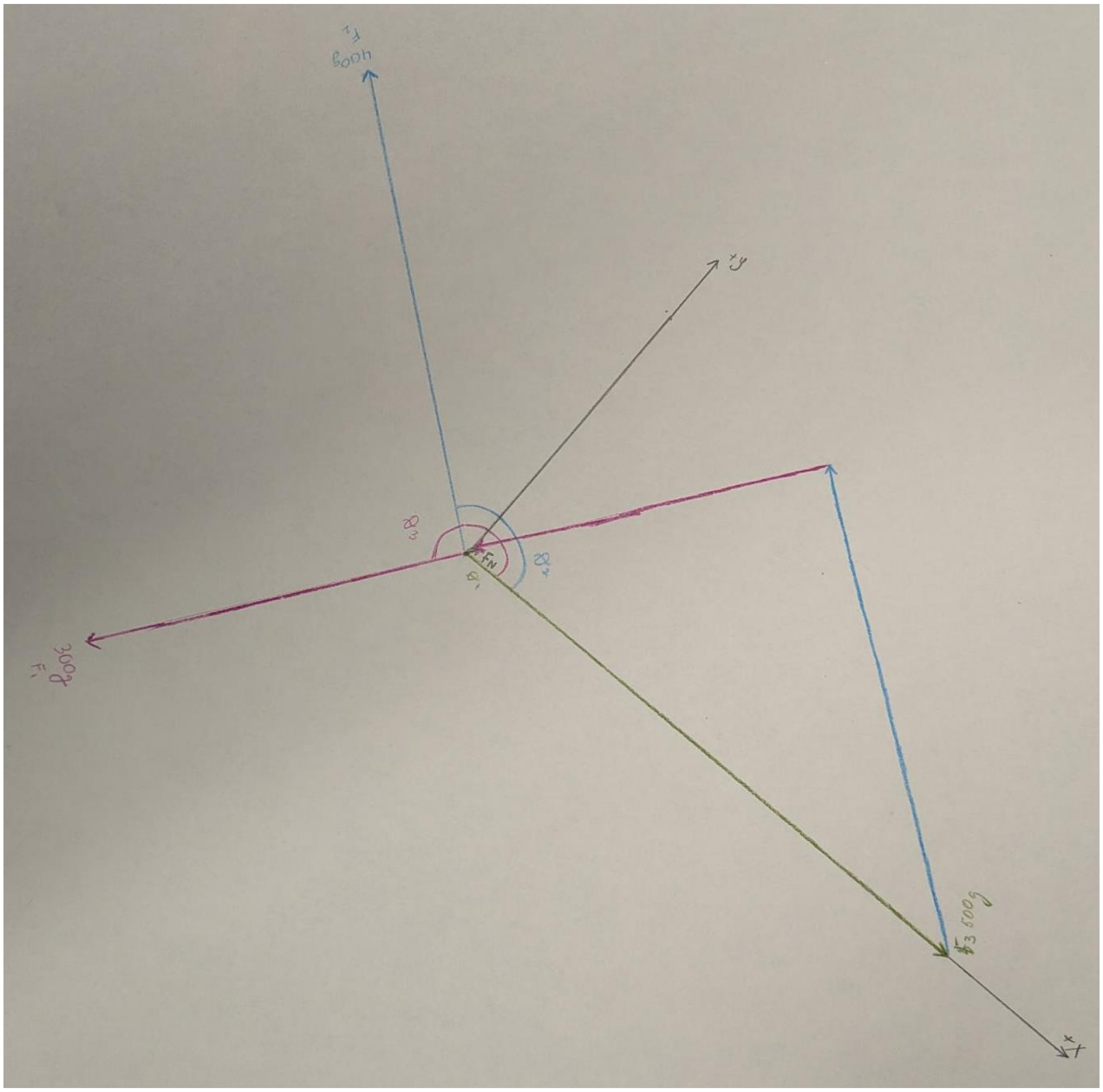

Figure 5. Vector diagram with angles. The vector from the 300g weight (F_1) is drawn in pink. It has a magnitude of 11.8cm and an angle (Θ_3) of 233° from the x-axis. The vector from the 400g weight (F_2) is drawn in blue. It has a magnitude of 15.7cm and an angle (Θ_2) of 143° from the x-axis. The vector from the 500g weight (F_3) is drawn in green. It has a magnitude of 19.6cm and an angle (Θ_1) of 0° from the x-axis. The x-axis extends from vector F_3 and the y-axis extends 90° from the x-axis.

17. Use an *Excel* formula to convert these angles into radians. Since this is a simple equation, you do not need to write it by hand on your sheet of equations.

18. Use *Excel* formulas to calculate the x and y components of each force. Note that these equations may change depending on which angles you choose to measure. Equations for each of these formulas should be written by hand on your equation sheet.

19. Add the components of the forces to find the components of the net force. Write this equation on your equation sheet.

20. Calculate the magnitude of the net force from its components. Write this equation on your equation sheet.

21. Calculate the direction of the net force from its components. Give this direction as an angle and explain where this angle is measured. Write the equation for this angle on your equation sheet.

22. Calculate the ratio of $\left|\vec{F}_{\text{net}}\right|$ to the magnitude of the force ($\vec{F}_1$, $\vec{F}_2$, or $\vec{F}_3$) with largest magnitude. This is a measure of how closely the forces summed to zero.

23. Paste part 2 of your *Excel* table here. Also paste a scan of your equations that correspond to the formulas in this part of the table. Include captions.

String	Angle (degrees)	Angle (radians)	F_x (N)	F_y (N)
1	233	4.07	-1.77	-2.35
2	143	2.50	-3.13	2.36
3	0	0	4.91	0

Net force *x* component (N)	0.01
Net force *y* component (N)	0.01
Net force magnitude (N)	0.01
Net force direction (degrees)	1.15
Net force magnitude / largest individual force magnitude	0.002

Table 2. Component vector addition.

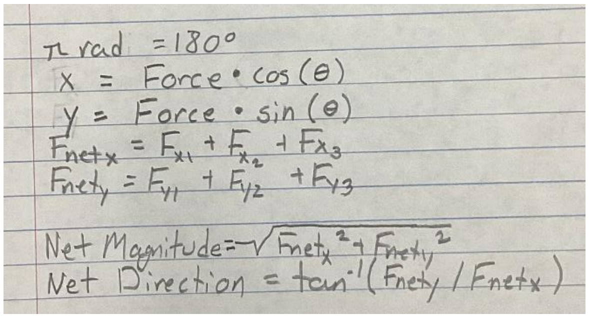

Figure 6. Component vector addition equations. F_x represents the x components of the vectors and was calculated by multiplying the force(N) of the vector and the cos of its angle(Θ). F_y represents the y components of the vectors and was calculated by multiplying the force of the vector and the sin of its angle (Θ). The net values are the sum of the individual vectors.

24. **Write a brief analysis of your results for Part 2 here.** Compare the part 2 results with those from part 1.

The net force was very close to the predicted net force of 0. They were even closer than the results from part 1. This may be because measuring the angles involved less fiddling with the paper and rules which reduced human error in the measurements.

25. **Write a brief conclusion here**. In your conclusion, report the measured magnitude of the net force from both parts.

The net force calculated from angles in part 2 was much closer to the prediction of 0 than the net force calculated from drawing the vectors in part 1. In fact, it was 10x closer with an overall net force of 0.01N compared to 0.1N. It would be interesting to rearrange the weights and the pulleys to see if and how that affected the vectors and the net force, theoretically it should not have an effect.

26. Adjust the formatting (pagination, margins, size of figures, etc…) of this report to make it easy to read. Save this report as a PDF document. Upload it to the course Moodle page.

27. Clean up your lab station. Put your equipment back where you found it. Remove any temporary files from the computer desktop. Ensure that the laptop is plugged in.

28. Check with the lab instructor to make sure that they received your submission before you leave.