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Lab Activity: 2-D Vector addition of forces on a stationary object ΣF = 0N

Objective: *Verify* through vector addition in 2-D that net force equals zero when objects are stationary (Static equilibrium).

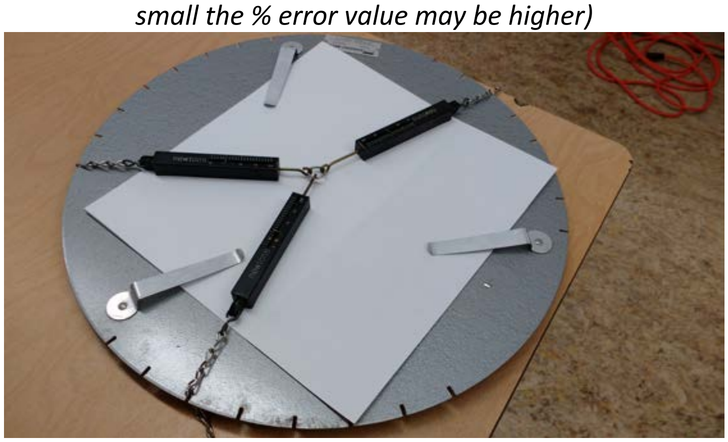
Materials:

- Metal disc (pictured below)
- Set of 3 spring scales joined at a central hub
- Sheet of blank paper to cover the metal disc
- Pencil
- Ruler/straight edge
- protractor

Step 1: Set up the apparatus:

Place paper on the disc and adjust the 3 spring scales on the disc so that angles and forces are not all the same (i.e. make your data more interesting than it would be if all the values were equal). The spring scales each pull on the central hub (metal ring). They exert tension forces on the central hub. Since the central hug is station, we know that the net force equals zero (Newton's 2nd Law: Σ**F** = m**a**, and since **a** = 0 m/s^2, Σ**F** = 0N)

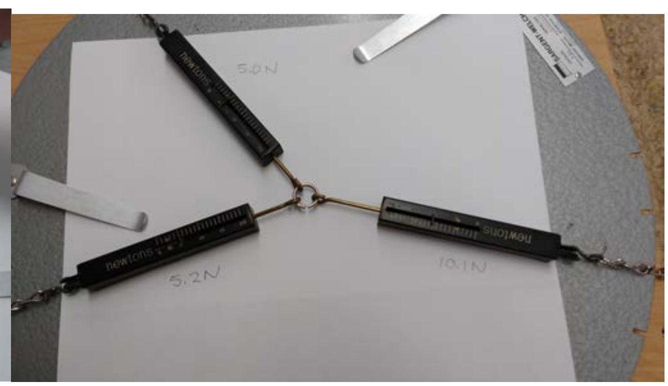
**__Practical Hint:__ Stretch your springs so that all forces are greater than 10N and less than 20N (if forces are too small the % error value may be higher)*



Step 2: Record your data: *magnitudes and directions of the 3 forces:*

- ***Direction arrows:*** Use the side of each spring scale as a straight edge to draw line in the direction of the tension force that the spring scale exerts on the central hub.
- ***Magnitudes of Forces:*** Label each of the direction arrows and write the value of the force that you read on the spring scale (**F**$_1$; **F**$_2$; and **F**$_3$). Estimate the force value to 1 decimal place.

After you have drawn the lines and recorded the force values, remove the paper from the disc apparatus.

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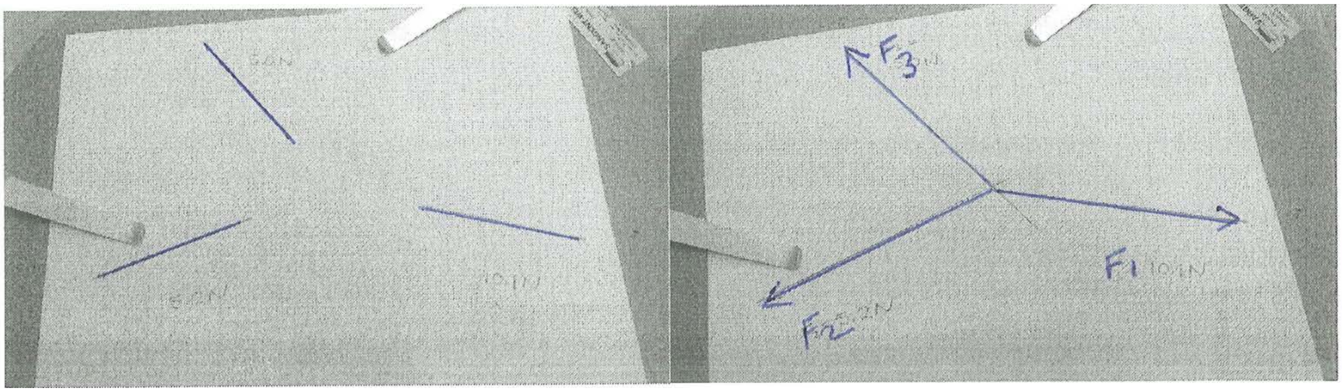
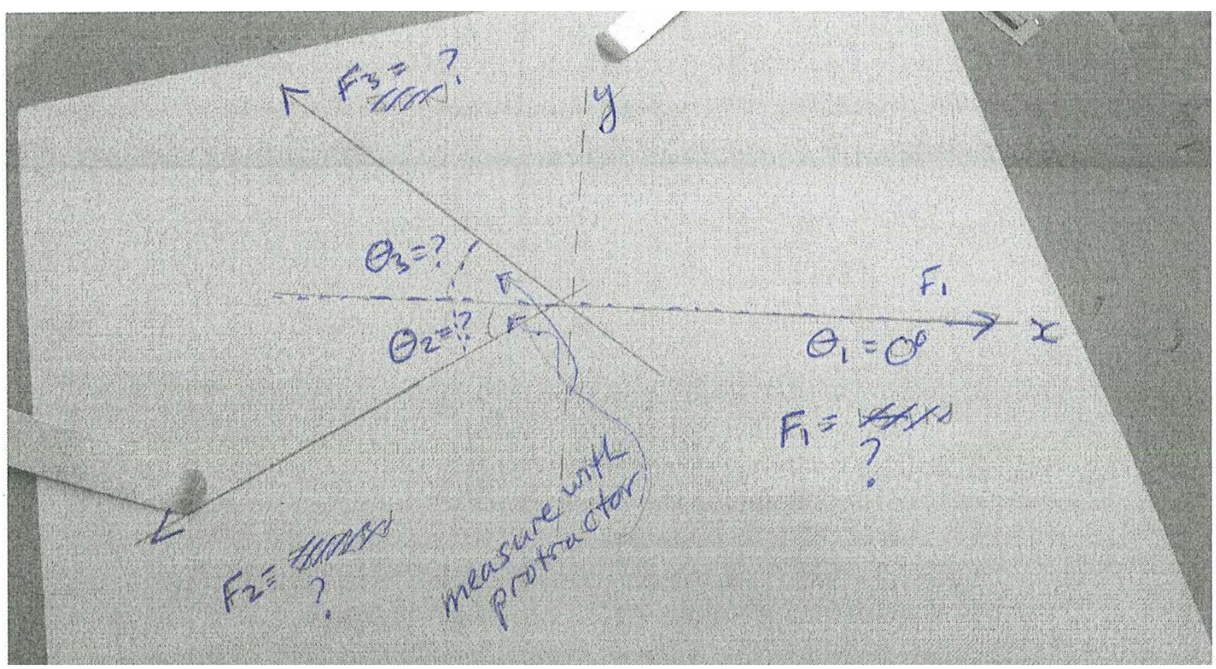
Step 3: Determine the values of the angles (direction of the forces):

1. *Use a ruler* to extend the lines that you drew beside the spring scales into the centre, until they converge (cross each other)
2. Draw arrows at the end of each line, showing the direction of the tension force that each spring scale exerted.



3. **Establish the x-y axis:**
   - o Choose one of the force lines and label that line as your x-axis *(it doesn't matter which line you choose – for the example, I have chosen F_1 as my x-axis).*
   - o The y-axis is perpendicular to the x-axis.

4. **Measure the angles relative to the x-axis:** *Use a protractor* to measure the angles
   - o θ_1 = _______________ (angle that F_1 makes with the x-axis)
   - o θ_2 = _______________ (angle that F_2 makes with the x-axis)
   - o θ_3 = _______________ (angle that F_3 makes with the x-axis)



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Note for Step 4 (the next step):
*For "**Orientation relative to the x-axis**" the following descriptors are examples of how the direction of the vector arrow is described:*

If the vector is within 90° of the positive (+) x-axis	***If the vector is within 90° of the negative (-) x-axis***
along the + x-axis	along the - x-axis
above the + x-axis	above the - x-axis
below the + x-axis	below the - x-axis

In this lab we'll use the x-axis as the main reference axis, but the y-axis could also be used as a reference axis. In that case, these are the possible descriptors:

If the vector is within 90° of the positive (+) y-axis	***If the vector is within 90° of the negative (-) y-axis***
along the + y-axis	along the - y-axis
to the right of the + y-axis	to the right of the - y-axis
to the left of the + y-axis	to the left of the - y-axis

Step 4: Data Analysis

1. Organize your data in the **data table** below:

Force Vector	**Magnitude (in Newtons)**	**Magnitude of angle θ (in degrees)**	**Orientation relative to the x-axis:**
F_1			
F_2			
F_3			

2. **Graphical Method to determine ΣF (i.e. scale diagram):**

a. *On a separate sheet of blank paper* draw and label a scale diagram of the vector sum: $\mathbf{F}_1 + \mathbf{F}_2 + \mathbf{F}_3$

b. *In a different colour* draw the resultant vector (the vector arrow that starts at the tail of F_1 and ends at the head of F_3).

c. *Resultant vector:* Measure the length of the resultant vector and convert that length into its force value in Newtons. Write the value on your vector diagram.
*[** State the value of **ΣF** in proper vector format, with both magnitude and direction**]*

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3. **Analytical Methods (components) to determine ΣF:**

   a. **Data table:** Determine and state the x and y components of each vector:

Force Vector	x component	y component
F_1		
F_2		
F_3		
Vector sum:	**ΣF_x =**	**ΣF_y =**

   b. Use Pythagorean theorem and trigonometry to calculate the magnitude and direction of **ΣF** (= vector sum of **ΣF_x + ΣF_y**)
   *[** State the value of **ΣF** in proper vector format, with both magnitude and direction**]*

$$\Sigma F = \sqrt{F_x^2 + F_y^2} = ?$$

$$\theta = \tan^{-1}\left[\frac{F_y}{F_x}\right] = ?$$

ΣF =____

Step 5: Sources of Error, Conclusion, and Discussion

In theory, we expect that **ΣF** = 0N, since the system is at rest. If there were no sources of error in the experiment, the 3 force vectors would add up to zero ("null vector"). But, in reality, there are several sources of experimental error that might mean the measured forces do not exactly add up to zero.

Sources of error in this lab include:

- Limits when drawing the lines (the thickness of the pencil line, and limits to hand-eye-coordination when drawing the lines parallel to the spring scales – e.g. the spring scale may have shifted position slightly).
- Measurement limits (the spring scale divisions are to the nearest Newton, thus force readings are roughly estimated to 0.1N; the ruler scale divisions are precise to 1 mm; the protractor scale is precise to 1 degree).
- The most significant source of error in this lab might be friction with the spring scales, limiting their ability to adjust and slide to depict the appropriate force value when the spring is stretch and released.

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<u>(excerpt from "Physics: Formal Lab Laboratory Reports" guide)</u>

<u>Instructions on how to write a Conclusion</u>: *In a few sentences, state your final results and the conclusions that you have reached. Refer back to the objective of the experiment and state how your results answer or address the questions posed in the objective. Also state the extent to which your experimental results matched expected results (i.e. % error or % difference)*

*** In the case of this lab, we expect that net force should equal zero. But, if net force is greater than zero, complete the following calculation to compare the <u>magnitude</u> (not direction) of the net force with the average of the magnitudes of the 3 forces (this is not a true % error calculation, but we will use this to describe % error anyway – it's an approximation):*

% error ≈ % of average force: $[\Sigma F/[(F_1 + F_2 + F_3)/3]\,] \times 100\%$ = (show calculation)

____ = ________________

a) <u>CONCLUSION:</u> In a short paragraph write a brief *<u>Conclusion</u>*, referencing your experimental results:

- *Sentence 1: State your final results (ΣF = ?)*
- *Middle few sentences: State the extent to which your experimental results matched expected results (i.e. % error or % difference). Based on your % error or % difference value, decide and state whether or not you believe that "Theory was verified within reasonable experimental limits".*
- *Last few sentences: Refer back to the original objective(s) of the experiment and state how your results answer or address the questions posed in the objective.*

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b) <u>DISCUSSION:</u> In 3 short paragraphs, write a Discussion section, referencing your experience and thoughts on the experiment and the results:

The *Discussion* section is, in essence, your conversation with other scientists and researchers about this experimental work. It is an important section for the researcher community as it raises questions and suggestions for further research and invites them into a conversation with you.

<u>How to write a *Discussion*</u>: In essay/paragraph form:

- *<u>Paragraph 1:</u>* ***The scientific meaning and implications of your results***: Explain your thoughts on the scientific relevance of the results
- *<u>Paragraph 2:</u>* ***Suggestions for improvement of the experimental design***: Include a description of how the procedures you used could be improved to provide more accurate and/or precise results.
- *<u>Paragraph 3:</u>* ***Suggestions/ideas for possible further research***: New ideas that the experiment stirred up in your mind.